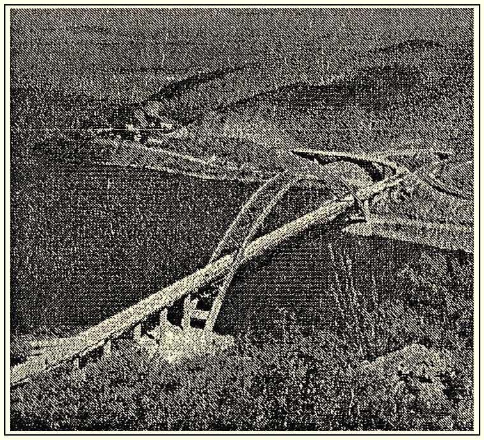
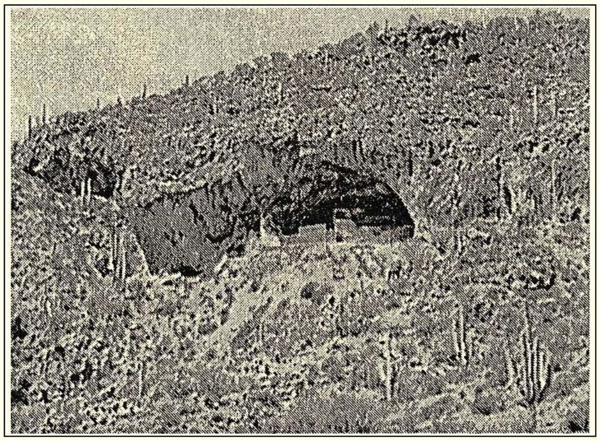
ARIZONA GEOLOGICAL SOCIETY
Fall Field Trip

Geology and Archaeology of the Theodore Roosevelt Dam Area and Tonto National Monument

November 18, 2000





Leaders: S. Richard, N. Priznar, and E. Miksa

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INTRODUCTION AND ACKNOWLEDGEMENTS

The Arizona Geological Society welcomes you to the AGS Fall Field Trip for Fall 2000. We expect this to be a rewarding and informative trip for everyone. A special welcome is extended to the Arizona Archaeological and Historical Society members in the group, all of whom will help make this trip a truly interdisciplinary experience full of a great many interesting conversations. One of the goals of this trip is to explore the influence of geology on man's activities, both modern and pre-historic. Recent mapping in 1999 by the Arizona Geological Survey in the area of the Theodore Roosevelt dam, Roosevelt Lake, and the Tonto National Monument was the original impetus for this field trip (AZGS Open File Report 99-6, 1999). The Arizona Department of Transportation and the U.S. Bureau of Reclamation have also conducted numerous investigations of the geology around the dam site and nearby highway exposures in order to design safe highway corridors around the dam and to provide for protection against flooding during a maximum probable storm event.

The pre-historic people of the Tonto Basin were also influenced in their day-to-day existence by the Precambrian rocks of Central Arizona. Whether for pot temper, tools, building construction materials, weapons, or pigment, the local rocks, rock materials, and outcrops were essential to the survival of the Tonto people. The cliff dwellings at the Lower Ruins and Upper Ruins at the Tonto National Monument were at one time thriving residential communities cradled safely in the fractured Precambrian Dripping Springs Quartzite. The overhanging cliffs provided some protection from the elements and would have given the Tonto people a defensive edge in a hostile conflict.

Several folks need to be acknowledged for their contributions as field trip leaders and authors. Field trip leader and author Steve Richard is assisted today by AZGS geologist Jon Spencer who co-authored AZGS Open File Report 99-6. Thanks go to Dr. Dale Nations for making the long journey to talk about the Tonto Basin. Nick Priznar, of the Arizona Department of Transportation leads the discussion of the history of the Roosevelt dam and subsequent modifications of the dam and nearby highway routes based on the ever-changing demands of nature. Beth Miksa of Desert Archaeology contributed the summary section on the people and culture of the Tonto Basin. Her colleagues Mark Elson and James Heidke at Desert Archaeology provided some of the information cited in the report. And lastly, the Society wishes to thank Susan Hughes of the Tonto National Monument for accomodating our large group and Steve Rudolf, Park Guide, for leading the archaeological hike to the Upper Ruins.

Corolla K Hoag
AGS Vice President Field Trips
Guidebook Compiler and Chief Miscellanist

Citations for future use:

Richard, Stephen M., Field trip to Theodore Roosevelt Dam and Tonto National Monument, 2000, *in* Hoag, C. K, compiler, Geology and archaeology of the Theodore Roosevelt Dam area and Tonto National Monument: Arizona Geological Society Fall Field Trip, Guidebook, November 18, 2000, p. 1-16.

Priznar, Nick M., Geologic site conditions and description of highway engineering works in the Roosevelt Dam area, 2000, *in* Hoag, C. K, compiler, Geology and archaeology of the Theodore Roosevelt Dam area and Tonto National Monument: A Arizona Geological Society Fall Field Trip, Guidebook, November 18, 2000, p. 17-33.

Miksa, Beth, Archaeology in the Tonto Basin, 2000, *in* Hoag, C. K, compiler, Geology and archaeology of the Theodore Roosevelt Dam area and Tonto National Monument: Arizona Geological Society Fall Field Trip, Guidebook, November 18, 2000, p. 34-40.

Promoting and encouraging interest in the science of geology and the geology of the State of Arizona since 1948.

Minor typographical changes were included prior to digitization.

FIELD TRIP TO THEODORE ROOSEVELT DAM AND TONTO NATIONAL MONUMENT, ARIZONA

Stephen M. Richard

ARIZONA GEOLOGICAL SOCIETY
FALL FIELD TRIP
NOVEMBER 18, 2000

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Introduction

This field trip will visit two areas of interest in the Tonto Basin of Central Arizona. Our first stop will be at the Theodore Roosevelt Dam, where we will discuss the geologic setting of the Tonto Basin, the engineering geology of the dam and adjacent bridge, and the stratigraphy of the interval between the top of the Mescal Limestone and the Devonian Martin Formation. The second stop will be at Tonto National Monument, where we will discuss the geologic setting of the cliff dwellings there, and the archaeology of the dwellings.

Description of Geology

Physiography

The Tonto Basin is located in the Transition zone province of Arizona, between the southern Mazatzal Mountains and Two Bar Ridge on the west and the Sierra Ancha on the east (Figure 1). A ridge of bedrock in the vicinity of Jakes Corner separates the Tonto Basin from the Payson Basin located to the north. The physiography of the Tonto Basin consists of broad terraces dissected by wide arroyos eroded by the active drainages. The terraces grade into variably dissected alluvial fans near the mountain fronts. Hills underlain by bedrock are present in a north-south zone that crosses the basin in the Windy Hill area. Elevation of the water level in Theodore Roosevelt Lake was about 2050 feet above sea level in January, 1999. Mountains flanking the basin range in elevation from 5000 feet to 7700 feet.

Rock Units

Mountain ranges surrounding the Tonto Basin consist of Early to Middle Proterozoic granitic and metamorphic rocks, overlain by Middle Proterozoic strata of the Apache Group and lower Paleozoic clastic and carbonate strata (Figure 3). Tertiary volcanic rocks crop out around the southeastern part of the basin. The Tonto Basin contains about 1700 feet of sandstone, mudstone, and conglomerate in its central part [Nations, 1987, 1988; Anderson et al., 1987; Richard, 1999]. These basin-fill deposits range in age from Early Miocene to Quaternary.

Precambrian and Paleozoic rocks

The southern Mazatzal Mountains consist mostly of a variety of Early and Middle Proterozoic granitic rocks. Starting about 4 miles NW of Theodore Roosevelt Dam, and southward onto Two Bar Ridge, these granitic rocks are overlain by sandstone, mudstone, quartzite, and limestone of the Apache Group, and intruded by diabase sills [Spencer and Richard, 1999]. The Sierra Ancha, which lies on the northeast side of the basin, consists mostly of sandstone, mudstone, quartzite, and limestone of the Apache Group and Troy Quartzite [Shride, 1967]. Very thick diabase sills have intruded these strata and now crop out over large parts of the mountain range. Northeast of the northern end of Theodore Roosevelt Lake, Middle or Early Proterozoic granitic rocks that underlie the Apache Group are exposed along the southwestern front of the Sierra Ancha [Bergquist et al., 1981].

Devonian and Mississippian sandstone, limestone and dolomite are preserved on the southwest side of the basin in the area immediately north and south of the Theodore Roosevelt Dam, and on the northeast side of the basin in the area just west of Armer Gulch. Thin Cambrian(?) sandstones are preserved in channels locally cut into the underlying Apache Group in these areas. Devonian rocks are the most widely distributed Paleozoic strata in this area, and typically include a basal sandstone member locally mapped as the Becker's Butte Member [Teichert, 1965]. The stratigraphy of overlying interbedded dolomite, marl, shale, and sandstone is variable between outcrops. Mississippian strata are mostly limestone with sparse sandstone, correlated with the Redwall Limestone [Purves, 1978]. Conodont alteration index numbers of 1-2 from Mississippian limestones [Wardlaw and Harris, 1984] indicate that these strata have never been deeply buried.

The unconformity at the base of Devonian strata transects stratigraphy in the underlying formations. In lower Mills Canyon, about 3 km north of the Salt River, the Devonian is deposited on diabase that forms a thick sill regionally intruded into the upper part of the Pioneer Formation. Just south of Theodore Roosevelt Dam, basalt and the upper argillite member of the Mescal Formation are present, as well as a thin sandstone unit interpreted to be the Troy quartzite [Spencer and Richard, 1999]. About 3 km southeast of the dam, Cambrian(?) sandstone and Devonian strata are preserved in a paleovalley cut into the Dripping Spring Quartzite. On the northeast side of the Tonto Basin, Devonian strata overly upper Dripping Spring Quartzite or lower Mescal Limestone in the hills north of Windy Hill, and Dripping Spring Quartzite in the southeastern Sierra Ancha.

Tertiary rocks

Tertiary basin fill strata consist of conglomerate, sandstone, and mudstone, with minor evaporite and carbonate beds. Nations [1987, 1988, 1990] identified two facies within this sequence, which he informally named the Tonto Basin formation. These are a basal and basin margin conglomerate facies and an upper and basin center fine-grained facies. The conglomerate facies consists of poorly stratified, very poorly sorted conglomerate. Clasts are locally derived and reflect the rock types present in nearby bedrock exposures. The conglomerate facies in the southern part of the basin contains abundant cobbles and boulders derived from Tertiary volcanic rocks, particularly the Apache Leap Tuff, which crop out around the south side of the Tonto Basin. The basin fill strata are younger than Apache Leap Tuff (18.6 Ma, McIntosh et al., 1998) in the southern part of the basin. The lower age limit is presently bracketed by the presence of a late Miocene or Pliocene vertebrate fossil in the mudstone member in the northern part of the basin. A K-Ar date of 18.6 Ma from a tuff interbedded near the top of the section in the northern part of the basin [Nations, 1987] suggests that much of the basin fill sequence in the Punkin Center area is older than the lower conglomerate in the southern part of the basin, and may in fact be correlative with strata referred to as Whitetail conglomerate in the southern part of the basin.

Much of the central part of the Tonto Basin is underlain by a red-brown to tannish-gray mudstone and very fine-grained sandstone facies of the Tonto Basin formation. Lance et al. [1962] measured 3 stratigraphic sections in the area around Punkin Center and proposed a stratigraphic sequence as follows: 1) a sequence of red beds, consisting of sandstone and mudstone; 2) a zone up to 300 feet thick of red beds containing abundant gypsum; and 3) a few tens of feet of light colored beds of clay, silt, tuff, and marl, which contains the fossiliferous beds. The gypsiferous zone thins northward, and the red-brown mudstone is overlain by conglomerate, and grades northward into conglomerate exposed around the northern margins of the basin (Tsy and Tcp of Ferguson et al., 1998). The mudstone overlies Rock Island conglomerate facies of the Tonto Basin Formation in the area between Rock Island and Pinto creek, but the details of the relationship between facies in the Tonto Basin formation have not been described in the literature.

Quaternary deposits

Quaternary alluvial deposits, which blanket much of the Tonto Basin; consist of non-indurated to moderately indurated, poorly stratified, moderately to poorly sorted conglomerate with scattered sandy lenses. The deposits form thin veneers (2-10 m) on pediment-terraces [Royce and Barsch, 1971; Anderson et al., 1987] that are cut into fine-grained basin fill deposits, and form terraces along major drainages incised into the basin fill sequence. Alluvial deposits in the terrace deposits may be more than 20 m thick in places. Near the basin margins, it becomes quite difficult to distinguish Quaternary pediment-veneer deposits (units Qm, Qo) from the younger conglomerate facies of the basin fill sequence (unit Tsy where differentiated). Deposits in the active flood plains of major drainages (Units Qycr, Qyr on Figure 3) contain rounded to well rounded clasts from a wide variety of sources. Terrace deposits representing accumulations of older floodplain deposits (units Qlr, Qmlr, Qmr, and Qor) also contain a wide variety of clast types and well rounded to rounded clasts. Old alluvium that forms pediment veneers and alluvial fans (Ql, Qml, Qm, Qo) generally contains more angular clasts (rounded to sub-angular), and an assemblage of clasts that represent rocks in the local drainage basin. Anderson et al. [1987] report that the older Qm and Qo deposits are commonly blanked by 2-25 cm of "fine grained deposits" that may be loess. North of Theodore Roosevelt Lake, older locally derived deposits (Qm, Qo) contain angular to sub rounded, locally derived clasts southwest of Tonto Creek, but on the northeast side of Tonto Creek these deposits are mantled by sub-rounded to rounded clasts derived from the Sierra Ancha [Ferguson et al., 1998].

Geologic History and Tectonics

Rocks in the Tonto Basin area record the effects of Proterozoic, Laramide(?) and middle Tertiary deformation events. Early or Middle Proterozoic granitic rocks form most of the basement throughout the Mazatzal Mountains and Sierra Ancha adjacent to the study area. These granites are intruded into a poorly understood boundary zone that separates the Mazatzal block on the north from the Pinal block on the south [Karlstrom and Bowring, 1991]. Contrasting assemblages of Early Proterozoic metasedimentary and metavolcanic rocks characterize the Mazatzal and Pinal terranes [Anderson, 1989]. Rocks of the Pinal block are some 20 Ma younger than those of the Mazatzal block. The granitic plutons in this boundary zone locally contain weakly developed, steeply dipping and northeast-trending (about 030°) foliation, and a few northeast-trending mylonite zones [Spencer and Richard, 1999]. These plutons have commonly been interpreted to be Middle Proterozoic [Reynolds, 1988; Anderson, 1989; Karlstrom and Bowring, 1991], but new U-Pb data from similar granitic rocks in the Usery Mountains [Isacson et al., 1999] suggests that some of the locally foliated granites in the boundary zone may be Early Proterozoic.

Clastic rocks of the Middle Proterozoic Apache Group and the Troy Quartzite were deposited on deeply eroded Early Proterozoic crystalline rocks [Shride, 1967; Wrucke, 1989]. These sedimentary rocks were intruded by large volumes of diabase at about 1100 Ma [Wrucke, 1989]. The diabase intruded as thick sills, and forms a significant part of the stratigraphic section in the preserved Apache group. High angle faulting must have accompanied intrusion of the sills, as indicated by abrupt changes in sill thickness and stratigraphic position across high-angle faults.

After a long (>500 Ma) period of inactivity, Paleozoic strata were deposited on Apache Group on an erosional surface of low relief. Some faulting and gentle tilting also predated deposition of the Paleozoic section, indicated by regional pinch out of Upper Apache group strata beneath the Paleozoic section [Shride, 1965; Wrucke, 1989].

Laramide structures are difficult to identify because of the absence of Late Cretaceous to early Tertiary rocks that would allow distinction of Mesozoic and Tertiary structures. Laramide monoclines and thrust faults have been identified north [Reynolds, 1998], east [Davis et al., 1981], and south [Richard and Spencer, 1998] of the Tonto Basin. One fault located south of Theodore Roosevelt Dam has been identified as a possible Laramide monocline [Spencer and Richard, 1999]. Other faults in the Sierra Ancha and Mazatzal Mountains may have Laramide movement as well.

Erosional removal of Paleozoic strata from the Sierra Ancha and in the Superstition Mountains predates eruption of early Miocene volcanic rocks, and is probably due to uplift and erosion in Late Cretaceous-Early Tertiary time. A major northeast-flowing drainage followed the present course of the Salt River Canyon northeast from the Tonto Basin in early Miocene time [Faulds, 1988, 1989; Potochnik, 1989; Potochnik and Faulds, 1998], and probably drained a Laramide orogenic highland (Mazatzal highlands) [Peirce et al., 1979]. The Apache Leap tuff (18.6 ±0.1 Ma [McIntosh and Ferguson, 1998]) flowed northeastward in this paleocanyon from a source to the southwest [Faulds, 1986; Potochnik and Faulds, 1998].

The net effect of Laramide and Middle Tertiary deformation is the northwest-trending regional synclinal structure of Paleozoic rocks in the central part of the Tonto Basin (see cross sections). This regional structure is delineated by northeast-dipping Precambrian Apache Group and Paleozoic strata in the Theodore Roosevelt Dam area, and southwest-dipping correlative strata in the Windy Hill and southwestern Sierra Ancha are. The timing of deformation to produce this tilting is not well constrained. The mesa-like, nearly horizontal Apache Group, Troy Quartzite and sparse Paleozoic strata of the Sierra Ancha are essentially part of the Colorado Plateau.

Available data on the age of basin fill suggest that mudstone and conglomerate in the basin east of Windy Hill may be younger than similar strata in the northwestern part of the basin, and southeast of the basin along the Salt River. Accumulation of sediment in the northern Tonto Basin began before eruption of the Apache Leap Tuff, based on a K-Ar date of 18.6±0.6 Ma from tuff in the upper part of the mudrock facies of the Tonto Basin formation (sample TB20 [Nations, 1987]). At the southeastern end of the basin, Apache Leap Tuff overlies conglomerate correlated with Whitetail conglomerate [Faulds, 1986; Potochnik and Faults, 1998]. This conglomerate apparently accumulated in the paleocanyon described above, because it thickens dramatically in the central part of the paleocanyon, and pinches out to the north and south (see cross section A-A', Potochnik and Faulds, 1998, p. 154). On the southwestern margin of the basin, the Rock Island Conglomerate facies of the Tonto Basin formation overlies Apache Leap Tuff [Nations, 1987], and conglomerate of this unit contains clasts of Apache Leap Tuff. Cuttings from an oil exploration well drilled in the south central part of the basin suggest the presence of Apache Leap Tuff at a depth of about 1700 feet beneath the surface (Sanchez-O'Brien Federal 1-4 [Richard, 1999]).

The youngest faults in the map area cut mudstone and conglomerate units that are interpreted to be Middle or Late Miocene in age [Nations, 1987]. These faults bound the southwestern side of the Tonto Basin [Royse and Barsch, 1971; Anderson et al., 1987; Ferguson et al., 1998; Spencer and Richard, 1999]. Gentle southwestward tilting of basin-fill strata is interpreted to be the result of displacement on these faults [Ferguson et al., 1998]. The faults are overlapped by conglomerate deposited in alluvial fans along the basin margins and in the flood plain along the ancestral Salt River and Tonto Creek. Geomorphic analysis by Anderson et al. [1987] suggests that the oldest of these conglomerate units are capped by geomorphic surfaces of probably Pliocene age.

Cessation of tectonic activity occurred before integration of the Salt River into the regional drainage system, which immediately predates the formation of the highest preserved geomorphic surfaces. The history of the basin subsequent to the integration of the Salt River has been one of progressive erosion of basin fill deposits. This erosion has been episodic, resulting in the formation of 10 or more geomorphic surfaces within the basin [Royse and Barsch, 1971; Anderson et al., 1987]. These surfaces record climate variations and possible tectonically induced base level changes, but the detailed chronology of surface formation, and the dynamics of the geomorphic processes that form the surfaces are uncertain.

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Field Trip Log

Meet in parking area on the north Side of Arizona Highway 88 (Apache Trail) between the intersection with Arizona Highway 188 (north to Payson) and Theodore Roosevelt Dam. We will first have an introduction to the region, and a discussion of the engineering of the dam and highway bridge, then walk along the Apache Trail to inspect outcrops.

Stop 1.

Geologic Setting of Theodore Roosevelt Dam and Bridge

Nicholas Prizner, Arizona Dept. of Transportation

This section based on Kiersch (1985).

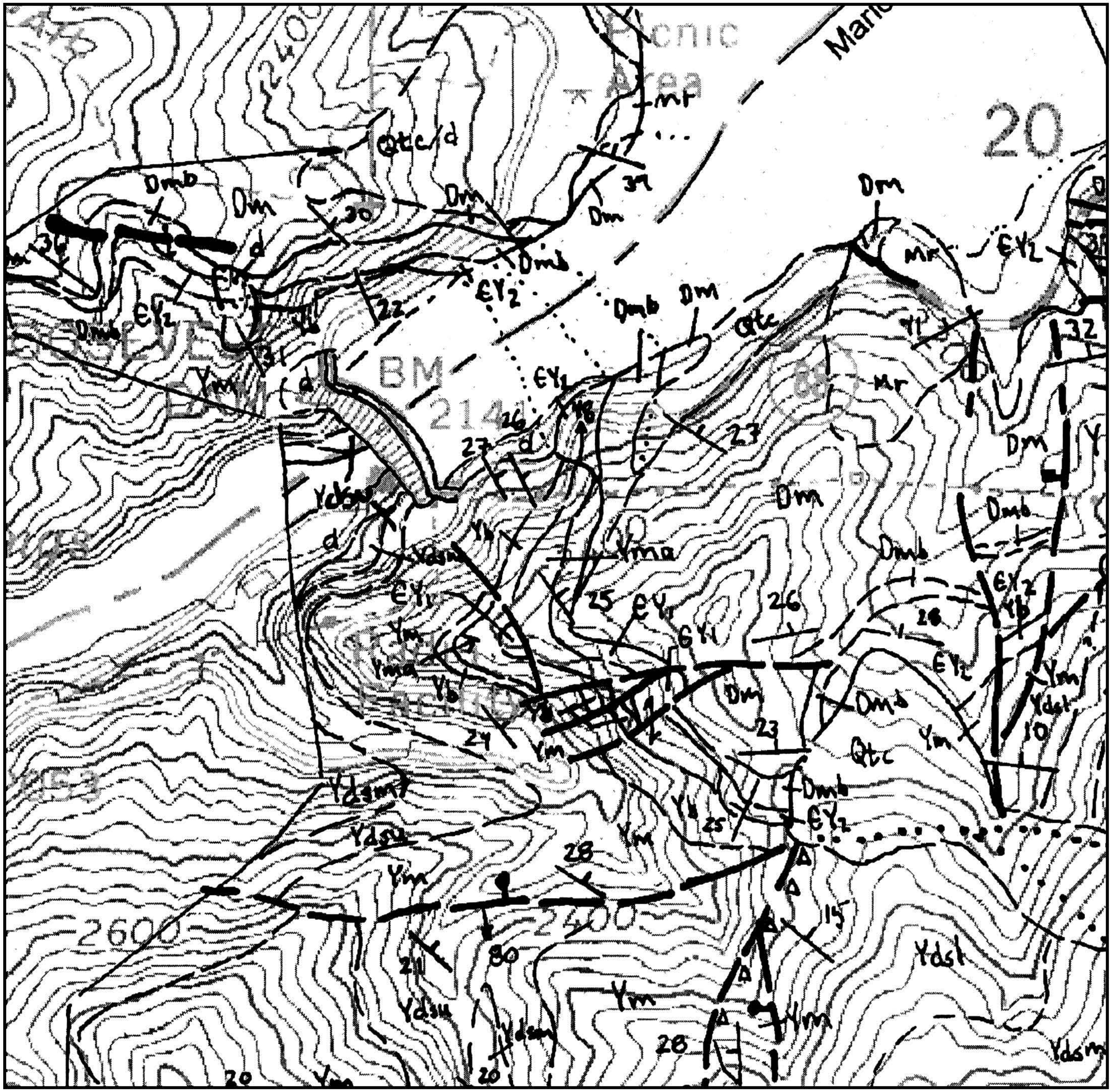
The principal formations in the vicinity of Theodore Roosevelt Dam and the Arizona Highway 188 bridge sites are the Younger Precambrian Mescal Limestone and-Troy Quartzite, the Devonian Martin Formation, and the Mississippian Redwall Limestone. These rocks have been deformed, faulted, and displaced several times throughout geologic history. Paleozoic rock of the Martin and Redwall Formations throughout the region have been largely removed by erosion during Laramide and mid-Tertiary time. Only isolated blocks of Martin and Redwall rocks remain today near the Salt River canyon in the area of the dam, and along Roosevelt Lake at Windy Gap, about 7 km east of the dam.

Generally NW-trending faults (parallel to the lake) are associated with northeastward tilting of strata in the area of the dam. Some of these faults flatten with depth and become bedding-faults. Numerous NW-trending faults occur in the vicinity of the bridge site on both the west and east walls. These faults commonly dip steeply and may exhibit either normal or reverse movement; the latter movement has repeated parts of the rock column in east wall outcrops of the Martin Formation between Highway 88 dam access road junction and the east pier site.

Faulting associated with the regional tilting was followed by a period of younger Basin and Range faulting that (13 to 4 Ma). Many N-S faults formed at this time, further displaced and segmented into fault-blocks the northeastward titled rocks along the southwest side of the Tonto Basin. One such N-S fault occurs in the canyon immediately east of the approach-sector and boring B-4 location.

An evaluation of information available in 1984, indicated that the ancestral Salt River drainage adjusted by accelerated downcutting across the Mazatzal Mountain block during Middle Tertiary orogenic activity, beginning about 20 m.y. ago (Kiersch, 1985). Boulders and cobbles of granite, basalt, and limestone, along with channel debris and cemented gravels blanket the bench-like area carved in

Mescal Limestone at about 2,400 feet above sea level, situated directly above the spillway of Theodore Roosevelt Dam. These deposits are interpreted to be remnants of a paleo-Salt River channel, higher, and much wider than the present canyon. The evidence indicates that the existing Salt River channel is superimposed--it has been carved into bedrock as uplift accelerated the downcutting process of an already established ancestral Salt River.



Detailed Geologic Map of the Theodore Roosevelt Dam Area

By J. E. Spencer and S. M. Richard
1999

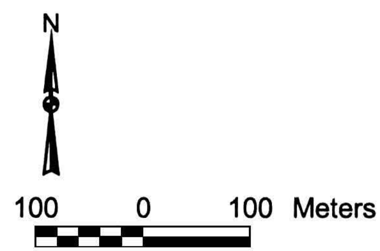
Extracted from Fig. 4, Arizona Geological Survey OFR 99-6

Explanation of Units

d -- Deposits resulting from human activity
Qs -- Undivided surficial deposits (Quaternary)
Qtc -- Talus and colluvium (Holocene)
QTs -- Conglomerate (Pliocene or Miocene)

Mr -- Redwall Limestone
Dm -- Martin Formation
DMb -- Martin Formation, Becker's Butte Member
CY2 -- Bolsa Quartizte
Ydb -- Diabase intrusions
CY1 -- Troy Quartzite

Apache Group (Middle Proterozoic)
Yma -- Mescal Limestone, upper argillite
Yb -- Basalt Lava
Ym -- Mescal Limestone
Yds -- Dripping Spring Quartzite
Ydsu -- Thin-bedded varicolored quartzite
Ydsm -- Interbedded shale, fine-grained sandstone and vitreous quartzite
Ydsl -- Thick-bedded vitreous quartzite



Stop 2

Troy, Bolsa, and Martin channels in the top of the Mescal Limestone

Discontinuous sandstone units representing the Troy quartzite, Bolsa Quartzite, and Beckers Butte Member of the Devonian Martin Formation overlie Apache Group strata and underlie dolomite or fossiliferous sandstone of the Martin Formation. Distinction of these units is difficult because of the lithological similarities of the sandstone and rapid thickness variations. All three units are exposed on the southeast side Theodore Roosevelt Dam, where a 90-foot-deep channel has been incised into Troy Quartzite, Mescal Limestone, and basalt (Yb). The channel fill includes a lower ferruginous sandstone, overlain by very poorly sorted feldspathic sandstone (See detail map, Figure 2). We have assigned the lower unit to the Bolsa Quartzite. It is typically ferruginous in its lower part, but variably bleached in the upper part to produce Liesegang banding. Sand is moderately sorted, feldspar is not a prominent constituent, but in some places magnetite is common. Troughy cross beds are abundant.

Overlying poorly sorted, iron poor, pale colored sandstone within this channel fill is assigned to the Beckers Butte Member. Coarse, angular feldspar fragments are present in this sand. Cross bedding is common, and boundaries between beds are not sharp. The sand generally becomes finer up section and greenish clay-rich bedding partings are present. Detrital(?) muscovite is commonly visible on these parting surfaces. A Devonian age for these strata is supported by paleomagnetic analysis (Elston and Bressler, 1978), and is consistent with Teichert's (1965) interpretation of this channel-fill as Beckers Butte Member.

Teichert (1965, p. 22) describes the Beckers Butte Member as consisting of "predominantly poorly sorted quartz grains that range from fine to coarse" and that "it differs from most sandstone subunits of the Jerome Member, which are generally well sorted." Feldspar and chert are locally minor components of the Beckers Butte Member, and most grains are subangular to angular. At Theodore Roosevelt Dam sandstone of the Beckers Butte Member is "easily distinguished by its susceptibility to disaggregation in hydrochloric acid, whereas the Troy Quartzite has siliceous cement and cannot be so disaggregated." (Teichert, 1965, p. 25). [See also Ransome (1916, p. 150-162), Hinds (1936, p. 33), and Huddle and Dobrovolny (1952, p. 105-106)]. It is not clear if the Troy referred to by Teichert (1965) is the sandstone we are assigning to the Troy (see below), or if it is the sandstone underlying the Beckers Butte Member in the channel fill sequence, which we assign to the Bolsa Quartzite.

On the south flank of the channel, the stratigraphically highest part of the Mescal Formation (argillite member) is preserved, and is overlain concordantly by sandstone we assign to Troy Quartzite. This sandstone is also red brown in color, but has sharp, nearly planar bedding boundaries, and while the unit as a whole is poorly sorted (contrasting with our Bolsa quartzite), grain size variations within individual beds are smaller than grain size variations between beds (contrasting with the Beckers Butte member). This unit also contain red-brown mudstone partings.

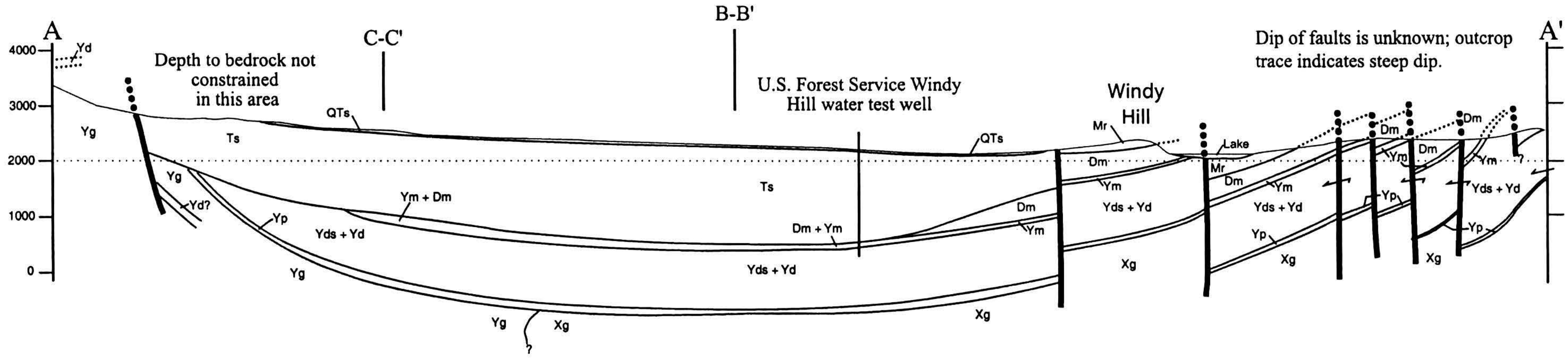
In lower Cottonwood Canyon, about 2.5 km southeast of the dam, pale gray sandstone, mapped as Beckers Butte Member of the Martin Formation, overlies brown sandstone mapped as Bolsa Quartzite. The Bolsa Quartzite occupies a channel cut into the upper Dripping Spring Quartzite. Apparent preservation of thicker, coarser-grained Beckers Butte Member on top of Bolsa Quartzite channel fill suggests that the channels in which sand accumulated during Bolsa Quartzite deposition persisted into Beckers Butte time as slightly wider channels. Sandstone we interpret as Troy Quartzite is preserved on top of Mescal argillite or the basalt that directly underlies the argillite. Although fragments of chert and basalt from the underlying units and onlap across older units indicates pre-Troy erosion, the Troy sands do not appear to be preserved in channels.

The Proterozoic diabase that intrudes the Apache Group was widely exposed when marine transgression began deposition of the Cambrian Bolsa Quartzite, and, in our interpretation, the highly ferruginous and magnetite-rich debris derived from the diabase was progressively less abundant as Bolsa Quartzite was deposited and diabase exposures were buried. This interpretation is supported by exposures in upper Roblas Canyon in the Picketpost Mountain quadrangle about 35 km (20 miles) to the south where a thick section of sandstone overlies diabase and contains a basal conglomerate with diabase cobbles. The sandstone is magnetite rich and chocolate brown at lower stratigraphic levels, and becomes increasingly clean and light colored over many tens of meters up section (Spencer and Richard, 1995). It is possible that Beckers Butte Member locally contains much sand derived from the diabase where it was not covered by Bolsa Quartzite, and so criteria outlined here for distinction are not definitive.

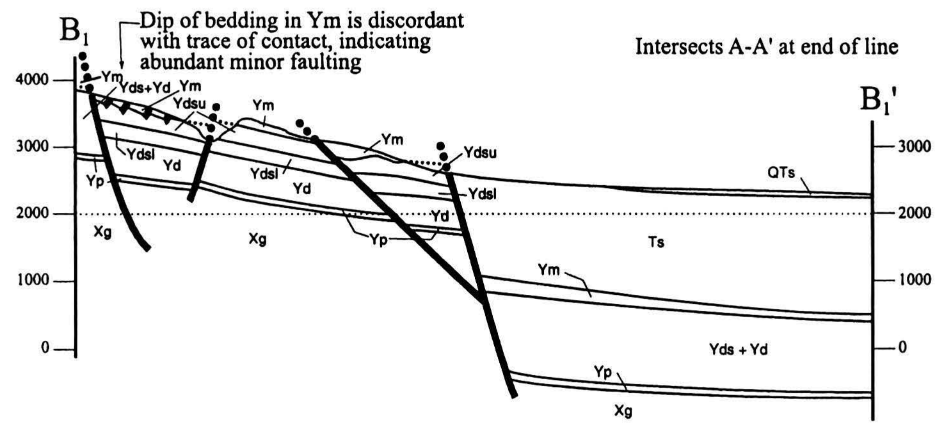
Stop 3

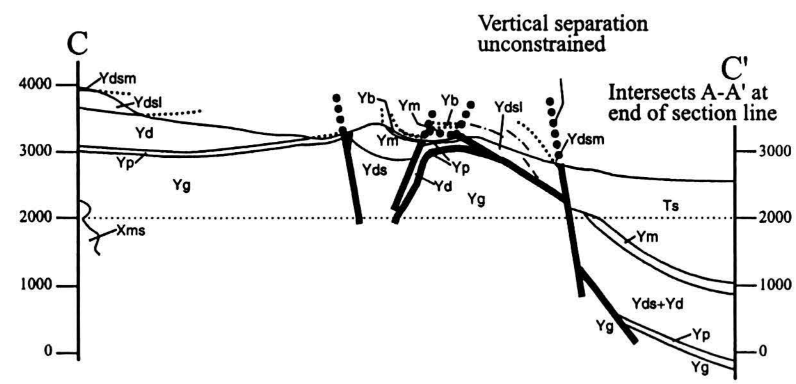
Tonto National Monument

Cross Sections of the Tonto Basin in the Tonto National Monument-Windy Hill Area

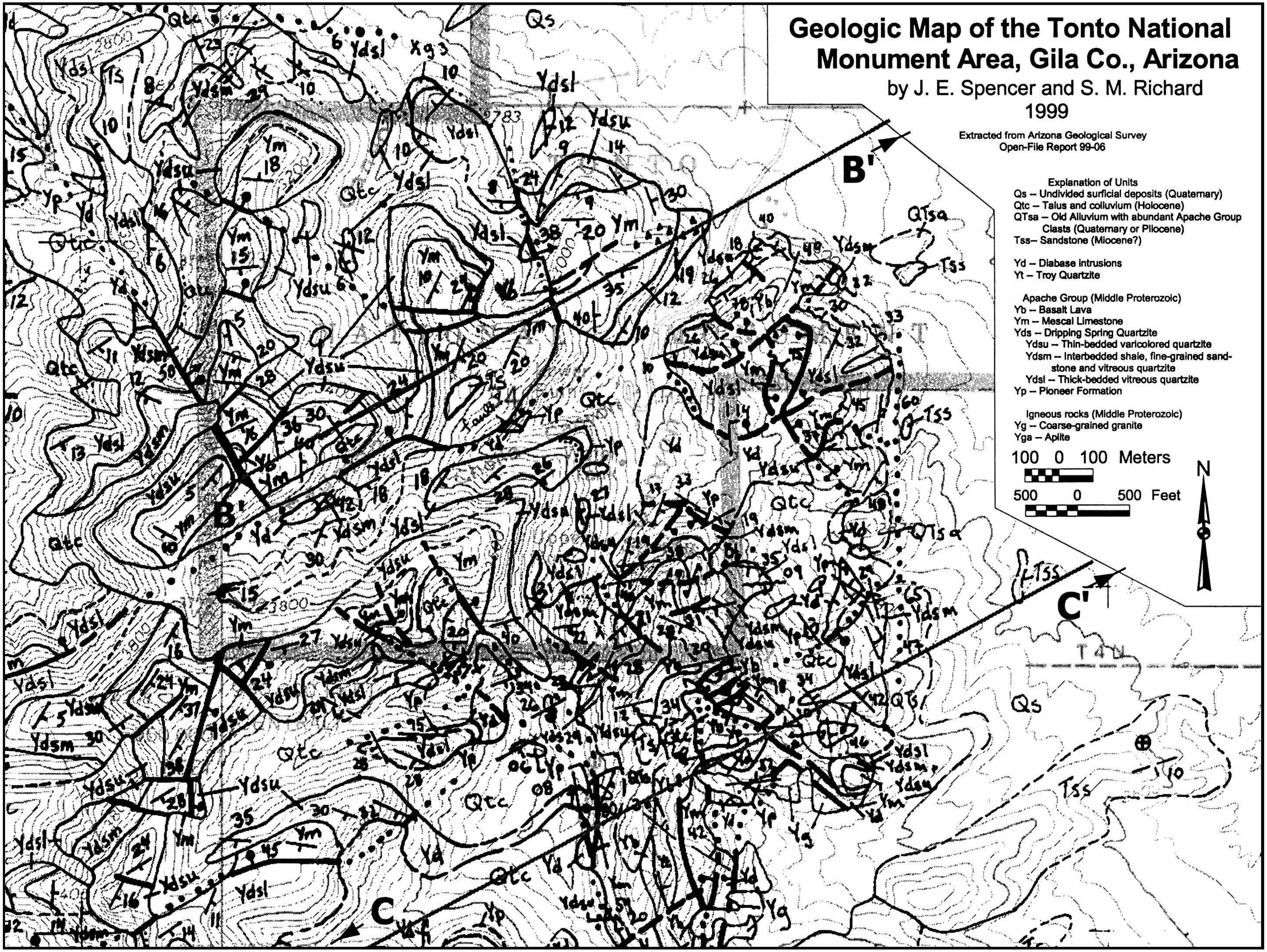


Tonto National Monument





Cross Sections from Spencer et al., AZGS OFR99-12


Geologic Map of the Tonto National Monument Area, Gila Co., Arizona
by J. E. Spencer and S. M. Richard
1999
Extracted from Arizona Geological Survey Open-File Report 99-06
Explanation of Units
Qs – Undivided surficial deposits (Quaternary)
Qtc – Talus and colluvium (Holocene)
QTsa – Old Alluvium with abundant Apache Group Clasts (Quaternary or Pliocene)
Tss– Sandstone (Miocene?)
Yd – Diabase intrusions
Yt – Troy Quartzite
Apache Group (Middle Proterozoic)
Yb – Basalt Lava
Ym – Mescal Limestone
Yds – Dripping Spring Quartzite
Ydsu – Thin-bedded varicolored quartzite
Ydsm – Interbedded shale, fine-grained sandstone and vitreous quartzite
Ydsl – Thick-bedded vitreous quartzite
Yp – Pioneer Formation
Igneous rocks (Middle Proterozoic)
Yg – Coarse-grained granite
Yga – Aplite
100 0 100 Meters
500 0 500 Feet
N
B
B'
C
C'

Geologic Site Conditions and Description of Highway Engineering Works, In the Roosevelt Dam Area

Nick M. Priznar, Engineering Geologist, Arizona Department of Transportation.

Roosevelt Dam, constructed and modified by the Bureau of Reclamation, and operated by the Salt River Project is located approximately 40 miles north west of Globe and 60 miles north east of Phoenix. State Routes 88 and 188 were relocated to accommodate modifications to the dam from 1985 through 1995. The highway engineering works consisted of constructing a new steel arch bridge upstream of the existing dam, re-routing SR 88 around the new dam infrastructure, and mitigating adversely oriented, and karstic strata that would impact the bridge foundation and the approaching highway corridor on both sides of the bridge. The geology in the area had a significant effect on the engineering and construction efforts necessary to accommodate these objectives.

The steep walled Salt River gorge (initially called the Tonto Dam site), was identified in the late 1800s ideal location for a large capacity flood control and irrigation structure to foster agricultural development in the Phoenix region. Economics prevented private development of the site. However, the newly formed Reclamation Service accepted the challenge of constructing its first masonry, thick arch gravity dam, in central Arizona, in 1903. Construction activity continued until 1911.

The original 280 foot high structure was founded in the Dripping Spring Formation and the Mescal Formation, a decision that proved to be very fortuitous. Certain strata in the Dripping Springs Formation not only made excellent founding material, it was also an excellent construction medium. Unconfined compressive testing originally estimated that selected strata of Dripping Spring sandstone averaged 1,400 tons per square foot and cement produced from the nearby Redwall Limestone crushed at an average 500 tons per square foot (Jackson,1992). These parameters are well in excess of the structural characteristic envisioned at the time which were only 20 tons per square foot. Additionally the "well developed sedimentary bedding dipping upstream at 20 to 30 degrees and striking cross canyon at N 40 W" (USBR,1997) created an ideal natural quarry in the two spillways on either side of the dam. Therefore a large portion of the excavated material was easily shaped and lower into the gorge by way of a simple cableway and derricks. The crest of the dam was approximately 16 feet wide, and used for a roadway, which was barely enough to room to allow two converging model-T ford automobiles to pass each other as they traversed the dam from either direction.

In 1986, modification began on the existing dam to mitigate safety of dams issues associated with the probable maximum flood. Modification activities were completed in 1996. The dam height was raised to 357 feet, and impounded 1.6 million acre feet of water. This was achieved by placing a layer of mass concrete on the downstream face of the structure. The process involved constructing a series of block forms 10 feet thick, 50 to 70 feet wide. The forms were incrementally attached to and poured against the existing dam to create the aesthetic flowing structural lines that are visible today. To fill the forms Quaternary Sediments were mined for rounded stubby aggregate from a borrow source located downstream of the confluence of the Salt River and Pinto Creek (in the vicinity of Grapevine Gulch). The sediments were screened to pass through a 4 inch mesh and washed. When the processed material was combined with Portland cement it resulted in a mass concrete product with a design strength that ranged between 3,000 to 5,000 psi. "The new dam was completed with over 200 individual concrete placements." (USBR,1997) Consequently the additional 77 feet in elevation necessitated rerouting most of the highway infrastructure in the immediate vicinity of the modified dam. The existing spillway structures were removed from both abutments and replaced by the thrust blocks. The thrust blocks provide abutments above elevation 2100.0

GEOLOGIC SETTING (Modified and abstracted from Kiersch 1985)

The Roosevelt Lake/Dam area is located within a region of very old sedimentary rocks that overlie Precambrian granites. The principal formations in the vicinity of the bridge sites are the Younger Precambrian Apache Group-Troy Quartzite, the Devonian Martin Formation and the Mississippian Redwall Limestone. These rocks have been deformed, faulted, and displaced several times throughout geologic history. However, only the more recent events of the past 20 million years (Mid-Tertiary Orogeney) are particularly relevant to the features and conditions of the rocks nearby the bridge site.

The Apache Group and Troy rocks were deposited on the Old Granite followed by the overlying Paleozoic Martin and Redwall Formations that once covered the entire region. The two Paleozoic rock units have been largely removed by massive erosion throughout the region since the strong mid-Tertiary deformation with uplifting and accelerating erosion was initiated. Only isolated blocks of Martin-Redwall rocks remain today near the west and east walls of Salt River canyon and Roosevelt Lake at Windy Gap.

The strong tectonic upwarping of the Mazatzal Mountains and Roosevelt Lake region about 19 million years ago reactivated some old Precambrian and Mesozoic faults and developed the main regional-areal structural features known today. The rock column was initially folded/deformed by NW-trending fold axis that formed such features as the Tonto Basin. This regional folding with tilting formed a homoclinal-block of Precambrian-Paleozoic rocks (Granite/Apache-Martin-Redwall) along the northwest-trending Mazatzal Mountains and the Salt River canyon to the southeast. The regional tilting northeastward that occurred 19.2 to 14.2 million years ago (Scarborough, 1981) caused a major NW-synclinal fold axes to form within the rocks of the Tonto Basin; contemporaneously numerous subsidiary folds formed throughout the fault-broken, homoclinal mass of rocks. Regionally the rock column (Apache-Martin-Redwall beds) are upfolded and block-faulted northward of the Tonto Basin and crop out in the Sierra Ancha Mountains as bold cliffs and mesa like caprock of fault-block masses along the Mogollon Rim and Colorado Plateau.

The prominent NW-trending faults (parallel lake) impart steep NE dips to the beds, but sometimes flatten with depth and become bedding-faults. Numerous NW-faults occur in the vicinity of the bridge site on both the west and east walls. These faults commonly dip steeply and may exhibit either normal or reverse movement; the latter movement has repeated parts of the rock column in east wall outcrops of the Martin Formation between Highway 88 dam access road junction and the east pier site.

Faulting associated with the regional folding (19 to 14 m.y. ago) was followed by a period of younger Basin and Range Faulting that occurred 13 to 4 m.y. ago. Many N-S faults formed at this time, further displaced and segmented into fault-blocks the northward dipping homoclinal mass of Granites-Apache-Paleozoic rocks of the Roosevelt Lake region. One such N-S fault occurs in the canyon immediately east of the approach-sector and boring B-4 location.

In the past few million years, Pliocene-Pleistocene sediments were deposited throughout the valleys of Salt River and Tonto Creek (Tonto Basin). The strong terraces carved in these Basin beds along the Salt River and Tonto Creek channels-and well represented in the pre-lake channel north of both the east and west pier sites, are not related to faulting. Terraces occur at several elevations in the Tonto Basin and represent Pliocene levels of the former river system.

Origin of Salt River Channel Near Dam

An evaluation of all information available (*in 1984*), indicates the ancestral Salt River drainage adjusted by accelerated downcutting across the Mazatzal Mountain block as arching and uplift occurred (beginning about 20 mil. yr. ago). Furthermore, boulders and cobbles of granite, basalt, and limestone along with channel debris and cemented gravels, are remnants of an earlier channelway. This relict drainage feature, flowed over the bench-like area carved in Mescal Limestone at about elevation 2,400 feet, and was situated on the west wall directly above the spillway of the dam. This evidence shows the location of the higher, much wider ancestral channel of the Salt River.

No direct evidence is known for fault(s) within the main bedrock channel of the Salt River channel of the Salt River upstream of Roosevelt Dam that parallel the channel and thereby traverse the alignment for the bridge. All evidence indicates the Salt River channel has been selectively carved in the bedrock as uplift accelerated the down cutting process of ancestral drainage.

THE ROOSEVELT STEEL ARCH BRIDGE

Background Information

Roosevelt Lake Bridge was designed by Howard, Needles, Tammen & Bergendoff (HNTB) for the Arizona Department of Transportation in 1986 and1987. The $21.3 million bridge was built to take traffic off the top of Roosevelt Dam. Construction began in October 1987. The bridge was completed and opened to traffic in October 1990. The bridge is the longest two lane, single span, steel arch bridge in North America. The structures overall design, size, eye-appeal and design challenge won it distinction from the American Consulting Engineers Council. It has been awarded status as one of the top 12 bridges in the nation.

The arch span is 1080 feet long and is symmetrical about the centerline of the roadway. The roadway width is approximately 38 feet. The horizontal distance between the centers of the arch ribs is 50 feet. The steel arch is anchored into two parallel massive concrete arch rib footings on either side of the structure. The entire lower portions of the footings were designed to be 24 feet wide 40 feet long and a minimum of 12 feet thick. Excavation into sound bedrock approached 35 feet depth on the west abutment. The contractor (Edward Kramer & Sons) found it easier to construct one large pit for each pair of arch rib footings. After construction of the rib footing the excavation itself was back filled with structural concrete.

GEOLOGIC CONDITIONS AFFECTING THE FOUNDATION OF THE ROOSEVELT STEEL ARCH BRIDGE

Roosevelt lake bridge lies in a region of gently dipping sedimentary rocks incised by predominately north-northeast trending drainages. Slopes are generally steep with occasional outcrops of resistant rock layers. Natural slopes in the area generally have an overall slope angle between 15 and 25 degrees (Dames & Moore, 1985).

Previous geologic work conducted by Ramsome (1916), Kiersch (1985) and Wellendorf (1987) for USBR suggested that the bridge foundations were located within Paleozoic Limestone. Specifically the Redwall Limestone (Mississippian) and the Martin Formation (Devonian). Furthermore several faults in the area appear to effect bedding within the construction limits of the bridge. The subsurface conditions for the bridge foundation and approaches were investigated by Kiersch (1985) and Dames and Moore (1985).

> "The east and west piers are founded on thinly-bedded limestones with minor interbeds of shale/claystone or sandstone. Associated weathering along joints/bedding planes (with clay seams, and partings) have weakened the rock mass to a depth 35 feet or more, before rock-quality improves." "Rock formations dip 30 to 40 degrees northward at both piers." A cavernous zone occurs near the Redwall Martin contact. "The subsurface was investigated by core boring, *(and indicated that)* bedrock dips are flatter than friction of bedding planes (Kiersch, 1998)."

The structural relationships between the Paleozoic rocks are illustrated by Kiersh's Geologic Cross-Section of the East Bridge Abutment (see attachments). The cross section *(which is perpendicular to the highway alignment)* exhibits an upper locally distressed block of Redwall/Martin lithologies in contact with a more steeply dipping Redwall/Martin block which is normally concealed by debris. *(NOTE: The highway depicted in the cross section is the former highway position, the new bridge alignment is depicted by east pier and east abutment locations).*

Dames and Moore(1985) working under several layers of sub contractors, investigated the bridge foundation site and described the structural geology. They state:

> Geologic structures within the mapped area appear to be controlled by folding and/or associated faulting. The orientation of joints (rock fractures) and bedding planes differ somewhat between the east and west reservoir slopes, reflecting the local geological structural changes across the area. For instance, the bedding planes strike approximately N 30 W and dip approximately 30 degrees to the north on the west reservoir slope, while on the east slope bedding planes strikes range from about N 30W to N44E and dip approximately 30 to 55 degrees to the north. A fold and/ or fault appears to cut through the site area.

Summary of Joint and Bedding Data

	Strike Direction	**Dip**
East Abutment		
Bedding	N30W-N44E	30-55 N
Primary Joint Set	N15W	75S
Secondary Joint Set	N5E	80S
West Abutment		
Bedding	N30W	30N
Primary Joint Set	N85E	70S
Secondary Joint Set	N35E	80N

Analysis by the Geologic subcontracts using surficial mapping , kinematic and limit equilibrium analyses, core borings and geo-mechanical testing resulted in a favorable (although difficult to construct) recommendation for the bridge at the proposed location. Foundation excavations were to he hampered by flooding, unpredictable weathered zones and poor quality rock , voids and solution cavities. Most of these problems were overcome with over-excavation , increases in concrete placement, grouting, and rock anchoring

The west arch rib footing was particularly challenging to construct. The footprint of the excavation extended out into the lake. In order to proceed a cofferdam and pumps were installed to excavate 600 cubic yards of weathered Martin Formation 30 feet below the existing bedrock surface. Unfortunately very little of the construction engineering efforts are visible today.

Cement Quarry Slide Re-Activation

Surface mapping in the east reservoir slope indicated that potentially unstable slopes were present. An anomalous slope geometry suggested a potential landslide area was present in the cement plant quarry on the east reservoir slope.

This feature was probably the result of undercutting of the lower portion of the Redwall Limestone by the quarry operation parallel to the bedding plane strike which allowed the slope to fail. A scarp of loose, blocky limestone probably represents the upper limit of the quarry operation. A layer of red shale or claystone was visible at the base of the scarf, and represents a part of the plane of sliding.

Heavy winter rain storms and flooding from two storms in January 1993 caused Roosevelt Lake level to rise to the 2139 foot level. Considerable damage was caused to the unfinished east dam spillway as it tried to accommodate a 700cfs flow. It was during this time the old land slide on the east reservoir slope became unstable as the concrete quarry gradually became saturated with more rain water than it could drain. For a brief time water was perched above the red clay layer and the unconsolidated debris in the old pit. Eventually the driving forces of the saturated materials re-activated the former slide mass transporting Redwall Limestone slabs approximately 30 feet down slope on the recently re-constructed Apache Trail and endangering the east abutment of Roosevelt Lake Bridge. Approximately 32,000 cubic yards of quarry materials and formerly intact rock mass had been disturbed in a 1.3 acre area.

A detailed engineering geologic study of the cement quarry area was undertaken and additional slope stability analyses performed. The basal sear of the reactivated rockslide was confirmed to be the red clay layer (Paleo-weathering horizon) between the Redwall Limestone and the Martin Formation. McKee & Gutschick (1969, p. 19) state that in areas south of the Grand Canyon "the surface of separation between the Redwall limestone and the underlying strata marks an erosional unconformity." Ramsome (1917pp 151-152) examined the fossils in the immediate area and concluded that the contact was conformable. Although the exact origin of this discontinuity was not investigated as part of this study, some details were observed at the two bore holes drilled in the quarry site which suggest that a brief time hiatus exists in this area.

> Mock & Ricker (1993), sub consultants to ADOT made the following comments. "The Upper Martin Formation below the red clay was altered for a depth of 19 feet. The alteration extended through the unit –1 limestone into the underlying Unit-2 shale.. The alteration is believed to be associated with subaerial weathering prior to deposition of the Redwall Limestone. Below the red clay, altered limestone of Unit-1 was encountered to a depth of 13 feet. The altered limestone contained numerous solution features ranging from small vugs to intermediate sized voids which were partly filled with red clay similar to the red clay layer. Six feet of altered unit-2 shale was encountered below the altered limestone."

It became apparent that this discontinuity became a major factor in controlling the stability of the slope in the area during conditions of heavy rainfall.

Mitigation of the slide consisted of removing 29,000 cubic yards of the destabilized limestone blocks and re-grading the slope below the quarry face to promote site drainage and to minimize infiltration into the slope. The upper portion of the slope was determined to be stable, however, deterioration of the quarry face could eventually led to rock fall onto the highway infrastructure below. A series of rock bolts were installed near the top of the quarry face to minimize deterioration of this area. An idealized cross section of the slide area is attached to this document.

Unidentified Cavity Under Pier #15
(approximately 450 feet east of Roosevelt Bridge)

During excavation for the foundation of Pier 15 of the southern bridge approach structure an inclined 6 foot wide angular cavity was uncovered underlying the footing. The cavity dipped steeply under the foundation and trended down under the lake. Glen Carter, resident engineer for the project estimated the length to be approximately 300 feet. Inspection of the void by contract geologists indicated that the structure did not display features that would normally be ascribed to a cave. The origin of the cavity is still not precisely known.

To mitigate this problem the part of the cavity impacting the footing was carefully excavated. This excavated area was contain in a form and 30 yards of structural concrete placed to bridge over the cavity and support the pier to be placed above it.

ADVERSELY ORIENTEED STRATA AND DISCONTINUITIES

TRB Special Report 176 identifies many of the fundamental geologic processes which can result in adversely oriented cut slopes. A few of these processes (which can be recognized in the Roosevelt area) will be summarized in this report.

Faults and Joint Systems:
Other geologic discontinuities, such as unconformities, cavities, formation contacts, oriented in a manner which tend to deteriorate the stability of the slope or accelerate erosion of the resulting slope.

Inclined Bedding:
Bedding or foliation inclined downward toward the slope

Relict Structure:
Residual soils, exhibiting structural characteristics of the geologic formation from which they were derived, conveying a preferred weakness in a directed manner

> *"Many slopes are stable at steep angles and at heights of several hundreds of feet, many flat slopes fail at heights of only tens of feet, This difference is due to the fact that stability of rock slopes varies with the inclination of discontinuity surfaces. When these surfaces are vertical or horizontal, simple sliding cannot take place and the slope failure will involve fracture of intact blocks of rock as well as movement along some of the discontinuities. On the other hand, when the rock mass contains discontinuity surfaces dipping towards the slope face at angles of between 30 and 70 degrees, simple sliding can occur and the stability of these slopes is significantly lower than those in which only horizontal and vertical discontinuities are present. Clearly, the presence or absence of discontinuities has a very important influence upon the stability of rock slopes."* ***(FHWA-TS-89-045 p.2.2)***

The northward dipping homoclinal mass of Granites-Apache-Paleozoic rocks of the Roosevelt Lake region form an ideal location for illustrating the effects of adversely oriented rock materials. Adverse orientations of the Martin Formation and Redwall Limestone had a pronounced effect on the highway approaches to Roosevelt Bridge. The gently northward dipping discontinuities were effectively in a state of equilibrium before the construction of the new bridge. However, rerouting SR 88 and SR 188 askew to the dip direction of these discontinuities effectively diminished support for portions of the of highway rock cuts. Adversely oriented formational contacts, inclined bedding, an unconformity, shaley and clay bed (weaker rock materials.) and undermining of the upper slope in the quarry all contributed to the reactivation of a former landslide during a high intensity rain fall event. Additionally, Pier No. 15 required extensive support work due to the unidentified inclined cavity and adversely oriented strata underneath its foundation.

Rock cuts on the west approach to the bridge were also adversely effected by inclined bedding, inclined formational contact, faulting an antiform fold and bedding plane joints.

Additionally inclined bedding, solution cavities, and formational contacts also contributed to excavation difficulties during the construction of the foundations for the bridge. Relict structure was also displayed at the colluval bedrock interface of the east arch rib foundation. The contact was described as a "buried bedrock surface of irregular geometry, apparently a product of a combination of erosion and block translational sliding failures along a steeply dipping bedding plane"(Weeks & Sargent,1988).

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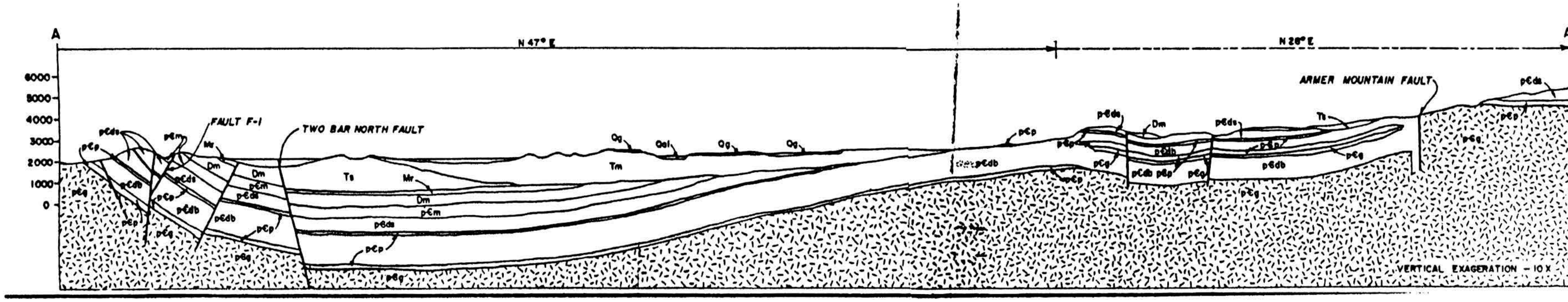


EXPLANATION

Quaternary
- Qal — Alluvial Deposits
- Qls — Landslide Deposits
- Qg — Pediment and terrace gravel

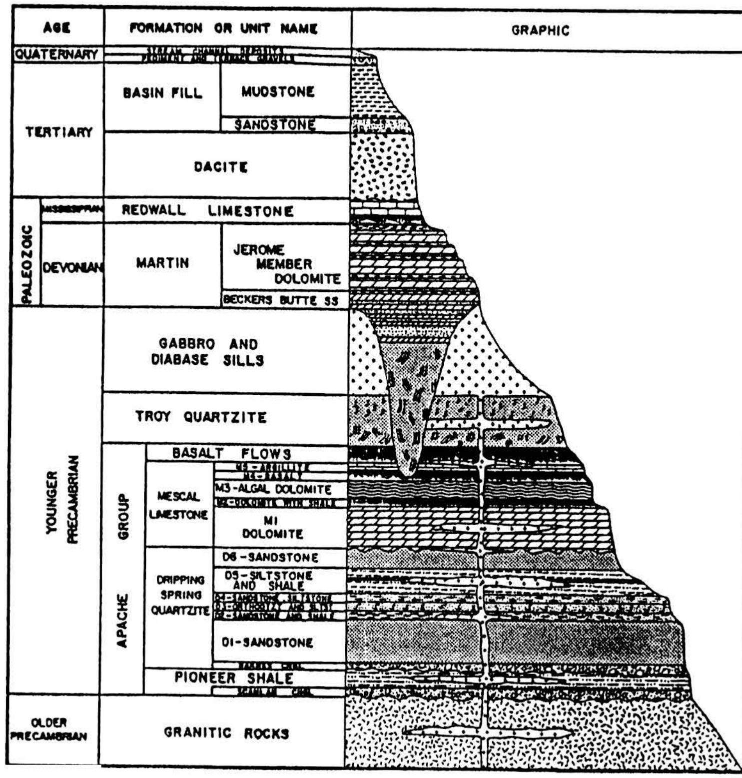
Tertiary
- Ts / Tm — Basin fill deposits
  - Tm, upper fine grain unit; mostly mudstone
  - Ts, lower coarse grain unit; mostly sandstone

Mississippi
- Mr — Redwall Limestone

Devonian
- Dm — Martin formation

Younger Precambrian
- p€db — Diabase
- p€t — Troy quartzite
- p€m — Mescal limestone
- p€ds — Dripping Spring quartzite
- p€p — Pioneer Shale
- p€au — Apache Group undifferentiated; includes Mescal limestone, Dripping Spring quartzite, and Pioneer Shale. Locally includes some Troy quartzite and Diabase.

Older Precambrain
- p€g — Granitic rocks. Predominantly granite, may include diabase, gneiss and quartzite

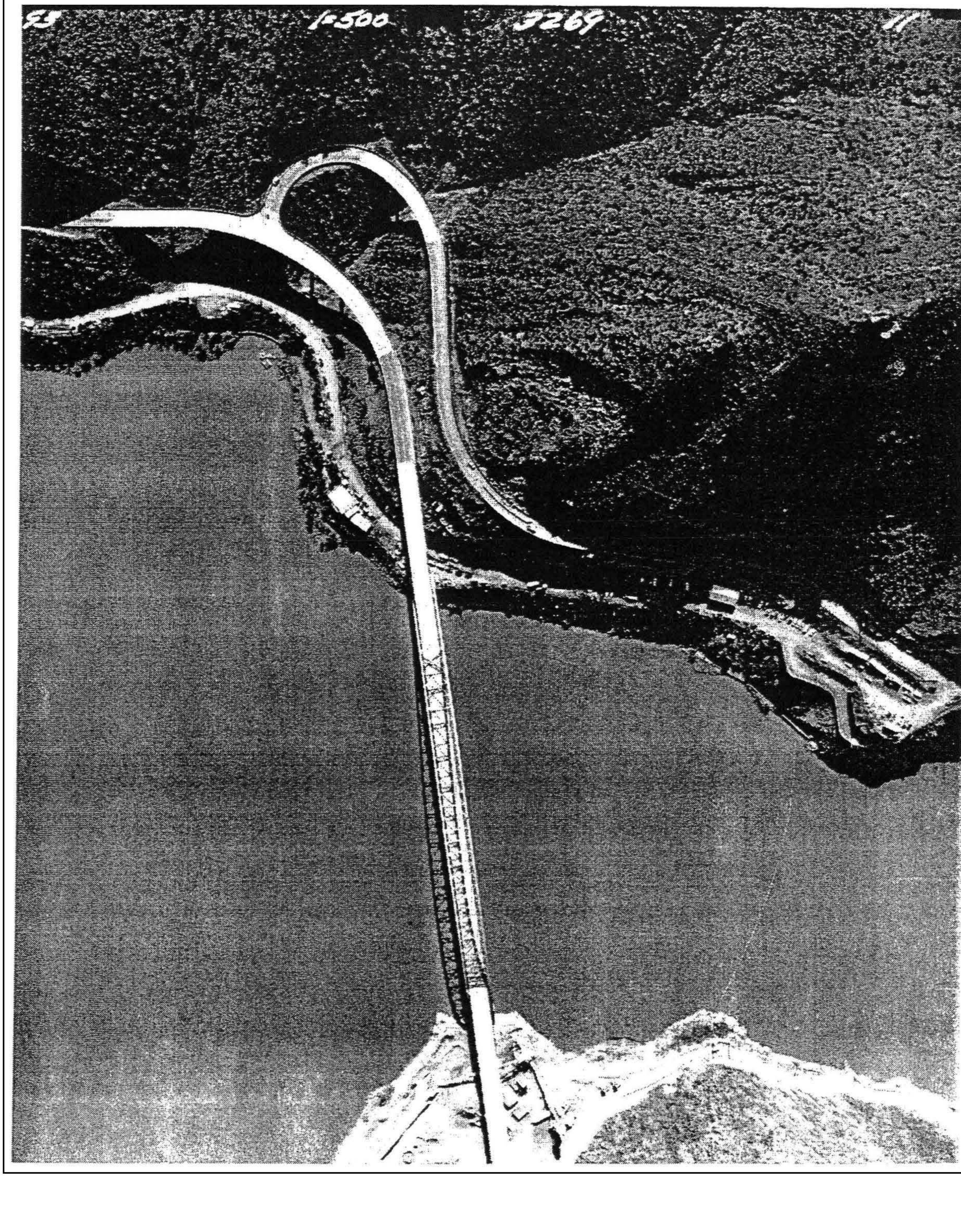


ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT–ARIZONA
SAFETY OF DAMS–MODIFICATIONS

THEODORE ROOSEVELT DAM
MODIFICATION
REGIONAL–GEOLOGY

GEOLOGY ... FIELD APPROVAL ...
DRAWN ... TECHNICAL APPROVAL ...
CHECKED ... APPROVED ...
PHOENIX, ARIZONA APRIL, 1987 25-330-G-100


93
1=500
3269
11

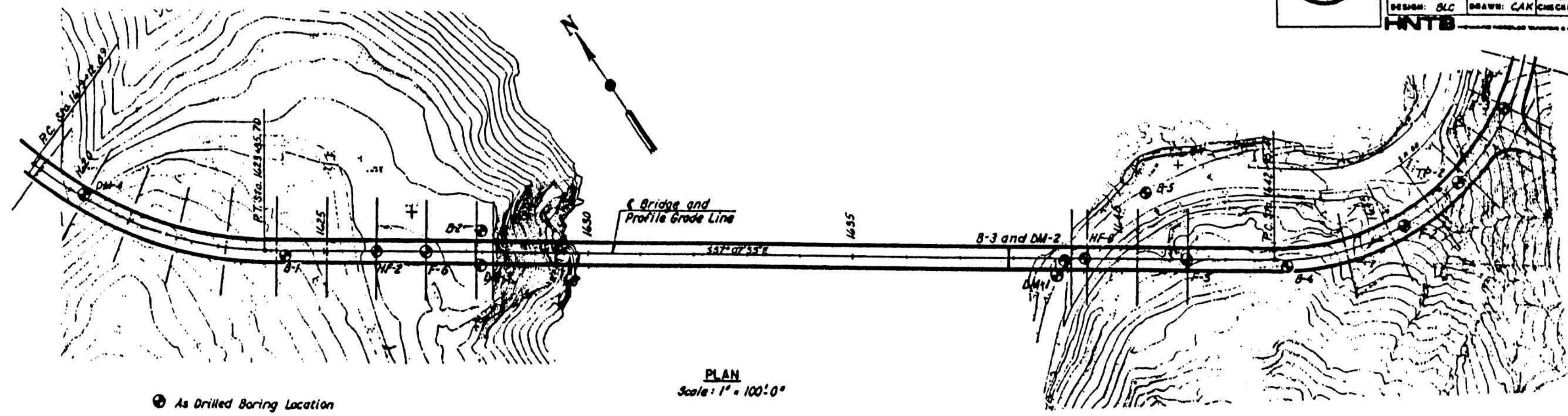
CLAYPOOL-JAKES CORNER HIGHWAY (SR 188)
ROOSEVELT LAKE BRIDGE
GILA COUNTY

F.H.W.A. REGION	STATE	PROJECT NO.	SHEET NO.	TOTAL SHEETS	AS BUILT
9	ARIZ.	FLH-038-1(9)	60	144	2-1-91 JMC

5/22/87 DATE — FOR THE CONSULTING ENGINEER

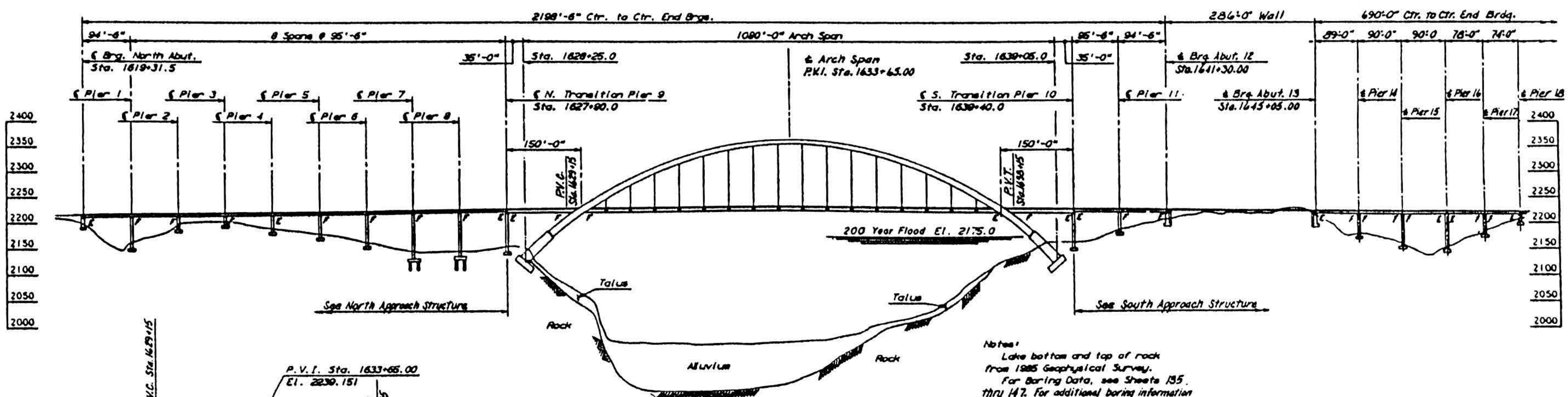
DESIGN: BLC | DRAWN: CAK | CHECKED: JEL

HNTB

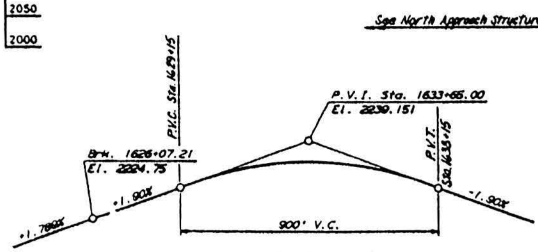


PLAN
Scale: 1" = 100'-0"

⊕ As Drilled Boring Location



ELEVATION
Scale: 1" = 100'-0"



PROFILE GRADE
Not to Scale

Notes:
Lake bottom and top of rock from 1985 Geophysical Survey.
For Boring Data, see Sheets 135 thru 147. For additional boring information see sheets 148 & 149.
Bench Marks:
BM
Sta. 1638+65 ± ; 70' Rt. P & M 1648-1.
A.D.O.T. Conc. Monument-1985
Elev. 2161.02
BM
U.S.B.R. Brass Cap "BM 2141"
Top of Roosevelt Dam
Elev. 2140.98

STEEL ALTERNATIVE
ARIZONA DEPARTMENT OF TRANSPORTATION
HIGHWAYS DIVISION
STRUCTURES SECTION
GENERAL PLAN AND ELEVATION

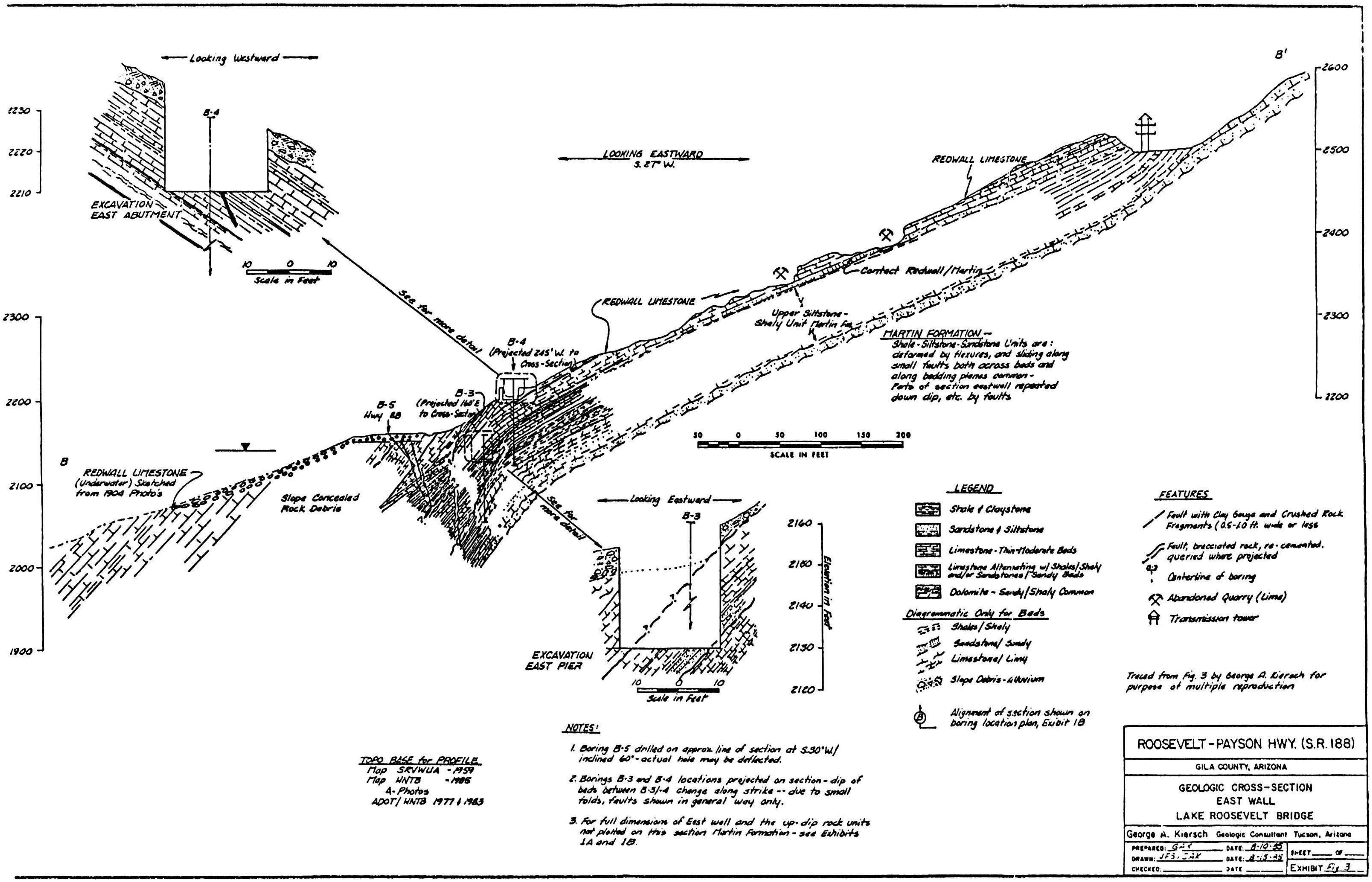
SHEET NO 8 OF 49	SR188 ROUTE	MILE POST	GILA COUNTY	2028 STRUCTURE NO	PROJECT NO

F-038-1(8) P.E.

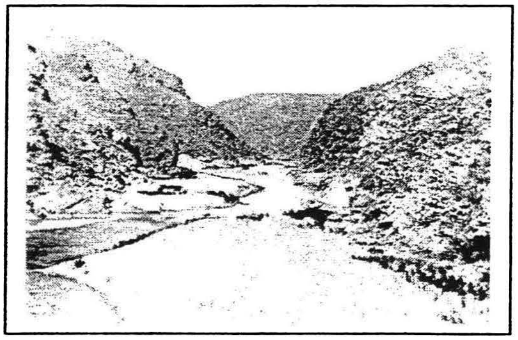
FLH-038-1(9) 60 of 149

244.27

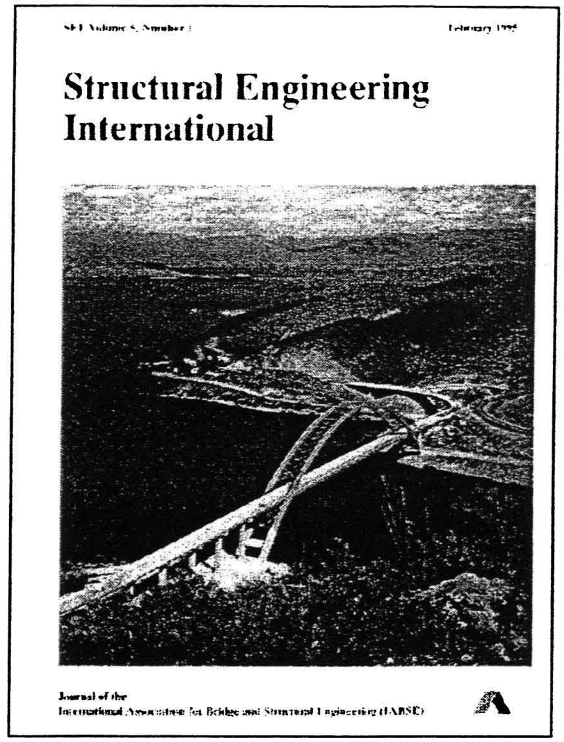
1 As Built



Looking Westward
B-4
EXCAVATION EAST ABUTMENT
10 0 10
Scale in Feet
2230
2220
2210
LOOKING EASTWARD S.27° W.
See for more detail
B-4 (Projected 245' W. to Cross-Section)
B-3 (Projected 160' E to Cross-Section)
B-5 Hwy 88
B
B'
REDWALL LIMESTONE (Underwater) Sketched from 1904 Photo's
Slope Concealed Rock Debris
REDWALL LIMESTONE
Upper Siltstone-Shaly Unit Martin Fm.
Contact Redwall/Martin
MARTIN FORMATION — Shale-Siltstone-Sandstone Units are: deformed by flexures, and sliding along small faults both across beds and along bedding planes common - Parts of section eastwall repeated down dip, etc. by faults
2600
2500
2400
2300
2200
2100
2000
1900
50 0 50 100 150 200
SCALE IN FEET
Looking Eastward
B-3
EXCAVATION EAST PIER
10 0 10
Scale in Feet
2160
2150
2140
2130
2120
Elevation in Feet
LEGEND
Shale & Claystone
Sandstone & Siltstone
Limestone - Thin-Moderate Beds
Limestone Alternating w/ Shales/Shaly and/or Sandstones/Sandy Beds
Dolomite - Sandy/Shaly Common
Diagrammatic Only for Beds
Shales/Shaly
Sandstone/Sandy
Limestone/Limy
Slope Debris - Alluvium
Alignment of section shown on boring location plan, Exhibit 1B
FEATURES
Fault with Clay Gouge and Crushed Rock Fragments (0.5-1.0 ft. wide or less
Fault, brecciated rock, re-cemented, queried where projected
Centerline of boring
Abandoned Quarry (Lime)
Transmission tower
Traced from Fig. 3 by George A. Kiersch for purpose of multiple reproduction
TOPO BASE for PROFILE
Map SRVWUA - 1959
Map HNTB - 1986
4-Photos
ADOT/HNTB 1977 & 1983
NOTES:
1. Boring B-5 drilled on approx. line of section at S.30°W./ inclined 60° - actual hole may be deflected.
2. Borings B-3 and B-4 locations projected on section - dip of beds between B-3/-4 change along strike -- due to small folds, faults shown in general way only.
3. For full dimensions of East wall and the up-dip rock units not plotted on this section Martin Formation - see Exhibits 1A and 1B.
ROOSEVELT-PAYSON HWY. (S.R. 188)
GILA COUNTY, ARIZONA
GEOLOGIC CROSS-SECTION
EAST WALL
LAKE ROOSEVELT BRIDGE
George A. Kiersch Geologic Consultant Tucson, Arizona
PREPARED: GAK DATE: 8-10-95
DRAWN: JFS, GAK DATE: 8-15-95
CHECKED: DATE
SHEET ___ OF ___
EXHIBIT Fig. 3



Dam & Bridge Site Before Construction



See above referenced Journal for additional information

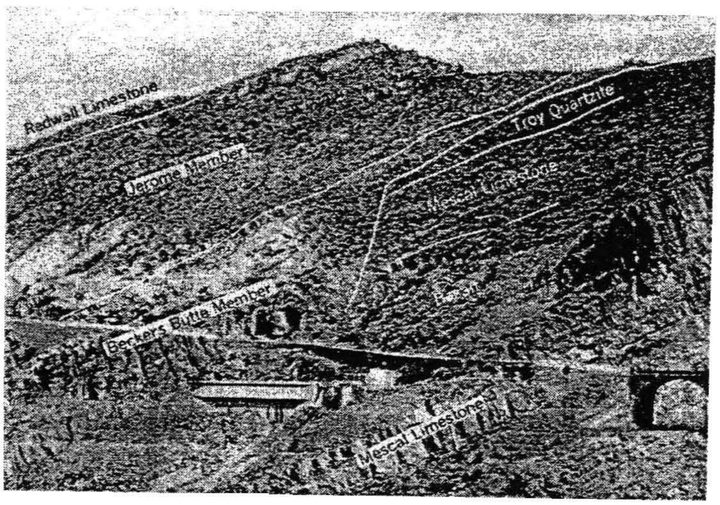
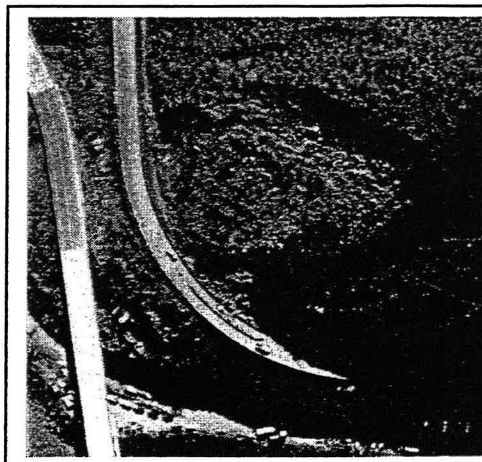
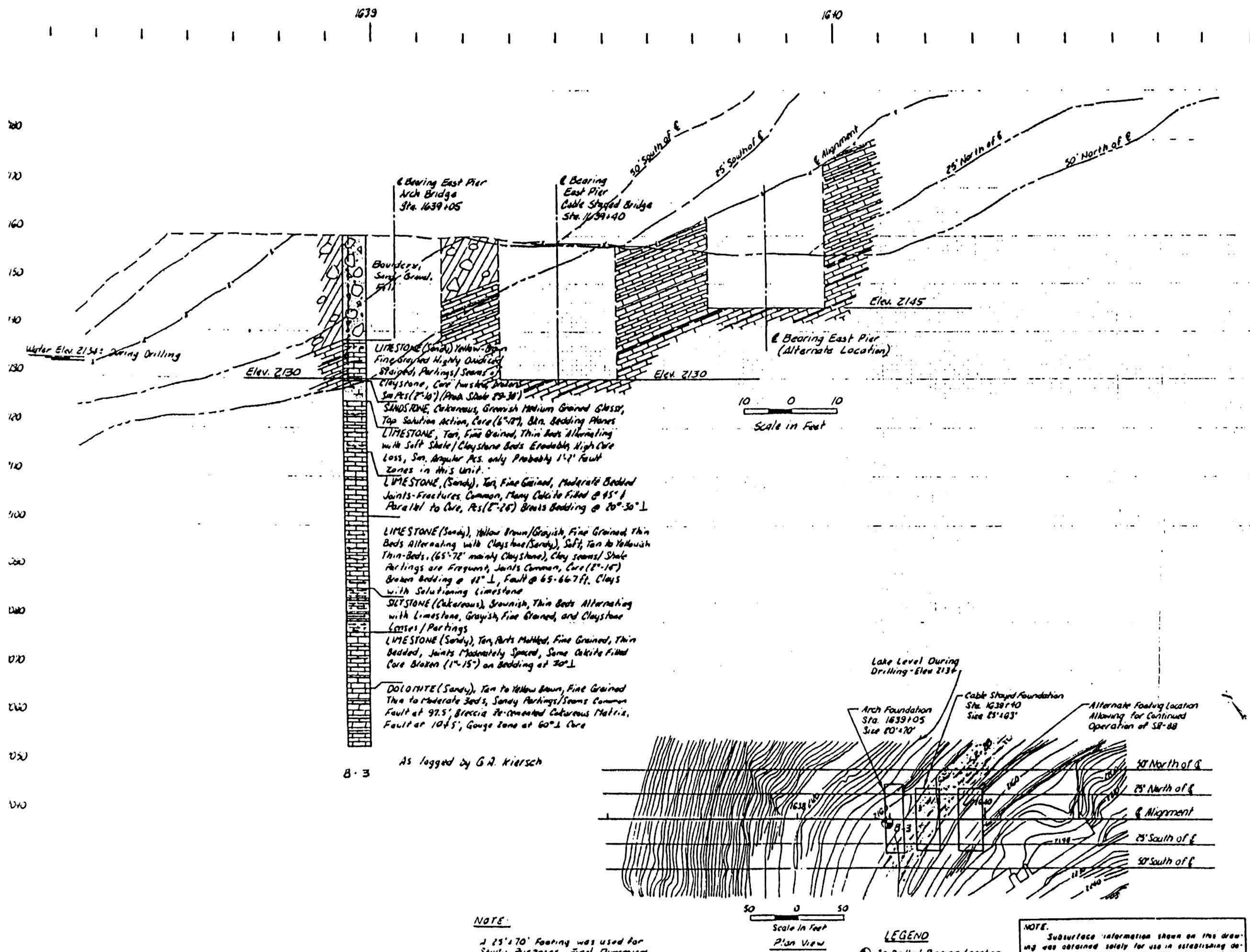


FIGURE 8.—Stratigraphic section on south side of Theodore Roosevelt Lake, directly southeast of Theodore Roosevelt Dam, showing channel of Beckers Butte Member 90 feet deep, overlain by Jerome Member and Redwall Limestone. (Section 36 of report is located here.)

From U.S.Geol Survey Prof. Paper 464



Aerial view of cement quarry area January 1993



NOTE:

A 25'x70' Footing was used for Study Purposes. Final Dimensions may vary.

NOTE:

Subsurface information shown on this drawing was obtained solely for use in establishing design controls for the project. The accuracy of this information is not guaranteed and it is not to be construed as part of the plans governing the construction of this project.

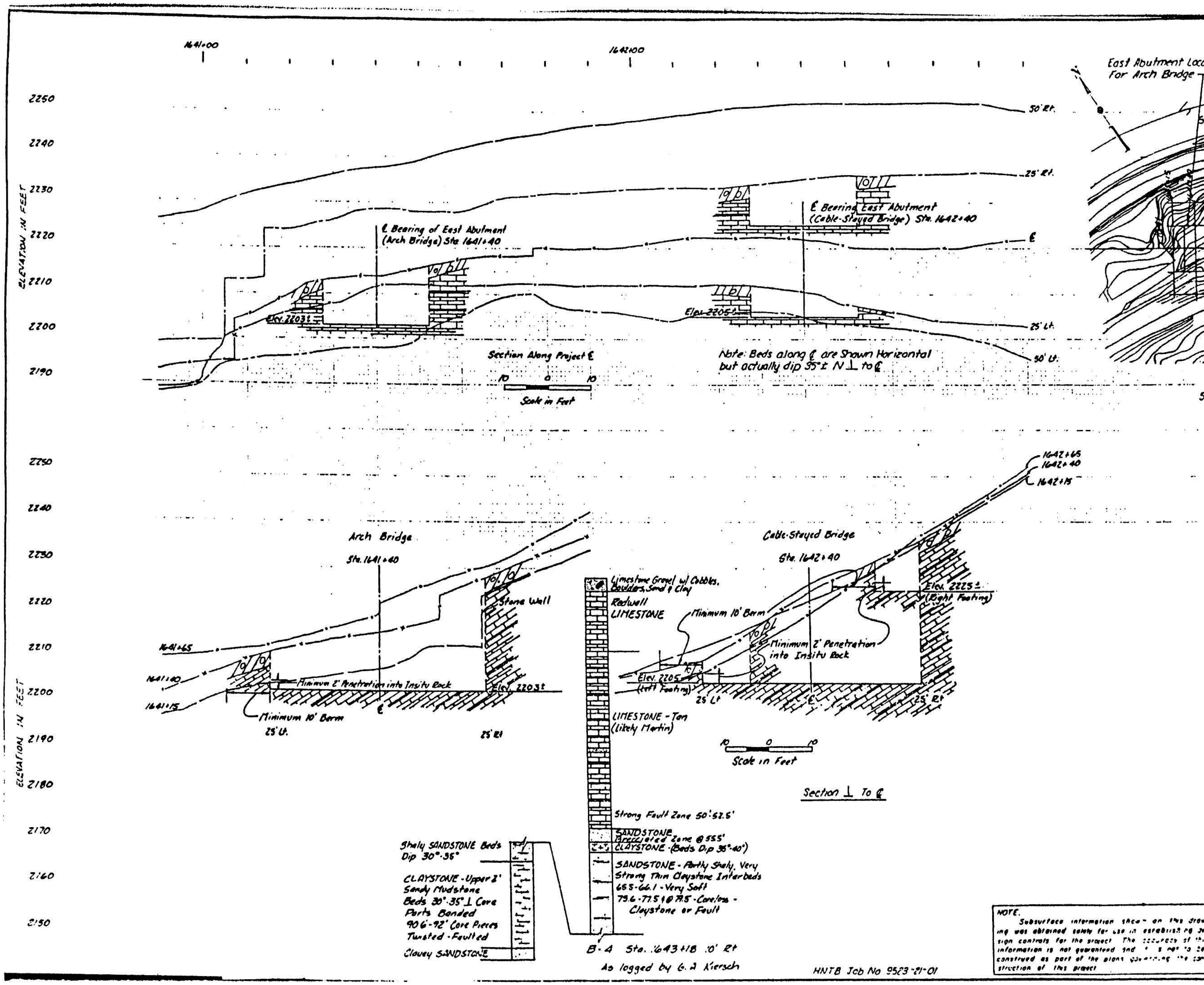
HNTB Job No. 9523-31-01

ROOSEVELT-PAYSON HWY. (S.R. 188)

GILA COUNTY, ARIZONA

STUDY SHEET - EAST PIER

PREPARED:	DATE:	SHEET
DRAWN:	DATE:	
CHECKED:	DATE:	EXHIBIT



NOTE.
Subsurface information shown on this drawing was obtained solely for use in establishing design controls for the project. The accuracy of this information is not guaranteed and it is not to be construed as part of the plans governing the construction of this project.

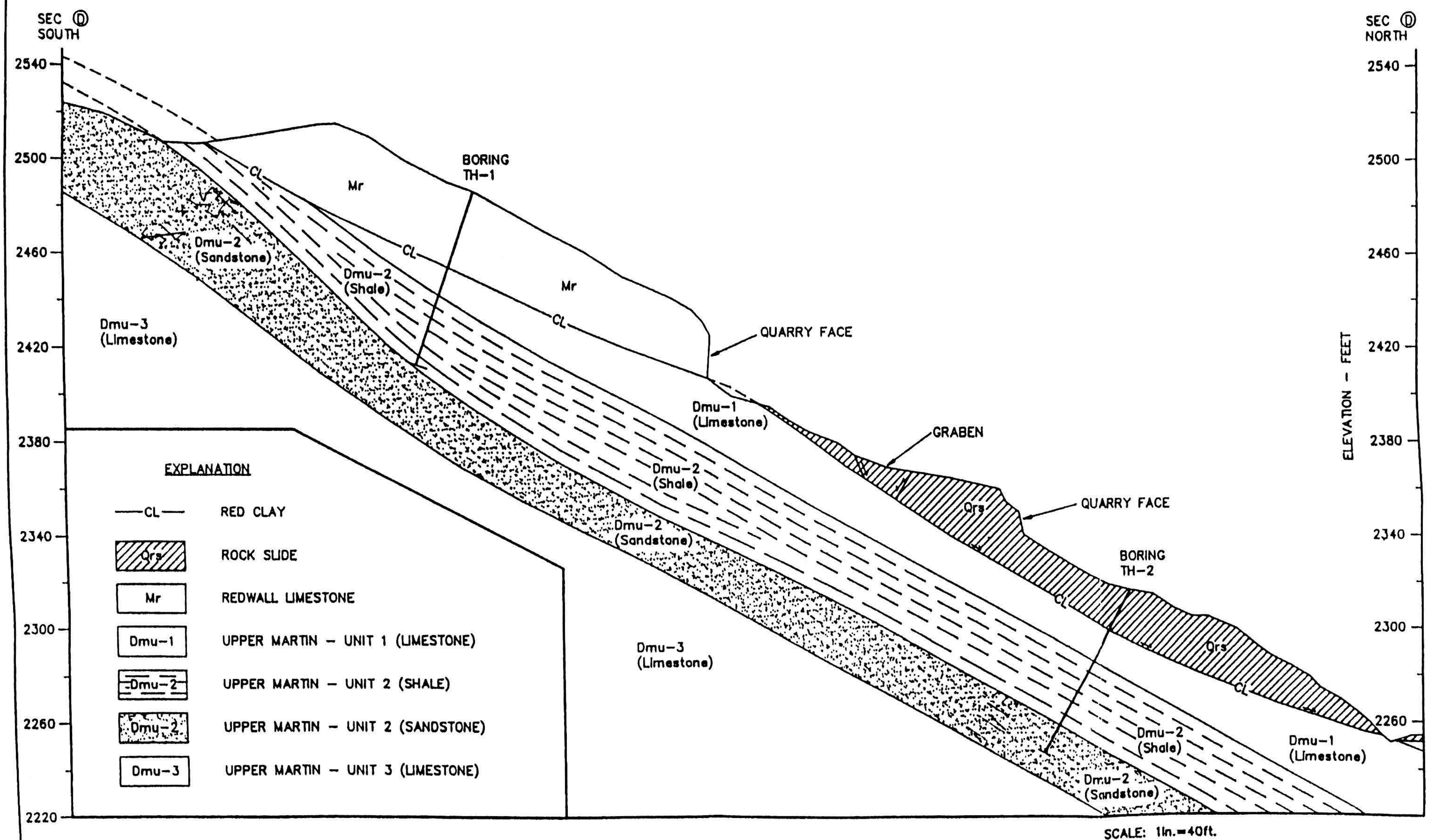
ROOSEVELT - PAYSON HWY. (S.R. 8

GILA COUNTY, ARIZONA

STUDY SHEET - EAST ABUTME

PREPARED	50J-FWL	DATE	2-1-95
DRAWN	IFS	DATE	2-1-95
CHECKED	SOJ	DATE	2-1-95

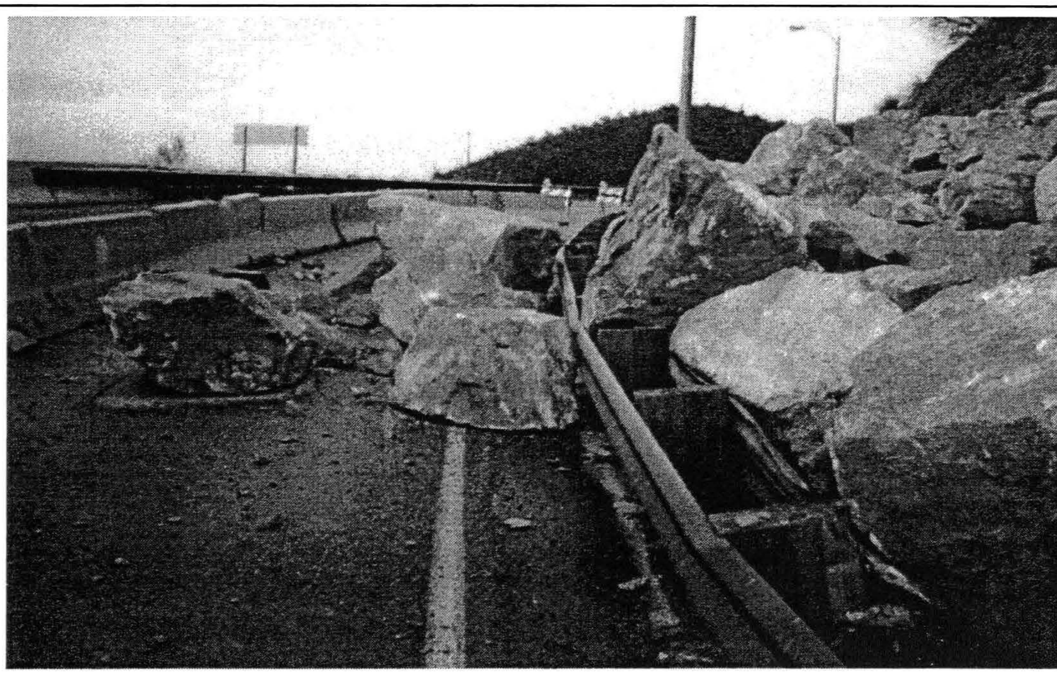
SHEET
EXHIBIT



93-0855 Thomas-Hartig & Associates	ROOSEVELT LAKE ROCKSLIDE	ROCKSLIDE CROSS-SECTION D	Fig. 6

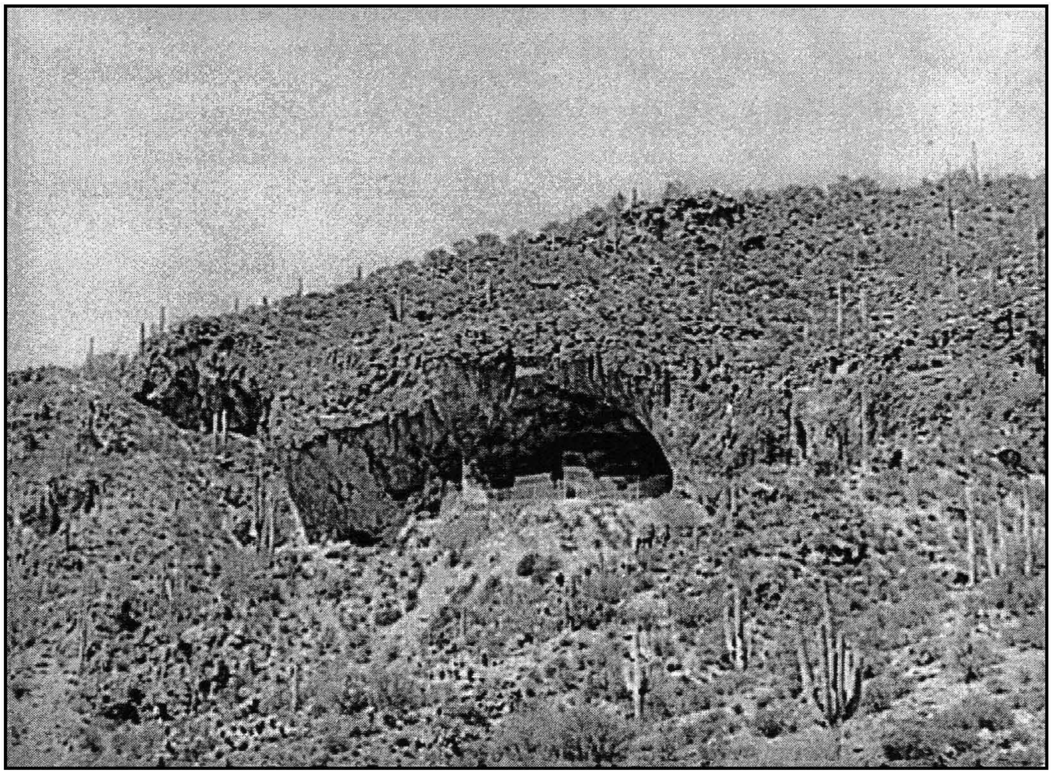
The Roosevelt Steel Arch Bridge January 1993

Rock Debris on SR 188 , Below Cement Quarry January 1993



Archaeology in the Tonto Basin

Compiled by Beth Miksa, Desert Archaeology
November 2000



Tonto National Monument, 1940

Table 1. Dates assigned to phases within the Roosevelt Tonto Basin Chronology (after Elson 1996).

Period	Phase	Date 1[a], years A.D.	Date 2[b], years A.D.
Late Classic	Gila	1320/1350 to 1450	1350 to 1450
Early Classic	Roosevelt	1250/1270 to 1320/1350	1250 to 1350
Early Classic	Miami	1150 to 1250/1270	1150 to 1250
Late Sedentary	Ash Creek	1025/1075 to 1150	1050 to 1150
Early Sedentary	Sacaton	950 to 1025/1075	950 to 1050
Late Colonial	Santa Cruz	850 to 950	850 to 950
Early Colonial	Gila Butte	750 to 850	750 to 850
Pioneer	Snaketown	600/700 to 750	675 to 750
Early Ceramic	Early Ceramic	100 to 600/700	100 to 600
Paleoindian and Archaic		prior to ca. A.D. 100	prior to ca. A.D. 100

[a]Date 1 is provided as a more accurate representation of phases.
[b]Date 2 is a more standard archaeological representation for ease of presentation.

The following information is summarized from Elson 1996; Elson et al. 1995; Fox 2000; and Heidke 2001.

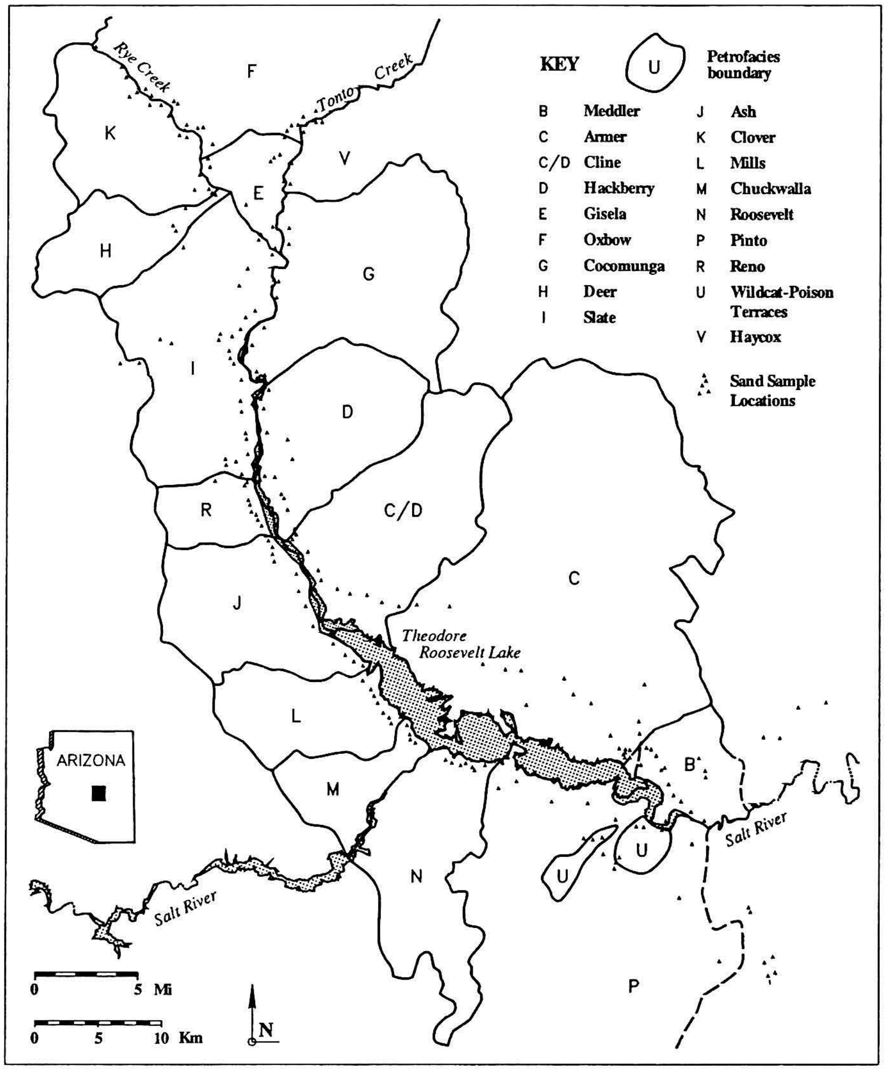
Who inhabited Tonto Basin?

Mid-twentieth century archaeologists thought that the Hohokam people inhabited Tonto Basin until Early Classic times, at which point they suggested that the Salado occupied the region. However, at this point, the inhabitants of the Tonto Basin are not assigned a definitive name, rather, they are thought to be an indigenous population that was variously influenced by the people living on all sides. At some periods, the influence of the Hohokam may have been stronger, while at other times, the Mogollon or Pueblo influence may have been more important. Furthermore, the Tonto and Salt arms of the Tonto Basin ("Upper Tonto" vs. "Lower Tonto") may have had different relationships with other groups. For instance, Lower Tonto Basin inhabitants seem to have had more Hohokam ties, while Upper basin folks probably interacted more with Mogollon or Puebloan groups.

What do ceramics tell us?

The people of the Tonto Basin produced much of their own pottery, and it was almost always sand tempered. Ethnographic data tells us that people prefer to get their sand close by (usually within 1 km of where they make pots), so if we know where the sand in pottery comes from, we can say where the pottery itself comes from. The geology of the Tonto Basin is extremely diverse, so sand from different parts of the basin can be extremely distinctive. Sands in the Tonto Basin have been mapped by their composition (how much quartz, feldspar, volcanic rock, etc.), and a map of different types of sand has been made (Figure 1). The sand composition zones, called petrofacies, have been used to identify where pottery was made, so we can trace the manufacture and distribution of pottery through time in the Tonto Basin. The following culture history discussion refers to production of pottery in these different petrofacies.

Figure 1: Current petrofacies map of the Tonto Basin



Culture History of the Tonto Basin – The very short version

Occupation of the Tonto Basin by prehistoric peoples began during Paleoindian times, but is not well-represented by sites and artifacts until Middle and Late Archaic times, when base camps and more specialized sites are found. In many cases, only isolated artifacts or features are found. This may be due in part to geomorphological and preservation factors; however, the end result is that the early occupation of the Tonto Basin remains poorly known.

Only one site dating to Early Ceramic times has been definitively identified. However, it is fairly large, with many pithouses and other features. It is possible that there are other Early Ceramic sites in the basin that have not been identified due to burial and lack of surface architecture. Analysis of features and artifacts at the one Early Ceramic site indicate that the settlement was relatively permanent. Despite being in the Lower Tonto Basin, its closest cultural affinity was with groups in the Forestdale and Point of Pines regions in the Mogollon Highlands to the northeast. Pollen and flotation samples recovered from the site indicate that a full suite of agricultural crops was cultivated (including corn, beans, and cotton), but a wide range of wild foodstuffs (including various cacti, grains, mustard greens, mesquite seeds, and agave) was gathered as well. Plain sand-tempered brown ware, basin metates, and Cienega and San Pedro style projectile points are common artifact types.

The next well-represented period in the Tonto Basin is the Colonial, when sites are found in both the Lower and Upper Tonto Basin. Hohokam style "houses-in-pits" are the dominant architecture; some are arranged into courtyard groups. Corn, cotton, and squash are common, as are agave, cactus fruits, and other wild plants. Hunting and fishing were also important sources of food. Side-notched projectile points are common, and shell artifacts are found. Distributional patterns of Colonial period pottery in the Tonto Basin point to an emphasis on local and intrabasinal pottery in the central and upper basin, while groups in the lower basin maintained Hohokam contacts, as indicated by the high proportion of crushed-schist-tempered wares found in these sites (Figure 2).

By the Sedentary period, the Tonto Basin was heavily populated. Settlements in the lower Tonto Basin became increasingly focused on other Tonto Basin local systems and shifted away from a focus on the Phoenix Basin. The inhabitants relied increasingly on cultivated crops such as corn and cotton, and less on wild plants, except for agave, which remains extremely important. Fishing, hunting, and gathering continue, but to a lesser degree. Small unnotched serrated projectile points are found, along with shell jewelry. Sedentary period ceramics indicate multiple changes in the direction of regional interaction by communities across the basin. In general, the amount of Hohokam buff ware ceramics decreased at settlements throughout the basin, and, in the lower basin, the amount of coarse muscovite schist-tempered plain ware declined. There is evidence of local plain ware production, but locally-produced pottery makes up a very small part of the collections. The Upper Basin appears to have been partially self-reliant, but less so than during the Colonial period. The Armer/Cline Petrofacies and the Ash Petrofacies are documented in all three project areas. Together the potters in those two petrofacies manufactured over 60 percent of the plain ware in the entire Tonto Basin. It appears that at least some households in those areas were producing pottery far beyond their own needs by the end of the Sedentary period.

Early Classic period occupation in the Tonto Basin is characterized by above ground architecture such as masonry and/or jacal structures, and both compound and room-block architecture. The first platform mound architecture also began at this time (Roosevelt Phase). Subsistence is still highly dependent on cultigens and agave, with addition of more cultigen types, though some different gathered resources are used as well. The shell artifacts and projectile point styles change as well. Locally produced plain wares and decorated wares are found. In fact, the early Classic period was a time of radical change in the production of utilitarian pottery: the amount of plain ware recovered from all three project areas declined precipitously,

Figure 2: Ceramic production in the Tonto Basin prior to the Classic Period. From Heidke 2001 and Miksa and Heidke 2001.

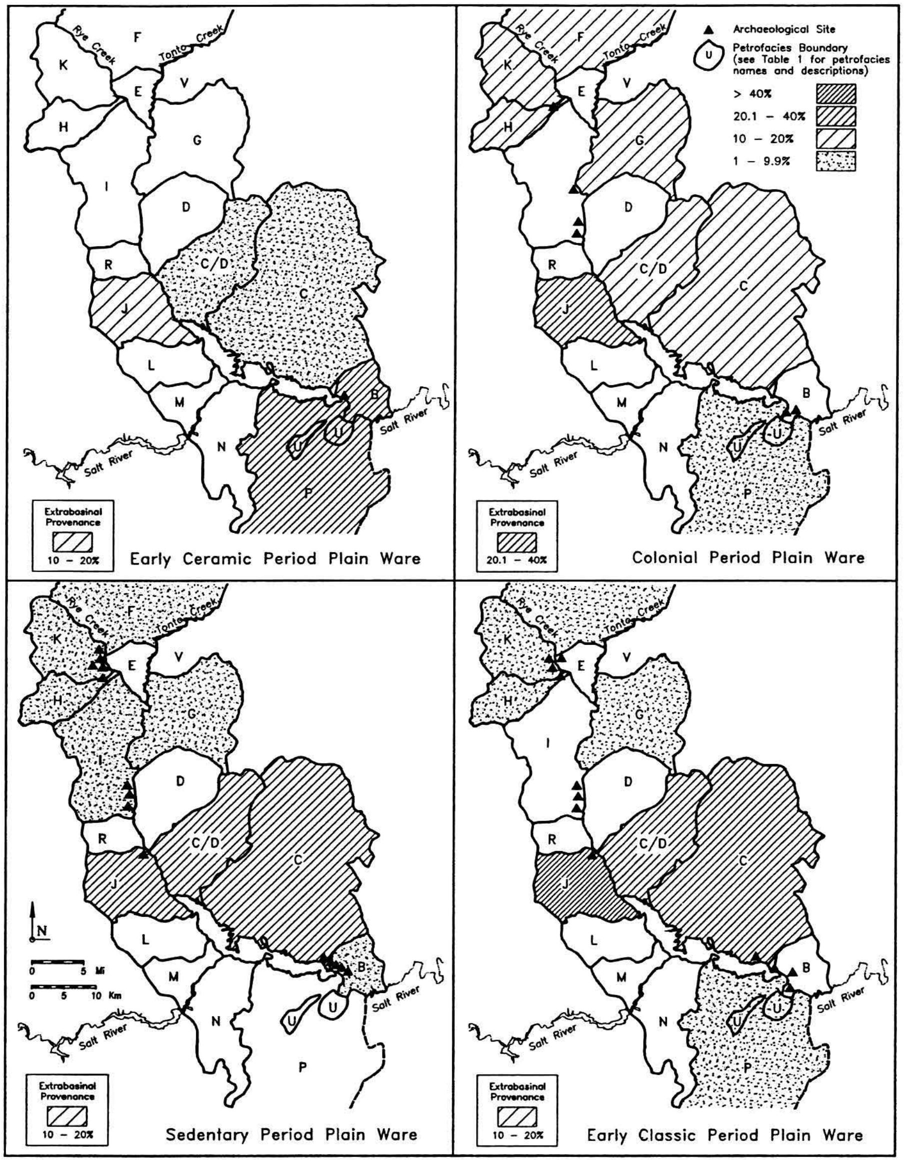
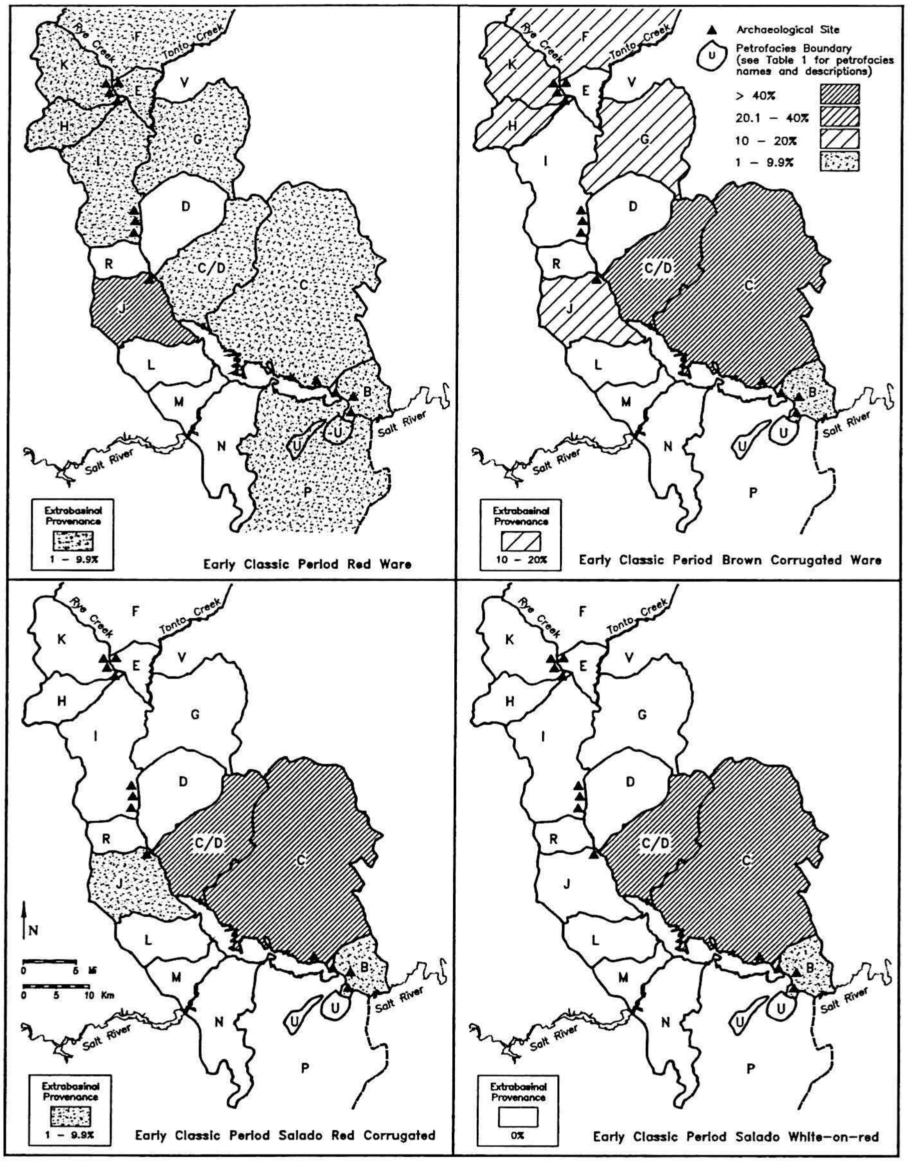


Figure 3: Early Classic period ceramic production in the Tonto Basin. From Heidke 2001 and Miksa and Heidke 2001.



with red ware (or red-slipped plain ware), brown corrugated, Salado Red Corrugated, and Salado White-on-red ceramics taking its place. The early Classic period utilitarian ceramic ware temper provenance data indicate that most plain wares and red wares were produced in the Ash Petrofacies (Figures 2.d and 3.a), whereas most corrugated wares were produced in the Armer/Cline Petrofacies (Figures 3.b - 3.d).

Finally, we get to the Gila Phase, the time during which the Tonto National Monument was occupied. During the Gila Phase, large platform mound sites continued. There were still smaller sites scattered around, but population aggregation is one of the hallmarks of the phase. Corn cultivation remained extremely important. It seems that the eastern part of the Lower Tonto Basin was largely abandoned around A.D. 1325. A small ceramic study at Tonto National Monument suggests that ceramic production and distribution systems that developed and dominated during the Sedentary and Early Classic periods did not entirely survive: Ceramics tempered with Ash Petrofacies sands are found, but little Armer/Cline sand temper is seen, consistent with the abandonment of that area.

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1997 A Revised Chronology and Phase Sequence for the Lower Tonto Basin of Central Arizona. *Kiva*, 62(2):117-147.

Elson, M.D., Stark, M.T., & Gregory, D.A., Eds.
1995 *The Roosevelt Community Development Study: New Perspectives on Tonto Basin Prehistory*. Anthropological Papers No. 15. Tucson, AZ: Center for Desert Archaeology.

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2001 Utilitarian Ceramic Production and Distribution in the Prehistoric Tonto Basin. In J.J.Clark (Ed.), 2000 Years of Settlement in the Tonto Basin: Tonto Creek Archaeological Project Overview and Synthesis (Draft). Anthropological Papers No. 25. Tucson, Az. Center for Desert Archaeology.

Miksa, Elizabeth J. and James M. Heidke
2001 it All Comes out in the Wash: Actualistic Petrofacies Modeling of Temper Provenance, Tonto Basin, Arizona. *Geoarchaeology* 16(2). In press.

ADDENDUM

HANDOUT FROM LEADER

AT FIELD TRIP

STRATIGRAPHY AND TECTONIC SIGNIFICANCE OF CENOZOIC BASIN-FILL SEDIMENTS, TONTO BASIN, ARIZONA

by
Dale Nations
Geology Department
Northern Arizona University
Flagstaff, Arizona

ABSTRACT

Cenozoic strata within the Tonto Basin consist entirely of syntectonic and post-tectonic sedimentary and volcanic rocks. The oldest documented Cenozoic event within the basin is represented by the 23.6 Ma basalt at the base of the basin-fill sediments in the Campaign Creek area. The basalt may signal the beginning of deep-seated normal faulting and the initiation of extensional tectonism. Exposures of 18.9 and 19.4 Ma dacite, which overlie the basalt and are also cut by normal faults, may be correlative with the Apache Leap Tuff, a 19.9 to 20.4 Ma volcanic unit that extends over a wide area from Globe to the Superstition Mountains.

Basin-fill sediments overlie the dacite and are largely composed of its erosional detritus, especially in the lower one-third of one section and along basin margins. The coarse-grained, chaotic nature of the basal and basin-margin sediments suggests that the lower part of the basin-fill sediments is syntectonic, having been deposited as the basin subsided. The basin-fill exhibits a rather abrupt fining-upward transition about 500 feet above the base of the section on Rock Island that suggests a cessation of tectonism, above which the distal basin-fill becomes very fine-grained. A K/Ar date of 18.5 Ma on tuff within undeformed fine-grained basin-fill near Punkin Center indicates that the Tonto Basin was well-defined by the early Miocene. The youngest age of basin-fill sediments is interpreted as late Miocene or early Pliocene, based on the occurrence of Pliohippus in the mudstone facies, about four miles east of Punkin Center.

Extensional tectonism in the Tonto Basin is documented by high angle normal faults that displace the mudstone facies of the basin-fill and older rocks along the southwestern margin and center of the basin. This faulting began soon after 18.9 Ma and the basin was well-defined prior to 18.5 Ma. In the Mills Canyon area one of these faults cuts lower basin-fill sediments, but is truncated by an erosion surface overlain by unfaulted fine-grained basin-fill, indicating that movement on that fault had ceased by late Miocene to early Pliocene time.

INTRODUCTION

The Cenozoic stratigraphy and tectonic history of Tonto Basin is very poorly known. The basinfill has been mapped only as Quaternary and Tertiary sediments on the Geologic Map of Gila County (1959), and as Pliocene sediments on the Geologic Map of Arizona (1969). More recent geologic mapping in the area has virtually ignored the basin-fill section because emphasis was on bedrock and structural geology in the adjacent Mazatzal Mountains and Sierra Ancha. This report is based on field work, including the measurement of eleven stratigraphic sections (Figure 1), lithologic description, and preliminary facies interpretations of Cenozoic basin-fill strata (Figure 2). Observations and measurement of sedimentary and tectonic structures have been used, in conjunction with four new radiometric dates, to interpret the Cenozoic tectonic history of Tonto Basin.

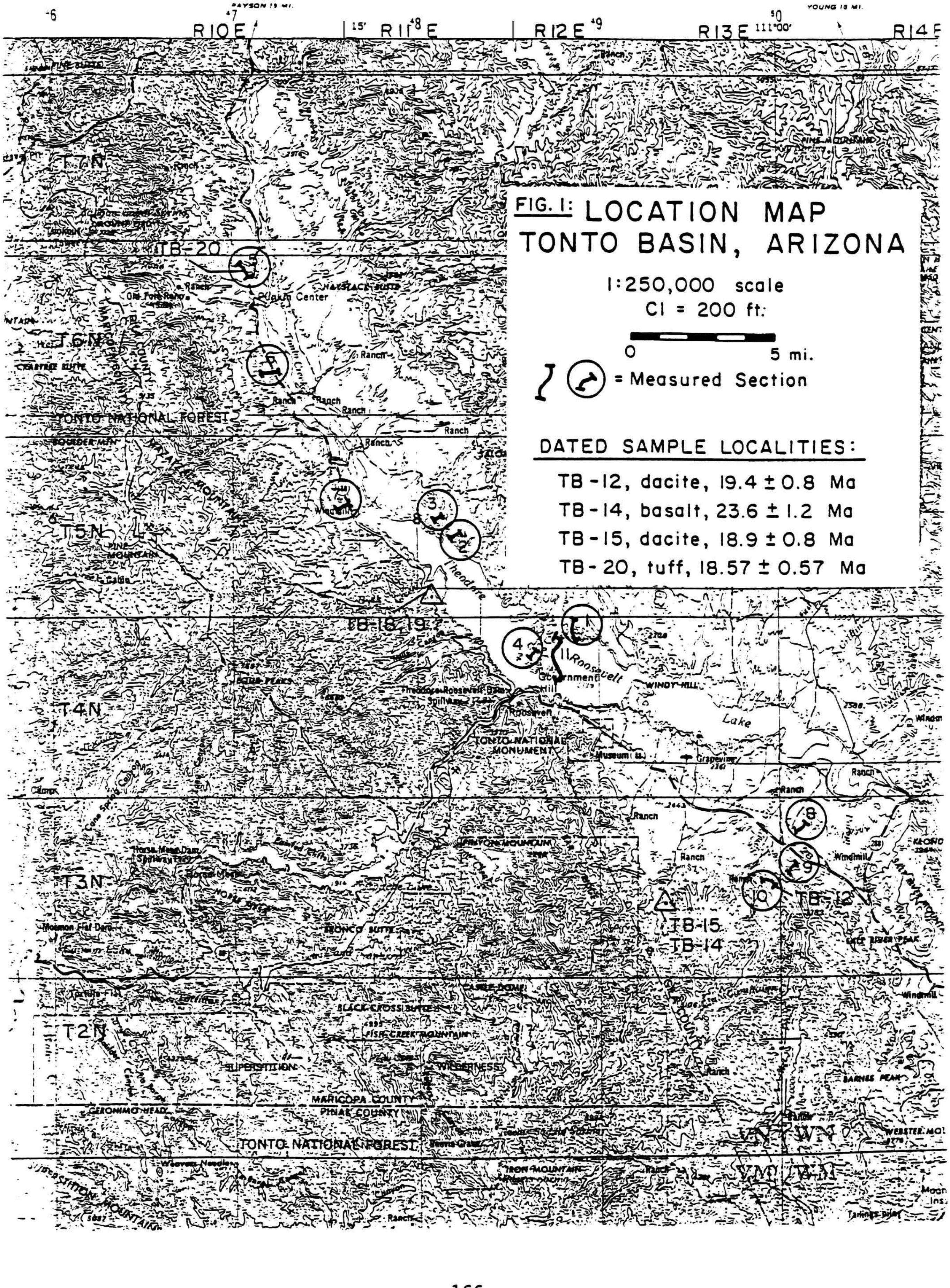
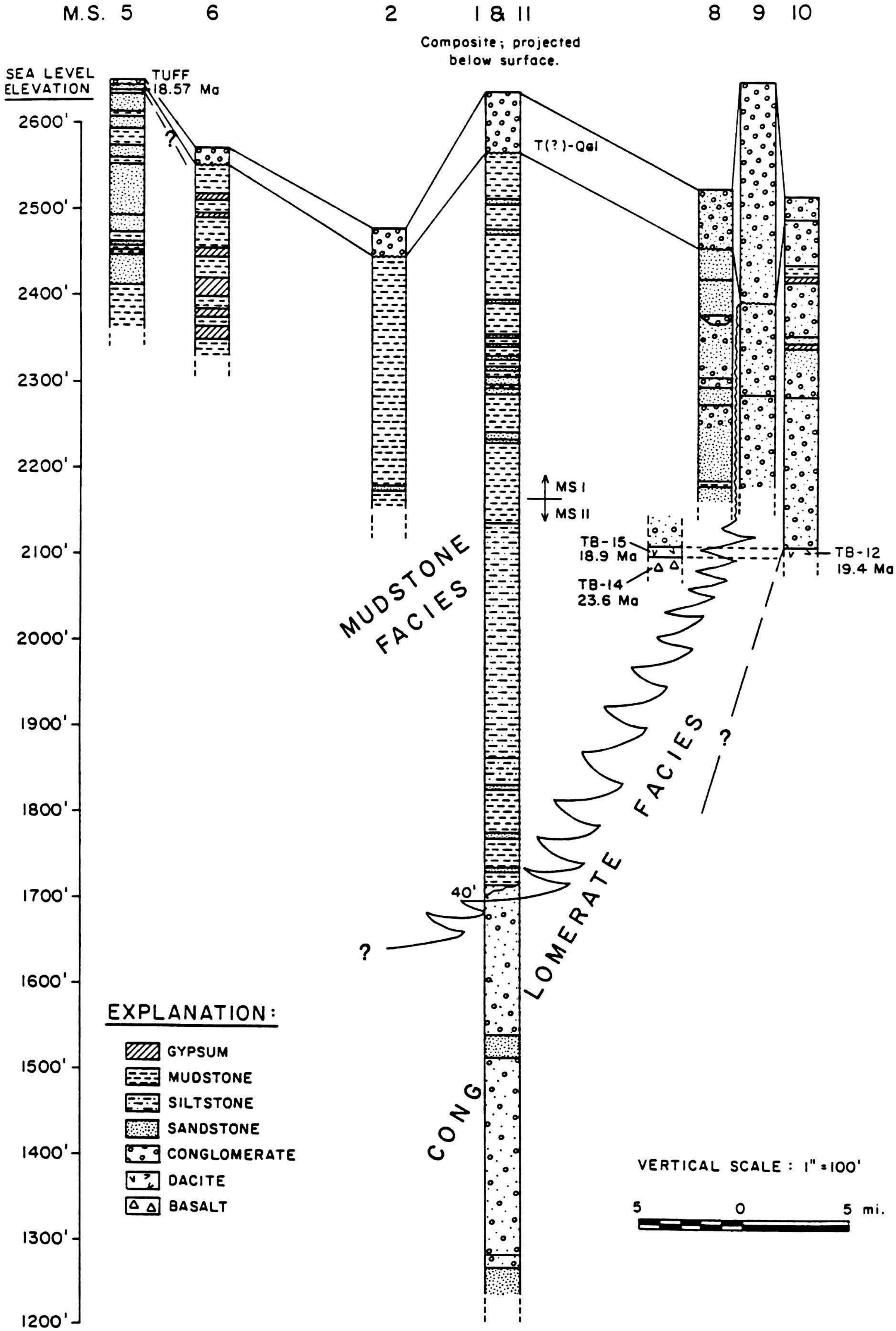


FIG. I: LOCATION MAP
TONTO BASIN, ARIZONA
1:250,000 scale
CI = 200 ft.
0
5 mi.
= Measured Section
DATED SAMPLE LOCALITIES:
TB -12, dacite, 19.4 ± 0.8 Ma
TB - 14, basalt, 23.6 ± 1.2 Ma
TB - 15, dacite, 18.9 ± 0.8 Ma
TB - 20, tuff, 18.57 ± 0.57 Ma
R10E
R11E
R12E
R13E
R14E
T7N
T6N
T5N
T4N
T3N
T2N
TB-20
TB-18,19
TB-15
TB-14
TB-12
TONTO NATIONAL FOREST
Roosevelt
Lake
Government Hill
WINDY HILL
TONTO NATIONAL MONUMENT
MARICOPA COUNTY
PINAL COUNTY
SUPERSTITION
WILDERNESS
FISH CREEK MOUNTAIN
BLACK CROSS BUTTE
BRONCO BUTTE
GERONIMO HEAD
Ranch

FIG. 2: CROSS-SECTION, TONTO BASIN-FILL

(Location of Sections shown on Figure 1)



FIELD TRIP

HANDOUTS

STRATIGRAPHY AND TECTONIC SIGNIFICANCE OF CENOZOIC BASIN-FILL SEDIMENTS, TONTO BASIN, ARIZONA

by
Dale Nations
Geology Department
Northern Arizona University
Flagstaff, Arizona

ABSTRACT

Cenozoic strata within the Tonto Basin consist entirely of syntectonic and post-tectonic sedimentary and volcanic rocks. The oldest documented Cenozoic event within the basin is represented by the 23.6 Ma basalt at the base of the basin-fill sediments in the Campaign Creek area. The basalt may signal the beginning of deep-seated normal faulting and the initiation of extensional tectonism. Exposures of 18.9 and 19.4 Ma dacite, which overlie the basalt and are also cut by normal faults, may be correlative with the Apache Leap Tuff, a 19.9 to 20.4 Ma volcanic unit that extends over a wide area from Globe to the Superstition Mountains.

Basin-fill sediments overlie the dacite and are largely composed of its erosional detritus, especially in the lower one-third of one section and along basin margins. The coarse-grained, chaotic nature of the basal and basin-margin sediments suggests that the lower part of the basin-fill sediments is syntectonic, having been deposited as the basin subsided. The basin-fill exhibits a rather abrupt fining-upward transition about 500 feet above the base of the section on Rock Island that suggests a cessation of tectonism, above which the distal basin-fill becomes very fine-grained. A K/Ar date of 18.5 Ma on tuff within undeformed fine-grained basin-fill near Punkin Center indicates that the Tonto Basin was well-defined by the early Miocene. The youngest age of basin-fill sediments is interpreted as late Miocene or early Pliocene, based on the occurrence of Pliohippus in the mudstone facies, about four miles east of Punkin Center.

Extensional tectonism in the Tonto Basin is documented by high angle normal faults that displace the mudstone facies of the basin-fill and older rocks along the southwestern margin and center of the basin. This faulting began soon after 18.9 Ma and the basin was well-defined prior to 18.5 Ma. In the Mills Canyon area one of these faults cuts lower basin-fill sediments, but is truncated by an erosion surface overlain by unfaulted fine-grained basin-fill, indicating that movement on that fault had ceased by late Miocene to early Pliocene time.

INTRODUCTION

The Cenozoic stratigraphy and tectonic history of Tonto Basin is very poorly known. The basinfill has been mapped only as Quaternary and Tertiary sediments on the Geologic Map of Gila County (1959), and as Pliocene sediments on the Geologic Map of Arizona (1969). More recent geologic mapping in the area has virtually ignored the basin-fill section because emphasis was on bedrock and structural geology in the adjacent Mazatzal Mountains and Sierra Ancha. This report is based on field work, including the measurement of eleven stratigraphic sections (Figure 1), lithologic description, and preliminary facies interpretations of Cenozoic basin-fill strata (Figure 2). Observations and measurement of sedimentary and tectonic structures have been used, in conjunction with four new radiometric dates, to interpret the Cenozoic tectonic history of Tonto Basin.