Boat log for southern half of Elephant Butte reservoir

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Rio Grande crossing before dam construction.

The Lake at Lake Valley, Sierra County. Photo Henry Schmidt ca 1890, New Mexico Bureau of Mines & Mineral Resources Collection, donated by R.H. Jahns.

BOAT LOG FOR SOUTHERN HALF OF ELEPHANT BUTTE RESERVOIR

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SUMMARY

This log focuses on the diverse geology and some of the historical features that can be observed around Elephant Butte reservoir. 1986 marks the 70th anniversary of the completion of Elephant Butte dam and the creation of the largest body of water in New Mexico, Elephant Butte reservoir (originally called Hall Lake). The dam was built between 1912 and 1916 to control high runoff on the Rio Grande and to store water for irrigation. Today, primarily due to outstanding fishing and boating opportunities, the reservoir has become New Mexico's most visited state park with over a million visitors annually, while still fulfilling its original flood control and irrigation functions.

Elephant Butte reservoir lies within two structural subdivisions of the Rio Grande rift, the Engle Basin to the west and the Cutter sag to the east (Fig. b-0a). Differences in rock types and landforms between the eastern and western shorelines are directly attributed to geological differences between the basin and the uplift. The mostly submerged Hot Springs fault marks the boundary between these two structural features. Rocks along the eastern shore are part of the uplifted block and consist chiefly of sandstones and shales of the Upper Cretaceous Mesaverde Gr. and Upper Cretaceous–Eocene(?) McRae Fm. Tertiary–Quaternary basalt flows cap most high mesas. Sediments along the western shore were deposited in the Engle Basin, and are mainly sands and gravels of the Plio-Pleistocene Palomas Fm. (upper Santa Fe Gr.). The now submerged Rio Grande channel crosses the Hot Springs fault in six places (Fig. b-0a) and has locally incised a channel into both the Santa Fe Gr. and bedrock of the uplifted block.

The choice of Elephant Butte for the dam site was based on the geologic setting of the area. This is the only place in southern New Mexico where the Rio Grande has cut a deep canyon into resistant bedrock. This bedrock, primarily Mesaverde Gr. sandstone, is part of the Cutter sag uplifted block. The deep canyon provides a natural constriction for the dam and the sandstone provides strong footing. The reason why the Rio Grande was able to cut a channel into the uplifted block is a problem in itself.

The tour begins at Hot Springs Landing Marina and follows a counterclockwise loop around the reservoir reaching as far north as Black Bluffs. Two stops have been included to examine firsthand the Mesaverde Gr. and McRae Fm. deposits exposed along the eastern shore. We urge interested boaters to stop and examine other sites as time and landing spots permit. Both axial-river and piedmont facies of the Palomas Fm. exposed along the western shore can be observed. Origins of major landforms such as Elephant Butte, Kettle Top, and Black Bluffs, as well as significant historical features seen around the reservoir, are described. Possible explanations for migration of the Rio Grande out of the Engle Basin and onto the uplifted block are also presented. Numbered site descriptions in the boat log correspond to numbered site localities shown in Fig. b-0b. For a more detailed geologic map of the area see Lozinsky (1986). Due to reservoir level fluctuations, some of the features described may not be visible. Please watch the wind, observe boating safety rules, wear your lifejackets, and enjoy the tour.

Station No.

1 Begin at New Hot Springs Landing concrete boat ramp. Head out **(note no wake zone)** and south around marina toward dirt dam. Horse Island due east of marina consisting of the Cretaceous Mesaverde sandstone across submerged Hot Springs fault.

2 Beaches on west (near) shore consist of moderately well-sorted, predominantly nonindurated fine- to coarse-grained sand that was eroded from Palomas Fm. of upper Santa Fe Gr. (Lozinsky & Hawley in this guidebook). These sediments of the Palomas Fm. were deposited by the ancestral Rio Grande and are called the axial-river facies. The ancestral Rio Grande was a broad (up to 3 km wide), braided river as evidenced by: (1) abundant trough crossbeds; (2) lack of clay beds, (3)

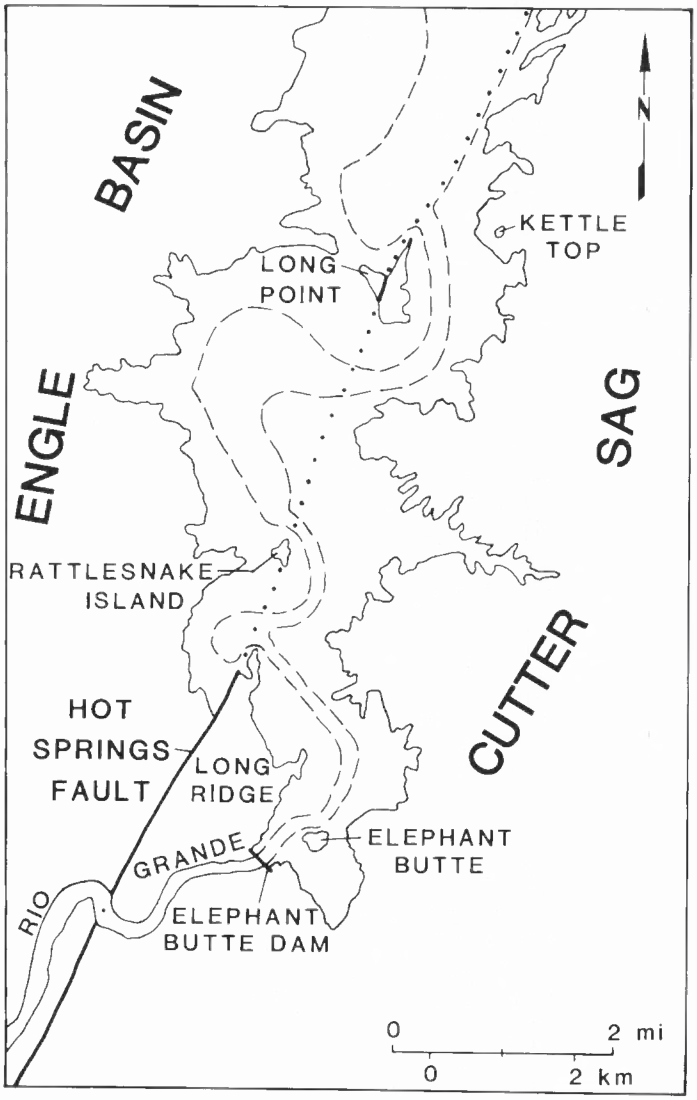

FIGURE b-0a—Map showing major structural features of reservoir area and submerged channel (dashed) of Rio Grande. Note channel crossing the Hot Springs fault at Long Point, Rattlesnake Island, and Long Ridge. Adopted from Lozinsky (1982, 1986).

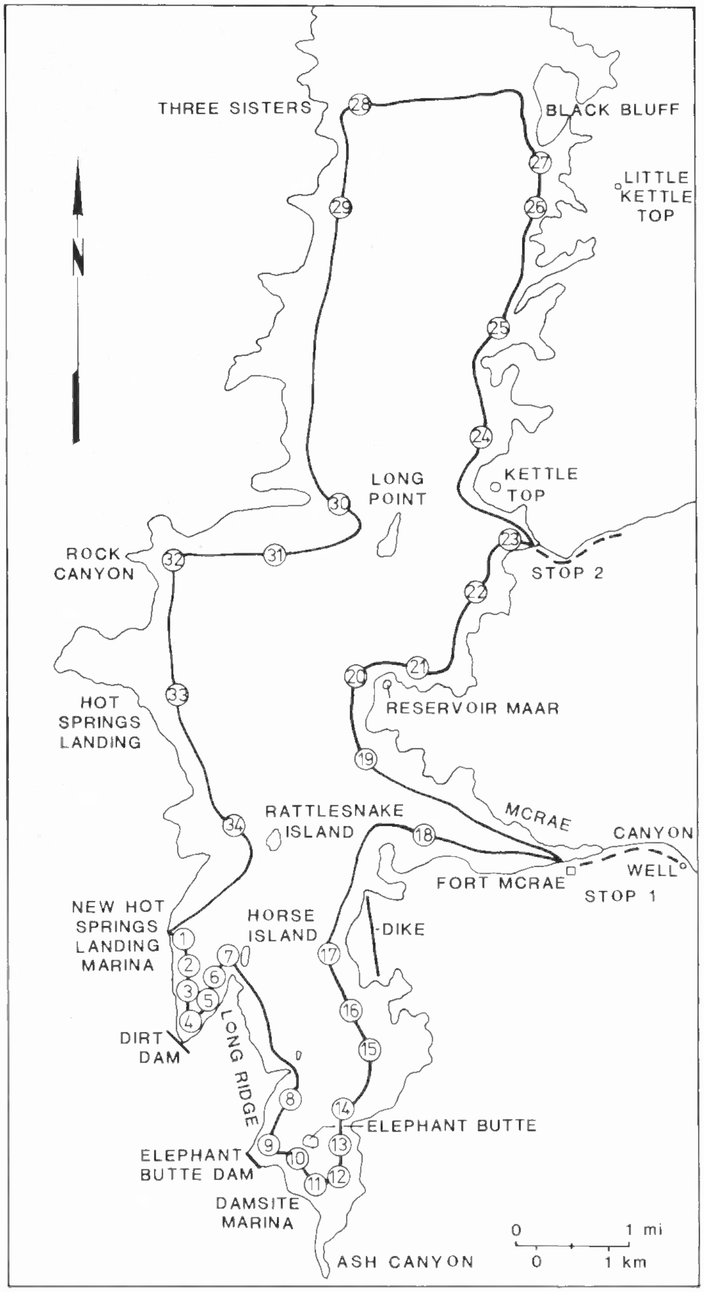

FIGURE b-0b—Tour route with station locations. Numbered sites refer to log station numbers.

lack of well-defined channels, and (4) areal distribution. Based on dated volcanic rocks and fossils, the age of the ancestral facies ranges from about 4.5 my to 400,000 years. The braided ancestral river contrasts with the present-day more meandering Rio Grande. Locally, coarse-grained sandstones in the axial-river facies are better cemented by ground water moving through these deposits and precipitating calcite.

3 Turtle Mtn., northern end of Caballo Mtns., due south. Turtle Mtn. consists mostly of resistant beds of Pennsylvanian carbonates. These beds are obviously deformed as evidenced by the kink folds visible from the west side of the mountain. Not quite so obvious is the vertical orientation of most of the Paleozoic section. Turtle Mtn. is on the vertical western limb of a large Laramide fold that extends southward at least to Palomas gap. Dips, fairly gentle in the Cretaceous strata in Cutter sag, steepen rapidly westward toward Turtle Mtn. Permian, Pennsylvanian, and lower Paleozoic strata are vertical in most places. Steeper overturned and gentler upright dips are locally present. This fold resembles hanging-wall anticlines above thrust faults which have been brought to our attention by oil exploration in the thrust terrains of Wyoming. See Optional Stop 2 of Day 2 road log for more details.

HISTORY OF ELEPHANT BUTTE DAM AND RESERVOIR

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Farmers in the Mesilla Valley of southern New Mexico and the El Paso–Juarez Valley of west Texas and northern Chihuahua filed protests in the 1880's and 1890's against upstream diversions which seriously depleted the natural spring and summer flows of the Rio Grande. Already plagued by natural drought—the channel of the Rio Grande at El Paso was completely dry in the summer of 1851—these farmers levied their complaints against the settlers of the San Luis Valley of southern Colorado and northern New Mexico who had diverted, for irrigation purposes, Rio Grande water during the period 1860–1890 (Lester 1977). To solve the water problem for El Paso, but to the detriment of southern New Mexico, Anson Mills of El Paso recommended in 1888 that a large dam and storage facility be built a few miles upstream of El Paso (Mills 1918). At about the time that the United States and Mexico agreed in the 1890's to construct a dam at the El Paso site, the Rio Grande Dam and Irrigation Company was chartered by the U.S. Department of the Interior to build a private dam on the Rio Grande near Engle, nearly 240 km by river upstream of El Paso. However, the Irrigation Company, beset by financial and legal problems, saw its charter for the dam expire in 1903 (Clark 1975).

More protests were filed by local farmers when drought produced record-low discharges at the El Paso cross section in 1902 and early 1903. In 1904, the Reclamation Service of the Department of the Interior completed its water study of the area and recommended the site at Elephant Butte for the installation of a large dam and reservoir. Elephant Butte dam was formally authorized by Congress in 1905 as part of the Rio Grande Project, and the dam was incorporated into the 1906 Water Allocation Treaty between the United States and Mexico. The treaty guarantees Mexico 60,000 acre-ft of water annually, to be delivered to the head of the Acequia Madre at Juarez (Hundley 1966).

Construction of the dam, begun in 1912, was completed in 1916 at a cost of $5 million. Downstream water-user associations, charged with repaying the cost of the dam through interest-free loans, were replaced in 1919 by the still functioning Elephant Butte Irrigation District. The debt on the dam was finally retired in 1971 (Lester 1977).

Elephant Butte dam, including the spillway, is 510 m long, 91.7 m high, and had a design storage capacity of 2,634,000 acre-ft and an estimated useful life of 50 years. Today, 60 years after the dam was completed, the reservoir retains nearly 80% of its original capacity. Sedimentation rates in the reservoir have been considerably less than the original estimates. A 24.3 megawatt hydroelectric powerplant was added to the dam in 1940 and is operated by the Bureau of Reclamation. Elephant Butte dam was designated a National Historic Civil Engineering Landmark in 1977 (Bureau of Reclamation Records, El Paso, Texas, 1986).

Also included in the Rio Grande Project is Caballo dam, constructed at a site 35 km downstream of Elephant Butte. Caballo was completed in 1938, and its principal function is to regulate water releases from Elephant Butte dam. Caballo reservoir still retains nearly all of its original storage capacity of 344,000 acre-ft. In March 1986 the two dams had a combined storage capacity of 2,453,000 acre-ft and their reservoirs were filled to 96% of capacity (U.S. Geological Survey 1986). Since their completion, the two dams have provided complete flood protection to the valleys of southern New Mexico. Also, irrigated acreage in southern New Mexico has increased from 38,876 acres in 1915 to nearly 85,000 acres today (Bureau of Reclamation Records, El Paso, Texas, 1986).

4 Dirt or wing dam. Drainage divide ahead was lower than the spillway on Elephant Butte dam. Therefore, to prevent the reservoir from spilling over divide and flowing out through the arroyo (and probably draining the lake), the wing dam was built in 1916. It is an earthen dam with a cement apron on the reservoir side. The wing dam rests primarily on piedmont-facies deposits of the Palomas Fm. which here consist mainly of detritus derived from the Mesaverde Gr. to the east. Intertonguing contact between the axial-river and piedmont facies can be seen west of wing dam. At high water levels, the wing dam has experienced some minor seepage. **Turn 180° and proceed north along east shore.**

5 Hot Springs fault. The fault lies under the eastern end of the wing dam and continues northeastward, just east of Rattlesnake Island, through Long Point Island, and into the Black Bluffs area on the eastern shore (Fig. b-5a). Exposures of the fault occur along the east shore (at low water levels) and also in the arroyo just south of the wing dam (Fig. b-5b). The fault is normal, downthrown to the west, contains many splay segments, and dips 70–80°W. In addition, some strike-slip motion is suggested by lateral offset of Permian beds to the south (Lozinsky 1982, 1986). The Hot Springs fault here juxtaposes Cretaceous Mesaverde strata against sandstone and conglomerates of the Plio-Pleistocene Palomas Fm. This juxtaposition suggests

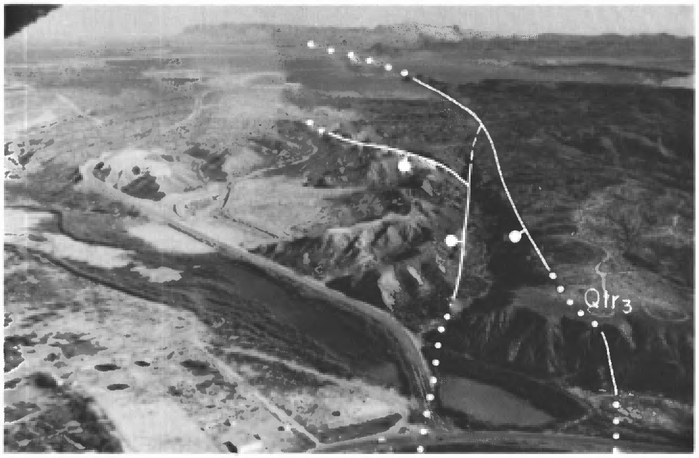

FIGURE b-5a—Oblique aerial view, looking north, of Hot Springs fault and associated splays. Wing dam area in foreground and Fra Cristobal Range in far distance. Note Hot Springs fault does not offset terrace at Qtr_3. From Lozinsky (1982, 1986).

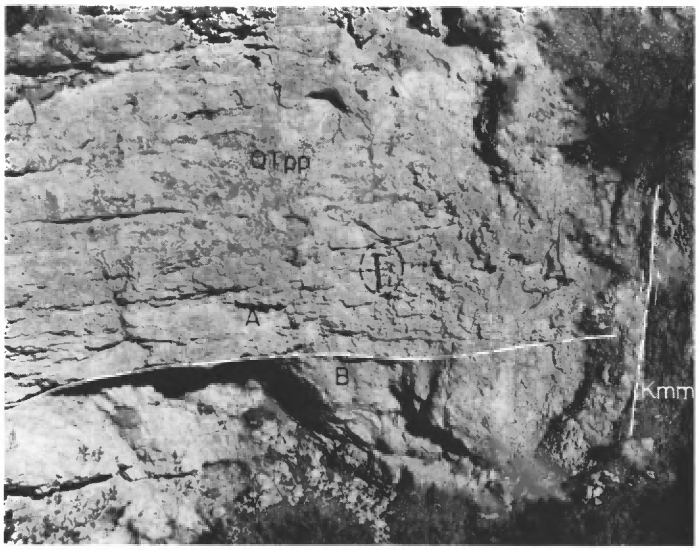

FIGURE b-5b—Fault plane of Hot Springs fault showing proximal subfacies of Palomas Fm. (QTpp) juxtaposed to Mesaverde strata (Kmm). Note bed "A" is less deformed than bed "B." From Lozinsky (1982, 1986).

vertical separation of at least 1,220 m. The Hot Springs fault, the most prominent structural feature in this area, merges with other faults to the north and south to form the main range-bounding fault for the Fra Cristobal–Cutter sag–Caballo uplift.

6 Long Ridge. Prominent ridge to east is a hogback of east-tilted Crevasse Canyon Fm. of upper Mesaverde Gr. (Wallin 1983), which consists of lenticular, medium- to coarse-grained, buff to brown sandstone beds with local pebble conglomerates interbedded with olive-gray to brown mudstone and siltstone beds. The 700 m thick Crevasse Canyon Fm. is mostly terrigenous and locally contains fossilized leaf imprints, thin coal seams, and petrified logs. It is interpreted to have been deposited by a braided-river system (Wallin 1983). Rattlesnake Island due north.

7 **Turn east through channel between Horse Island and Long Ridge and then continue south along east side of Long Ridge.** Purplish and olive-drab beds exposed along shoreline are McRae Fm. shales and sandstones faulted against Mesaverde strata. The purplish beds are part of the upper Hall Lake Mbr. and the olive-drab beds farther south are lower Jose Creek Mbr. deposits.

The McRae Fm. was first named by Kelley & Silver (1952) after the old army fort in McRae Canyon during the late 1800's. Outcrops of McRae Fm. only occur in the Cutter sag and Jornada del Muerto area. Bushnell (1953) divided the formation into two members, the lower Jose Creek and the upper Hall Lake. Total thickness of this unit may approach 976 m.

The Jose Creek Mbr. rests unconformably upon Mesaverde Gr. and consists of sandstone, shale, conglomerate, and a coarse-grained breccia conglomerate. The Hall Lake Mbr. conformably overlies the Jose

Creek and is distinguished by its abundance of purple and maroon shales. A basal conglomerate usually marks the contact between these members; where absent, the contact has been mapped at the lowest purple or maroon shale. The top of the Hall Lake is absent in all areas. It is usually eroded and overlain by various Cenozoic units or locally may be faulted out. Numerous plant and dinosaur fossils have been found in the lower part of the section (see Lozinsky et al. 1984).

8 Small hill or knob on shoreline consists of Jose Creek conglomeratic sandstone. Clasts include subangular to well-rounded andesite and latite fragments. Volcanic fragments in the Jose Creek beds are thought to be from a Laramide volcanic center; Copper Flat about 40 km to the southwest is about the right age. Previously, a local eruptive center was postulated (Bushnell et al. 1955), but all deposits have strong sedimentary characteristics. The coarse fragments (up to 2 m) that suggested a local vent are believed to have been transported by debris flows. Elephant Butte to east.

9 Elephant Butte dam. This site was chosen for dam construction because of the steep and resistant nature of the Mesaverde sandstone in the canyon walls. Engineers label this a gravity dam, as opposed to an arched dam, because it is the mass of the structure that holds back the water. The dam itself is composed of large Mesaverde sandstone blocks that were placed in a mold and surrounded with a concrete matrix (Fig. b-9). The dam is 92 m high, 510 m long (including spillway), and has a maximum storage capacity of more than 2 million acre-feet of water. The construction of the dam was quite an engineering feat back in the early 1900's. A small city of about 900 people sprang up around the dam site during construction. Numerous construction photographs are on display at the Geronimo Springs Museum in T or C and the Elephant Butte State Park visitor center. Just east of the dam, old cement foundations visible at low water levels are remnants of construction buildings.

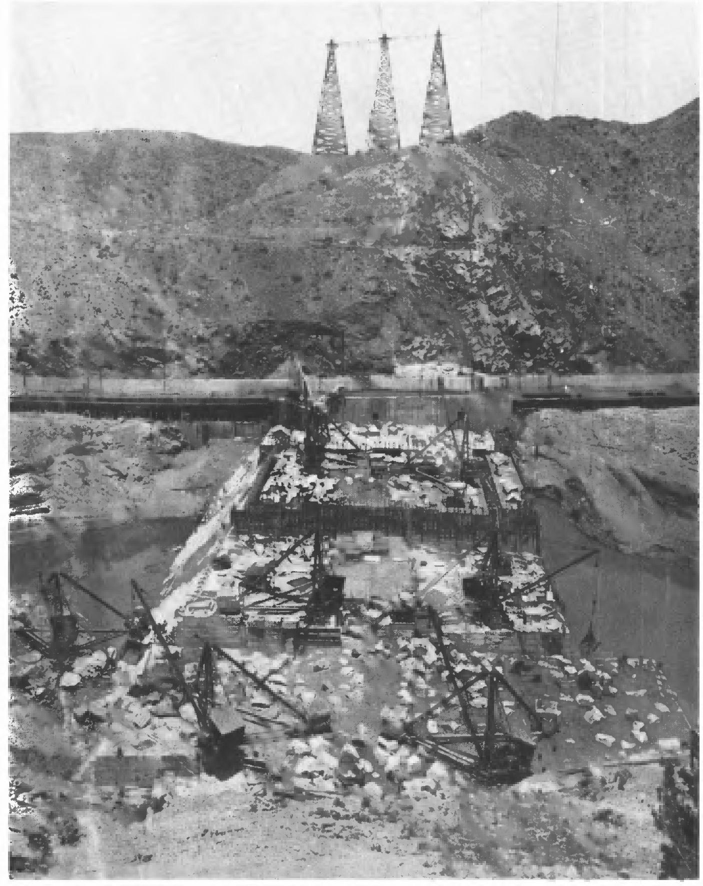

FIGURE b-9—Looking west along dam axis on 29 May 1914 during dam construction. Blocks of Crevasse Canyon Fm. sandstone are being placed into dam structure. The blocks were quarried from Ash Canyon and transported by rail to the damsite. Steep bedding at west end illustrates some of the structural problems that are said to complicate the dam-building progress.

10 Elephant Butte. Distinctive 90 m high landform from which the area derives its name. From this perspective, the butte resembles an elephant (Fig. b-10). The butte is a volcanic plug consisting of alkali-olivine basalt (47.34% SiO_2, 6.64% total alkalis). It may have supplied lava to an overlying flow and cinder cone that is now eroded away. Petrographically, the basalt contains anhedral to subhedral phenocrysts of olivine (up to 8 mm) in a groundmass of plagioclase, olivine, Ti-magnetite, and partially devitrified glass. The overall texture is intergranular to intersertal and trachytic.

Included within the Elephant Butte basalt are ultramafic inclusions as large as 15 cm in diameter. The inclusions are easily visible from a passing boat along the north and west flanks. The most common inclusion type is spinel lherzolite, which usually exhibits an allotriomorphic granular texture and 120° triple junctions in thin section. These are thought to be fragments of the mantle from or above the zone of melting which produced the basalts.

East-dipping, purplish Hall Lake Mbr. beds are exposed on east side of butte. These beds have yielded fossilized dinosaur bones (Lozinsky et al. 1984, Wolberg et al. in this guidebook). Besides the elephant, about 30 goats live on the island.

FIGURE b-10—Elephant Butte. Can you see the elephant?

11 Damsite Marina. First developed area on the reservoir. Many of the buildings and landscaping are a product of the WPA, but some date back to dam-construction days. Hills behind marina are composed of poorly sorted pebble to boulder conglomerates, sandstones, and mudstones of the Jose Creek Mbr. Most clasts are moderately to well-rounded porphyritic-andesite lavas (see Optional Stop 2 of Day 2 for more detailed discussion).

12 Steep bluff on east shore is a fault-line scarp and consists of Mesaverde sandstone (Crevasse Canyon Fm. of Wallin 1983). At low water levels, the downdropped McRae Fm. crops out along shoreline. Fault is normal, dips 50–70°W, and continues into Ash Canyon southward and into small canyon northward. Note broad syncline in Mesaverde beds in incised valley just north of old road.

13 McRae Fm. on Elephant Butte. Note slump scars in Hall Lake Mbr. on north side of island caused by recent high water levels eroding material at toe of slide.

14 Basalt-capped mesas. After passing Mesaverde bluffs, basalt-capped mesa can be seen to the east. These lavas originated from narrow north-trending fissures to the east, which have subsequently been covered by cinder-cone activity. The flows extended farther to the west at one time but have since been eroded. Kettle Top Butte and Little Kettle Top, two basalt-capped mesas to the north, are erosional remnants of the fissure basalts. An age date on the flood basalts is lacking; however, they are older than the 2.1 ± 0.4 my date reported by Bachman & Mehnert (1978) for an overlying cinder cone to the east.

Mineralogically, the fissure basalts resemble other basalts in the area with phenocrysts (and microphenocrysts) of olivine and plagioclase. Sparse augite microphenocrysts can be present, but augite is more typically confined to the groundmass. A trachytic texture, indicative of flow, discriminates fissure basalts form the basaltic lavas associated with, and in close proximity to, the eight cinder cones to the east. North-dipping beds beneath basalt-capped mesa are primarily Jose Creek Mbr. sandstones. From this point north, the eastern shore consists of the more erodable McRae Fm. beds that produce lower-relief topography. In the dam area, steeper relief is due to the more resistant Mesaverde sandstone.

15 Thickness of the Hall Lake Mbr. As defined by Bushnell (1953), the type locality of the Hall Lake Mbr. is just to the east. Hall Lake is the formal name of the reservoir, but it is not commonly used today. This is the thickest exposed section of Hall Lake strata in the area, but the entire section is not exposed here. Bushnell (1953) measured a thickness of 488 m at this locality. (The basal 30 m was measured farther north, near Kettle Top at Stop 2). In addition, he estimated at least another 366 m of this section to underlie the lake. Thus, assuming that the submerged section is unfaulted, Bushnell (1953) arrived at a total thickness of at least 884 m for the Hall Lake Mbr.

16 Basalt flows and cinder cones. To the northeast, cinder cones with 61–91 m of relief are visible on the horizon (Fig. b-16). These cones represent the culmination of volcanic activity in the area and consist of thick sequences of pyroclastic debris (reddish-brown cinders and bombs) interbedded with lava flows, cone sheets, and radial dikes. Their shape is roughly symmetrical with circular vents; however, it is common to see breached cone rims caused by outpouring lavas.

Compositionally, samples from the cones are alkali-olivine basalts with SiO_2 from 45 to 47 wt% and total alkalis between 4.2 and 5.5 wt%. Petrographically, the chief microphenocryst phases are olivine and plagioclase, with Ti-rich augite usually confined to the groundmass. The texture is intergranular to intersertal. Because of the vesicular nature of the cone basalts, secondary amygdale fillings are quite common; analcite, calcite, and chlorite have been identified.

17 Andesite dike. Prominent, north-trending ridge along eastern shoreline is formed by an andesitic dike (56% SiO_2 as reported by Loeber 1976) intruding through the Hall Lake Mbr. strata (Fig. b-17). The andesite is generally porphyritic and greenish gray in hand sample. Petrographic analysis reveals plagioclase as the dominant mineral type, making up more than 60% of the rock. Clinopyroxene occurs as rare phenocrysts. The groundmass contains plagioclase, opaques, chlorite, sparse biotite, and devitrified glass. Calcite commonly forms amygdales. Note how the dike holds up the rib of the ridge. Other andesitic dikes occur in the eastern-shore area. Rattlesnake Island to the north.

18 **STOP 1.** McRae Canyon has been cut primarily into Hall Lake strata. A large eolian-sand sheet with coppice dunes buries the Hall Lake along the southern shore of McRae Canyon behind the dike ridge. Stop 1 (Fig. b-18a) begins at the end of McRae Canyon where we will visit the site of historical Fort McRae, if not flooded. This stop involves a 1.6 km hike up

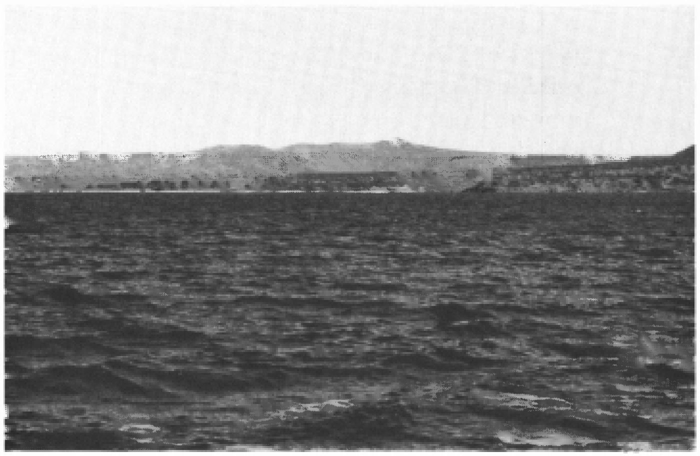

FIGURE b-16—Cinder cones overlying basalt flow north of McRae Canyon.

FIGURE b-17—Aerial view of linear-dike ridge. Note how dike forms the rib of the ridge.

McRae Creek to view Hall Lake and fossiliferous Jose Creek Mbr. strata (Fig. b-18b) and an andesite dike. A refreshing oasis rewards the hiker with a drink from the artesian well under cottonwoods (Fig. b-18c). This well was one of the few sources of water for travelers along the Jornada. Return to boat and exit McRae Canyon turning north.

19 Shoreline just north of McRae Canyon. Bedrock along shoreline is purple and maroon shales and sandstones of the Hall Lake Mbr. Linear ridges in near foreground are cored with andesitic dikes. San Andres Mtns. in far distance.

20 Reservoir maar. Dark, isolated hill along shore is Reservoir maar. This maar is one of several located within and along Elephant Butte reservoir. These deposits were formed by phreatomagmatic eruptions caused by the interaction of rising magma with ground water,

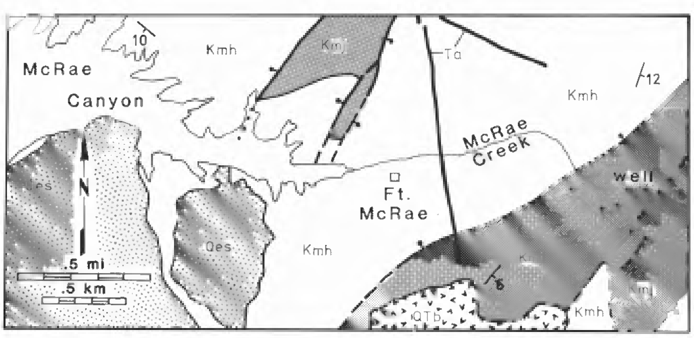

FIGURE b-18a—Geologic strip map of Stop 1 area. Land boat as far up McRae Canyon as possible and then follow McRae Creek to well. Qes = eolian-sand sheet; QTb = basalt flow; Ta = andesite dike; Kmh = Hall Lake Mbr.; Kmj = Jose Creek Mbr. Lake level shown at the 4,400′ contour. Modified from Lozinsky (1982, 1986).

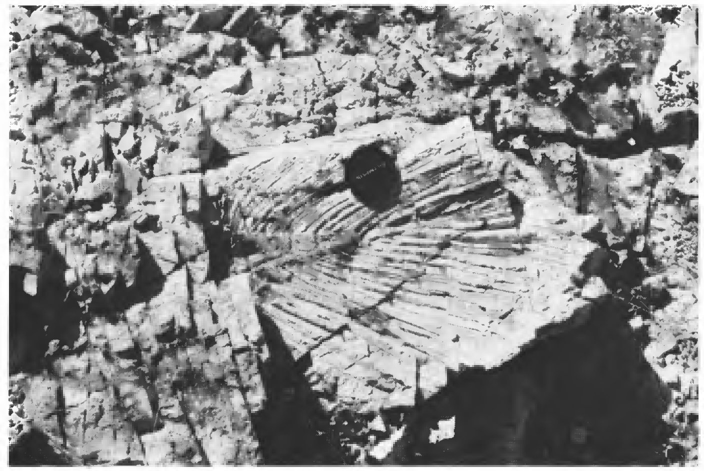

FIGURE b-18b—Fossil palm leaf in Jose Creek strata found along McRae Creek.

here associated with the Rio Grande drainage (Aubele et al. 1976). Only the inner portion of Reservoir maar is preserved and it comprises McRae sandstones overlain by pyroclastic deposits. A few basaltic dikes can be seen cutting the pyroclastics.

21 Shoreline consists predominately of Hall Lake Mbr. beds. Dinosaur fossils have been recovered from this area. Long Point Island to northwest. San Mateo and Magdalena Mtns. in far distance.

22 Kettle Top Butte. Next to Elephant Butte, Kettle Top is probably the most recognizable landform around the reservoir (Fig. b-22). It is not a volcanic plug like Elephant Butte, but rather a mesa consisting of east-dipping Hall Lake Mbr. strata capped by a basalt flow. The basalt on top of the butte was once continuous with the basalt-capped mesa to the east. The high relief of Kettle Top (about 122 m above reservoir) is due to the resistant basalt cap rock that protects the underlying Hall Lake Mbr.

23 **STOP 2.** 3.25 km round-trip hike to examine a well-exposed section of the McRae Fm. Land boat in un-

FIGURE b-18c—Cottonwoods surrounding artesian-well area.

FIGURE b-22—Kettle Top with basalt cap. Hall Lake Mbr. strata underlie basalt. A walk up the east side rewards the hiker with a commanding view of the reservoir area.

named canyon as shown on map (Fig. b-23a) and hike up creek. Exposures of Hall Lake beds and andesitic dike (same dike seen at Stop 1) occur along creek. In wooded area, spring occurs at fault. Good exposures of fault plane with slickensides on small side creek to north (Fig. b-23b). Cross fault into upper Mesaverde Gr. (Crevasse Canyon Fm.) sandstone which contains good examples of large-scale hummocky crossbedding and scattered petrified logs. The thickness of the Mesaverde Gr. here is about 90 m. Disconformable contact between Mesaverde Gr. and Jose Creek beds occurs about 0.5 km east of fault. Contact is placed where sandstone becomes more feldspathic. Bushnell (1953) defined this locality as the type section for the Jose Creek Mbr. and measured a thickness of about 122 m. Continue up creek. Note angular unconformity between underlying McRae beds and basalt flows to north. About 1.6 km from fault is a gradational contact between the olive-drab and brown Jose Creek Mbr. and the purple and maroon beds of the Hall Lake Mbr. The contact is placed at the first maroon or purple bed seen along the creek bed; however, a basal conglomerate marks the contact in other places. The conglomerate

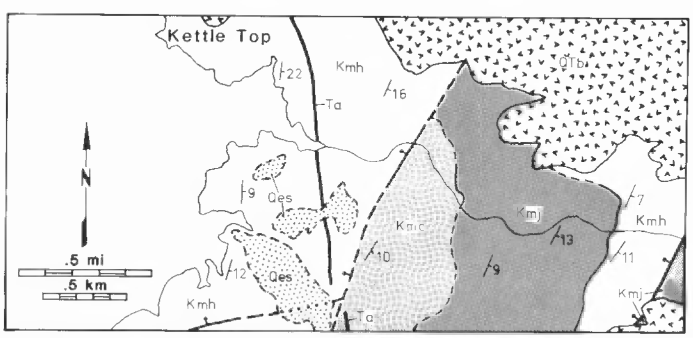

FIGURE b-23a—Geologic strip map of Stop 2 area. Land boat at mouth of unnamed creek and then follow creek. Qes = eolian-sand sheet; QTb = basalt flow; Ta = andesite dike; Kmh = Hall Lake Mbr.; Kmj = Jose Creek Mbr.; Kmc = Mesaverde Crevasse Canyon Fm. Lake level shown at the 4,400′ contour. Modified from Lozinsky (1982, 1986).

FIGURE b-23b—Fault plane showing mostly vertical slickensides. Fault juxtaposes Hall Lake strata (left) with Mesaverde strata (right). This offset indicates less than 200 m of stratigraphic separation. Daypack for scale.

clasts include well-rounded pebbles and cobbles of quartzite with lesser amounts of granite, gneiss, and andesite porphyry. The resistant, light-pink, 30–60 cm thick beds near the contact are interpreted as tephra or ash-fall deposits from some distant volcanic eruption. About 30 m of the Hall Lake Mbr. is exposed here. Follow creek back to boat. Sierra Cuchillo and Black Range in far distance to west. The dissected plain leading up to the mountains is the Cuchillo surface (Lozinsky & Hawley in this guidebook). Continue boat route north around Kettle Top.

24 Shoreline north of Kettle Top. Outcrops of Hall Lake occur along shoreline just north of Kettle Top. This is the area where a *Tyrannosaurus rex* jaw was recovered (Gillette et al. in this guidebook). An andesite dike extends through gap between Kettle Top and basalt-capped mesa. It is the same dike as at Stops 1 and 2. Note unconformity under basalt cap with Hall Lake beds. Resistant, light-colored, east-trending ridge near shoreline is part of a faulted, south-plunging syncline composed of Jose Creek strata.

25 Vineyard road. Dirt road and pipeline near shoreline were built for the vineyards in the Jornada del Muerto. The vineyards were started in 1981 by a group of German, French, and Swiss investors. Water is purchased from the City of Albuquerque and delivered via the Rio Grande to the reservoir where it is pumped through the pipeline and into the fields. Light-colored ridge is the west half of the syncline seen at locality 24. Offset on fault suggests right-lateral strike–slip movement along fault, possibly a splay of the Hot Springs fault.

26 Little Kettle Top Butte. A flat-topped butte a short distance to the east is Little Kettle Top. This butte is capped by a resistant basalt flow about 1 m thick, overlying maar deposits from the Black Bluffs eruption. The basalt is at the same stratigraphic horizon

and shares the same source fissure as mesa-capping basalts to the east; however, differences in mineral and whole-rock chemistries between this basalt and basalts to the east suggest that there are lateral chemical variations within the same flow unit (Kelly unpublished) or more than one flow. Fra Cristobal Range to northeast is a generally east-tilted horst containing Precambrian igneous and Paleozoic sedimentary rocks. The western edge of the range is an intensely deformed Laramide deformational front (Chapin & Nelson in this guidebook).

27 Black Bluffs. Of the four maars observed on this boat trip, Black Bluffs is the best preserved (Fig. b-27). A thick sequence of basalt (displaying good columnar jointing along the cliff) formed as a lava lake within the maar crater. This crater was surrounded by a tuff ring (tuff and lapilli breccias). Spectacular angular unconformities between outward- and inward-dipping beds occur on the west side. Contrasting dips develop in tuff rings because of deposition on both inward and outward slopes. Weathering out of the basalt are clear to milky white anorthoclase ($An_{12}Ab_{71}Or_{17}$) and black, vitreous augite ($En_{42}Fs_{14}Wo_{44}$) megacrysts.

Warren (1978) mapped the rift-bounding Hot Springs fault up through the canyon just south of Black Bluffs and showed it as offsetting basalt flows. North of Black Bluffs, Palomas Fm. deposits occur on both east and west shorelines of Elephant Butte reservoir. **From Black Bluffs, turn westward toward opposite shore.** We have left the uplifted Fra Cristobal–Cutter sag block after crossing the Hot Springs fault and are now in the Engle Basin. **Beware of strong winds** while crossing reservoir.

28 Three Sisters maar. This maar, when visible at low water levels, displays typical pyroclastic deposits associated with maar craters. **Before hitting shore, turn south back toward marina.**

29 Distal-piedmont facies and axial-river facies. Western shoreline is composed of axial-river facies of the Palomas Fm. Reddish-pink bluffs in near distance to west are composed of distal-piedmont facies. These sediments were deposited by a large alluvial-fan complex emanating from the mountains to the west. The Cuchillo surface caps these sediments.

30 Long Point Island. The Hot Springs fault cuts across the eastern side of Long Point Island. Exposures of Palomas Fm. juxtaposed with McRae Fm. beds can be seen on the island. At very low water levels, Long Point Island is connected to the western shore. Caballo Mtns. due south in distance (Fig. b-30).

31 Submerged course of the Rio Grande. As stated earlier, the now submerged Rio Grande channel meanders back and forth across the basin-bounding Hot Springs fault six times to cut into bedrock of a margin uplift (Fig. b-0a). During Palomas time (5–0.4 my), the ancestral Rio Grande flowed completely within the Engle Basin just west of the Hot Springs fault (Lozinsky 1986). Thus, sometime between Palomas time and the present, the river has partly migrated out of the Engle Basin. The Elephant Butte area is the only place along the southern Rio Grande rift where this has occurred. How the Rio Grande was able to migrate out of the basin fill and into bedrock is an interesting question addressed in two previous studies. Lee (1907: 27) recognized this character of the Rio Grande in the first published geologic report of the area and suggested that during a lull in downcutting the river cut laterally "flowing in part over rock and in part over detrital beds . . ." to cross the Hot Springs fault. Kelley & Silver (1952: 184–185) thought that "before downcutting the Rio Grande flowed over a buried part of the north end of the Caballo Mts." Later, "with uplift of the region the Rio Grande became entrenched and soon superimposed upon the bedrock structure."

Although these theories may provide a possible explanation for the crossings around Long Point and Rattlesnake Island, work by Lozinsky (1986: 21–22) suggests they are insufficient in explaining the crossings around Long Ridge. There a model involving

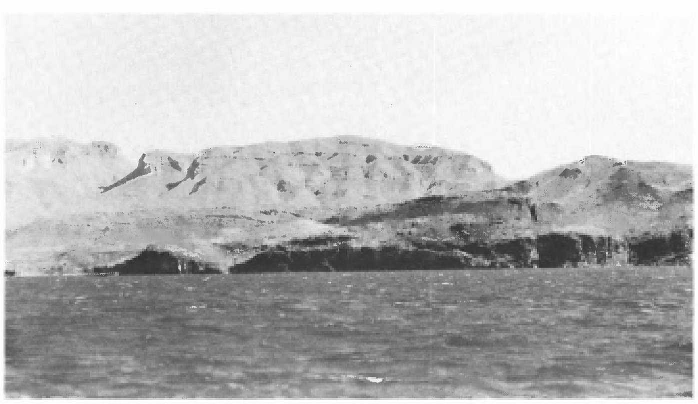

FIGURE b-27—Basaltic cliffs of Black Bluffs with good examples of columnar jointing. Fra Cristobal Range in background.

FIGURE b-30—Northern Caballo Mtns. with Turtle Mtn. Houses of Old Hot Springs Landing along shore.

stream piracy and capture may best explain the downcutting through bedrock.

32 Rock Canyon maar. Resistant cliffs around canyon are composed of pyroclastic material ejected from the maar. Good examples of crossbedding, bomb sags, and local unconformities. Clasts found within the deposit include basalt, pumice, and scattered pieces of sandstones from the Palomas Fm. Basaltic dikes later intruded the pyroclastics. The maar is interbedded with axial river deposits of the Palomas Fm.

33 Old Hot Springs and Mud Springs Mtns. Houses along shoreline are part of the settlement of Hot Springs. The original Hot Springs marina was built here, but in 1980 was moved to the present site. On the horizon to the southwest are the Mud Springs Mtns., a northeast-tilted, inter-rift horst. The peculiar "swirling" pattern sometimes seen from this angle is not folding but rather beds exposed by canyons cut into the northeast-dipping Pennsylvanian limestone.

34 Rattlesnake Island. Due to the high water level only the upper basalt flows and radial dikes are visible on the island. Underlying the basalts are typical maar deposits possessing sedimentary structures such as crossbedding, tuff breccias, convolute bedding, and bomb sags (Loeber unpubl.). A very prominent cross-cutting basaltic dike (with a nearly vertical dip) can be seen at the northern end of the island.

Lee (1907) mapped the Hot Springs fault on the east side of the island and showed the fault as offsetting the maar deposits. However, Loeber (1976) examined the fault zone at low water levels and concluded that the maar deposits are not offset. Due to the high water levels of the past few years, these observations could not be substantiated. If the maar deposits are not offset, then an age date on the basalt would constrain the timing of the most recent displacement of the Hot Springs fault. Kelly (unpublished) dated the north-end dike which intrudes the maar deposits at 2.5 ± 0.3 my.

Return to marina. Strobe light on shoreline at Lion's Beach is a device warning of high wind.

End of trip.