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Preliminary Report

Initial Design Phase Geological Investigations

Claypool-Jakes Corner Highway

Roosevelt Lake Bridge
Gila County, Arizona

Prepared By:

George A. Kiersch
Geologic Consultant

for

HOWARD NEEDLES TAMMEN & BERGENDOFF

September 20, 1985

NOTE:

The geologic data included in this report was acquired using conventional literature search, field reconnaissance, observation of core drilling and interpretation/correlation of core borings. The geologic interpretations and recommendations are the result of application of professional judgement to this data. As with all geological work, differences of opinion and interpretation are possible.

The user of the information contained in this report is advised that neither the Owner nor HNTB warrant the accuracy or applicability of these interpretations and recommendations and any use of this information is made with this understanding and at the user's risk.

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July 3, 1985

HOWARD NEEDLES TAMMEN & BERGENDOFF
9200 Ward Parkway
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Kansas City, Missouri 64141

ATTENTION: Mr. Gay D. Jones, P.E.
Chief GeoTechnical Group

RE: Preliminary Report / Progress on Geological Investigations - Evaluation of Steel Bridge Site at Roosevelt Lake, Arizona for Re-Alignment Highway 188.

EXECUTIVE SUMMARY

The planned re-alignment of Highway 188 with the proposed steel bridge across Roosevelt Lake will be founded on the rocks of two major formations of Central Arizona--the softer, thin-to moderate-bedded uppermost units of the Martin Formation and the basal, harder, moderate-bedded units of the Redwall Limestone. Both the East and West piers are founded on thinly-bedded limestones that alternate with thin interbeds of Shale/Claystone or Sandstone; clay seams and partings are common. The frequent joints and bedding planes with associated weathering have weakened and deteriorated the rock masses to depth of at least 35 feet; below the rock quality improves. The two rock formations are tilted and beds dip 30° to 40° Northward at both the East and West pier/approach-sites. In addition the rock masses are further broken by three prominent joint sets and by numerous small- to moderate-scale faults (reverse, normal, and bedding plane movement). The region has a very low seismic potential--an Intensity IV (Mag 2.5); features are paleo-faults and not active.

The West pier subsurface area has been investigated by two cored borings (B-1/-2) and the East pier area by three cored borings (B-3/-4/-5). The Salt River Canyon and thickness of channel-fill sediments have been explored by a geophysical survey. Areal geological evidence indicates the Salt River gorge near Roosevelt Dam has been downcut across the Mazatal Mountain block by the ancestral stream throughout the past 20 million years; no evidence is known for fault(s) within the channel that would traverse the proposed bridge alignment.

1.0 INTRODUCTION

In response to an invitation of October 1984 and subsequent requests of January-February, 1985 from Robert W. Luscombe, project manager HNTB/Phoenix and Gay D. Jones, chief of geotechnical Kansas City, George A. Kiersch agreed to serve as the geological reviewer and consultant to the field investigations (STAGES I and II). A contract for geological services was authorized by ADOT to begin on May 9, 1985.

The pre-contract discussions with HNTB generated a considerable amount of background information on the project. Field data was compiled from scattered sources, such as: the Phoenix office was visited on January 22nd and RWL provided a general explanation of plans; the site was initially visited parts of January 29-30th to assess the main geologic features and conditions pertinent to drilling and field mapping; relevant published and unpublished geological data was assembled; and requests were made of HNTB for base maps, aerial-photographs, and pre-dam construction photographs of the Salt River channel and vicinity that would show the rock units and channel walls, now flooded by the lake. In addition other reports and items of value to the geological studies were forwarded by RWL, such as two sets of base aerial-photographs, and an enlarged photographic base map for both the East and West pier areas.

No requests were made of GAK for an input into the location of the 4-borings and/or specifications for the cored borings scheduled for STAGE I. However as part of the contract details GAK advised on May 2nd of the advantages/desirability to: drill two or more of the STAGE I borings at inclinations of 30-degree from vertical (about normal dip of bedrock); utilize a swivel, double-tube core barrel and appropriate bits to attain maximum core recovery; and for the on-site drilling inspector to give close attention to recording all "fugitive" drilling data, such as hard-vs-soft penetration rates, color changes of return water that may indicate a rock change, contacts, clay seams, interbeds, faults, mineralization, deeply weathered zones, etc., all important rock features not available from or recorded by a study of the permanent core.

Past discussions with HNTB and this review and investigations of May-June have focused on: the areal geologic history and deformation of the rock units/formational members that occur in the vicinity of the proposed alignment; the nomenclature and critical properties/characterization of the units; the inherent structural features of the rocks; as well as the subsurface conditions that may be involved with the approach-sector and main bridge foundations. The interpretations reported have benefited from a review of Borings B-1, -2, -3, and upper -5 drilled in June 1985. A total of 9-field days was spent on the area, site, borings, and travel (May 27-28, June 6-8, June 10-13, and June 19-20) and some 11-office days were utilized acquiring background information, analyzing/assimulating data, plotting sketches of field information, preparing photographic documents, etc. (May-June). Preparation of the progress report and supplemental materials/graphic illustrations, documentation totalled 5 days (June-July 3).

2.0 BACKGROUND SOURCES - - - PRINCIPAL REFERENCES

The following representative reports and publications/maps have been reviewed to provide background on the geological conditions and features of the proposed bridge site and vicinity for re-alignment of highway 188--Roosevelt Lake, Gila County, Arizona. These sources along with personal field observations (January-June, 1985) and an interpretation/correlation of available cored borings during June 1985 are the basis for comments on and evaluation of the geologic setting and subsurface conditions in vicinity of approach-sectors and main pier foundations of bridge site.

.. Huddle, J. W. and Dobrovolny, E. 1952 Devonian and Mississippian Rocks of Central Arizona: U.S. Geological Survey, Prof. Paper 233-D. (Measured sections of Martin and Redwall Formations East Wall-Windy Gap.)

.. ABM, 1959 Geologic Map of Gila County, Arizona: Arizona Bureau of Mines, Univ. of Arizona, Tucson.

.. Tahmazian, G. A. 1964 Petrography of Troy and Martin Clastic Sequence at Roosevelt Dam, Gila County, Arizona: M.S. Thesis, Univ. of Arizona, Tucson. (Measured section on West Wall of dam/channel.)

.. Teichert, Curt 1965 Devonian and Mississippian Rocks of Central Arizona: U. S. Geological Survey Prof. Paper 465. (Measured sections East Wall and Windy Gap with thick Becker Butte Member Martin as channel fill near dam.)

.. ABM 1971 Geologic Guidebook 4- Highways of Arizona 88 and 188: Arizona Bureau of Mines, Bull. 184, p. 33-38 on Roosevelt Dam Area.

.. Meador, S. J. 1976 Paleocology of the Upper Devonian Percha Formation of South-Central Arizona: M.S. Thesis, Univ. of Arizona, Tucson. (The series of green shales and thin-bedded, yellow-brown dolomites uppermost of Martin section at Roosevelt are designated Percha Formation to the southeastward.)

.. Elston, D. P. and Bressler, S. L. 1978 Stratigraphic and Paleomagnetic Relations Between Basal Cambrian and Devonian Strata in Central Arizona, in Guidebook on Geology of Central Arizona: Ariz. Bur. Geology Special Paper No. 2, p. 138-143.

.. Scarborough, R. B. 1981 Reconnaissance Geology--along Salt River between Roosevelt and Granite Reef Dams: Fieldnotes, Ariz. Bur. Geology, vol. 11, no. 4, p. 6-10.

.. S & W 1981 Proposed Alchesay Pumped Storage Project, Salt River, Arizona, Volume I: Stone & Webster Engr. Corp., Denver, Colorado (May 26, 1981) (unpubl).

.. USBR 1982 Topography- Geology Map-- Theodore Roosevelt Dam: U.S. Bur. Reclamation, Phoenix, 3-sheets, scale 1"=100 feet (unpubl).

.. DuBois, S. M. et al. 1982 Arizona Earthquakes, 1776-1980: Ariz. Bur. Geology Bull 193. (Maximum intensity recorded/expected in Roosevelt Dam area--Intensity 4-5.)

Aerial-Photographs Evaluated/Interpreted for Field Evidence- Base Map Plotting

.. 1977 Photos of 1648 Project: Ariz. Dept. Transportation; 10-14-77, set of 3; no. 1-2-3. Scale 1 inch-250 ft.

.. 1983 Photos of 2093 Project: Ariz. Dept. Transportation; 6-6-83, set of 3; no. 1-1/1-2/1-3. Scale 1 inch-1,000 ft.

Photographs of Roosevelt Dam Site and Vicinity--Prior and During Construction

.. 190[illegible]-08 Photographs of the channel, East and West Walls that show pre-construction and pre-lake exposures of rocks in vicinity of both west and east pier foundation sites.

3.0 GEOLOGIC SETTING

3.1 General- History of Rock Deformation

The Roosevelt Lake/Dam area is located within a region of very old sedimentary rocks that overlie Precambrian granites (TABLE I). The principal formations in the vicinity of the bridge site 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 past 20 million years (mid-Tertiary Orogeny) are particularly relevent to the features and conditions of the rocks nearby the bridge site (shown in photographs--Figures 4 thru 10).

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 (See TABLE I). The two Paleozoic rock units have been largely removed by massive erosion throughout the region since the strong mid-Tertiary deformation with uplifting and accelerated 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 and at Windy Gap.

The strong tectonic upwarping of the Mazatzal Mountains and Roosevelt Lake region about 19 mil. yrs. ago reactivated some old Precambrian and Mesozoic faults and developed the main regional-areal structural features known today. This deformation was part of the strong Laramide Orogeny that affected other western states during Eocene-Miocene time (57 to 5 mil. yr. ago). The rock column was initially folded/deformed by NW-trending fold axes that formed such features as the Tonto Basin. This regional folding with tilting formed a homoclinal-block of the Precambrian-Paleozoic rocks (Granite/Apache-Martin-Redwall) along the northwest-trending Mazatzal Mountains and the Salt River canyon to the southeastward (Fig. 7). The regional tilting northeastward that occurred 19.2 to 14.2 mil. yrs. ago (Scarborough, 1981) caused a major NW-synclinal fold axis to form within the rocks of Tonto Basin (site of Lake Roosevelt today); 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 Tonto Basin and crop out in the Sierra Ancha Mountains as the bold cliffs and mesa-like caprock of fault-block masses along the Mogollon Rim of 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 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. yr. ago) was followed by a period of younger Basin and Range faulting that occurred 13 - 4 mil. yrs. ago. Many N-S faults formed at this time further displaced and segmented into fault-blocks the northward dipping homoclinal mass of Granite-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 (Fig. 3). 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 West and East pier sites (SRP-Photos, 1904)--are not related to faulting. Terraces occur at several elevations in the Tonto Basin and represent Pleistocene levels of the former river system.

3.2 Origin of Salt River Channel Near Dam

The origin of the Salt River gorge near Roosevelt Dam and downstream across the Superstition Mountains (up to 2,000 feet deep) is relevant to possible conditions that might be encountered for any bridge pier in the channel. An evaluation of all available information indicates the ancestral Salt River drainage adjusted by accelerated downcutting across the Mazatzal Mountain block as arching and uplift occurred (beginning about 20 mil. yrs. ago). Furthermore, boulders and cobbles of granite, basalt, and limestone along with channel debris and cemented gravels--are remnants of an earlier channelway--that flowed over the bench-like area carved in Mescal Limestone at about elevation 2,400 feet situated on the West Wall directly above the spillway of 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 upstream of Roosevelt Dam that parallel the channel and thereby traverse the alignment for proposed bridge. All evidence indicates the Salt River channel has been selectively carved in the bedrocks as uplift accelerated the downcutting process of ancestral drainage.

3.3 Principal Rock Units

The Devonian Martin Formation and overlying Mississippian Redwall Limestone are the two principal rock units occurring at or in vicinity of the Highway 188 approach-sectors and bridge pier foundation sites (Fig's 1,2,3).

The column of Martin rocks in vicinity of Roosevelt Lake has been measured, analyzed, and described by some 10 separate investigators over the past 70 years. The individual limestone/dolomite beds with associated sandy limestone, sandstone, shale and siltstone beds comprise a thick sequence of about 486 feet (Teichert, 1965) in the Roosevelt Lake region; however, the total rock column has not been defined and subdivided in the same manner by any of the past investigators. After a review of the varied studies, the general limits of Teichert (1965) and Huddle and Dobrovolny (1952) are followed by the writer with some additions/modifications from Tahmazian (1964) and Meador (1976). The Martin Formation rock column is composed of two prominent and distinctly different members as follows:

Jerome Member (Upper/Middle member of others)--characterized by an uppermost brownish-gray, fine-grained Sandstone beds (s... 25

feet thick) that are underlain by softer, greenish-gray Shale beds with minor sandy Sandstones that total some 35 feet thick. Beneath these two topmost units, the Jerome Member is mainly composed of varied colored Sandstone beds (brown, green, reddish, pink, and gray) with thin interbeds of Dolomite and thicker Sandy Dolomite beds. The Jerome Member total some 388 feet thick near dam, but faulting repeats some parts of section and masks the exact thickness on both East and West Wall exposures.

Becker Butte Member (Included Lower member of others)--mainly a series of channel-fill units and clastic beds throughout the region. Occurs on East Wall as deposits in a steep-walled channel carved in the underlying Troy Quartzite and Mescal Limestone with basalt that is exposed immediately upstream of dam. The seven clastic units that comprise the Lower Martin are varied Sandstones which are poorly-sorted to cross-bedded with a Basal 10-foot unit of weathered siltstone and limestone boulders.

The Redwall Limestone that overlies the Martin Formation occurs as a thin cover (15-30 feet) of medium-to thick-bedded limestone beds on the East Wall uphill from the re-alignment (Fig. 3). The Redwall crops out at the abandoned cement quarries (Photo 4) and possibly as a fault-displaced block near Highway 88 (Fig.1-B). On the West Wall, the lowermost beds of Redwall Limestone are apparently in fault contact with the Martin Formation and shale-sandstone units on Hotel Point and were cored in boring B-2. The lower Redwall Limestone beds that overlie the Martin Formation consist mainly of thin-to medium-bedded, white, buff, yellow-brown, and grayish crystalline limestone units; crinoidal and coral fossils and chert nodules are common and distinctive of these rocks. The Redwall beds are exposed along Highway 188 northwest of Hotel Point (Fig. 1-A).

TABLE I - ROCK COLUMN NEAR ROOSEVELT LAKE

Engineered-Works	Formational Name	Age
	Redwall Limestone	Mississippian
Bridge Foundations	Martin Formation	Devonian
	Jerome-Upper/Middle Member	
	Becker Butte-Lower Member	
	Tapaets Sandstone	Cambrian
	Troy Quartzite	Younger Precambrian
	Diabase Intrusive	

TABLE I - ROCK COLUMN NEAR ROOSEVELT LAKE (continued)

Engineered-Works	Formational Name		Age
Roosevelt Dam-Foundation	Mescal Limestone	Apache Group	Younger Precambrian
	Upper Basalt	Apache Group	
	Dripping Spring Quartzite	Apache Group	
	Barnes Conglomerate	Apache Group	
	Pioneer Shale	Apache Group	
	Scanlan Conglomerate	Apache Group	
	Granites (± 1.4 Bil. yrs. old)		Old Precambrian

3.4 Areal Features

The main fault pattern of the area-region consists of NW-, NE-, N-S and E-W trending structures that are old (youngest 4 mil. yrs.) and not active (paleo-faults). The area possesses a very low seismic potential--an Intensity IV (Mag. 2.5) according to the published records (DuBois, et al. 1982). The principal joint sets in the Paleozoic and Apache rocks trend similar to the main faults--generally NW, NE, and E-W.

Bedding plane faults are common in the Martin rocks due to the northward sliding on limb of the regional homoclinal structure. These bedding plane shifts downdip occurred as an adjustment to the regional folding and has resulted in a repeating/duplication of some parts of the Martin rock column--particularly evident along the shale interbeds within the more massive dolomite and sandstone units and within the shale and shaly sandstone units represented by the uppermost Martin beds. Such faults and displacements are exposed in the Highway 88 outcrops near the East Wall pier site.

Local solution action and small voids/cavities were encountered by borings in the Martin rocks (B-3 at 63-64 ft. and B-2 at 99-102 and 108-110 feet). These cavities in calcareous units of the Martin occur at some depth beneath any proposed foundation grade.

4.0 SITE-SPECIFIC INVESTIGATIONS

4.1 Subsurface Investigations

Field investigation of the Paleozoic rocks and an evaluation of features/ properties relevant to the bridge site has included general plotting of formational boundaries and structural features and subdivision of significant units on base maps, aerial photographs and sketch geologic sections. Observation of field occurrences and features has utilized road cuts and quarry exposures, on-the-ground traverses, jeep trails and helicopter landings to areas of rock outcrops important to the evaluating the site conditions. Personal observations have been correlated with the interpretations and findings of earlier investigators (published/unpublished reports--listed Section 2.0).

4.2 Subsurface Exploration

The Stage I exploration plans of HNTB scheduled four cored borings to be drilled in early June, as shown on Exhibit C of May 8th. Two borings were allocated for both the West and the East Wall sites; a deep vertical or inclined hole of 200 feet was located at each proposed pier site and a 100-foot vertical boring near each approach-sector.

After reviewing the geological conditions of the East Wall area with geologist John Sztro (June 6-8) and G. D. Jones (June 10-12), HNTB decided to shorten hole B-1 and add a fifth hole B-5 to explore the East pier site in more detail. The purpose of B-5 at 30-degree inclination was to traverse and sample the full section of softer shale-sandstone beds (Martin) that occur at this site and furthermore acquire data on such associated features as expected NW-trending faults, bedding plane slips, and the general physical properties of the softer units.

Hole B-2 at Hotel Point/West pier site was drilled at 20-degree inclination to a total depth of 117 feet--where abandoned when the driller lost bit and reamer shell in hole. B-3, a vertical hole at the East pier site was drilled to 105 feet. Hole B-5, drilled at a 30-degree inclination (normal to bedding) experienced difficulty with core recovery in softer shale-sandstones and with a caving of the hole during the four days of drilling (June 18-21); the hole was abandoned at 184 feet due to uphole caving and time restrictions.

The writer reviewed the core logging of borings B-1 and upper part B-2 (June 11-12 visit) and remainder of B-2, B-3 and upper 69 feet of B-5 (available June 20 visit). Comments and recommendations were made to the drill inspector and John Sztro for identification of faults, classification of select beds and rock features and the general description and care of core; an additional request to collect the "fugitive" boring data was made. A generalized geologic log of the four borings reviewed and evaluated by GAK was prepared for correlation with the engineering data as recorded by the Western Technologies log. Boring B-5 below 69 feet and Boring B-4 of July have not been reviewed/logged.

Core recovery was generally low to moderate throughout the upper 30 to 35 feet of Borings B-1 and B-2; B-3 and B-5 penetrated fill/rubble to 21 and 15 feet respectively. The poor core recovery partly represents the near-surface effects of the weathering processes--with an abundance of oxidized joints and bedding planes and zones of soft, weathered rock which cause a deterioration of the rock mass. However, the in-situ rock units should provide a much greater overall strength and stability than the sketchy core pieces imply, even though some of the loss is likely due to small fault zones, clay seams and soft shaly interbeds.

The low core recovery throughout the shale-sandstone unit penetrated from 84 to 144 feet in B-5 was disappointing. Besides the soft properties of the rocks penetrated, the losses very likely represent faults with gouge zones, interbeds, partings, and numerous bedding plane faults, slips and seams. An actual record and forecast of the in-situ rock conditions may be needed for the foundation design at East pier--and excavation planning.

4.3 Submarine Studies

On June 12th, GAK met with Earl D. Van Reenan of Van Reenan International and reviewed the general geologic conditions of Salt River channel and alignments to be investigated by sub-bottom profiling, side scan sonar, and a fathometer survey. Van Reenan was supplied with copies of 1904 photographs by GAK showing the channel walls of both East and West sides (before lake) to aid his submarine studies. No results of this geophysical investigation have been made available to GAK for correlation with the geologic setting and channel interpretations given herein.

5.0 COMMENTS - RECOMMENDATIONS

... Although evidence was not collected by the B-5 boring, one or more NW-trending fault(s) occur in vicinity of the proposed East pier foundation as well as the approach-sector structure. The zone(s) is expected to be several feet wide and consist of clayey gouge with small limestone and sandstone fragments (an example of such fault gouge is in B-1 at 40 feet).

... The drilling of one or more additional borings should be considered for the East pier site, due to the somewhat unclear and lack of factual knowledge gained from Boring B-5. These holes would identify and delimit fault(s) and secure representative samples of these zone(s) and the soft host rocks.

... The near-surface 10-35 feet of rock at sites is important to the engineered design and plans for excavation. Because this zone and other parts of subsurface are not wholly represented by core--consideration should be given to performing a suite of geophysical logging measurements on each boring soon after completion; do not backfill hole immediately. Such logging information correlated with the sketchy core can provide a meaningful insight for interpretation of the in-situ rock features/conditions where there is no recovery. (Two reputable logging companies of Grants, New Mexico are available for such work). An appropriate geophysical logging program would include density, porosity, natural gamma, spontaneous-potential, and resistance logging.

... Future drilling would benefit from an improved set of guidelines-specifications to drill contractor, such as: means of keeping holes open to complete target depths; and providing return drill water so all "fugitive" data can be recorded for correlation with the permanent core (described Section 1.0).

I would be pleased to supply additional details on any geological aspect as you may request.

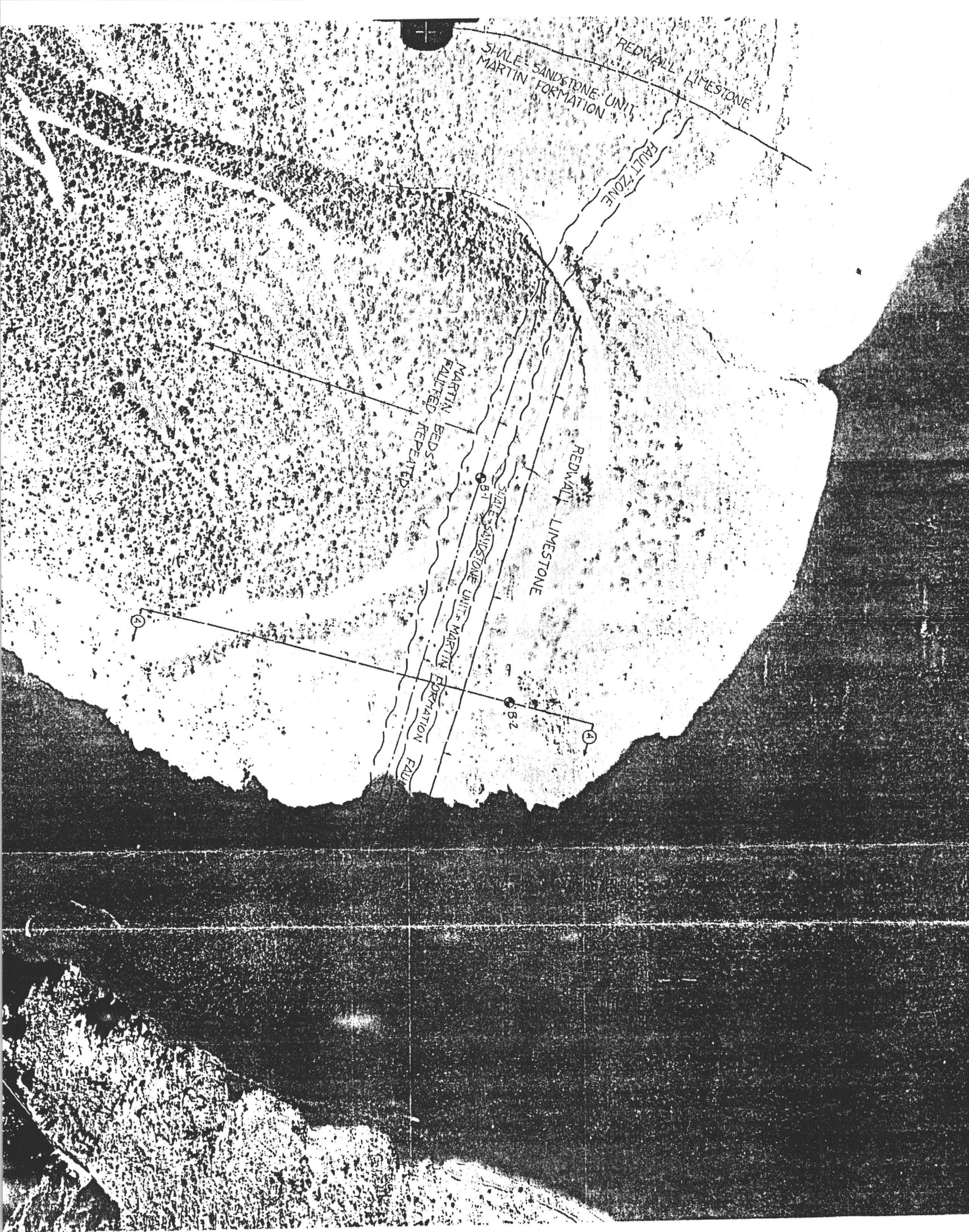
Respectfully Submitted,

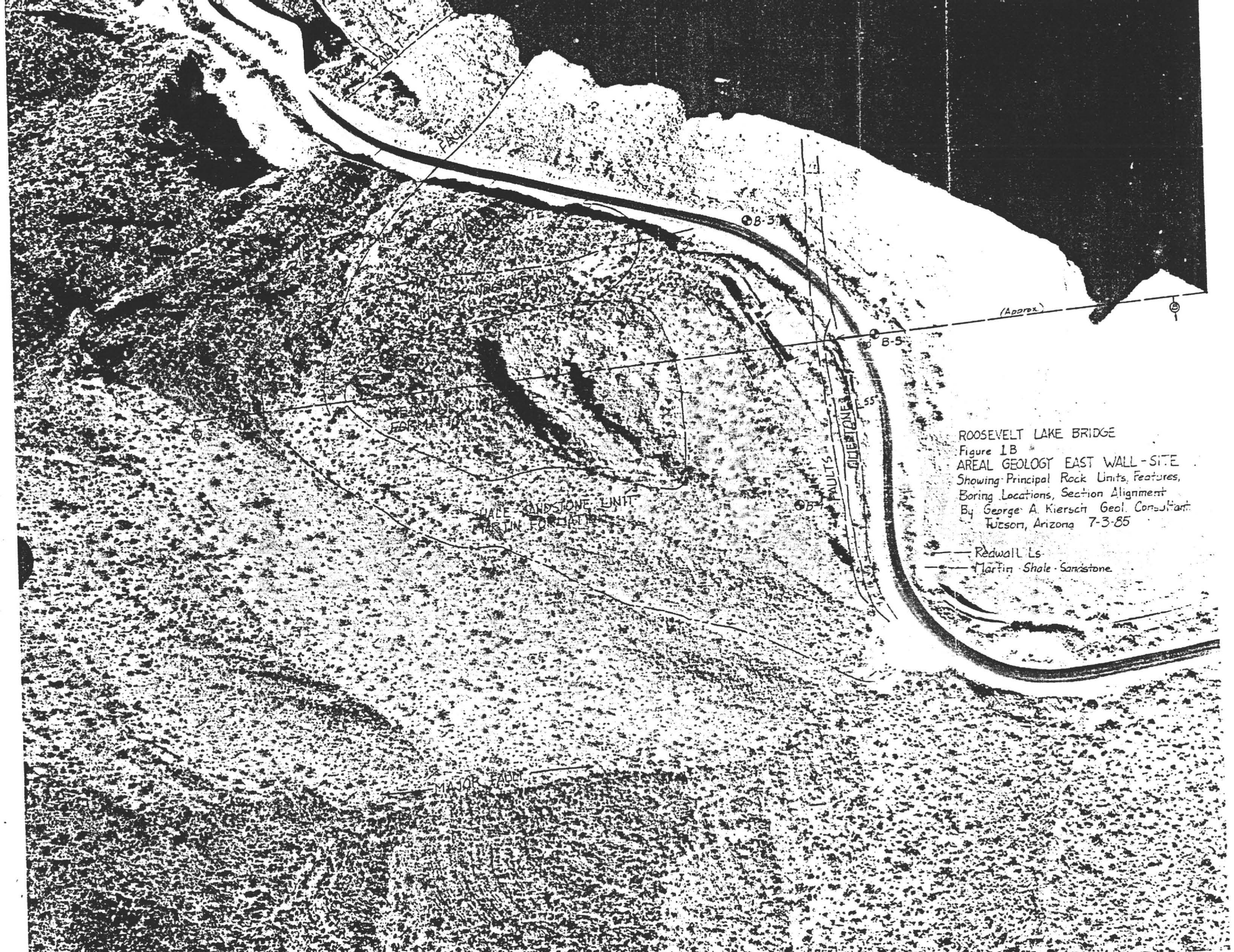
George A. Kiersch

George A. Kiersch

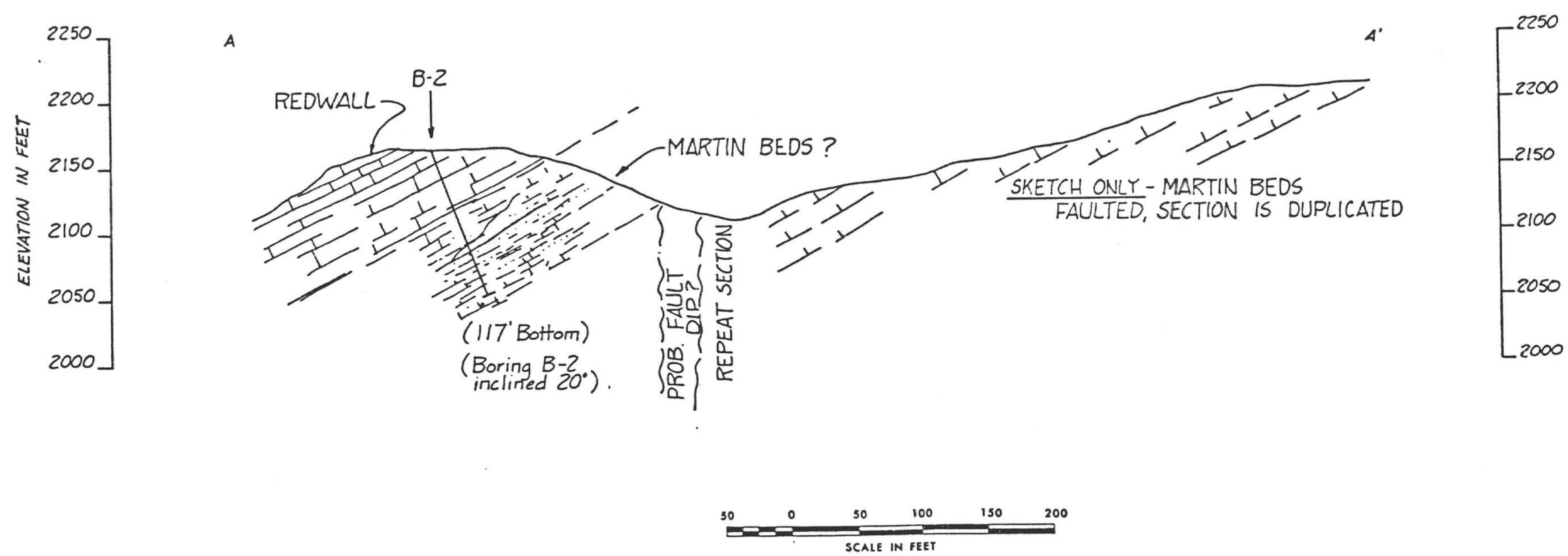
GAK/em

Attachments: Fig. 1 - Plan Maps-West(A)/East(B) Sites
Fig. 2 - Cross-Section/West Pier
Fig. 3 - Cross-Section/East Pier
Fig. 4a/b - Photographs East Wall/Canyon
Fig. 5 - Photograph East Wall/Shale-Sandstone Unit
Fig. 6 - Photograph Shale-Sandstone Unit/East Site
Fig. 7 - Photograph West Wall-Site
Fig. 8 - Photograph Beyond West Wall/Shale-Sandstone Unit
Fig. 9 - Photograph 1908-Hotel Point Rocks of B-2 Drill Hole
Fig. 10 - Photograph 1909-Hotel Point Rocks of B-2 Drill Hole


REDWALL LIMESTONE
SHALE-SANDSTONE UNIT
MARTIN FORMATION
FAULT ZONE
MARTIN BEDS
FAULTED REPEATED
REDWALL LIMESTONE
SHALE-SANDSTONE UNIT-MARTIN FORMATION
B-1
B-2
A
A



ROOSEVELT LAKE BRIDGE
Figure 1B
AREAL GEOLOGY EAST WALL-SITE
Showing Principal Rock Units, Features, Boring Locations, Section Alignment
By George A. Kiersch Geol. Consultant
Tucson, Arizona 7-3-85

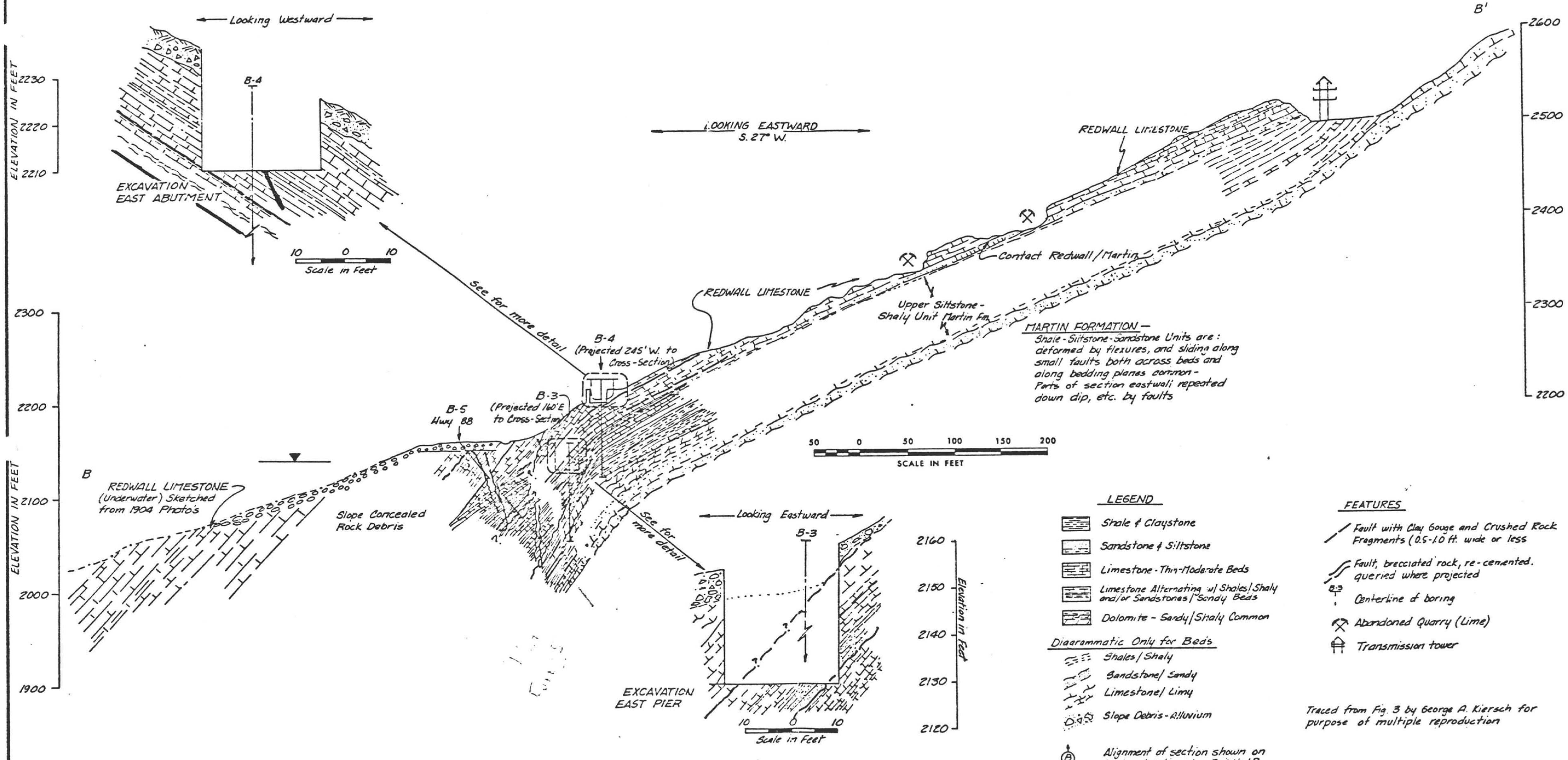


Traced from Fig. 2 by George A. Kiersch for purpose of multiple reproduction.

See Fig. 3 for Notes & Legend

Alignment of Section A-A' shown on Exhibit 1A.

ROOSEVELT-PAYSON HWY. (S.R. 188)		
GILA COUNTY, ARIZONA		
GEOLOGIC CROSS-SECTION WEST WALL LAKE ROOSEVELT BRIDGE		
George A. Kiersch Geologic Consultant Tucson, Arizona		
PREPARED: G.A.K	DATE: 6-30-85	SHEET ___ OF ___
DRAWN: JFS/GAK	DATE: 8-1-85	EXHIBIT Fig. 2
CHECKED:	DATE:	



TOPO BASE for PROFILE
Map SRVWUA - 1959
Map HNTB - 1985
A-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 8-10-85	SHEET ___ OF ___
DRAWN: JFS/GAK DATE 8-15-85	
CHECKED ______ DATE ______	EXHIBIT Fig. 3

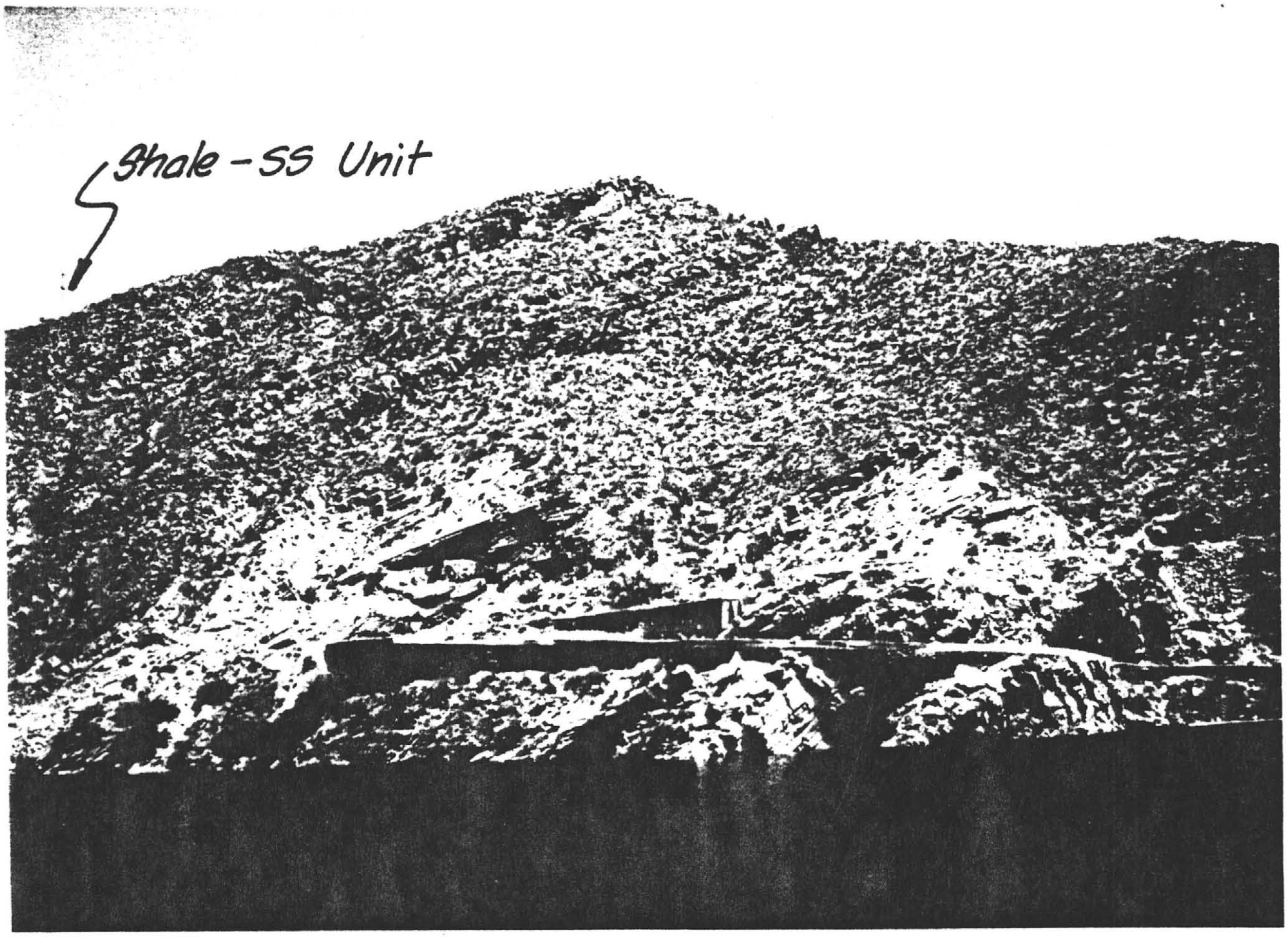


Figure 4-A East Wall

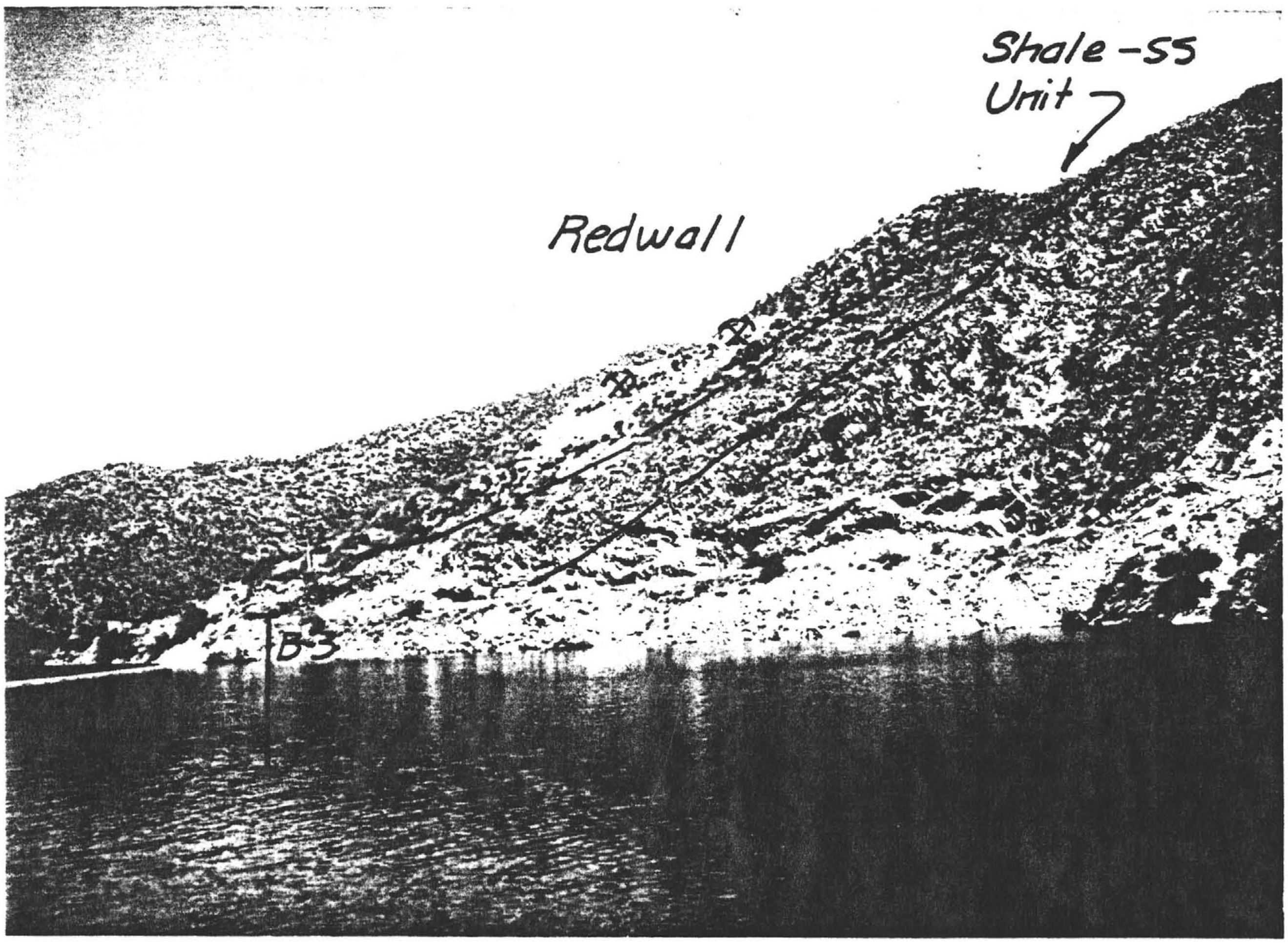


Figure 4-B East Wall - Site

Figure 5 Shale - Sandstone Unit/ East Wall - Site

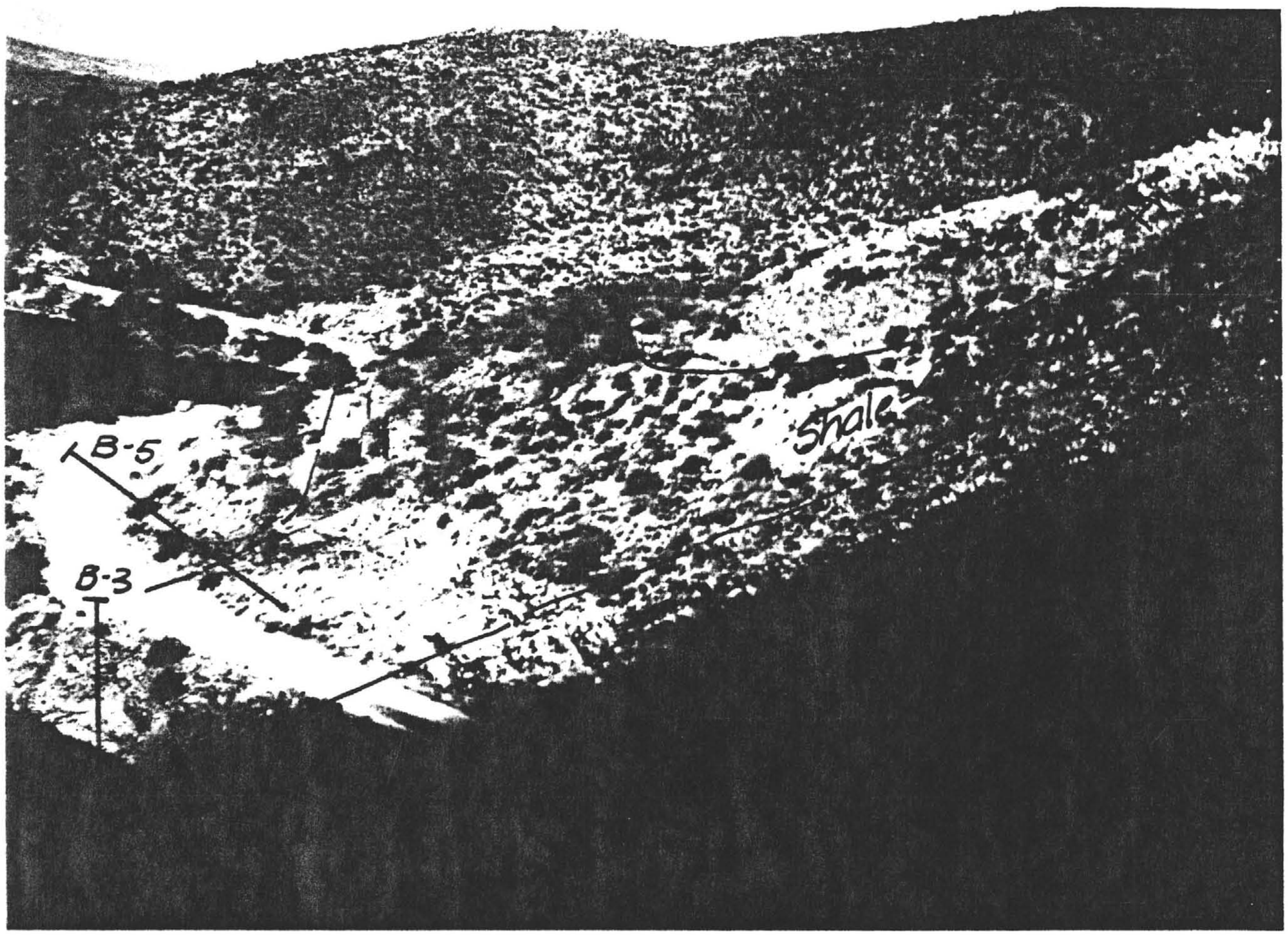


Figure 6 - East Wall - Shale-Sandstone Unit

Fig. 7 - Westwall / Shale - Sandstone Unit
Eastwall Foreground / Shale - Sandstone Unit

Fig. 8- Westwall / Shale - Sandstone Unit
Martin Beds (See Fig. 7)

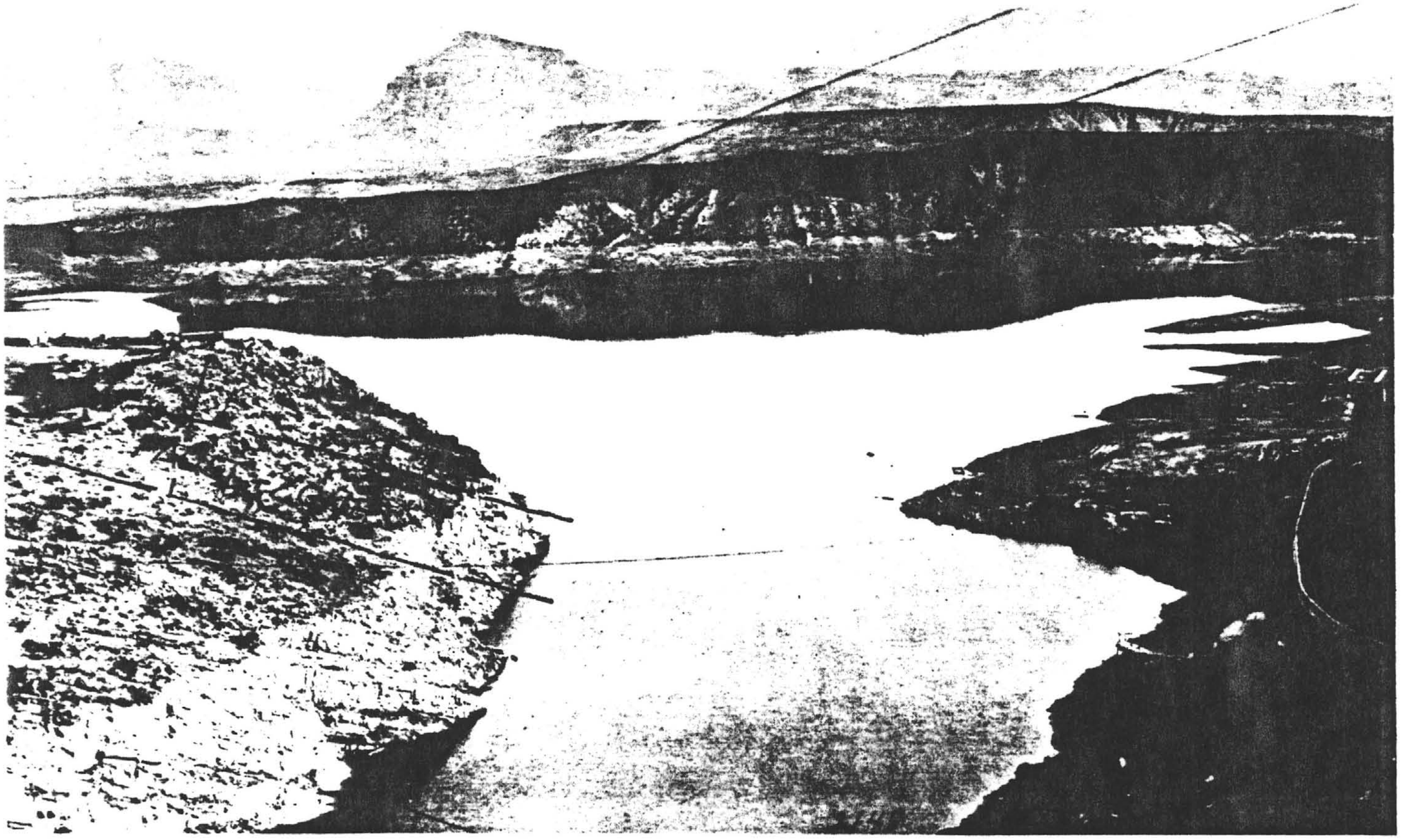


Fig. 9 - Hotel Point 1908; Rocks penetrated B-2 Boring

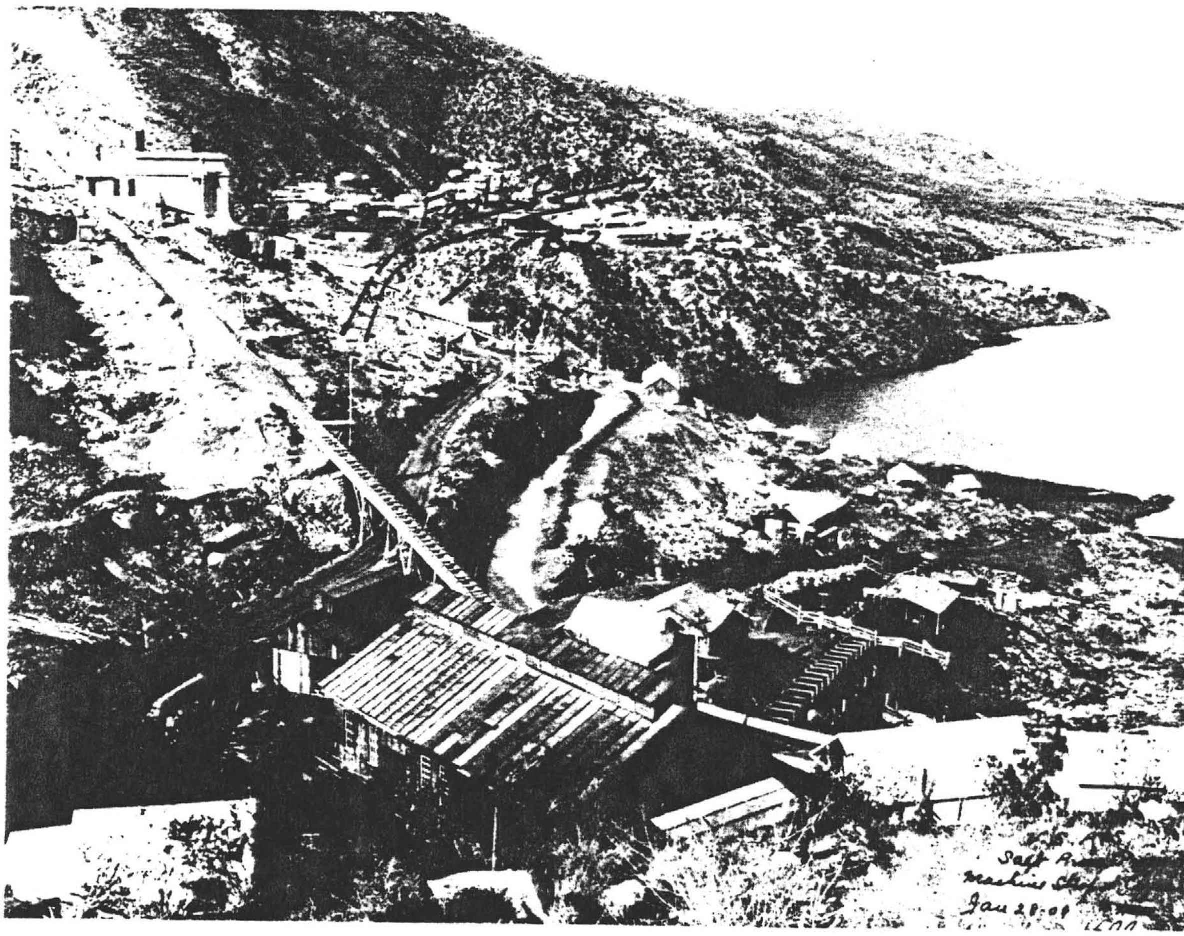


Fig. 10 - Hotel Point 1910; B-2 Location Rocks and Fault Zone Side Canyon

7-3(6)
1720-1513

ARIZONA FH-9

CHOLLA BAY-HOTEL POINT

September 1984

Investigation by Bob Blenk, Engineering Geologist
and Wayne Folkman, Field Exploration Supervisor

Report by Sam Holder, Geotechnical Engineer
and Wayne Folkman, Field Exploration Supervisor

Materials Branch
Central Direct Federal Division
Federal Highway Administration

Denver, Colorado

Distribution
Project Development
Western Bridge (2)
Construction
Project Engineer (through Project Development)
Planning and Coordination
CDFD Files
Materials (2)

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INTRODUCTION

During March and April 1984 the Materials Branch of the Central Direct Federal Division, Federal Highway Administration, conducted a materials investigation for approximately 3.9 miles of proposed new alignment for Arizona FH-9 (State Route 188) along Roosevelt Lake.

The 3.9 mile section begins in the vicinity of Cholla Bay at Station 1420± and runs roughly parallel to the existing roadway in a southeasterly direction to Station 1625± in the vicinity of Hotel Point. A location map is included in appendix A.

Present plans are to construct this section in two parts. Construction is tentatively scheduled to begin on the first portion (Station 1420 to 1513) during FY 1985 and complete our portion of the route to Hotel Point in 1986. The State will finish the Route with a bridge from Hotel Point to SR 188.

The purpose of this investigation was as follows:

1. Conduct a soils survey over the proposed alignment.
2. Conduct foundation investigations for the proposed bridges at No Name and Mill Canyon sites, and partial investigations at the Bachelor Cove and Vineyard Canyon sites.

SOILS SURVEY

The soils survey consisted of a visual survey together with subsurface drilling and sampling. The results and recommended slope ratios are summarized on soils and engineering geology sheets that follow.

A total of 16 samples were tested for gradation, Atterburg limits and R-values and the results are included in appendix D. R-values are low throughout the section tested (Station 1399 to 1625±). Based on the R-value test results an R-7 was selected for design (see Chart IA, Design of Flexible Pavement Structure).

All fills extending beyond the present high water level of Roosevelt Dam (elevation 2136 should be constructed to high water elevation with competent rock and no steeper slopes than 2:1. Borings taken in these fill areas show granular material, so no long term settlement is anticipated.

During our investigation the proposed alignment at Station 1504 to 1505+50± was causing a sliver fill into the lake. The alignment through this area should be shifted approximately 20 ft. right to avoid this problem.

SUMMARY OF SOILS & ENGINEERING GEOLOGY

Soil Survey Project: ARIZONA FH-9; CHOLLA BAY - ROOSEVELT DAM   Date Performed April 1984

From Station to Station	Description of Soil or Rock	Estimated Type Excavation	Remarks
1399+00± to 1404+00±	Alluvial fan deposits of clayey silt or silty clay, cemented (becoming silty shale or shaley silt with depth).		Recommend 1:1 cutslope Shrink factor 10%±
1404+00± to 1409+00±	Alluvial fan deposits of interlayered sand, silt and fine gravel with occasional cobbles and small boulder zones, partially cemented.		Recommend 1:1 cutslope Shrink factor 10%±
1409+00± to 1413+15±	Rock outcropping, moderate to well fractured and dipping toward roadway.		Recommend 3/4:1 cutslope Swell factor 5%± Recommend wide ditches
1413+15± to 1422+00±	Alluvial fan deposits of interlayered sand, silt and fine gravel with occasional cobble and small boulder zones; partially to well cemented.		Recommend 3/4:1 cutslope Shrink factor 5-10%
1422+00± to 1427+00±	Alluvial deposits of loose to moderately dense silt, sand and gravel with cobbles and boulders.		No cut required (Fill)
1427+00± to 1431+00±	Alluvial fan deposits of interlayered sand, silt and fine gravel with occasional cobble and small boulder zones; partially to well cemented.		Recommend 3/4:1 cutslope Shrink factor 5%-10%
1431+00± to 1433+25±	Alluvial deposits of loose to moderately dense silt, sand and gravel with cobbles and boulders.		No cut required (Fill)
1433+25± to 1440+00±	Alluvial fan deposits of interlayered sand, silt and fine gravel with occasional cobble and small boulder zones; partially to well cemented.		Recommend 3/4:1 cutslope Shrink factor 5%-10%
1440+00± to 1444+00±	Alluvial deposits of loose to moderately dense silt, sand and gravel with cobbles and boulders.		No cut required (Fill)

SUMMARY OF SOILS & ENGINEERING GEOLOGY

Soil Survey Project: ARIZONA FH-9; CHOLLA BAY - ROOSEVELT DAM Date Performed April 1984

1512 this project ↓

From Station to Station	Description of Soil or Rock	Estimated Type Excavation	Remarks
1444+00± to 1484+70±	Alluvial fan deposits of interlayered sand, silt and fine gravel with occasional cobble and small boulder zones; partially to very well cemented with depth. Some PI, especially in shallow overburden deposits.		Recommend 3/4:1 cutslope Shrink factor 5% - 10%
1484+70± to 1487+30±	Alluvial depostis of loose to moderately dense silt, sand and gravel with cobbles and boulders.		No cut required (Fill)
1487+30± to 1514+50±	Shallow deposits of clayey sand and gravel, with cobbles and boulders; above well cemented alluvial fan deposits.		Recommend 3/4:1 cutslope Shrink factor 5% - 10%
1514+50± to 1518+50±	Alluvial deposits of loose to moderately dense silt, sand and gravel with cobbles and boulders.		No cut required (Fill)
1518+50± to 1529+00±	Shallow deposits of clayey sand and gravel, with cobbles and boulders. Well cemented alluvial fan deposits with depth.		Recommend 3/4:1 cutslope Shrink factor 10%±
1529+00± to 1539+00± 1538+50 ↓ 1542+50	Colluvial deposits of sand and gravel with mostly large boulders and possible PI. Possible rock with depth.		Recommend 1:1 cutslope Shrink factor 5% - 10%
1539+00± to 1568+50±	Moderate to well fractured rock, dipping toward roadway; with shallow colluvial debris deposits in spots.		Recommend ½:1 cutslopes Swell factor 5%-10% Recommend wide ditches.
1568+50± to 1587+00±	Colluvial debris and alluvial fan deposits with cobbles and boulders; possibly some cementation with depth.		Recommend 1:1 cutslope Shrink factor 5%-10%

SUMMARY OF SOILS & ENGINEERING GEOLOGY

Soil Survey Project: ARIZONA FH-9; CHOLLA BAY - ROOSEVELT DAM Date Performed April 1984

From Station to Station	Description of Soil or Rock	Estimated Type Excavation	Remarks
1587+00± to 1590+00±	Shallow deposits of colluvial debris above moderate to well fractured rock, dipping toward roadway.		Recommend ½:1 cutslope in rock. Recommend clean off colluvial debris deposits off rock. Recommend wide ditches. Shrink-swell factor = 5% to 10% shrink for colluvial debris and 5% to 10% swell in rock.
1590+00± to 1601+30±	Moderately fractured rock, dipping toward roadway.		Recommend ½:1 cutslope Swell factor 10%± Recommend wide ditches.
1601+30± to 1607+00±	Colluvial debris deposits of sandy gravel with probable PI, above moderate to well fractured rock, dipping toward roadway.		Recommend 3/4:1 cutslope Shrink-swell factor = 0%±
1607+00± to 1625+00±	Moderate to well fractured rock, dipping toward roadway. Shallow colluvial debris deposits in spots.		Recommend 1/2 to 3/4:1 cut-slopes. Swell factor 5%-10%. Recommend wide ditches.

FLEXIBLE PAVEMENT DESIGN

The following data was used in developing a flexible pavement design for the proposed project.

ADT	1984	558
ADT	2004	1860
% Trucks		2%
D		55%

Regional Factor 1.0

Eq. 18k Single axle loads per day = 14

Structural number required = 2.83

Using the design R-value of 7 the following structural section is recommended. This is the same section used for previous project 9-8(4) stations 1298 to 1343 and 1343 to 1399 as recommended in our report of March 1982.

Hot Bituminous pavement	4-1/2"	x	.40	=	1.80
Crushed aggregate base	4"	x	.12	=	.48
Crushed aggregate subbase	6"	x	.10	=	.60
	Total			=	2.88

PREPARED BY Folkman

PROJECT ARIZONA FLH-9 CHOLLA BAY TO HOTEL POINT-Stn.1399 to 1625 DATE June 11, 1984

Checked by T. Samuel Holdc

DESIGN OF FLEXIBLE PAVEMENT STRUCTURE

REGIONAL FACTOR

Precipitation	16"	IN/YR	= 0.5
Mean Elevation	2,200	ft	= 0
Drainage	Fair'		= 0.5
Total Regional Factor		:	1.0

DESIGN TERMINAL SERVICEABILITY

Pt = 2.5

TRAFFIC FACTOR

ADT (1984) + ADT (2004) X D = AVPD

$\frac{558 + 1860}{2}$ X (.55) = 665

Average VDP one way, 20 yr design

AVDP X % trucks = 18 kip load from trucks(T18K)

665 X 0.02 = 13.3
AVDP - T18K

(665 - 13.3)X .0002 = .13

Total 18 Kip Design Load = 13.43 Use 14

STRUCTURAL NUMBER REQUIRED FOR SECTION

Soil Classification	Resistance Value	ROADWAY SECTION from	ROADWAY SECTION to	Weighted Structural Number Required SSV	
	7	1399	1625±	2.71	2.83

RECOMMENDED ULTIMATE DESIGN

Pavement Component	Structural Coef. Range	DEPTH Altn 1	DEPTH Altn 2	DEPTH Altn 3	Coef for Structural Component	Total Struc. Number Altn 1	Total Struc. Number Altn 2	Total Struc. Number Altn 3
Seal Coat								
Plant Mix Seal	.25 - .30							
Plant Mix Surf.	.35 - .45	4½"			0.40	1.80		
Road Mix Surf.	.20 - .25							
Stab. Base P.M.	.25 - .30							
Stab. Base R.M.	.15 - .20							
Stab. Base, Emulsion	.12 - .17							
Cement T-Base	.12 - .17							
Ca (OH)2 T-Base	.12 - .17							
Crushed Agg. Base	.10 - .15	4"			.12	.48		
Gravel Base	.07 - .12							
Subbase	.07 - .12	6"			.10	.60		
Select Borrow	.05 - .10							
	Total Depth	14½"			Total SN	2.88		

Central Direct Federal Division
Denver, Colo.

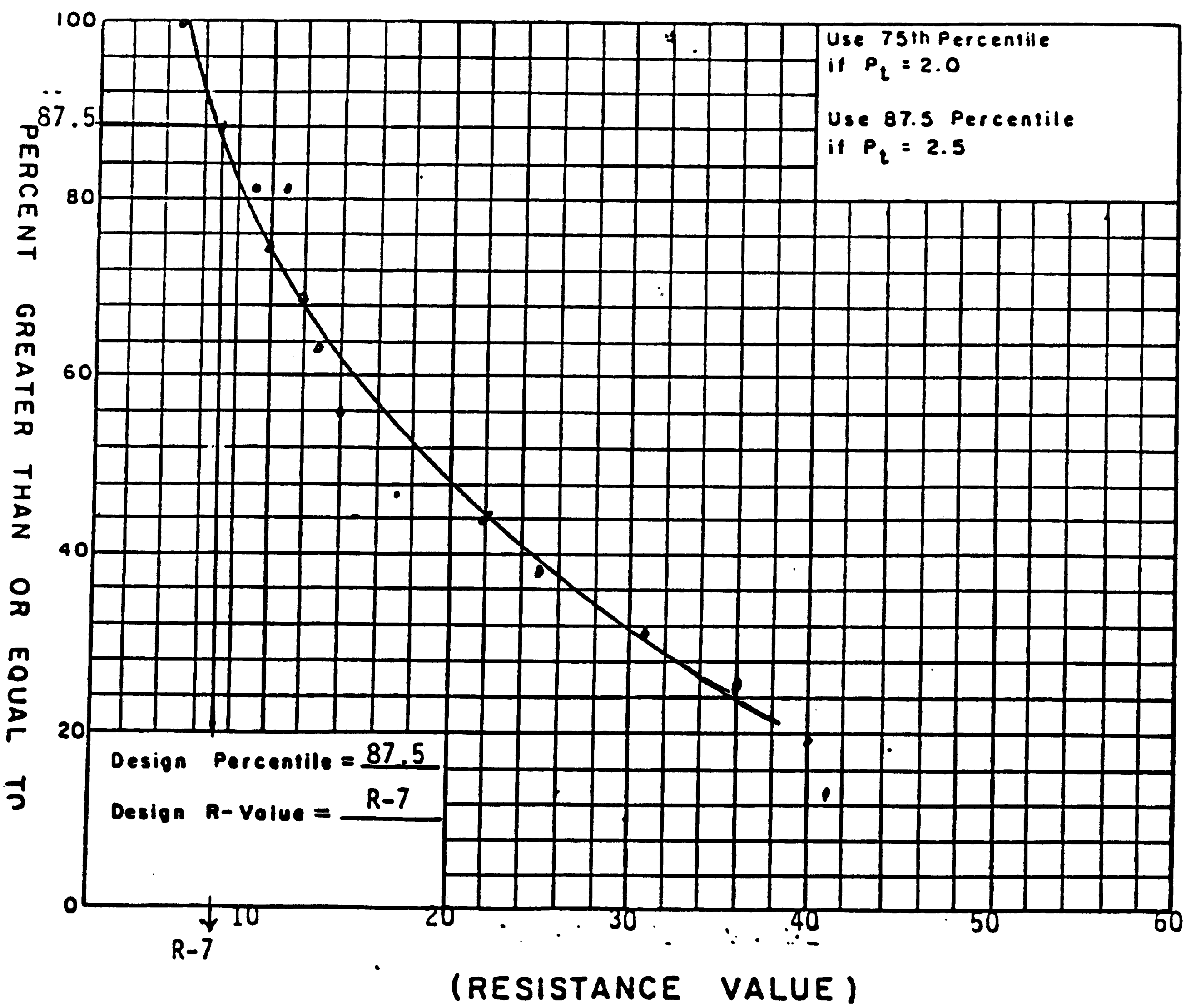
SELECTION OF DESIGN SUBGRADE RESISTANCE VALUE

PROJECT AZ FLH-9 CHOLLA BAY - HOTEL POINT STA. 1399 TO 1625

BY Folkman DATE: 6/11/84 LAB NO.

Checked by Holder

	TEST VALUE	TEST VALUE IN DESENDING ORDER	NUMBER GREATER THAN OR EQUAL TO	PERCENT EQUAL TO OR GREATER THAN
1414+15	25	69	1	(1/16)100 = 6
1421+00	40	41	2	(2/16)100 = 13
1451+15	31	40	3	(3/16)100 = 19
1451+15	22	36	4	(4/16)100 = 25
1456+00	69	31	5	(5/16)100 = 31
1465+35	14	25	6	(6/16)100 = 38
1476+35	12	22	7	(7/16)100 = 44
1476+35	5	14		
1500+00	13	14	9	(9/16)100 = 56
1505+00	7	13	10	(10/16)100 = 63
1509+15	9	12	11	(11/16)100 = 69
1511+95	10	10	12	(12/16)100 = 75
1523+00	5	9	13	(13/16)100 = 81
1581+00	36	7	14	(14/16)100 = 87
1582+75	41	5		
1605+00	14	5	16	(16/16)100 = 100



BRIDGE FOUNDATIONS

Bachelor Cove

The northerly abutment (Station 1421±) for this structure will be founded in a dense to very dense, cemented sand and gravel formation (see photo #1).. A spread footing with structural loadings up to 5 TSF (with less than 1 inch settlement) is recommended.

In the boring for Pier 1 (B 217) the cemented sand and gravel formation was encountered at elevation 2128± (5.5 feet below top of bore hole).

The lake was too high, Pier 2 and abutment 2 (southerly) were under water and not drilled. The subsurface investigation for this structure will be completed this fall. After completing the subsurface investigation, final foundation recommendations for the piers will be made.

The design high water elevation for the reservoir is 2136 (100 year flood). The ground line elevation in the vicinity of the southerly abutment is 2120±; during the subsurface investigation for Pier 1, the water elevation was 2124. The anticipated height of the approach fill is about 55 feet. Because up to 16 feet of the approach fill may become inundated with water, we recommend constructing the fill to elevation 2136 with durable, angular rock for the following reasons.

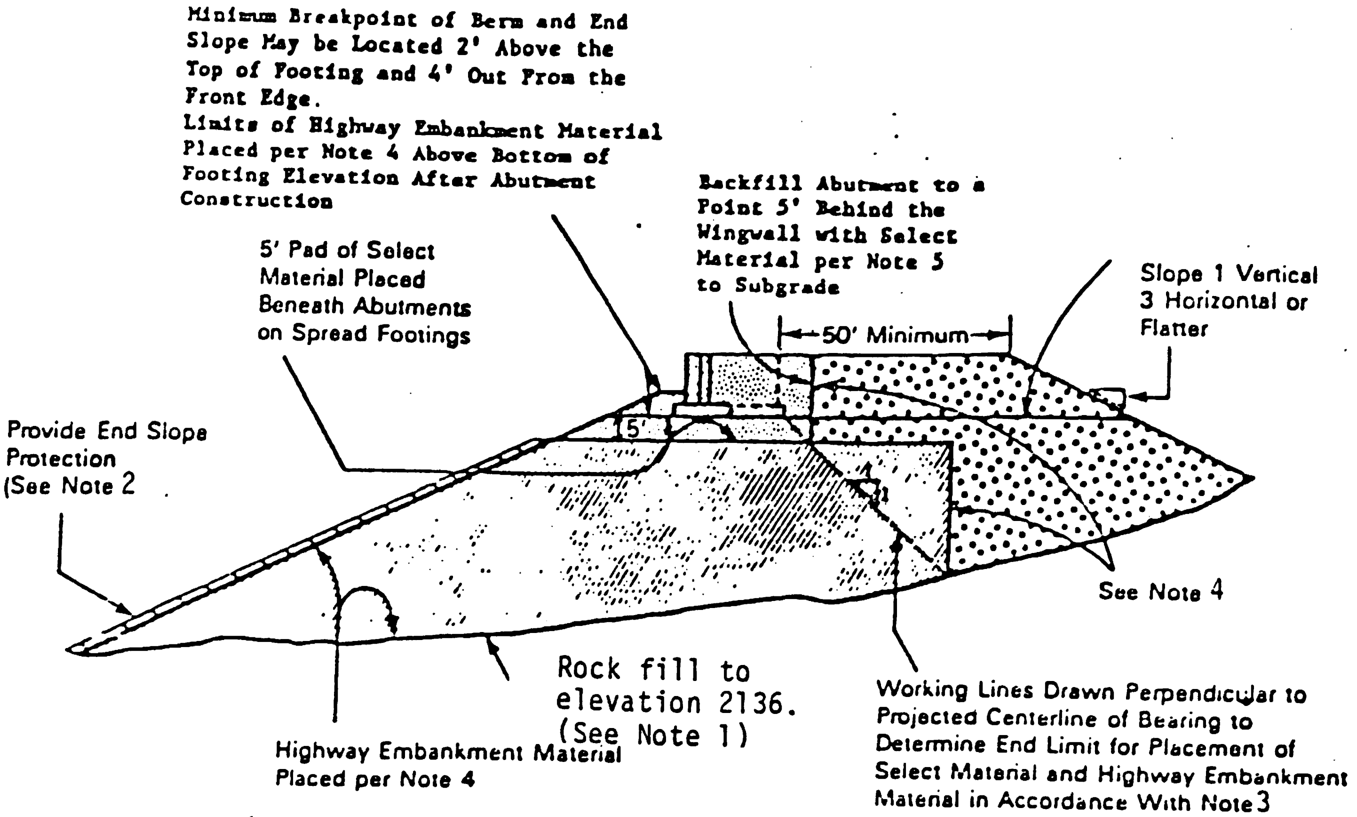
1. Fill constructibility If the water elevation is higher than 2120 (highly likely), a portion of the fill will have to be constructed under water, and dumped rock will be the most economical method of constructing a stable fill under water.

2. Fill stability
Fine grained soils are much more susceptible to slope stability problems when saturated than rock fills (such as slope failures caused by rapid draw down or seismic activities).

3. Consolidation If angular, durable rock is end-dumped into the water, the rock will consolidate as the fill is built (cohesionless material).

The soil overlying the cemented sand and gravel formation at Pier 1 is cohesionless (talus debris, sandy gravel with cobbles and boulders--see Boring B 217). Similar material underlying Pier 2 at the southerly abutment is anticipated. This material will also consolidate as the 55 foot high approach fill is constructed. If the approach fill above the rock fill at elevation 2136 is constructed in accordance with Figure 1, spread footing in the approach fill with structural loadings up to 3 TSF (with <1" settlement) are recommended.

For a deep foundation to be constructed at abutment 2 (and southerly pier), the foundation would have to penetrate through the rock fill (see Figure 2). Limiting the maximum size of rock in the vicinity of Pier 2 and abutment 2 to 6 inches would help; however driven piles would still have to be pre-bored and advancing drilled shafts through the rock fill would be much more difficult.



NOTE 1: Angular rock fill to high water for fill stability.

Note 2: Slope protection treatment shall be as specified by the Bridge Engineer.

Note 3: Highway embankment material placed within these limits shall have a maximum dimension of 6 inches and shall be compacted to 95% of maximum density. Quantity to be included in highway estimate.

Note 4: Highway embankment material and select material shall be placed simultaneously of the vertical payment line.

SUGGESTED APPROACH EMBANKMENT DETAILS

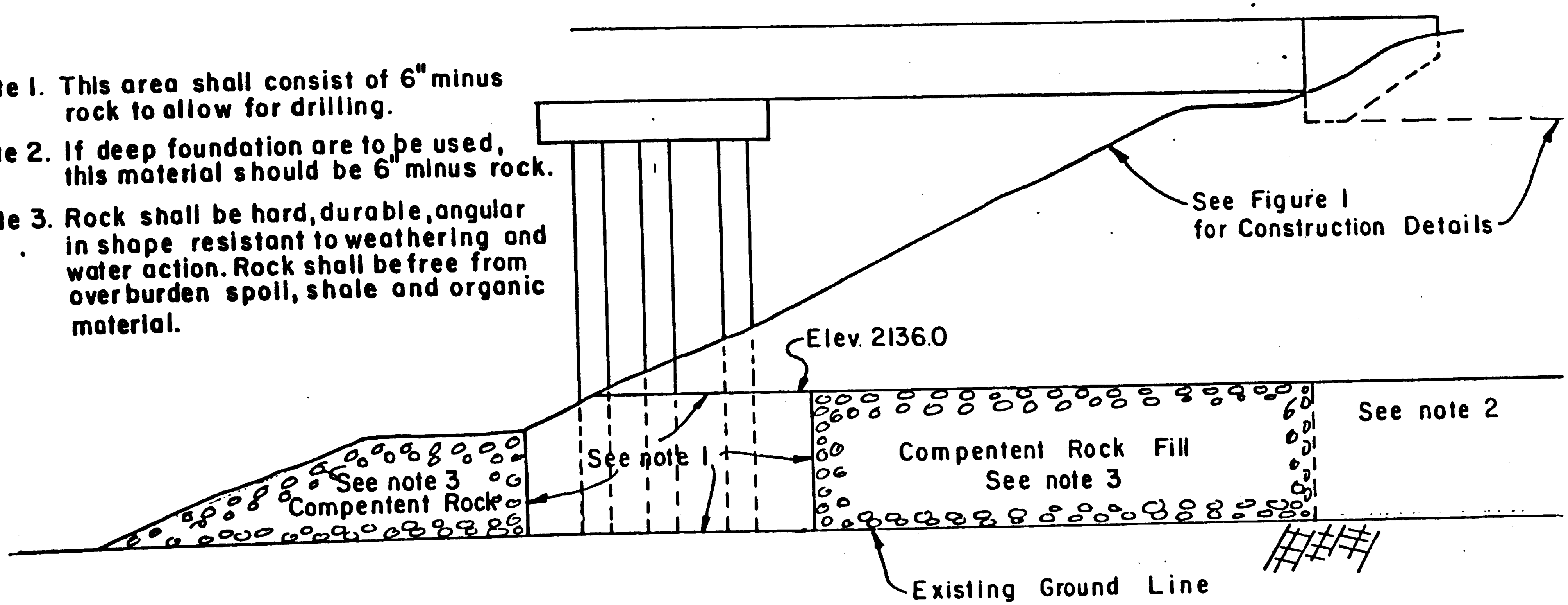
Figure I

FIGURE 2 APPROACH EMBANKMENT DETAIL BACHELOR COVE/NONAME

Note 1. This area shall consist of 6" minus rock to allow for drilling.

Note 2. If deep foundation are to be used, this material should be 6" minus rock.

Note 3. Rock shall be hard, durable, angular in shape resistant to weathering and water action. Rock shall be free from overburden spoil, shale and organic material.



No Name

The northerly abutment is underlain by 14-1/2 feet of alluvial material (Boring B-219) consisting of sand and gravel with occasional cobbles and small boulders. A cemented sand and gravel formation underlying the alluvial material extends to at least elevation 2090± (35.4'). (See the subsurface profile in appendix E.) The water table was encountered within 1/2 foot of the surface (elevation 2125±).

The southerly abutment boring encountered 18-1/2 feet of alluvial material (B-222) (sand and gravel with occasional cobbles and small boulders) underlain by the cemented sand and gravel formation.

Because the natural ground elevation for the abutments is 2125.4 (northerly) and 2129.5 (southerly), constructing the abutments under 5 or more feet of water may be necessary. As noted for the Bachelor Cove structure, the fills should be constructed out of angular, durable rock to elevation 2136.

Because installing deep foundation through the rock fill will be difficult and the anticipated height of the approach fills (50 ft.±), the recommended foundation for the abutments is spread footing in the approach fill with up to 3 TSF structural loading. The approach fills should be constructed in accordance with Figure 1.

A more costly and much more difficult to construct alternate foundation is driven H-Piles (HP 12 X 53). The piles should be driven a minimum of 5 feet into natural ground. The allowable loading for the piles is 70 tons. The piles should have reinforced tips and pre-boring should be anticipated (through the rock fill). If deep foundations are opted, the maximum size of the rock fill in the vicinity of the piles should be specified as 6" minus (see Figure 2).

PIERS

At the piers the sand and gravel layer is 34 feet deep (Pier 1, B-220) and 22-1/4 feet deep (Pier 2, B-221). Underlying the sand and gravel layer is the cemented sand and gravel formation. (See the subsurface profile in appendix E.) The recommended foundations for the piers are 4 ft. diameter drilled shafts as shown in tables 1 and 2.

Table 1 - 4 Ft. Diameter Shafts for Pier 1; No Name

Elevation	Allowable Skin Friction (Tons)	Allowable End Bearing (Tons)	Total Allowable Load (1" Maximum Deflection) (F.S. = 2.0)
2070	160	126	286 Tons
5.9 tons additional skin friction allowable for each additional foot penetration			

Table 2, 4 Ft. Diameter Drilled Shafts for Pier 2; No Name

Elevation	Allowable Skin Friction (Tons)	Allowable End Bearing (Tons)	Total Allowable Load (1" Maximum Deflection) (F.S. = 2.0)
2073	158	126	283 Tons
6.8 tons additional skin friction allowable for each additional foot penetration			

If the structure's dead load is added in such a manner that 2 inches of total settlement per pier is acceptable, Table 1 and 2 can be modified as follows:

Table 3: Pier 1 2" Deflection

Elevation (feet)	Allowable Skin Friction (Tons)	Allowable End Bearing (Tons)	Total Allowable Load (Tons)
2080	96	213	309
Additional skin friction per foot = 4.5 tons			

Table 4: Pier 2 2" Deflection

Elevation (feet)	Allowable Skin Friction (Tons)	Allowable End Bearing (Tons)	Total Allowable Load (Tons)
2083	97	213	310
Additional skin friction per foot = 4.0 tons.			

Because the drilled shafts are relying on both skin friction and end bearing for support, the casings must be removed.

Mills Canyon

The abutments for Mills Canyon are to be founded in the exposed conglomerate (see photo 23). Spread footings with up to 10 tons per square foot loading are recommended with < 1" settlement).

At all 3 piers' locations, an alluvial deposit of sand and gravel overlays the conglomerate formation. The depth to the conglomerate varies as follows:

(Northerly Pier 1	36' 1"	(B-207)
(Middle) Pier 2	57-1/2 feet	(B-208A)
(Southerly) Pier 3	6'11"	(B-209)

Four-foot diameter drilled shafts are recommended for all three piers. The drilled shafts will have to be cased to the conglomerate formation.

A minimum of 10 feet penetration into the conglomerate formation is recommended with 300 tons total allowable loading. Thirty-five tons of additional skin friction is available for each additional foot of penetration. Because the shafts are relying on a combination of skin friction and end bearing, the casings must be removed.

Vineyard

The northerly and southerly abutments for the Vineyard Canyon structure has been drilled. Because of high water, the piers have not been drilled.

At the northerly abutment (B 226), 13 ft. 2 in. of dense sand and gravel was encountered, underlain by a very dense cemented sand and gravel formation. At the southerly abutment (B-227), 27 ft. 2 in. of moderately dense to dense, clayey gravel was encountered. The material was partially cemented with depth. no rock

The material encountered would support spread footing. However, a deeper foundation may be required because of slope stability problems.

The final foundation recommendations with a subsurface profile will be completed after completion of the subsurface investigation.

ARIZONA FH-9, CHOLLA BAY to HOTEL POINT

Prepared by ____________________
T. SAMUEL HOLDER

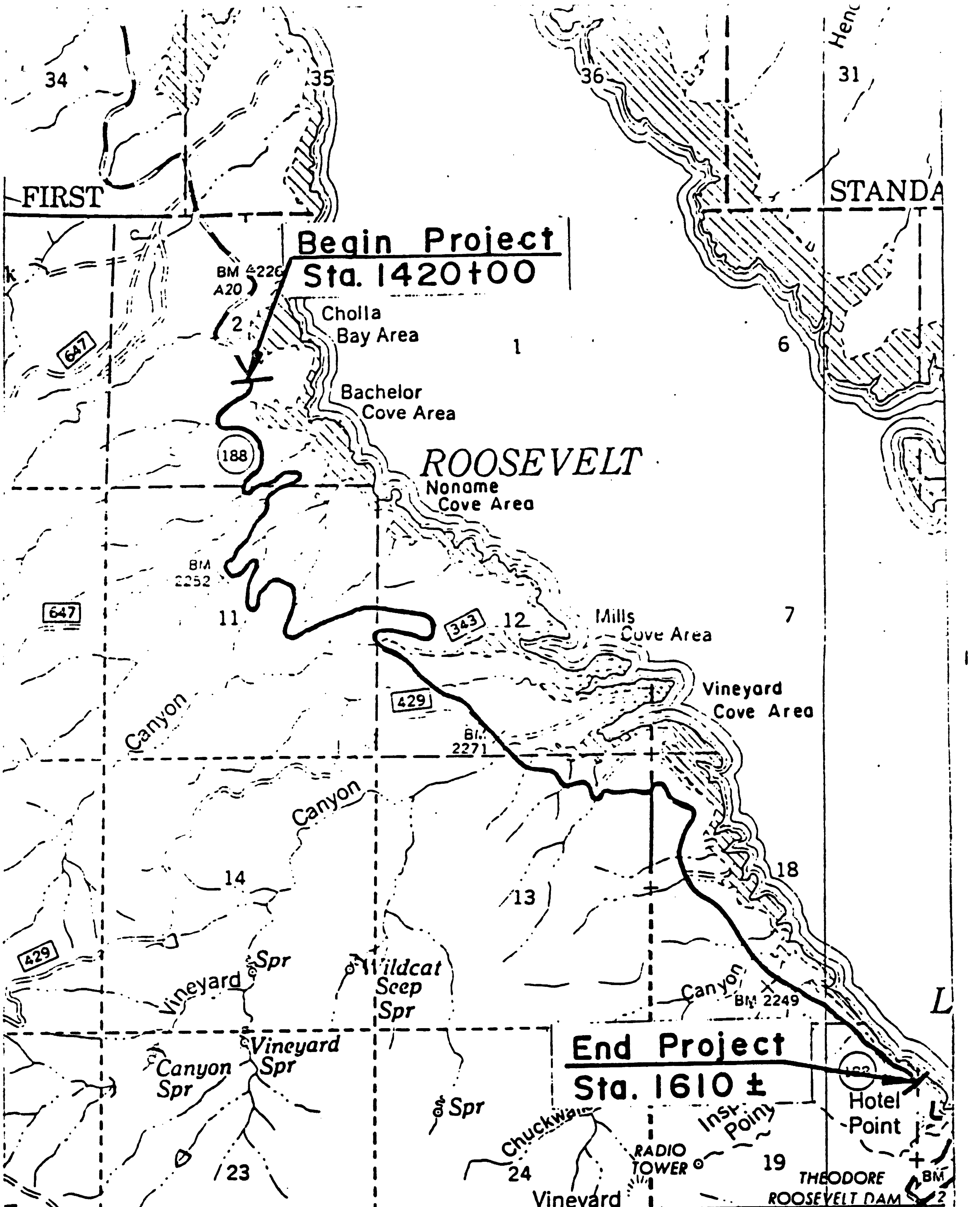
____
WAYNE C. FOLKMAN

Approved for distribution by ____________________
JOSEPH H. CLEM
Materials Engineer

September 10, 1984

APPENDIX A

Location
Map



FEDERAL HIGHWAY ADMINISTRATION
CENTRAL DIRECT FEDERAL DIVISION
MATERIALS DIVISION

Date: ____________

ARIZONA FOREST HIGHWAY FH-9
BACHELOR COVE - HOTEL POINT

APPENDIX B

Bridge Boring Logs
and
Lab Test Results

BORING LOG

MATERIALS DIVISION

off project

Project	Ariz FH-9; Batchelor Cove
Boring Location	1421+90, 25' RT
Boring No.	B-217
Sheet	1 of 1
Date Began	4/25/84
Completed	4/25/84
Type of Boring	Rotary
Casing Type	Hollow Stem Auger
Size	6 in
Mud	
Ground Elev.	2133.5
Weather	
Inspector	Blenk
Operator	Houseman

Water Level			
Time			
Date			

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						0–2	0 – 5'5" talus debris, sandy gravel with cobbles and boulders, possibly some cementation
						2–4	SPT #1 – Recovered 16"; 11" Talus debris; 5" cemented sand and gravel, partially decomposed.
#1	SPT	4'4" – 5'10"	16"	89%	12/18/26	6	5'5" – 15'2" dense, partially decomposed well cemented sand and small gravel, moist
						8	SPT #2 – Recovered 16" partially decomposed sand and small gravel, moist.
#2	SPT	9'4" – 10'10"	16"	100%	20/48/52 (4 in)	10	
						12	
						14	SPT #3 – Recovered 10" cemented sand and small gravel, moist
#3	SPT	14'4" – 15'2"	10"	100%	22/50 (4 in)	16	15'2" End of boring
						18	no rock
						20	

BORING LOG

MATERIALS DIVISION

Project	Ariz. FH-9; No Name	Boring No. B-219	Sheet 1 of 1
Boring Location	STA. 1440+65	Date Began 4/26/84	Completed 4/26/84
		Type of Boring Rotary	
		Casing Type Hollow Stem Auger	Size 6in, Mud
Water Level		Ground Elev. 2125.4'	Weather
Time		Inspector Blenk	Operator Houseman
Date			

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						0–14	0-14'6" Loose, saturated sand and gravel with occasional cobbles and small boulders.
						14–18	14'6"-36' Moderately to well cemented sand and small gravel (with cobbles and small boulders 32' to 36').
#1	SPT	19'8"-19'11"	0"	0%	50(2½")	20	SPT#1 - No Recovery, signs of cemented sand and small gravel in tip of spoon.
#2	SPT	29'8"-30'	4"	100%	50(4½")	30	SPT#2 - Recovery 4" of cemented gravelly sand, moist.
						36	36' End of boring
						38–40	

BORING LOG

MATERIALS DIVISION

Project	Gila F.H. 9; McNarie	Boring No.	B-220
Boring Location	STA. 144+50, 19' LT	Sheet	1 of 2
		Date Began	4/20/84
		Completed	4/28/84
		Type of Boring	Rotary
Water Level		Casing Type	Hollow Stem Auger
Time		Size	6in
Date		Mud	
		Ground Elev.	2124.8'
		Weather	
		Inspector	Blenk
		Operator	Houseman

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
							0-34' Loose to Dense sand and gravel with cobbles and boulders. (more cobbles and boulders 17' to 34')
						2	
						4	
						6	
						8	
						10	
						12	
						14	
						16	
						18	
						20	
						22	
						24	
						26	
						28	
						30	
						32	
						34	34'-44'11" Moderately to well cemented sand and small gravel. ([illegible] partially decomposed at surface)
						36	
						38	
						40	

BORING LOG

MATERIALS DIVISION

Project	Ariz. FH-9 ; No Name
Boring Location	STA. 144+50 ; 19' RT
Boring No.	B-220
Sheet	2 of 2
Date Began	4/26/84
Completed	4/28/84
Type of Boring	Rotary
Casing Type	Hollow Stem Auger
Size	6 in
Mud	
Ground Elev.	2124.8'
Weather	
Inspector	Blenk
Operator	Hinsenkamp

Water Level			
Time			
Date			

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						42	SPT #1 – Recovered 6" Cemented sand and small gravel, with occasional coarse zones.
						44	44'11" – End of boring
#1	SPT	44'4"–44'11"	6"	86%	40/50 (1")	46	
						48	
						50	

BORING LOG

MATERIALS DIVISION

Project Ariz. FH-9, No Name	Boring No. B-221	Sheet 1 of 2	
Boring Location STA. 1442+50, 19' LT	Date Began 4/28/84	Completed 4/28/84	
	Type of Boring ROTARY		
Water Level	Casing Type Hollow Stem Auger	Size 6 in	Mud
Time	Ground Elev. 2125.7'	Weather	
Date	Inspector BLENK	Operator HOUSEMAN	

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						0–2	0-22'3" Loose to Dense, saturated sand and gravel with cobbles and small boulders.
						2–4	
						4–6	
						6–8	
						8–10	
						10–12	
						12–14	
						14–16	
						16–18	
						18–20	
						20–22	
						22–24	22'3"-45'2" Cemented sand and small gravel (with occasional coarser zone with cobbles and possible small boulders)
						24–26	
						26–28	
						28–30	
						30–32	
						32–34	
#1	SPT	34'10"-35'6"	8"	100%	66/34(2in)	34–36	SPT#1 - Recovered 10" Cemented sand and small gravel.
						36–38	
						38–40	

BORING LOG

MATERIALS DIVISION

Project	Ariz. FH-9; NoName	Boring No. B-221	Sheet 2 of 2
Boring Location	Sta. 1442+50, 19'Lt	Date Began 4/28/84	Completed 4/28/84
		Type of Boring Rotary	
Water Level		Casing Type Hollow Stem Auger	Size 6in · Mud
Time		Ground Elev. 2125.7'	Weather
Date		Inspector Blenk	Operator Houseman

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						42	
						44	SPT #2 - Recovered 3" Cemented Sand and cm. gravel, slightly moist.
#2	SPT	44'10"-45'2"	3"	75%	50 (4in)		45'2" - End of boring
						46	
						48	
						50	

BORING LOG

MATERIALS DIVISION

Project	Ariz. FH-9; No Name	Boring No. E-222	Sheet 1 of 1
Boring Location	STA. 1443+35; Ȼ	Date Began 4/30/84	Completed 4/30/84
		Type of Boring Rotary	
Water Level		Casing Type Hollow Stem Auger	Size 6in Mud
Time		Ground Elev. 2129.5'	Weather
Date		Inspector Blenk	Operator Holzeman

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						0	0–18'6" Loose to moderately dense sand and gravel with occasional cobbles and small boulders (more cobbles and bo… 10'6"–18'6")
#1	SPT	10'–10'6"	6"	100%	35/R - spoon bouncing	10	SPT #1 – 10'–10'6" – Recovered 6" saturated sandy gravel
						18	18'6"–30'5" Cemented sand and small gravel
#2	SPT	24'10"	0"	0%	R - spoon bouncing	24	SPT #2 – No Recovery – spoon bouncing
#3	SPT	29'10"–30'5"	7"	100%	80/20 (1in)	28	SPT #3 – Recovered 7" Cemented sand and small gravel.
						30	30'5" – End of boring

Depth scale: 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40

BORING LOG

CENTRAL DIRECT FEDERAL DIVISION
MATERIALS DIVISION

Project	Ariz. FH-9; Mills Canyon	Boring No. B 707	Sheet 1 of 2
Boring Location	STA 1434+93, 20' LT	Date Began 3/27/84	Completed 3/28/84
		Type of Boring Rotary	
Water Level		Casing Type Hollow Stem Auger	Size 6 in / Mud
Time		Ground Elev. 2125.8	Weather
Date		Inspector Blenk	Operator Houseman

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						0–14	0 - 36'1" Loose sand with cobbles and small boulders.
#1	RC	14'8"-17'8"	4"			14–16	Run #1 - Recovered 4" cobble fragments.
#2	RC	17'8"-19'4"	1"			18–20	Run #2 - Recovered 3 cobble fragments.
#3	RC	19'4'-24'4'	8"			22–24	Run #3 - Recovered 8" cobble fragments.
#4	RC	24'4"-29'3"	0"			26–28	Run #4 - No Recovery
#5	RC	29'3"-34'3"	0"			30–32	Run #5 - No Recovery
#6	RC	34'3"-38'8"	1"			34–40	36'1" - 49'2" Very hard drilling.. cemented sand and gravel, conglomerate. Run #6 - Recovered few small cobble fragments with [illegible]

BORING LOG
CONTINUATION SHEET

FEDERAL HIGHWAY ADMINISTRATION
CENTRAL DIRECT FEDERAL DIVISION
MATERIALS DIVISION

Project: Ariz. FH-9; Miles Canyon

Boring No. B-207

Sheet 2 of 2

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
#7	RC	38'8" – 41'2"	18"			42	Run #7 – Recovered 18" of cobble fragments, all with signs of cementation
#8	RC	41'2" – 43'8"	0"			44	Run #8 – No Recovery
						46	
#9	RC	43'8" – 49'2"	6"			48	Run #9 – Recovered 6" of cobble fragments with signs of cementation; + Conglomerate fragments.
						50	49'2" – End of boring.

BORING LOG

CENTRAL DIRECT FEDERAL DIVISION
MATERIALS DIVISION

Project	Ariz. FH-9; Mills Canyon	Boring No. B-208	Sheet 1 of 1
Boring Location	STA. 1485+95 ℄	Date Began 3/28/84	Completed 3/28/84
		Type of Boring Rotary	
		Casing Type Hollow Stem Auger	Size 6 in / Mud
		Ground Elev. 2126.6	Weather
		Inspector Blenk	Operator Houseman

Water Level			
Time			
Date			

Sample Number	Sample Type	Depth From—To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
							0-30'6" Loose sand with occasional cobbles and small boulders.
						30	30'6" End of boring (broke auger)

BORING LOG

CENTRAL DIRECT FEDERAL DIVISION
MATERIALS DIVISION

Project	Ariz. Fhig · Mills Canyon	Boring No. E-302A	Sheet 1 of 2
Boring Location	STA. 1485+99, E	Date Began 3/ /84	Completed 3/ /84
		Type of Boring ROTARY	
Water Level		Casing Type Hollow Stem Auger	Size 6in / Mud
Time		Ground Elev. 2124.1	Weather
Date		Inspector BLENK	Operator HOUSEMAN

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						2	0-57'6" Loose Sand and gravel with occasional cobbles and small boulders.
						4	
						6	
						8	
						10	
						12	
						14	
						16	
						18	
						20	
						22	
						24	
						26	
						28	
						30	
						32	
						34	Run #1 – Recovered 3-4" of cobble fragments.
1	RC	33'3"-38'3"	4"			36	
						38	Run #2 – No recovery, barrel plugged
#2	RC	38'3"-38'11"	0"			40	

BORING LOG
CONTINUATION SHEET

FEDERAL HIGHWAY ADMINISTRATION
CENTRAL DIRECT FEDERAL DIVISION
MATERIALS DIVISION

Project: Ariz. FH-9; Mills Canyon

Boring No. B-208A

Sample Number	Sample Type	Depth From – To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
#3	RC	38'11"-43'11"	3"			42	Run #3 - Recovered few inches of cobble fragments.
#4	RC	43'11"-47'4"	8"			44–46	Run #4 - Recovered 8" of cobble fragments.
#5	RC	47'4"-48'2"	3"			46–48	Run #5 - Recovered few inches of cobble fragments.
						50	
						52	
						54	
						56	
						58	57'6" - 62'4" Very hard drilling, cobbles, and boulders, possibly cemented fragments
						60	
						62	62'4" - 77' Less cobbles and boulders, hard drilling, conglomerate.
						64	
						66	
						68	
						70	
#6	RC	71'4"-73'3"	12"				Run #6 - Recovered 12" cobble fragments with some signs of cementation.
#7	RC	73'3"-75'4"	NR			72–74	Run #7 - No recovery
#8	RC	75'4"-77'	8"			74–76	Run #8 - Recovered 8" cobble and conglomerate fragments.
						78	77' End of boring.
						80	

BORING LOG

MATERIALS DIVISION

Project	Ariz. FH-9 : Mills Canyon
Boring Location	STA. 1487+15, ℄
Water Level	40' of boring below water.
Time	
Date	

Boring No.	B-209	Sheet 1 of 1	
Date Began	5/1/84	Completed	5/1/84
Type of Boring	Rotary		
Casing Type	Hollow Stem Auger	Size 6in	Mud
Ground Elev.	2124.1'	Weather	
Inspector	Blenk	Operator	Houseman

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
							0-6'11" Loose to moderately dense sand and gravel
						2	
						4	
						6	6'11" - 15'6" Well cemented sand and small gravel, possibly partially dis. disintegrated (conglomerate)
						8	
						10	
						12	
						14	15'6" - End of boring
						16	
						18	
						20	

BORING LOG

MATERIALS DIVISION

Project: Ariz. FH-9; Vineyard Canyon
Location: 1513+56±; 6.6' LT

Boring No. B-226	Sheet 1 of 1
Date Began 4/10/84	Completed 4/10/84
Type of Boring Rotary	
Casing Type Hollow Stem Auger	Size 6in	Mud.
Ground Elev. 2180±	Weather
Inspector Blenk	Operator Houseman

Water Level			
Time			
Date			

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						0–2	0 – 13'2". Dense Sand and Gravel, mostly cobbles and boulders, with PI
						13–17	13'2" - 17'6" Very dense, cemented sand and gravel with occasional cobbles. SPT #1 - Recovered 13" of blowup material and 3" cemented sand and gravel with cobble fragments.
#1	SPT	17'2"-17'6"	3"	75%	20/50(3½")	18	17'6" End of boring

Depth scale: 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

BORING LOG

MATERIALS DIVISION

Project	ARIZ FH-9; VINEYARD CANYON	Boring No. B-227	Sheet 1 of 1
Location	STA 1519+79, ℄	Date Began 4/11/84	Completed 4/11/84
		Type of Boring ROTARY	
Water Level		Casing Type HOLLOW STEM AUGER	Size 6in / Mud.
Time		Ground Elev. 2188.3	Weather
Date		Inspector BLENK	Operator HOUSEMAN

Sample Number	Sample Type	Depth From — To (in Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						0–2	0-27'2" Moderately dense to dense clayey gravel, partially cemented with depth, with abundant cobbles and boulders.
						4	SPT #1 - Recovered 6" very stiff clay and cobble fragments. * Second 6" pushing cobble - not representative blow count.
#1	SPT	5'4"-6'4"	6"	50%	30/50*	6	
						8	SPT #2 - Recovered 14" silty clayey gravel (with cobble fragments).
#2	SPT	8'-9'6"	14"	78%	27/36/46	10	
						12	
						14	
						16	
						18	
						20	
						22	
						24	
						26	27'2" End of boring
						28	
						30	

Rev 9-28-83

Central Direct Federal Division

DATE 5/21/84

SUMMARY OF SOIL OR AGGREGATE TESTS

PROJECT ARIZONA FLH 9-8(5) Rock Creek to Cholla Bay

SUBMITTED BY Bob Blenk TESTED BY DH,KW,KR REPORTED BY Alan Held

DISTRIBUTION: Project Engineer-1, CDFD File 1, Materials Lab-3 Design ______ Construction ______

SAMPLE NUMBER	Field No.			
	Hole No.	B-217	B-217	B-219
	Lab No.	84-683-SB	84-684-SB	84-685-S.
SAMPLE LOCATION	Station or Location	1421+93	1421+93	1440+65
	Offset	25' R	25' R	--
	Depth	9'4"-10'	14'4"-14'10'	29'8"-30
	3"			
	1 1/2"			
	1"			
	3/4"	100		
	1/2"	96		100
	3/8"	89		90
	#4	81	100	74
	#8			
	#10	69	98	59
	#16	58	95	51
	#30			
	#40	38	72	36
	#50			
	#100	24	43	25
	#200	20.2	32.2	21.3
	0.05mm			
	002mm			
	0.002mm			
	0.001mm			
% Moist.		10.3	12.6	11.0
AASHTO T-99, D892	SL			
	LL	44	42	41
	PI	21	19	19
AASHTO M-145	Class	A-2-7	A-2-7	A-2-7
	GI	(1)	(2)	(1)
AASHTO T-190	R			
	W(%)			
	γ_o(pct)			
	W(%)			
	γ_o(pct)			

*Indicates there was an inadequate amount of material to perform the test.

ev 9-28-83

Central Direct Federal Division

DATE 5/21/84

SUMMARY OF SOIL OR AGGREGATE TESTS

PROJECT Arizona FLH 9-8(5) Rock Creek to Cholla Bay

SUBMITTED BY Bob Blenk TESTED BY DH,KW,KR REPORTED BY Alan Held

DISTRIBUTION: Project Engineer-1, CDFD File 1, Materials Lab -3 Design ______ Construction ______

NUMBER	Field No.							
	Hole No.	B-220	B-221	B-222	B-226	B-227	B-227	
	Lab No.	84-686-SB	84-687-SB	84-688-SB	84-689-SB	84-690-SB	84-691-SB	
LOCATION	Station or Location	1441+50	1442+50	1443+35	1513+60	--	--	
	Offset	19' R	19' L	--	8' L	--	--	
	Depth	44'4"-44'10"	34'10"-35'4	29'10"-30'2	17'2"-17'4"	5'4"-5'10"	8'-8'6"	
	3"							
	1 1/2"							
	1"	100					100	
	3/4"	91			100	100	87	
	1/2"	85	100		70	61	76	
	3/8"	83	97	100	67	54	68	
	# 4	79	90	91	62	43	60	
	# 8							
	# 10	71	78	76	52	36	56	
	16	64	66	64	46	32	55	
	# 30							
	# 40	42	44	40	35	26	49	
	# 50							
	#100	25	29	25	22	22	43	
	# 200	20.3	23.6	20.2	17.5	20.1	39.9	
	0.05mm							
	0.02mm							
	0.002mm							
	0.001mm							
% Moist.		13.1	13.9	12.1	5.8	4.2	7.7	
AASHTO T-89, T-90	SL							
	LL	51	42	37	*	*	45	
	PI	31	21	16	*	*	27	
AASHTO M-145	Class	A-2-7	A-2-7	A-2-6	*	*	A-7-6	
	GI	(1)	(1)	(0)			(5)	
AASHTO T-190	R							
	W(%)							
	γ_D(pcf)							
T-?0	W(%)							
	γ_D(pcf)							

*Indicates there was an inadequate amount of material to perform the test.

APPENDIX C

Soil Survey
Boring Logs

BORING LOG
SOILS SURVEY

MATERIALS DIVISION

Project	Ariz. FH-9	Boring No. 3-218	Sheet 1 of 1
Boring Location	STA 1432+75; 100' LT	Date Began 4/25/84	Completed 4/25/84
		Type of Boring Rotary	
Water Level		Casing Type Hollow Stem Auger	Size 6in / Mud
Time		Ground Elev. 2140.'±	Weather
Date		Inspector Blenk	Operator Houseman

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						0–2	0 - 13'9" Loose to moderately dense sand and gravel
#1	SPT	3'9" - 5'3"	10"	56%	9/7/8	4–6	SPT #1 - Recovered 10" moist to very moist gravelly sand.
#2	SPT	8'9" - 10'3"	11"	61%	13/23/29	8–10	SPT #2 - Recovered 11" moderately dense gravelly sand with cobble fragments at end. moist.
						14	13'9" - End of boring

BORING LOG

MATERIALS DIVISION

Project	Ariz. FH-9	Boring No. B-223	Sheet 1 of 2
Boring Location	1451+15; 27'RT	Date Began 5/1/84	Completed 5/1/84
		Type of Boring Rotary	
Water Level		Casing Type Hollow Stem Auger	Size 6in; Mud
Time		Ground Elev. 2333.0±	Weather
Date		Inspector Blenk	Operator Houseman

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						0–33'	0-33' Partially Cemented sand and small gravel with occasional cobble & small boulder layers. Some PI, especially near surface.
						33'–40	33'-49'6" Well cemented sand and small gravel with occasional cobble layers. Possibly more PI.

Depth scale: 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40

BORING LOG

MATERIALS DIVISION

Project	ARIZ. FH-9.	Boring No.	B-223
Sheet	2 of 2		
Boring Location	1457+15 ; 27' RT	Date Began	5/1/84
Completed	5/1/84	Type of Boring	ROTARY
Casing Type	HOLLOW STEM AUGER	Size	6 in
Mud		Ground Elev.	2333.0' ±
Weather		Inspector	BLENK
Operator	HOLSEMAN		

Water Level			
Time			
Date			

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						42	
						44	
						46	
						48	
						50	49'6" - End of boring

BORING LOG

MATERIALS DIVISION

Project	Ariz. FH-9	Boring No. B-230	Sheet 1 of 1
Boring Location	STA 1476+35, 4' LT	Date Began 4/12/84	Completed 4/12/84
		Type of Boring Rotary	
Water Level		Casing Type Hollow Stem Auger	Size 6in · Mud
Time		Ground Elev.	Weather
Date		Inspector Blenk	Operator Houseman

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						2	0-40'3" Partially to well cemented sand and small gravel with occasional cobble layers.
						4	
						6	
						8	
						10	
						12	
						14	
						16	
						18	
						20	
						22	
						24	
						26	
						28	
						30	
						32	
						34	
						36	
						38	
						40	40'3" - End of boring

BORING LOG

MATERIALS DIVISION

Project	Ariz. FH-9
Boring Location	STA. 1500+00; 65' RT
Boring No.	S-229
Sheet	1 of 1
Date Began	4/11/84
Completed	4/11/84
Type of Boring	Rotary
Casing Type	Hollow Stem Auger
Size	6 in
Mud	
Ground Elev.	
Weather	
Inspector	Blenk
Operator	Houseman

Water Level			
Time			
Date			

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
						0	0-5' Overburden clayey gravel with occasional Cobbles.
						5	5'-9'6" Well cemented sand and gravel with probable PI.
						9'6"	9'6" End of boring
						2, 4, 6, 8, 10, 12, 14, 16, 18, 20	

BORING LOG

MATERIALS DIVISION

Project	Ariz. FH-9	Boring No. B-22B	Sheet 1 of 1
Boring Location	STA. 1505+00; 65' RT	Date Began 4/11/84	Completed 4/11/84
		Type of Boring Rotary	
Water Level		Casing Type Hollow Stem Auger	Size 6 in · Mud
Time		Ground Elev.	Weather
Date		Inspector Blenk	Operator Houseman

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
							0-6' Overburden clayey sand and gravel
						2	
						4	
						6	6-15' Well cemented sand and gravel with [illegible] PI
						8	
						10	
						12	
						14	15' - End of boring
						16	
						18	
						20	

MATERIALS DIVISION

Project	Akr. FH-9	Boring No.	B-225	Sheet	1 of 1
Boring Location	STA. 1523+00	Date Began	4/11/84	Completed	4/11/84
		Type of Boring	Rotary		
ater Level		Casing Type	Hollow Stem Auger	Size	Mud
Time		Ground Elev.		Weather	
Date		Inspector	Blenk	Operator	Houseman

Sample Number	Sample Type	Depth From — To (In Feet)	Length of Rec.	% Recovery	S.P.T. N Count	Depth	DESCRIPTION
							0-3' Silty clay with cobbles and occasional small boulders.
						2	
						4	
						6	
						8	
						10	
						12	
						14	
						16	
						18	
						20	

APPENDIX D

SOIL SURVEY LAB TEST RESULTS

Central Direct Federal Division

DATE 3/29/84

SUMMARY OF SOIL OR AGGREGATE TESTS

PROJECT ARIZONA FH 9-8(6) Cholla Bay to Roosevelt Dam

SUBMITTED BY Bob Blenk TESTED BY DH,KW,KR REPORTED BY Al Held

DISTRIBUTION: Project Engineer-1, CDFD File 1, Materials Lab -3 Design Construction

SAMPLE NUMBER	Field No.							
	Hole No.							
	Lab No.	84-602-S	84-603-S	84-604-S	84-605-S	84-606-S	84-607-S	
SAMPLE LOCATION	Station or Location	1414+15	1456+00	1465+35	1509+15	1511+95	1581+00	
	Offset	Rt.Ct.Bank	Exposed	2'R	35'L	35'L	43'R	
	Depth		Right Cut	0-15'	0-13'	0-5'	0-13'	
A... T O 80	3"	100						
	1 1/2"	91	100					
	1"	87	97	100	100	100	100	
	3/4"	83	95	99	99	99	96	
	1/2"	78	92	98	97	95	92	
	3/8"	74	90	96	94	91	85	
	# 4	66	82	89	89	77	77	
	# 8						54	
	# 10	54	67	70	79	66	41	
	# 16	45	55	57	71	60	35	
	# 30							
	# 40	27	31	40	54	51	28	
	# 50							
	#100	15	13	31	40	43	24	
	# 200	12.6	9.5	26.5	34.0	38.9	22.4	
	0.05mm							
	002mm							
	0.002mm							
	0.001mm							
% Moist.								
SHTO T-99, 0892	SL							
	LL	38	NV	33	37	43	32	
	PI	16	NP	16	20	25	16	
SHTO -145	Class	A-2-6	A-2-4	A-2-6	A-2-6	A-7-6	A-2-6	
	GI	0	-	0	2	4	0	
SHTO -190	R	25	69	14	9	10	36	
	W(%)	10.5	10.4	9.1	17.5	16.7	9.2	
	γ_d(pcf)	123.5	124.8	132.9	112.0	108.5	129.4	
SHTO	W(%)							
	γ_d(pcf)							

ev 9-78-63

Central Direct Federal Division

DATE June 4, 1984

SUMMARY OF SOIL OR AGGREGATE TESTS

PROJECT ARIZONA FHI 9-8(6) CHOLLA BAY TO ROOSEVELT DAM

SUBMITTED BY Bob Blenk TESTED BY DH,KW,KR,JM,BW REPORTED BY Alan Held

DISTRIBUTION: Project Engineer-1, CDFD File1, Materials Lab-3 Design ______ Construction ______

NUMBER	Field No.							
	Hole No.	Exposed Bank	B-223	B-223	B-230	B-230	B-229	B-228
	Lab No.	84-655-S	84-656-S	84-657-S	84-658-S	84-659-S	84-660-S	84-661-S
LOCATION	Station or Location	1421+00	1451+15	1451+15	1476+35	1476+35	1500+00	1505+00
	Offset	-	27' R	27' R	4' L	4' L	65' R	65' R
	Depth	-	0-33'	33'-49'6"	0-15'	20-35'	5'-9'6"	0-10'
	3"	95						
	1 1/2"	80						100
	1"	75	100				100	99
	3/4"	70	99	100	100	100	99	98
	1/2"	63	95	99	98	99	93	95
	3/8"	59	92	97	96	99	89	91
	#4	50	82	90	88	95	77	77
	#8							
	#10	37	60	72	67	83	60	62
	#16	31	47	59	54	71	51	54
	#30							
8 88	#40	20	29	38	37	49	37	42
	#50							
	#100	12	20	26	27	35	28	33
	#200	9.3	15.6	21.6	22.5	31.2	23.6	29.2
	0.05mm							
	002mm							
	0.002mm							
	0.001mm							
	Moist.							
SHTO	SL							
99,	LL	30	26	22	21	24	29	33
892	PI	8	7	6	7	9	12	17
SHTO	Class	A-2-4	A-2-4	A-1-b	A-2-4	A-2-4	A-2-6	A-2-6
145	GI						(0)	(1)
SHTO	R	40*	31	22	12	5	13	7
190	W(%)	8.0	7.6	8.1	7.4	10.5	9.2	12.3
	γ_0(pcf)	133.0	131.8	133.1	135.9	120.9	127.8	119.7
	W(%)							
	(pcf)							

*R-value decreases rapidly below 300 psi exudation pressure.

Central Direct Federal Division

DATE June 4, 1984

SUMMARY OF SOIL OR AGGREGATE TESTS

PROJECT ARIZONA FLH 9-8(6) CHOLLA BAY TO ROOSEVELT DAM

SUBMITTED BY Bob Blenk TESTED BY DH,KW,KR,JM,BW REPORTED BY Alan Held

DISTRIBUTION: Project Engineer-1, CDFD File1, Materials Lab-3 Design ______ Construction ______

SAMPLE NUMBER	Field No.							
	Hole No.	B-225	Rt. Cutbank	Lt. Cutbank				
	Lab No.	84-662-S	84-663-S	84-664-S				
SAMPLE LOCATION	Station or Location	1523+00	1582+75	1605+00				
	Offset	CL	20'R	--				
	Depth	0-3'	--	--				
T 88	3"	100	100	77				
	1 1/2"	98	90	62				
	1"	95	85	58				
	3/4"	94	82	57				
	1/2"	92	79	55				
	3/8"	90	77	54				
	# 4	83	73	52				
	# 8							
	# 10	79	69	50				
	# 16	76	67	49				
	# 30							
	# 40	68	57	45				
	# 50							
	# 100	61	46	41				
	# 200	55.3	35.6	35.7				
	0.05 mm							
	0.02 mm							
	0.002 mm							
	0.001 mm							
% Moist.								
AASHTO T-99, T-89, T-90 / D 892	SL							
	LL	49	28	25				
	PI	29	6	8				
AASHTO M-145	Class	A-7-6	A-4	A-6				
	GI	(13)	(0)	(1)				
AASHTO T-190	R	L.T. 5	41*	14				
	W(%)	15.4	11.4	11.8				
	γ_0(pcf)	110.0	117.9	119.6				
T0 / 0	W(%)							
	γ_0(pcf)							

REMARKS

APPENDIX E

NO NAME
MILLS CANYON

Subsurface Profiles

(See Pocket in Back)

APPENDIX F

Photographs

Photo 1 – Back to [illegible] Bachelor Cove (1 of [illegible])

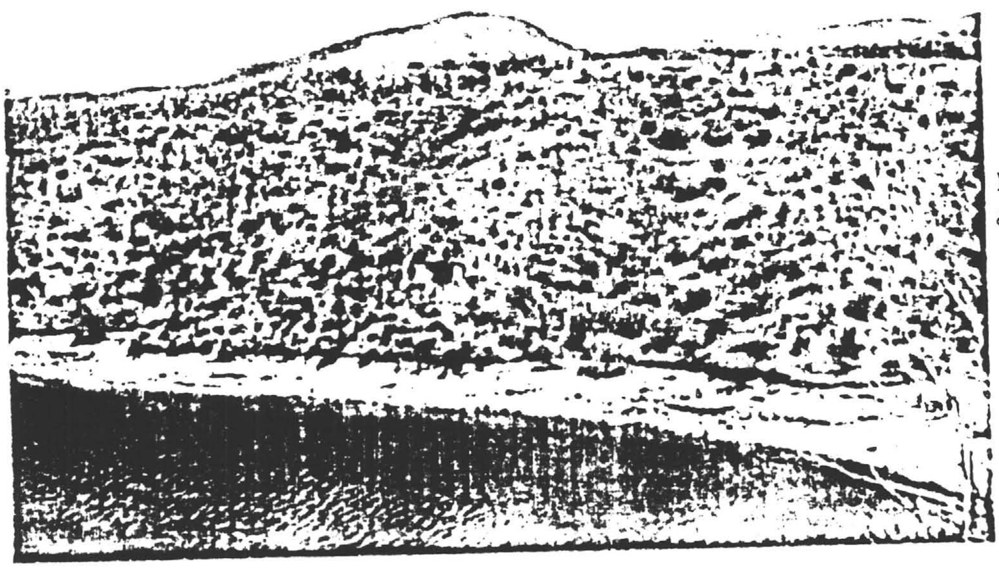


Photo 2-Far side Bachelor ahead on line

Photo 3 – Back to [illegible] Canyon


Photo 4 - Back on line, near side Mills Canyon


Photo 5 - Ahead on line, far side Mills Canyon


Photo 6 -Long shot ahead far side Mills Canyon

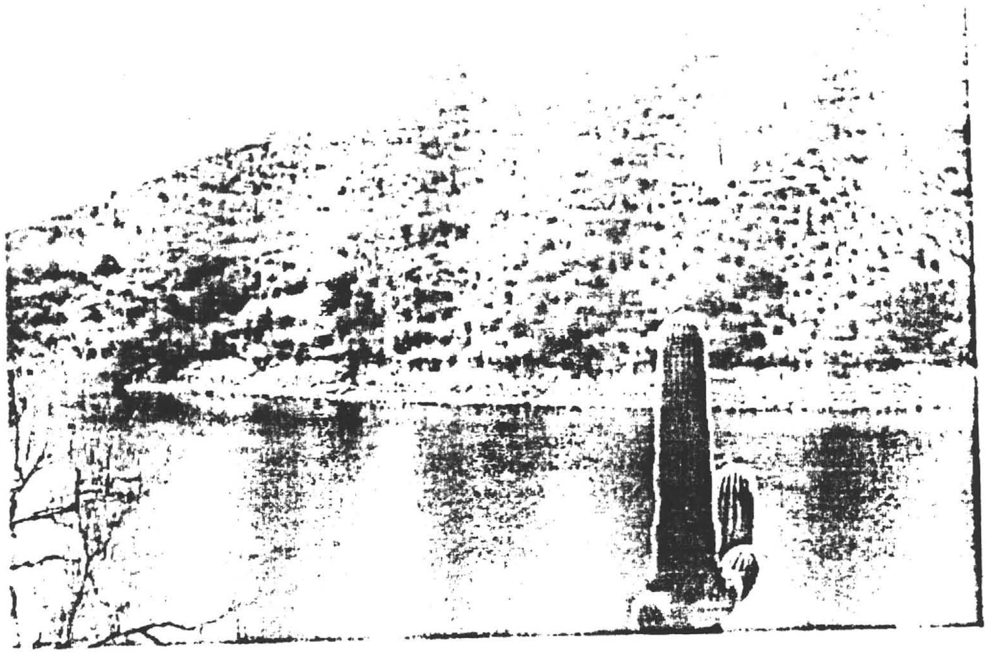


Photo 7 - Ahead across vineyard

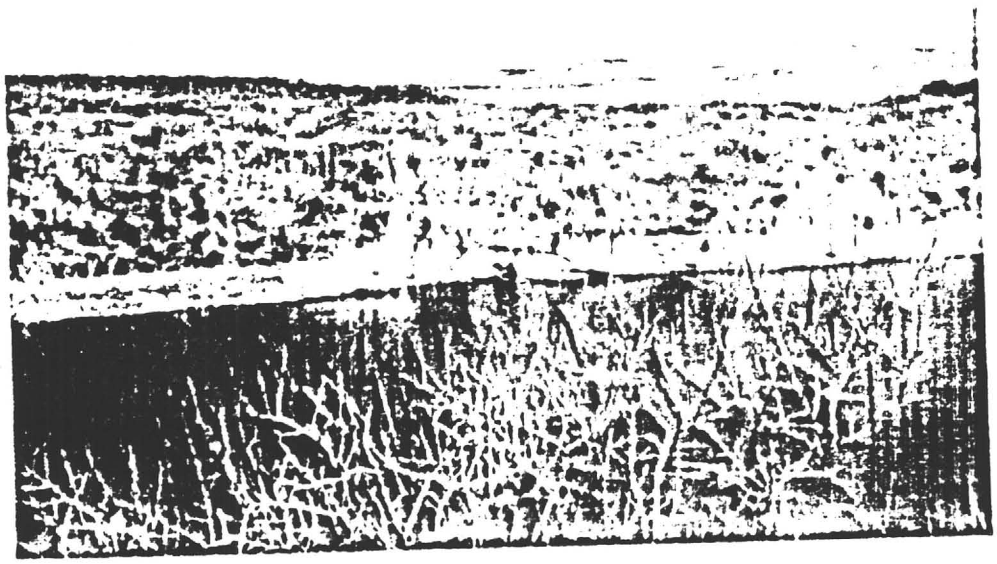


Photo [illegible]
yard [illegible]

Photo 9 -Back to [illegible]
[illegible]

Photo 10 - Ahead on line from 1451+15

Photo 11 - Back on line from 1508±

Photo 12 - Ahead from station 1535±

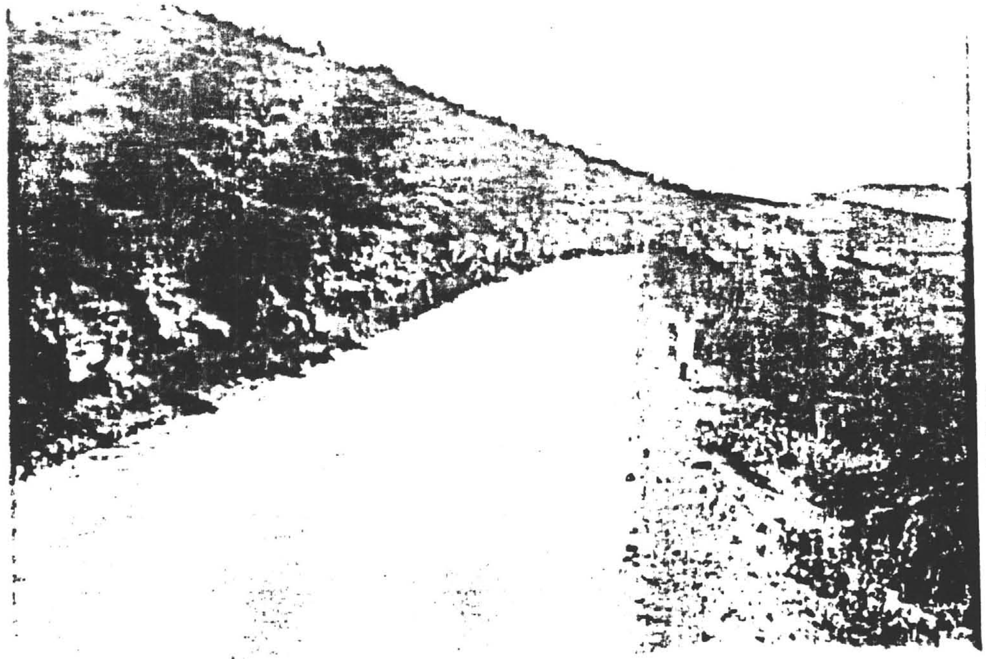


Photo 13 - Back, showing exposed rock, from point at 1544±


Photo 14 - Ahead from poi at 1544±

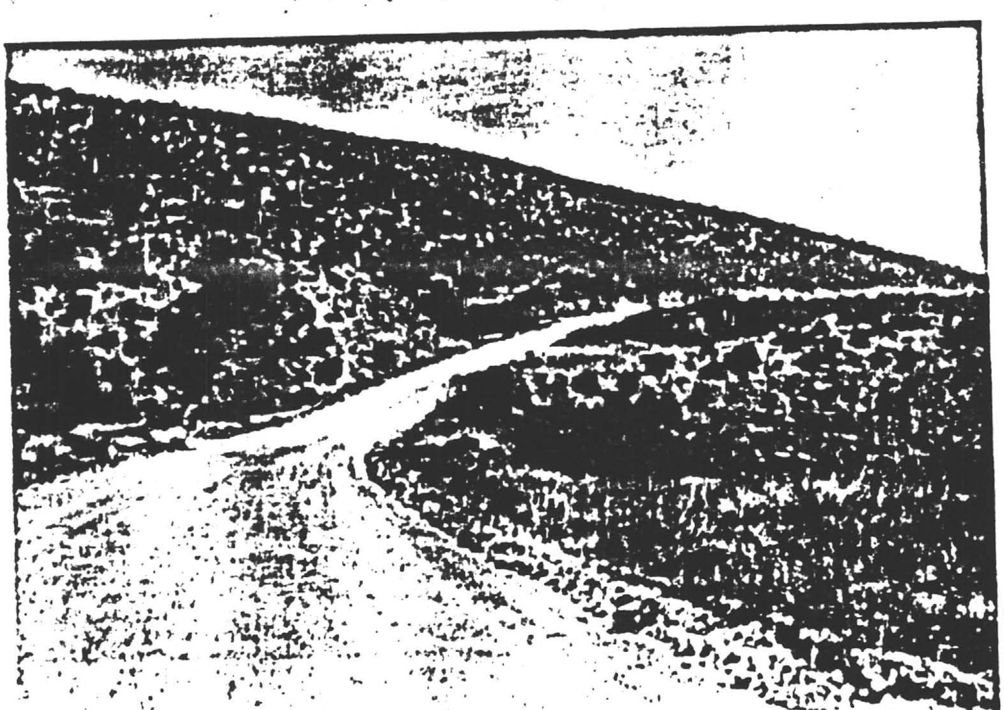


Photo 15 - Back from station 1577±

Photo 16 - Back from station 1580±

Photo 17 - Ahead to exposed rock in cuts 1590± to 1601+30±

Photo 18 - View of expos rock in cuts ahead from 1606±

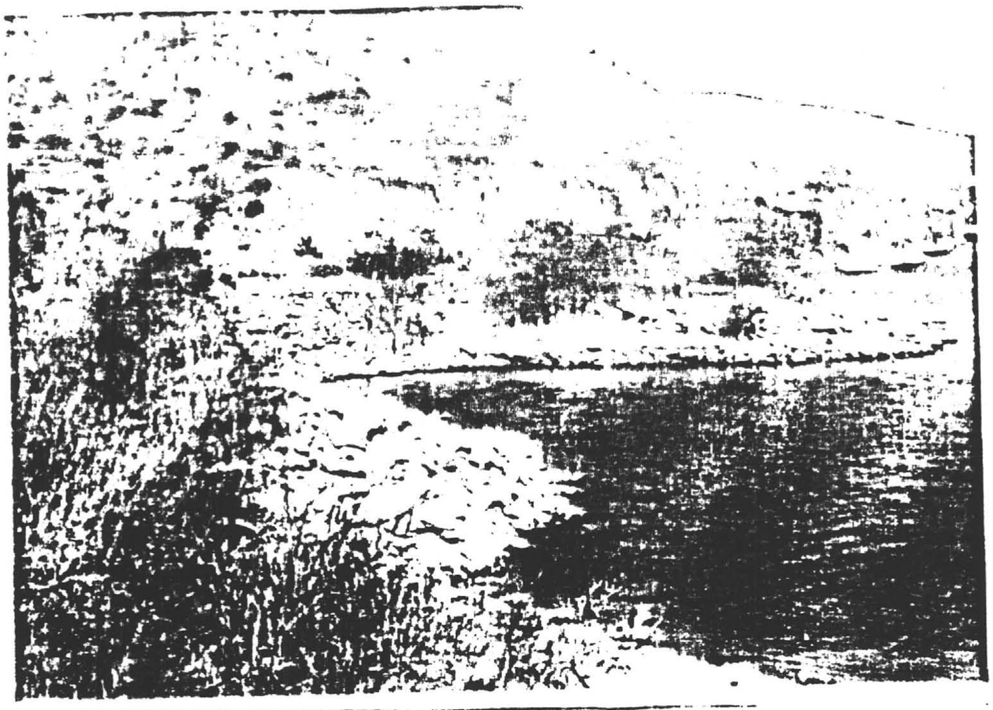


Photo 19 -Closer view back
on line across bay at 1606

Photo 20 - Back on line to
rock slopes past bay at
1606

Photo 21 - back on line to
rock slopes past bay at
1619 to 1621

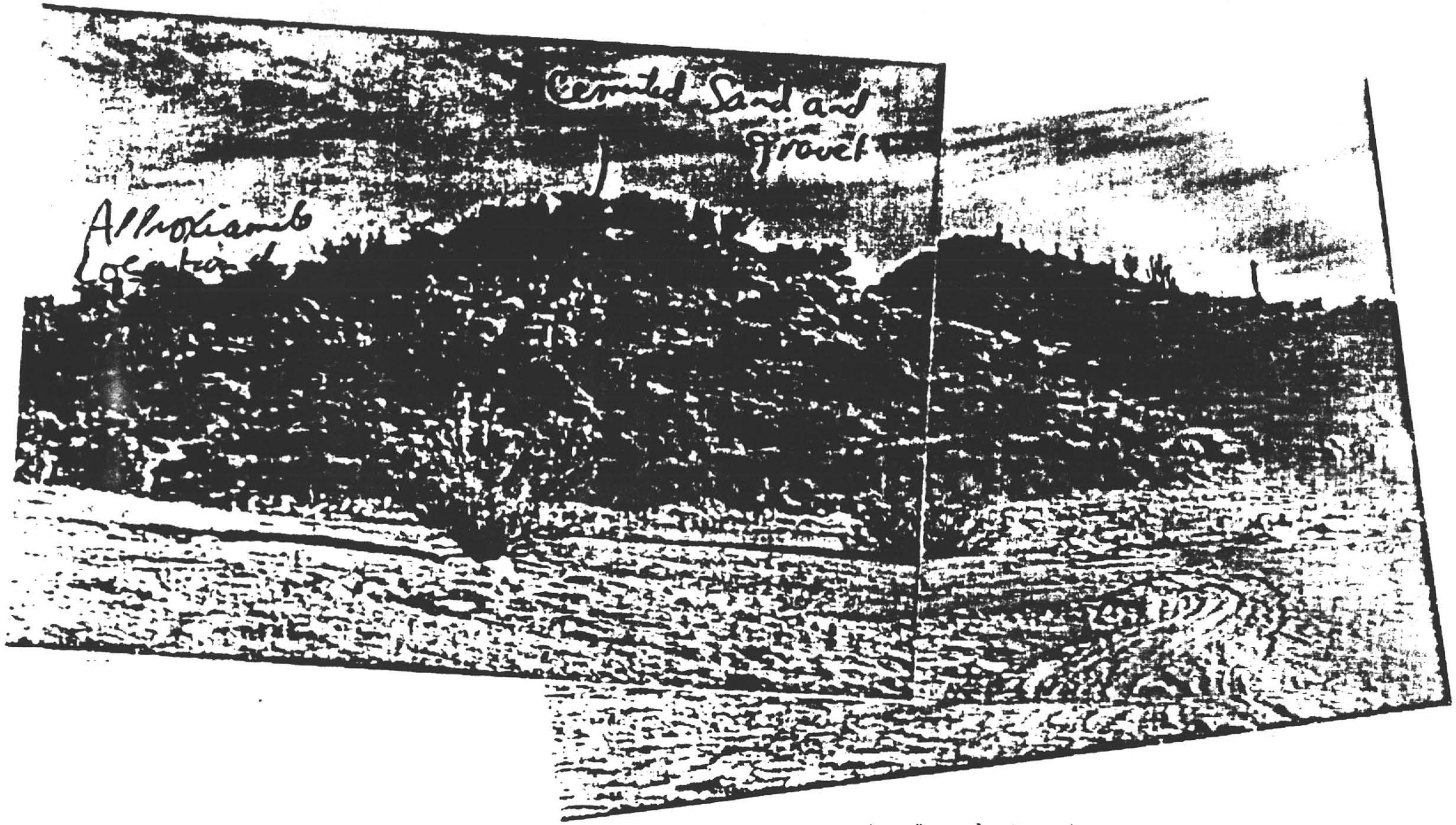


Photo 22 - Bachelor Cove northerly abutment

Photo 23 - Exposed conglomerate formation
Mills Canyon

Verde Valley / Roosevelt Dam
Materials

From FWS Files Denver

Az FLH 9-8(4)
Notes received from
Mat'ls 3/5/86

Station	Rock Description
S A 1588+50 to 1590+20	Fault Breccia composed of Boulders and silt and clay fines. ± 10-15% Boulders ~~larger than 2 ft dia~~ 2-3 ft. dia.
STA 1590+20 - 1591 ±	Arkosic quartzite, slightly weathered, very hard ± 50% Class V Riprap
STA 1591± - 1594±	Fractured quartzite, decomposed to moderately weathered, moderately hard to very hard. ± 20% class V Riprap
STA 1594± - 1598±	Arkosic quartzite, moderately weathered to unweathered, moderately hard to very hard. ± 60% class V Riprap
1598± - 1598+50	Fractured quartzite, highly weathered, very hard < 10% Class V Riprap
Sta 1598+50 - 1599+20	Arkosic quartzite, ~~hard to very~~ highly weathered to moderately weathered, hard to very hard ± 50% Class V riprap
Sta 1599+20 - 1600+10±	Arkosic quartzite, ~~moderately weathered~~ unweathered, very hard ± 90% Class V riprap
Sta 1600+10± - 1601+30	Arkosic Quartzite, mod. weathered, hard to very hard. ± 25% Class V riprap.

Note: The stationing was taken from the existing road and may vary slightly at the proposed ...

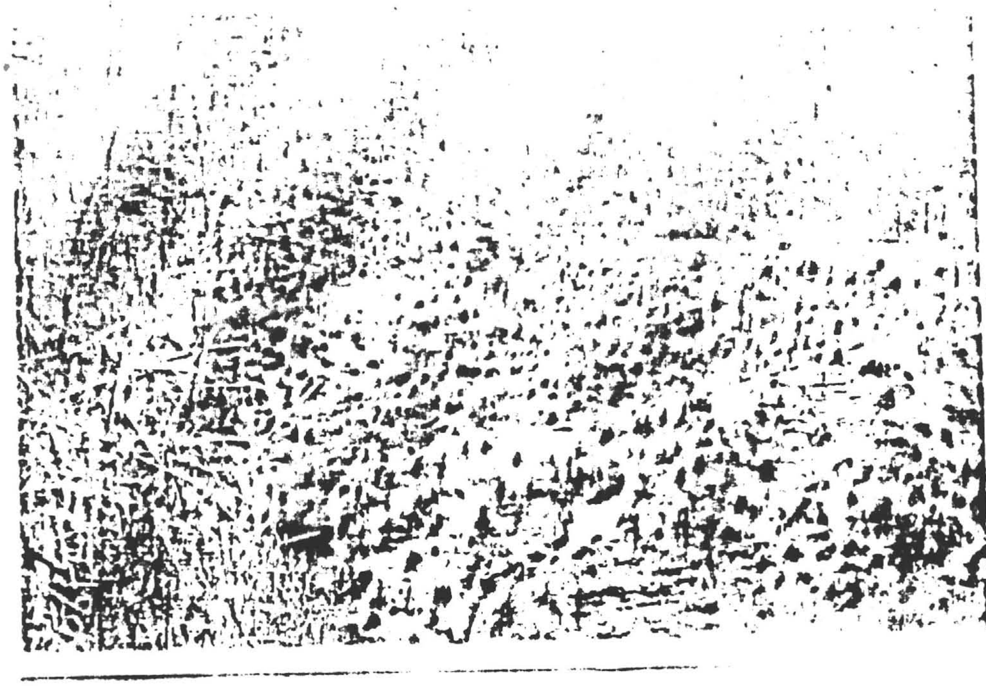


Photo 10 - Ahead on line
from 1451+15

Photo 11 - Back on line
from 1508±

Photo 12 - Ahead from
station 1535±

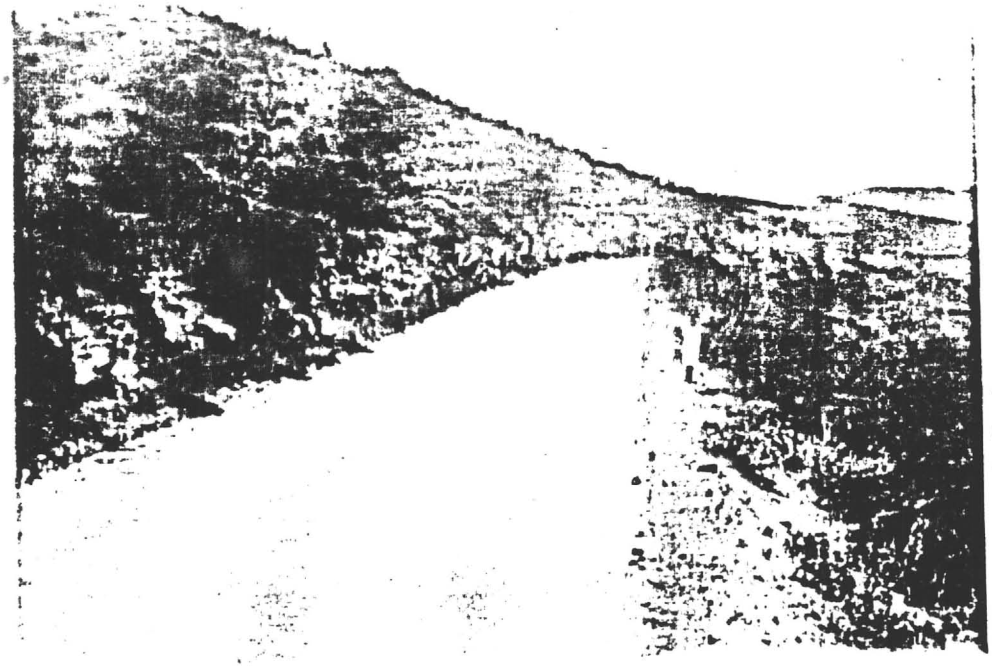


Photo 13 - Back, showing exposed rock, from point at 1544±

Photo 14 - Ahead from poi at 1544±

Photo 15 - Back from station 1577±

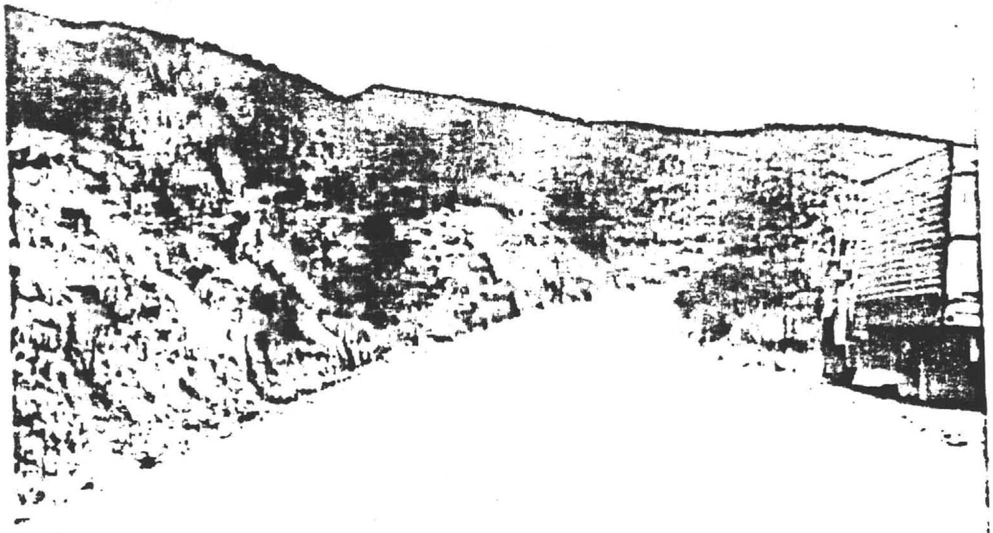


Photo 16 - Back from station 1580±

Photo 17 - Ahead to exposed rock in cuts 1590± to 1601+30±

Photo 18 - View of expos[illegible] rock in cuts ahead from 1606±

Photo 19 -Closer view [illegible]
on line across bay at 1606

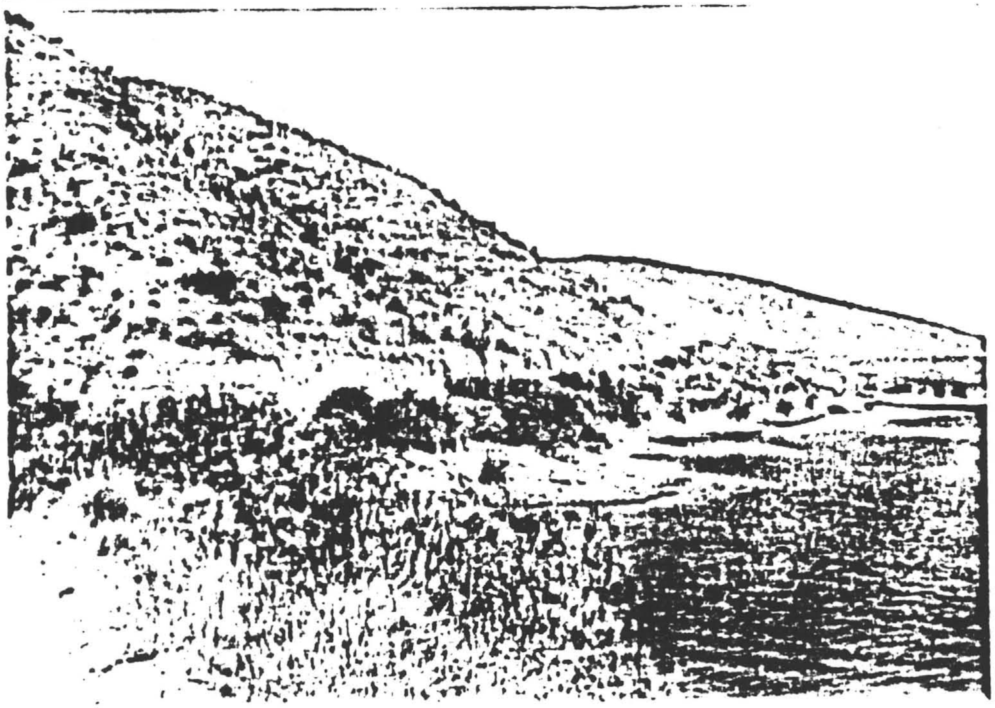


Photo 20 - Back on line to
rock slopes past bay at
1606

Photo 21 - back on line [illegible]
rock slopes past bay at
1619 to 1621

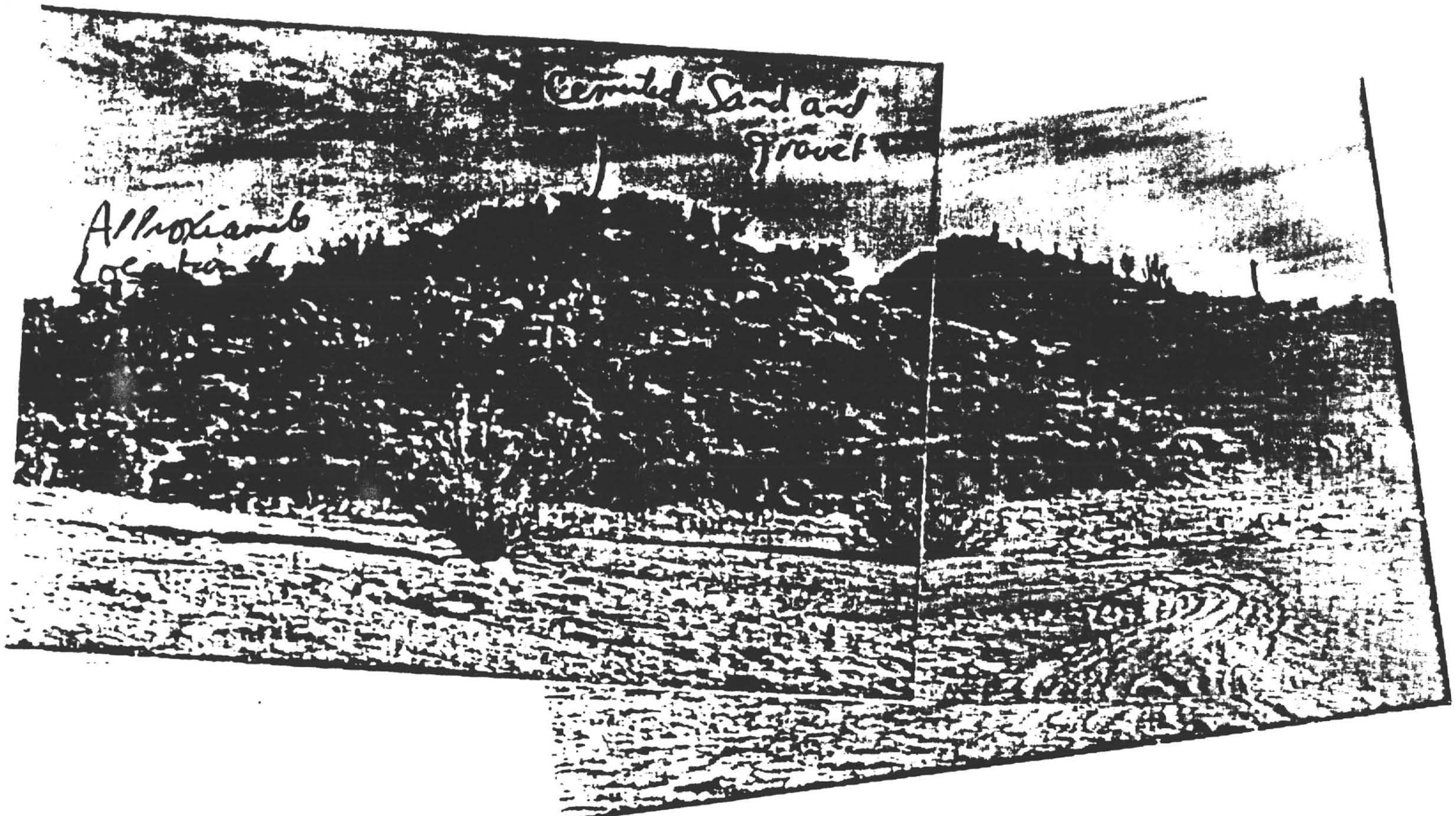


Photo 22 - Bachelor Cove northerly abutment

Photo 23 - Exposed conglomerate formation
Mills Canyon

Verde Valley / Roosevelt Dam

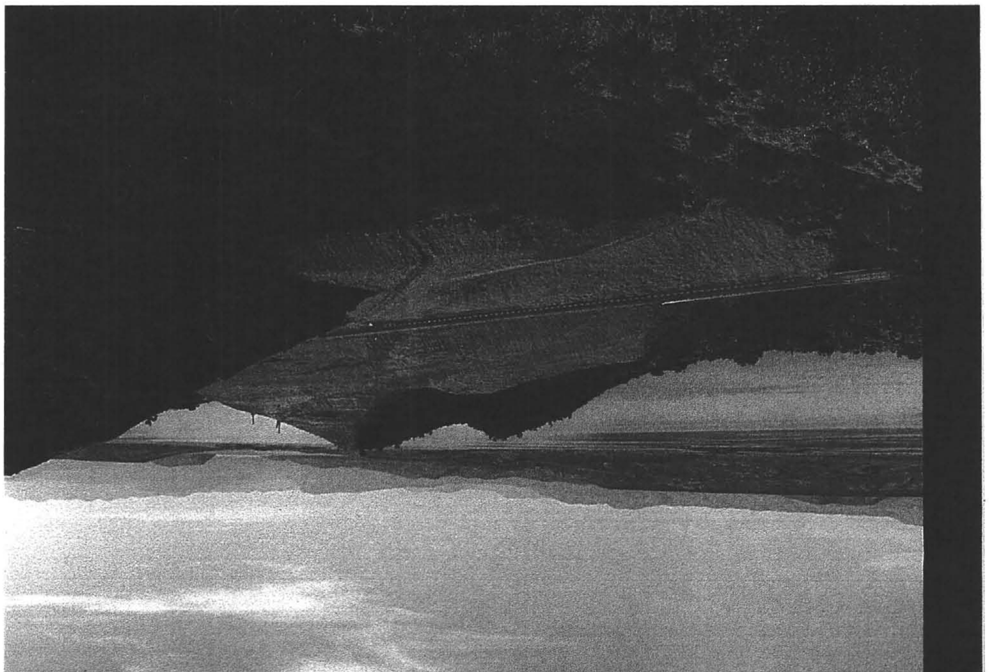
MAterials

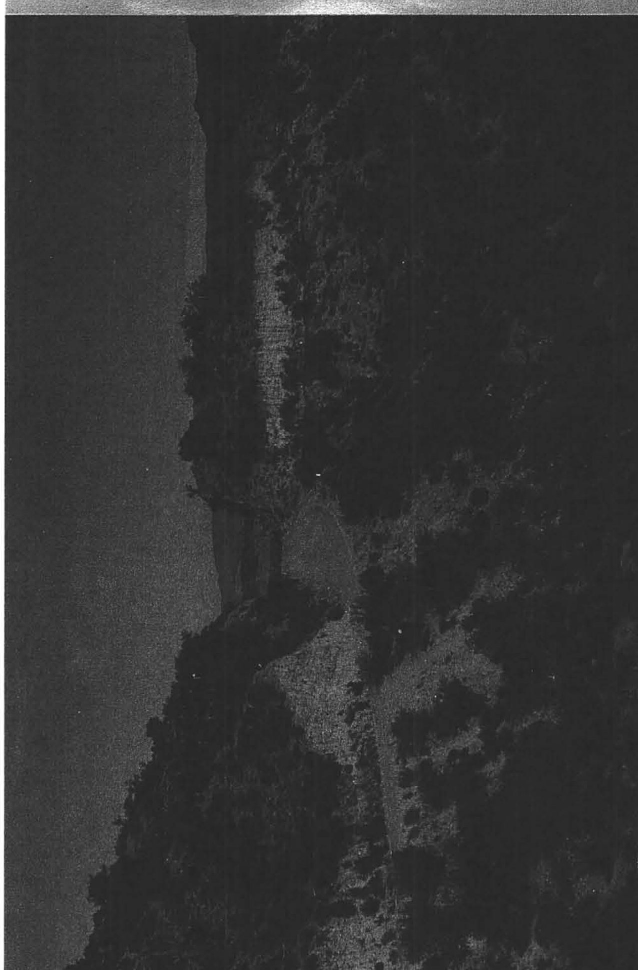
From FdWS Files Denver

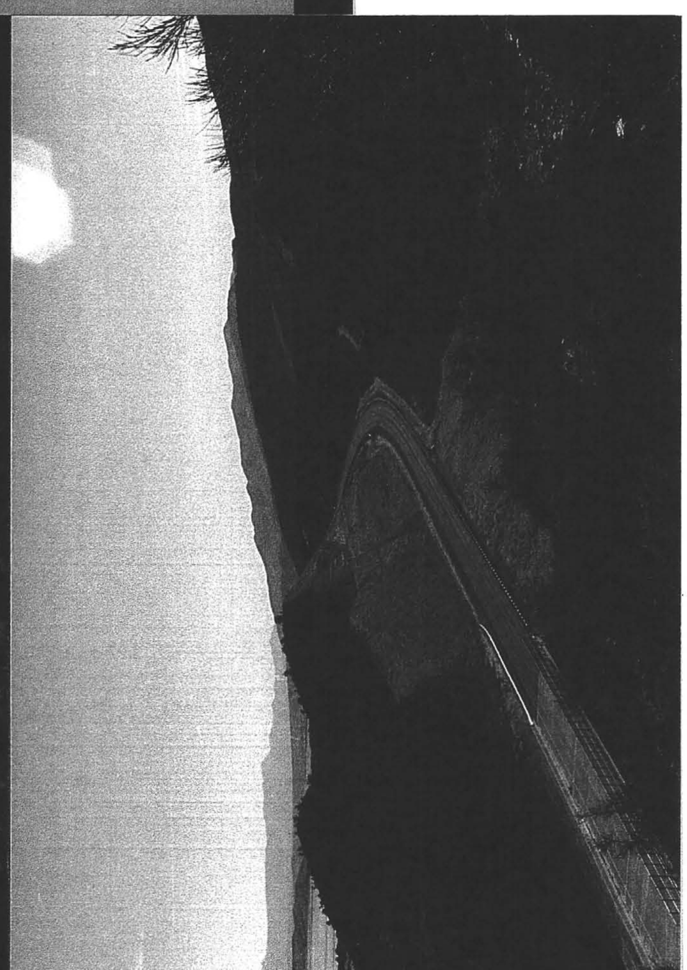
Az FLH 9-8(1)
Notes received from
Mat'ls 3/5/86

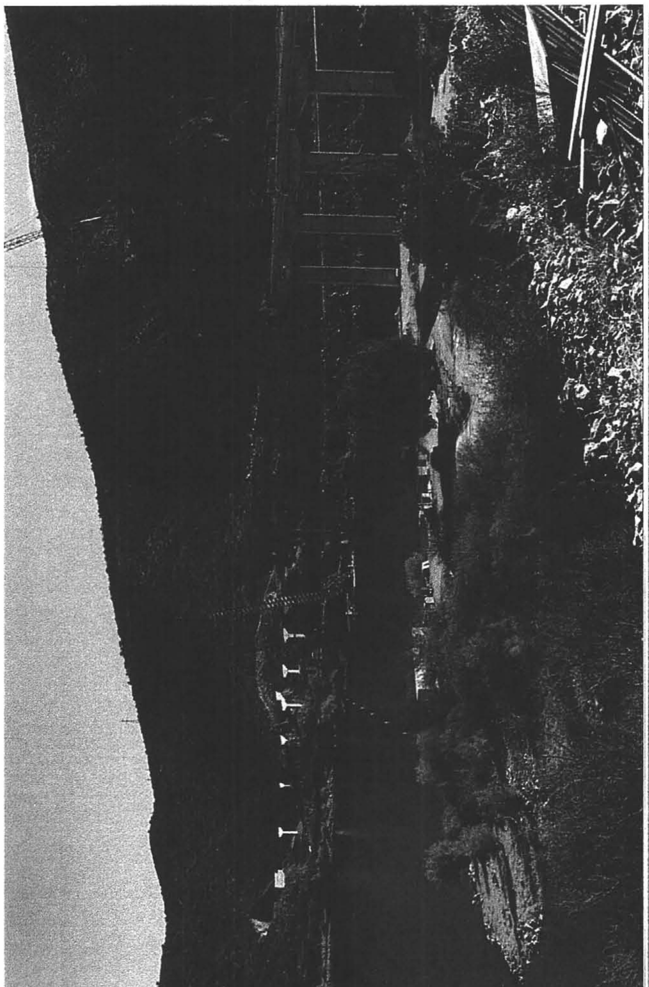
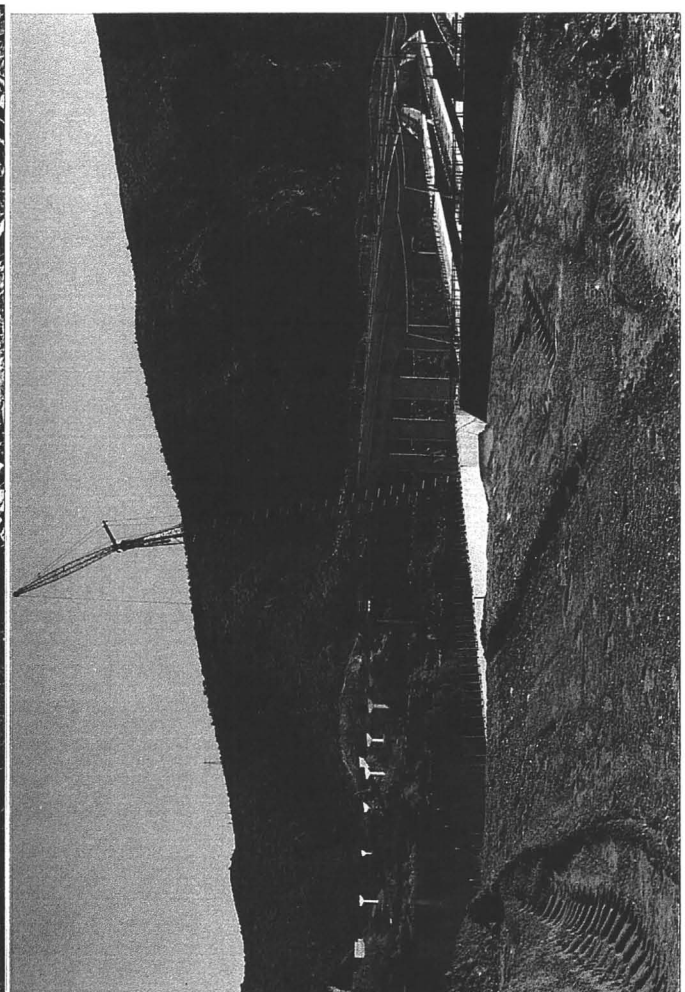
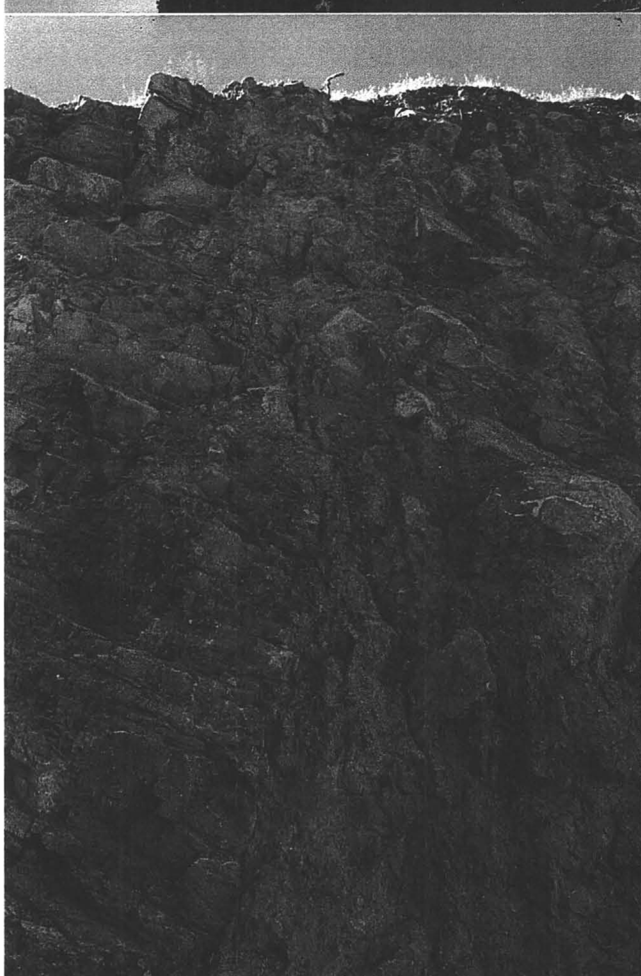
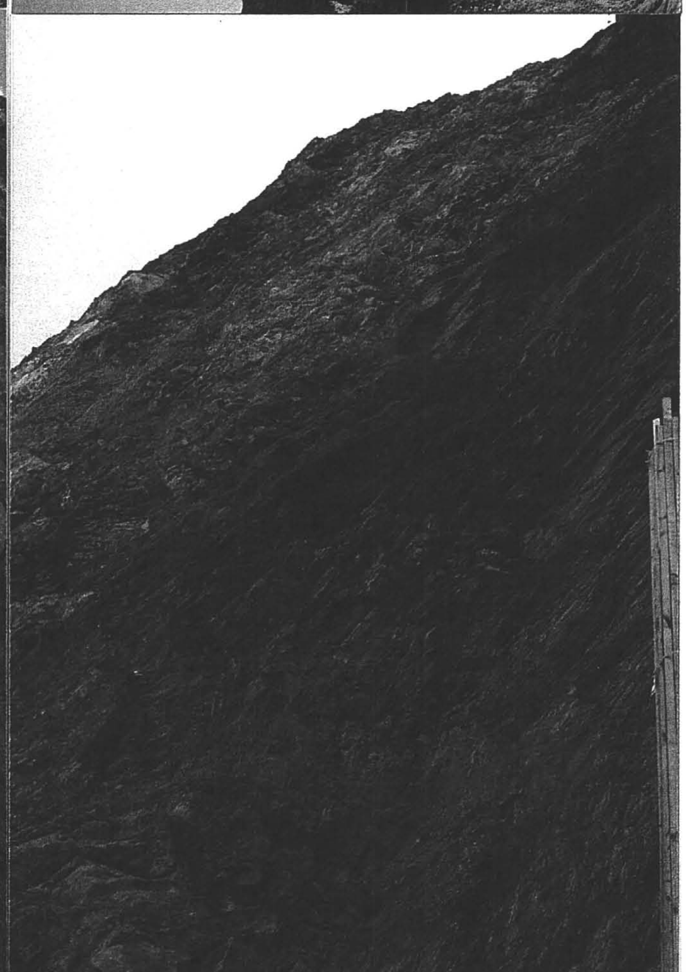
Station	Rock Description
S A 1588+50 to 1590+20	Fault Breccia composed of Boulders and silt and clay fines. ± 10-15% Boulders ~~larger than 2 ft dia~~ 2-3 ft. dia.
STA 1590+20 - 1591 ±	Arkosic quartzite, slightly weathered, very hard ± 50% Class V Riprap
STA 1591 ± - 1594 ±	Fractured quartzite, decomposed to moderately weathered, moderately hard to very hard. ± 20% class V Riprap
STA 1594 ± - 1598 ±	Arkosic quartzite, moderately weathered to unweathered, moderately hard to very hard. ± 60% class V Riprap
1598 ± - 1598+50	Fractured quartzite, highly weathered, very hard < 10% Class V Riprap
Sta 1598+50 - 1599+20	Arkosic quartzite, ~~hard to very~~ highly weathered to moderately weathered, hard to very hard ± 50% Class V riprap
Sta 1599+20 - 1600+10 ±	Arkosic quartzite, ~~moderately weathered~~ unweathered, very hard ± 90% Class V Riprap
Sta 1600+10 ± - 1601+30	Arkosic Quartzite, mod. weathered, hard to very hard. ± 25% Class V riprap.

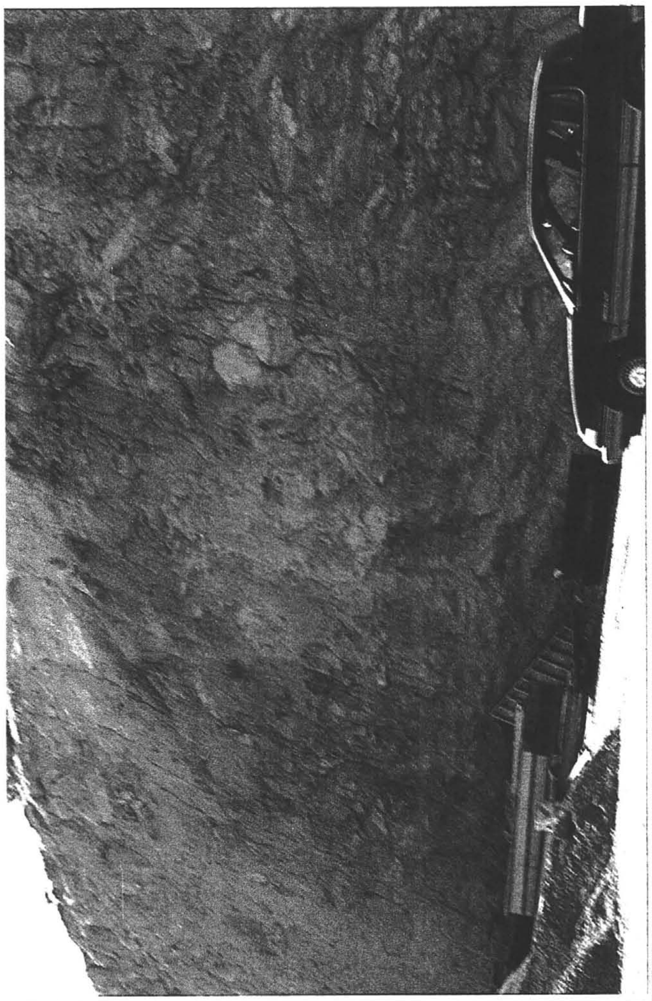
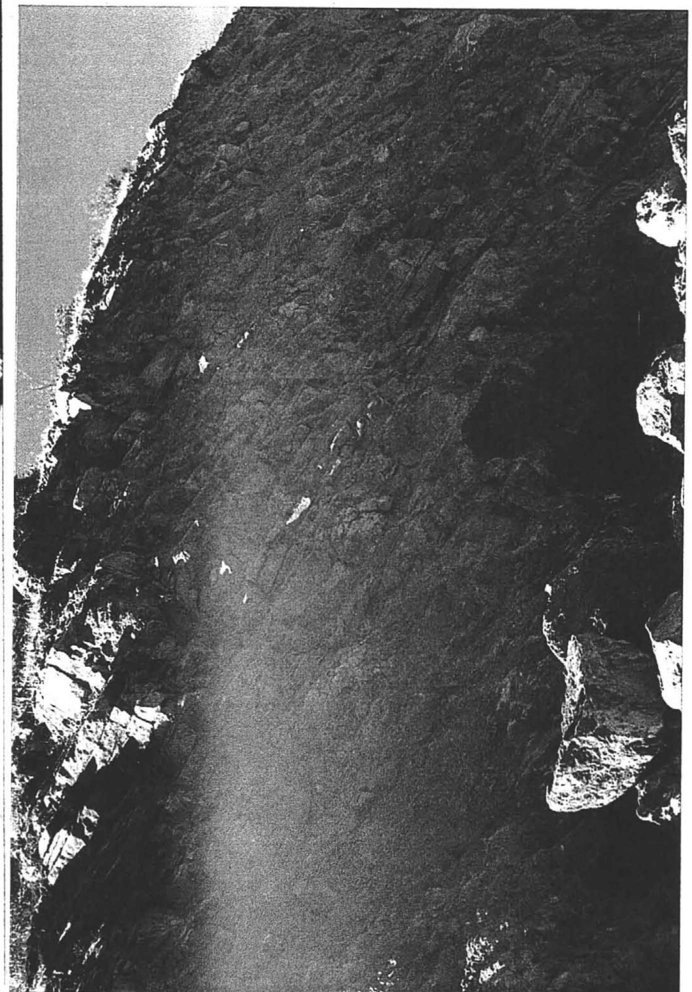
Note: The stationing was taken from the existing road and may vary slightly

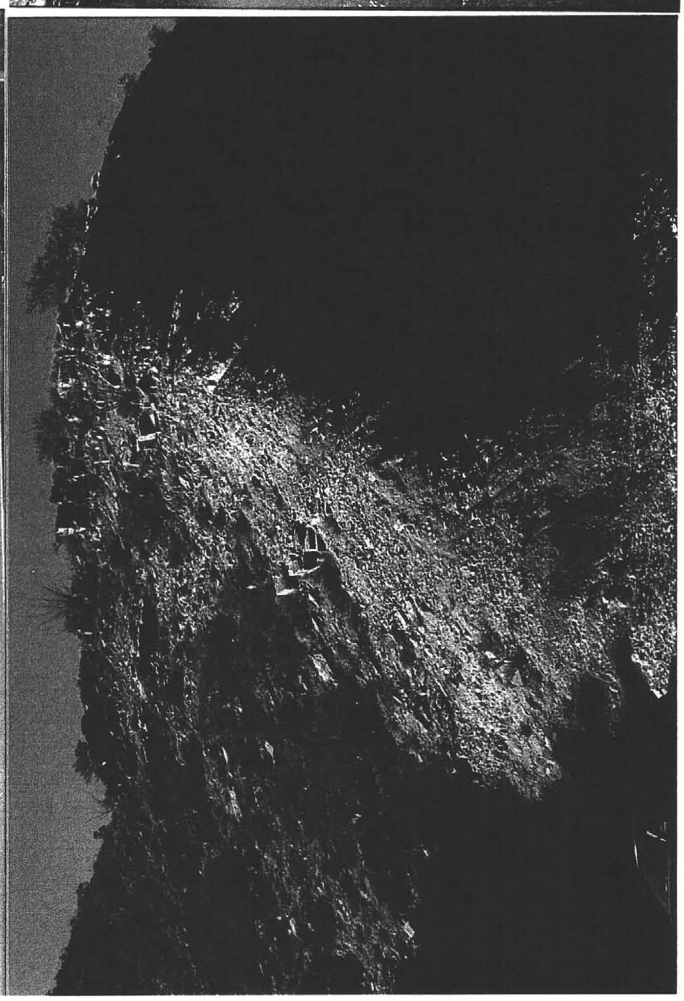


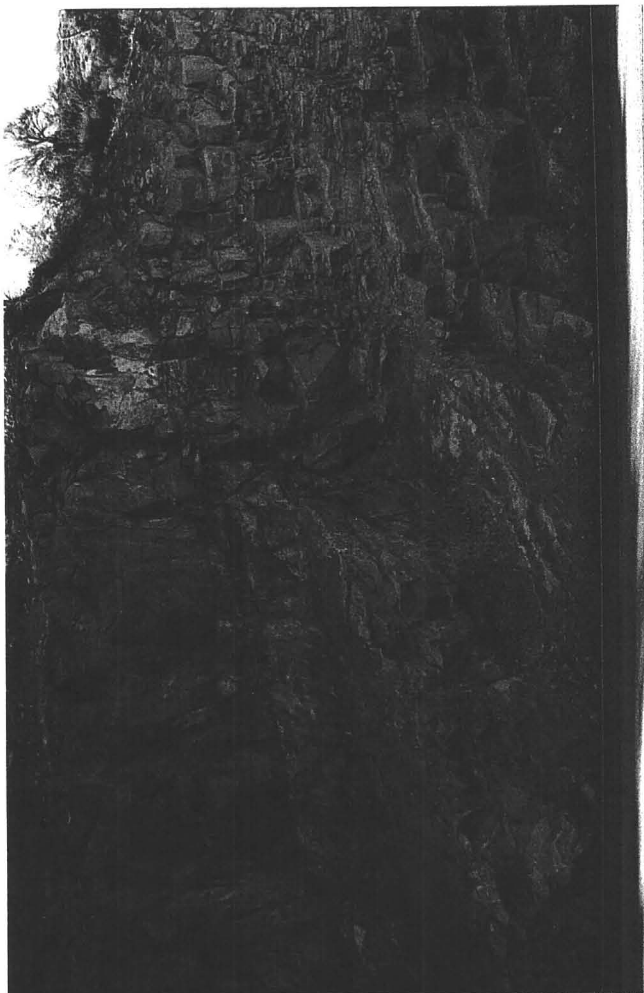


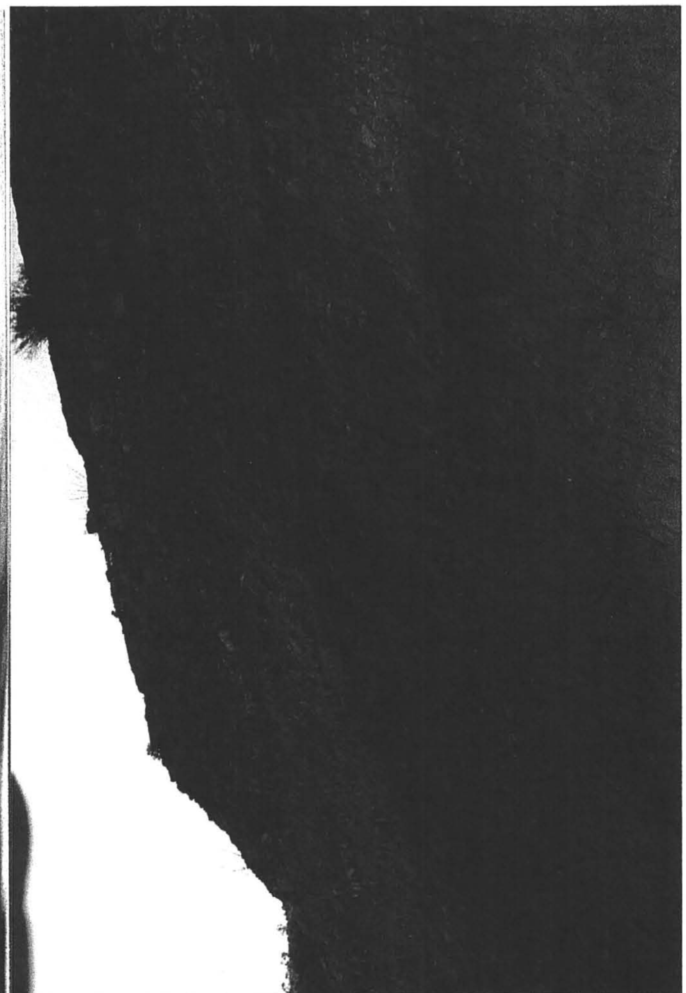


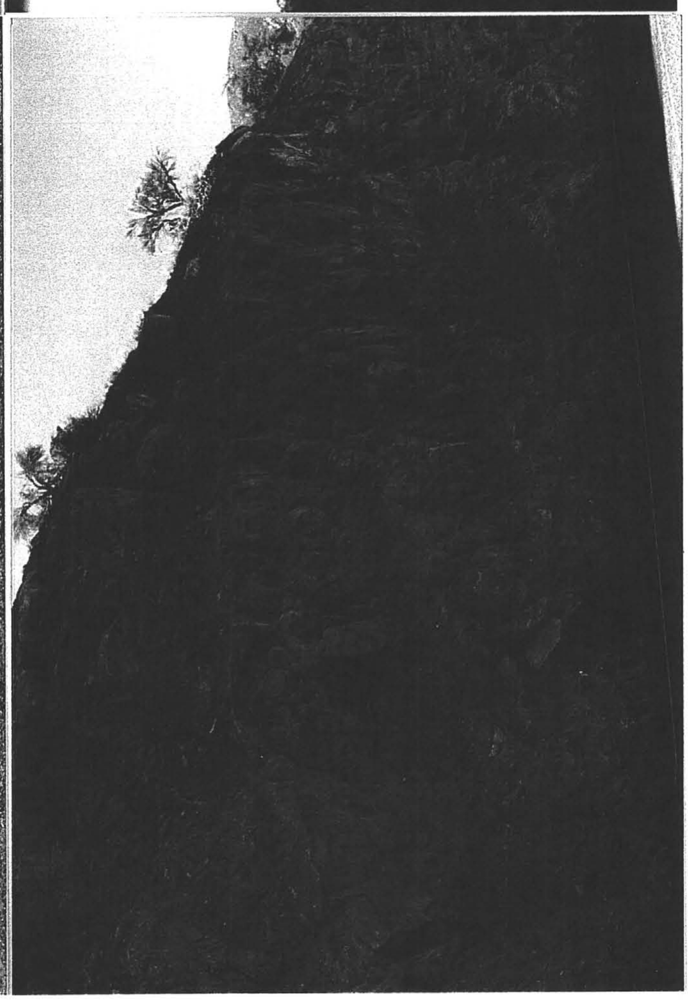





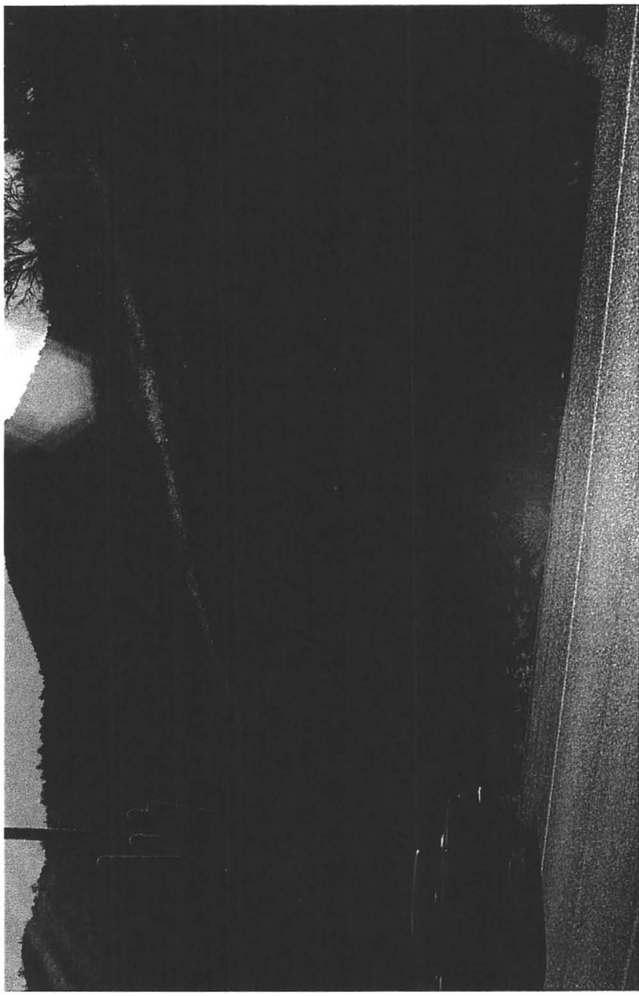
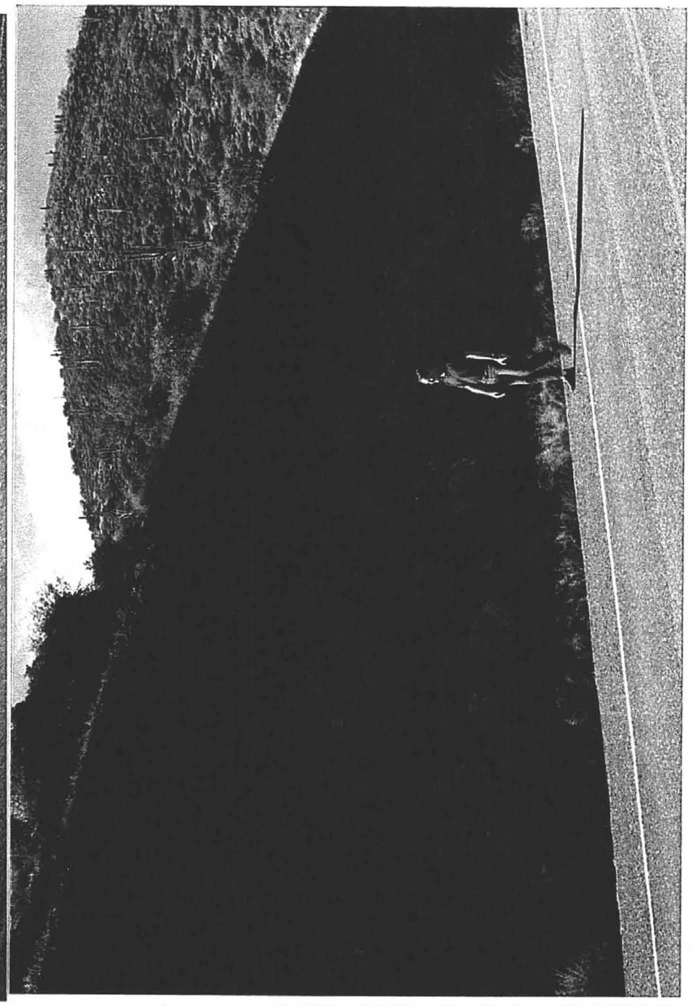
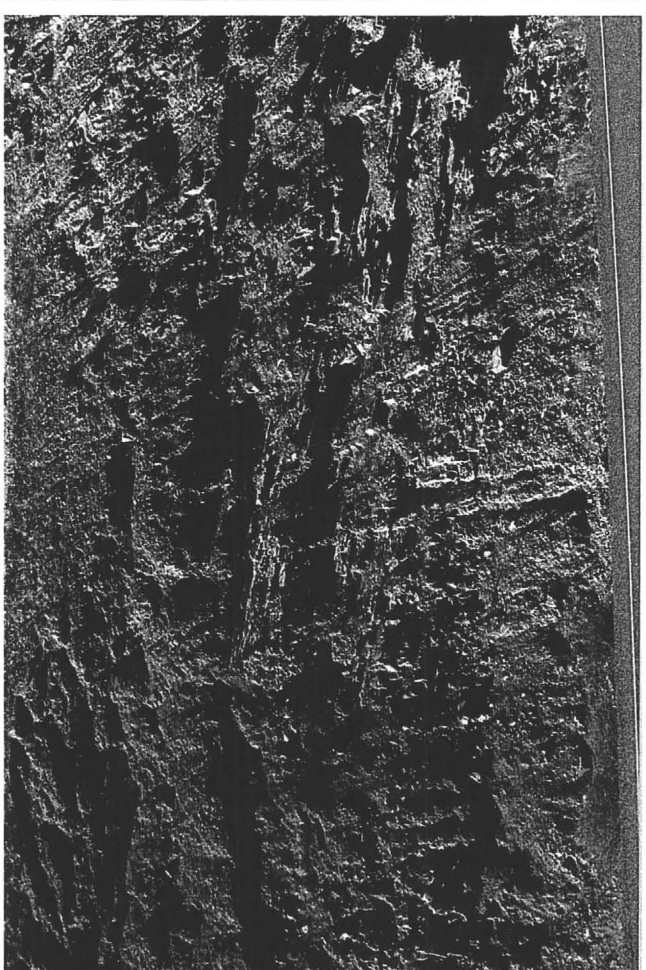
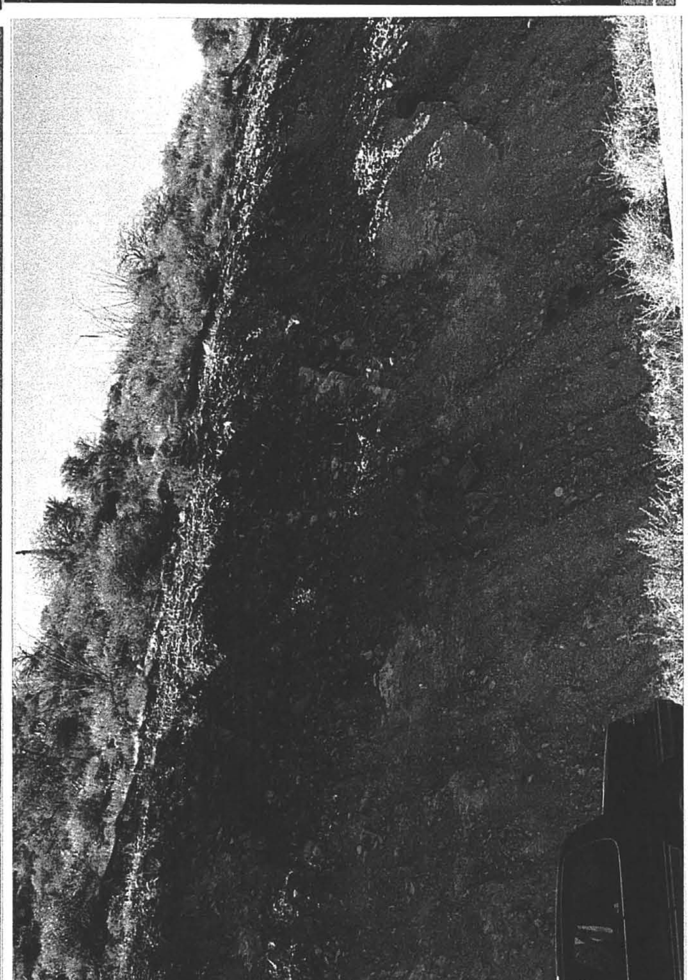



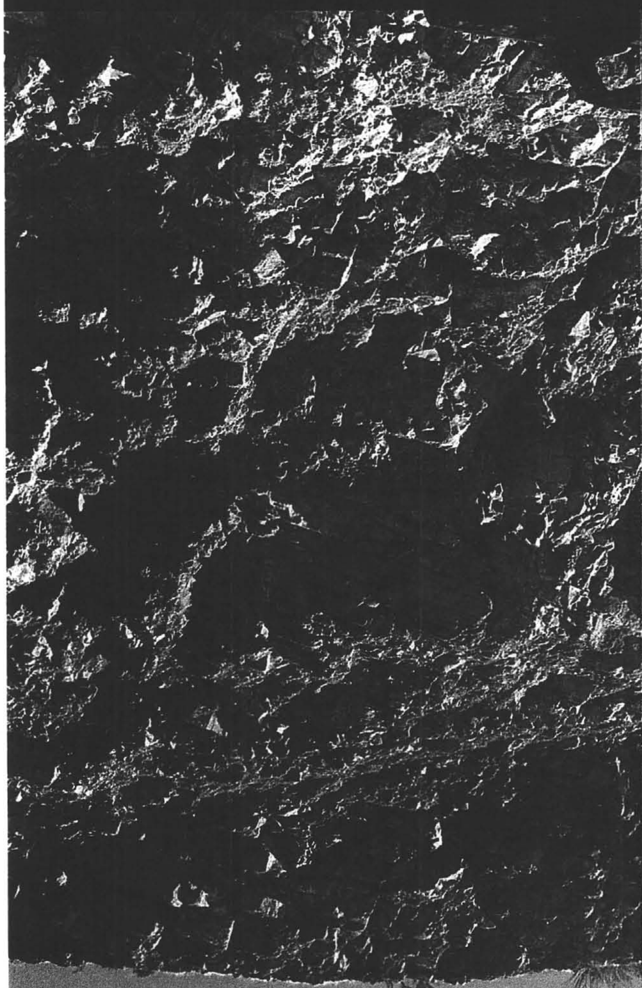
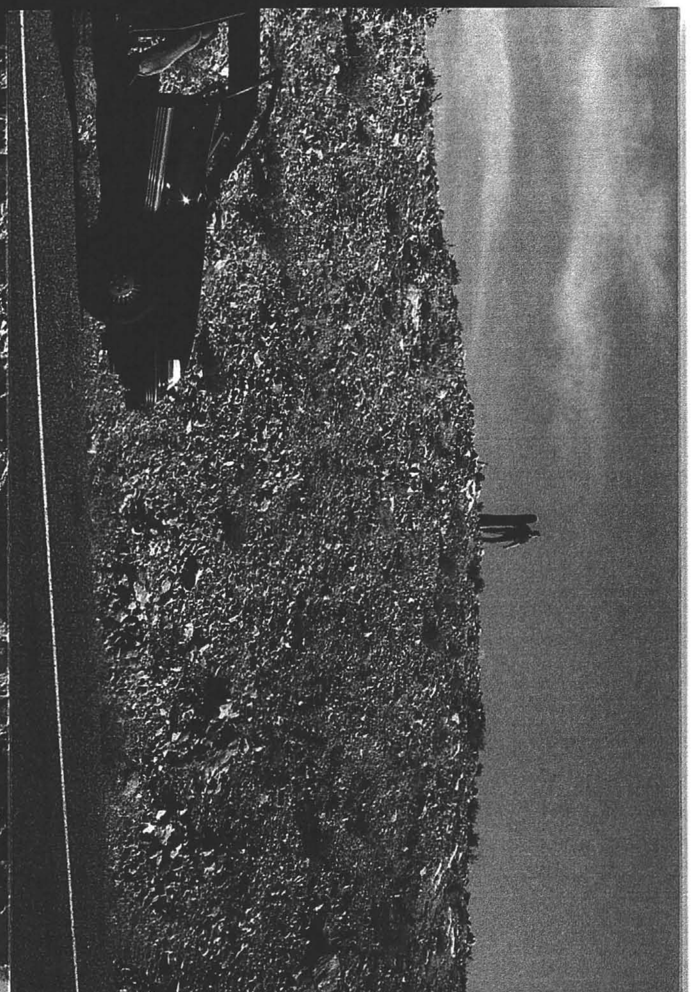
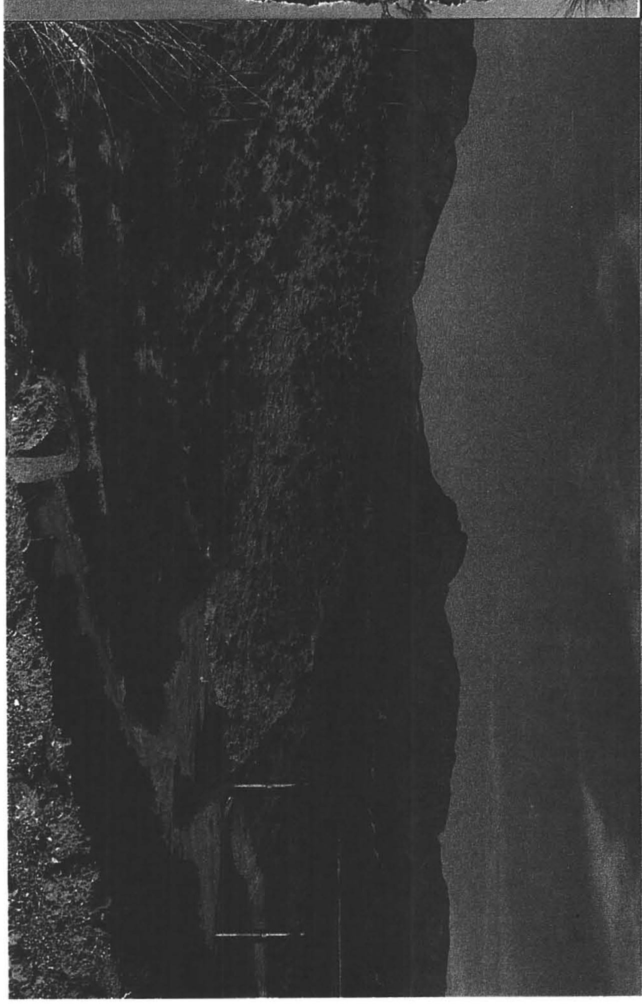






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WILLIAM R. ZOBERST

*ALSO ADMITTED IN ALASKA
** ALSO ADMITTED IN OREGON

December 22, 1988

Dear Mr Henricks,

I received your report today and was very impressed with the depth and insightfullness of its contents. Thank you very much for the extra effort and the timeliness of your response.

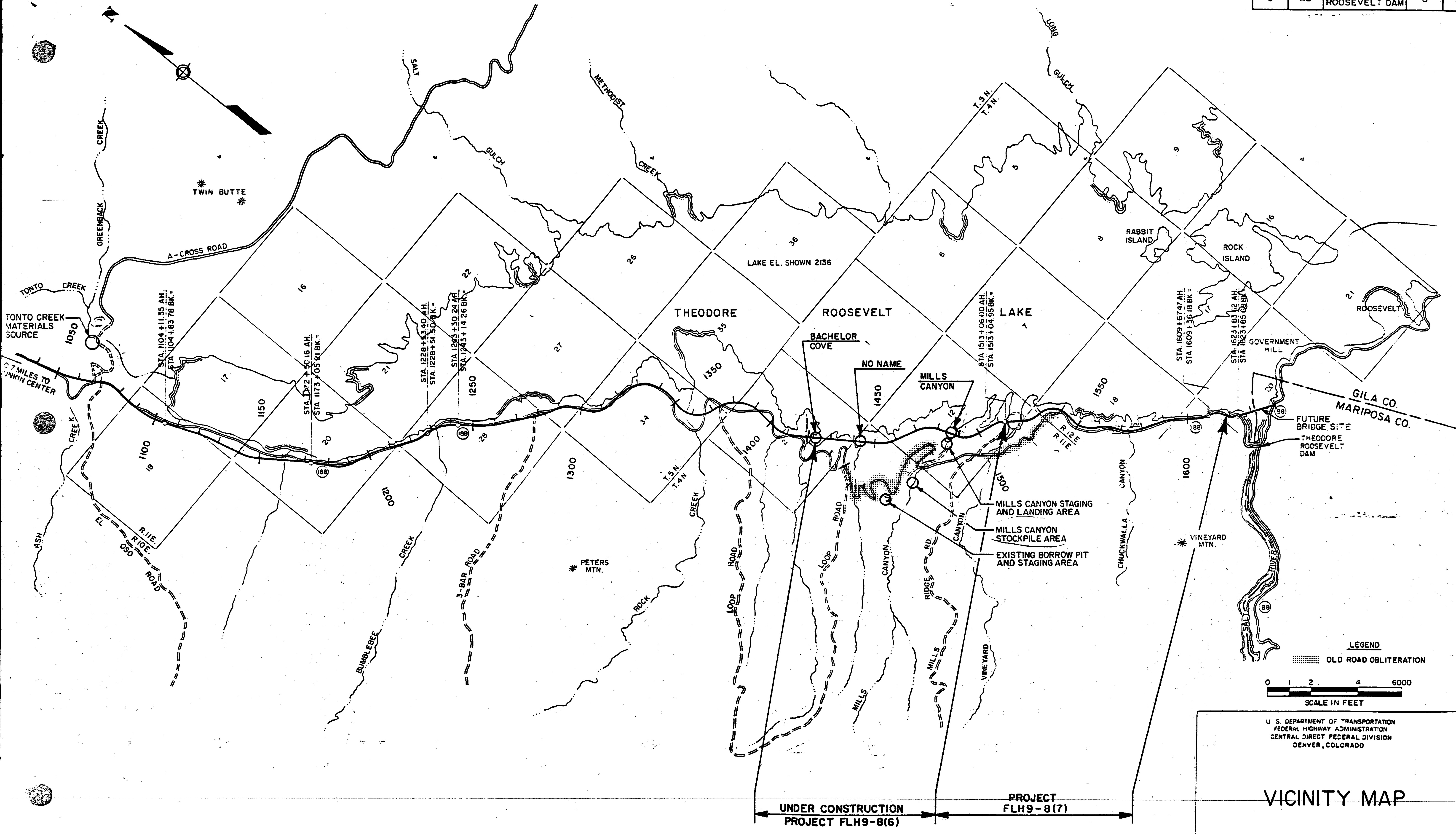
We have not yet reached any decision on testing, but I will keep you informed should we desire any further information.

Thanks again for a job well done. Happy holidays to you and your family.

Very Truly yours,

David Hattery

REG.	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
9	AZ	FLH9-8(7) ROOSEVELT DAM	3	53



U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
CENTRAL DIRECT FEDERAL DIVISION
DENVER, COLORADO

VICINITY MAP

THE FOLLOWING QUANTITIES ARE APPROXIMATE UNLESS NOTED AS A FINAL PAY ITEM. PAYMENT WILL BE MADE FOR THE ACTUAL QUANTITIES OF WORK PERFORMED AND ACCEPTED OR FOR MATERIALS FURNISHED IN ACCORDANCE WITH THE CONTRACT.

SUMMARY OF QUANTITIES

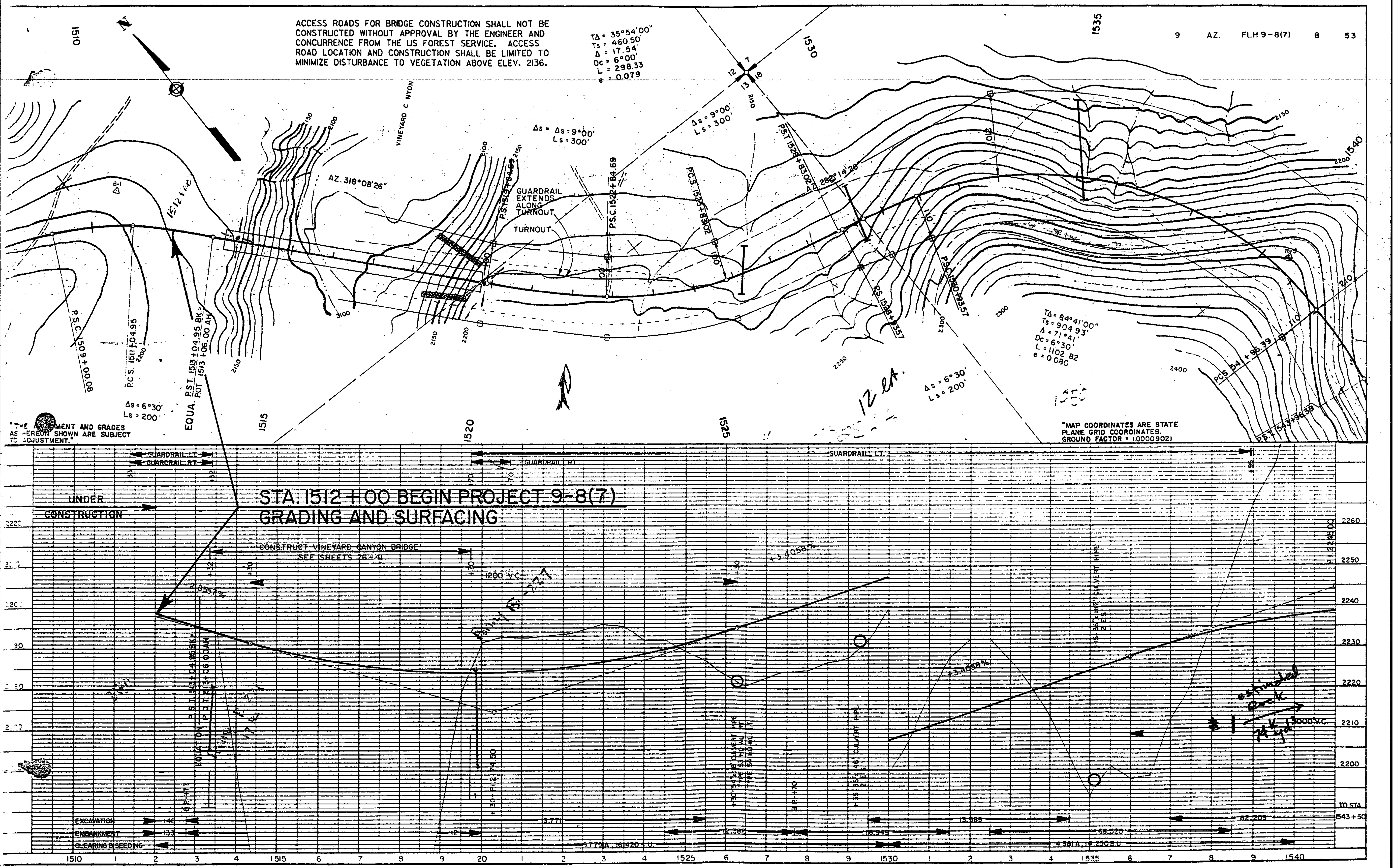
REG.	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
9	AZ	F.L.H. 9-8(7) ROOSEVELT DAM	4	53

	SHEET NUMBER →		2	6	7	8-11	13	14	15	16	18	26-42	ESTIMATED QUANTITIES		REMARKS AND/OR
	SHEET DESCRIPTION →		TYPICAL SECTION	DRAINAGE SUMMARY	GRADING SUMMARY	PLAN & PROFILE	SPECIAL 2	SPECIAL 3	SPECIAL 4	SPECIAL 5	SPECIAL 7	BRIDGE PLANS	PLAN	BID SCHEDULE	DETERMINATION OF ESTIMATED QUANTITIES
[illegible]	ITEM	UNIT													
105(03)	STAKE AND PLOT CULVERT PIPE	EACH				18							18	18	
105(04)	SET GRADE FINISHING STAKES	MILE				4.018							4.018	4.018	
105(05)	PERMANENTLY REFERENCE TRANSIT POINTS	EACH				4							4	4	
106(02)	CONTRACTOR INSPECTION SYSTEM, SERIES 200 ITEMS	L. S.												AS SPEC'D	
106(03)	CONTRACTOR INSPECTION SYSTEM, SERIES 300 ITEMS	L. S.												AS SPEC'D	
106(04)	CONTRACTOR INSPECTION SYSTEM, SERIES 400 ITEMS	L. S.												AS SPEC'D	
106(05)	CONTRACTOR INSPECTION SYSTEM, SERIES 500 ITEMS	L. S.												AS SPEC'D	
106(06)	CONTRACTOR INSPECTION SYSTEM, SERIES 600 ITEMS	L. S.												AS SPEC'D	
109(01)	EXTRA AND MISCELLANEOUS WORK	C.S.												ALL REQ'D.	
201(01)	CLEARING AND GRUBBING	ACRE				37.131							37.131	37.500	
203(01)	ROADWAY EXCAVATION	CU. YD.		239	408,507								408,746	410,000	
203(08)	FURROW DITCHES	LN. FT.												1,000	ESTIMATED QUANTITY
203(09)	ROUNDING CUT SLOPES	LN. FT.												9,000	ESTIMATED QUANTITY
204(01)	SOIL EROSION AND POLLUTION CONTROL	C. S.												ALL REQ'D.	
205(01)	OVERHAUL	C. Y. MI.												64,700	FINAL QUANTITY, 2,000 FREEHAUL DISTANCE
206(01)	STRUCTURE EXCAVATION	CU. YD.		1,565					1,630	1,612			4,807	5,000	
206(02)	BRIDGE EXCAVATION	CU. YD.										150	150	150	FINAL QUANTITY
207(01)	WATERING	M. GAL.												8,000	ESTIMATED QUANTITY
210(03)	ROADWAY OBLITERATION	HOUR												200	ESTIMATED QUANTITY
304(01)	AGGREGATE BASE, GRADING E	TON	10,986										10,986	11,400	
304(03)	SUBBASE, GRADING A	TON	18,386										18,386	19,000	
311(04)	STOCKPILED ROCK SECTION 619	CU. YD.												90,000	ESTIMATED QUANTITY
401(01)	HOT ASPHALT CONCR. PAVEMENT, CLASS B, GRADING C	TON	9,230										9,230	9,570	
401(03)	ASPHALT CEMENT, GRADE AC-20	TON	553.9										553.9	575	
410(01)	ASPHALT, GRADE MC-70, PRIME COAT	TON	77.22										77.22	80	
410(03A)	EMULSIFIED ASPHALT, GRADE CSS-1H, TACK COAT	TON												8	ESTIMATED QUANTITY
410(03B)	EMULSIFIED ASPHALT, GRADE CRS-2 H, SEAL COAT	TON	43.34										43.34	45	
410(11)	COVER AGGREGATE, TYPE 3 SEAL COAT	TON	349										349	360	
551(04A)	CAST-IN-PLACE CONCRETE PILES, 4' DIAMETER	LN. FT.										172	172	172	
551(04B)	CAST-IN-PLACE CONCRETE PILES, 5'-6" DIAMETER	LN. FT.										459	459	459	
551(12A)	CAST-IN-PLACE CONCRETE PILES, 4' DIA. ADD'L DEPTH	LN. FT.										20	20	20	
551(12B)	CAST-IN-PLACE CONCRETE PILES, 5'-6" DIA. ADD'L DEPTH	LN. FT.										387	387	387	
551(13)	PERMANENT CASING, 66-IN. O.D., 3/8-IN. THICK, GALVAN.	LN. FT.										180	180	180	
551(14)	PERM. CASING, 66-IN. O.D., 3/8-IN. THICK, BARE STEEL	LN. FT.										339	339	339	
552(01A)	STRUCTURAL CONCRETE, CLASS A(AE), 3,000 PSI	CU. YD.										1,221	1,221	1,221	FINAL QUANTITY
552(01B)	STRUCTURAL CONCRETE, CLASS A(AE), 4,500 PSI	CU. YD.										871	871	871	FINAL QUANTITY
552(02)	STRUCTURAL CONCRETE, CLASS A(AE), 3,000 PSI FOR DRAINAGE STRUCTURES	CU. YD.		124.12					205.67	276.11			605.90	605.90	FINAL QUANTITY
553(01A)	PRESTRESSED CONCRETE GIRDERS, 128'-2"	EACH										12	12	12	
553(01B)	PRESTRESSED CONCRETE GIRDERS, 125'-4"	EACH										18	18	18	
[illegible]	REINFORCING STEEL	LB.		7,864					32,018	33,694		653,700	727,276	727,276	FINAL QUANTITY
601(01)	MOBILIZATION	LUMP SUM												AS SPEC'D	
603(01E)	24-INCH PIPE CULVERT	LN. FT.		800									800	840	
603(01G)	36-INCH PIPE CULVERT	LN. FT.		328									328	340	
603(01H)	42-INCH PIPE CULVERT	LN. FT.		190									190	200	
603(01K)	54-INCH PIPE CULVERT	LN. FT.		202									202	210	

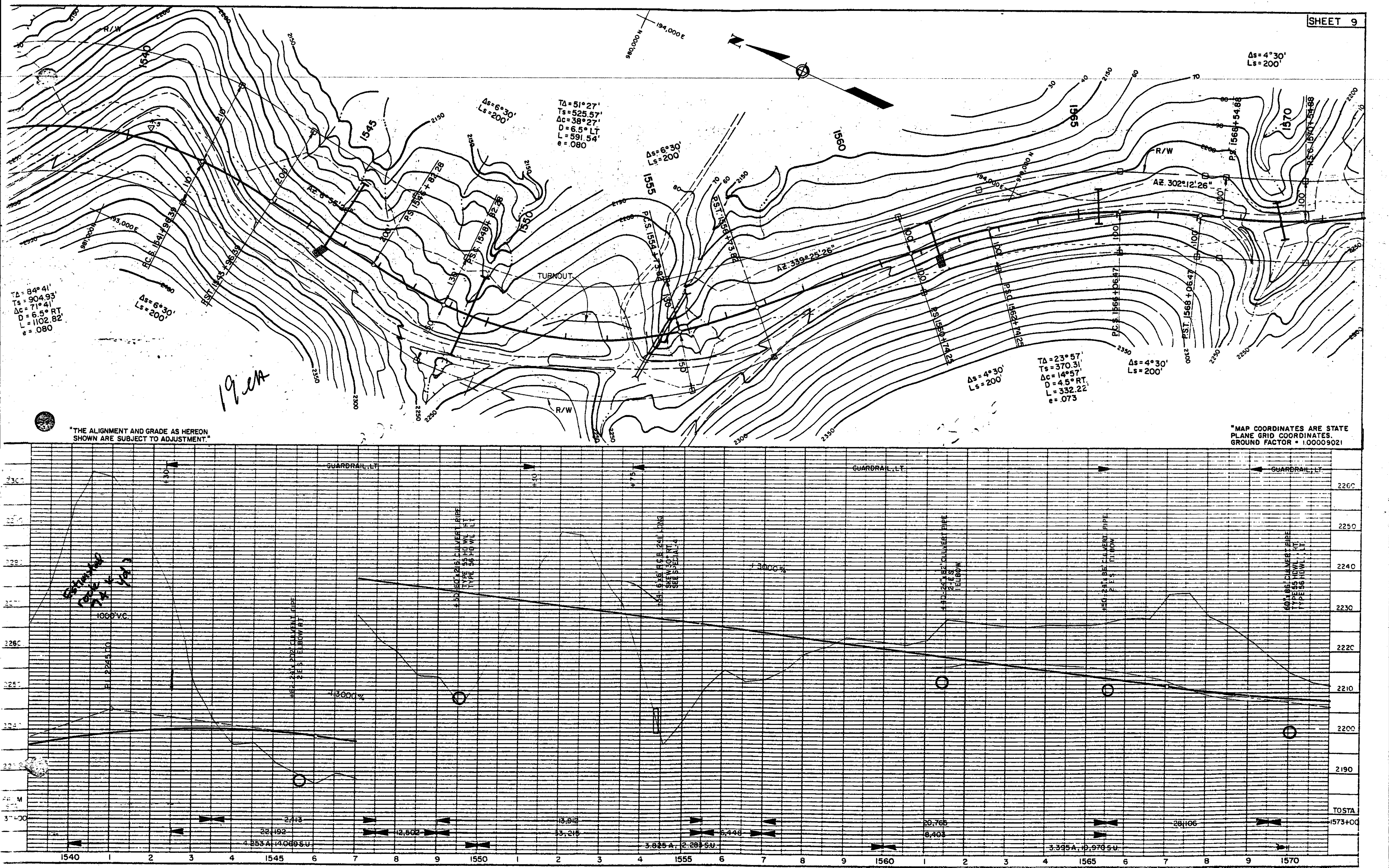
REG.	STATE	PROJECT	SHEET NO.	TOTAL SHEETS
9	AZ	F.L.H. 9-8(7) ROOSEVELT DAM	7	53

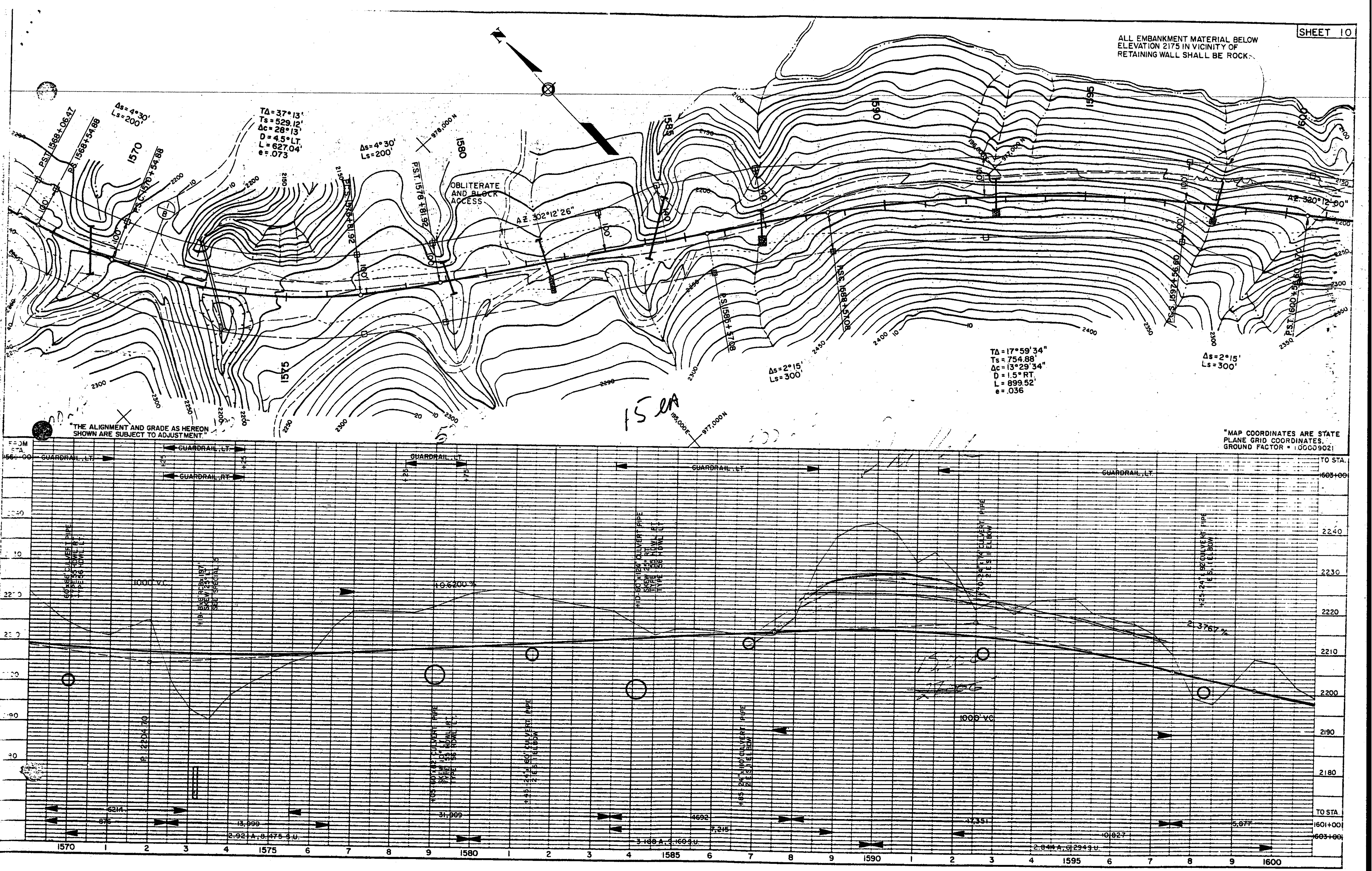
GRADING SUMMARY

STATION TO STATION	EXCAVATION PRISM	EXCAVATION TOTALS	EMBANKMENT PRISM	EMBANKMENT TOTALS	MISC. ADDED QUANTITIES: ROCK REMOVAL (EST.)	TEMPORARY CONNECTION FILL	ROADWAY OBLITER. (REMOVAL) (EST.) sec. 37	ROCK REMOVAL CLASS 5 RIPRAP
1512+00 - 1512+77	148	148	133	133				
BALANCE POINT								
1512+77 - 1513+32	57	57	10	10				
1513+32 - 1519+70	VINEYARD	CANYON	BRIDGE					
1519+70 - 1527+62	13,714	13,714	11,874	11,874				520
BALANCE POINT		(13,771)		(11,834)	Balace		Point	
1527+62 - 1534+50	13,589	13,589	26,449	26,449				
1534+50 - 1538+50	3,386	3,386	59,339	59,339				2,925
1538+50 - 1542+50	73,542	73,542	0	0	40,000 (9A A?)		42,500	
1542+50 - 1547+50	7,688	7,688	22,192	22,192	Bid = 74K cy			335
1547+50 - 1549+00	0	0	12,502	12,502				
1549+00 - 1555+50	13,912	13,912	33,215	33,215				
1555+50 - 1557+00	0	0	6,448	6,448				
1557+00 - 1565+50	20,765	20,765	8,403	8,403				
1565+50 - 1569+50	28,106	28,106	0	0				
1569+50 - 1573+00	6,214	6,214	2,493	2,493				
1573+00 - 1576+50	609	609	12,382	12,382				
1576+50 - 1583+50	31,300	31,300	0	0				
1583+50 - 1589+00	9,552	9,552	7,215	7,215				280
1589+00 - 1592+00	22,607	22,607	0	0				
1592+00 - 1603+00	40,155	40,155	10,827	10,827				585
1603+00 - 1604+88	48,573	48,573	0	0	20,000 (41.2?)			
BALANCE POINT		(319,998)		(201,465)	(60,000 Total)		(42,500) Total	(4175)
1604+88 - 1616+63	51,918	51,918	32,697	32,697	7,497 ✓	8,330		2,835
BALANCE POINT								
1616+63 - 1618+00	22,668	22,668	0	0	22,503 ✓			
TOTALS	408,355	408,355	246,046	246,046	90,000	8,330	42,500	7,480

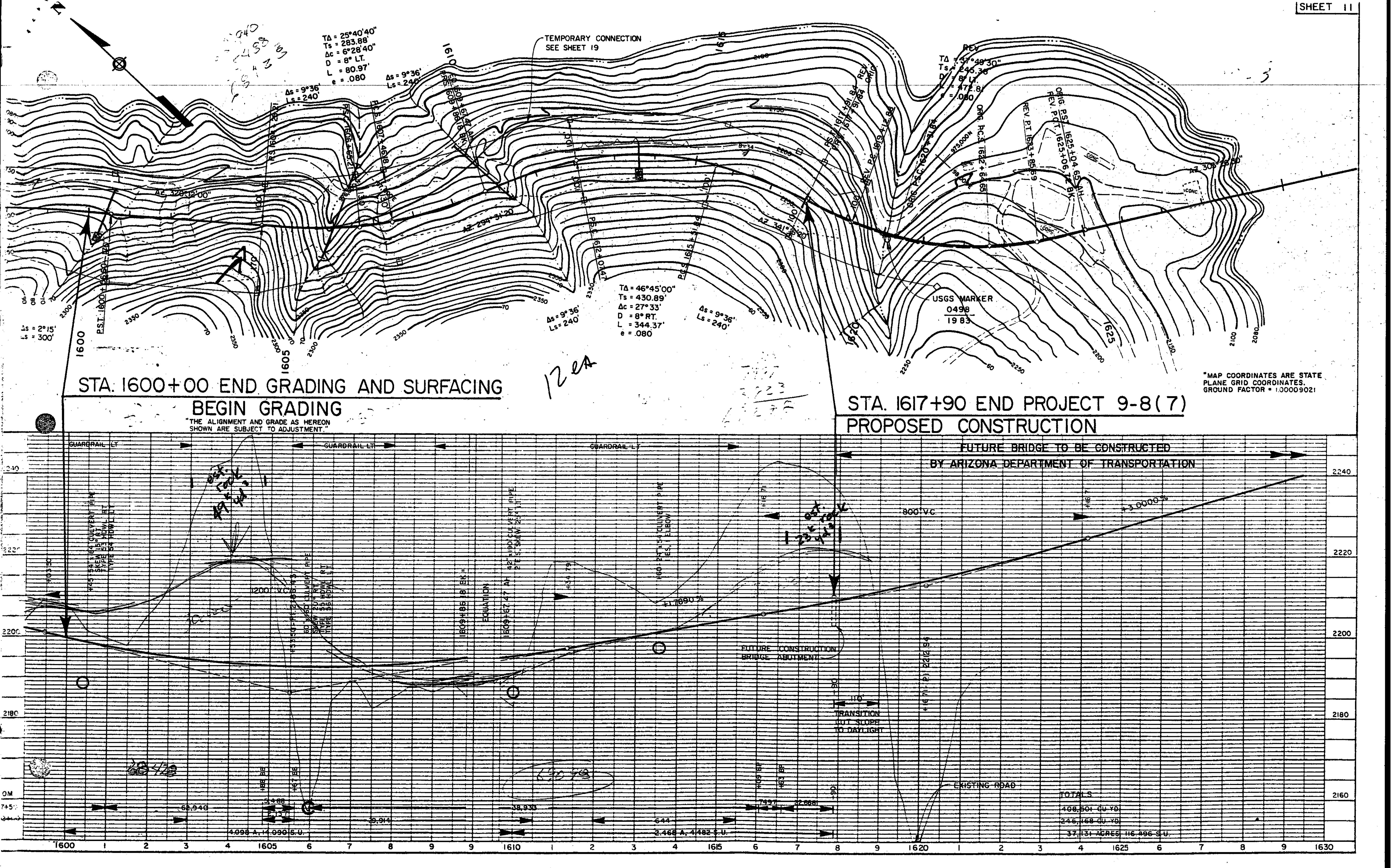


9 AZ. FLH 9-8(7) 8 53
ACCESS ROADS FOR BRIDGE CONSTRUCTION SHALL NOT BE CONSTRUCTED WITHOUT APPROVAL BY THE ENGINEER AND CONCURRENCE FROM THE US FOREST SERVICE. ACCESS ROAD LOCATION AND CONSTRUCTION SHALL BE LIMITED TO MINIMIZE DISTURBANCE TO VEGETATION ABOVE ELEV. 2136.
TΔ = 35°54'00" Ts = 460.50' Δ = 17.54' Dc = 6°00' L = 298.33 e = 0.079
TΔ = 84°41'00" Ts = 904.93' Δ = 71°41' Dc = 6°30' L = 1102.82 e = 0.080
VINEYARD C NYON
AZ. 318°08'26"
GUARDRAIL EXTENDS ALONG TURNOUT
TURNOUT
P.S.C. 1509+00.08
P.C.S. 1511+04.95
EQUA. P.S.T. 1513+04.95 BK = POT 1513+06.00 AH
P.S.T. 1519+04.69
P.S.C. 1522+84.69
P.C.S. 1525+83.02
P.S.T. 1528+83.02
P.S. 1528+93.57
P.S.C. 1530+93.57
P.C.S. 1534+96.39
P.S.T. 1543+96.39
Δs = 6°30' Ls = 200'
Δs = 9°00' Ls = 300'
"THE ALIGNMENT AND GRADES AS HEREON SHOWN ARE SUBJECT TO ADJUSTMENT."
"MAP COORDINATES ARE STATE PLANE GRID COORDINATES. GROUND FACTOR = 1.00009021"
GUARDRAIL LT.
GUARDRAIL RT.
UNDER CONSTRUCTION
STA. 1512+00 BEGIN PROJECT 9-8(7)
GRADING AND SURFACING
CONSTRUCT VINEYARD CANYON BRIDGE
SEE SHEETS 26-41
1200' V.C.
1000' V.C.
+3.4056%
+3.4068%
EQUATION P.S.T. 1513+04.95 BK = P.O.T. 1513+06.00 AH
+30 - P.I. 2174.50
+30-54" x 18' CULVERT PIPE TYPE 53 HDWL RT TYPE 54 HDWL LT
+35-35' 1 46" CULVERT PIPE 2 E.S.
+15-35' 1 18" CULVERT PIPE 2 E.S.
B.P. +70
B.P. +77
EXCAVATION
EMBANKMENT
CLEARING & SEEDING
5.779 A. 16,1420 S.U.
4.381 A. 14,250 S.U.
TO STA. 1543+50


SHEET 9
"THE ALIGNMENT AND GRADE AS HEREON SHOWN ARE SUBJECT TO ADJUSTMENT."
"MAP COORDINATES ARE STATE PLANE GRID COORDINATES. GROUND FACTOR = 1.00009021
TΔ = 84°41' Ts = 904.93' Δc = 71°41' D = 6.5° RT. L = 1102.82' e = .080
Δs = 6°30' Ls = 200'
TΔ = 51°27' Ts = 525.57' Δc = 38°27' D = 6.5° LT. L = 591.54' e = .080
TΔ = 23°57' Ts = 370.31' Δc = 14°57' D = 4.5° RT. L = 332.22' e = .073
Δs = 4°30' Ls = 200'
P.C.S. 1541+96.39
P.S.T. 1543+96.39
P.S. 1546+82.28
P.S.T. 1548+82.28
P.C.S. 1554+73.82
P.S.T. 1556+73.82
P.S. 1560+74.25
P.S.C. 1562+74.25
P.C.S. 1566+06.47
P.S.T. 1568+06.47
P.S. 1568+54.88
P.S.C. 1570+54.88
AZ. 339°25'26"
AZ. 302°12'26"
TURNOUT
R/W
194,000 E
980,000 N
GUARDRAIL, LT.
1000' V.C.
-1.3000%
TOSTA
1573+00



SHEET 10
ALL EMBANKMENT MATERIAL BELOW ELEVATION 2175 IN VICINITY OF RETAINING WALL SHALL BE ROCK.
"THE ALIGNMENT AND GRADE AS HEREON SHOWN ARE SUBJECT TO ADJUSTMENT."
"MAP COORDINATES ARE STATE PLANE GRID COORDINATES. GROUND FACTOR = 1.00009021"
P.S.T. 1568+06.47
P.S. 1568+54.88
P.S.C. 1570+54.88
Δs=4°30' Ls=200'
TΔ=37°13' Ts=529.12' Δc=28°13' D=4.5° LT. L=627.04' e=.073
Δs=4°30' Ls=200'
P.T.S. 1576+81.92
P.S.T. 1576+81.92
OBLITERATE AND BLOCK ACCESS
AZ. 302°12'26"
P.S. 1585+57.08
P.S.C. 1588+57.08
Δs=2°15' Ls=300'
TΔ=17°59'34" Ts=754.88' Δc=13°29'34" D=1.5° RT. L=899.52' e=.036
Δs=2°15' Ls=300'
P.C.S. 1597+56.60
P.S.T. 1600+56.60
AZ. 320°12'00"
978,000 N
977,000 N
195,000 E
GUARDRAIL LT.
GUARDRAIL RT.
1000' V.C.
+0.6200 %
2.3767 %
1000' V.C.
P.I. 2204.70
FROM STA. 1565+00
TO STA. 1603+00
TO STA. 1601+00
1603+00


TEMPORARY CONNECTION
SEE SHEET 19
TΔ = 25°40'40"
Ts = 283.88'
Δc = 6°28'40"
D = 8° LT.
L = 80.97'
e = .080
TΔ = 46°45'00"
Ts = 430.89'
Δc = 27°33'
D = 8° RT.
L = 344.37'
e = .080
Δs = 9°36'
Ls = 240'
Δs = 2°15'
Ls = 300'
AZ. 320°12'00"
AZ. 294°31'20"
AZ. 341°18'00"
USGS MARKER
0498
1983
"MAP COORDINATES ARE STATE
PLANE GRID COORDINATES.
GROUND FACTOR = 1.00009021
STA. 1600+00 END GRADING AND SURFACING
BEGIN GRADING
"THE ALIGNMENT AND GRADE AS HEREON
SHOWN ARE SUBJECT TO ADJUSTMENT."
STA. 1617+90 END PROJECT 9-8(7)
PROPOSED CONSTRUCTION
FUTURE BRIDGE TO BE CONSTRUCTED
BY ARIZONA DEPARTMENT OF TRANSPORTATION
GUARDRAIL LT
800' V.C.
+3.0000%
1200' V.C.
+1.7090%
EQUATION
1609+86.18 BK =
1609+67.47 AH
FUTURE CONSTRUCTION
BRIDGE ABUTMENT
TRANSITION
CUT SLOPE
TO DAYLIGHT
EXISTING ROAD
TOTALS
408,501 CU YD
246,168 CU YD
37.131 ACRES 116.496 S.U.
4.098 A. 14.090 S.U.
2.468 A. 4.482 S.U.
1600
1605
1610
1615
1620
1625
1630
2240
2220
2200
2180
2160

MEMORANDUM

TO: Wade R. Dann

FROM: David Hattery

DATE: September 26, 1988

RE: Sletten Construction, Verde Valley/Roosevelt Dam Project

ISSUE: Is Sletten Construction Company entitled to recover additional excavation costs associated with an increased quantity of rock cut under the theory of a differing site condition?

LAW: Two provisions of the contract between the Federal Highway Administration and Sletten Construction are of particular interest here. Paragraph 52.236-2 is entitled Differing Site Conditions and basically contains provisions for proper notice to the owner from the contractor. Assuming this has all been complied with in this instance, the real crux of the matter is addressed in paragraph 52.236-3:

> SITE INVESTIGATION AND CONDITIONS AFFECTING THE WORK. (April 1984).
>
> (a) The contractor acknowledges that it has taken steps reasonably necessary to ascertain the nature and location of the work, and that it has investigated and satisfied itself as to the general and local conditions which can effect the work or its cost, including but not limited to (1) conditions bearing upon transportation, disposal, handling, and

> storage of materials; . . . . (4) the confirmation conditions of the ground; and (5) the character and equipment and facilities needed preliminary to and during work performance. The contractor also acknowledges that it has satisfied itself as to the character, quality and quantity of surface and subsurface materials or obstacles to be encountered insofar as this information is reasonably ascertainable from an inspection of the site, including all exploratory work done by the government, as well as from the drawings and specifications made apart of this contract.

The purpose of the differing site conditions clause is to eliminate from the contractor's price any contingencies covering discovery of subsurface or latent physical conditions differing from those described in the contract, and unknown physical conditions of an unusual nature differing materially from those that would normally be expected at the work site. Basic to the concept of a changed condition is that the condition must be physical, it must have been unknown, or could not have been anticipated reasonably by the parties at the time they entered into the contract, Clack v. United States, 84 Ct. Cl. 40, 395 F.2d 773 (1978). Cursory research yields a number of cases where the courts have found contractors have been entitled to an equitable adjustment under the differing site conditions clause when excavations contain a great deal more rock than they had anticipated. See generally, Government Contracts, McBride &

Touhey, Section 29.70[8], see also CCH Government Contracts Reports, ¶ 10,330, (attached).

The bottom line appears to be a comparison of the conditions actually encountered with the conditions which would be reasonably anticipated after diligent review of all contract documents and specifications. Therefore, it is critical to review the information which was available to Sletten at the time of their bid and to understand what could reasonably have been inferred from this information.

Basically the presence of rock on an excavation site can be determined in three ways:

1. On-site investigation either through boring or through seismic tests;
2. Geologic analysis of surface conditions in the area; and
3. Analysis of actual excavations in the area.

On this project it appears that all three of these indicators point away from the existence of substantial quantities of rock which, in fact, where encountered on this project.

It is important to keep in mind that the project that Sletten contracted to do (Project FLH9-8(7)) was actually a continuation of another project (Project FLH9-8(6)). The soils report upon which they relied and which they were provided by the government was actually prepared primarily from the first project. For example, the report is comprised of 22 borings but only three of these borings (14%) are located on the 2.0 mile Project FLH9-8(7). Further, only 7 of the 29 samples analyzed were taken from the second part of the project (24%). Possible justification for this emphasis on the first half would be that once the first half of the project is excavated the subsurface soil conditions will be evident making detailed analysis of the second half of the project unnecessary.

The soils report also includes a summary of soils and engineering geology based on borings, engineering experience and judgment, and in light of observed site conditions in the field. This summary notes that rock is likely to be encountered in three spots on Sletten's project.

Undisputably, the best evidence that Sletten had to determine whether there was excessive rock on this site was an analysis of the excavation which was done on the first half of this project. The fact that the soils report was incomplete with respect to FLH9-8(7) shows that the Federal Highway Administration knew this as well. The facts set forth in the claim for equitable adjustment states that both Sletten and White & McNeil Excavating visited the job site and analyzed the bid results before concluding that there would not be excessive rock on this project. The supplement to the entitlement for Differing Site Conditions prepared by Dwayne Nelson contains a narrative by Steve McNeil detailing this extensive investigation. Mr. McNeil makes several statements that are very important to understanding the pre-bid phase of this project:

1. On a visit to the site, Steve talked with Bruteco, who was the contractor on the first phase of the project. They related to him that they had been able to rip all of the rock in the excavation and also relayed to him that there was a problem with the rock in that it had too much fracture to be consistently used as acceptable rip-rap. This was consistent with the soils report which indicated well fractured rock which would not have to be excavated through drilling and blasting.

2. After moving up the line to look at the location for the project to be bid, Steve noted, "It was obvious

however, there was more rock on the next two miles, then what Bruteco had to contend with."

3. Mr. McNeil then narrates some of his assumptions for the bid with respect to dirt work. Mr. McNeil assumed that the rock was well fractured. This assumption was supported by both the soils report and from his observations and conversations with Bruteco. In addition, cursory calculations based on the grating summary sheet indicated that it was designed with an overall ~~swell~~ 6% shrink factor which reflects the design assumption that any rock encountered would be, in fact, well fractured.

~~As~~ Despite this conclusion, in order to be on the safe side McNeil decided to include 35% of the quantity listed as roadway excavation as rock excavation. This 35% figure was arrived at through analysis of the mass diagram on the plan and profile sheets. Calculations assumed that areas designated in the soils reports as possibly containing rock did, in fact, contain

100% rock which would have to be excavated in more expensive manner. Sletten calculated 35% of the excavation, 144,000 cubic yards, would be rock and based their bid upon that assumption. In fact the ultimate rock excavation on this project exceeded 70% with some 270,576 cubic yards which had to be excavated by drilling and blasting. In Section 1 of their claims for equitable relief, Sletten asks for the difference between what the excavation actually cost and what would it have cost had the materially different site condition not be encountered. Here that totals $805,075.20, which is the difference between the amount of rock actually excavated and the amount of rock contemplated to be excavated in the contract times the contract unit price for excavation of rock ($6.40/c.y.).

FURTHER RESEARCH:

1. I need to do some further research into exactly what the construction conditions were on the first half of this project. As I mentioned the actual conditions encountered are undoubtedly the best indication of what the actual soil conditions are. Borings are indications of what the soil is at that particular spot on this project due to the wide spacing between the borings that were actually done coupled with the fact that not

many borings were done in the first place suggested the borings are of little value in determining whether there is rock being counted on this site. Analysis of the surface geology of the site is a better alternative. However, in this case it seems to have been misleading. If we can show that the amount of rock excavated on the first half of the site was negligible or within the limits contemplated by Sletten in their prebid phase, then our likelihood of success on this claim seems very high.

2. I would like to take a more detailed look at the mass diagram as compared with where the rock was actually encountered. I think I can get this information from what is contained in equitable claim for relief. It would be helpful to know whether all the rock was encountered in one particular stretch of the project or whether in fact it was encountered throughout the project excavation. It would seem to make our claim stronger if, in fact, the rock were encountered throughout the project site.

3. If possible, it would be helpful to analyze the unsuccessful bid on this project. If they did not contemplate a quantity of rock would seem to suggest that Sletten was, in fact, reasonable in similarly not contemplating this quantity of rock in the excavation. The equitable claim for relief states that Sletten was, in fact, low bidder for this project and gives the

name and address of the high bidder which was Givens & Reid Company of Salt Lake City, Utah. If I am not mistaken, these bids become part of the public record and could be obtained fairly easily.

DPH/mdt

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CRAIG D. MAGNUSSON

MARGARET EASTON ARMS
PHILIP G. BARDSLEY
MARK S. BEAUFAIT
CHARLES M. GREENBERG
DAVID P. HATTERY
PHILIP E. HICKEY
** SCOTT A. HOGAN

DAVID TROY LARSON
CARL L. LIVINGSTON
FRANK MICHIELS
JEFFREY G. POOLE
JOHN L. RADDER
THOMAS E. STANLEY
* ANDREW W. TORRANCE
PAUL G. WINTER
WILLIAM R. ZOBERST

*ALSO ADMITTED IN ALASKA
** ALSO ADMITTED IN OREGON

December 6, 1988

RECEIVED
DEC - 8 1988
BOX 5964
TUCSON, AZ. 85703

Terrametrics Associates
Attention: Mr. Walter E. Heinrichs, Jr.
810 West Grant Road
P.O. Box 5964
Tucson, AZ 85703-0964

Re: Sletten/Roosevelt Dam, Seismic Testing.

Dear Mr. Heinrichs:

As we discussed on the phone today, enclosed are the following items for your review:

1. A video tape of the project site filmed on October 11, 1988.

2. A set of plan/profile sheets for this project, showing the existing centerline grade, and a mass diagram takeoff.

3. A copy of the FHWA provided materials report, including a handwritten rock analysis not provided the contractor.

4. A memorandum dated September 26, 1988 addressing Sletten's perspective recovery under a differing site condition theory. This memo begins with a very short explanation of our legal theory, which is followed by a brief factual description.

I have made arrangements to meet with you in Tucson on Tuesday afternoon. I plan to arrive in Tucson mid-afternoon and will be in contact with you regarding our meeting agenda. I enjoyed talking with you on the phone today and look forward to working with you on this project.

Very truly yours,

David P. Hattery

DPH:mdt
Enclosures

MEMORANDUM

TO: Sletten/Roosevelt Dam File (1533-008)

FROM: David P. Hattery

DATE: December 16, 1988

RE: Walter Heinrichs' Site Visit

On Tuesday, December 13, 1988, I met with Walter Heinrichs, Jr. of Terrametrics Associates in Tucson, Arizona. On Tuesday afternoon in his office, we discussed at length the project plans and specifications, the scope of work anticipated, and the actual excavation work performed. We were aided in this discussion by plans and specifications, the FHWA Materials Report, the videotape of the project site, and several factual memos from the file. We also discussed geophysical site investigation techniques available and their relative feasibility for a project of this type.

I told Mr. Heinrichs that we were interested in his opinion as to three aspects of this project.

1. The reasonableness of the site investigation work performed by Sletten and McNeil, and the reasonableness of the conclusions reached as to the type of rock likely to be encountered on this project.

2. An analysis of the geophysical features encountered on this site, and an opinion as to whether these features were unusual and unanticipated based on a reasonable survey of the surface geology.

3. An opinion as to the coverage and content of the FHWA provided materials report, including an opinion as to the information contained on a handwritten sheet discovered in the job files in Denver listing the type of rock along the project. This latter item was not provided to the contractor in the pre-bid phase, thus I asked Mr. Heinrichs as to his opinion of what the content of this withheld memo reveals.

On Wednesday, December 14, 1988, Walter Heinrichs and I drove from Tucson to the job site and spent the entire day investigating the geological characteristics of the area. We looked at Bruteco's section of the project, the old road, the haul road, the rock on the ground in the area of Sletten's project, the rock in the exposed cuts in the area of Sletten's project, and the rock exposed in the area of the dam site and adjacent hillside. Following this investigation, we looked at each cut performed by Sletten and McNeil in detail. Mr. Heinrichs possesses a staggering amount of knowledge of geology and geophysical formations, and an impressive ability to translate that knowledge into layman's terms.

In a nutshell, Mr. Heinrichs' preliminary conclusions based on the above investigation are as follows:

1. **Comparisons between Bruteco and Sletten Projects.**

Mr. Heinrichs is of the opinion that the geological formations encountered on Sletten's project are dramatically more complex than that encountered by Bruteco. Further, in his opinion these dramatic differences are not readily apparent from a cursory examination of the rocks visible on the surface and in the exposed cuts.

By complex structure, Mr. Heinrichs means that the rock has a high degree of faulting, layering of materials in nonconformable sequence, and an interspersing of unexpected types of material within the formation. Mr. Heinrichs found that the individual cuts were highly variable from one cut to another, and that the type of rock encountered within a cut was sometimes highly variable. In his opinion, this complexity was not revealed through a cursory examination of the rocks on the ground, without a detailed attempt at geological mapping made by an experienced geologist.

2. Effect of Complexity on Rippability.

As a geological expert, Mr. Heinrichs has expert opinions as to the forces required to break up certain types of rock formations. He has stated that rippability is certainly adversely effected by highly variable formations such as those on this project. The reason for this when the rock layers are not aligned, and consist of variable rock hardness layers, a ripper operator is frustrated in his attempts to achieve any sort of productivity. There may be layers in such a formation which appears easily rippable but a ripper operator can't get to them because they are overlain or underlayed by hard unrippable rock. As a result, the entire formation must be excavated by drilling and blasting.

3. **Reasonable Site Investigation.**

As stated above, Mr. Heinrichs is of the opinion that the high degree of faulting and material variability encountered on the Sletten project is not readily ascertainable from an examination of the surface geology in the immediate area. However, because of his wealth of experience with geology of the Southwest and of this area in particular, he was not entirely surprised at this degree of faulting and variety of rock types was encountered in this area. He stated that if one were to investigate thoroughly the road cuts in an area between Globe, Mesa and Punkin Center, one could find several areas with similarly complex geology.

Mr. Heinrichs is presently preparing a report summarizing his conclusions based on our job site investigation. In addition, he is putting together a cost estimate for seismic testing which will buttress and verify his above tentative conclusions.

ACTION STEPS

1. I am preparing a memo summarizing the information we have concerning each individual cut on this project. Included will be materials report description, plan excavation quantities, description of actual work performed (rippability/blasting). From this memo we can focus our attention on the specific problem areas of the project.

2. Once we receive Mr. Heinrichs' cost estimate and conclusions regarding seismic testing, we need to reanalyze our cost benefit analysis and strategy for use of this scientific data. Mr. Heinrichs is preparing his estimate with a breakdown of the cost associated with testing for each particular cut, therefore, it would be possible to analyze and direct him to perform limited testing.

3. We need to take a hard look at the strategic use of seismic test results. If the tests show rippability or are inconclusive, they support our reasonable site investigation. Alternatively, if the tests show high transmissibility, therefore indicate nonrippability, they support the reasonableness of our required drilling and blasting operations. Of course, the Federal Government may have some problems with this win/win scenario.

DPH:mdt
cc: Mr. Wade R. Dann
Mr. Walter Heinrichs, Jr.
Mr. Martin Becker

SLETTEN/McNEIL - ROOSEVELT DAM

REQUEST FOR EQUITABLE ADJUSTMENT

IV. ISSUE, REVIEW AND ANALYSIS

1. SITE AVAILABILITY

The fact that Sletten suffered disruption of its as-bid method and manner of performing excavation work due to late completion of the prior FHWA supervised project raises the issue of the FHWA's duty to provide site access as represented in the contract.

Contract Section 105.05 represented Brutoco's project and completion date as follows:

> 105.05(b) Other Contracts. Add the following:
>
> A contract for construction of 1.77 miles of State Route 188 ending near the northwest abutment of the proposed vineyard canyon bridge (Station 1513+50) is currently in progress. Brutoco Engineering & Construction, Inc., P.O. Box 429, Fontana, California 92335 is the contractor. The work is scheduled to be completed in mid-November 1986. The stockpile, staging and landing areas listed in the contract may also be jointly used by this contractor until the work is completed. Traffic control devices and roadway finishing operations may overlap this contract in the vicinity of Station 1512 to 1513+50.

Sletten and McNeil reasonably relied upon this contract assertion that the Brutoco project would be finished in mid-November. Specifically, Sletten and McNeil bid this project assuming that there would be no interference with the travelling public along the designated haul road for obliteration and riprap material. They reasonably assumed, based on the above contract provision, that traffic would be running on the new road allowing Sletten/McNeil exclusive use of the haul road.

However, Brutoco did not finish the project until late April 1987. As a direct result, Sletten/McNeil were forced to incur increased costs due to unanticipated interference between its hauling equipment and the travelling public. First, pursuant to direction from FHWA project engineer Robert Sowder, Sletten/McNeil was forced to use smaller rock trucks than planned in order to limit damage to the roadway. Second, Sletten/McNeil were prevented from performing contract road obliteration work because the road to be obliterated was still in use. As a result, instead of being able to utilize the material closest to obliteration site as planned, Sletten/McNeil were forced into greatly increased haul distances.

This failure to provide access as promised in the contract constituted a change in Sletten/McNeil's method and manner of performance authenticating it to an equitable adjustment under the changes clause of the contract. The changes clause reads as follows:

52.243-4

CHANGES. (APRIL 1984)

(a) The Contracting Officer may, at any time, without otice to the sureties, if any, by written order designated or indicated to be a change order, make changes in the work within the general scope of the contract, including changes--

(1) In the specification (including drawings and designs);

(2) In the method or manner of performance of the work;

(3) In the Government-furnished facilities, euipment, materials, services, or site; or

(4) Directing acceleation in the performance of the work.

(b) Any other written or oral order (which, as used in this paragraph (b), includes direction, instruction, interpretation, or determination) from the Contracting Officer that causes a change shall be treated as a change order under this clause; <u>provided</u>, that the Contractor gives the Contracting Officer written notice stating (1) the date, circumstances, and source of the order and (2) that the Contractor regards the order as a change order.

(c) Except as provided in this clause, no order statement, or conduct of the Contracting Officer shall be treated as a change under this clause or entitle the Contractor to an equitable adjustment.

(d) If any change under this clause causes an increase or decrease in the Contractor's cost of, or the time required for, the performance of any part of the work under this contract, whether or not changed by any such order, the Contracting Officer shall make an equitable adjustment and modify the contract in writing. However, except for a "proposal for adjustment" (hereinafter referred to as proposal) based on defective specifications, no proposal for any change under paragraph (b) above shall be allowed for any costs incurred more than 20 days before the Contractor gives written notice as required. Int he case of defective specifications for which the Government is responsible, the equitable adjustment shall include any increased cost reasonably incurred by the Contractor in attempting to comply with the defective specifications.

(e) The Contractor must submit any proposal under this clause within 30 days after (1) receipt of a written change order under paragraph (a) above or (2) the furnishing of a written notice under paragraph (b) above, by submitting to the Contracting Officer a written statement describing the general nature and amount of the proposal, unless this period is extended by the Government. The statement of proposal for adjustment may be included in the notice under paragraph (b) above.

(f) No proposal by the Contractor for an equitable adjustment shall be allowed if asserted after final payment under this contract.

Courts and Boards have often stated that the strict notice requirements under the Changes Clause are to be liberally interpreted. As in this case, despite no immediate written notice of the changed condition, a contractor's claim is entitled to consideration on its merits where the government had actual notice, or where the government can not show its interests were prejudiced by lack of timely notice. Eggers/Higgins v. U.S., 403 F2d 225 (Ct.Cl. 1968); C.H. Leavell & Co., ASBCA No. 16099, 72-2 BCA Para. 694 (1972); R. R. Taylor, ASBCA No. 381, 77-1 BCA Para 12,227. Therefore, because in this case Sletten/McNeil gave the FAWA oral notice of the problems caused by Brutoco's late completion, and because the FAWA knew of these problems and were working to alleviate them, Sletten/McNeil's request for equitable adjustment does not fail for lack of notice.

It is well settled law the contractor may recover where there is a delay in completion by a prior contractor when the owner has given an express warranty of availability at a certain time. For example, in Fruehauf Corp. v. United States, 218 Ct.Cl. 456, 587 F.2d 486 (1978), a contractor was delayed due to the actions of a prior contractor. As with this contract, an overly optimistic completion date for the prior contractor was included in contract and relied upon by the contractor. That despite neither the government nor the contractor being at fault, the only way to properly allocate the unforseen costs of delay is by way of an equitable adjustment. Fruehauf Corp. v. United States, 218 Ct.Cl. 456, 587 F.2d 486 (1978).

Boiled down to its essence, the issue here is risk allocation. Courts and boards have repeatedly held that where the contract represents completion dates for prior dependent contracts, the owner assumes the risk of late completion of those contracts. Merritt-Chapman & Scott Corp. v. United States, 194 Ct.Cl. 461, 439 F.2d 185 (1971), see also, Day & Zimmerman-Madway, ASBCA 13367, 71-1 BCA Para. 8622 (1970). Therefore, because its contract contains an express representation of Brutoco's completion date, Brutoco's failure to achieve this represented completion date entitles Sletten/McNeil to an equitable adjustment upward in the contract price to compensate for increased costs due to delay and disruption of its construction effort.

2. DIFFERING SITE CONDITION

The contract between Sletten/McNeil and the Federal Highway Administration contains a differing site condition clause. On its face, this clause promises an equitable adjustment when physical conditions are encountered which are materially different than those either represented in the plans or from those ordinarily expected. On the Roosevelt Lake road project, Sletten/McNeil encountered rock conditions which differed materially from both those represented in the plans, and those ordinarily expected to be encountered in the area.

The text of differing site condition clause is as follows:

52.236-2
DIFFERING SITE CONDITIONS. (APRIL 1984)

> (a) The contractor shall promptly, and before the conditions are disturbed, give a written notice to the contracting officer of (1) subsurface or latent physical conditions at the site which differ materially from those indicated in this contract, or (2) unknown physical conditions at the site,of an unusual nature which differ materially from those ordinarily encountered and generally recognized as inhering and work of the character provided for the contract.
>
> (b) The contracting officer shall investigate the site conditions promptly after giving the notice. If the conditions do materially so differ and cause an increase or decrease in the contractor's cost of, or the time required for, performing any part of the work under this contract, whether or not changed as a result of the conditions, an equitable adjustment shall be made under this clause and the contract modified in writing accordingly.

(c) No request by the contractor for an equitable adjustment to the contract under this clause shall be allowed, unless the contractor has given the written notice required; provided, that the time prescribed in (a) above for giving written notice may be extended by the contracting officer.

(d) No request by the contractor for an equitable adjustment to the contractor for differing site conditions shall be allowed if made after final payment under this contract.

Courts and Boards have recognized two categories of differing site conditions; "type one", where conditions encountered are materially different than those indicated in the plans, and "type two", where the plans are silent but conditions are encountered which differ from those ordinarily expected.

Central to an understanding of the difering site conditions clause is a firm grasp on its underlying purpose. One court has stated the policy supporting the differing site conditions clause as follows:

> The starting point of the policy expressed in the changed conditions clause is the great risk, for bidders on construction projects, of adverse subsurface conditions: "no one can ever know with certainty what will be found during subsurface operations." Kaiser Industries Corp. v. United States, 169 Ct.Cl. 310, 332, 340 F.2d 322, 329 (1965). Whenever dependable information on the subsurface is unavailable, bidders will make their own borings or, more likely, include in their bids a contingency element to cover the risk. Either alternative inflates the cost to the government. The government therefore often makes such borings and provides them for the use of bidders, as part of a contract containing the standard changed conditions clause.

> Bidders are thereby given information on which they may rely in making their bids, and are at the same time promised an equitable adjustment under the changed conditions clause, if subsurface conditions turn out to be materially different than those indicated in the logs. The two elements work together; the presence of the changed conditions clause works to reassure bidders that they may confidently rely on the logs and need not include a contingency element in their bids. Reliance is affirmatively desired by the government, for if bidders feel they cannot rely they will revert to the practice of increasing their bids.
>
> The purpose of the changed conditions clause is thus to take the sum of the gamble on subsurface conditions out of bidding. Bidders need not weight the cost and ease of making their own borings against the risk of encountering an adverse subsurface, and they need not consider how large a contingency should be added to the bid to cover the risk. It will have no windfalls and no disasters. The government benefits from more accurate bidding, without inflation for risks which may not eventuate. It pays for difficult subsurface work only when it is encountered and was not included in the logs.
>
> All this is long-standing, deliberately adopted procurement policy, expressed in the standard mandatory changed conditions clause and forced by the courts and the administrative authorities on many occasions.

Foster Constr. C.A. and Williams Bros. Co. v. United States, 193 Ct.Cl. 587, 435 F.2d 873 (1970).

Thus the stated policy of the Federal Government is to assume the risk of differing site conditions in return for eliminating costly contingency amounts from contractor proposals for construction.

A clear reading of the differing site conditions clause presents two threshold questions. ~~which must be answered before we can consider the merits of a differing site condition claim.~~ First, did the contractor promptly give notice? Secondly, does the contractor have a right to rely on subsurface indications in the plans and specifications despite general exculpatory language in the contract?

a. **Notice.**

The purpose of the notice requirement in the differing site conditions clause is to allow the government an opportunity to investigate and to exercise some control over the amount of cost and effort expended in resolving the problem. Charles T. Parker Constr. Co., DCAB PR-41, 61-1 BCA Para. 4780 (1965). Notice need not follow any specific format but must merely show the existence of the condition. T&B Builders, Inc., ENGBCA 3664, 77-2 BCA Para. 12,663 (1977), J.J. Welcome Constr. Co., ASBCA 19653, 75-1 BCA Para. 10,997 (1974).

Thus, where the contractor has given oral notice or where the government has received actual notice of the conditions encountered, because the government's interest has not been prejudiced, Courts and Boards have waived the requirement that the notice be in writing. S. Kane & Sons, Inc., VACAB 1254, 78-1 BCA Para. 13,100 (1978), Sheperd v. United States, 125 Ct.Cl. 724, 113 F. Supp. 648 (1953).

In this case, a lack of written notice immediately upon discovery of the materially different physical properties of the roadway excavation, is not fatal because the government had both actual and oral notice of the conditions encountered.

Upon discovery, the manifest aspect of the differing site condition encountered was that the rock was unrippable. Unmistakably, project engineer Robert Sowder had actual knowledge of this fact due to his presence on the job site and his attendant duties to supervise the construction. In addition, Steve McNeil reports discussing the unexpected excavation problems with Mr. Sowder on several occasions.

Further, the government was not prejudiced by the lack of immediate written notice. FHWA documentation of this project, although incomplete due to the apparent unavailability of Robert Sowder's daily diary, clearly shows that the FHWA was involved in investigating and controlling the cost and method of the excavation work.

Therefore, because the FHWA had both oral and actual knowledge of the differing site condition, and were not prejudiced by the lack of immediate written notice, Sletten/McNeil's claim is not barred due to the lack of immediate written notice.

b. Exculpatory Contract Language.

Sletten/McNeil's request for equitable adjustment based on a differing site condition hinges upon a right to rely upon indications in the plans and specifications regarding the type of material to be excavated. However, the contract contains the following provision:

52.236-3
SITE INVESTIGATION AND CONDITIONS AFFECTING THE WORK (APRIL 1984)

> . . . .
>
> (b) The government assumes no responsibility for any conclusions or interpretations made by the contractor based upon the information made available by the government. Nor does the government assume responsibility for any understanding arranged or representation made concerning conditions which can affect the work by any of its officers or agents before the execution of this contract, unless that understanding or representation is expressly stated in the contract.

When faced with this question, courts and boards have consistently held that broad exculpatory language such as this does not excuse the government from liability for differing site conditions.

One court has stated the proposition as follows:

> Plaintiff had a right to rely on the government specifications and drawings and the government is bound by any assertions made therein notwithstanding the fact that it was stated that the data would be for information only. Moreover, this court has repeatedly held that the specifications cannot alter the effect of the specific language of the changed conditions section of the contract. <u>See</u> <u>Vade P. Loftis v. United States</u>, 110 Ct.Cl. 551; <u>Peter Kiewit Sons' Co. v. United States</u>, 109 Ct.Cl. 517; <u>Walsh Bros. v. United States</u>, 107 Ct.Cl. 627;

> Gustav Hirsch v. United States, 94 Ct.Cl. 602.

Fehlhaber Corp. v. United States, 138 Ct.Cl. 571, 151 F. Supp. 817 (1957).

Therefore, the broad, exculpatory language in the contract between Sletten/McNeil and the Federal Highway Administration does not excuse the Federal Highway Administration from liability for differing site conditions.

With the threshold issues of notice and right to rely on the contract indications aside, Sletten/McNeil's claim for equitable adjustment based on differing site condition rests on its merits.

c. Type One Differing Site Condition.

In a recent case, the United States Claims Court set forth the requirements for type one differing site conditions as follows:

> (a) Whether the conditions encountered by plaintiff differed materially from those indicated in the contract documents,
>
> (b) Could the changed condition have been reasonably anticipated from the site examination and review of the contract documents, and
>
> (c) Did plaintiff, in fact, rely on its interpretation of the contract documents.

Baltimore Contractors, Inc. v. United States, 12 Cl.Ct. 328, 34 CCF 75267 (1987). Each of these factors will be addressed in turn.

A. <u>Material Difference in the Conditions Actually Encountered</u>.

In this case, contract indications all point toward a preponderance of ripable, fractured rock within the roadway prism to be excavated. Indications of the predominantly ripable nature of the excavation are found in two areas of the plans and specifications; in the materials report, and on the grading summary sheet. These indications are readily apparent to a reasonably prudent contractor experienced in earth work construction.

1. **Materials Report**

Two aspects of the materials report in particular indicate ripable rock on this project. First, the soils survey section describes all the rock to be encountered on this job as "moderate to well fractured", and recommends a swell factor for this rock in the range of 5-10%, further indicating the well-fractured nature of the material. **[insert expert description of rock with only 5-10% swell.]**

Second, the fact that the materials report encompasses the entire 3.9 miles of new alignment along Roosevelt Lake indicates a perceived similarity in the materials being encountered along the entire project area. Further, other than the soils summary, which indicates moderate to well-fractured rock, the materials report indicates that the materials to be encountered along

Sletten's portion of the job will be similar to that encountered by Brutoco on the previous section of this project.

2. Grading Summary Sheet - Design Shrink Factor

Sheet No. 7 of the design drawings is a summary in tabular form of the grading work to be performed on this project. One of the most important variables to an earth work contractor is the shrink or swell characteristics of the material to be excavated. Because the grading summary sheet exposes the engineering design assumptions concerning shrink and swell of the excavation, a prudent earth work contractor studies the grading summary sheet in great detail. Such study and calculations performed on the grading summary sheet in this case show that between balance points at stations 1527 + 62 and 1604 + 88, the FHWA anticipated an overall **6% shrink factor** from excavation to embankment.

To one experienced in earth work, a 6% shrink factor indicates that a great deal of material to be excavated consists of soil or extremely well-fractured rock. **[insert discussion of swell/shrink for various materials?]**

Therefore, based on a careful review of the contract documents, Sletten and McNeil reasonably anticipated that a preponderance of the material to be excavated would consist of either soil or highly fractured rock. The materials report furnished by the FHWA described the material as at worst "moderate to well fractured rock" and tacitly compared the project to one in which no unripable material was encountered.

Further, a study of the grading summary sheet indicated that the FHWA design engineer assumed an overall 6% shrink factor which points away from the possibility of encountering hard rock.

B. Conditions Actually Encountered.

In fact, Sletten and McNeil encountered a great deal of hard rock on this project which could not be excavated by ripping. Contrary to materials report conclusions, the rock encountered on this project is in fact only slightly fractured with depth and contains a high degree of material variability, faulting, folding, and geological complexity which combine to make excavation by ripping a virtual impossibility.

Contrary to the implications in the materials report, the rock on this project stands in stark contrast to the material encountered on the Brutoco section of roadway. While Brutoco encountered highly consistent material consisting of no unripable rock, Sletten encountered highly inconsistent formations of rock which could not be ripped by any available equipment.

Contrary to the assertions of the materials report, the swell factor of the rock encountered far exceeded the 5-10% swell indicated. In fact, a preliminary overall swell factor calculation shows that the actual swell factor encountered of all the material on this project exceeds 18%. [Insert discussion of swell factor dolomite limestone]

Contrary to the design assertions contained in the grading summary sheet, the material excavated certainly did not show 6% shrink factor from excavation to embankment. In fact, as above, preliminary calculations indicate an overall swell factor of 18%.

From the above it is clear that Sletten and McNeil encountered conditions which differed materially from those indicated in the contract documents. Specifically, the contract documents indicated that the excavation material would be at worst moderately to well-fractured rock in places, and that the overall excavation would show a 6% shrink factor. In fact, the material excavated exhibits a swell factor in excess of 18% and included a great deal of rock with little fracture contained in unexpected formations precluding excavation by ripping.

B. Anticipation of Unrippable Rock.

Under the contract, Sletten/McNeil had the duty to investigate the site prior to bidding. Contract clause 52.236-3 reads in part as follows:

> . . . The Contractor also acknowledges that it has satisfied itself as to the character, quality, and quantity of surface and subsurface materials or obstacles to be encountered insofar as this information is reasonably ascertainable from an inspection of the site, including all exploratory work done by the Government, as well as from the drawings and specificationsmade a part of this contract.

In interpreting the site investigtion requirement within the context of a differing site condition situation, Courts have carefully limited its scope:

> Faithful execution of the policy requires that the promise in the changed conditions clause not be frustrated by an expansive concept of the duty of bidders to investigate the site. That duty, if not carefully limited. could force bidders to rely on their own investigations, lessen their reliance on logs in the contract and reintroduce the practice sought to be eradicated - the computation of bids on the basis of the bidders' own investigations, with contingency elements often substituting for investigation.
>
> * * *
>
> The contractor is unable to rely on contract indications of the subsurface only where relatively simple inquiries might have revealed contrary conditions.

Foster Constr. C.A. and Williams Bros. Co. v. United States, 193 Ct.Cl. 587, 435 F.2d 873 (1970).

Therefore, in this case Sletten/McNiel is entitled to rely upon the above contract indications of predominantly rippable rock unless "relatively simple" site investigation inquiries might have revealed contrary conditions.

On September 8, 9 and 10, 1986, Sletten/NcNeil conducted their pre-bid site investigation. In a sworn affidavit, Steve McNeil describes the investigation results as follows:

> "From this initial visit it appeared that the material to be excavated was a well fractured lime stone deposit overlaid in some areas sith a clay silt, sand, and gravel mixture. In some areas there appeared to be some sedimentation but in general most of the material appeared to be workable.
>
> Although I felt we could rip most of the rock, I decided to put a "safety" factor in the job just in case there were some areas which had to be blasted. To do that, I used the quantity that the FHWA had for excavation at the areas designated for rock removal at stations 1540 + 00 and 1604 + 00. This is approximately 144,000 cy for about a 35% rock job."

Steve McNeil personally walked the site, aided by slope stakes in the ground, a materials report, and a set of plans.

Nothing in his site investigation led Steve McNeil to disbelieve the assertions of the plans and soils report.

> "I reviewed the soils report there and it seemed consistent with what I had seen on the job as far as the shrink, swell and well-fracture rock was concerned."

Sletten/NcNeil did not perform its own borings of the project site. Nor did they hire a geologist or other geotechnical expert to assist them. However, Courts and Boards have consistenly held that a contractor is not required to undertake such elaborate measures. As the Court of Claims stated recently,

> "Although bidders in the present case were instructed to make their own interpretations of the sub-service conditions, '[a} bidder does not have the obligation to make a scientifically educated and skeptical analysis of the contract, and is entitled to rely on the contract indications if he has made a reasonable site investigation.'"

<u>Higgins</u>, AGBCA NO. 76-128, 79-2 PCA Para 14, 050 at 69, 264 (1979), as quoted in <u>Baltimore Contractors</u>, 12 Ct. Cl. 328 (1987). Therefore, Sletten/McNeil's site investigation was reasomable in content and scope thereby discharging its contractual duty. Further, Sletten/McNeil could not have reasonably anticipated from its site investigation review of the contract documents that a materially differing site condition existed on the Roosevelt Dam road project.

<u>C. Sletten/McNeil Reliance On Contract Interpretations</u>

Sletten/McNeil clearly relied on the contract indications suggesting that excavation work for the project could be done with ripping equipment. As Steve McNeil relates in his affidavit set forth above, he felt that ripping equipment would be adequate. Despite this belief, McNeil prudently included the cost of drilling and blasting 35% of the excavation in his bid. Sletten in turn relied on this interpretation of the plans and specifications regarding rock in its bid submitted to the Federal Highway Administration.

Therefore, Sletten/McNeil is entitled to an equitable adjustment upward in the contract price as compensation for increased performance costs due to a type one differing site condition. The contract documents indicate rippable well-fractured rock. Sletten/McNeil encountered unrippable slightly fracture geologically complex rock formations which defied excavation with ripping equipment. Sletten/McNeil could not have reasonably anticipated the true nature of the rock formation based upon their site examination and review of the contract documents. Lastly, Sletten/McNeil relied upon the indicated character of the rock in pricing its proposal to the Federal Highway Administration.

Having satisfied all of the requirements of the differing site condition section of its contract, Sletten/McNeil hereby requests a equitable adjustment upward in the contract price in order to compensate it for the increased costs of construction due to encountering rock which could not be excavated in the method and manner reasonably anticipated.

c. Type II Differing Site Conditions

Alternatively, the problem Sletten/McNeil encountered on the Roosevelt Lake Road project can be characterized as a Type II differing site condition. Courts have described the difference between Type I and Type II differing site conditions as follows:

> "In the case of a "category one" changed condition, the government has, with relative precision, represented the subsurface or latent physical conditions to be encountered, and if it turns out that they have been materially misrepresented, a claim has been established. Under "category two", in contrast, the government has elected not to presurvey and represent the subsurface condition with the result that a claimant must demonstrate that he has encountered something materially different from the "known" and the "usual"."

<u>Charles T. Parker Construction Co. v. United States</u>, 193, Ct. Cl. 320, 333-34, 433 F.2d 771 (1970).

Essentially, a Type II differing site condition exists where a contractor is faced with unknown, unusual physical conditions which are materially different from those ordinarily expected. In this case, Sletten/McNeil encountered unexpected rock conditions ~~formations~~ which are unusual ~~in the area~~ and differ materially from those ordinarily encountered and generally recognized as inhering of the work character provided for in the contract.

As with type one, the first step of analyzing a type two differing site condition is to establish a baseline set of conditions reasonably expected to be encountered. In order to establish entitlement to an equitible adjustment, a contractor must show that the conditions encountered could not reasonably be anticipated from a study of the contract documents, a site investigation, or knowledge of ordinary, usual conditions in a particular geographic area.

As above, the contract documents and a reasonable site investigation both indicated predominately rippable fractured rock. In fact, weathered fractured rock is not at all unusual or unexpected in the Roosevelt Lake area. Sletten and McNeil knew of this fact and were not at all suprised to find that the materials report and the plans described the rock as moderately to well fractured.

In the course of their investigation, Sletten/McNeil contacted representatives from Brutoco Engineering, inquiring as to the quality of rock in the area. Sletten/McNeil learned that Brutoco encountered no unrippable rock, and in fact, encountered difficulties because the rock was too fractured.

Accordingly, Sletten/McNeil were as suprised as the FHWA when the true nature of the rock in this area became evident. Although the rock appears rippable at the surface, its actual fracture is disjointed by unexpected folding and faulting, frustrating attempts to excavate by ripping. Because the true character of the fracture was unknown, not reasonably anticipated, and differs materially from that ordinarily found in the type of work, Sletten/McNeil is entitled to an equitible adjustment under type two of the differing site condition clause.

3. **FHWA CHANGES IN SLETTEN/McNEIL'S METHOD OR MANNER OF PERFORMANCE**.

Under the contract, the Contractor is entitled to an equitable adjustment when the government directs changes in the contractor's method or manner of performance of the work. The Changes Clause in this contract reads as follows:

52.243-4

CHANGES. (APRIL 1984)

(a) The Contracting Officer may, at any time, without otice to the sureties, if any, by written order designated or indicated to be a change order, make changes in the work within the general scope of the contract, including changes--

(1) In the specification (including drawings and designs);

(2) In the method or manner of performance of the work;

(3) In the Government-furnished facilities, euipment, materials, services, or site; or

(4) Directing acceleation in the performance of the work.

(b) Any other written or oral order (which, as used in this paragraph (b), includes direction, instruction, interpretation, or determination) from the Contracting Officer that causes a change shall be treated as a change order under this clause; <u>provided</u>, that the Contractor gives the Contracting Officer written notice stating (1) the date, circumstances, and source of the order and (2) that the Contractor regards the order as a change order.

(c) Except as provided in this clause, no order statement, or conduct of the Contracting Officer shall be treated as a change under this clause or entitle the Contractor to an equitable adjustment.

(d) If any change under this clause causes an increase or decrease in the Contractor's cost of, or the time required for, the performance of any part of the work under this contract, whether or not changed by any such order, the Contracting Officer shall make an equitable adjustment and modify the contract in writing. However, except for a "proposal for adjustment" (hereinafter referred to as proposal) based on defective specifications, no proposal for any change under paragraph (b) above shall be allowed for any costs incurred more than 20 days before the Contractor gives written notice as required. Int he case of defective specifications for which the Government is responsible, the equitable adjustment shall include any increased cost reasonably incurred by the Contractor in attempting to comply with the defective specifications.

(e) The Contractor must submit any proposal under this clause within 30 days after (1) receipt of a written change order under paragraph (a) above or (2) the furnishing of a written notice under paragraph (b) above, by submitting to the Contracting Officer a written statement describing the general nature and amount of the proposal, unless this period is extended by the Government. The statement of proposal for adjustment may be included in the notice under paragraph (b) above.

(f) No proposal by the Contractor for an equitable adjustment shall be allowed if asserted after final payment under this contract.

Sletten/McNeil experienced delays and increased costs of performance of the contract work due to FHWA disruptions in its intended method or manner of performance in three areas. First, the traffic plan directed by FHWA's project engineer, Robert Sowder, was a great deal more disruptive than that contemplated in the plans and specifications of the contract. Second, Sletten/McNeil was directed to perform riprap sorting operations throughout the project, instead of only in three areas of the project, as shown in the contract documents. Third, Sletten/McNeil was forced to incur additional costs and delay due to being forced to stockpile riprap in an area too small to accommodate stacked in the manner reasonably contemplated.

a. Traffic Plan.

The contract specifications regarding maintenance for traffic reads in the pertinent parts as follows:

> "Unless otherwise provided, the existing road while undergoing improvements shall be kept open to all traffic by the Contractor.
>
> The Contractor may bypass traffic over approved detour routs or by approved part width construction as shown in the contract.
>
> The portion of the project being used by public traffic, whether it be through or local traffic, shall be maintained in a safe and satisfactory condition."

Sletten/McNeil reasonably interpreted these sections of the specifications to allow for an eight-work day. This would be accomplished by controlling one-way traffic with adequate flag people in pilot cars allowing part with construction during the time the road was open to the traveling public. However, on March 4, 1987, FHWA project engineer Robert Sowder informed Sletten Construction of his interpretation of the above specifications as follows:

> "The intent of the two-hour period of opening the road was to allow the traffic to move through unimpeded. There will be occasions when the traffic will be restricted to one lane (min. 10 ' wide), at that time flagging and pilot cars, if required, will be used to guide the traffic. This portion of the road will not have construction equipment useing (sic) or working at the time of of opening to public travel."

Sletten/McNeil responded on March 5, 1987 by offering to provide more flag people accompanied by pilot cars. By letter to Robert Sowder dated March 5, 1987, Sletten/McNeil stated the following:

> "Item No. 2. Flag people.
> A meeting was held on January 15 with engineers. Contractors informed engineers of dangers of working long sections of road with only two flag people. At that meeting, various methods of obtaining flag people for the 2 and 1/2 hours in question were discussed. Contractor indicated he would obtain flag people from his labor force. This would allow us to obtain additional flag people and pay only the time they were used and not have to pay four or eight hours. To our knowledge, no final decision was made and so we have been trying to operate with two people which has caused problems. The system had been working fairly well until recently when construction was spread out so far that it was impossible for the flag people to see what was happening in the middle sections.
>
> Another problem is the starting and stopping times. We do not get the full three-hour period that we are allowed. We lose approximately 1/2 to 1 hour in every day. To alleviate this problem, we propose using more flag people and/or flag cars.
> ...
>
> By not allowing the work to proceed during the period in question, our costs are increasing by 25% and we must request additional time and money for the delay."

Despite this offer to provide additional flag people to alleviate the problem, Sletten/McNeil continued to experience disruptions and delays due to Sowder's unreasonable interpreation of the specifications for traffic. Steve McNeil described the problems in a letter to Robert Sowder, dated April 20, 1987:

> "...the reason we are behind is we are not allowed to utilize the period between 11:00 A.M. and 1:00 P.M. During this period, we are not allowed to work in any areas that we used by the traveling public. This restricted our working areas, and our anticipated

production, and we could not use all the equipment we had on the project. During this time, we made repeated requests to be allowed to use more flag people, and/or pilot cars, but these requests were ignored or refused. We even offered to shut down some of our equipment and use these operators for flag people, so that your costs could be held to a minimum, but this was refused. It is an industry practice that flag people will be allowed to facilitate the moving of traffic through a construction zone. This allows for construction to continue at a reduced pace, and not come to a complete halt. In this case, consideration was given to the traveling public, and very little to the contractor. Our production was hindered by as much as 25% which has increased our costs proportionately. This hinderance applies to our operations wherever our work interferes with the traveling public, (unclassified exc., dumped rip rap, etc.). It has also interfered with the box culvert subcontractor.

...I will be forwarding our additional costs for your review as soon as possible. In the meantime, I would appreciate any help that you can give to alleviate the above mentioned problems."

Robert Sowder's unreasonable interpretation of the traffic maintenance specifications also disrupted Sletten's method and manner of installation of box culverts. On numerous occasions, Sletten sought permission to detour around the box culvert sites off the presently traveled way in order to allow the installation of the box culverts in one sequence. One piece construction of box culverts is recognized in the industry as the most economical and cost effective, and is utilized wherever practicable. On this project, detour roads are available in the vacinity of both box culvert installations. However, Robert Sowder refused to allow Sletten to utilize the available detours.

Similarly, Sletten requested the use of available detours to allow excavation at the plub between stations 1535 and 1542.

Robert Sowder's denial of this request prevented Sletten/McNeil from timely removal of rock from the roadway and completion of work in this area.

In sum, Robert Sowder's unreasonable interpretation of the traffic plan specifications greatly increased Sletten/McNeil's costs for performance of the contract work. Sletten/McNeil was forced to suffer severe losses of productivity, stacking of operations, costlier box culvert installations, and delays due to constructive changes in the traffic maintenance specifications. Under the changes clause of the contract, Sletten/McNeil is entitled to an equitable adjustment upward in the contract price to compensate Sletten/McNeil for the above increased costs of performance of the contract work.

B. RIP RAP SORTING.

Sheet number 7 of the contract drawings is a grading summary sheet. On the sheet, rip rap removal is shown to take place on only two areas of the project; station 1538 + 50 to station 1542 + 50, and station 1603 + 00 to station 1618 + 00. Sletten/McNeil relied on this representation in preparing their as-bid method and manner of performance.

However, contrary to the plan assertions, Sletten/McNeil was forced to change its method and manner of excavation in order to attempt to obtain acceptable rip rap throughout the project. Because of this change in the contract, Sletten/McNeil was forced to handle the excavated material a great deal more than anticipated. First, all excavated material had to be dumped through a sorting "grizzly". Then the sorted material had to picked up and loaded into the appropriate trucks for either roadway obliteration or rip rap stockpiling. One hauled to the appropriate destination, the rock was handled again in unloading operations. Without being forced to sort the material, the rock would have been handled only once, when loaded into the truck and then dumped in either fill operations or roadway obliteration.

Sorting operations also impacted Sletten/McNeil blasting efforts. Drill patterns and powder loading factors were modified to produce material which would make acceptable class V rip rap throughout the project. This change escalated blasting costs by forcing Sletten/McNeil to handle larger than otherwise necessary chunks of rock. In addition, time was lost due to experimentation and modifications in order to produce rip rap.

Because Sletten/NcNeil was forced by the FHWA to perform rip rap production and sorting operations throughout the project, where the plans show these operations only in two areas of the project, Sletten/McNeil is entitled to an equitable adjustment under the changes clause for its increased costs of compliance with the FHWA directive.

C. AREA FOR RIP RAP STORAGE

The plans and specifications for this project indicate an area to be used for storage of 90,000 cubic yards of class V rip rap in the Mills Canyon area. Sletten/McNeil reasonably assumed that the area designated would be adequate in size for normal rip rap stockpile operations. These normal operations would entail end dumping of class V rip rap in one stack, close together.

However, as rip rap stockpile work progressed, it became apparent that the area provided was a great deal smaller than the area required for the storage of 90,000 cubic yards of class V rip rap. By letter dated May 6, 1987, Steve McNeil informed Robert Sowder of the problem as follows:

> "In regards to the stockpile of rip rap. We are running out of room to stockpile rock. You have suggested placing dirt on top of rock and starting a second layer. This is difficult to do, and also costly. Where will we get the dirt to cover rock and how will we be paid for this extra work. It seems the simplest plan would be to find another area to stockpike rock.
>
> ...Would you please advise as soon as possible."

Robert Sowder responde by referring Steve McNeil to sub section 311.05 which states that "preparation or construction of a stockpike site will not be measured for payment, but will be considered subsidiary to other contract items."

2190112a

EMPIRE
MACHINERY
CATERPILLAR

Recd: 1/26/89
Phx, Az
[illegible]

May 20, 1987

White & McNeal
P.O. Box 339
Tonto Basin, Arizona 85553

Dear Steve:

Enclosed is the Rock Analysis performed by Caterpillar on the samples we sent them. As you can see, the results are "non-rippable". If you have any questions, please give me a call.

Regards,

Al Hodson

Al Hodson
Metro Division Sales Manager

ls
enclosure

A DIVISION OF EMPIRE SOUTHWEST

1725 S. Country Club Drive, Mesa, Arizona 85202 • P.O. Box 2985, Phoenix, Arizona 85062 • 602/898-4400

5/4/87

Rock Mechanics Analysis

of the

Bridge Project

near

Mesa, Arizona

IMPORTANT NOTE

Caterpillar's rock mechanics analysis is intended to forecast what machine (or range of machines) are likely to successfully rip the materials tested at a given site and determine whether a site investigation is justified. The only true test concerning a machine's performance, at a given site, is to put that piece of equipment on the given site and rip. Therefore, Caterpillar makes no express warranties and disclaims all implied warranties concerning the Rock Mechanics Analysis and recommendations thereof. Caterpillar shall have no liability for damages, consequential or otherwise, arising from use of the Rock Mechanics Analysis or any part thereof.

Prepared by:

J. S. Burdick
Caterpillar Inc.

S. W. Schoening
Caterpillar Inc.

4/14/87

Objective:

To determine what machine (or range of machines) is likely to successfully rip the materials tested and if a site investigation is justified in order to fully assess the feasibility of ripping at the Bridge Project near Mesa, Arizona by conducting laboratory tests to measure the strengths, densities, brittleness, etc. of selected representative rock samples.

The results of these lab tests are used to:

A) identify likely difficulties;
B) indicate breakout characteristics;
C) indicate potential productivity ranges; and, more

Procedures:

Caterpillar conducts the following suite of laboratory tests:

- rock identification
- density
- unconfined compressive strength
- indirect tensile strength (Brazilian)
- point load strength
- laboratory seismic velocity
- tangent modulus
- Schmidt hardness

All testing is as per A.S.T.M. guidelines

Laboratory Tests:

4 representative rock samples were sent in from the bridge project near Mesa, Arizona for laboratory analysis.

Sample A is a light gray - very fine crystalline limestone
Sample B is a dark gray - very fine grained crystalline limestone
Sample C is a dark gray - very fine grained crystalline limestone
Sample D is a yellow-marl? limonite?

Sample	A		B		C		D	
	Avg	Peak	Avg	Peak	Avg	Peak	Avg	Peak
Density ($Tons/Yd^3$)	2.27		2.27		2.32		2.33	
Unconfined Compressive Strength (psi)	38,362	40,414	33,993	37,338	42,310	44,793	47,300	49,451
Indirect Tensile Strength (psi)	1,692	1,811	1,580	1,838	2,663	3,165	2,123	2,443
Point Load Strength (psi)	860	987	909	953	1,882	2,089	2,062	2,444
Laboratory Seismic Velocity (ft/sec)	22,513	22,531	22,724	22,841	20,510	20,872	21,944	22,500
Tangent Modulus (psi)	NOT CALCULATED							
Schmidt Hardness	45	50	47	54	41	46	49	54

5/4/87

Based on this rock mechanic's analysis alone, these samples represent materials that if encountered intact in-situ would be considered non-rippable for any track-type tractor currently manufactured w/o preblasting.

5/4/87

DALE R. ULIN
WADE R. DANN
RICHARD L. LAMBE
• GARTH A. SCHLEMLEIN
CRAIG D. MAGNUSSON

MARGARET EASTON ARMS
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• ANDREW W. TORRANCE
PAUL G. WINTER
WILLIAM R. ZOBERST

•ALSO ADMITTED IN ALASKA
•• ALSO ADMITTED IN OREGON

February 10, 1989

RECEIVED
FEB 13 1989
BOX 5964
TUCSON, AZ 85703

Walter E. Heinrichs, Jr.
TERRAMETRICS ASSOCIATES
P. O. Box 5964
Tucson AZ 85703-0964

RE: SLETTEN/McNEIL

Dear Mr. Heinrichs:

As we discussed on the phone yesterday, I am enclosing your original Affidavit, along with a copy for your file.

Only pages 19 and 20 have been added, and the remainder of the Affidavit remains as it was when you initially signed it. After you have reviewed the above referenced change pages, and if you concur, please sign the original before a Notary Public, and return to my office at the above address.

Don't hesitate to give me a call if you have any questions.

Very truly yours,

David P. Hattery (gjz)

David P. Hattery

DPH/gjz
Encl.
2190210a

COPY

AFFIDAVIT OF WALTER E. HEINRICHS, JR.

STATE OF ARIZONA)
) ss.
COUNTY OF PIMA)

WALTER E. HEINRICHS, JR., being first duly sworn upon oath, deposes and says:

1. That I am a professional geological engineer with extensive experience in practical geology, geophysics and hydrogeology. I am 70 years old.

2. I have devoted the past 53 years of my life to the study of geology, geological engineering, subsurface investigation methods and related fields.

3. I have been involved in geological projects throughout the continental United States, Alaska and throughout the world.

4. I was born in Superior, Arizona, on January 16, 1919. I was raised in Pittsburgh, Pennsylvania, Golden, Colorado, and in mining camps throughout the western United States and the Philippine Islands.

5. My father was a mining engineer employed by various mining concerns throughout the world. He earned a degree in mining engineering from the Colorado School of Mines in 1913.

6. Throughout my formative years, my father was involved with gold mining in Breckenridge, Colorado; copper mining in Ruth, Nevada; molybdenum mining in Climax, Colorado; gold mining in the "Mother Lode" gold camp in Grass Valley, California; gold and chromite operations on Luzon Island in the Philippines; and copper mining in Nchanga, South Africa (now Zambia).

7. I completed high school in Golden, Colorado, while living with my grandmother. The following fall, I entered the Colorado School of Mines in Golden.

8. I graduated from The Colorado School of Mines in 1940, with a professional degree in geological engineering, with a major in geophysics.

9. Upon graduation, I went to work for National Geophysical Company in Greenwood, Mississippi, as a geophysicist. My duties included overseeing the recording and testing for seismic petroleum investigation throughout the midcontinent of the United States. I personally conducted and recorded tests in Mississippi, Arkansas, Texas and throughout the region.

10. In 1942, I went to work for Seismograph Service Corporation in Tulsa, Oklahoma, as a geophysicist. I worked on projects throughout the Gulf Coast, West Texas, Central Texas, Oklahoma and Wyoming. This experience includes a great many seismic investigations in search of petroleum bearing strata and the training of other seismic observers.

11. Despite being qualified for continuing deferments because of employment and expertise in an essential war industry, I enlisted as an officer in the U. S. Naval Reserves in 1944. I entered active duty in 1944 as an ensign at Officers Indoctrination School in Hollywood Beach, Florida.

12. Subsequently, I was assigned to Armed Guard School in Camp Shelton, Virginia. Eventually, I became involved with training of armed guard officers in life saving and small boat operations.

13. From this assignment, I was briefly assigned to an advanced base supply training unit in Camp Perry, Virginia.

14. In early 1945, I was assigned to the Office of Naval Petroleum Reserves in Washington, D.C., as a geologist. In this capacity, I was assigned to assist in mapping geological sections along the Chandler River in the north slope of Alaska in conjunction with Petroleum Reserve Number Four. During the course of these investigations, we also performed identification and measurements of the Umiat Anticline and its exposed geological strata with the purpose of determining anticlinal closure.

15. In the winter of 1945, I was assigned back to Washington, D.C., to complete reports of the Alaskan work.

16. In the spring of 1946, I was assigned to Lake Charles Air Force Base in Louisiana where the Office of Petroleum Reserves was conducting the first practical off-shore aerial magnetometer survey of the Gulf Coast region. I con-

tinued work on this project as a geophysicist until my discharge from the U. S. Navy in 1946.

17. Following my career in the Navy, I joined the U. S. Bureau of Reclamation as an Assistant Chief Geophysicist with the Chief Engineer's Office in Denver, Colorado. My duties with the Bureau of Reclamation were to help reestablish viability of a post-war geophysical department within the Bureau. In this capacity, I was involved with the design, construction and procurement of the necessary geophysical instruments and equipment suitable for the Bureau's purposes. In addition, I was involved with the investigation and analysis of the future uses of geophysical investigation in conjunction with present and future Bureau of Reclamation projects. As a result of budget cuts and reassignment to the sedimentology department, I decided to leave the Bureau of Reclamation in 1947.

18. In 1947, I joined Newmont Mining Corporation as an Assistant Chief Geophysicist. Newmont Mining Corporation was interested in establishing a complete mining geophysical department to assist their efforts in mineral exploration and development.

19. Essentially, my duties with Newmont were an extension of my duties with the Bureau of Reclamation. In addition, because Newmont was primarily concerned with minerals exploration and development, I was involved with implementing state of the art geophysical investigations in mining technology.

20. Specifically, we were heavily involved with the perfection of Newmont's newly developed induced polarization method of geophysical investigation, which, for the first time, was able to detect disseminated sulfide deposition which is most commonly economically identified with copper and molybdenum production in the western United States and elsewhere.

21. Geographically, my work with Newmont Mining Corporation was initially in the Goldfield, Nevada, region, then spread to investigations of the Foothill Copper Belt in California and later to the newly discovered San Manuel disseminated copper deposit in Arizona near Tucson. Later, Newmont Mining Corporation established a formal geophysical base of operations and laboratory in Jerome, Arizona.

22. As part of my work with Newmont Mining Corporation, I designed and oversaw the construction of a state of the art custom seismic system which was used on the Goldfield project in Nevada, San Manuel in Arizona, and on other important projects.

23. After leaving Newmont Mining Corporation in 1949, I participated in a partnership in Jerome, Arizona. The purpose of this partnership was to pursue opportunities for geophysical exploration of hard minerals.

24. As a result of this effort, we established an office in Tucson, Arizona, under the auspices of United Geophysical Company based in Pasadena, California. At the direc-

tion of Mr. Herbert Hoover, Jr. (son of President Herbert Hoover), United Geophysical Company's founder and president, we conducted grass roots hard mineral exploration.

25. Initially, we performed a thorough reconnaissance of almost all of the known mining districts throughout southwestern New Mexico, southeastern Arizona, and elsewhere. Based on the results of this reconnaissance, we decided to focus our efforts on the Pima District in Pima County, Arizona, approximately twenty miles south of Tucson.

26. Our first application of geophysical techniques in the Pima District included acquisition of physical property samples from the surface and underground, and long magnetometer profiles of the area. As a result, we were able to confirm the presence of magnetically responsive magnetite which, together with the known geology and economic geological associations, indicated the possible presence of viable deposits. Consequently, mining leases and mineral claims were established on state and Federal lands in this area.

27. These mining claims were then investigated in a great deal further detail with an assortment of geophysical investigation methods. Among these were detailed magnetics work, electromagnetic profiles, resistivity studies, self-potential, as well as gravity and seismic analysis. Two drill targets of major interest were identified.

28. Results of the first drill hole confirmed our predictions of the subsurface based on geophysical investiga-

tion to a remarkable degree. For example, we estimated bedrock depth to be 210 feet in this area. In fact, the first drill hole encountered bedrock at 209 feet. In addition, as we predicted, massive sulfide containing high-grade copper and magnetite were encountered at 255 feet.

29. Ultimately, this property was developed, first as an underground mine, and then as a low grade open pit copper mine. This discovery became known as the Pima Mine, and became the forerunner to the eventual development of the largest copper producing district in the United States. To date, the Pima Mine has produced over $1 billion worth of copper. The Pima Mine is recognized as being the first major "blind" (unexposed) copper mine in the United States discovered exclusively through the use of geophysical analysis methods.

30. Following the discovery of the Pima Mine in 1952, Union Oil Company of California acquired the mine in 1954. I joined Union Oil Company to assist in the formation of, and serve as General Manager of their newly established Minerals Exploration Company, a wholly-owned subsidiary, engaged exclusively in exploration for hard minerals including uranium.

31. With Minerals Exploration Company, I was actively engaged in investigations throughout the southwestern third of the United States. My work with Minerals Exploration Company resulted in the identification of several significant copper deposits throughout this area. Geophysical methods used to locate these deposits included almost all of the usual state of

the art geological and mining geophysical investigation methods.

32. As a result of the oil recession of 1958, Union Oil decided to cut back in the area of hard minerals exploration. As a result, I was offered the opportunity to purchase the files, library and equipment inventory of Minerals Exploration Company which would enable me to start my own company.

33. In 1958, I decided to take advantage of this opportunity and, along with my brother, founded Heinrichs GEOEXploration Company (hereinafter referred to as "GEOEX").

34. GEOEX eventually worked on every continent of the world with the exception of Antarctica. Operations included the Tri-State lead-zinc district of Missouri, Oklahoma, and Kansas, as well as the Illinois, Wisconsin and Iowa lead-zinc district, North Carolina, and all of the western United States including Alaska. Abroad, we operated in a number of Central American countries, Haiti, Peru, British Columbia, Australia, New Guinea and New Zealand.

35. In 1964, GEOEX began the manufacturing of its own brand of electrical geophysical equipment, including self-potential, resistivity and induced polarization. This equipment has been exported to countries such as China, Egypt, South Africa, Morocco, Korea, Philippine Islands, Australia, Pakistan, Nepal, Ecuador, Peru, Chile, El Salvador, Nicaragua, and Argentina.

36. Commodities involved in GEOEX's contract work included nickel, copper, gold, silver, lead, zinc, iron ore, strategic materials, rare earths, non-metallics and hard mineral energy compounds, such as uranium, thorium, etc.

37. Engineering projects included small dam sites, canals, large structure foundations, bridge abutments, highway cuts, and a constant bit of work in ground water hydrogeology conducted mainly in connection with the development of southwestern water resources.

38. During GEOEX's history, we contributed to numerous substantial discoveries of various types of hard mineral commodities. This occurred in a large majority of the various areas of corporate effort.

39. The electrical instruments developed by GEOEX were the result of a desire to improve the quality of instrumentation available and its ability to assist in the ore discovery process. The method chosen to conduct induced polarization work was the frequency domain system as opposed to the time domain system developed by Newmont. Each has its unique advantages and disadvantages, but we felt that the frequency domain method held a superior reconnaissance capability. The primary impetus in the development of this effort was the then current boom in disseminated copper exploration, particularly in the southwestern United States.

40. Essentially, the theory behind frequency domain induced polarization is that disseminated sulfides, and other

metallic lustered minerals, are detectable in part after being energized by differing frequencies of electricity. GEOEX's equipment has been proven effective throughout the world in detecting such types of mineral deposits and in the development of groundwater and geothermal resources.

41. GEOEX also utilizes equipment to measure resistivity of rock formations. Resistivity studies measure differences in electrical potential over distance compared with a known current applied nearby. This has proven to be an effective indicator of various subsurface rock conditions, as well as water quantity and quality.

42. GEOEX utilizes two methods to measure local variations in the earth's potential fields which are useful in subsurface investigations. First, a gravity meter measures differences in the earth's gravitational pull which may indicate subsurface anomalies. Second, a magnetometer is used to similarly measure differences in the earth's magnetic field.

43. GEOEX also uses several applied field methods, and at least two methods which measure natural physical or chemical phenomena at or near the earth's surface. First and foremost is induced polarization and resistivity as explained above, and a virtual miriad of inductive and galvanic electromagnetic methods. Secondly, is the self-potential system which measures localized shifts in potential often associated with actively oxidizing sulfide. Third, GEOEX utilizes radiometric measurements to detect radioactive minerals.

44. GEOEX has aided in the development and perfection of equipment in addition to the induced polarization system explained above. Among this equipment is the mobile magnetometer ("MoMag"). The mobile magnetometer was developed as a result of Pima Mine magnetic work performed for United Geophysical Company. Thereafter, we developed the first mobile magnetometer which was first used extensively by United Geophysical for the discovery of considerable iron ore in Nevada. GEOEX first utilized this mobile magnetometer and also developed a successful towed trailer version for iron ore exploration in the midwest. The MoMag also contributed to various exploration projects throughout the southwestern United States.

45. In 1966, GEOEX established an office in Crows Nest, North Sydney, Australia. Through this office, we conducted numerous studies into the feasibility of mining operations primarily for nickel, copper and gold throughout most of the continental areas of Australia. GEOEX also assisted mining exploration operations on the southern island of New Zealand.

46. In 1986, GEOEX entered into an informal partnership with Geotechnical Corporation of Laramie, Wyoming, which was headed by a former GEOEX employee. At that time, we adopted the name of Terrametrics Associates for this joint venture entity.

47. I hold the following professional certifications: registered professional engineer in the States of Ari-

zona and Colorado, registered professional geophysicist in California, and certified professional geologist by the American Institute of Professional Geologists (charter member).

48. I am a member of the following professional associations: American Institute of Mining, Metallurgical, and Petroleum Engineers; Society of Exploration Geophysicists; Society of Economic Geologists; Arizona Geological Society; European Association of Exploration Geophysicists; and American Institute of Professional Geologists (charter member).

49. In 1972, I was appointed by the Governor of Arizona to serve on the Board of Governors of the Arizona State Department of Mineral Resources. In 1977, I served as Chairman of this Board of Governors.

50. In addition, I have served as a member of the advisory counsel to the Board of Trustees for the Colorado School of Mines in Golden, Colorado.

51. I have personal knowledge regarding Federal Highway Administration Project Arizona FLH 9-8 (7) constructed by Sletten Construction Company of Great Falls, Montana.

52. I have obtained this personal knowledge through a detailed review of the plans, specifications, and FHWA provided materials report for this project.

53. I have talked with Mr. Steve McNeil of White and McNeil Excavating concerning his pre-bid site investigation and his experience with the rock excavation for this project.

54. On Wednesday, December 14, 1988, I personally examined the project site. During the course of this investigation, I observed the exposed rock in the cut sections of this project, the exposed rock in the cut sections on the previous project, the geology exposed in the area of the haul road, and observed the geological formations of the area in general.

55. I examined each cut area along the Sletten section, and each cut along the Brutoco section of roadway. Particularly, I identified the various types of rocks and tested their physical properties with a rock hammer. I observed and took photographs of each cut along Sletten's section, noting the various geological factors - folding, faulting, slumping, re-cementing, and so forth.

56. I paid particular attention to the surface geology of the undisturbed areas adjacent to the roadway project. I investigated the exposed rock along the old road through Sletten's project and Brutoco's project, as well as the area of the new bridge abutment and the rock exposures on the north side of the Salt River Canyon adjacent to Theodore Roosevelt Dam.

57. Based upon these investigations and further based upon my professional engineering, geological and geophysical judgment, I have formed an opinion as to the geology and the characteristics of the rocks of this area. The site is unusual in the degree in which the preponderence of weathered and broken up material seen at the surface, belies the hardness of numerous beds lying just below the surface. The apparent sur-

face investigation mistake was made in assuming that reasonable "at surface" apparent rippability would reasonably persist to depth.

58. The geological formations in the vicinity range from Mississippian Redwall Limestone, to Devonian Martin Formation, Cambrian Tapeats Sandstone, Precambrian Troy Quartzite and Mescal Limestone, Dripping Springs Quartzite, Barnes Conglomerate, Pioneer Shale and Scanlan Conglomerate of the Apache Group. Along the Sletten section, these beds are tilted easterly about 35 degrees and dissected by steep easterly trending gullies and washes, with considerable folding, faulting, slumping, fracturing and some possible brecciation added.

59. In the vicinity of the Brutoco section, the exposed rocks are homogenous and consistent, indicating a possibly younger layer lying on top of the older formations found on the Sletten section. Surface geology in this area clearly indicates this type of material and these surface indications prove correct with depth.

60. The exposed canyon wall adjacent to the Dam shows the massive older formations of mostly quartzite underlying the surface in this area. However, the presence of this bed is not relevant to a prediction of the rock formations likely to be encountered along Sletten's section. The reason for this is because this massive quartzite appears to lie much deeper than the excavations along Sletten's project.

61. Because of the easterly trending gullies and washes, and accompanying shallow sand and gravel deposits which cross the Sletten section, there are no observable exposures in the creekbeds.

62. Based upon these investigations and further based upon my professional engineering, geological and geophysical judgment, I have formed an opinion as to the character of the rock encountered on this project.

63. In my opinion, the rock conditions encountered by Sletten/McNeil on this project are unusual conditions which differ materially from those ordinarily encountered and generally recognized as work of the type provided for in the contract. Specifically, the degree to which the preponderence of weathered and broken up material seen at the surface belies the hardness of various beds lying below the surface is unusual and not to be expected upon observing surface conditions. The subsurface in this area is unusual in that its true nature is not indicated by surface conditions.

64. It is not unusual to encounter highly weathered and fractured materials at the surface. Further, it is not unusual to encounter very hard subsurface beds. On this specific site, the unusual aspect is the combination of both of these characteristics in such close proximity. As a result, one is faced with the unusual condition of surface indications which do not hold with depth.

65. Rock formations along Sletten's project exhibit a high degree of variability. The material composition of the beds changes dramatically over short distances. Composition ranges from very hard massive white quartzite, through massive to fractured limestone and/or dolomite, sandy limestone, spongy conglomerate, caliche, and finally, in softness, down to highly altered, weathered, faulted and/or fractured components of these, to the rather soft friable clay, shale and colluvial detritus.

66. The rock encountered along Sletten's project is quite complex geologically. In addition to the above-described dramatic material variability, the beds themselves are interrupted by a high degree of faulting, folding, slumping, fracturing and brecciation.

67. Faulting is a unidirectional major interruption of one or more beds. With faulting, one side of the fault is displaced with respect to the other. A fault may be spherically oriented in any direction.

68. Folding is where the bed has been disrupted to the point of being overturned on itself. On this project, folding was mainly evident in the form of warping with strong undilations.

69. Slumping is a disruption of the normal structure of the bed whereby one portion falls away from the main orientation of the bed.

70. Fracturing is where one or more beds is subjected to various tensional or compressional forces resulting in rock breakage in one or more directions.

71. Brecciation is a random natural breaking process. As a result of major energy events or solution processes over time, rocks exhibit a random pattern of breakage and disorientation, somewhat similar in appearance to conglomerate beds.

72. All of the above mechanisms are present in some degree or another along Sletten's project. As a result, the formations encountered were unusually complex and unexpected.

73. Based upon these investigations and further based upon my professional engineering, geological and geophysical judgment, I have formed an opinion as to the conclusions that a prudent and reasonable contractor could make based upon an investigation of the surface conditions.

74. A reasonable prudent contractor observing the undisturbed surface geology along the right of way on Sletten's project could reasonably conclude that rock to be encountered would be predominantly weathered, fractured, and capable of excavation by using ripping equipment.

75. To a contractor, the pre-bid surface conditions indicating the weathered, fractured, slumped nature of the rock point away from the presence of hard massive rock. In other words, a contractor had nothing to observe on the surface which would indicate the dominant presence of hard massive rock below the surface.

76. Based on my prior experience with geological and geophysical rippability studies, Sletten/McNeil's assumption of excavation with predominantly ripping equipment was reasonable in light of the observable undisturbed surface conditions along the right of way.

77. Specifically, because of the degree of observed fracturing, weathering, slumping, and relative softness evident on the surface, had these conditions continued with depth, as normally expected, excavation with ripping equipment would be feasible.

78. Based upon these investigations and further based upon my professional engineering, geological and geophysical judgment, I have formed an opinion as to the efforts necessary to accurately predict the subsurface conditions encountered on this project.

79. In order to accurately predict subsurface conditions in this area based upon a site investigation of undisturbed conditions, at a minimum, one would have to engage a qualified geologist to prepare a geological map of the right of way and vicinity. This would take approximately one man-week of field work with an additional man-week of office research and analysis. If the results from mapping are uncertain, seismic work (a combination of refraction and reflection) would be required. Seismic work would entail a crew-week of field work and an additional man-week for analysis and interpretation. The cost of the above geological mapping work would be in the

neighborhood of $4,000.00, while seismic work would cost roughly $7,500.00. At this point, drilling would be required in areas identified by the above methods in order to confirm the geological and geophysical interpretations.

80. As stated above, I have reviewed the materials report provided by the FHWA for this project. In my opinion, based upon my knowledge of geology, geophysics and geological engineering, and upon my personal investigation of the project site, the materials report is inadequate in coverage and misleading in content.

81. Specifically, the materials report provides considerably less useful subsurface information for Sletten/McNeil's portion of the project as compared with the previous section. In my opinion, FHWA efforts to investigate the subsurface fell far short of those required to disclose the true nature of the rock likely to be encountered.

82. Moreover, the information conveyed in the materials report is misleading in that the materials report suggests the majority of the subsurface will be either alluvial material or fractured rock. In only one instance, from Station 1529 + 00 to 1539 + 00 does it mention, "possible rock with depth", with all other rock described as moderate to well fractured rock. Soil survey logs give even less indication of rock.

83. The fact that substantially less subsurface information was provided for Sletten/McNeil's section of the project suggests that the FHWA believed that subsurface conditions would be

clearly indicated in the cuts on the previous project, thereby obviating the need for detailed investigations on this project. Or, perhaps the greater topographic relief on the Sletten portion made drill accessibility more difficult and less convenient. In any event, the materials report provided for Sletten's portion was inadequate, incomplete and misleadingly indicated the presence of predominately rippable subsurface material.

FURTHER AFFIANT SAYETH NOT.

Walter E. Heinrichs Jr.

WALTER E. HEINRICHS, JR.

SUBSCRIBED AND SWORN to before me this 14 day of February, 1989.

NOTARY PUBLIC in and for the State of Arizona, residing at Pima County

My Commission expires July 3, 1991

2190207a

TERRAMETRICS ASSOCIATES
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Tucson, Arizona
December 19, 1988

David P. Hattery, Esq.
c/o Ulin, Dann and Lambe
4800 Colombia Center
701 Fifth Avenue
Seattle, WA 98104-7010

Re: Sletten Construction Company
Arizona Highway 188
GEOEX #1865

Dear David:

First, some general conclusions will be stated then followed by fairly broad discussion.

1. In lieu of any seismic data, in my opinion the contractor's investigation was reasonable and, based on that investigation, the conclusions arrived at were reasonable.

2. The site is unusual in the degree to which the preponderance of weathered and broken up material seen at the surface, belies the hardness of numerous beds lying just below the surface. The apparent surface investigation mistake was made in assuming that reasonable "at surface" apparent rippability would reasonably persist to depth.

3. The geological formations in the vicinity range from Mississippian Redwall Limestone, to Devonian Martin Formation, Cambrian Tapeats Sandstone, Precambrian Troy Quartzite and Mescal Limestone, Dripping Springs Quartzite, Barnes Conglomerate, Pioneer Shale and Scanlan Conglomerate of the Apache Group. Along the Sletten section, these beds are tilted easterly about 35 degrees and dissected by steep easterly trending gullies and washes, with considerable folding, faulting, slumping, fracturing and some possible brecciation added. This makes for much variability in character when compared with the Bruteco section which represented geological formations much more consistent and softer and perhaps much younger in age (?) than the Sletten section. This, is a very common situation in Arizona geology.

4. Fed. Hwy. Adm. (F.H.W.A.) was also misled by the surface appearance as mentioned in their soils report of September 1984. In only one instance, from Station 1529+00 to 1539+00 do they mention: "Possible rock with depth". Every where else, Stations 1587+00 thru 1625+00, wherever rock is mentioned they say "moderate to well fractured rock". In the Bruteco section, only one "rock outcropping" is mentioned with everything else "alluvial".

5. Bridge boring logs mention very hard drilling in several instances but use only the words conglomerate or cemented material, not rock per se. Soil survey logs give even less indications of rock.

Regarding the 26 September 1988 Memo from David Hattery to Wade Dann the following comments are offered:

Page 3:

1. The F.H.W.A. related Project FLH 9 - 8 (6)(Bruteco) to Project FLH 9 - 8 (7) (Sletten) as being similar and not just consecutive in time and simply one, a geographic continuation of the other. Their soils report also suggests such a relationship.

The similarity in fact is emphasized by the soils report in that substantially less information was obtained relative to Project FLH 9 - 8 (7) than was obtained on Project FLH 9 - 8 (6).

2. On site investigation, geologic analysis of surface and analysis of Project FLH 9 - 8 (6) Bruteco results, all tend to point away from substantially more hard rock quantities to be anticipated on Project FLH 9 - 8 (7) (Sletten). The general impression is maybe only a little more.

Page 4:

1. In my opinion F.H.W.A. Soils Report is inadequate, misleading and especially so for the Sletten portion. Moreover, I do not believe that this aspect was totally oblivious to the F.H.W.A. Most likely, the greater topographic relief on the Sletten portion made drill accessibility more difficult and less convenient. But, letting that influence obtaining significantly less coverage when just the opposite is mandated by surface geological indications as well as the much greater topographic relief, seems inexcusable. This aspect is at least partly confirmed by Steve McNeil's initial surface investigation as quoted on pp 5 & 6 (Memo).

The mere fact that the F.H.W.A. decided to do the Cholla Bay - Hotel Point work on two separate bid segments may indicate some logical differences were perceived and assigned by them and yet no physical reasons for this were apparently made evident in the contract.

Under these circumstances it would seem that "Differing Site Conditions" were definitely encountered, at least on the basis of Governmental non feasance in the form of the above methodology and/or soils report.

After my own site examination on 12/14/88, I believe seismic refraction results would have reinforced Steve McNeil's initial personal observations (Memo pp 5 & 6) in general, i.e. "more rock than Bruetco had". Also I believe seismic work would have identified some specific differentiation of the rather high variation of conditions encountered, both laterally and with depth along the route, i.e. from very hard massive white quartzite, through massive to fractured limestone and/or dolomite, sandy limestone, spongy conglomerate, caliche, and finally, in softness, down to highly altered, weathered faulted, and/or fractured components of these, to the rather soft friable clay and shale and colluvial detritus.

Seismic refraction work theoretically cannot "see" beneath the first interface encountered in which the velocity decreases with depth. This means that energy penetration will rarely go beyond the first hard layer encountered especially if it is then followed by a softer layer. This condition is very prevalent in the Sletten cut banks and, in one or two instances or more, a hard layer was noted to actually be the top surface layer Thus, it is conceivable that a seismic interpretation, without the benefit of the now visible cuts, would have indicated MORE hard rock than actually existed, rather than less. This statement assumes more or less continuous seismic coverage over the whole Sletten Project length.

Incidently, simple hammer seismic work of the sort most commonly done in connection with rippability studies, can usually penetrate to fifty feet below surface in an increasing velocity with depth section, but rarely to more than 75 to 100 feet below surface under any conditions. For this and other reasons mentioned, we now do less single trace hammer energy refraction work and more multiple trace reflection work, using better energy sources than a simple sledge hammer and with better cost benefit ratios and consistency of results.

Even if the pre-bid hypothetical seismic budget had been limited to just those zones where hard rock was clearly exposed or inferred, i.e. most of the ridges, it is difficult to visualize a scenario that would have given misleadingly low velocities. The reason for this is that in almost every case, within 50 feet of the surface, at least one hard-high velocity layer or interface would have been encountered and, beyond that, little or inadequate evidence of the softer layers or zones beneath would have been indicated. Technically, with what we now see exposed in the cut banks we could carefully design seismic refraction coverage over the softer zones and probably come up with a lot of rippable low rock velocities over much of the topographic profile lows, also of the side slopes and maybe even one or two of the ridges, but this would have to be artificially discontinuous coverage, i.e. designed mainly for the purpose of obtaining lowest velocities possible.

All of the previous discussion assumes that the seismic velocities of the harder formations observed in the cut banks, when measured in situ, would exceed 7,500 to 8,500 feet per second which is about the maximum sonic velocity that most rock can exhibit and still be rippable. The most practical way to prove this is to make in situ measurements in the field on the ground. An alternative way is to carefully select representative fist size samples from in place exposures in the field and subject them to velocity tests in the laboratory. Of course, the in situ approach retains the best credability of results.

Estimated seismic costs for portable single trace, hammer energized, refraction work is based on spreads about 200 feet long (slope distance). This is about as far as sledge hammer-generated energy will commonly travel through the earth. Two simple standard vertical component seismometers (geophones) about the size of a common door knob are "planted" at the surface 200 feet apart and electrically connected by flexible wire cable to the seismograph. The sledge hammer is also connected to the seismograph through a wire cable 200 feet long. The hammer hits a metal plate on the ground at measured intervals from 5 to 25 feet apart between the two geophones. This generates the sonic energy transmitted through the earth and recorded by the seismograph. The hammer cable provides the shot instant or zero time break indication on the seismograph record. Depending on accessibility, and how easy it is to find survey stations on the ground to locate each spread accurately, from four to eight of these spreads can be run in one average eight hour field day using a geophysicist or qualified operator, one helper and one vehicle. Each field operating day will require about one professional man day in the office to make a final compilation, presentation of results, interpretation and report. Rough plots of results are commonly made in the field as work progresses.

One time equipment and personnel mobilization and demoblization on this kind of a short two man job would be $700.00. Mileage costs to place men and equipment in Globe would be $324.00. Field work is $975 per 8 hour field day, and for office report and interpretation a one time charge of $750.00, plus $410.00 per field operating day. Thus, the first field day would cost $3159.00 and each succeeding field day $1385.00. At from four to eight spreads for the first day, costs would run about from $400.00 to $790.00 per spread or, roughly, $595.00 each on average. After that, each added spread would add anywhere from $173.00 to $346.00 per spread, or an average of about $260.00 per added spread.

Time was not taken to review all potential sources of pertinent reference geology available including that in the hands of the U.S. Bu. of Reclamation, Salt River Project Corporation, etc., but obtained and now have on hand: Reconnaissance Geology Salt River - from Roosevelt Dam to Granite Reef Dam, Central Arizona, by: Robert B. Scarborough, U.S. Bu. Reclamation, 1981 and Preliminary Report Initial Design Phase Geological Investigations Claypool-Jakes Corner Highway Roosevelt Lake Bridge Gila County, Arizona by: George A. Kiersch for Howard Needles Tammen & Bergendoff, 1985. The latter item is the most directly relevent and useful. A copy is enclosed.

Your Memorandum to file 1533-008 of 16 December 1988 was received this morning (12/19/88). At the top of page 3 where it says: "dramatic differences are not readily apparent", should be changed to read: "are fairly apparent".

Two sets of pictures taken on 12/14/88 are enclosed. Captions are omitted because of time required to correlate accurately.

Please let me know right away if there are any questions.

Respectfully submitted,

Walter E. Heinrichs, Jr., Principal
Geological Engineer - Geophysicist
P.E. & C.P.G

WEH:jh
Encl: Kiersch Report
2 photo sets.

81-30

RECONNAISSANCE GEOLOGY

Salt River - from Roosevelt Dam to Granite Reef Dam, Central Arizona

by

Robert B. Scarborough

Geologist

Bureau of Geology and Mineral Technology

Tucson, Arizona

This work was done under

United States Bureau of Reclamation

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Dated September 12, 1980

United States Bureau of Reclamation

Lower Colorado Regional Office

Boulder City, Nevada

June 1981

Table of Contents

Reconnaissance Geology Along the Lower Salt River from Roosevelt Dam to Granite Reef Dam, Central Arizona

by Robert B. Scarborough

June 30, 1981

Introduction

The accompanying geologic maps depict the general geology of a two-mile wide strip centered about the Salt River, starting just below Roosevelt Dam and extending westward 36 miles to just below Granite Reef Dam. The geology was accomplished from October 1980 through April 1981, with the aid of about 25 hours of helicopter logistical support time. Discussions and/or field assistance by Mike Pryor, Joe Bailey, Dick Raymond, Paul Damon, and Tom McGarvin are greatly appreciated.

Geologic Summary

The lower Salt River below Roosevelt Dam has cut a gorge which exposes much of the geology of the northern Superstition volcanic field. The silicic field of late Oligocene (?) and Miocene age is one of the half dozen or so found in southern and western Arizona. The volcanics extend continuously from around Apache Lake Resort westward to Stewart Mountain Dam, and discontinuously farther west to the Mt. McDowell area, around Granite Reef Dam. The Superstition volcanics were deposited on Precambrian crystalline rocks, dominated by a biotite quartz monzonite which age dates at about 1400 m.y., and which is probably equivalent to the Ruin and Oracle granites further east and south. The northern Superstition volcanics are dominated by silicic pryoclastics, plugs, ash flows, agglomerates, and late stage instrusive domes. Rocks of andesitic composition are subordinate in volume although important in the eastern part of the area.

The volcanics in the main volcanic field are divisible into two series based on gross lithology and style of tectonics which have affected them. Their mutual boundary extends in a Northwest direction and crosses the River a short distance downstream from Mormon Flat Dam. East of this line lies a very thick series dominated by ash flows and pyroclastics and which rests on Precambrian metarhyolite and granite. The series has several east-west trending fold structures traversing it. Overlying the youngest of the volcanics in this eastern block is an obvious fanglomerate apparently deposited in an erosionally carved trench. Several northwest trending high angle faults with some evidence of reverse (compressional) movement have cut this fanglomerate and older volcanics. Some east-west trending faults which cut volcanics a mile or so southwest or Horse Mesa Dam display strike slip lineations, and have apparent south side-down throw. A N 70° W trending fault along the north shore of Apache Lake has apparent north sides down throw and apparent reverse movement estimated at 1000 feet or more, and may have helped to localize the river course to its present position.

The western volcanic series is exposed in the mass of the Goldfield Mountains. These rocks weather to distinctive interbedded very dark brown and light yellowish colors, and have a curious moderate homoclinal northeast dip throughout their extent in the map area. They are depositional on Precambrian granite below Stewart Mountain Dam, but strike into an east-west fault which juxtaposes them against granite upstream from Stewart Mountain Dam, indicative of complexities possibly involving listric faulting. The fanglomerate which covers part of the eastern block may never have been deposited on this block. An antiform with east-west trend has been exploited by the west-flowing Salt River just upstream from Stewart Mountain Dam. This antiform has imparted dips of 25° on sediments of probable late Miocene age, and clearly involves warping of the Precambrian granites in the area.

The interval from Stewart Mountain Dam downstream to Granite Reef Dam contains a clastic redbed-dominated Tertiary section deposited on Precambrian granite. Both at Coon Bluff and around Mt. McDowell (Red Mountain) the section is tilted westward, but between the two areas, around the Orme damsite, severe structural complications are present. Major faults in this interval strike WNW to WSW and juxtapose granite against volcanics around Blue Point picnic area, and different parts of the Tertiary section together around Coon Bluff and Mt. McDowell. South of Blue Point, major E-W shear zones are present in the granitic terrain. From Bureau drillhole data, two areas containing possible abandoned meanders of the Salt-Verde Rivers may be identified by great thickness of basin fill sediments in the Mt. McDowell area.

No direct evidence for young (Quaternary) faulting was found during this study. However, a series of accordant high ridge crests resulting from erosion of young (probably late Miocene-Pliocene) basin fill sediments north of Saquaro Lake have a trend alignment very parallel to the youngest fault set known in the area. This alignment could possibly be explained by either young reactivation of this northwest fault direction in basin fill time or a complex downcutting history of streams tributary to the Salt River during the past several million years. A curious scarp-like feature was noted several miles north of Roosevelt Lake during aerial reconnaissance in May 1981. This feature appears to cut a Pleistorene surface remnant. Downstream--convergent strath terrace deposites in the region indicate that complex Quaternary climates and/or tectonics are operational.

Stratigraphy of the Northeastern Structural Block

The following is a general stratigraphic order in the map area east of the structural boundary noted in the above section of text, listed in order of increasing age:

1. river gravels related to Salt River downcutting.

2. basin fill sedments.

3. fanglomerate of Mesquite Flat with included andesite.

4. upper rhyolite-dacite flows which cap mesas

5. upper yellowish tuffs (2 patches noted).

6. NW-trending rhyolite dikes

7. white tuff series (serves as marker stratigraphic horizon).

8. andesite flows along north shore of Apache Lake.

9. series of dacite flows, ignimbrites, and tuffs, with thickening tendency eastwardly where it includes lahars and debris flows. To the west, includes vitrophyre fissure vent deposits.

10. andesite flows, flows breccias, and agglomerates.

11. rare patches of Whitetail Conglomerate, defined here as a prevolcanic, post-Laramide fluvially deposited conglomeratic series.

12. Precambrian rocks dominated by coarse grained granite but including a foliated, lineated metarhyolite (?) along the north shore of Apache Lake (perhaps equivalent to the 1700 m.y. Red Rock rhyolite of the region), and the younger Precambrian Apache Group rocks exposed at Roosevelt Dam.

Notes on the Above Units

1. River gravels related to Pleistocene incision of the Salt River are found on benches astride the modern river course at three or more levels, the highest being about 200 feet above Apache Lake level.

They are composed of small to large sub-rounded to well-rounded cobbles composed of hard quartzite and schistose lithologies, most of which can probably be derived from Apache Group and older Precambrian rocks around Roosevelt Dam and in the Sierra Anchas. Lithologies such as Mescal Limestone, Paleozoic carbonates, and volcanics are virtually absent. Only one Paleozoic gray limestone cobble was noted in the entire study area. Any attempt at quantifying the incision history of the river would require relating these gravel levels to heights above the canyon bottom, not lake level.

2. Basin fill in this report is used according to the definition set forth in Scarborough and Peirce (1978), as that sedimentary material deposited in southern Arizona basins in response to that episode of block faulting which is thought to be of primary importance in producing the modern basin and range physiography. Work thus far indicates this material in this region in between about 12 and 2 m.y. of age. Pediments cut on bedrock of the southern Mazatzals and on Superstition volcanics around Apache Lake are in this report correlated to erosion during basin filling. Some of these pediment remnants are noted on the maps.

Basin fill sediments are found as remnant patches north of Apache Lake, where they were graded to mountain front elevations of about 3,900 or 4,000 feet, all around the southern flank of the Mazatzal Mountains, at a time before initiation of incision of the Salt and Gila Rivers.

Around Saguaro Lake, they were probably deposited to elevations about 2,600 feet, but have been surface stripped down to elevations of about 1,600 feet.

The sediments comprising basin fill grade from proximal alluvial fan conglomerates with sandy channel lenses (fanglomerates) near the Mazatzal mountain front, to distal alluvial fan facies along the north shore of Saguaro Lake, consisting of pebbley sands, gravel lenses, and silty sand layers indicative of nearly main trunk stream positions of ancestral river systems. Clast lithologies north of Apache Lake are representative of Precambrian outcrops upslope along the southern flank of the Mazatzals, and upstream along the pre-canyon Salt River stream course toward Roosevelt Dam. Clast lithologies along northern Saguaro Lake presumably represent lithologies of the western Mazatzals.

Along Cottonwood Creek, 2.5 miles north of Mormon Flat Dam, the clast lithologies represented in the basin fill sediments at creek level were 80-100% Superstition volcanics in a very indurated matrix. The clast composition very quickly changes upsection to a dominance of hard Precambrian lithologies. There is also a change of source direction noted at this break, with volcanic clasts displaying pebble imbrication directions pointing toward N - NW, while the higher Precambrian clast beds display imbrication pointing toward the SW (toward means direction of stream flow). Clearly, an older sedimentation event coming off the northwest flank of the Superstition volcanic pile was eventually overridden by debrs shed off the western and southwestern flanks of the Mazatzal Mountains.

Two miles north of Horse Mesa Dam, basin fill remnants appear to have filled a fairly deep paleo channel that trends NW-SE. This could represent an old course of the Salt River before its incision to form the present canyon. The elevation of the base of basin fill at the channel bottom is about 2,600 feet, which is about 980 feet above the present river channel bottom (1,620 feet) at Horse Mesa Dam. The maximum basin fill thickness in the channel is 1,180 feet in this area north of Horse Mesa Dam. The axis of this channel nearly coincides with the axial trace of the Syncline of Goat Mountain, which could have localized the stream course to that track in basin fill time.

3. The fanglomerate of Mesquite Flat (MF on the maps), is exposed on both the Mormon Flat Dam and Horse Mesa Dam quads, and was apparently deposited in a NW-SE trending synclinal trough (see maps), with remanents exposed as far west as about one mile west of Mormon Flat Dam. An andesite flow near Tortilla Flat which concordantly underlies the fanglomerate in a one square mile area yields a 22.6 m.y. K/Ar age (UAKA 81-30). Based on this date, an erosional unconformity probably separates these two units, as discussed below.

The fanglomerate unit is well enough indurated to stand as vertical cliffs, but has a tendency to exfoliate like granite in a badlands setting.

Generally, the fanglomerate consists of a sequence of numerous thin mud flows and debris flows with a hard muddy, tuffaceous matrix and rounded to subangular blocky clasts of all sizes up to 3 feet diameter composed almost exclusively of Superstition silicic volcanic lithologies. Precambrian quartzite ad dioritic lithologies are rarely represented. Better sorted and washed fluvial units were noted only locally and occassionally.

To the northeast, the fanglomerate is seen to lap up depositionally on the Superstition volcanics in the region south of Horse Mesa Dam, but its southern limit, where examined, is a high angle fault contact with the volcanics. This fault, and others parallel to it, are the only ones that cut the fanglomerate unit. A fault involving this fanglomerate appears to pass somewhere under Mormon Flat Dam. One mile east of Mormon Flat Dat, the first mentioned fault can be demonstrated to have some reverse movement on it. The predominate movement on these faults is northeast side down, indicating a possible compressional vergence from the southwest if they are all indeed reverse faults.

The K/Ar dated andesite flow mentioned in this section concordantly underlies the fanglomerate in the area around Tortilla Flat, and is in turn underlain by perhaps 10-30 feet of laminar bedded pink-to-buff colored mudstones of fluvial origin, and then by some white colored tuffs (pyroclastic units and ash flow units) and possibly some welded dacite flows that are only exposed to the southeast. When this andesite sample was collected, it was thought that this flow would be a relatively young one, just preceeding fanglomerate deposition, or perhaps intercalated into the fanglomerate deposition cycle if one assumed that the 10-30 feet of mudstone was part of the fanglomerate. In fact, this andesite yields the oldest K/Ar age encountered in this entire study area, and hence suggests a period of erosion in the Mesquite Flat area down to the level of this old andesite prior to the deposition in the NW-SE trough of the fanglomerate of Mesquite Flat. It is assumed that the fanglomerate post dates the entire silicic sequence, and hence is probably younger than 15 m.y. in age, simply by virtue of the fact that it is seen to cut out a thick white tuff series around Fish Creek Canyon, and nowhere has any volcanics preserved above it, and yet is composed of nearly 100% Superstition volcanic lithologies.

Around where Apache Trail crosses Fish Creek Canyon the fanglomerate can be seen to thicken from a depositional pinchout in the north, to more than 600 feet, 0.7 mile southward toward the trough axis. One must wonder as to the origin of the carved trough filled with the fanglomerate. Except for the mudflow lithologies that dominate the fanglomerate, the trough reminds one of a now-abandoned river course. But fluvially-deposited gravels and sand, the earmarks of a river system, are much too rarely represented for the paleo-river hypothesis to be considered.

4. The most obvious high mesa caps around Apache Lake are a series of dense rhyolite flows with an approximate average thickness of 150-300 feet. They appear to correlate physiographically with the quartz latite flows on top of Geronimo Head (see Stuckless ASU Thesis, p. 30), a mile south of Tortilla Flat. They weather to very dark colors, but are light-colored flow rocks with quartz phenocrysts. On Goat Mountain, north-south trending feeder vents for these flows are visible. A sample of a flow from this series from Horse Mesa has a K/Ar age of 17.5 ± 0.4 m.y.*

5. Two small isolated patches of yellowish colored bedded tuffs with northerly dips rest upon unit 6 (below) on the south side of the river on the Horse Mesa Dam quad. They are erosional remnants and contain dips discordant to underlying beds. It is not determined whether they are, in fact, older or younger than the upper capping rhyolites because the two were not seen to interfinger. They could become important as chronological units if they recorded explosive activity following deposition and some appaarent erosion of the upper capping rhyolites.

Note: *The plus or minus value relates to uncertainty in the chemical analysis and in no way relates to geological uncertainty.

6. A series of N50°W-trending vertical rhyolite-dacite dikes are mapped around upper Canyon Lake (see Mormon Flat and Horse Mesa Dam quads). Three prominent ones align approximately with four dacite tuff plugs on the Mormon Flat quad. The southernmost of these plugs is visible on one of the photos. The highest strata clearly cut by these dikes is unit (7), below.

7. The white tuff series served as an easily traceable marker lithology from Goat Mountain on the east to north of Canyon Lake Marina on the west, and southward past Tortilla Flat. As seen on the maps, it interfingers with other darker colored silicic tuffs and flows in many places, but the white colors proved useful in correlations.

In the field, this series is distinguishable into well bedded units (with beds one inch to 5-10 feet thick) and more massive cliff-forming units which lack bedding when viewed from a distance. Around Horse Mesa the massive units cap the bedded units, while farther west the opposite is true in places.

The tuffs probably are recording explosive events related to ignimbrite-forming events. To what extent these tuffs, especially the massive ones, are "caldera fill", or simply phyroclastic deposits which blanketed open countryside cannot be determined without more regional mapping. Some of the better bedded units are reminiscent of typical base surge deposits, while some of the more massive units appear to be primary air fall ashes grading lithologically into unwelded ash flows.

The eastern limit of the white tuff series south of Apache Lake is a north-south line passing just east of the edge of the highest mesas of Horse Mesa, 2.5 miles west of Apache Lake resort. This limit appears to be a depositional pinch-out against what was then higher country to the east composed of unit 8 tuffs and lahars. However, north of Apache Lake, the white tuffs extend eastward at least one mile into the slump terrain east of Goat Mountain. This outcrop pattern of the white tuffs is thus displaced about 3 miles eastward when crossing northward across Apache Lake, a most curious offset. Whether any tectonic affect or simple erosional removal of the white tuffs south of Apache Lake are needed to account for this offset was not determined in the course of this study.

The white tuffs are in excess of 700 feet thick in the Painted Cliffs area along the northern shore of Apache Lake, but farther south and west are 100 - 200 feet thick, and are seen to pinch out depositionally in several areas to the south and west of Apache Lake.

8. Immediately under the white tuffs both north and south of Apache Lake is a thin section of andesite flows, agglomerates and pyroclastics. These are not well exposed except along the banks of Apache Lake. These appear to be separated from the lower thick andesites by a series of brown tuffs and lahars seen clearly along the Painted Cliffs - Goat Mountain area. The thickness of this unit is 100 - 240 feet. Farther west just below Horse Mesa Dam, an andesite exposed at river level may correlate to this unit or to the basal andesites (9 below). Andesites under the fanglomerate of Mesquite Flat around lower Canyon Lake bear un unknown relation to the andesites around Apache Lake, but appear to be stratigraphically higher since they rest on top of white tuff units.

9. Under the white tuff series is a very diverse assemblage of rock types which must be lumped into an "older" category for the purpose of this report because of insufficient time to work out the stratigraphic details between the units.

Along Horse Mesa, particularly around the eastern end lies a very thick (1200 - 1500 feet estimated) series of massive tuffs, unwelded ash flows, with abundant detrital deposits such as lahars, mudflows, and debris flows. No attempt was made to break out all the various units because of the time involved in the task. Members of this series can be tracked westwardly to very near Horse Mesa Dam but in that area strata in this position consist of bedded vitrophyre flows of gray, black, and green colors and of probably rhyolite-dacite composition.

Farther west along Canyon Lake, the white tuffs rest on a very diverse assemblage of: a) rhyolite-dacite flows and tuffs, including some ignimbrites, b) a large mass of fissure-type eruptive masses of vitrophyre in the region surrounding El Recortado Butte-Sheep Mountain, and c) a series of circular vents probably filled with intrusive tuffs and flow material which have erupted through the above units. Three of these are found along a N 40° W trend and are seen along the western side of Sheep Mountain. One mile up Cottonwood Wash, in the area about 1 to 1.5 miles north of Mormon Flat Dam, these vitrophyres lie on Precambrian granite in what is probably a badly sheared depositional contact. Near-vertical flow foliation trends in the vitrophyre terrain are generally ENE-WSW, and are indicated on the maps. It is suggested that a tract of land 3 miles (N-S) by 6 miles (E-W), and centered near the northern limit of El Recortado Butte is dominated by those vitrophyres. They must represent a major fissure-type intrusive-extrusive event which occurred near the northern boundary of the Superstition volcanic field. These rocks certainly deserve more attention in future work, particualarly their placement in time with respect to any caldera cycle represented in the area.

An unwelded rhyolite-dacitic ash-flow belonging to category (a), above, along the south shore of Saguaro Lake, and being almost the highest stratigraphic unit preserved beneath the fanglomerate of Mesquite Flat in this area, yields a K/Ar age of 15.4±0.4 m.y. (UAKA 80-128). If this interpretation is correct, this is further evidence that the fanglomerate is post 15 m.y. in age (see section 3, discussion on the fanglomerate).

10. The earliest known volcanic rocks of the northeastern Superstition volcanic field are a series of andesite flows, flow breccias, agglomerates, and interbedded red-colored fluvial sediments. These rocks are exposed well at the base of the section around the east end of Horse Mesa. Here they appear to vary in general thickness from 200 to perhaps 800 feet. Along the south shore of Apache Lake, they continue to be exposed to just west of Camp Waterdog, but in this eastern interval are in high angle fault contact with Precambrian granites to the south and the east. The red-colored fluvial sediments which are interbedded into the andesites are exposed at several locations along the south shore of Apache Lake both west and east of Apache Lake resort. They are colored dark shades of red and red brown and where examined were fluvial floodplain and distal alluvial fan facies. A nice section of these sediments is seen on the promintory along the south side of the Lake about 0.6 miles west of the water tank at Camp Waterdog. Included in the sediments here are river overbank silts and sands which must have been deposited by a fair

sized stream system. They overlie andesite flows, and are now in high angle fault contact with various andesitic pyroclastic units.

An andesite flow from the shores of Apache Lake at the resort, representing the stratigraphically lowest flow noted in the Horse Mesa area, was K/Ar dated at 21.4 m.y. (UAKA 81-31).

The andesitic unit contains abundant examples, especially towards its eastern limit, of cinder deposits with some steep initial dips still intact. These are seen in the same terrain as andesite flows, mudflows, debris flows and probable lahars of orange-brown color. A small remnant of what must be an old rhyolite-dacite ash fall deposit is seen in a small cove along the south shore of Apache Lake about 0.7 miles SW of the Camp Waterdog water tower. This material is beautifully bedded and may represent base surge of an explosive eruptive event.

It is questionable whether these oldest andesites, seen to be depositional on Precambrian granite along eastern and southern Horse Mesa, are represented <u>anywhere</u> to the west in this study area, except the andesite flow at Tortilla Flat under the fanglomerate. The general stratigraphic feel of this author is that the andesites found to the west in this study area still have more volcanics under them and hence reside somewhere above these oldest andesites in the section. This is because elsewhere in Southern Arizona andesites and dark-colored redbeds are typical of Oligocene-aged sections, very similar to the eastern Horse Mesa section, while the andesites in the western part of this field area do not contain interbedded redbeds. Perhaps the andesites and redbeds seen one mile south of Apache Gap (along Apache Trail) which reside at the base of the volcanic section there are equivalent to these older andesites. No. K/Ar ages are known to this author from any of these andesites, and none are given by Sheridan (1978, GSA guidebook to Central Arizona, P. 86). However, near Lake Pleasant, an andesite at the base of a volcanic section there which rests upon Yavapai Schist dates at 27 m.y. (Scarborough and Wilt, 1979). Also, an andesite seen at Blue Point forest camp, a few miles below Stewart Mountain Dam, along the north side of the River, was deposited against a colluvial slope built on Precambrain granite and was covered with an unwelded ash flow. The andesite dates at 18.1 m.y.

(UAKA 77-144). An andesite at the base of the exposed tuff section at the north shore of Saguaro Lake dates at 18.3 m.y. (UAKA 77-145), and an andesite one mile north of Stewart Mountain dates at 15.5 m.y. (UAKA 77-146). So around Saguaro Lake the oldest andesites are no older than about 19 m.y. Similarly, an andesite flow which apparently blanketed an already tectonically disturbed terrain of Superstition tuffs dates at 18.3 m.y. (this locality is 0.6 miles NW of where Apache Trail crosses Apache Gap). See Shafiqullah, et. at. (1980 Ariz. Geol. Soc. Digest, vol 12, pp. 252-256) for the cited dates.

11. The Whitetail Conglomerate was first defined in the Globe area by early works of Ransome as a conglomerate which was deposited before the initiation of mid-Tertiary volcanism since it contains no clasts of any of these rocks. Sediments corresponding to this group have since been recognized throughout Arizona, including the "rim gravels" along the southern Mogollon Rim (see Peirce, et. al., 1979, Tectonophysics 61, p. 1-24), and a complex assemblage of basinal deposits, generally of red-brown and other bright colors, in the southeast part of the state. Sediments of this category were only noted at one locality in the study area, as a 50 foot thick channel deposit about 2.0 miles upstream from Horse Mesa dam on the south shore of Apache Lake. The deposit is made of red-brown colored fluvial channel gravelly sands, with pebble imbrication directions pointing to a flow direction toward the north to northwest, around the west side of the Mazatzal Mountains, which may or may not have been present as a positive area at this time. The only other pre-volcanic conglomerates noted are redbeds 2 miles south of Blue Point picnic area, and also along Apache Trail at the base of the volcanic section, outside this study area, perhaps 6 miles north of Apache Junction. The redbeds noted in paragraph 9 above, contain abundant andesite clasts, and hence do not predate volcanism in the region. However, these could be part of the same general cycle of sedimentation.

12. Precambrian basement lithologies are noted on the maps in the general way. The vast majority of the Precambrain rocks of the study area are a biotite ± chlorite bearing quartz monzonite with large phenocrysts of potash feldspar. Another lithology noted was an altered metarhyolite (?) with an aphanitic ground mass and quartz ± potash feldspar phenocrysts up to 2 mm diameter,

exposed along the north shore of Apache Lake in an altered red-brown color, and along the River below Stewart Mountain Dam near the Blue Point forest camps in a less altered state with bluish colored quartz phenocrysts. North of Goat Mountain, the Superstition volcanics are deposited and faulted against a metarhyolite complex which is foliated and lineated. The foliation where observed strikes E-W and dips shallow to the north. The contact between these rhyolites and the granite were not observed.

The granitic terrain contains the expected variety of dikes, including quartz-rich pegmatites and bull quartz veins and veinlets, pinkish stained aplite dikes and some pods resembling alaskites. Diabase intrusions are common in the granitic terrain, especially in the few miles below Roosevelt Dam in the granitic terrain underlying the Apache Group sediments. The diabase appears to not outcrop farther west than 3-4 miles downstream from Roosevelt Dam, with the farthest west outcrop in the study area being along Chukar Wash, perhaps 3 miles east of Goat Mountain.

The granite is hydrothermally altered in a small area 0.5 miles upstream of Camp Waterdog, along the south shore. The feldspars are altered intensely to clays and the rock is now very punky. Local brecciation and chloritization effects in the granite, are noted in an area 1-2 miles south of the Blue Point picnic area. The brecciation may relate to a WNW fault zone involving granite and volcanics in the area.

Fracture trends in the granite are noted on the maps. Northwest and northeast trends are most common, with very often the course of the Salt River channel paralleling one of the more obvious fracture trends in any given area. Below Roosevelt Dam a short distance, a silicified fissure zone in the granite which exactly parallels the trend of the river channel (N40°E) stops abruptly at the base of the Apache Group sediments.

Prominent shear zones are noted in the granite that trend E-W, 1-2 miles south of Blue Point picnic area, and that trend about N70°W in northern Arizona Dam Butte, about 0.5-1.0 miles NW of the Orme Dam site. These are vertically oriented where observed. It is hard to gauge the age of these, but it should be noted that they are roughly parallel to a prominent fault mapped just west of the Blue Point picnic area which juxtaposes granite on the south with Superstition andesites on the north. This fault has unknown true displacement, but may, by guess work, have considerable strike-slip movement, which must be post-18.1 m.y. in age.

Just north of Saguaro Lake, about 1.0 mile north of Stewart Mountain Dam two different lithologies are noted on the map in the granites. They are separated by a strongly schistose zone which trends east-west. A zone of foliated granite is found in the area map. The exact contact here between foliated and non-foliated granite was not located in this latter area.

In terms of regional correlations, this granite very much resembles the Ruin Granite and Oracle Granite found east and south of here by nearly 90 miles. These rocks have been repeatedly dated at about 1350-1450 m.y. of age, and have been regionally likened to equivalent lithologies found along the trans-continental arch in the eastern part of the continent. Another series of older granites is known in the Central Arizona Region which are finer grained, more equigranular, and usually more red in color, such as the Payson granite. These date at 1650-1750 m.y. of age, but were not noted in this study area.

The Precambrian rhyolites in the study area may be equivalent to the Red Rock rhyolite found north and east of here. This rock has been dated at about 1715 m.y. of age in at least two places, and is likely a volcanic (arc ?) assemblage found beneath a metasedimentary sequence termed the Mazatzal Series and the Hess Canyon Series. The diabase intrusions noted downstream of Roosevelt Dam are most likely equivalent to those elsewhere which intrude rocks as young as the Troy Quartzite and date at 1100-1200 m.y.

A series of pediment surfaces have been incised into the easily weathered Precambrain granite where it is extensively exposed. These are indicated on the maps. They are especially well developed around Stewart Mountain in the west, and surrounding Camp Waterdog in the east. They are graded to the 40 foot terrace level (Blue Point), and hence have been developing only since the river's position has somewhat stablized, probably within the past 2 or so million years. Pediment remnants are noted on high levels of Superstition volcanics which presumably were graded to high level positions of basin fill deposits deposited against the southern Mazatzal Mountains at or near 4000 feet of elevation. No equivalent levels of pediments on granites in the region were noted.

Stratigraphy of the Southwestern Structural Block

West of the major structural boundary already noted, the gross lithologies present are in sharp contrast to those already discussed. The main stratigraphic succession is not as apparent because of much NW-SE trending faulting which has presumably served to repeat much of the stratigraphy. In the main mass of the Goldfield Mountains south of Stewart Mountain Dam, one is impressed by what first appears to be a very thick sequence (measured in terms of miles) of alternating very dark brown and yellowish weathering tuffs and flows. Upon closer scrutiny, it appears more likely that a succession of these volcanics has been repeatedly faulted and tilted to the northeast to cause the present picture.

Within the area of the Goldfield Mountains the yellowish bedded materials are very light to white-colored, laminar bedded air-fall ashes, thicker nonbedded tuff beds, including some fluvially reworked pyroclastics, and some mudflow or lahar-like units which lack internal bedding but are laminar bedded on the whole. The units that weather to very dark colors, where examined, are a complex assemblage of massive dacite lgnimbrites (unwelded ash flows), some welded units, and some vitrophyre flows.

The original thickness of this assemblage, if faulted, is not immediately apparent, but may not exceed 1000-2000 feet or so. A K/Ar age date done for this report on a flow-banded rhyolite in the tilted section (UAKA 80-126) is 19.2±0.5 m.y. Because of faulting, the exact stratigraphic position in the sequence of this flow was not determined, but it certainly has 500-1000 feet of strata above it.

The stratigraphic succession above this tilted section is recognized as basically four-fold, consisting of: a) intrusive domes and sills of dacites/latites, b) some deformed fanglomerate off the map area which are probably equivalent to the fanglomerate of Mesquite Flat, c) a younger faulted basalt flow as a mesa cap in the south, and d) undeformed basin fill sediments in the north around Stewart Mountain.

A variety of intrusive domes, not examined in detail for this report, are reported by various ASU M.S. theses authors (Stuckless, Fodor) to intrude the Goldield Mountains. A large one appears to reside approximately in the position indicated by Fodor in the Goldfield Mountains as viewed from the air. A volcanic mass thought by Dr. Michael Sheridan of ASU to be a late-stage dome at Apache Gap on Apache Trail gives a K/Ar age date of 20.6 m.y. (UAKA 68-16). This author on a brief visit could not assess the stratigraphic order in the area enough to convince himself that the 20.6 m.y. rock was either a late stage feature, or was, in fact, part of the main mass of volcanic strata which comprise the area, but the 19.2 m.y. age above on the stratified sequence suggests <u>perhaps</u> that the 20.6 m.y. rock may be older, and hence not intrusive into the tilted rocks.

A small obvious outcrop of highly contorted fanglomerate, thought to be perhaps equivalent to the fanglomerate of Mesquite Flat, outcrops just west of the obvious basalt-capped mesa south of Canyon Lake, on the Goldfield quad, at First Water Ranch. This area was seen only from the air and needs to be ground checked, but there appears to be a nestled outcrop of fanglomerate, highly contorted into a N-S elongate synform, resting unconformably upon more highly deformed yellow and dark brown tuff outcrops. The homoclinally dipping basalt-capped mesa just east of here is cut by a high angle fault but obviously escaped the tectonics which warped these older units. The mesa capping basalt K/Ar dates at 14.2 m.y. As mentioned earlier, this is the only outcrop seen in this study of fanglomerate probably equivalent to that of the fanglomerate of Mesquite Flat found in the southwestern structural block of this entire study area. The mapping of this area becomes important in establishing stratigraphic and tectonic order in the region.

The youngest volcanic rocks in the study area based on degree of tectonic involvement and stratigraphic context are two thin basalt flows which cap Hackberry Mesa and Black Mesa, south of Canyon Lake. A sample of this lithology from the extrene north of Hackberry Mesa has been K/Ar dated at

14.2±0.5 m.y. (UAKA 80-129). This mesa has been cut by a NNW trending high angle normal fault, with west side down by about 150 feet. Stuckless (1969 ASU thesis) suggested that lahars of the Superstition volcanics overlie these basalts (p. 34 of that thesis). This author did not critically examine the juxtaposition of the basalt and a knob of sedimentary material mapped on the mesa, but assumed that the knob was an "island" of older material around which the basalts flowed. The K/Ar determination indicates that the latter hypothesis is correct. The K/Ar date also tests the "Black Mesa caldera" hypothesis of Stuckless since the basalts capping this mesa are inferred by him to be part of the normal caldera fill cycle since it is at the geometrical center of this caldera. The tilted rocks of the Goldfield Mountains date no younger than 19.2 m.y., and were homoclinally tilted by a large-scale event before the extrusion of the 14.2 m.y. basalt. This information suggests the basalts are not part of that caldera, but belong to a younger time and assumed different tectonic environment. Note that in central Arizona, generally northwest of here extending north of the Mingus Mountain area, west of Verde Valley, are outpourings of the so-called "Hickey basalts", well dated now at between 15 and 10 m.y. of age. This basalt-capped mesa is likely to be the farthest southeast remaining outcrop of these basalts, based on this new K/Ar age.

Scarborough and Wilt (1979, p. 71) report K/Ar ages of 14.7 and 14.8 m.y. for 2 samples of basalt that cap New River Mesa, 6 miles north of Cave Creek, which are probably closely related stratigraphically to the basalts capping Hackberry Mesa.

One or two miles east of Stewart Mountain, north of Saguaro Lake are extensive exposures of sediments interbedded with and overlying Superstition volcanic flows. An older, more lithified series of these sediments are conglomerates with predominate volcanic clasts. Some are mixed with and others overlie the volcanics with a slight discordance, and both the sediments and volcanics are tilted northward away from Saguaro Lake at about 15-20 degrees. The upper of these conglomerates grades quickly stratigraphically upward into a fluvial conglomerate-sand series with predominate hard Precambrain clast lithologies and with no northward tilt. However, this upper series appears involved in one or more small amplitude northwest trending asymmetric folds or nomoclines, seen on the map. One to two miles farther north are a series of high ridges with exposures of higher level basin fill sediments, apparently not deformed by folding. The record here seems to be a folding event along an east-west axis centered through what is today Saguaro Lake involving the Superstition volcanics and overlying fanglomerate, followed by continued sedimentation with Precambrian rocks in source areas, followed by much milder folding and still continued sedimentation of upper Basin Fill units. All this tectonic activity presumbaly postdates or is synchronous with the earlier sediments in this area. A basalt from the base of the exposed volcanic section at the north end of Saguaro Lake dates at 18.3 m.y. (UAKA 77-145), and gives a maximum age for the disturbance. An approximate axis alignment of this fold, here called the anticline of Saguaro Lake, is shown on the maps.

Further Notes on the Tilted Terrain

The most obvious distinctive feature of the rocks involved in the tilted terrain of the Goldfield Mountains is the alternating light yellow and dark brown weathering colors. This characteristic is easy to track in the area, and certainly allows one to place a northeast boundary on the extent of these rocks through the western part of Canyon Lake as shown on the maps. It is not so clear, however, what happens to these lithologies in the southeast direction as one goes from the southern part of Canyon Lake toward Geronimo Head. The rocks that comprise Geronimo Head do not weather to these colors and they are not homoclinally tilted. Three possibilities exist for this relationship: 1) the Geronimo Head rocks are nontilted facies of the tilted rocks farther north and west, 2) the units around Geronimo Head comprise a sequence which effectively, if not actually, overlies the tilted rocks, as suggested by Stuckless (ASU MS, p. 29) and was deposited post-tilting, and 3) in the event that (2) above is correct, it remains to be established whether or not the Geronimo Head units are more genetically linked to the tilted rocks or to the units of the northeastern structural block, as previously discussed. Only more field work could narrow down the possibilities.

The northwestern Goldfield Mountains southwest of Stewart Mountain Dam were examined for faulting style. The faults which were most obvious were oriented about N65-80°W and were consistently down on the south side. Some clearly were arcuate in cross-section, shallowing with depth with decreased southerly dip angles going down the fault plane. However, the strike direction on the volcanic beds which are homoclinally tilted in this area is much more N35-50°W. If this tilt pattern was produced by listric faulting, this would require movement along faults whose mean orientation is strike-parallel to the beds. None of these strike-parallel faults were noted during the brief examination of the area. However, faults of this orientation and SW side down displacement are noted on the recon maps by Fodor and Sheridan (1978 guide book).

The large fault mapped about 2.2 miles due south of the Blue Point picnic area is typical of the faults in this area. An upper mass of Superstition dacitic tuffs depositionally lies on granite on the SW flank of the hill in the area, with the contact dipping 40-50°NE under the hill. On the NE flank of the hill, a normal fault contact which juxtaposes granite against tuffs strikes about N70°W and dips 50-60°SW. However, the strike direction of the tuffs is about 30-40° more northerly than the strike of the fault. If this fault is a downward-bowing listric fault responsible for the tilt on the volcanics, then this outcrop area probably resides near the northwest extent of the fault outcrop which on a larger scale bows concave in plan view to the southwest.

Another fault which trends about N70°W, and lies about 1.8 miles SW of Stewart Mountain Dam lies in a similar geometric setting to the above fault, except the fault plane consistently dips about 80°NE, and hence has apparent reverse offset, as indicated on the map. This fault may record either real reverse movement, or normal distensional movement with superimposed rotation of the fault plane due to perhaps folding as witnessed by the nearby anticline of Saguaro Lake. Clearly, the tectonic story in this region shall only be unraveled by detailed mapping in the area.

Structural Geology

The major structural features uncovered in this area are a series of generally east-west trending folds and at least three generations of faults affecting the Superstition volcanics and related sediments.

Folds

A series of fold structures were noted in the volcanic terrain. Not all of these are necessarily denoting compressive tectonics; some of the synclines could be basins or depocenters caused by a variety of factors. But they are shown on the maps with the normal fold symbology. The following are recognized:

1. syncline of Mesquite Flat
2. anticline of Lewis and Pranty Creek
3. syncline of Goat Mountain
4. anticline of Saguaro Lake
5. monocline of Tonto Basin

Syncline of Mesquite Flat

This synformal structure is a WNW-ESE elongate depositional center of the fanglomerate of Mesquite Flat. Along its northern flank the fanglomerate clearly laps up on to the older volcanics to the north. Its southern flank, where examined, is a high angle fault contact of the fanglomerate with older volcanics to the south. Dips of beds within the fanglomerate rather well define a synform. Whether or not there was a structurally produced snycline which then filled with fanglomerate entering from all sides could not be determined.

The axis of the syncline coincides with a erosionally carved channel filled with up to 500 feet of fanglomerate, but the issue of what localized the erosion to that area, while unanswered, may well have been a synclinal warp.

To the west, the outcrop pattern of the fanglomerate along the synclinal axis is disrupted by a NW-trending fault, where the axis appears offset left-laterally along the fault, about 0.5 miles east of Tortilla Flat. The outcrops of the fanglomerate west of this area become progressively structurally disturbed and the obvious trace of the syncline axis is lost around Canyon Lake.

Anticline of Lewis and Pranty Creek

The west-flowing Lewis and Pranty Creek appears to coincide very nearly with an anticlinal axis involving Precambrian granites on the east, an older tuff series dipping away from the axis 20° on both flanks of the fold, and the white tuff series, dipping away from the axis about 5-10° on the north flank only (being removed and/or covered by the younger fanglomerate on the south flank). The axis was not tracked westward past Fish Creek and quickly disappears eastward in the Precambrian granite terrain.

Syncline of Goat Mountain

A synform, plunging several degrees westward, was noted in the volcanic stratigraphy trending WNW-ESE, with axis about a mile or so north of the center of Apache Lake. Dips toward the axis average 5-10°. The axis can be tracked from Goat Mountain in the east to north of Horse Mesa Dam in the west, where it dives, along with the involved stratigraphy, under a cover of basin fill sediments. It could not be seen to emerge on the west side of this area, mostly due to poor exposures.

The northern extent of the Superstition volcanic field in this area consists of a faulted depositional contact of volcanics on Precambrian terrain of the southern Mazatzals. North of Horse Mesa Dam, several facies in the volcanic strata can be seen which imply depositional pinchout against a Precambrian high to the north and northeast. However, around Goat Mountain, farther east, a series of high angle E-W faults have juxtaposed the two series, and 100 feet wide fault slices of Precambrian metarhyolite interleaved with volcanic slices imply more than just minimal fault readjustment in the area. This faulting could relate temporally with the formation of the syncline of Goat Mountain. See photo for illustrations of the contact.

Immediately east of Goat Mountain lies a chaotic slump terrain (north of Apache Lake), which limits exposures of the syncline of Goat Mountain to the east. Farther east, across the lake, around Camp Waterdog, basal Superstition andesites are downthrown against granite along a large N30°E trending fault, which is today's absolute SE boundary of the volcanics in that area.

Anticline of Saguaro Lake

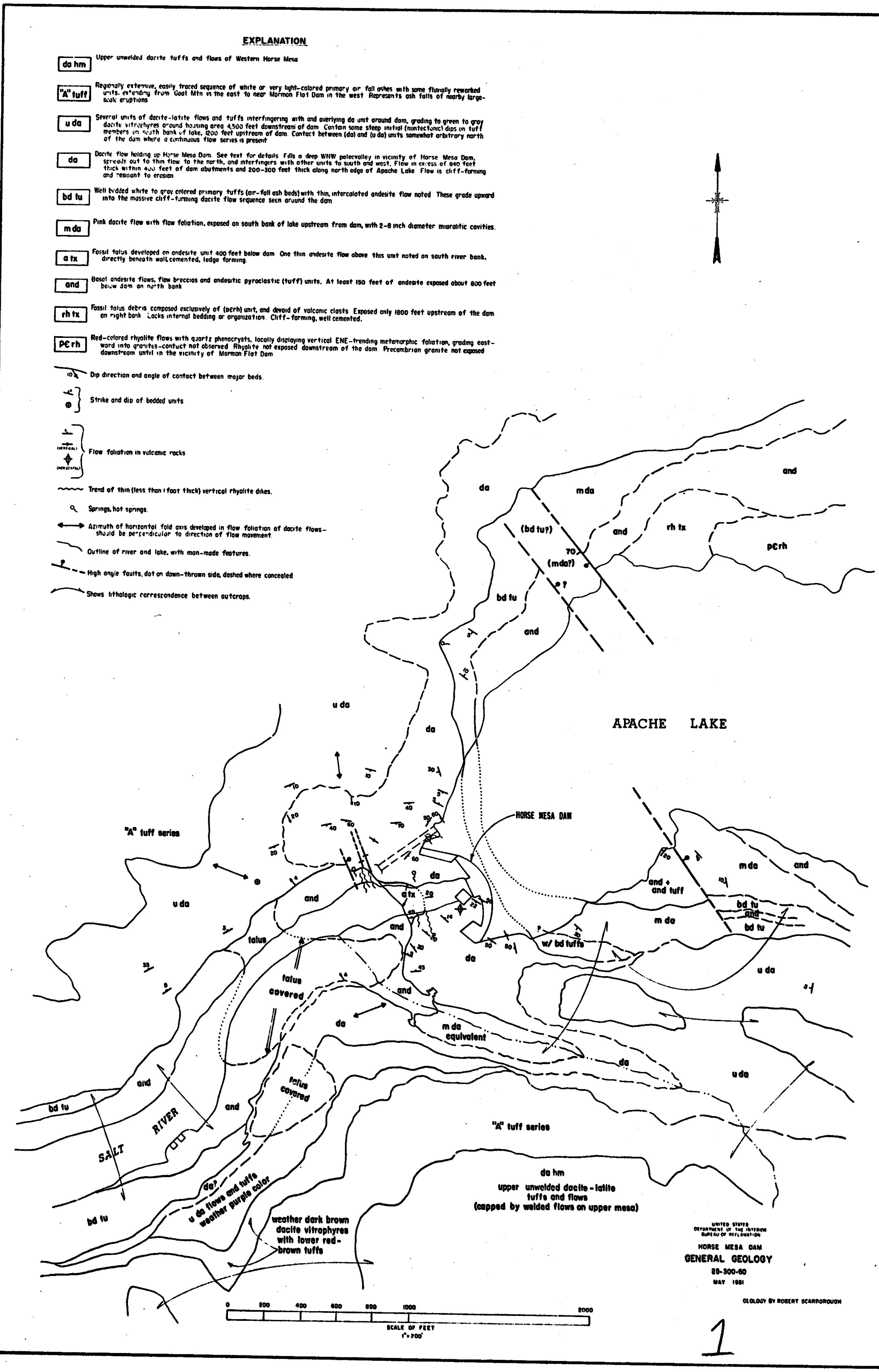
Exposures of Precambrian granite along a narrow east-west zone centered through Saguaro Lake mark the trace of the axis of this fold-like structure. Along its northern flank, the basal contact of the volcanics on granite and the stratified volcanics themselves dip 15-40° northward, and the contact is sheared in places while not in others. The south flank of the fold in the west; however, is composed of a southward dipping fault contact with granite under a section of stratified volcanics which strike into the fault and are truncated by it. These are the yellow and brown volcanics of the tilted terrain of the Goldfield Mountains.

With this relationship one probalby needs to apply at least a two stage deformational model to this area. An earlier event, perhaps of listric faulting causing an initial 15-20° of homoclinal NE tilt to these stratified rocks, could well have been overprinted by N-S compression forming the E-W directed fold which produced the dips on the north flank, and modified the south flank by shearing along the volcanic-granite contacts. However, it was noticed that the dips in the south flank rocks increase toward the anticlinal axis up to 50° or so near the axis. If a simple anticlinal fold had affected these rocks, then their dips would have decreased, not increased toward the fold crest. Hence Listric faulting appears to be involved. See the cross-sections accompanying the maps for illustrations of this problem. The dip data can be most easily explained by variations of amount of listric rotation in different areas, subsequently modified by shearing along the basal volcanic contact during formation of the Saguaro Lake anticline.

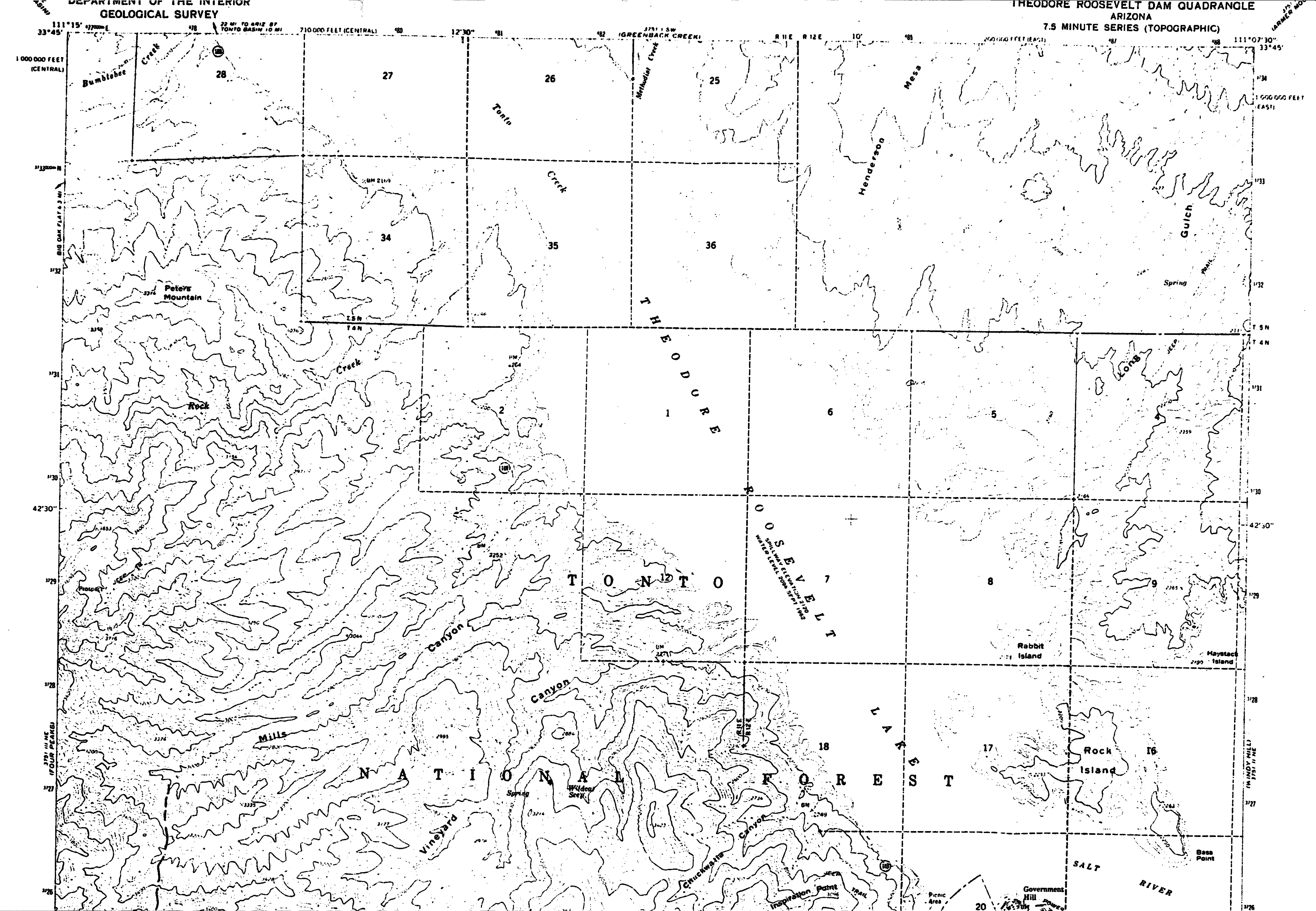
The Saguaro Lake anticline could not be tracked east of the high angle reverse faults one mile east of Mormon Flat Dam, where the stratigraphy changes, or west of Stewart Mountain Dam into the Precambrian granite terrain around Stewart Mountain.

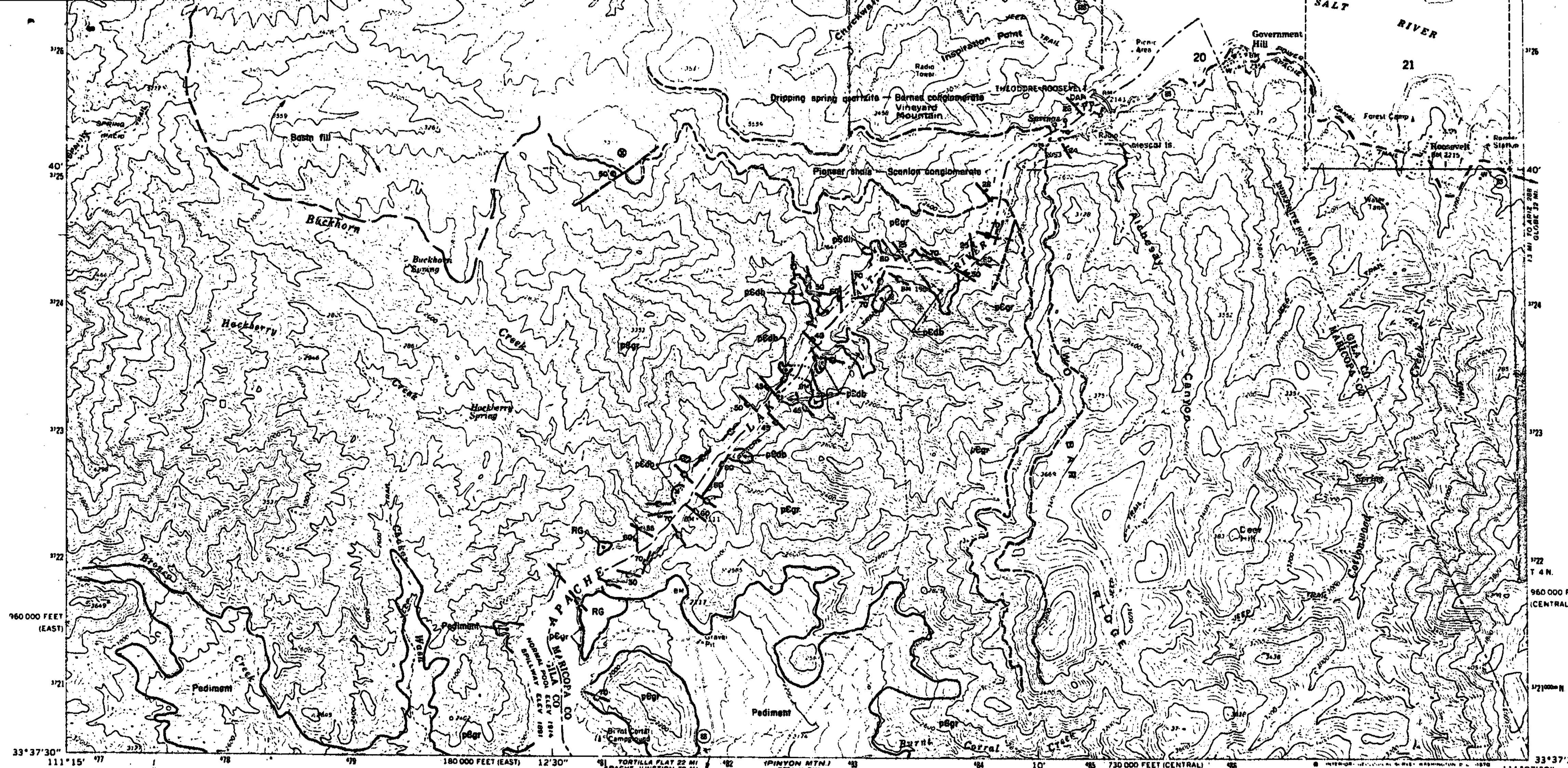
Monocline of Tonto Basin

Outcrops of Apache Group sediments around Roosevelt Dam contain 25° eastward dips. To the east in the Sierra Ancha extensive outcrops of the Apache Group


EXPLANATION
da hm — Upper unwelded dacite tuffs and flows of Western Horse Mesa
"A" tuff — Regionally extensive, easily traced sequence of white or very light-colored primary air fall ashes with some fluvially reworked units, extending from Goat Mtn in the east to near Mormon Flat Dam in the west Represents ash falls of nearby large-scale eruptions
u da — Several units of dacite-latite flows and tuffs interfingering with and overlying da unit around dam, grading to green to gray dacite vitrophyres around housing area 4,500 feet downstream of dam Contain some steep initial (nontectonic) dips on tuff members on south bank of lake, 1200 feet upstream of dam. Contact between (da) and (u da) units somewhat arbitrary north of the dam where a continuous flow series is present
da — Dacite flow holding up Horse Mesa Dam. See text for details Fills a deep WNW paleovalley in vicinity of Horse Mesa Dam, spreads out to thin flow to the north, and interfingers with other units to south and west. Flow in excess of 840 feet thick within 400 feet of dam abutments and 200-300 feet thick along north edge of Apache Lake Flow is cliff-forming and resisant to erosion
bd tu — Well bedded white to gray colored primary tuffs (air-fall ash beds) with thin, intercalated andesite flow noted These grade upward into the massive cliff-forming dacite flow sequence seen around the dam
m da — Pink dacite flow with flow foliation, exposed on south bank of lake upstream from dam, with 2-8 inch diameter miarolitic cavities.
a tx — Fossil talus developed on andesite unit 400 feet below dam One thin andesite flow above this unit noted on south river bank, directly beneath wall, cemented, ledge forming.
and — Basal andesite flows, flow breccias and andesitic pyroclastic (tuff) units. At least 150 feet of andesite exposed about 800 feet below dam on north bank
rh tx — Fossil talus debris composed exclusively of (pЄrh) unit, and devoid of volcanic clasts Exposed only 1800 feet upstream of the dam on right bank Lacks internal bedding or organization. Cliff-forming, well cemented.
pЄrh — Red-colored rhyolite flows with quartz phenocrysts, locally displaying vertical ENE-trending metamorphic foliation, grading eastward into granites-contact not observed Rhyolite not exposed downstream of the dam Precambrian granite not exposed downstream until in the vicinity of Mormon Flat Dam
Dip direction and angle of contact between major beds.
Strike and dip of bedded units
Flow foliation in volcanic rocks
(VERTICAL)
(HORIZONTAL)
Trend of thin (less than 1 foot thick) vertical rhyolite dikes.
Springs, hot springs.
Azimuth of horizontal fold axis developed in flow foliation of dacite flows-should be perpendicular to direction of flow movement.
Outline of river and lake, with man-made features.
High angle faults, dot on down-thrown side, dashed where concealed
Shows lithologic correspondence between outcrops.
da
m da
and
rh tx
pЄrh
(bd tu?)
70
(mda?)
bd tu
and
u da
da
APACHE LAKE
HORSE MESA DAM
"A" tuff series
u da
and
a tx
da
talus
talus covered
and
da
m da equivalent
w/ bd tuffs
and + and tuff
m da
bd tu
and
bd tu
u da
da
u da
and
bd tu
SALT RIVER
and
talus covered
"A" tuff series
da hm
upper unwelded dacite-latite tuffs and flows
(capped by welded flows on upper mesa)
da?
u da flows and tuffs weather purple color
weather dark brown dacite vitrophyres with lower red-brown tuffs
bd tu
0 200 400 600 800 1000 2000
SCALE OF FEET
1" = 200'
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HORSE MESA DAM
GENERAL GEOLOGY
28-300-60
MAY 1981
GEOLOGY BY ROBERT SCARBOROUGH
1

1


DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
THEODORE ROOSEVELT DAM QUADRANGLE
ARIZONA
7.5 MINUTE SERIES (TOPOGRAPHIC)
111°15'
33°45'
111°07'30"
33°45'
1 000 000 FEET (CENTRAL)
710 000 FEET (CENTRAL)
12'30"
10'
42'30"
(GREENBACK CREEK)
(FOUR PEAKS)
(WINDY HILL)
BIG OAK FLAT 4.3 MI
Bumblebee
Creek
Tonto
Creek
Methodist Creek
Henderson
Mesa
Gulch
Spring
Peters Mountain
Rock
Creek
Long
Canyon
Canyon
Mills
Vineyard
Spring
Wildcat Seep
Chuckwalla
Canyon
Inspiration Point
Picnic Area
Government Hill
THEODORE
ROOSEVELT
LAKE
SPILLWAY ELEVATION 2150
WATER LEVEL 2086 SEPT 1962
TONTO
NATIONAL
FOREST
Rabbit Island
Haystack Island
Rock Island
Bass Point
SALT
RIVER
R 11 E
R 12 E
T 5 N
T 4 N
28
27
26
25
34
35
36
2
1
6
5
12
7
8
9
18
17
16
20



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1962. Field checked 1964

Polyconic projection. 1927 North American datum
10,000-foot grids based on Arizona coordinate system, east and central zones
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Fine red dashed lines indicate selected fence lines

Where omitted, land lines have not been established

Areas covered by dashed light-blue pattern are subject to controlled inundation

UTM GRID AND 1964 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

GEOLOGY BY UNIVERSITY OF ARIZONA GEOLOGISTS AND BUREAU OF RECLAMATION GEOLOGISTS

				61
66	65	64	63	62

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

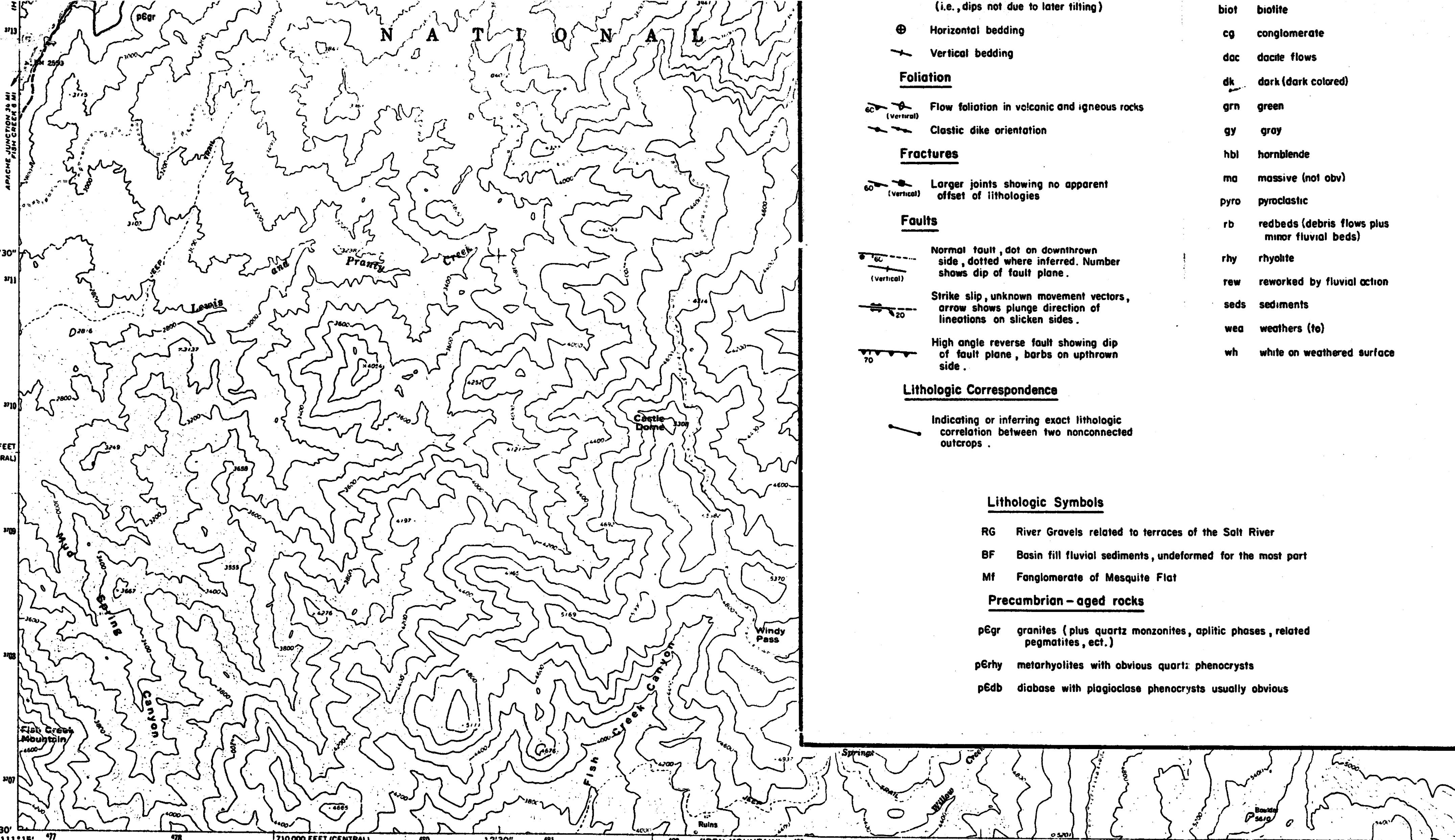
SALT RIVER PROJECT

REGIONAL GEOLOGY

25–300–61

MARCH 1981

2



(i.e., dips not due to later tilting)

⊕ Horizontal bedding

Vertical bedding

Foliation

60 (vertical) Flow foliation in volcanic and igneous rocks

Clastic dike orientation

Fractures

60 (vertical) Larger joints showing no apparent offset of lithologies

Faults

60 (vertical) Normal fault, dot on downthrown side, dotted where inferred. Number shows dip of fault plane.

20 Strike slip, unknown movement vectors, arrow shows plunge direction of lineations on slicken sides.

70 High angle reverse fault showing dip of fault plane, barbs on upthrown side.

Lithologic Correspondence

Indicating or inferring exact lithologic correlation between two nonconnected outcrops.

biot	biotite
cg	conglomerate
dac	dacite flows
dk	dark (dark colored)
grn	green
gy	gray
hbl	hornblende
ma	massive (not obv)
pyro	pyroclastic
rb	redbeds (debris flows plus minor fluvial beds)
rhy	rhyolite
rew	reworked by fluvial action
seds	sediments
wea	weathers (to)
wh	white on weathered surface

Lithologic Symbols

RG	River Gravels related to terraces of the Salt River
BF	Basin fill fluvial sediments, undeformed for the most part
Mf	Fanglomerate of Mesquite Flat

Precambrian – aged rocks

p€gr	granites (plus quartz monzonites, aplitic phases, related pegmatites, ect.)
p€rhy	metarhyolites with obvious quartz phenocrysts
p€db	diabase with plagioclase phenocrysts usually obvious

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Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1962. Field checked 1964

Polyconic projection. 1927 North American datum

10,000-foot grids based on Arizona coordinate system, central and east zones

1000-metre Universal Transverse Mercator grid ticks, zone 12, shown in blue

Where omitted, land lines have not been established

UTM GRID AND 1964 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

GN MN 0°06' 2 MILS 14° 249 MILS

SCALE 1:24 000

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 KILOMETRE

CONTOUR INTERVAL 40 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929

GEOLOGY BY UNIVERSITY OF ARIZONA GEOLOGISTS AND BUREAU OF RECLAMATION GEOLOGISTS

				61
66	65	64	63	62

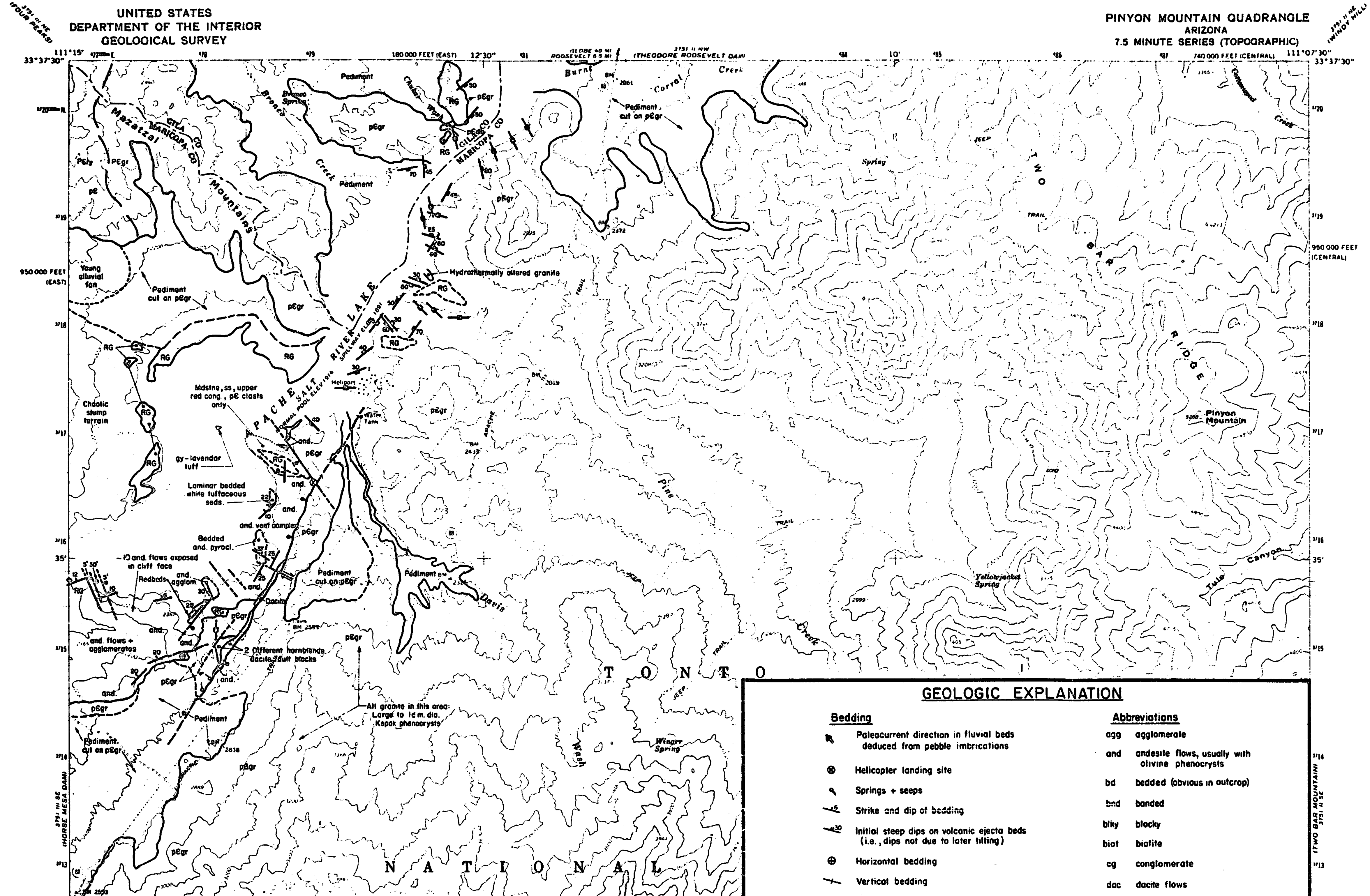
3

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT

REGIONAL GEOLOGY

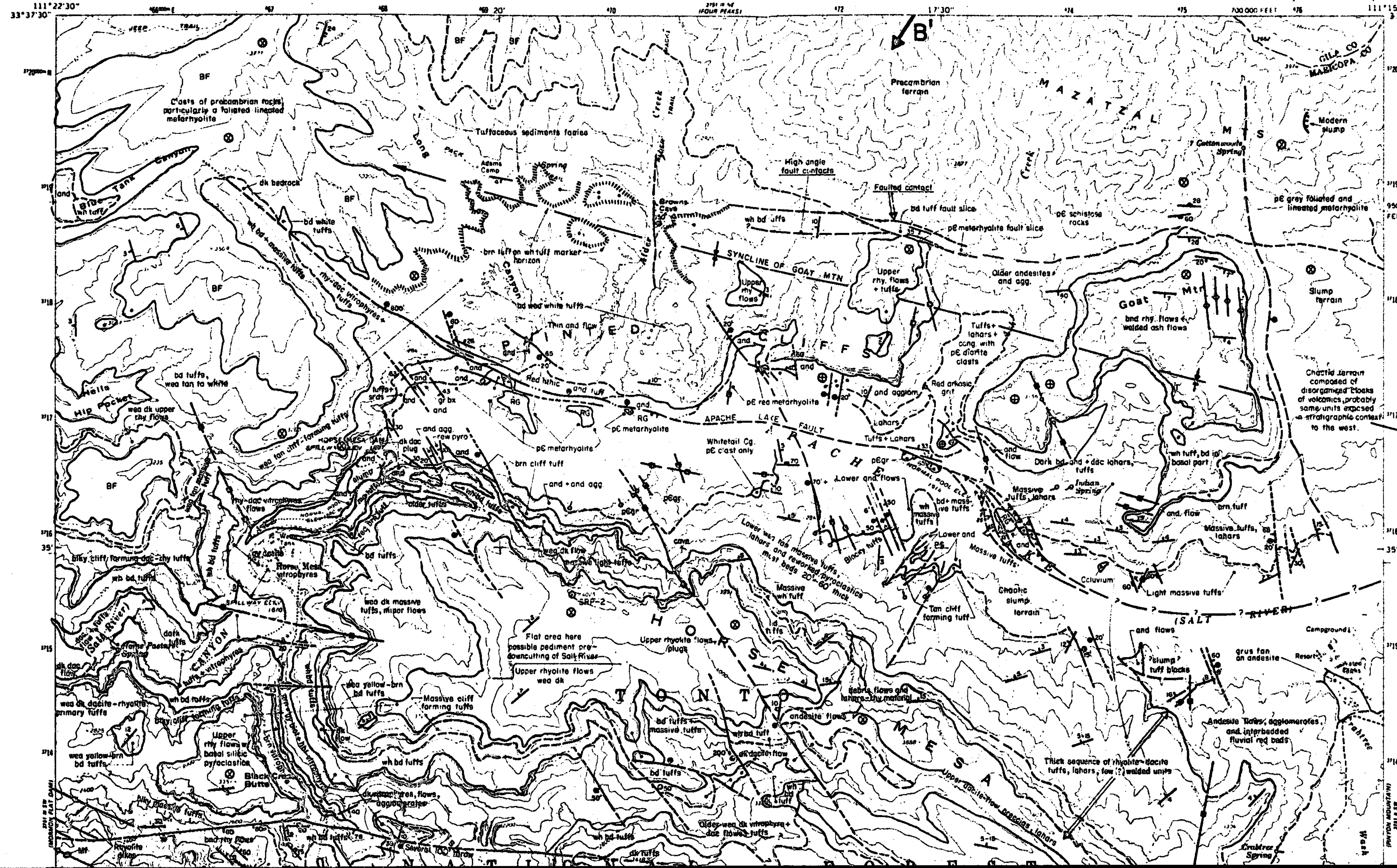
25-300-62

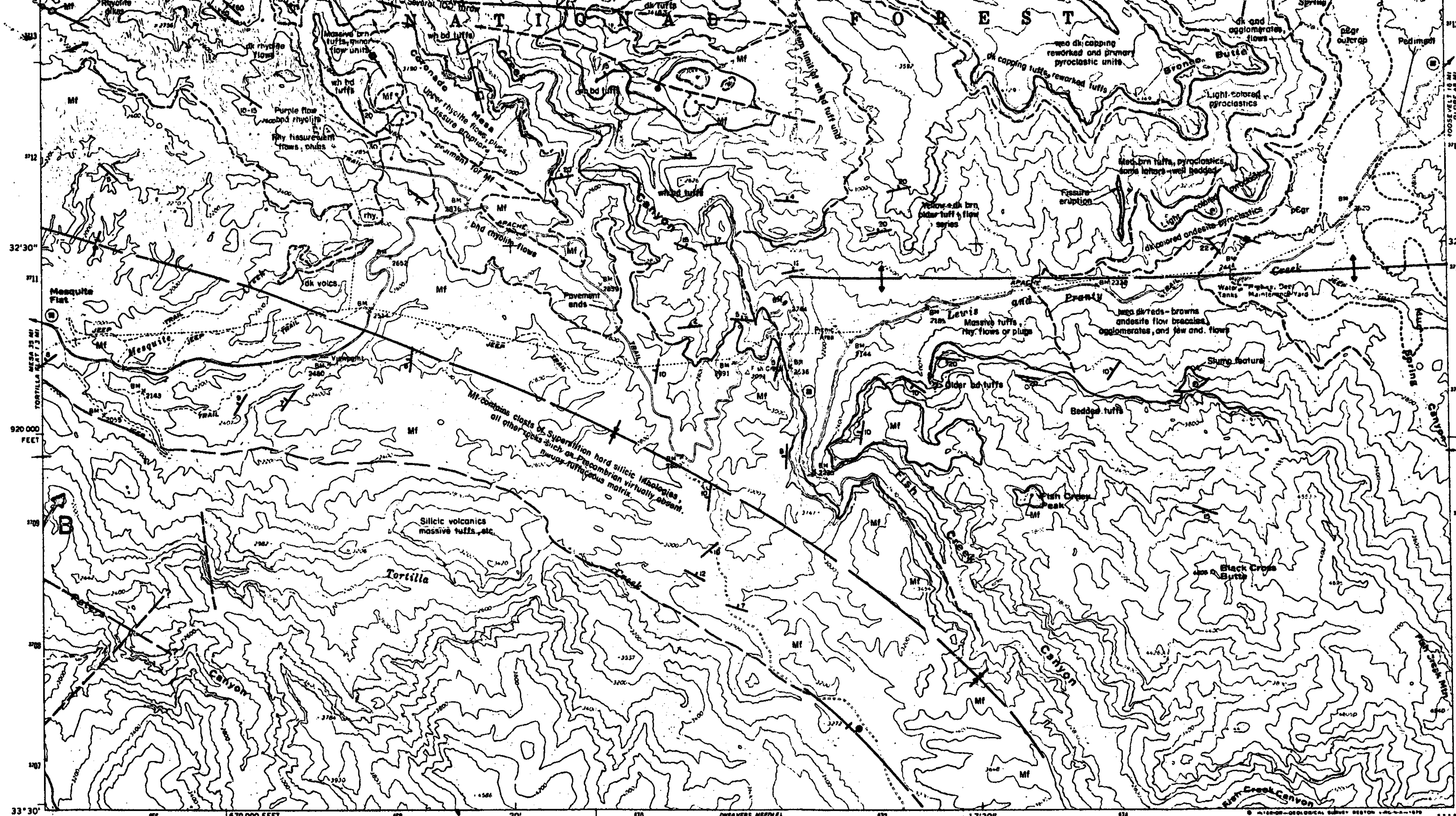
MARCH 1981


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
PINYON MOUNTAIN QUADRANGLE
ARIZONA
7.5 MINUTE SERIES (TOPOGRAPHIC)
3751 III NE (FOUR PEAKS)
3751 II NE (WINDY HILL)
3751 III SE (HORSE MESA DAM)
(TWO BAR MOUNTAIN) 3751 II SE
3751 II NW (THEODORE ROOSEVELT DAM)
111°15'
33°37'30"
111°07'30"
12'30"
10'
35'
180 000 FEET (EAST)
740 000 FEET (CENTRAL)
950 000 FEET (EAST)
950 000 FEET (CENTRAL)
Mazatzal Mountains
GILA CO
MARICOPA CO
APACHE SALT RIVER LAKE
NORMAL POOL ELEV 1914
SPILLWAY ELEV 1891
Bronco Spring
Bronco Creek
Chalker Wash
Burnt Corral Creek
Pine Creek
Davis Wash
Tule Canyon
Yellowjacket Spring
Wingfr Spring
Pinyon Mountain
TWO BAR RIDGE
TONTO NATIONAL
Pediment
Pediment cut on p€gr
Young alluvial fan
Chaotic slump terrain
Hydrothermally altered granite
Mdstne, ss, upper red cong., p€ clasts only
gy-lavendar tuff
Laminar bedded white tuffaceous seds.
and. vent complex
Bedded and. pyrocl.
~10 and. flows exposed in cliff face
Redbeds
and. agglom.
and. flows + agglomerates
2 Different hornblende dacite fault blocks
All granite in this area: Large to 1 cm. dia. Kspar phenocrysts
Helipor
Water Tank
GEOLOGIC EXPLANATION
Bedding
Paleocurrent direction in fluvial beds deduced from pebble imbrications
Helicopter landing site
Springs + seeps
Strike and dip of bedding
Initial steep dips on volcanic ejecta beds (i.e., dips not due to later tilting)
Horizontal bedding
Vertical bedding
Abbreviations
agg agglomerate
and andesite flows, usually with olivine phenocrysts
bd bedded (obvious in outcrop)
bnd banded
blky blocky
biot biotite
cg conglomerate
dac dacite flows

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HORSE MESA DAM QUADRANGLE
ARIZONA
7.5 MINUTE SERIES (TOPOGRAPHIC)





Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1962. Field checked 1964

Polyconic projection. 1927 North American datum
10,000-foot grid based on Arizona coordinate system, central zone
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue
To place on the predicted North American Datum 1983 move the projection lines 2 meters south and 63 meters east as shown by dashed corner ticks

Where omitted, land lines have not been established

There may be private inholdings within the boundaries of the National or State reservations shown on this map

UTM GRID AND 1964 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

GEOLOGY BY UNIVERSITY OF ARIZONA GEOLOGISTS
AND BUREAU OF RECLAMATION GEOLOGISTS

				61
66	65	64	63	62

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT

REGIONAL GEOLOGY

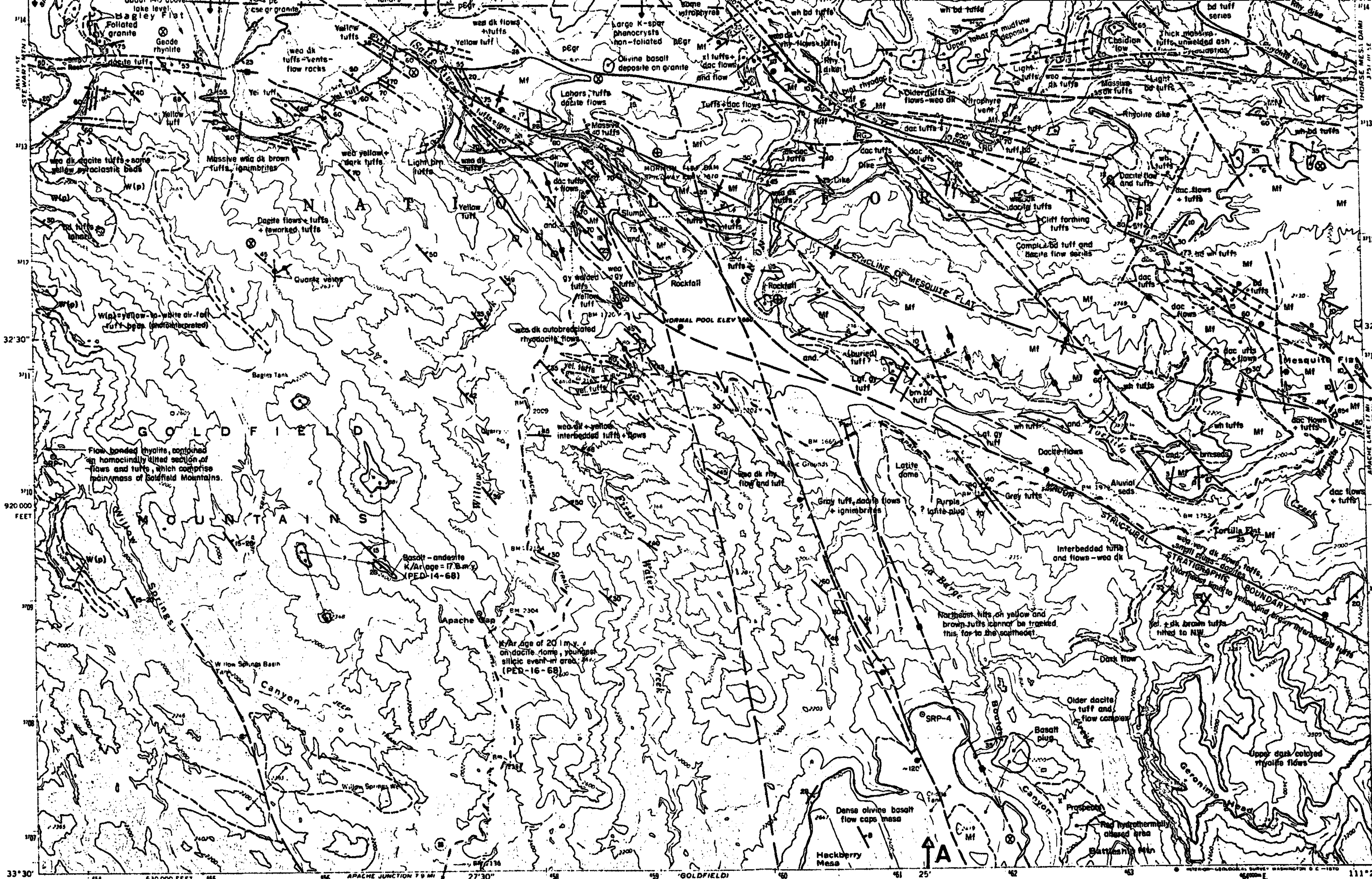
25-300-63

MARCH 1981

4

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MORMON FLAT DAM QUADRANGLE
ARIZONA–MARICOPA CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1962. Field checked 1964

Polyconic projection. 1927 North American datum
10,000-foot grid based on Arizona coordinate system, central zone
1000 meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Where omitted, land lines have not been established

Areas covered by dashed light blue pattern are subject to controlled inundation

UTM GRID AND 1964 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24000

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

GEOLOGY BY UNIVERSITY OF ARIZONA GEOLOGISTS
AND BUREAU OF RECLAMATION GEOLOGISTS

		61		
66	65	64	63	62

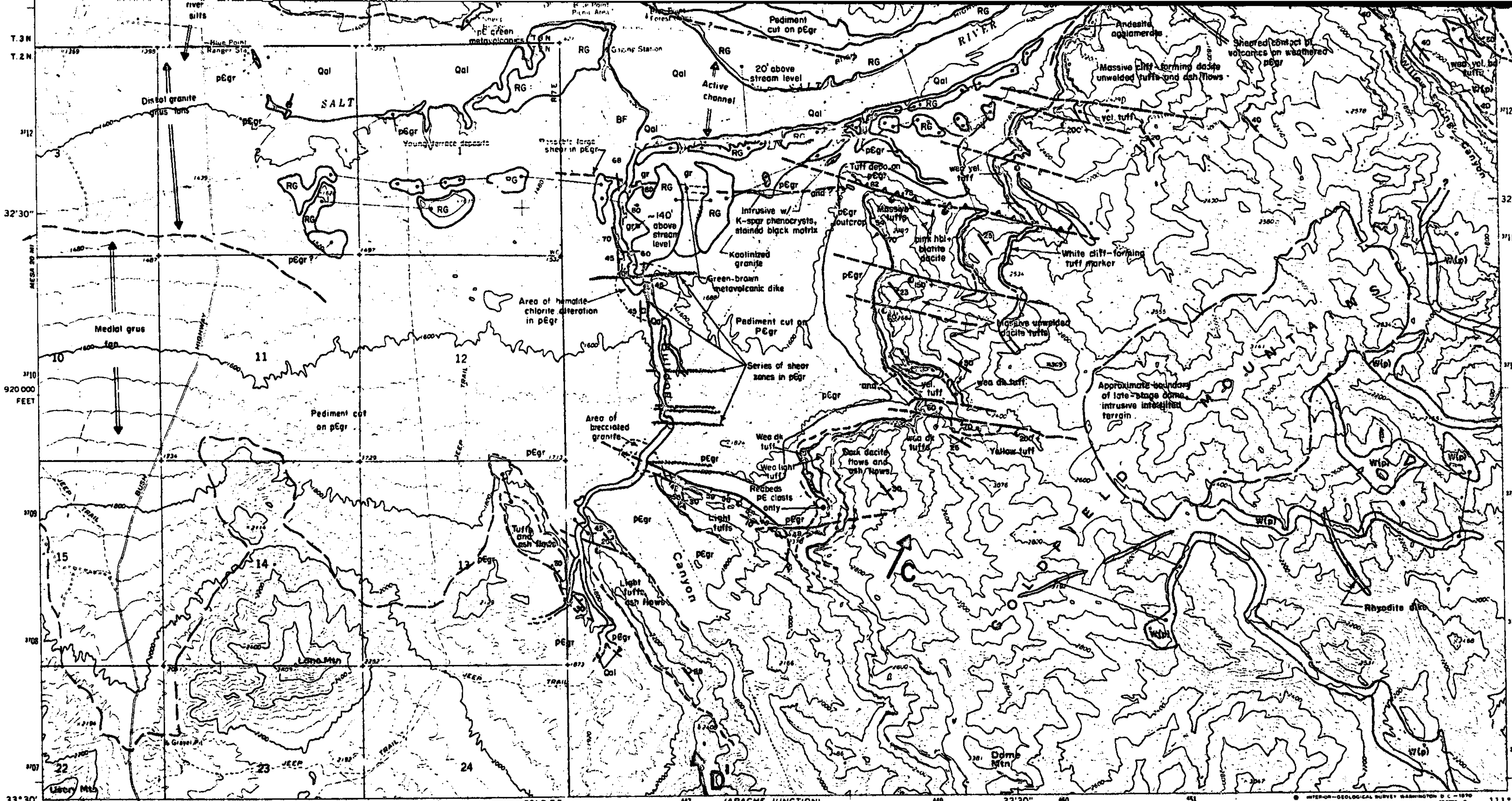
5

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT

REGIONAL GEOLOGY

25-300-64

MARCH 1981



Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1962. Field checked 1964

Polyconic projection. 1927 North American datum
10,000-foot grid based on Arizona coordinate system, central zone
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Fine red dashed lines indicate selected fence lines

Where omitted, land lines have not been established

Areas covered by dashed light-blue pattern are subject to controlled inundation

UTM GRID AND 1964 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

GEOLOGY BY UNIVERSITY OF ARIZONA GEOLOGISTS AND BUREAU OF RECLAMATION GEOLOGISTS

				61
66	65	64	63	62

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT

REGIONAL GEOLOGY

25-300-65

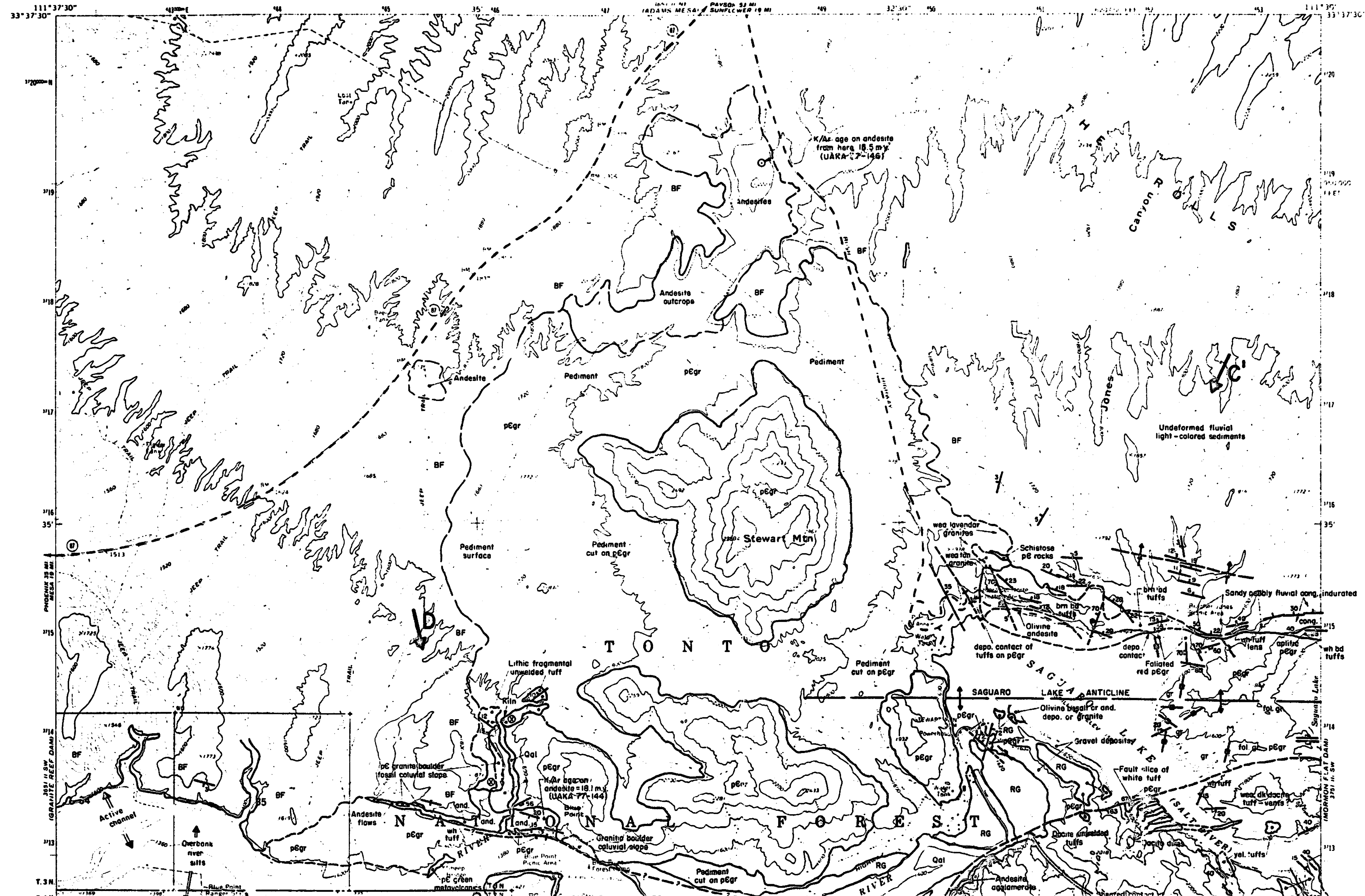
MARCH 1981

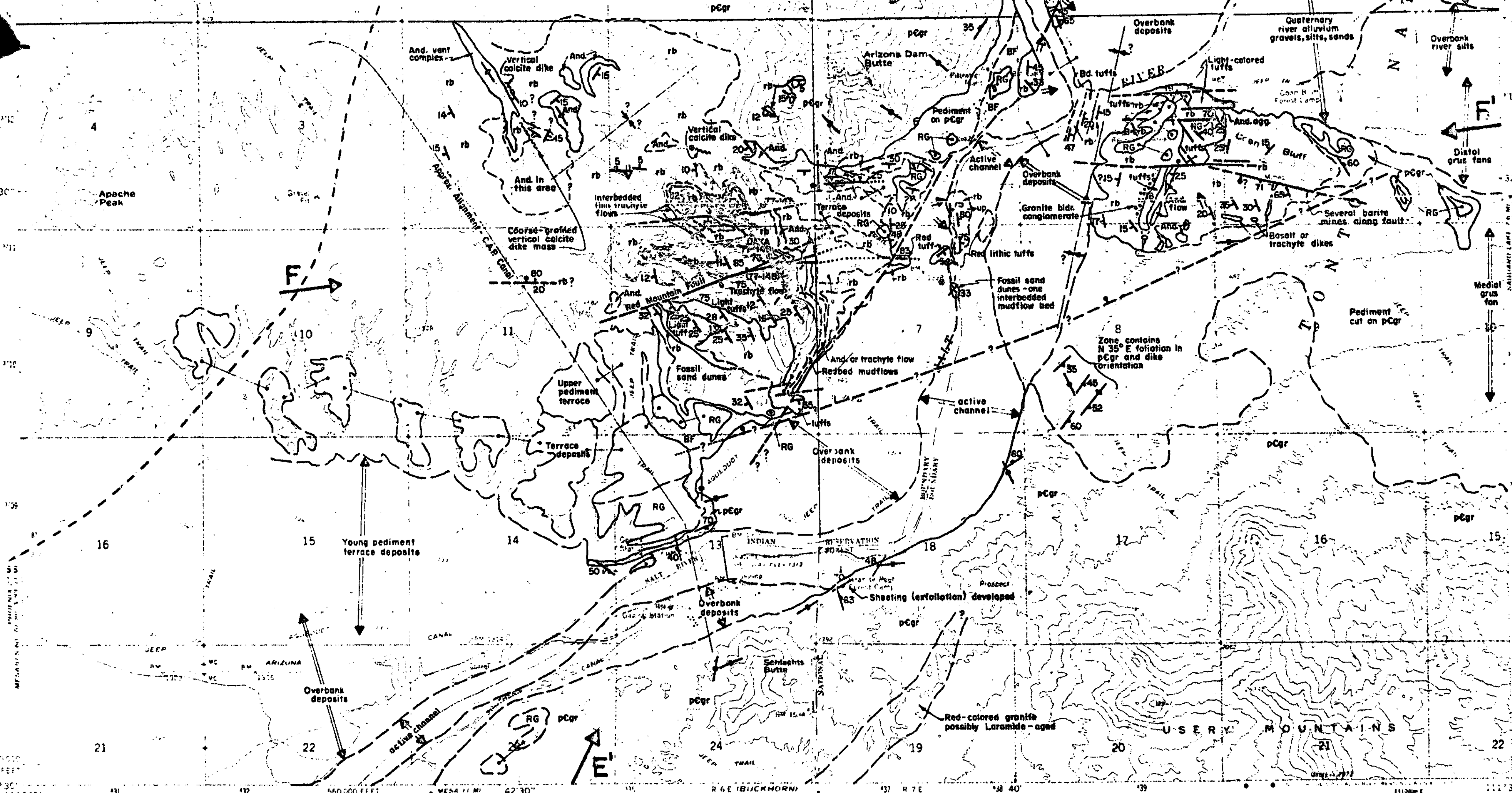
6

6

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STEWART MTN. QUADRANGLE
ARIZONA–MARICOPA CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)





Mapped edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial photographs taken 1962. Field checked 1964

Polyconic projection. 1927 North American datum. 10,000 foot grid based on Arizona coordinate system, central zone. 1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Where omitted, land lines have not been established

Revisions shown in purple compiled from aerial photographs taken 1974. This information not field checked

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

GEOLOGY BY UNIVERSITY OF ARIZONA GEOLOGISTS AND BUREAU OF RECLAMATION GEOLOGISTS

				61
66	65	64	63	62

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT

REGIONAL GEOLOGY

25-300-66

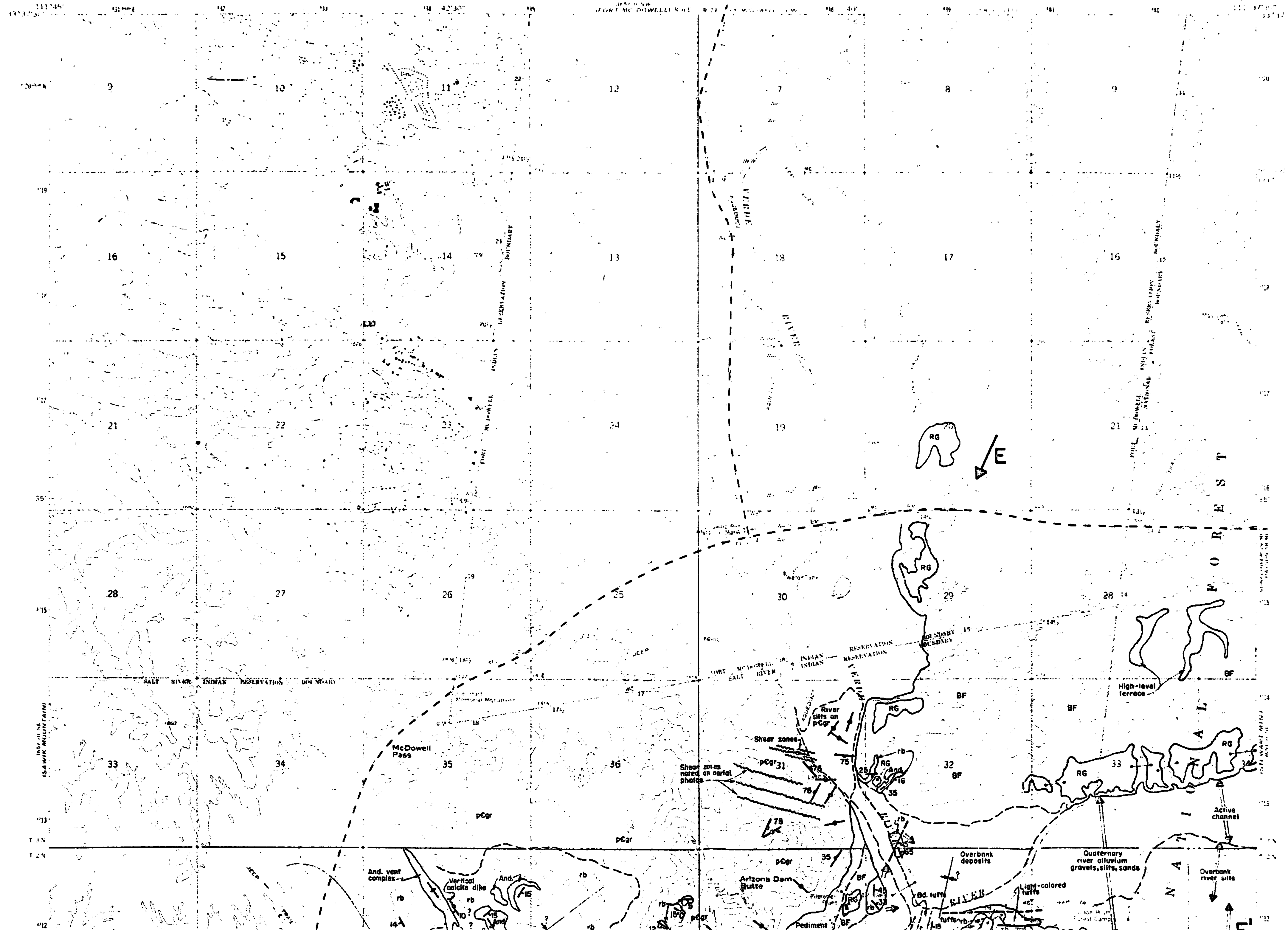
MARCH 1981

7

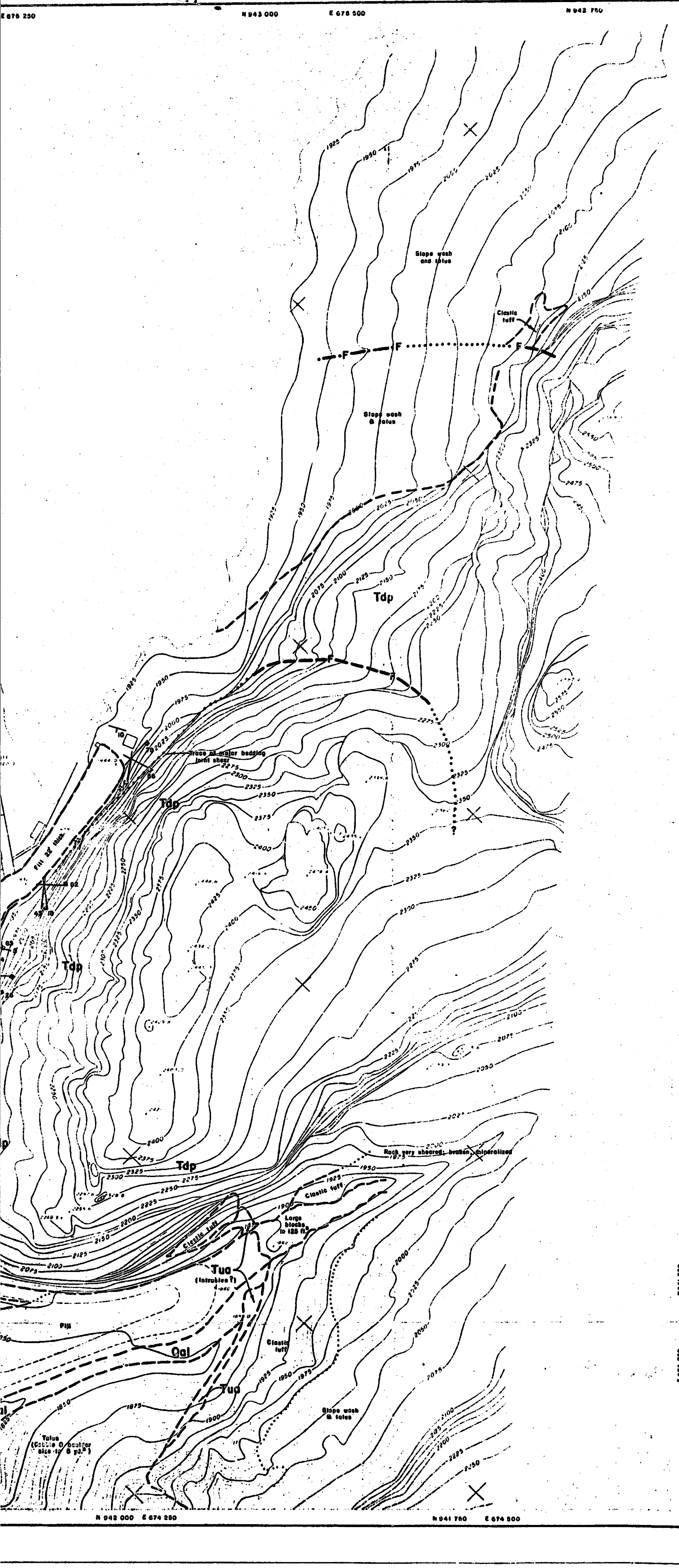
7

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GRANITE REEF DAM QUADRANGLE
ARIZONA–MARICOPA CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



N 943 500
E 678 000
N 943 250
E 676 250
TALUS
Bedding in clastic tuff
Rt. abut. traverse
Intersections form sheeted zone
Shear
Tdp
Begin
Rt. Abutment line traverse
Lft. d/s traverse
Sheeted zone
End
Large fracture
Fractured along Tdp-Tag contact
Small patch of tag under overhang of Tdp
Tag
Tla
Talus
Large talus blocks of Tdp to 700 yd.³
1-3" weathered Tag each contact
Tdp dikes in Tla strike 34t dip 65
Extensively sheared & saprolitic
Salt River
1-2 ft³ blocks w/saprolite in joints.
Boulders
Trd - Tua
Contact undercut at base of cliff
Moderately - closely jointed
Altered & Sheared
Tua
Air Fall Tuff
Rock broken into irregular 0.5 yd.³ blocks has shifted out of place.
Thin lens of sand sized, old erosion surface
Lft. abut. traverse
Bedding plane set
Tua - Tdp contact undercut
Fill w/intermittent concrete to 0.5' thick
Fill 2d thick
TOPOGRAPHY IN THIS AREA HAS BEEN MODIFIED. SEE DWG NO. 25-300-59
Qal
Fill
N 942 250
E 674 000



EXPLANATION

Joint Symbol
Dip adjacent to flag
Spacing opposite flag

Strike and Dip of beds

Fault Trace

Approximate Contact, structural feature

Concealed Contact, structural feature

Shear Zones

Dikes

Scarp

Detail Line Traverse

TERITARY ROCKS

GERONIMO HEAD FORMATION ?

Tut — UPPER TUFFS, well bedded (upper) to massive (lower) tuffs surrounding the area of interest. A generic term for rocks above El. 2700 to the north and beyond the talus slope to the south of the river. Individually described where mapped.

APACHE GAP RHYODACITE ?

Trd — RHYODACITES, massive ash flow, buff colored, fine grained volcanic ejecta that has been fused into a hard homogeneous mass, discretely banded along flowage lines, difficult to break with hammer blow. Contains irregularly spaced near vertical joints 3-10 feet apart. One set about parallel to canyon wall; a second about perpendicular. Horizontal fractures are irregular and discontinuous across vertical joints.

Tdp — DACITE PORPHYRY, a flow banded mass of igneous rock, light grey to red, except for flow bands, a homogeneous porphyrite of plagioclase with hornblend and mica in a fine matrix. Contains clasts of andesite near lower contact. Difficult to break with heavy hammer blow. Light to moderate near vertical jointing oriented northwest and northeast on 3-5 ft. centers, 2-5 yd³ blocks are formed by 0-40° dipping joints formed along flow structure lines.

Tua — UPPER ANDESITE, a basaltic flow, dark gray; with red molted zones of olivine altered to iddingsite. Fragments ring when struck with hammer. Highly to intensely jointed; especially near lower contact. Joints are short and discontinuous; tend to be oriented along flow, forming sharp edged interlocking plates.

Tag — AGGLOMERATE, a lahar or mudflow type deposit, light purple; contains 20% subangular clasts of mostly scoriaceous basalt fragments 1/2-2"; 15% 1 ft and a few up to 6 ft in a fine grained matrix. Both clasts and matrix can be broken with a moderate hammer blow. Individual clasts are very well bonded by the surrounding matrix; clasts cannot be broken out. A few poorly defined near horizontal joints and a 40-60° dipping set break the mass into 2-5 yd³ blocks where exposed.

Tla — LOWER ANDESITE, a basaltic flow, dark gray; with red mottled zones of olivine altered to iddingsite. Fragments ring when struck with hammer except for some deeply weathered upper surfaces which are shattered to soil like. Highly to intensely jointed; especially near shear zones and around upstream terminous of unit except lightly jointed downstream north side. Joints are short and discontinuous; tend to nearly parallel structure features otherwise perpendicular to cooling surfaces, some slight columnar structure

50 0 50 100 150
SCALE OF FEET

CONTOUR INTERVAL - 5 FEET

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT RIVER PROJECT — ARIZONA

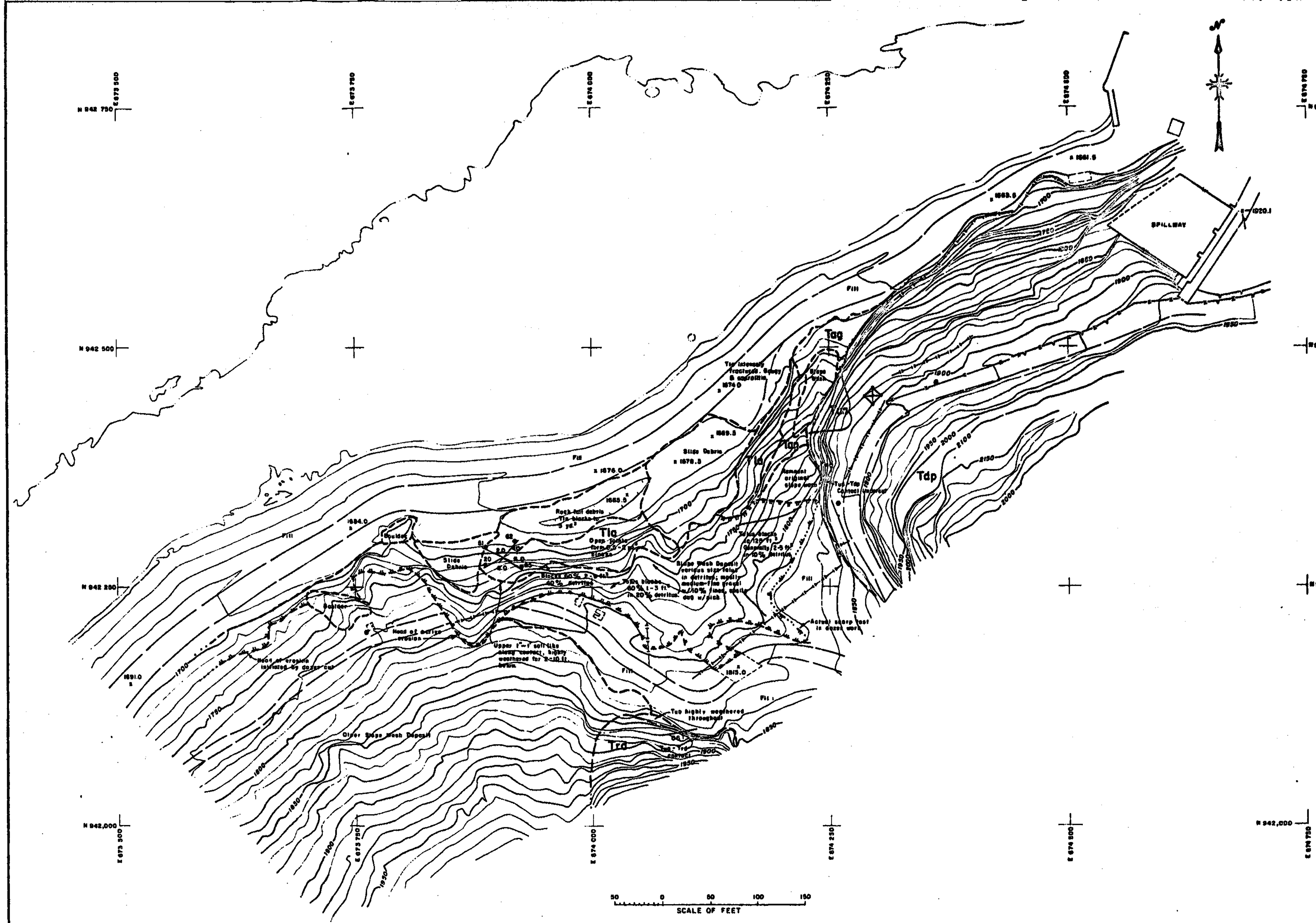
HORSE MESA DAM
GEOLOGY

8

GEOLOGY BY ________ TECHNICAL APPROVAL ________
DRAWN C. Ford ________ SUBMITTED ________
CHECKED ________ ADMIN. APPROVED ________ REGIONAL ENGINEER

BOULDER CITY, NEVADA FEBRUARY 6, 198_ SHEET 1 OF 2 | 25-300-58

RED OVERLAY
DWG. NO. 25-300-58



NOTE

For geologic explanation, see Dwg. No. 25-300-60.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

SALT RIVER PROJECT – ARIZONA

HORSE MESA DAM
GEOLOGY

9

GEOLOGY BY .... TECHNICAL APPROVAL ....
DRAWN ... C. R... .... SUBMITTED ....
CHECKED .... RECOM. APPROVED ....

BOULDER CITY, NEVADA — SHEET 2 OF 2 — 25-300-5[illegible]

RED OVERLAY
DWG NO. 25-300-59

sediments are basically sub-horzontal and stand at 5000-6500 ft. elevations. To the west, the top of the Mazatzal Mountains at elevations of 6000-7600 feet consists of older Precambrian sediments, so that any Apache Group sediments formerly there have been eroded off the top of the mountains. Hence the emerging picture seems to suggest a N-S trending monoclinal flexure involving basement and Apache Group rocks, with the middle limb of the monocline consisting of the 25° east dipping rocks near Roosevelt Dam. Although the question of when the monocline formed remains unanswered, at least two important points need to be mentioned which point to a late Cenozoic period for at least some of the movement. First, an unmapped assemblage of probable early Miocene volcanics and sediments along western Tonto Basin north of Roosevelt Lake are deformed, and at several places dip easterly at 15-25°. Curiously, these dips approximate the dips of the Apache Group sediments as noted above. Secondly, a monocline farther south around Tucson is known in the San Pedro Valley which has identical vergence, a parallel, on-line strike direction, and has produced similar northeast dips on volcanics and sediments as young as about 22 m.y. (20 m.y. old Apache Leap tuff was not affected by the fold). The moncline in the San Pedro Valley cannot be continously tracked to the northwest to the Roosevelt Dam area past the area of Superior, because of geological complications, but the two structures follow the same trend. Hence, there is some evidence that the warping of the Apache Group rocks around Roosevelt Dam could be an early Miocene event, which could of course relate to the tectonics affecting the Superstition volcanic field. Mapping of the disturbed volcanics in the northern Lake Roosevelt area would be important in resolving this problem.

Faults

At least three orientations of major faults were noted in the field area. 1) a N70°W set which in the Goldfield Mountains appears to be involve listric-style movement, and south of Horse Mesa Dam are south side down with some strike-slip lineations; 2) a N25-45°W set, seen to die out up section, possibly related to volcano tectonics, and 3) a N50-60°W set of high angle faults, consistently down to the northeast, affecting post-volcanic sediments, and displaying some apparent reverse movement.

The northern Goldfield Mountains west of Stewart Mountain Dam were examined and found to contain evidence of listric faults. The faults shown on the maps trend N70°W and were observed to change dip angle from near vertical at the tops of cliffs to about 45-55° SW dips in the canyon bottoms. This is the general orientation needed to affect a NE homoclinal dip on the involved volcanics. It is this author's opinion after seeing a few examples of these faults that a listric style deformation has imparted most of the dip to these rocks. However, as noted in the section "Further notes on the tilted terrain" these faults are not strike parallel to the tilted volcanic beds and hence may not be solely responsible for the tilting. Another set of faults oriented more N45°W may reside in the Goldfield Mountains. One fault in the northwest Goldfields is indicated on the map as having reverse movement, with Precambrian granite on the north side up against volcanics on the south side, with the fault plane dipping about 80°N. Note that this fault parallels the "Apache Lake fault" mapped along the north shore of Apache Lake, which also has apparent reverse movement, but the two faults have opposite vergence directions.

A nearby E-W major fault can be seen crossing the Horse Mesa Dam access road just south of Black Cross Butte. It was tracked over a total distance of 5 miles, from Canyon Lake (see photo) eastward to the south center part of Horse Mesa. The fault plane dips south, and south side is down by several hundred feet, using the white bedded tuffs and upper capping rhyolites of Black Cross Butte, Horse Mesa, and Coronado Mesa as marker units. This fault, combined with the north-side down Apache Lake fault suggest that the Black Cross Butte-Horse Mesa area has acted as a horst block relative to Mesquite Flat and the Painted Cliffs area (see cross-section B-B'). Sparce slickenside lineations in the area south of Black Cross Butte suggests exclusive dip-slip movement on this fault.

The N25-45°W set of faults are demonstrated by numerous examples along the shores of Canyon and Apache Lakes. The sense of offset is highly variable, and one gets the impression of a "piano keyboard" set of alternating up and down blocks for most of the region. Where the exposures are good, many of these faults can be seen to die out upward and often do not offset the white bedded tuff marker series at all. Often, though, steep-sided canyons cut into undisplaced upper volcanics lie on the trace of these faults. Around Apache Lake, springs are very often localized along these faults.

The N50-60°W faults cut through both Canyon and Apache Lakes. These have clearly involved the fanglomerate of Mesquite Flat (a distinctive marker lithology), and the faults are consistently down on the NE side, in some cases by many hundreds of feet. Reverse movement is indicated on these faults at two places. Along the north shore of Apache Lake along a fault trending N60-80°W, Precambrian granite and metarhyolite are in the hanging wall of a fault which dips 65°S. The footwall contains lahars and tuffs of the lower Superstition volcanics. Further, the general sense of stratigraphic offset across the fault on either side of the Lake agrees with this sense of movement-the base of the white bedded tuffs on the south side of the lake are at 2,800 feet, while directly across on the north shore they are at 2,400 feet. Projecting the dips on the bedded tuffs to the fault plane produces dip-slip throw estimates of perhaps over 1000 feet, southwest side-up, on this fault. This fault is termed the Apache Lake fault on the map. From the map data it appears that the Salt River, and Apache Lake have localized near the trace of this fault.

The longest continously traceable fault in the map area is the other example of this category of fault. It was tracked in the helicopter continuously from Cottonwood Wash, 2 miles NNW of Mormon Flat Dam in the northwest, to a mile east of Tortilla Flat in the southeast, a distance of 5 miles. It was tracked on the ground farther southeast by another 5 miles to near Fish Creek Canyon. Where it intersects the north shore of Canyon Lake is clear evidence of southwest side up (reverse) movement on the fault plane which dips 75° SW, by probably 500 feet. The stratigraphy here appears clear-cut, involving older rhyolites and fanglomerate of Mesquite Flat. Two miles southeast of here, the top of the fanglomerate has been offset by an apparent 400 feet, SW side up. However, here the fault planes dip 60-73°NE, implying normal displacement. These conflicting senses of normal vs. reverse faulting imply that we must be careful in assessing the nature of the forces involved here. We are seeing rotation of volcanics and sediments under varying circumstances, and one must wonder if there has been later rotation affecting the orientation of the fault planes.

GEOLOGY FROM STEWART MOUNTAIN DAM DOWNSTREAM TO GRANITE REEF DAM

In the interval between Stewart Mountain Dam and Granite Reef Dam, Tertiary volcanics and sediments were observed to be depositional on Precambrian granitic rocks at three places, just northwest of Blue Point picnic area, at Coons Bluff, and on the south flank of Arizona Dam Butte, around the filtration plant. At the first of these areas, the Tertiary rocks are tuffs and andesites overlain unconformably by basin fill sediments, and at the latter two areas, the Tertiary rocks are dominated by redbeds with subordinate tuffs and andesites.

Blue Point Picnic Area

Along the north bank of the Salt River, just west of the picnic area, a thin section of volcanics, consisting of an upper white-colored, non-welded, lithic ash flow sheet and an underlying andesite flow, were deposited on Precambrian granite. However, the presence of a wedge of fossil talus below the volcanics (seen on the map) indicates that high relief was present at the time of deposition of the volcanics, and the relief on the higher Precambrian granite hills to the east of these exposures is in part a fossil Miocene relief. The andesite from this locality yields a 18.1 m.y. K/Ar age (UAKA 77-144). A low potassium content of a modified feldspar concentrate used in the K/Ar determination indicates this rock may be termed a basaltic andesite. Indeed curious are some very high initial dips (to 35 or 40°) on some fluvially sorted, wedge-planar cross bedded volcanoclastic sandstones which separate the overlying dark volcanics from underlying granite boulder talus which maintains its initial dip on slopes of granite. This area lies upslope but in plain view of the trail along the north bank of the river, 800 feet west of the Blue Point forest camp. To the west the volcanics appear to be truncated by a horzontal surface, and overlain unconformably by bedded basin fill fanglomerates. To the south, the volcanics are in fault contact with granite along a E-W trending fault with a 7-10 foot wide, red colored clay-rich gouge zone, exposed along the trail mentioned above. To the north, they depositionally pinch out.

To the south of the river, along the northwest flank of the Goldfield Mountains, similar lithic tuffs with basal andesites are depositional on the granite. And they also have been involved in nearly E-W directed faulting, as mapped along Bulldog Canyon, 2 miles south of Blue Point picnic area. The faults along Bulldog Canyon are south side down, while the one at Blue Point is north side down, suggesting the existance of an E-W elongate horst block composed of granite encompassing the area around the present river channel. A family of E-W shears are noted in the granite terrain south of the river.

An extensive pediment surface, graded nearly to the 30-foot terrace level and called the Bush pediment by Pewe (1978) is developed in granite on the south side of the river from the northwestern Goldfields, westward to beyond Granite Reef Dam. Three sets of gravel-capped terraces are present in the area three miles below Stewart Mountain Dam on remnant benches at levels of about 20-40, 160-220, and 250 feet above present stream elevation.

The gravel-capped terrace along the obvious spur 0.5 miles SE of Stewart Mountain Dam is about 240 feet above river (not lake) elevation. It, or perhaps a nearby smaller remnant (above left abutment of Stewart Mountain Dam at 200 feet above river level) is probably snychronous with the 160-220 foot terrace set seen along the south bank of the river up to four miles downstream of Stewart Mountain Dam. These gravel-capped terrace remnants are called the Mesa Terrace by Pewe (1978). Along with the older, 90 foot higher Sawik Terrace (Pewe, 1978), these gravel caps contain extensive plugged caliche zones and fractured boulders littering the surface. Based on general Southwestern desert soil ages, these caliche zones are probably 0.5-2 million years old (C. Menges, pers. comm., May 1981).

Coon Bluff Area

Farther downstream at Coon Bluff, a Tertiary clastic-dominated section is exposed throughout the bluffs, while across the river on the north side, well-exposed undeformed basin fill deposits overlap the poorly exposed Tertiary clastics (redbeds). Granites of the Usery Mountains to the south can be found outcropping at the east end of Coon Bluff.

As seen on the map, the Tertiary rocks at Coon Bluff dip 15-30° WSW, and consist of about 1,350 feet of lower mudflow and debris flow redbeds, 200-600 feet consisting of a lower andesite and several unwelded ash flows interbedded into redbeds, and an upper 600 feet or so of debris flow and fluvially washed lighter colored redbeds. Several thin flow remnants of andesite or Trachyte, some of which have dike-like character, are found in the lower redbed sequence in southern Coon Bluff. The entire exposed Coon Bluff section is estimated to be about 2,550 feet thick, assuming an average dip angle of 25° for the lower two members and 15° for the upper member, and the outcrop lengths shown on the map. Clasts are predominantely granitic, with Tertiary andesite and silicic volcanic clasts sparcely represented.

Dips in the bluffs consistently are to the west, but nearby to the west, at the Salt-Verde confluence, redbeds and bedded tuffs dip 15-50° to the east, implying a structural discontinuity at the west edge of Coon Bluff which could be either a fold axis, or more probably a fault. At the east end of Coon Bluff, the redbeds are clearly depositional on deeply weathered red-colored granite. The contact is hard to establish, but probably dips westward parallel with bedding in the redbeds. The sediment-granite contact at the south end of Coon Bluff is not exposed, but could be either a depositional pinchout, a high angle fault, or possibly a low angle fault related to low-angle denudational (gravity) sliding. This author suspects a high-angle fault as the most likely choice.

Two sets of faults were recognized around Coon Bluff, WNW to W, and NW directed. The first set offsets the middle volcanic unit right laterally along the main fault seen at Coon Bluff, which suggests north side down if dip-slip movement occurred, as suggested by sparce slickensides lineations. Assuming pure dip-slip fault motion, about 330 feet of movement is implied for the E-W segment of this fault. The WNW-trending branch of this fault is well exposed cutting the redbeds, and dips about 70° south. No movement indicators were noted for this segment, but sense of movement would be reverse if the north side were down, as it was for the other segment. This WNW-trending segment is the locus of barite mineralization which was exploited by mining. According to Brobst (1969) and Stewart and Pfister

(1960), about 312,000 tons of barite were mined from properties at Coon Bluff between 1929 and 1955, under the names of Granite Reef, Arizona Barite, and Macco mines. This production makes this the largest barite producer in Arizona to date. Barite veins followed the main N75°W fault, but are also found as a series of an echelon N20°W veinlets both north and south of the main fault (see Stewart and Pfister's figure 10). The barite, according to the above authors, has a small amount of associated azurite and malachite staining and is found entirely in the faulted redbeds, although granite is supposidly found on the south (hanging) wall at the east end of the fault. This author could not confirm in the field that the fault juxtaposed granite against redbeds anywhere along its present exposure. The haulage shaft at the main mine had been sunk 320 feet, and more than 2,500 feet of drifts had been completed, when, in July 1955, during mining a "heavy flow of water" was encountered at the west end of the mine and operations were suspended (Stewart and Pfister, 1960, p. 32). The source of this water is probably ground water related to the nearby Salt River.

The northwest set of faults at Coon Bluff are recognized where light-colored tuffs are in contact with redbeds. The detailed faulting picture is complex, but seems to involve shuffling of the stratigraphy along high angle faults.

Two sets of river gravel-capped terraces are found on Coon Bluff astride the present river, at elevations of about 140 and 170 feet above river level. Along the north bank of the Salt River, northeast of Coon Bluff, a single set of terrace remnants are mapped which rest 100-130 feet above present river elevation. Above the east bank of the lower Verde River, a single set of river gravel-capped terraces rest about 140-160 feet above river level. Two patches of lower gravels are at about 30-50 feet above the river near the filtration plant and about one mile up the Verde from its confluence with the Salt River, along the east bank. As mentioned previously, the gravel-capped terrace remnants at elevations of 100-170 feet are those called the Mesa Terrace by Pewe (1978), and those at elevations of 30-50 feet are Pewe's Blue Point Terrace. The terrace gravels contain abundant clasts of Precambrian Mazatzal Series rocks, Apache Group rocks, metarhyolite, and lesser amounts of Superstition volcanic lithologies. Paleozoic lithologies are rare. See Kokalis (1971) for pebble count studies on these gravels.

Mount McDowell Area

The discussion of the geology around Mount McDowell for convience will be divided into two parts, north and south of the large fault that passes 1,500 feet south of the crest of Mt. McDowell, because of the variation in stratigraphic order in these two areas.

North of the large fault, here called the Red Mountain fault, the Tertiary section, dominated by redbeds, is depositional on Precambrian granites of Arizona Dam Butte. Small remnants of the redbeds are still preserved plastered against the southern slopes of this butte, and indicate the presence of nearly 1,000 feet of fossil relief on the butte, preserved since early Miocene time. The Tertiary section consists of at least 1,400 feet of light to medium red colored mudflow and debris flow fanglomerates. Occassional boulders in some units range up to 10-12 feet in diameter. The lower part of the section contains interbedded dark volcanic flows (andesites ?) which outcrop irregularly to the west of Mount McDowell, and locally at the base of the section at the south end of Arizona Dam Butte. In the western area, the dark volcanics are clearly interbedded with the redbeds, and at least one NW-trending fissure vent complex displaying vertical foliation was mapped. However, in this area, the lowest strata consisted of redbeds. Roughly two-thirds up Mt. McDowell, two thin andesite or trachyte flows are interbedded into the redbeds. They appear to have rather uniform thickness throughout the butte. The upper one is 10-15 feet thick, and the lower one slightly thicker. The map also indicates the position and orientation of two small dike masses composed of very coarsely crystalline gray-colored calcium carbonate.

Both have been sheared somewhat along their length, but are not simple gouge fillings. The NW-trending mass in the west is mixed with andesite breccia material, along a trend parallel to the dark volcanic fissure vent noted above. The carbonate material is most logically remobilized and recrystallized Tertiary limestone.

Materials comprising the redbeds are predominantly granitic, and secondarily, Superstition volcanic lithologies. Both rock types are found in the matrix material and as clasts. Other rock types, such as Precambrian metavolcanics or Paleozoic sedimentary material, are not common.

At Mt. McDowell, the section dips 10-12° westward. Against Arizona Dam Butte, the units dip 12-30° southward, off the south flank of the butte. One mile northwest of Mt. McDowell, dips of redbeds and volcanic flows are to the southeast. This dip reversal may imply the persence of a syncline in the position shown on the map. A K/Ar age of 18.7 m.y. was obtained on a boulder of trachyte (UAKA 77-147) contained in the lower part of the redbeds at Mt. McDowell, perhaps 200 feet above the base of the exposed section. Another trachyte flow intercalated into the redbeds above the boulder dates at 18.0 m.y. (UAKA 77-148), while a sanidine-bearing ash flow tuff above the trachyte flow dates at 17.7 m.y. (UAKA 77-149). All these dates are from the east side of Mt. McDowell, facing the Salt-Verde confluence.

South of the Red Mountain fault, the Tertiary section dips 25-35° SW, and is composed of the following strata, listed from bottom to top:

1. unknown total thickness (greater than 300 feet) of redbed debris flows.

2. 20-150 feet of andesite, thinning southwestward, and possibly involved in a fault contact along it SW extent.

3. 10-50 feet of an upper poorly organized redbed mudflow.

4. locally, a thin (10-20 feet) dark gray to purple colored andesite-trachyte flow. Apparently, this flow was the one sampled for K/Ar age analysis (UAKA 77-148), and yeilded an 18.0 m.y. age.

5. 200-1000 feet of light colored, red-stained, rhyolite to dacite unwelded ash flows (ignimbrites), thinning rapidly to the southeast, and reaching maximum thickness near the Red Mountain fault. A lower most unit of this assemblage was K/Ar age dated (UAKA 77-149) at 17.7 m.y. on a sanidine concentrate.

6. 200-1000 feet of redbed debris flow fanglomerates, rapidly thinning to the northwest. The contact between this and the underlying tuffs is highly irregular, as seen on the map, and appears to record redbed deposition

in an area of high relief erosionally cut into the older tuffs.

7. an upper section of 100-400 feet of very light colored unwelded dacitic lithic ash flows, which, just like the two underlying units (5&6) is very irregular in thickness, thinning rapidly to the southeast.

8. at least 700 feet (top not exposed) of a sequence of fossil sand dunes, composed of trough cross-bedded orange-colored well-sorted sandstones. In the lower part, many interbeds of gravelly units, and a few tabular debris flow lenses suggest the sand dunes were deposited very near the locus of deposition of redbeds, probably on piedmont slopes at the base of granitic hills. The redbeds in the general area are dominated by granitic debris, with subordinate dark and light volcanic clast and matrix material, which suggests local sources as the major contribution to the redbeds.

9. Basin fill sediments, up to 380 feet thick. These are undeformed sediments which unconformably overlap the sand dunes and redbeds south and west of Mount McDowell, and rest on granite near the right (north) abutment of Granite Reef Dam. USBR drill data in the Granite Reef Dam area suggests the presence in the subsurface of 280 feet of basin fill resting on sheared granite at a point in a tributary streambed 2,300 feet NNW of the right abutment of the dam, with another 100 feet of basin fill exposed in the bluffs above the drillhole collar. Hence, the presence of an abandoned Salt River channel course is suggested in this area. Note that an exposed knob of Precambrian granite now separates the present stream course in the Granite Reef Dam area from this 380 foot thick basin fill sequence to the north. It is the absence of Tertiary rocks below basin fill in this drill hole which suggests that the Tertiary rocks are missing this for south either because of erosion (perhaps by a paleo-Salt River source) or south side-up faulting along a hypothesized N70°E-trending fault shown on the map.

Coon Bluff - Mt. McDowell Stratigraphic Correlation

In the Mt. McDowell area, the redbeds north of the Red Mountains fault are a local base of deposition of the Tertiary since they are seen to be plastered against the granites to the north. No light colored tuffs are exposed in these beds. South of the Red Mountain fault, two tuffaceous units are interbedded with redbeds, but the base of the exposed section consist of redbeds. Hence, the tuffaceous units must reside higher in the section, and must be downthrown against redbeds along the Red Mountain fault. Similar tuffaceous and andesitic units at Coon Bluff are underlain by redbeds which are depositional on granite, and which most likely correlate with the tuff and dark volcanics on redbeds south of Mt. McDowell.

The amount of offset along the Red Mountain fault is questionable. If listric rotation and lateral ENE - directed movement affected the block south of Red Mountain fault (see section on structural interpretation), then more tuffaceous rocks should be present north of the fault west of Mt. McDowell. None were observed, including along the CAP canal before it was concrete lined. Until they are found, absolute movement vectors on this fault cannot be confirmed.

Precambrian Terrain

The Precambrian terrain around the Verde-Salt confluence was examined in reconnaissance. The rock, best described as a quartz monzonite with phenocrysts of potash feldspar, usually displays some biotite-to-chlorite alteration, and contains a complex array of prominent directions of jointing, as seen on the maps. Two miles southeast of the crest of Mt. McDowell, a zone about 2,000 feet wide contains NE directed high angle foliation in the granite and parallel alignment of quartz veins and dark-colored fine grained diorite masses. At the north end of Arizona Dam Butte, a series of vertical, red clay-filled shear zones trending about N70°W were mapped, and subsequent air photograph examination suggested several more shear zones to be present in the butte. These may be genetically related to the E-W shears previously noted in the granite just south of Blue Point picnic area. One mile southeast of Granite Reef Dam, a NE-elongate body of a red colored granite cuts the Precambrian terrain. This body is approximately outlined on the map, but its contacts with the Precambrian rocks was not observed. It is mapped on the published State and county geologic maps as Laramide in age.

As noted on the map, two major sets of joints trend approximately N10-40°W, and N30-60°E. Both sets are noted north and south of the Salt River. A set of joints around Granite Reef Dam trends about N60°E, and may control the river alignment in the immediate area.

No pods or zones of pervasive hydrothermal alteration (feldspars to kaolinite) were noted in the granite in this area, similar to those noted along Bulldog Canyon south of Blue Point picnic area.

As elsewhere in this region, the granites are most likely of the Ruin-Oracle quartz monzonite association, of 1350-1450 m.y. age. And the dioritic pods encased in the granite southwest of Coon Bluff and elsewhere are possibly of the older Precambrian Madera Diorite (dated at 1540-1730 m.y. farther southeast by D. Livingston, U. of Arizona, PhD, Thesis, 1969). See also Stuckless and Naeser (1972) for supporting age dates in the Precambrian terrain around the Superstitions.

Structural Interpretation - Stewart Mtn. to Granite Reef Dam

The present outcrop pattern of the Tertiary clastic-dominated section along this stretch of the Salt River, at Blue Point, Coon Bluff, and Mount McDowell, with the base of the section generally below river level, is topographically low compared to the base of the volcanic-dominated section in the northwest Goldfield Mountains, where the base rises to the south to elevations 400 feet above river level along Bulldog Wash, and up to 1500 feet above river level at Pass Mountain, 5 miles south of Blue Point picnic area. Assuming the clastics were deposited in a paleo basin bounded on the south by volcanics, then the river course today around the Verde-Salt confluence is in a topographic low that may have also been a low in redbed (mid-Miocene) time. This sense of "low" vs. "high" is hinted at in cross-section D-D'. Similarly, Stewart Mtn. appears to have been a topographic high around which volcanics were deposited, since they depositionally pinch out against its west, north, and east sides.

The most obvious faults in the area are the E-W ones which clearly involve the Superstition volcanics, and, because they are parallel with the average Salt River trend in the area, may have helped position the river in its present course.

The Redbeds at Mt. MCdowell reach an elevation of 2,830 feet, while the granites on Arizona Dam Butte (the depositional base of the redbeds) reach 2,470 feet. Clearly, the redbeds and volcanics were deposited in some kind of a low elevation feature, the apparent axis of which coincides very nearly with todays average river course in the region. Imbrication directions in the redbeds are shown on the maps, and appear to reflect Arizona Dam Butte as a source area for the Mt. McDowell redbeds, and the Usery Mountains as the southerly source for the Coon Bluff redbeds.

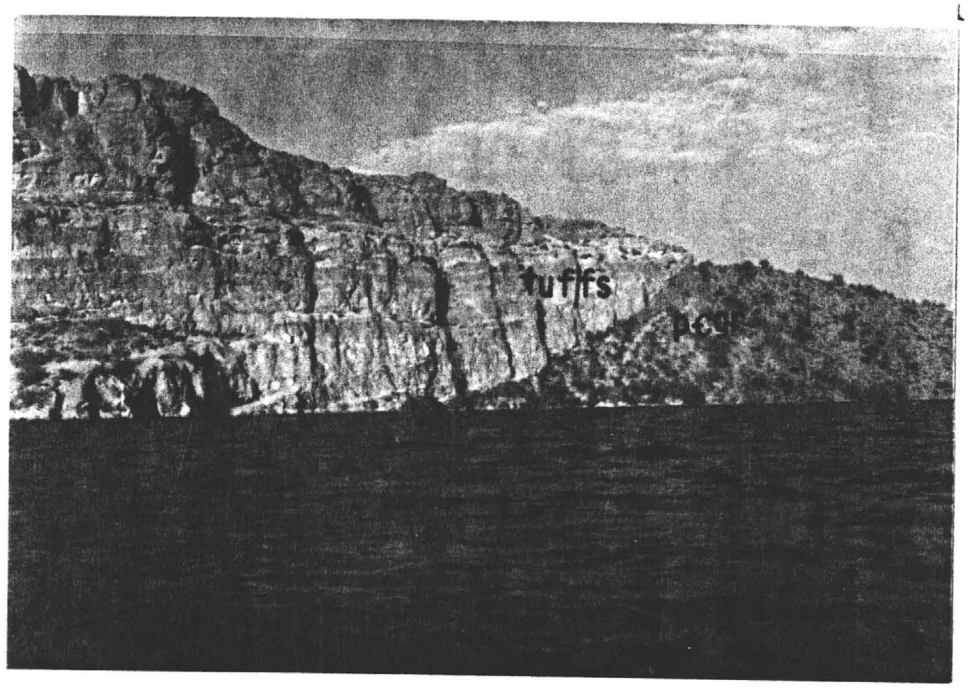
The tilt patterns of the Tertiary rocks are indeed curious. The section at Coon Bluff dips about 25° westward. At Mt. McDowell, north of the Red Mountain fault, the section dips about 10° westward, and about 30° westward south of the fault. These main dip directions are perpendicular to the E-W fault traces. No faults were mapped which are strike-parallel to the beds. Throughout most of the northern Goldfield Mountains just east of here, the beds dip homoclinally northeast at 20-40°. Whatever the cause of tilting, deformational forces have imparted nearly opposite tilt directions to the Tertiary rocks in these two areas. One could imagine ENE-directed listric-style faulting affecting the Tertiary rocks near the river, causing the WSW dips, mainly in the structural block south of the Red Mountain fault and north of the parallel fault proposed on the maps. In this model, the E-W faults serve as transform-style faults, along which differential amounts of fault-parallel horzontal movement are accomodated, with the main listric fault(s) buried to the west of Mt. McDowell.

The main problem with this model is that in the entire low-relief area between Mt. McDowell and the western edge of Coon Bluff, <u>all</u> dips of redbeds and aeolian beds (exposed discontinuously at or very near river level) are toward the southeast quadrant, nearly opposite to the main westerly pattern. Are there NNE-SSW fold axes in this interval buried near the Salt River? Or is this intermdeiate block a graben dropped along NNE faults? Kinematically, simple graben formation by movement along high angle normal faults should not tilt beds since the necessary rotation is not present. Other factors appear necessary to explain the observed tilt pattern. Probably the most useful information to narrow down the many possible explanations would be: (a) the thickness and lateral extent of the Tertiary rocks north of the Verde-Salt confluence, south of Coon Bluff, and southeast of Mt. McDowell; (b) the nature of the Tertiary-granite contact south of Coon Bluff; and (c) the presence of more redbeds or volcanics in the falt area 2-3 miles due west of Granite Reef Dam, on the north side of the river.

PHOTOGRAPHS

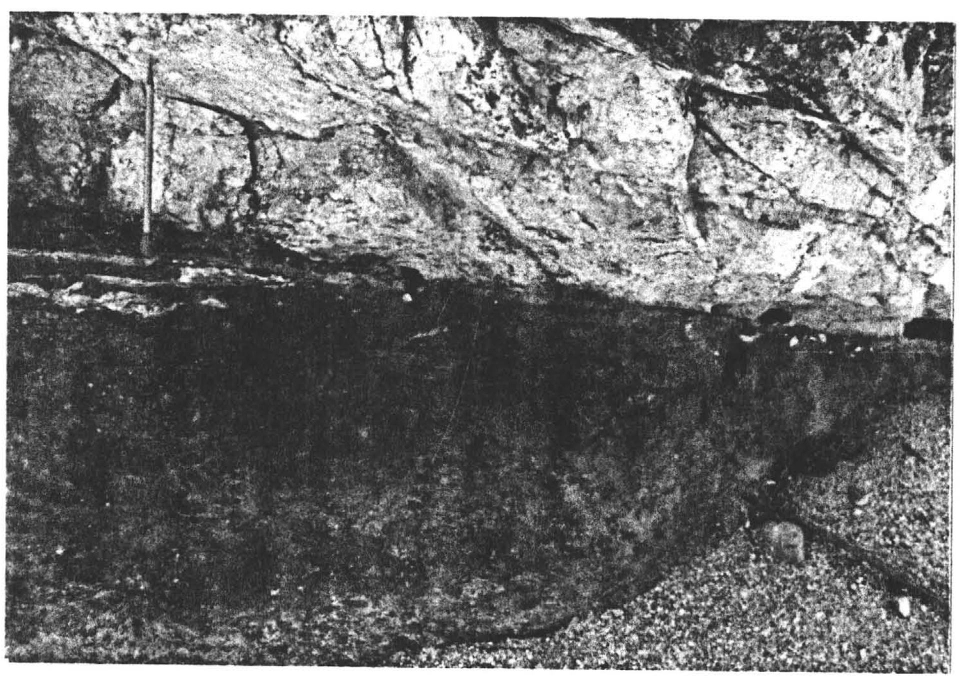
Pages P-1 to P-4	--	Goldfield Mtns. - Saguaro Lake
Pages P-5 to P-9	--	Canyon Lake Area
Pages P-10 to P-14	--	Apache Lake Area

View looking northwest into Goldfield Mtns. from along Apache Trail showing homoclinal NE tilt of the brown and yellow tuff series. Unit in foreground is a lithic fragmental pyroclastic tuff.



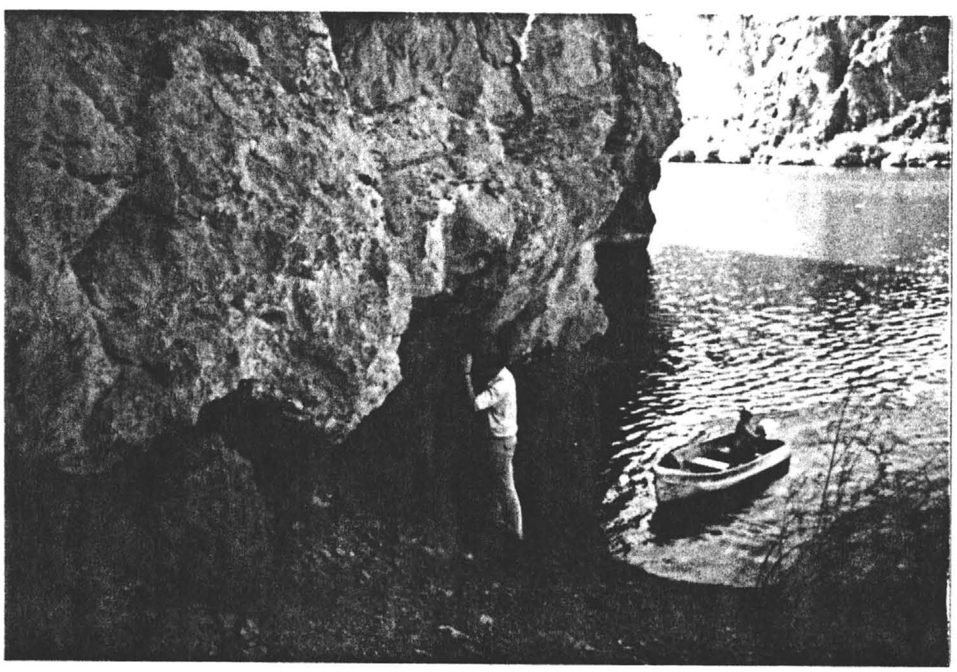
Unwelded tuffs depositionally thinning and pinching out on top of a paleo-high of dark colored Precambrian granite, north shore of Saguaro Lake, 1.2 miles ENE of Stewart Mountain Dam. View looks NNE. Stewart Mtn. Quad. These tuffs dip northward away from camera, along north flank of Saguaro Lake anticline.

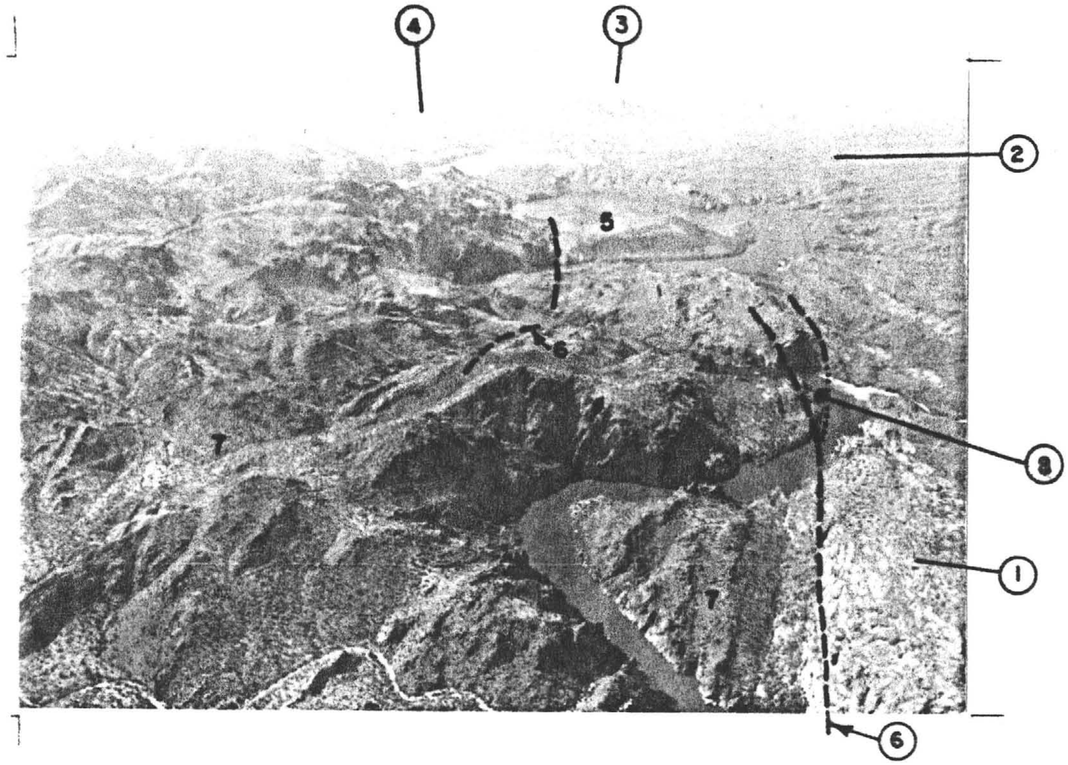
Sheared depositional contact of unwelded ash flow tuffs on Precambrian granite along NW side of Cottonwood Creek, about 800 feet above its confluence with Saguaro Lake (Mormon Flat Dam quad). View looks west.



Close-up of above contact, showing sheared, weatherd aspect of granite surface and planar nature of the contact.

Sheared depositional contact of unwelded ash flow tuffs or Precambrian granite (dark colored) along south flank of Saguaro Lake anticline, along east bank of Saguaro Lake, just easy of Bagley Flat. View looks SW. Mormon Flat Dam quad. Contact dips 23°SE here. 2.28 straight line miles downstream of Mormon Flat Dam.

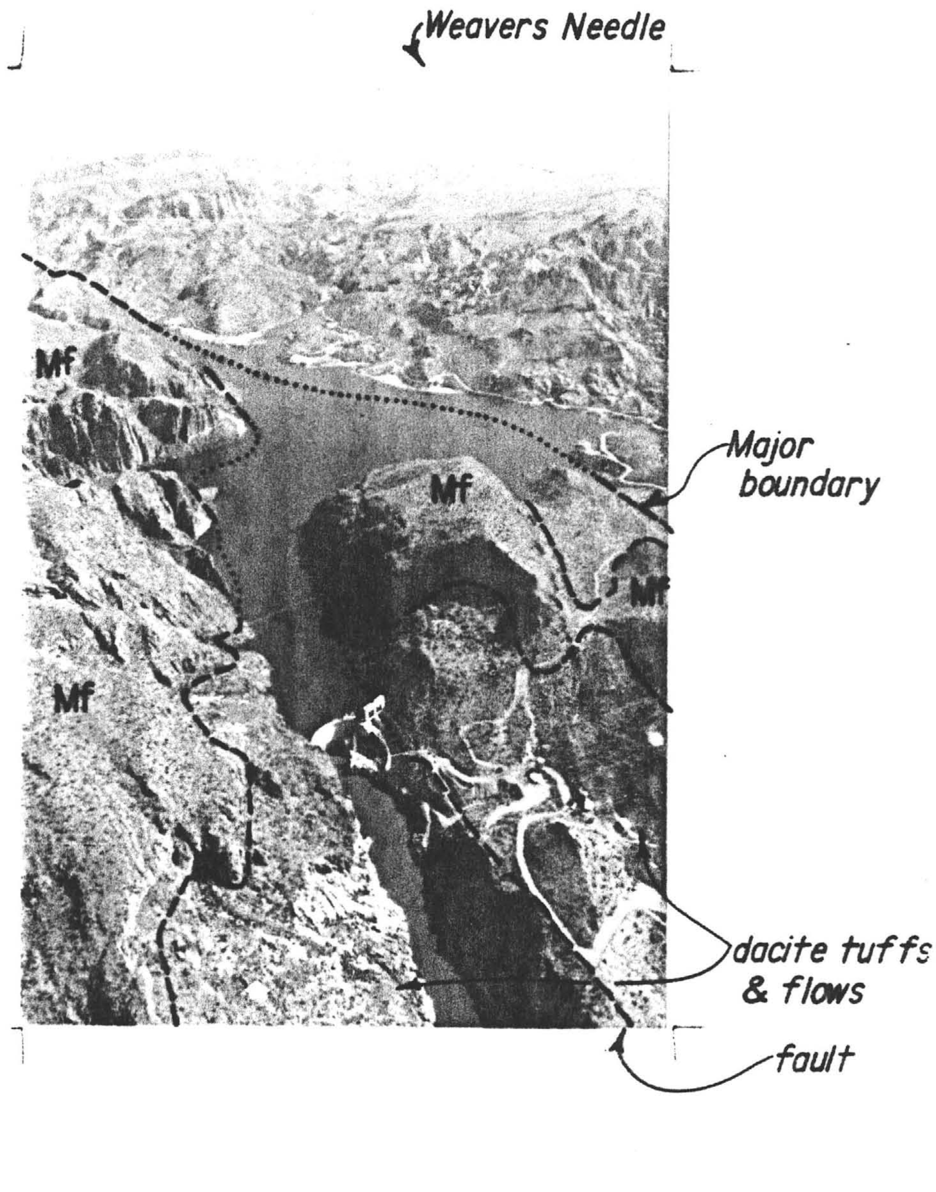


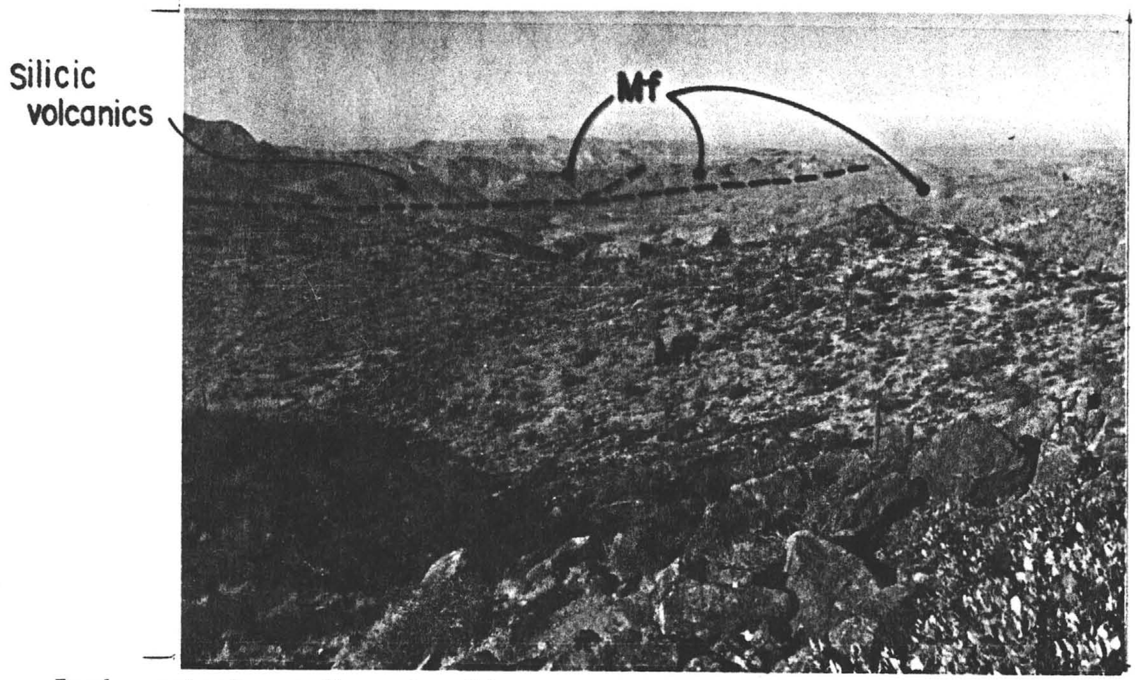


Air view looking WNW at Saguaro Lake

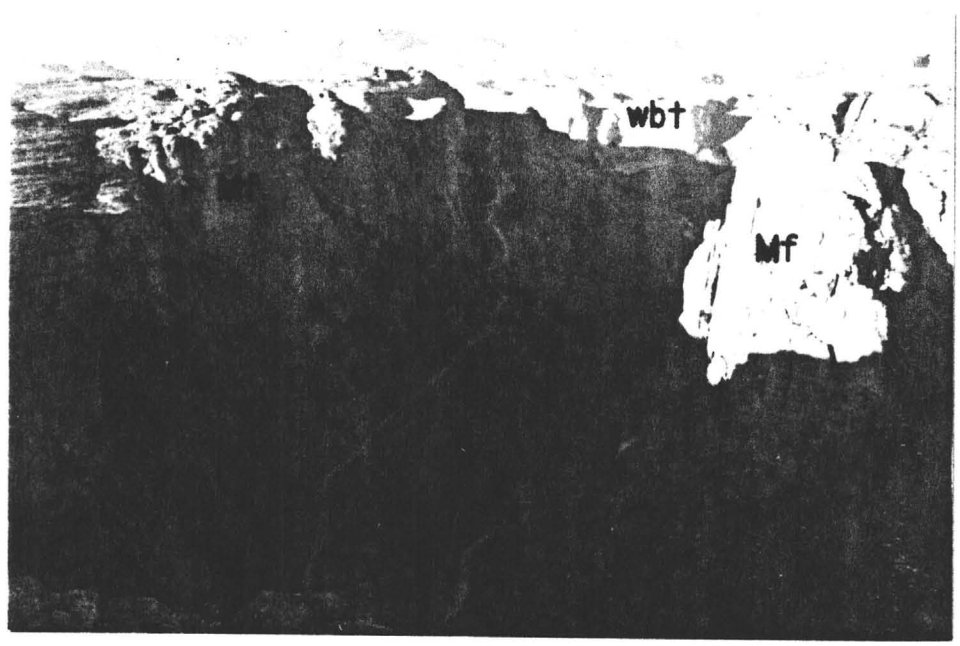
1. Farthest west outcrop of fanglomerate of Mesquite Flat
2. incised basin fill desposits
3. Stewart Mountain
4. Mt. McDowell
5. Bagley Flat - granite overlain by river gravels
6. major faults - fault on right is the major structural boundary noted in text
7. terrain of NE homoclinal tilted brown and yellow tuffs
8. collection point of K/Ar sample UAKA 80-128 (SRP-3)

View looking SE at Mormon Flat Dam and south arm of Canyon Lake. Major structural-stratigraphic boundary shown, to the south of which is the homoclinally tilted yellow and brown tuff series. In foreground, Mf (fanglomerate of Mesquite Flat) is depositional on older tuffaceous volcanic series. Weaver's Needle in center skyline. Fault in foreground passes under left abutment of the dam, and juxtaposes darker and lighter dacitic-rhyolitic unwelded ash flow tuffs.

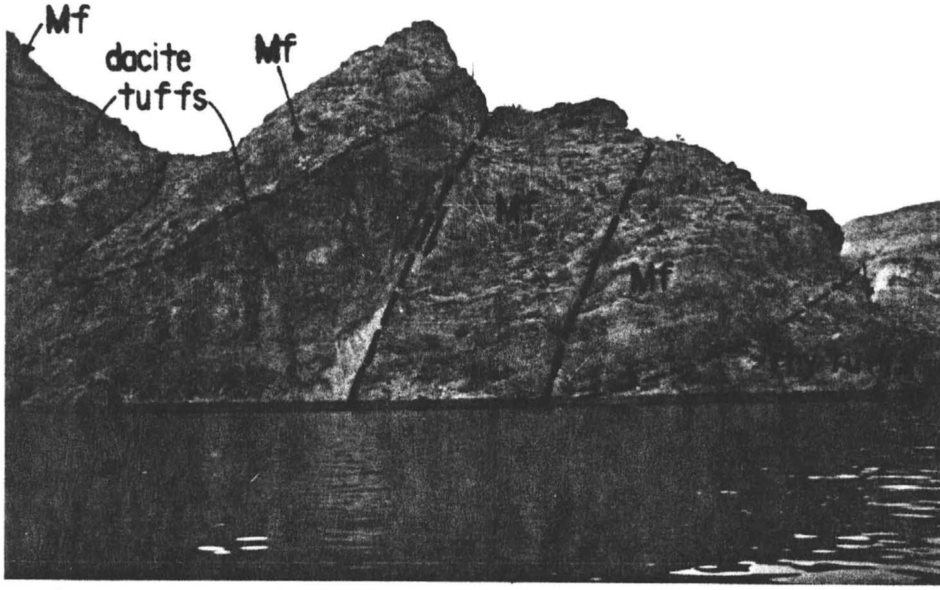




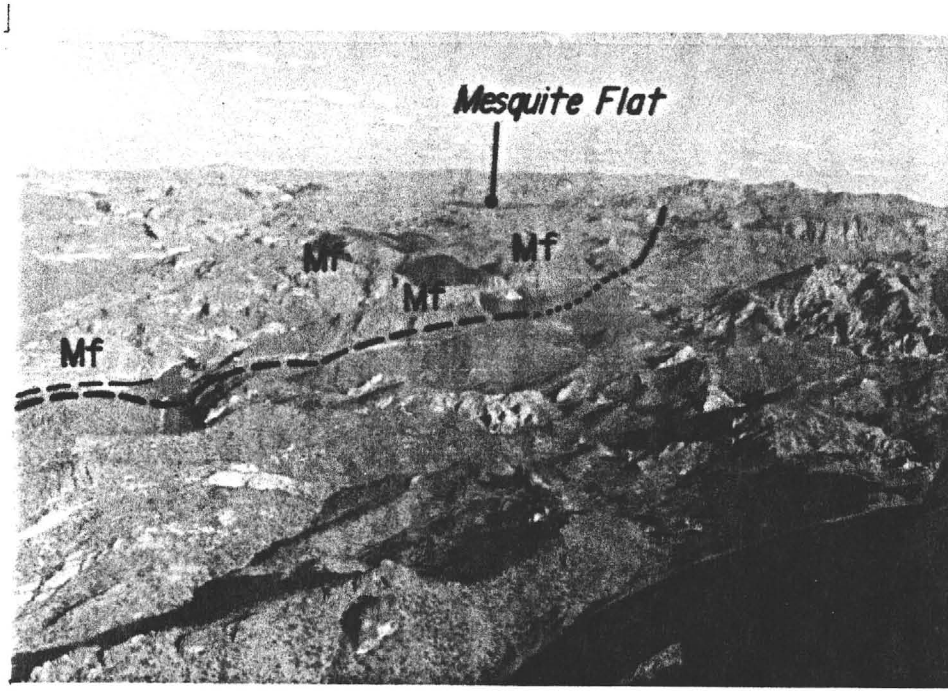
Look westerly at Mesquite Flat, composed of a syncline filled with fanglomerate of Mesquite Flat (Mf). Right foreground is welded ash flow of Superstition volcanics at depositional edge of fanglomerate. Fault trace shown is the NE-side-down high angle fault which, projected to Saguaro Lake, displays reverse movement.



Look north down Fish Creek Canyon from near top of hill 3141. Vertical cliffs composed of fanglomerate of Mesquite Flat (Mf), where they fill deep channel cut into Superstition volcanics. Cliffs of white bedded tuffs (wbt) are north of depositional pinchout of Mf unit.

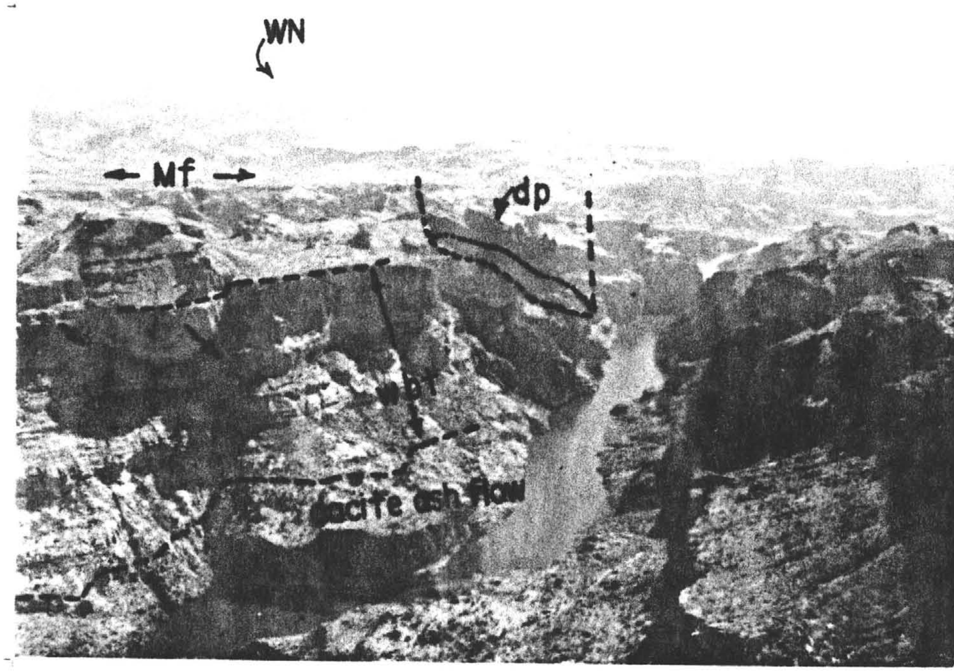


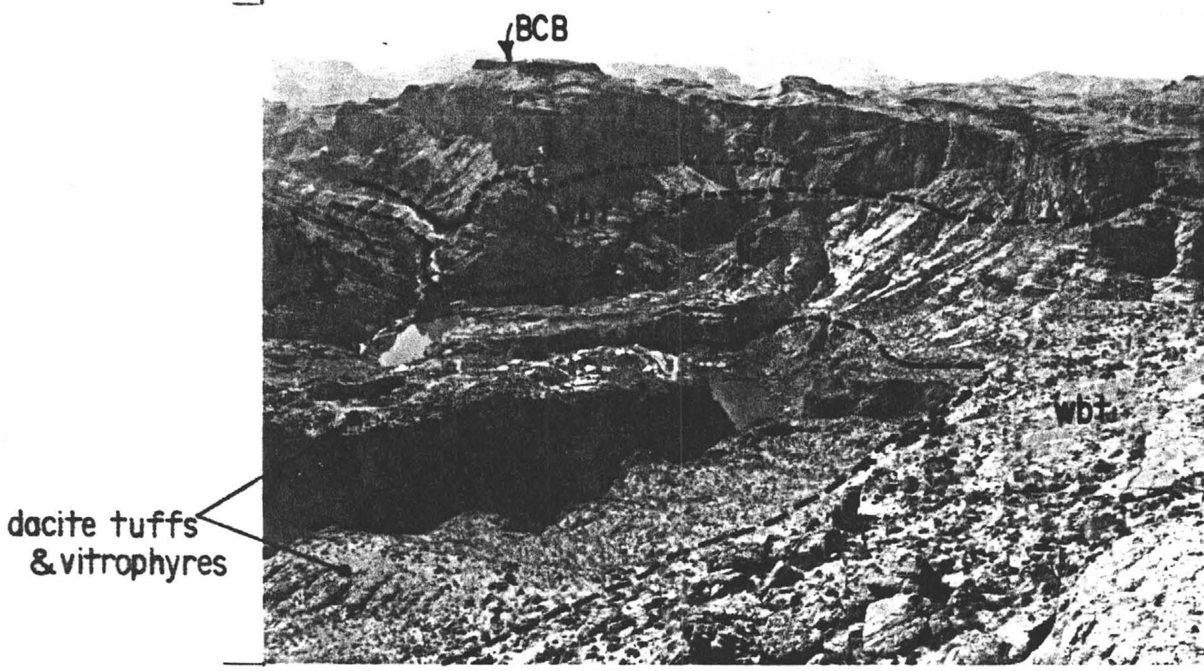
High angle reverse fault exposed along north shore of Canyon Lake 1.2 straight line miles above Mormon Flat Dam, where fanglomerate of Mesquite Flat (Mf) depositional on rhyolite-dacite unwelded tuffs contact is repeated by a fault dipping 75° SW. View looks NW.



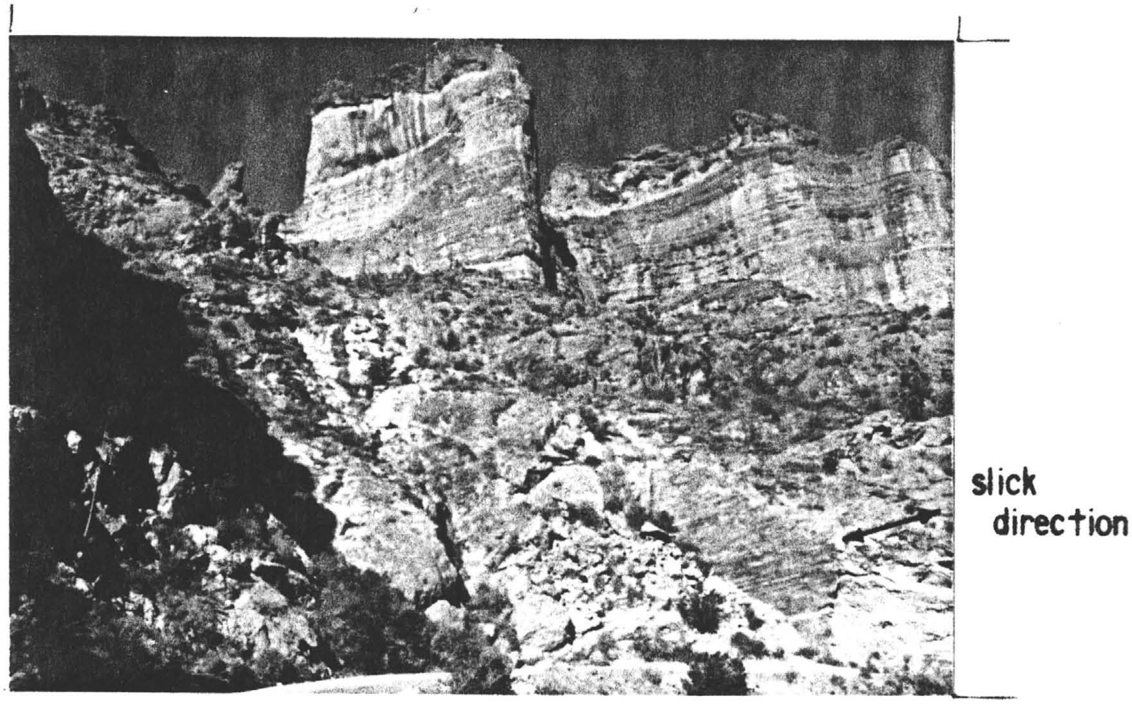
Aerial view looking easterly toward Canyon Lake from over Goldfield Mtns. showing the regional structural-stratigraphic boundary (dashed line) discussed in text. Mf is outcrops of fanglomerate of Mesquite Flat. No Mf is exposed in tilted brown and yellow tuff terrain in foreground.

View looking SSW at upper part of Canyon Lake with Mesquite Flat (MF) and Weavers Needle (WN) in background. Circular dacite tuff volcanic plug (dp) on southeast side of river is noted on map 1.5 miles south of Sheep Mtn. Small magnitude N-S faults (shown by arrows) are traced on both sides of lake. Photo shows well bedded nature of wbt (white bedded tuff) series, which represents large-scale air-fall ash component of some related ash-flow erruption(s). Beneath wbt unit is blocky-weathering dacite partially welded ash flow.

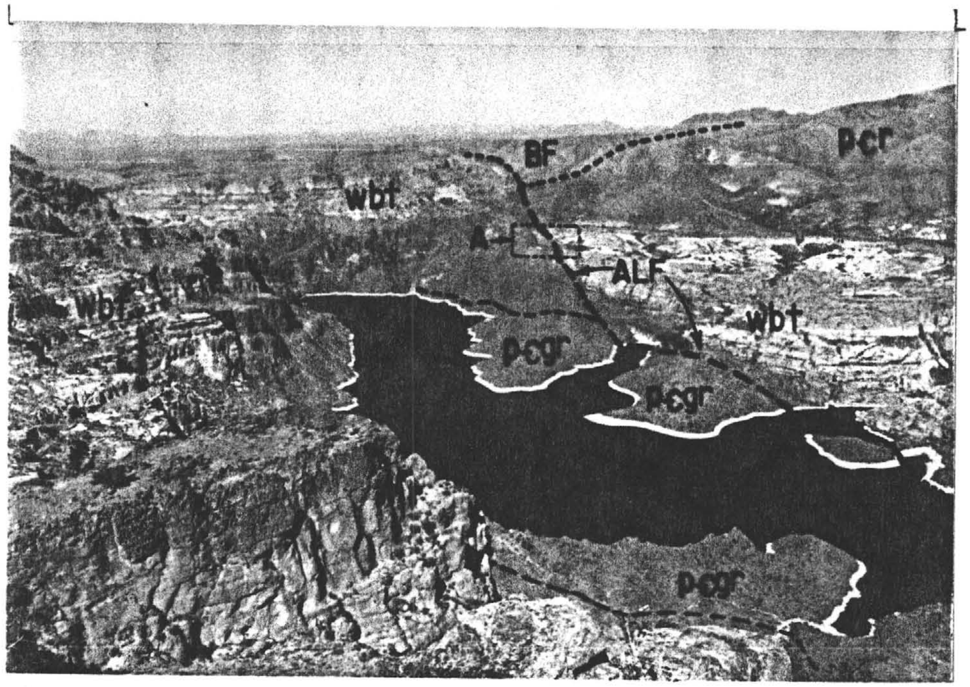




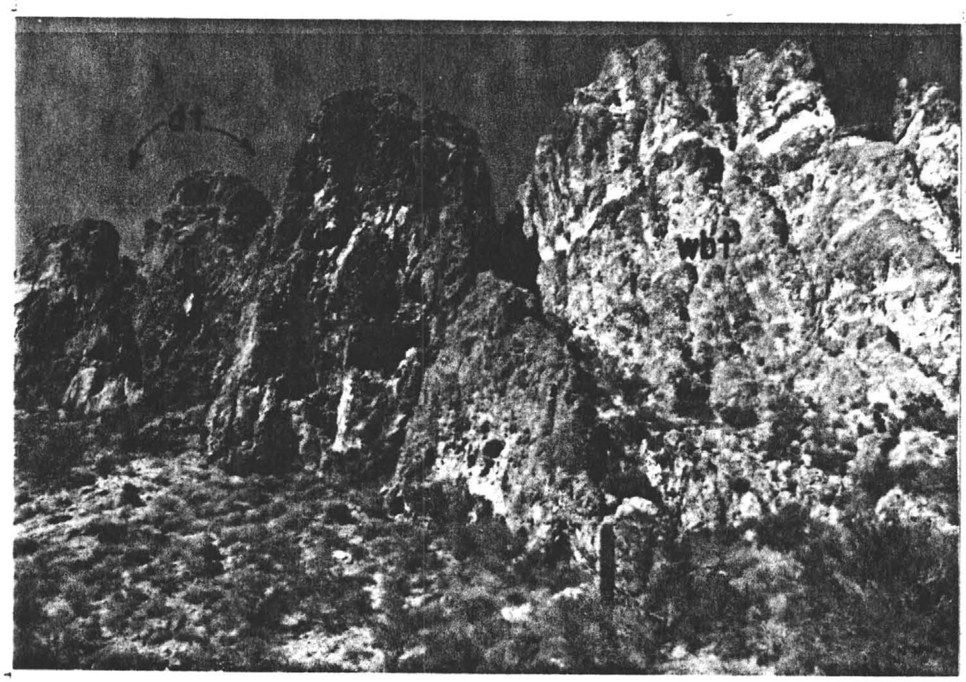
View looking generally southward at uppermost Canyon Lake, just below Horse Mesa Dam (family housing visable on point). Black Cross Butte (BCB) capped by upper welded rhyodacite flows seen also on Horse Mesa. White bedded tuffs (wbt) are outlined on both sides of the lake. Older dacitic tuffs and vitrophyres are lowest units exposed here.



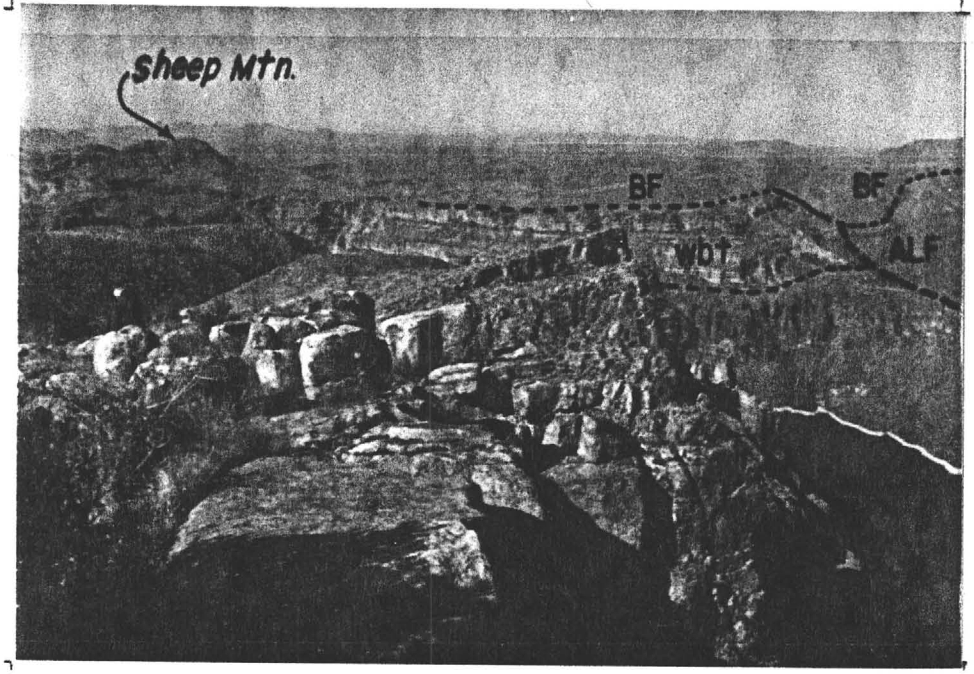
View looking north along access road to Horse Mesa Dam showing subhorzontal slickenside lineations on E-W fault. (wbt) unit of above photo forms cliffs, and represents air fall ash and base surge.



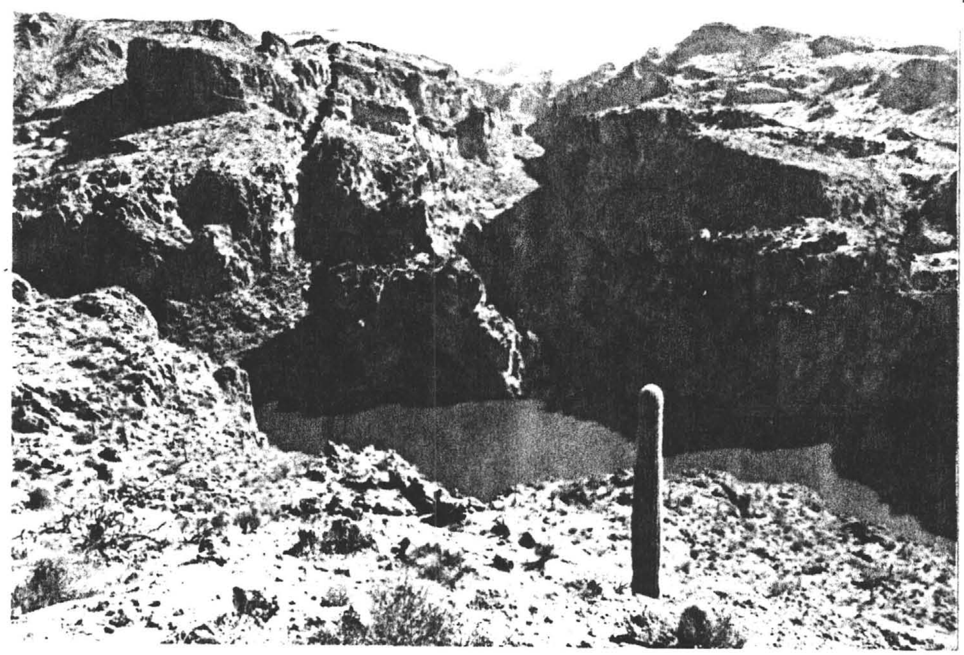
View looking NW at lower Apache Lake showing trace of Apache Lake fault (ALF) with obvious NE side down offset of white bedded tuff (wbt) series. BF is basin fill, with photo looking nearly down axis of paleochannel developed in BF, discussed in text. Precambrain granite (p€gr) exposed at lake level, and found in hanging wall of ALF farther east, implying reverse fault movement.



View of area "A", above, looking northwest, showing Apache Lake fault at center, with white bedded tuffs (wbt) downthrown against dacite tuffs (dt). Complete fault story here involves complex cross-faulting.

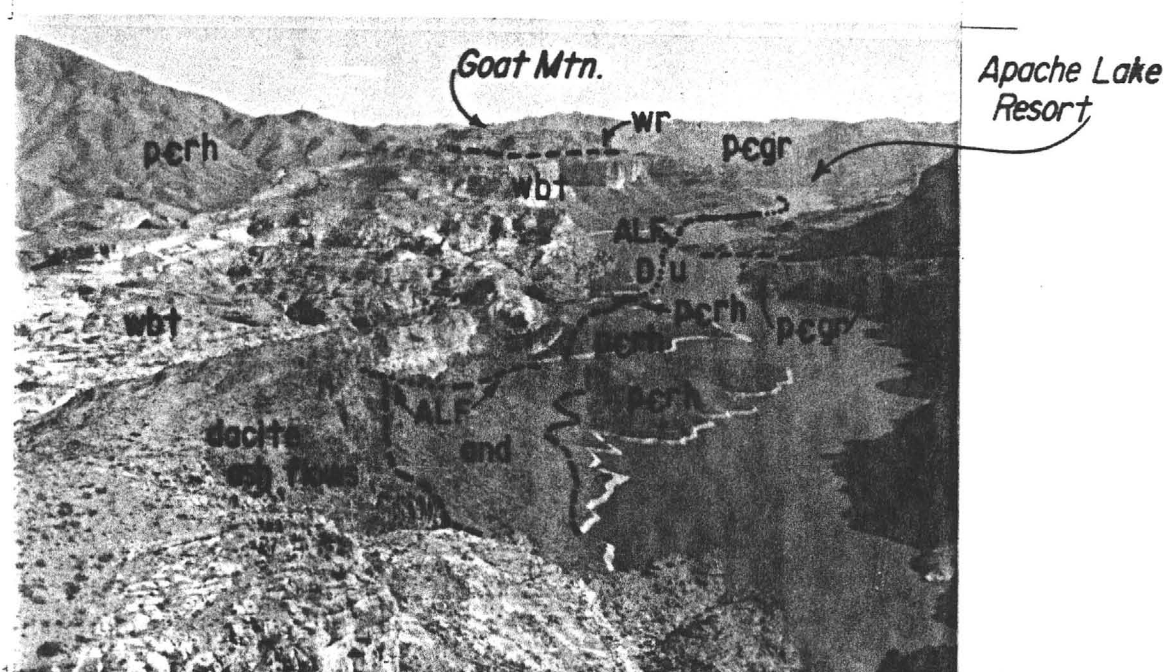


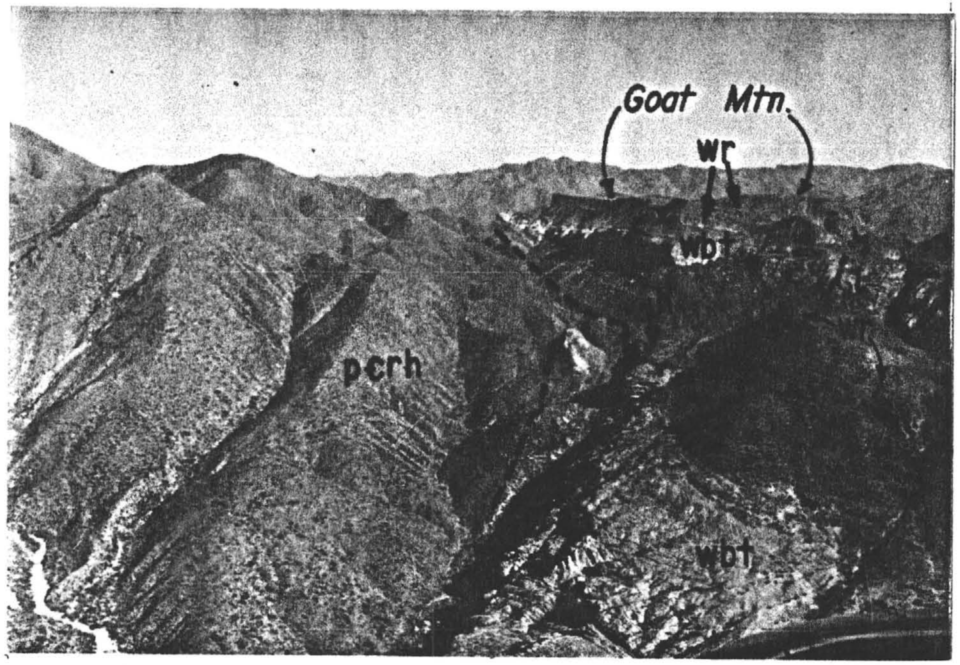
View NW from near top of Horse Mesa, hill 4025, with Apache Lake below. Paul Damon stands at collection point of SRP-2 (UAKA 80-127) K/Ar sample. This sample is a welded rhyodacite flow which caps western Horse Mesa, and Black Cross Butte to the west. White bedded tuffs (wbt) serve as good stratigraphic marker in the region. Apache Lake fault (ALf) enters the right side of photo. BF is undeformed basin fill.



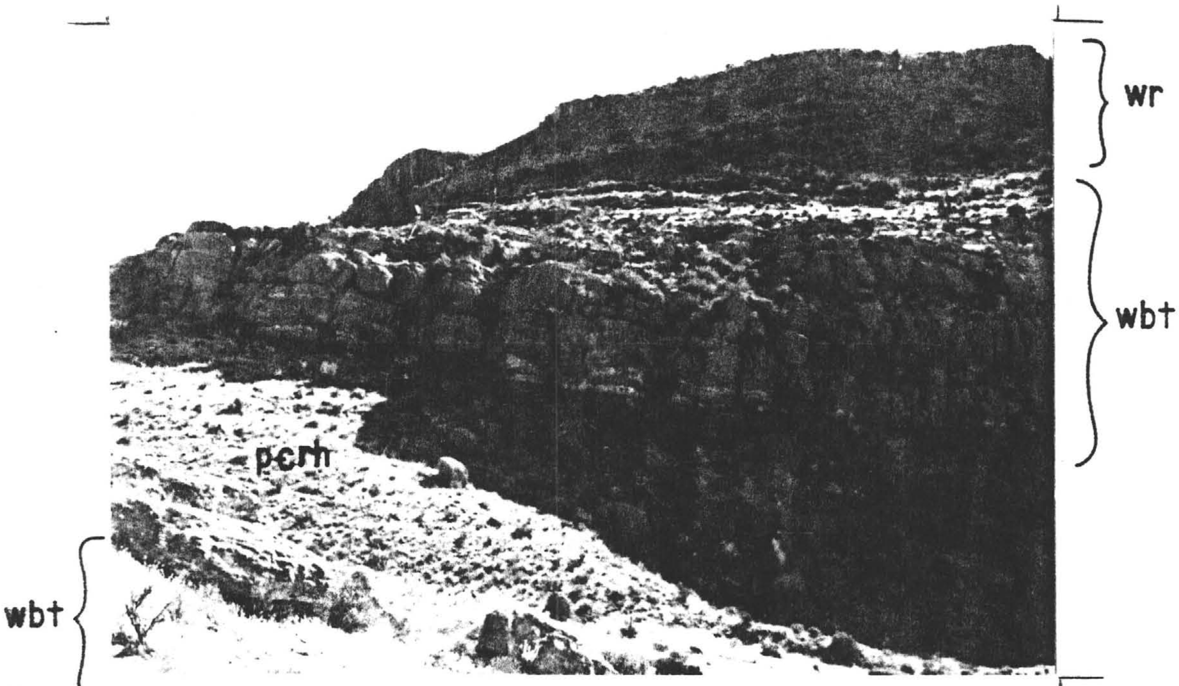
Arrows (in shade) point to an E-W large normal fault and several smaller magintude scissors faults in this view looking east at a side canyon entering Canyon Lake, about 2.5 straight line miles ENE of Mormon Flat dam. This large fault can be tracked 5 miles eastward to Horse Mesa, where it defines the south limit of Horse Mesa horst block shown in cross-section B-B'.

View eastward of Apache Lake, showing Apache Lake fault (ALF) with apparent reverse movement, Precambrian rhyolites (p€rh) and granites (p€gr); and Superstition volcanics - andesites and breccias (and), white bedded tuff unit (wbt), dacite ash flows, and capping welded rhyolites (wr). Contact between p€rh and andesite units is both faulted and depositional.

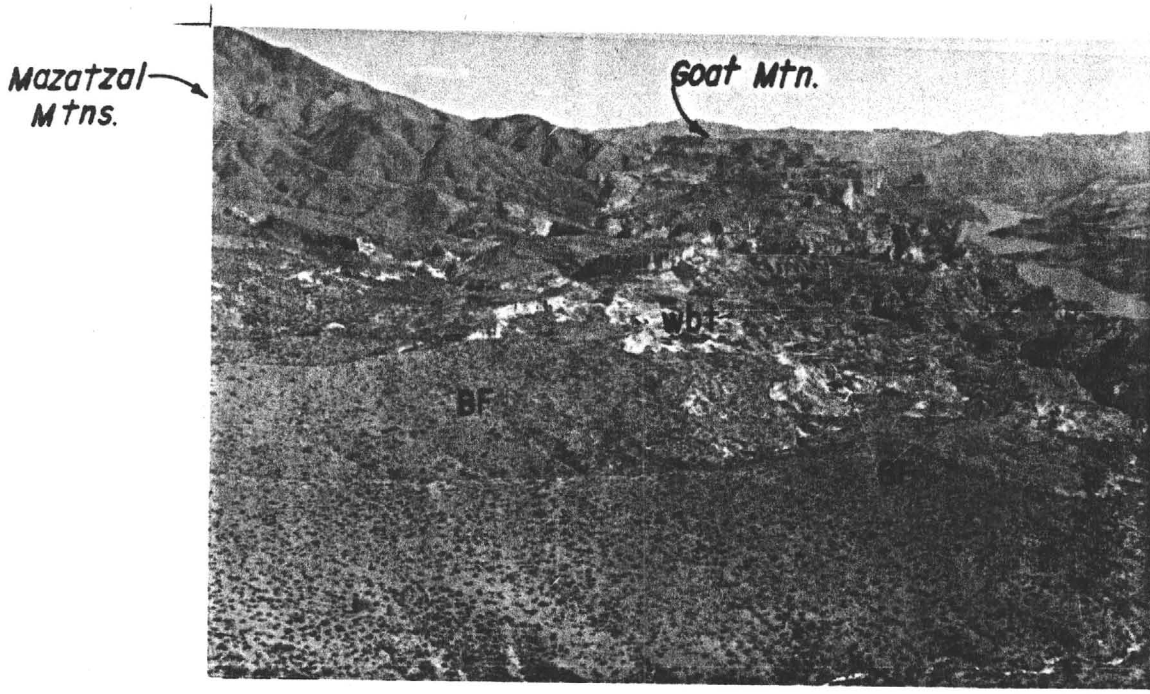




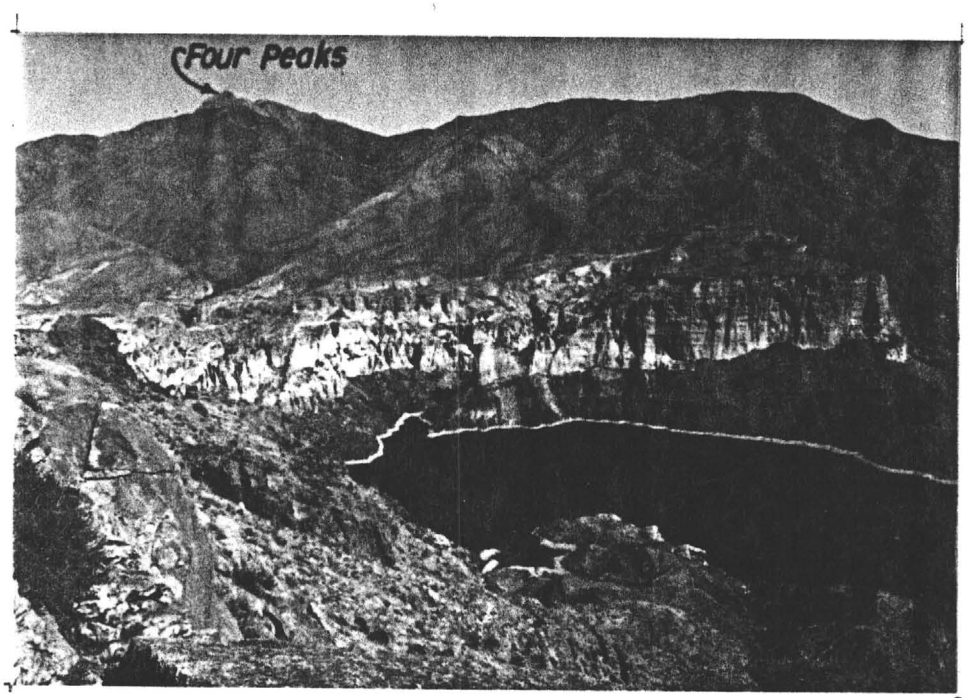
Close-up view looking east toward Goat Mtn. of faulted contact of wbt unit and capping welded rhyodacite flows (wr) of Goat Mtn., against Precambrian metarhyolite (foliated) of southern Mazatzals. Dashed line is main fault. (h) and arrow locate helicopter position of photo, below.



View looking southward of hill 3.0 miles ENE of Horse Mesa Dam. Helicopter in view is located at (h) in above photo. Fault slices of Precambrian metarhyolite (pЄrh) at base of cliff, and white bedded tuff (under camera position) indicate fair amount of faulting has altered original nature of depositional contact.



View eastward of western part of Apache Lake, with light pyroclastics of white bedded tuff unit (wbt) in faulted depositional contact of Precambrian rhyolites and granites of southern Mazatzal Mtns. Rounded hillslopes in foreground are basin fill fluvial sediments (BF).



View north from Horse Mesa across Apache Lake at white bedded ruffs (wbt) deposited against southern Mazatzals. Wbt here is underlain by an andesite flow series related to basal andesites and redbeds of eastern Horse Mesa. Foreground rocks are lahars (hot volcanic mudflows). Photo taken from main saddle on Horse Mesa, 3 miles east of Horse Mesa Dam.

SUMMARY OF GEOCHRONOLOGY

In this field area, thirteen K/Ar age dates have been determined for the Bureau of Reclamation by the Laboratory of Isotope Geochemistry, University of Arizona, mostly between 1977 and 1981. The entire age range determined for the silicic to andesitic volcanic sequence in the northern Superstitions is 22.6 to 15.4 m.y., based on 12 samples. The other date of 14.2 m.y. on a capping basalt is the youngest age for any volcanic rock in the area. Within the silicic sequence, rhyolitic to dacitic units range in age from 20.6 to 15.4 m.y. (5 samples), three samples described as basaltic, range in age from 22.6 to 18.1 m.y.; two trachyte samples date at 18.7 and 18.0 m.y., and two andesitic samples date at 21.4 and 15.5 m.y. These petrologic rock assignments are based on both field characteristics and potassium content of dated materials, although these potassium contents are of selective material, and are not meant to be representative of the whole rock material. Based on these ages, the Oligocene period is not represented in this part of the volcanic field, its boundary with the Miocene being placed now at about 22.5 m.y. on international time scales.

The age dates in the structural block around the Goldfield Mountains (Southwest structural block) suggest the production of older flows and domes around 20 m.y. (UAKA 68-16), the continued out-pouring of the brown and yellow tuff and flow series around 19 m.y. (UAKA 80-126), and then a homoclinal tilting event due to listric faulting before a planation of some of the terrain and covering by an apparently lesser deformed basaltic andesite flow at 18.3 m.y. (PED-14-68). A later post-tilting basalt flow at 14.2 m.y. at Hackberry Mesa (UAKA 80-129) covers the older sequence and in turn is cut by a high-angle N-S fault.

In the northeastern structural block (circa Horse Mesa and eastern Canyon Lake) early andesitic flows at 22.6 m.y. (UAKA 81-30) and some undated massive vitrophyres north of Canyon Lake were overlain by a series of unwelded ash flows dating as young as 15.4 m.y. (UAKA 80-128). Farther east around Horse Mesa, older andesites (21.4 m.y., UAKA 81-31) were succeeded by a series of lahars, tuffs, and capping welded rhyodacites as young as 17.5 m.y. (UAKA 80-127). These latter flows cap all the high mesas around Horse Mesa, including Goat

Mountain. East of Horse Mesa, the volcanic stack has subsequently downthrown against granites along faults that trend parallel to the present Salt River course.

Farther downstream, andesitic to trachytic volcanism proceeded along with redbed deposition and minor silicic ash flow activity between 18.7 and 15.5 m.y. age (UAKA 77-144, 145, 146, 147, 148, and 149). Curious tilt patterns in the Mt. McDowell - Coon Bluff area are divergent from those in the nearby Goldfield Mountains, and suggest structural complexities in the zone now astride the Salt River around Mt. McDowell.

Around Saguaro Lake, white tuffs and conglomerates of presumed 15 m.y. age are involved in the Saguaro Lake anticline. Units as young as the fanglomerate of Mesquite Flat (post - 15.4 m.y., UAKA 80-128) are clearly involved in some apparent reverse high angle faulting around Tortilla Flat (possibly equivalent to the Apache Lake fault in movement timing and style). Hence some middle Miocene NE-SW compression due to unknown regional tectonics appears to have been operative. It is now thought that in several parts of southern Arizona and adjacent California, low angle "denudational" or "gravity-fed" low angle faulting was occurring in mid-Miocene time (Reynolds, 1980; Scarborough and Wilt, 1979) which clearly involves rocks as young as 15.8 m.y. in the Harcuvar Mountains (Scarborough and Wilt, p. 77), but generally predates 13 m.y. (Reynolds, p. 11). The tilting, anticlinal formation, and presumed high angle reverse faulting along the lower Salt River are presumed to be part of these regional tectonics.

QUATERNARY TECTONISM

No direct evidence was found during this study of any faulting of Quaternary age in the field area of this report. However, three phenomena which relate to the possibility of young tectonics deserve attention. The first is a curious arrangement of stream drainages four miles north of Mormon Flat Dam. The second is a possible scarp with relief that offsets a Pleistocene surface northwest of Roosevelt Lake in the Tonto Basin. And the third is the downstream convergence of Pleistocene strath terraces with present stream level in this field area. They will be discussed in the above order.

In the area called "the Rolls" on the Mormon Flat Dam quadrangle, just west of Cottonwood Creek, there is a one mile wide zone trending about N60°W composed of a terrain of high accordant ridge crests dissected by small gullies which individually trend N30°E. This overall ridge trends to the northwest for about 3.5 miles, slowly decreasing in relief to the west above the lower elevation terraces which lie astride it both to the north and south. Occasional outcrops in these hills are of fluvially dominated basin fill fanglomerates, with very low overall dips to the southwest. The stratigraphically highest of these deposits exposed in this area are probably late Miocene or Pliocene age (8-3 m.y.) based on regional correlations, while the gravels which cap the ridges are probably Pleistocene age (2-1 m.y.). It appears difficult to derive todays drainage pattern in this area without at some time during the late Pliocene or early Pleistocene having a fault-bounded horst block produced with the N60°W trend which was subsequently modified by stream erosion. The most compelling evidence for this is that the N-60°W faults already mentioned are those which displace the post-volcanic fanglomerate of Mesquite Flat, and hence are the youngest known in the area. And the major trend of this fault set is about one mile south of the trace of the southernmost of the horst-bounding faults proposed here. A quick reconnaissance around Cottonwood Creek failed to disclose any evidence of fault traces through the basin fill sediments. Exposures of sections cut by the proposed fault traces are virtually nonexistant.

It is interesting to note that in a report by FUGRO, Inc. (cited below) a "proven" Quaternary fault east of Sugarloaf Mountain, 6-8 miles north of "the Rolls", trends northwest, and is northeast side-down. The fault trace is arcuate, with the southeastern most part trending about N50°W. This trend and sense of movement is consistent with the movement on the fault which cuts the fanglomerate of Mesquite Flat, and would be parallel to these faults proposed for "the Rolls".

The probability of Quaternary surface rupturing in central Arizona obviously is an important issue. The general published literature known to this author which specifically deals with the occurrence of Quaternary faults (surface ruptures) in Southern Ariozna is very scant. The FUGRO, Inc. report to WPRS dated February 1981, entitled "Seismotectonic Study, Roosevelt Dam, Arizona" concludes that an elongate zone oriented NW-SE through central Arizona does exhibit potential for large earthquakes (magnitude 5.5) and that a "maximum credible earthquake" in the region is likely to be about magnitude 6.5 or so with recurrence interval of several thousand years (even thought Dubois and Smith (1980) suggest a magnitude of 7.2 for the 1887 earthquake centered in Sonora, south of Douglas). The FUGRO report suggests the presence of several Quaternary-aged faults of the "proven" category within 30 miles or so of the dams on the lower Salt River.

This author has examined several Quaternary and possible Quaternary breaks throughout the central Arizona Mountain Province and is in agreement with the report that the southwest border of the Colorado Plateau contains a zone with a history of Quaternary surface rupturing. In additiona, this author suggests that in the northern Tonto Basin around Punkin Center, there are several more fault traces visible from low altitude reconnaissance in addition to the one mapped in the FUGRO report. The first set of traces are about 5 to 8 miles south of Punkin Center, and about 1.5 miles west of Tonto Creek and parallel to it. These consist of erosional effects on a series of accordant ridge crests, and a vegatated fault line which appears to cut young basin fill deposits. The second obvious feature that deserves attention is a linear feature about 2 miles north of Punkin Center and 2 miles west of Tonto Creek (SE¼ sec. 33, T 7 N., R 10 E., and NE¼ sec 4, T 6 N., R 10 E.,). The feature is an apparent offset of the surface of a Pleistocene pediment terrace, traceable for 1000 feet, along a linear zone which trends about N15°W. The remaining terrace remnant is "V" shaped in plan view, with the notch of the "V" consisting of an ephemerial stream course aligned perfectly with the possible fault trace. The feature shown on the FUGRO map was not noted in the aerial reconnaissance. These two sets of features in the Tonto Basin should be examined on the ground to ascertain the prevalance of Quaternary fault ruptures in this region.

Judging from topographic sheet contours, and information in Pewe (1978), the Mesa Terrace consistently diverges upstream from present stream gradient from the Tempe area, at least to the area of Mormon Flat Dam. See the details given in the section entitled "Blue Point picnic area". Along the several-mile stretch of river below Stewart Mountain Dam, the Mesa Terrace diverges by 60-80 feet from the river, and in this interval lies 160-220 feet above river level. Tracking this terrace level farther downstream, it appears to coincide with a 140-160 foot level at Coon Bluff and most probably with a 100-120 foot level to the north and west of Granite Reef Dam. Closer to Phoenix, Pewe suggests the Mesa Terrace is 10 feet above river elevation, and in the other direction, around Lake Rooseelt, Pewe suggests this terrace is more than 300 feet above the river. This last correlation is a long distance extrapolation and may or may not be warranted. Judging from the regionally imcomplete picture thus for assembled, this downstream convergence of terraces and present stream elevation could be due to either tectonic or climatic causes or both. Without an overall terrace profile for much, if not all, of the Gila River drainage system, tectonic effects are hard to judge, expecially if they involve gentle, broad crustal warping with wavelengths greater than distances between adjacent mountain ranges. It is becoming clear from soils studies around Phoenix that the Phoenix basin has been a center of aggradation during Quaternary time (Cm Menges, pers. comm., May 1981) and a slight relative uplift of the mountain province with respect to the basin could produce this terrace divergence effect. But Climatic change effects, acting episodically to flush slugs of sediment from the hillslopes in the Mountain province, could also cause complex terrace divergence patterns, especially along the large river systems where they transact both mountain ranges and easily erodable intermontaine basins. Pierce (1976) suggests that the Phoenix, Luke, and Picacho basins served as sumps for evaporite sediments (halite, anhydrite, etc.) during late Cenozoic time, and he defined this general area the "Gila Low", to contrast with upland basins to the southeast and elsewhere that have a clastic-dominated basin fill assemblage. Hence, the Quaternary behavior of the region may be mirroring a long-established trend of a regional, tectonically produced sump in the Phoenix-Luke area.

Whether or not this possible upwarping of the central mountain province is accompanied by seismicity, or is being accomplished aseismically is not known at this time.

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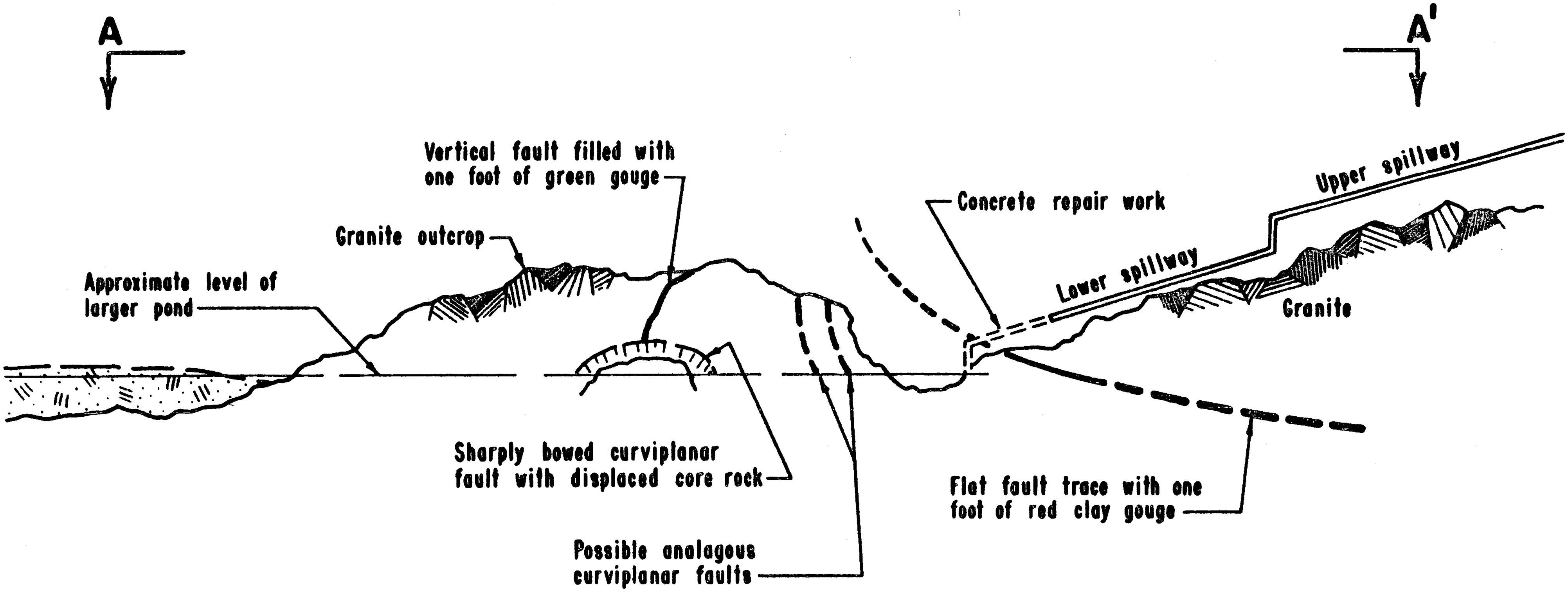
APPENDIX I

Sketch Cross-Sections

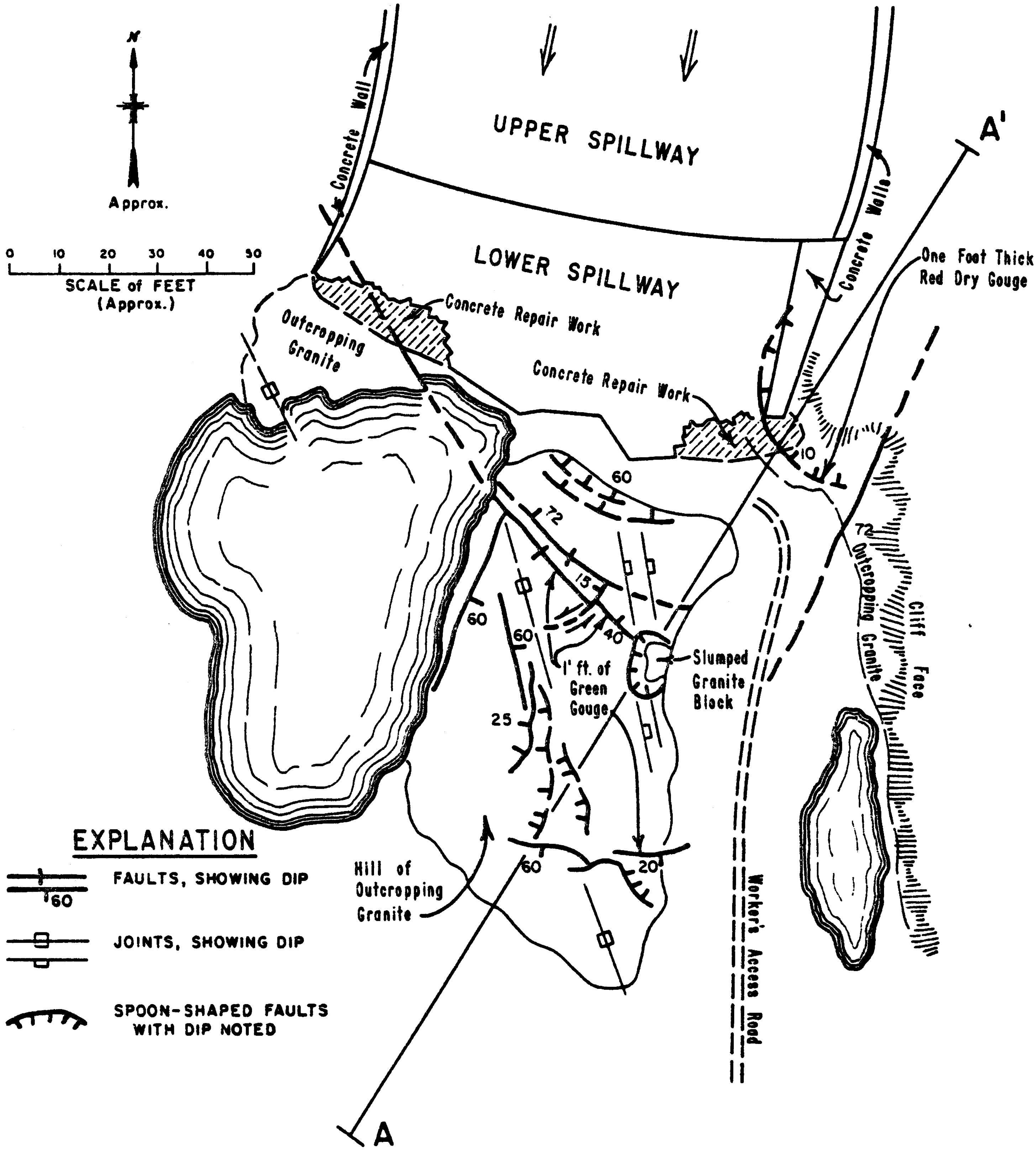
(note: these are sketches only - not drawn to scale).

See the 1:24,000 maps for locations of these sections.



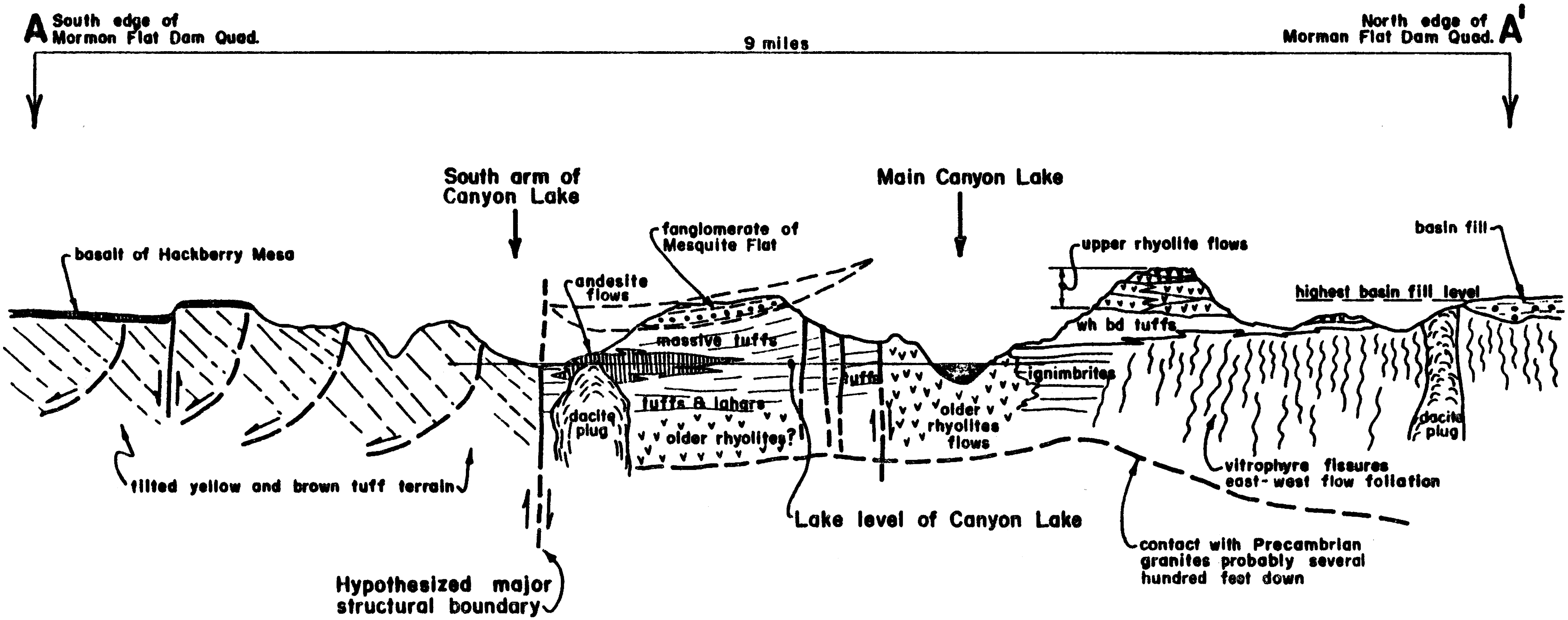
CROSS-SECTION A-A' ON MAP SHOWING FOOT OF SPILLWAY, STEWART MOUNTAIN DAM

R. Scarborough
Dec. 19, 1960



SKETCH
STEWART MTN. DAM
BASE OF SPILLWAY
FAULT AND JOINT TRACES IN GRANITE
DEC. 4, 1980

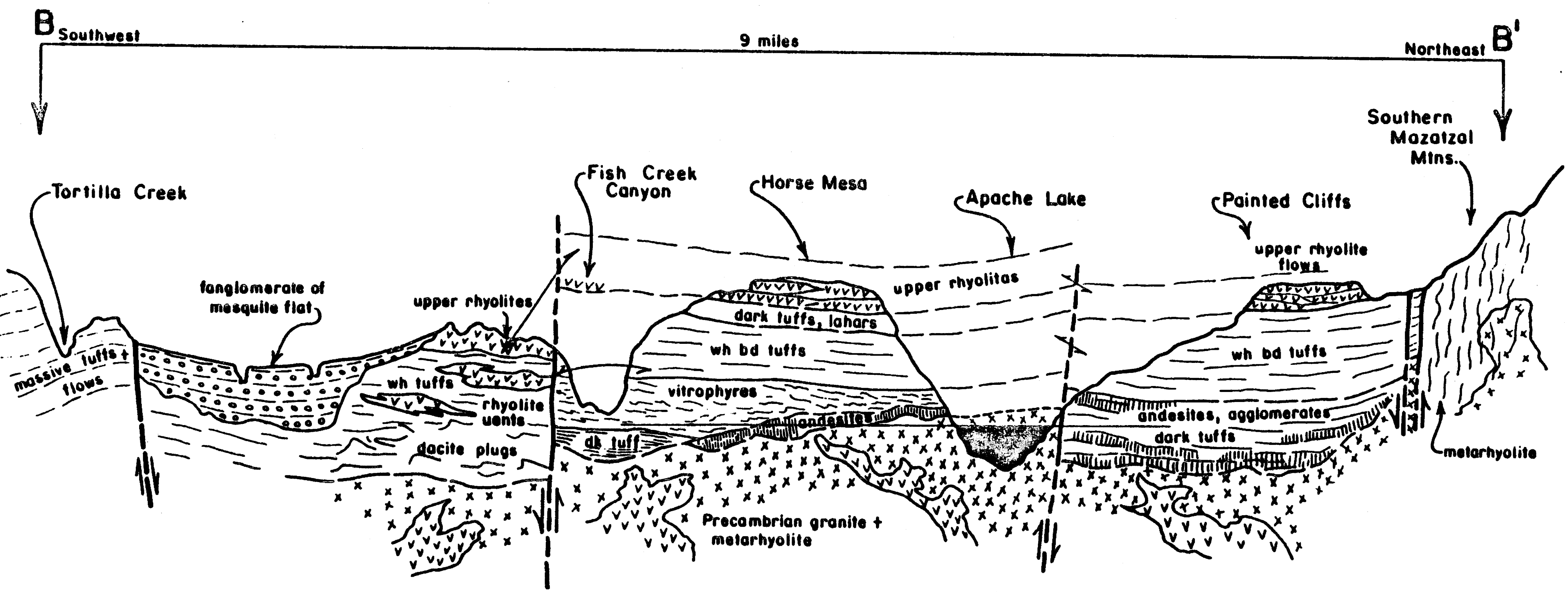
R. Scarborough



Cross-Section A-A' oriented north-south through Canyon Lake, about 2 miles east of Morman Flat Dam

(on Mormon Flat Dam quadrangle)

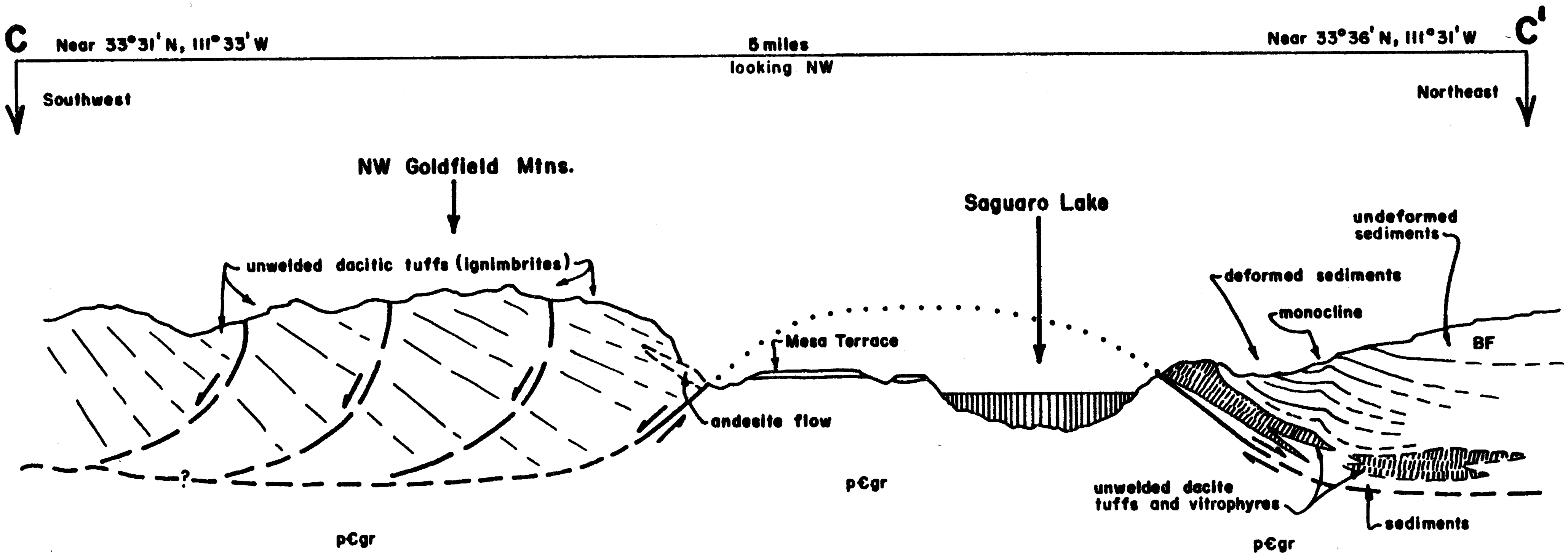
R. Scarborough



Sketch Cross-Section Oriented SW-NE Through Apache Lake Crossing The Lake One Mile East Of Horse Mesa Dam

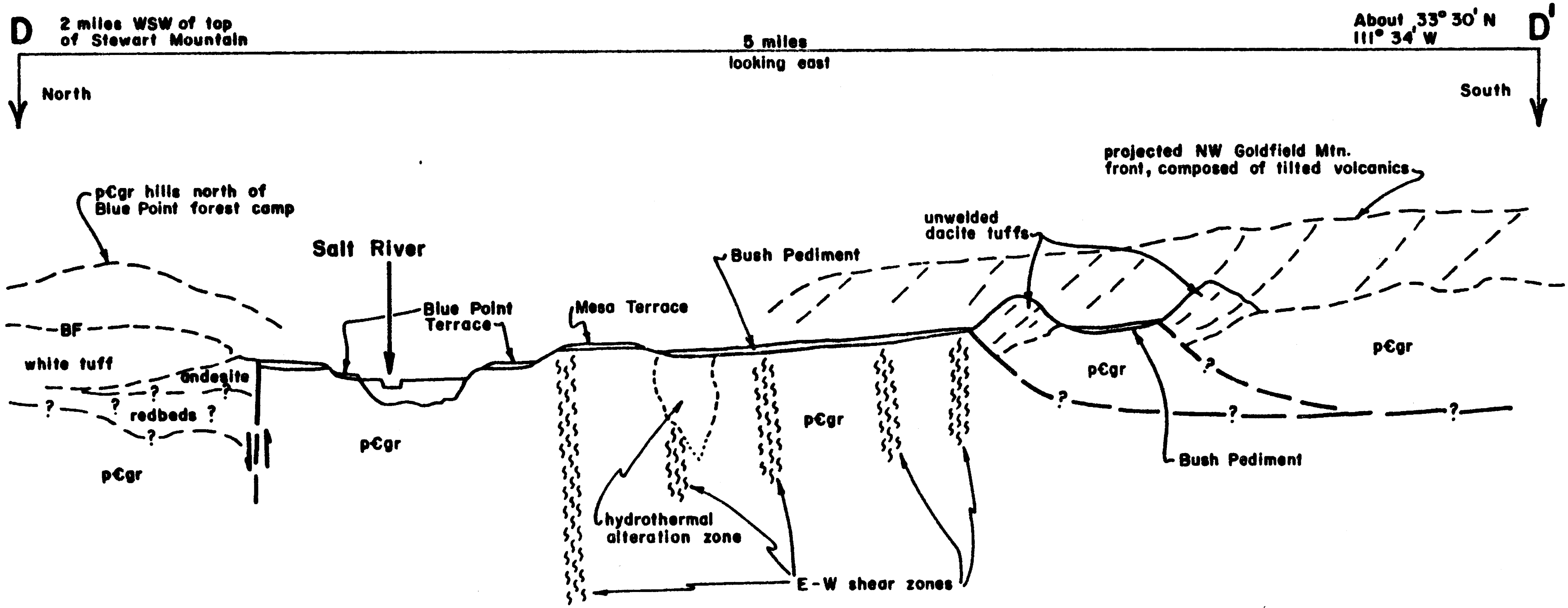
(On Horse Mesa Dam Quadrangle)

R. Scarborough



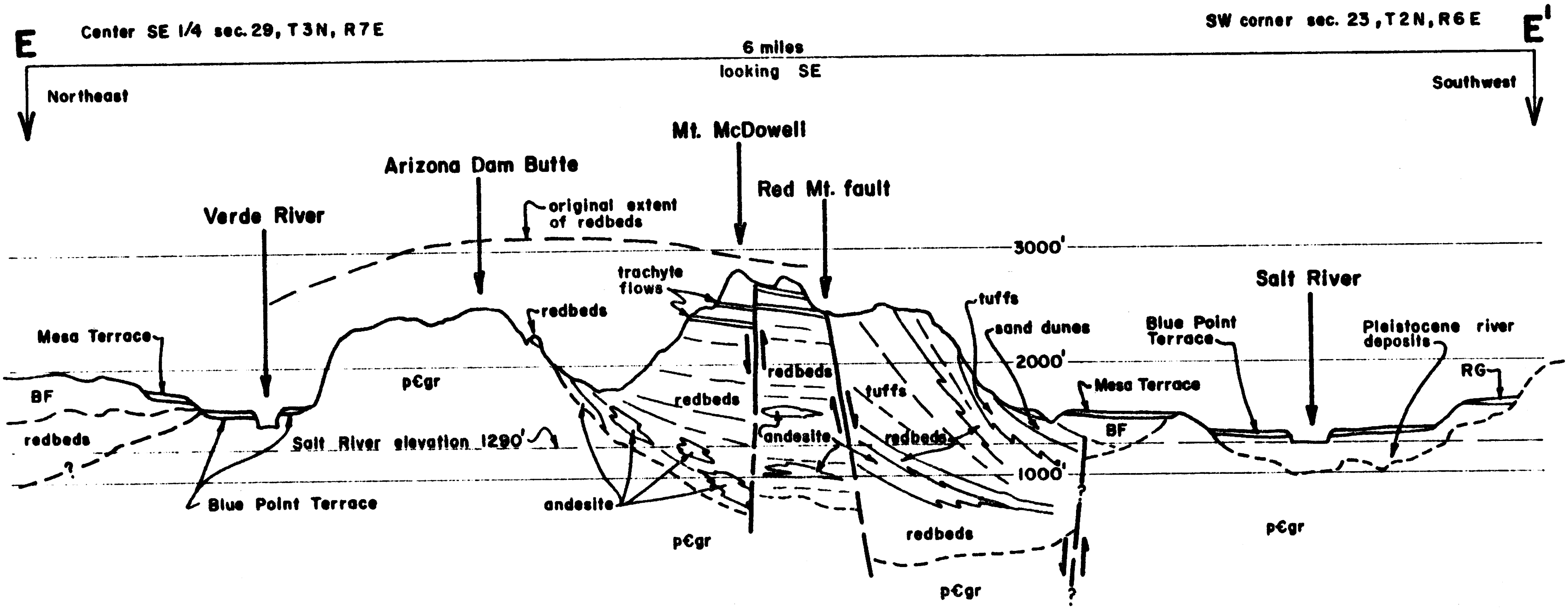
Northeast - southwest Cross-Section C-C' along northwest front of Goldfield Mountains, showing Saguaro Lake anticline

R. Scarborough



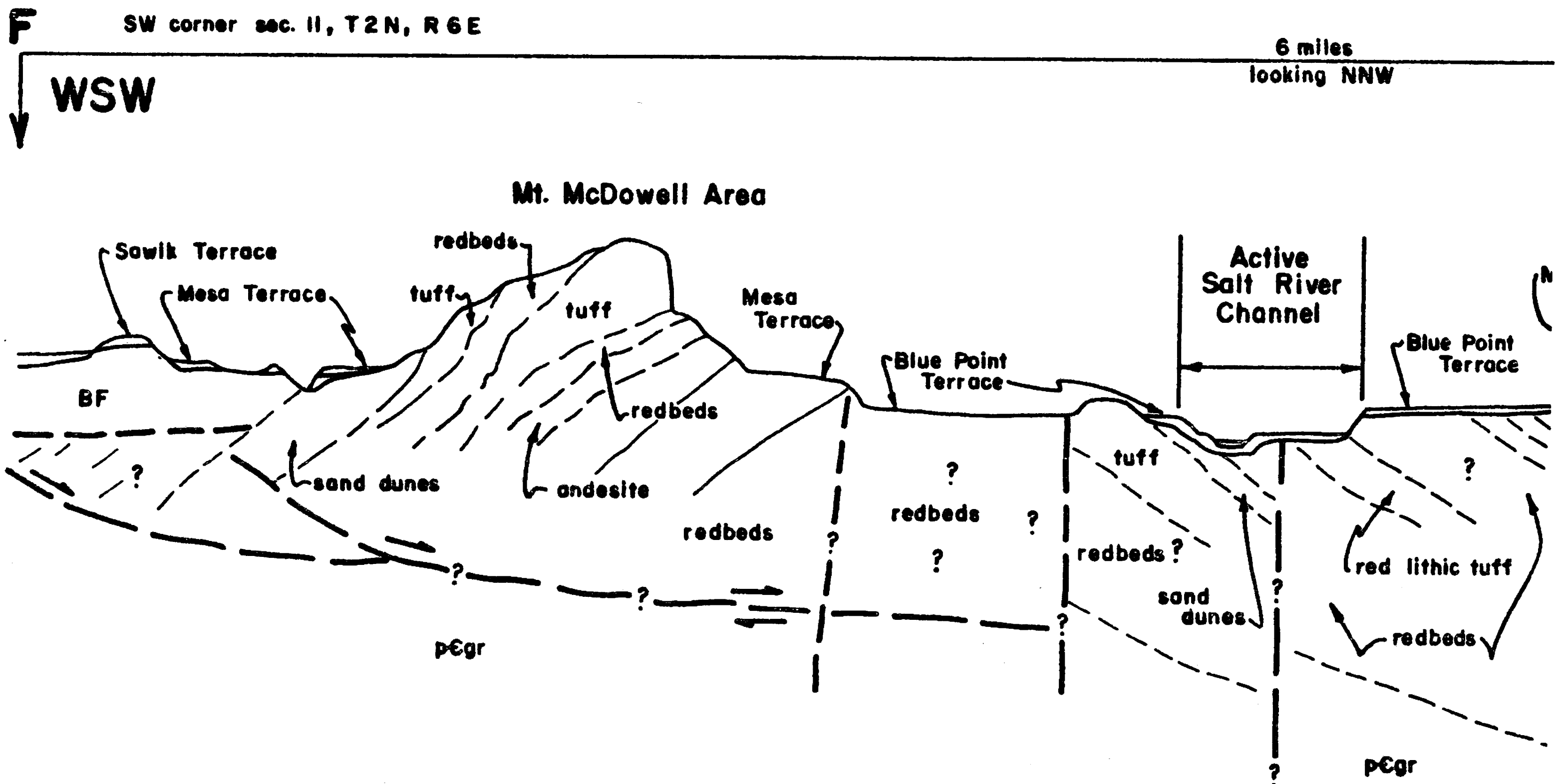
Cross-Section D-D' one-half mile west of Blue Point picnic area showing sparsely preserved Tertiary rocks on granite (North-South)

R. Scarborough
June 5, 1981



Cross-Section E-E' looking Southeast through Arizona Dam Butte and Mt. McDowell, showing thick redbed section astride present Salt River

R. Scarborough
June 5, 1981



ENE-WSW Cross-section through Coon Bluff and Mt. McDowell sh

APPENDIX 2

Table of potassium-argon age dates in the field area of this report, published in Shafiqullah, et. al.(1980), Ariz. Geol. Soc. Digest, volume 12, pp. 243-260.

Ser. No.	Sample No.	Sample description and location	K Analysis	% K Used	$^{40}Ar_{rad}$ x10-12 mole/g	% air argon-40	Age in m.y.
86	UAKA-68-16	Biotite, dacite Superstition Mountains, near Willow Springs caldera (#PED-16-68) Mormon Flat Dam Quad., Maricopa Co., AZ Lat 33° 31.18'N, Long 111° 27.42'W	7.183 7.176	7.180	257.9	31.1	20.60 ± 0.62
101	UAKA-77-147	Whole rock, trachyte (ultrapotassic) Boulder of autobrecciated, purple-red trachyte contained within a red bed fanglomerate unit that underlies flow breccia # 107 (UAKA-77-148). The fanglomerate also contains cobbles and boulders of older crystalline rock and unmetamorphosed pyroxene andesite. Granite Reef Dam Quad., Maricopa Co., AZ Lat 33° 32.43'N, Long 111° 41.24'W	9.330 9.299 9.328	9.319	302.3 304.5 304.0	4.0 3.6 3.7	18.70 ± 0.44
104	UAKA-77-145	Whole rock, basalt This flow, from the north end of Saguaro Lake, is overlain by a poorly welded ash-flow tuff unit that contains pumice and rhyolite chips. Gross lithology is similar to # 106 (UAKA-77-144) Stewart Mtn. Quad., Maricopa Co., AZ Lat 33° 34.53'N, Long 111° 31.54'W, Alt. 1590 ft.	1.067 1.068 1.080	1.072	33.89 34.24 34.49	38.2 38.7 35.9	18.31 ± 0.46
106	UAKA-77-144	Whole rock, basalt This flow unit is part of a fractured and disturbed volcanic sequence overlying a tilted fanglomerate-conglomerate unit. The clastic unit strikes N 30°W, dip 20°SW. Stewart Mtn. Quad., Maricopa Co., AZ Lat 33° 33.54'N, Long 111° 34.78'W, Alt. 1440 ft.	0.987 0.987	0.987	31.18 31.22	17.3 17.6	18.15 ± 0.44
107	UAKA-77-148	Whole rock, trachyte (ultrapotassic) Autobrecciated, purple-red flow unit overlies red bed fanglomerates. #101 (UAKA-77-147). Granite Reef Dam Quad., Maricopa Co., AZ Lat 33° 32.18'N, Long 111° 41.12'W	10.715 10.634 10.676	10.675	329.2 336.7 339.1	6.5 6.3 6.8	18.01 ± 0.43
111	UAKA-77-149	Sanidine, rhyolite ash-flow This flow unit overlies trachyte breccia # 107 (UAKA-77-148) and the red bed fanglomerate in places. Granite Reef Dam Quad., Maricopa Co., AZ Lat 33° 32.15'N, Long 111° 41.12'W	9.237 9.280 9.284	9.267	285.8 286.0 286.1 286.2	15.7 15.5 15.7 15.5	17.71 ± 0.43
122	UAKA-77-146	Whole rock, basaltic andesite The hill of basaltic andesite is flanked by flat-lying gravel containing mid-Tertiary volcanic rocks, metamorphic and granitic cobbles. Stewart Mtn Quad., Maricopa Co., Lat 33° 36.58'N, Long 111° 33.27'W, Alt. 2040 ft.	1.102 1.113	1.108	29.48 30.40	31.1 30.0	15.53 ± 0.39

K-Ar Data on Samples from Salt River Area
Cooperative Research Project with
The Bureau of Land Reclamation

University of Arizona
Isotope Geochemistry Lab
Date: March, 1981

Constants used:
$\lambda_{\beta} = 4.963 \times 10^{-10}\ yr^{-1}$
$\lambda_{e} = 0.581 \times 10^{-10}\ yr^{-1}$
$\lambda = 5.544 \times 10^{-10}\ yr^{-1}$
$^{40}K/K = 1.167 \times 10^{-4}$ atom/atom

Sample No.	Sample description and location	K-analyses Individual % K	K-analyses Mean	Radiogenic ^{40}Ar $\times 10^{-12}$ m/g Individual Analyses	Radiogenic ^{40}Ar Mean	Percent atmospheric argon-40 Individual Analyses	Percent atmospheric argon-40 Mean	Age in million years
UAKA 80-126	Anorthoclase Sanidine, flow-banded rhyolite The rhyolite flow is from a homoclinally tilted volcanic sequence and appears to be related to Goldfield Mountains. Sampled in Willow Springs Canyon, 3.53 miles WSW of Apache gap along Apache Trail, Superstition Mtns., elev. 1720', Mormon Flat Dam Quad., Maricopa Co. Lat. 33° 31.95' N Long. 111° 29.88' W (#SRP-1)	1.475 1.459 1.432 1.444	1.452	48.52 48.92	48.72	30.8 30.7	30.8	19.24±0.42
UAKA 80-127	Groundmass, welded rhyolite Vuggy welded cliff forming rhyolite flows from northeastern Superstition volcanic field, underlain by vast array of lahars, tuffs, and a thick andesite flow sequence. Near top of Horse Mesa, south side of Apache Lake, elev. 4000'. The flow appears to cap several mesas. Horse Mesa Dam Quad., Maricopa Co., Lat. 33° 34.78' N Long. 111° 19.60' W (#SRP-2)	4.506 4.484 4.506 4.490	4.497	136.4 136.5 137.5	136.8	8.9 9.1 9.0	9.0	17.46±0.36
UAKA 80-128	Plagioclase, unwelded rhyolite ash flow. Sampled 20' above level of Saguaro Lake, just upstream from mouth of Cottonwood Creek. The ash flow is from a series of silicic pyroclastics that unconformably underlie an extensive fanglomerate in the area, and are in high angle fault contact along a complex NW-trending fault with a lithologically distinct homoclinally NE tilted series of welded tuffs, flows and ignimbrites, Superstition Mtns., elev. 1580', Mormon Flat Dam Quad., Maricopa Co. Lat. 33° 33.80' N Long. 111° 27.78' W (#SRP-3)	1.725 1.705	1.715	45.65 45.35 45.44 46.04 46.56 47.43	46.08	53.3 53.5 53.4 52.3 52.0 51.6	52.7	15.43±0.34
UAKA 80-129	Groundmass, basalt The flow unconformably overlies the silicic extrusive rocks of the northern Superstition Mountain volcanic field. It is gently tilted (3-5°) while the underlying sequence has a 20-30° dip to the northeast. Sample from northern prong of Hackberry Mesa, on eastern upthrown block of a high angle normal fault. Basalt overlies Geronimo Head tuffs and a fluvial conglomerate, Canyon Lake area, elev. 2280', Mormon Flat Dam Quad., Maricopa Co. Lat. 33° 30.72' N, Long. 111° 25.00' W (#SRP-4)	0.732 0.743	0.738	18.64 18.14 18.22 18.60 17.83	18.29	76.3 77.2 77.1 76.6 76.2	76.7	14.23±0.47

APPENDIX 2 (Continued)

University of Arizona
Isotope Geochemistry Lab
Date: 15 June 1981

K-Ar data on Salt River mapping project area, Central Arizona
Cooperative research project with U.S. Bureau of Reclamation
and Arizona Bureau of Geology

Constants used:
$\lambda_\beta = 4.963 \times 10^{-10}\ yr^{-1}$
$\lambda_e = 0.581 \times 10^{-10}\ yr^{-1}$
$\lambda = 5.544 \times 10^{-10}\ yr^{-1}$
$^{40}K/K = 1.167 \times 10^{-4}$ atom/atom

Sample No.	Sample description and location	K-analyses Individual % K	K-analyses Mean	Radiogenic $^{40}Ar \times 10^{-12}$ m/g Individual Analyses	Radiogenic ^{40}Ar Mean	Percent atmospheric argon-40 Individual Analyses	Percent atmospheric argon-40 Mean	Age in million years
UAKA 81-30	Whole rock, groundmass, basalt Flow underlies an extensive blanket of fanglomerate around Tortilla Flat and overlies white tuff beds and dacite flows, Northeast side of Tortilla Creek across from Forest Service campground near the Town of Tortilla Flat. Superstition Mountains, Mormon Flat Quad., Maricopa Co., Arizona Lat. 33° 31.72' N, Long. 111° 23.55' W	0.5096 0.5054	0.5075	19.78 20.28 19.89	19.98	68.0 67.3 68.0	67.8	22.6 ± 0.9
UAKA 81-31	Whole rock, groundmass, andesite Flow from basal sequence of Superstition Mountain volcanics that rest on Precambrian granite along southern margin of Apache Lake, east end of Horse Mesa, Apache Lake Resort, Horse Mesa Quad., Maricopa Co., Arizona Lat. 33° 34.43' N, Long. 111° 15.32' W	1.812 1.812	1.812	67.9 67.3 67.7	67.6	23.6 23.9 24.0	23.8	21.4 ± 0.5

ROCK TYPE, SAMPLE NO. AND LOCATION	MINERAL	K %	^{40}Ar RAD. $\times 10^{-10}$ moles/gm	$^{40}Ar/^{40}K$ $\times 10^{-3}$	^{40}Ar ATMOS. %	APPARENT AGE m.y.
Younger basalt (PED-14-68), Black Mesa Caldera 33° 31' 26" N, 111° 28' 02" W Mormon Flat Dam Quad., Maricopa Co., Arizona	whole rock	1.54	0.490	1.05	88.6	17.8 ± 3.1 [18.3]
Dacite dome (PED-16-68), Vicinity of Willow Springs Caldera 33° 31' 11" N, 111° 27' 25" W Mormon Flat Dam Quad., Maricopa Co., Arizona	biotite	7.18	2.58	1.19	31.1	20.1 ± 1.2 [20.6]
Quartz latite lava (PED-17-68), Vicinity of Willow Springs Caldera 33° 28' 21" N, 111° 34' 45" W SW¼, SW¼ Sec. 30, T2N, R8E Apache Junction Quad., Maricopa Co., Arizona	biotite	7.40	2.91 2.78		78.8 48.6	
	*weighted average:		2.82	1.26		21.3 ± 0.8 [21.8]
Welded tuff (PED-18-68), Black Mesa Caldera 33° 28' 36" N, 111° 25' 41" W Goldfield Quad., Maricopa Co., Arizona	biotite	7.41	2.53 3.16 3.02		82.4 65.8 47.6	
	*weighted average:		2.99	1.34		22.6 ± 1.0 [23.1]

above dates are from Damon, et. al. (1969), Correlation and Chronology of Ore Deposits and Volcanic Rocks, AEC progress report # COO-689-120, p. 49. Hand-posted revised dates above are due to revisions in decay constants.

APPENDIX 3

Auxilary note on Stewart Mounatin Dam Spillway

On December 4, 1980, the spillway at Stewart Mountain Dam was visited, while repair work to the concrete spillway lower part was in progress. The accompanying sketch geologic map and cross-section were made, based only on general relationships, not on detailed measurements.

The granite exposed here was mostly badly shattered, especially obvious at the right (east) lower spillway terminus, where the fault trace of a very flat fault containing one foot of bright red clay rich gouge is exposed. (Concrete repair work will virtually hide all of this fault beneath the spillway). In places the granite appeared finer-grained than usual, taking on more the appearance of a hypabyssal porphyry rather than the usual K-spar porphyritic quartz monzonite of the area.

Three main sets of faults and a ubiquitous joint set were noted in the granite outcrops of the area. The first fault set trend about N 40° W, and are vertical, with one foot of green gouge lining the dominant of two parallel faults. The dominant fault at one point is displaced 3 feet in a left-lateral sense by a 15 degree northwest dipping shallow spoon-shaped fault.

The second set of faults are spoon- or bowl-shaped, bowing upward, faults. The one exposed under the washed-out concrete work at the southeast corner of the spillway dips very shallow northeastward and contains one foot of bright red clay gouge. Two others exposed at the north end of the nearly granite massif start nearly vertical and also bow downwards towards the north or northeast. Three other sets of spoon-shaped faults were noted on the map in the central massif. One fault set on the west side dips westward at 25°, another on the southeast corner dips northeast at 20°, and a third odd one marked with a "slumped granite block" notation on the map contains 200+ degrees of a complete circle, with a block of granite still intact on what should be the downthrown, foot wall side. The radius of curvature of this fault is about 15 feet.

The third fault orientation is seen by a single fault east of the southeast spillway corner which trends roughly N 20° E and dips 72° E. It appears to postdate the fracturing which accompanied the red gouge-filled spoon-shaped fault, and may be the youngest episode of faulting represented here.

A pervasive vertical to high angle joint set trends roughly N 10-20° W through the granite knob.

The spoon-shaped faults may record either a time of stress readjustment of the granite basement as the overlying rock load is removed by erosion of the Salt River during downcutting, or perhaps a time of tectonic activity as during the production of the Saguaro Lake anticline discussed in the report. The north-south joints are recorded as well in the granite outcrops one mile to the east on the shore of the lake. The N 40° W faults with green clay gouge appear to be the oldest of the fault sets here, but have a curious parallel alignment with the strike direction of the tilted volcanic rocks of the Goldfield Mountains to the southeast, and to the prime structural boundary which goes through Canyon Lake, noted also in this report.

APPENDIX 4

HORSE MESA DAM SUPPLEMENT

Two additional field days were spent in late April, 1981 gathering data to allow the drawing of a 1"=200' map in the vicinity of Horse Mesa Dam. During this time, the interpretation of certain contacts around Apache Lake was revised from those presented on the regional map. This supplement is not meant to describe the stratigraphy in detail, but rather to emphasize the basic geology at the damsite. Reference was made to an earlier report on the Horse Mesa and Mormon Flat Dams by F. L. Ransome date April 15, 1935.

Summary of Geology

A summary of stratigraphy around Horse Mesa Dam is presented in the legend of the 1"=200' map. The exposed Precambrian basement in the map area consists of metarhyolite with local ENE vertical foliation, exposed only along the north shore of Apache Lake. This is overlain by a thick assemblage of silicic to andesitic volcanics of the Superstition volcanic field. These rocks, around Horse Mesa Dam, consist of lower andesite flows containing minor bedded tuffs and flow breccias, overlain by basically two kinds of units, dacite-latite vitrophyres, ash flow tuffs, with some welded units; and a regionally continuous series of primary well-bedded, light-colored, air-fall tuffs, termed the "A" tuff series on the regional maps and on this map.

Within two miles of Horse Mesa Dam, the stratified sequence consists of about 150-180 feet of andesite (base not exposed), overlain by about 600 feet of dacite vitrophyres, tuffs, and ignimbrites, 300 feet of "A" tuff series, and at least 1,300 feet of upper dacite flows, tuffs, and ignimbrites, of which the capping flows on Horse Mesa are dense, welded units. The "A" tuff series is mapped on the Horse Mesa Dam and Mormon Flat Dam 7.5 minute quads of the regional map series.

The strata around Horse Mesa Dam dip a few degrees genearlly in the downstream direction, both above and below the dam. This is not easy to see on the 1"=200' map because only a few contacts wrap around the lake, concave in the upstream direction, but none the less this is the trend within perhaps one mile upstream and one-half mile downstream of the dam. Except for a normal amount of interfingering of various units, the basic geology around the dam consists of a only slightly deformed sequence of strata, with one important exception. The dense flow rock which forms both dam abutments, here termed a dacite flow (da unit of detailed map), measure somewhat more than 600 feet thick near the abutments, yet thins to, and merges with welded flow units 50-150 feet thick, in all directions from the dam. All available field data, including well developed flow foliation in the dacite and the nature of contacts, indicate the dacite flow is thick where it filled a pre-existing paleo valley, about 600 feet wide, cut into the older volcanics, and thin where it flowed over a relatively flat topography adjacent to the paleo valley. The dacite mass around the Dam is clearly a flow, and not a plug or fissure vent, because of the shallowing instead of steepening of flow foliation near the center of the mass, as observed on the rock walls near both abutments. See the flow foliation data for the left (south) dam abutment on the map. Along the river about 400 feet downstream of the Dam the basal part of the dacite is depositional on a wedge of talus (a tx unit of 1"-200' map) developed on the andesite flow exposed along the river below the Dam. The basal contact of the (a tx) unit dips nearly 50° upstream, which may coincide with the local slope developed on the andesite flow during the existance of the paleo valley. The contact between the (a tx) unit and the overlying dacite adjacent to the lower dam access road dips 20° upstream, which projects to about 100 feet below normal water line at a point beneath the Dam. However, the statement made by Ransome in his 1935 report that only the dacite was encountered in drill holes 100 feet beneath the base of the dam suggests the contact of the base of the dacite plunges upstream at some angle greater than 20°. It appears to be unknown now just how far below the base of the Dam the dacite flow mass extends, since its base has not been encountered in drilling.

The only evidence which is contrary to the flow hypothesis for the mode of emplacement of the dacite, as opposed to the dacite intruding the andesite, is seen in the walls of the rugged NW-trending canyon at a point 800 feet SSW of the center of the Dam. Here, as seen on the 1"=200' map, some andesite has been clearly caught and squeezed up into a partially welded phase of the dacite, as though the dacite erupted through, brecciated, and engulfed some of the andesite. However, this entrapment of blocks of andesite could conceivably have taken place as an advancing dacite flow enfulfed blocks from the paleo valley canyon edge which were already loose and about to fall. The entraped andesite masses are found at elevations some 30 feet above the top of the outcrop of the andesite flow, but could have been carried for some short lateral distance from where the andesite was at higher elevation.

Under the hand lens, the welded parts of the (da) unit from near the Dam consist of large alkali feldspar (1 to 8 mm diameter) and brown biotite phenocrysts with occassional metallic black (hematite-magnetic?) one mm diameter crystals, set in a pink aphanitic groundmass. Quartz phenocrysts are not common. Some of the biotites are altering to iron oxides. Pneumatolytic devitrification of the groundmass has affected various parts of the flow. A kind of eutaxitic structure serves to define flow foliation in many parts of the flow. The entire (da) map unit within 1,000 feet or so of the Dam is not a single ignimbrite flow, but could be part of a single cooling unit, because wedges of primary, air-fall ash are intercalated into the mass. Some of these are visible in the vertical walls above the lake just north of the right (north) Dam abutment. These features indicate deposition of air fall material during periods of time between advances of lobes of flow material.

Structural Geology

Two episodes of high-angle faulting are noted in the area of the 1"=200' map. The first is pre- the (da) dacite unit, and the second is post- the (u da) unit. The latter is evidenced by a large-scale fault which lies off the 1"=200' map area to the NE.

Along both shores of Apache Lake, about 1,200 feet upstream from the Dam, several N40°W trending high angle faults affect the strata older than the (da) unit, but appear to not offset the base of the (da) unit. Two parallel faults are postulated to exist along the north shore to explain the absence of andesite in a graben block where andesite is clearly absent, with its presence on either side of the graben confirmed. The northeast most of these two faults is visible, and dips 70°SW. Another fault on the south shore of the lake juxtaposes older andesites and andesite tuffs against an overlying distinctive dacite ignimbrite containing miarolitic cavities. The faults on the north shore nearly project to the fault on the south shore, but appear to miss it to the NE by a short distance. These three faults are subparallel to a large-scale NW trending, NE side down high angle fault seen on the regional map as running along the north shore of Apache Lake, and coming to within about 0.6 mile of Horse Mesa Dam. However, this large-scale fault cuts strata as young as the (u da) map unit of the 1"=200' map, and hence is younger than the local faults.

There is also evidence of some N25°W directed small scale, high angle faults which cut the lower most (da) unit about 600 feet downstream of the Dam on the north side of the Salt River. The farthest downstream of these faults appears to have offset the (da)-(and) contact down on the NE side perhaps 10 feet or more. Associated with these faults below the Dam are some parallel-trending, vertical, pink-colored rhyolite dikes from 1 inch to about 1 foot thick. These cut the (and), (a tx), and the lower part of the (da) units. They may be a more aphanitic phase of the (da) unit, or they may be part of later eruptions.

No other faults were found in, or in the immediate vicinity of, the (da) unit. It appears to be a weakly fractured but structurally sound, partially welded dacite ash flow, capable of withstanding the stresses placed upon it because of its thickness and lateral extent across the canyon.