Lunar and Planetary Laboratory
Department of Planetary Sciences

PTYS 597a

PLANETARY FIELD GEOLOGY PRACTICUM

Field Trip 24 -26 April 1992

The University of Arizona
Tucson, Arizona

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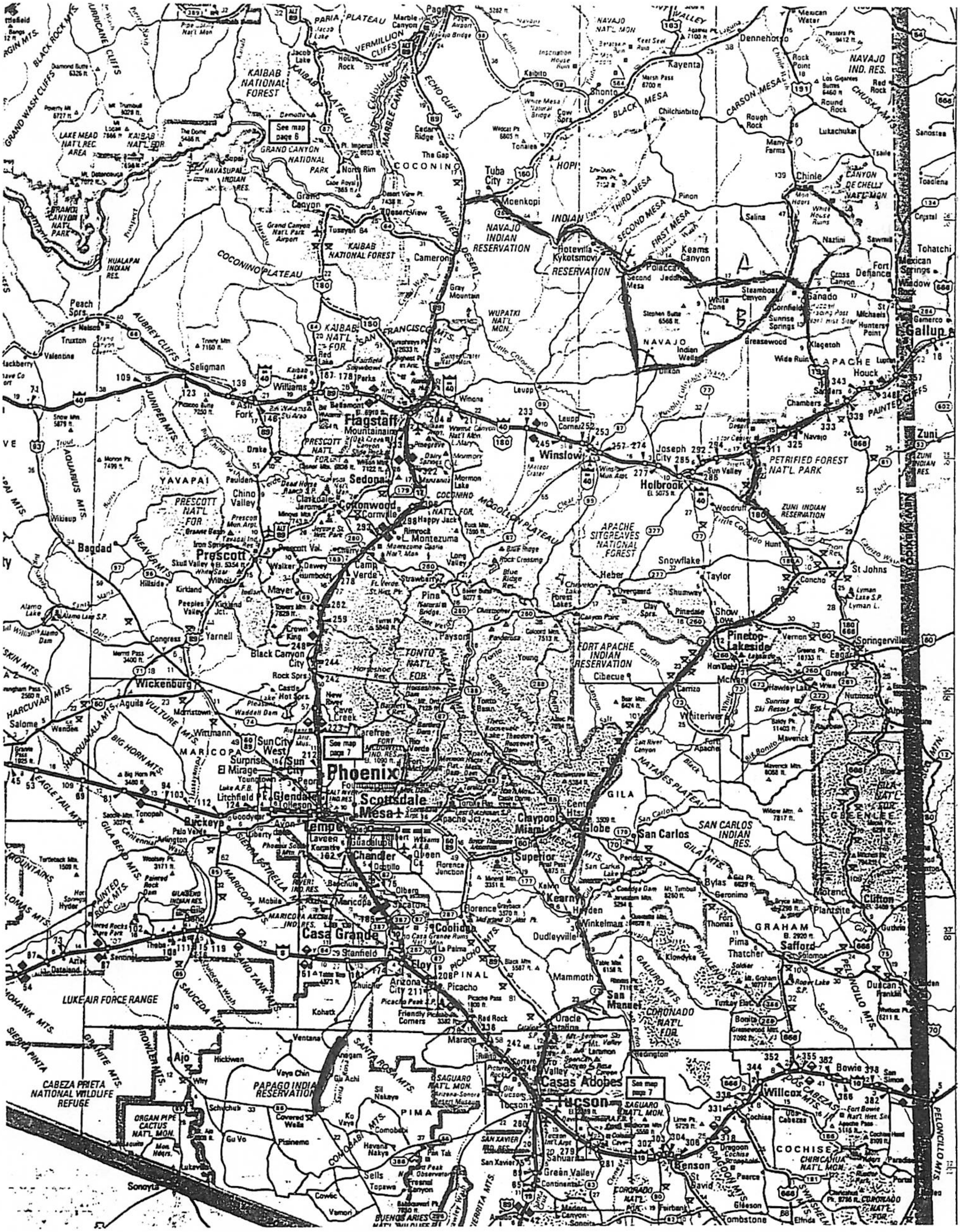
[1] West.
[2] Your helpful hosts.
[3] May be moved to day 2, depending on time.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Marble Canyon
Navajo Bridge
Jacob Lake
House Rock
KAIBAB NATIONAL FOREST
KAIBAB PLATEAU
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PRESCOTT NAT'L FOR.
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Chino Valley
Sedona
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Rimrock
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MOGOLLON PLATEAU
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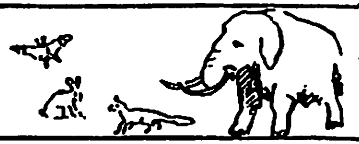
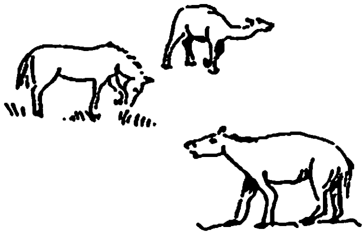
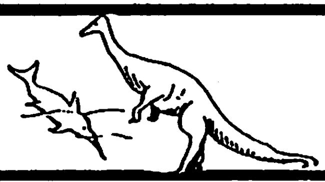
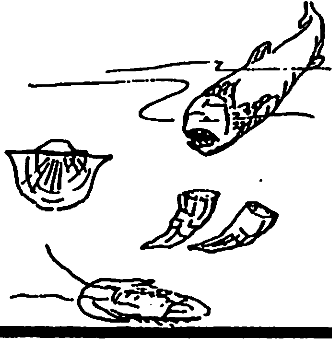
Miami
Globe
Cent. Hts.
GILA
San Carlos
SAN CARLOS INDIAN RES.
Carrizo
Whiteriver
Hon Dah
McNary
Fort Apache
NATANES PLATEAU
GILA NAT'L FOR.
GREENLEE
Clifton
Morenci
Plantsite
Kearny
Hayden
Winkelman
Dudleyville
Florence
Coolidge
Casa Grande
Stanfield
Maricopa
Eloy
Picacho
PICACHO MTS.
PINAL
Arizona City
Red Rock
Marana
Mammoth
San Manuel
Oracle
Catalina
Oro Valley
Casas Adobes
Tucson
SAGUARO NAT'L MON.
Bylas
Geronimo
Fort Thomas
Pima
Thatcher
Safford
GRAHAM
PINALENO MTS.
GALIURO MTS.
CORONADO NAT'L FOR.
Bonita
Duncan
PELONCILLO MTS.
Willcox
Bowie
San Simon
Cochise
COCHISE
DRAGOON MTS.
CHIRICAHUA NAT'L MON.
Benson
St David
Pearce
Gleeson
Tombstone
Elfrida
Vail
Green Valley
Sahuarita
Continental
San Xavier
Sells
Topawa
Covered Wells
PAPAGO INDIAN RESERVATION
SANTA ROSA MTS.
COMOBABI MTS.
PIMA
Gila Bend
Sentinel
Dateland
Theba
Ajo
Why
LUKE AIR FORCE RANGE
CABEZA PRIETA NATIONAL WILDLIFE REFUGE
ORGAN PIPE CACTUS NAT'L MON.
Lukeville
Sonoyta
SAUCEDA MTS.
GROWLER MTS.
MOHAWK MTS.
BUENOS AIRES NAT'L WILDLIFE REFUGE
NEW MEXICO

ERA	PERIOD	EPOCH	AGE (mil yr)	DOMINANT LIFE FORMS	EVENTS IN ARIZONA
CENOZOIC Age of Mammals	Quaternary q	Holocene	.01		Present erosion cycle gouges Pleistocene and Tertiary deposits. Basalt volcanism continues near San Francisco Peaks and at a few other sites.
		Pleistocene	2		Regional uplift accelerates erosion; cyclic erosion creates terraces. Basalt volcanism occurs in several areas; San Francisco Peaks grow, collapse, and are glaciated. Colorado River flows through to Gulf of California. Pluvial lakes occupy some valleys.
	Tertiary t	Pliocene	5		Colorado River turns west, initiates canyon cutting on Colorado Plateau. Little Colorado reverses as recurrent movements lift plateaus. In south, basins fill with stream and lake deposits.
		Miocene			Basin and Range Orogeny 15 to 8 million years ago creates fault-block ranges with NW-SE grain. Basalt volcanism widespread.
			24		Mid-Tertiary orogeny 30-20 million years ago pushes up mountains with NE-SW grain. Metamorphic core complexes form. Colorado Plateau rises; Colorado River flows south, east of Kaibab Arch. Downdropped Verde Valley intercepts northward drainage. Explosive volcanism common, with calderas in Chiricahua and Superstition Mountains.
		Oligocene	38		Tension faulting in south is accompanied by volcanism and intrusion of dikes, stocks, laccoliths. Intermountain valleys fill with debris from mountains. Verde Valley begins to form.
		Eocene	55		Laramide Orogeny ends 50 million years ago, leaving undrained intermountain valleys, some with lakes. No volcanism or intrusions mark "Eocene magma gap." Northbound streams deposit rim gravels.
		Paleocene	63		In south, Laramide Orogeny creates mountains with NE-SW trend: overthrusting may have occurred. Explosive volcanism occurs. Abundant small intrusions appear, some containing copper, silver, gold. In north, plateaus begin to form as large blocks are lifted or dropped.
MESOZOIC Age of Reptiles	Cretaceous K		138		Seas invade briefly from west and south; volcanism widespread. Laramide Orogeny begins 75 million years ago as west-drifting continent collides with outlying plates.
	Jurassic J		205		Deserts widespread; thick sand dune deposits in north. Explosive volcanism in south and west is followed by erosion.
	Triassic Ꞧ		240		Extensive coastal plain, delta, and dune deposits spread north from mountains in central and southern Arizona. Faulting, small intrusions, explosive volcanism occur in south.
PALEOZOIC Age of Fishes	Permian P		290		Dunes form across northern Arizona, then a western sea invades briefly. Alternating marine and non-marine deposition in south and west.
	Pennsylvanian IP		330		Marine limestones deposited in south and south-central Arizona; floodplain and desert prevail in north.
	Mississippian M		365		Widespread deposition of fossil-bearing marine limestone is followed by emergence and development of karst topography with sinks and caves.
	Devonian D		410		Marine deposits form, then are removed from many areas by erosion.
	Silurian S		435		No record.
	Ordovician O		500		Brief marine invasion, then no record.
	Cambrian Є				A western sea advances across denuded continent, depositing conglomerate and sandstone, then shale and limestone.
			570		Great Unconformity — long erosion.
PRE-CAMBRIAN pЄ	Younger		1700		Several episodes of mountain-building and intrusions of sills and dikes are followed by marine and near-shore sedimentation, faulting, and uplift.
	Older				Sedimentary and volcanic rocks accumulate, then are compressed and altered into NE-SW-trending ranges extending beyond Arizona. 1.7 billion years ago granite batholiths intrude these older metamorphic rocks.

After Chronic, 1983.

PTYS 597a

PLANETARY FIELD GEOLOGY PRACTICUM

Field Trip 24–26 April 1992

Day 1
Tucson to Show Low

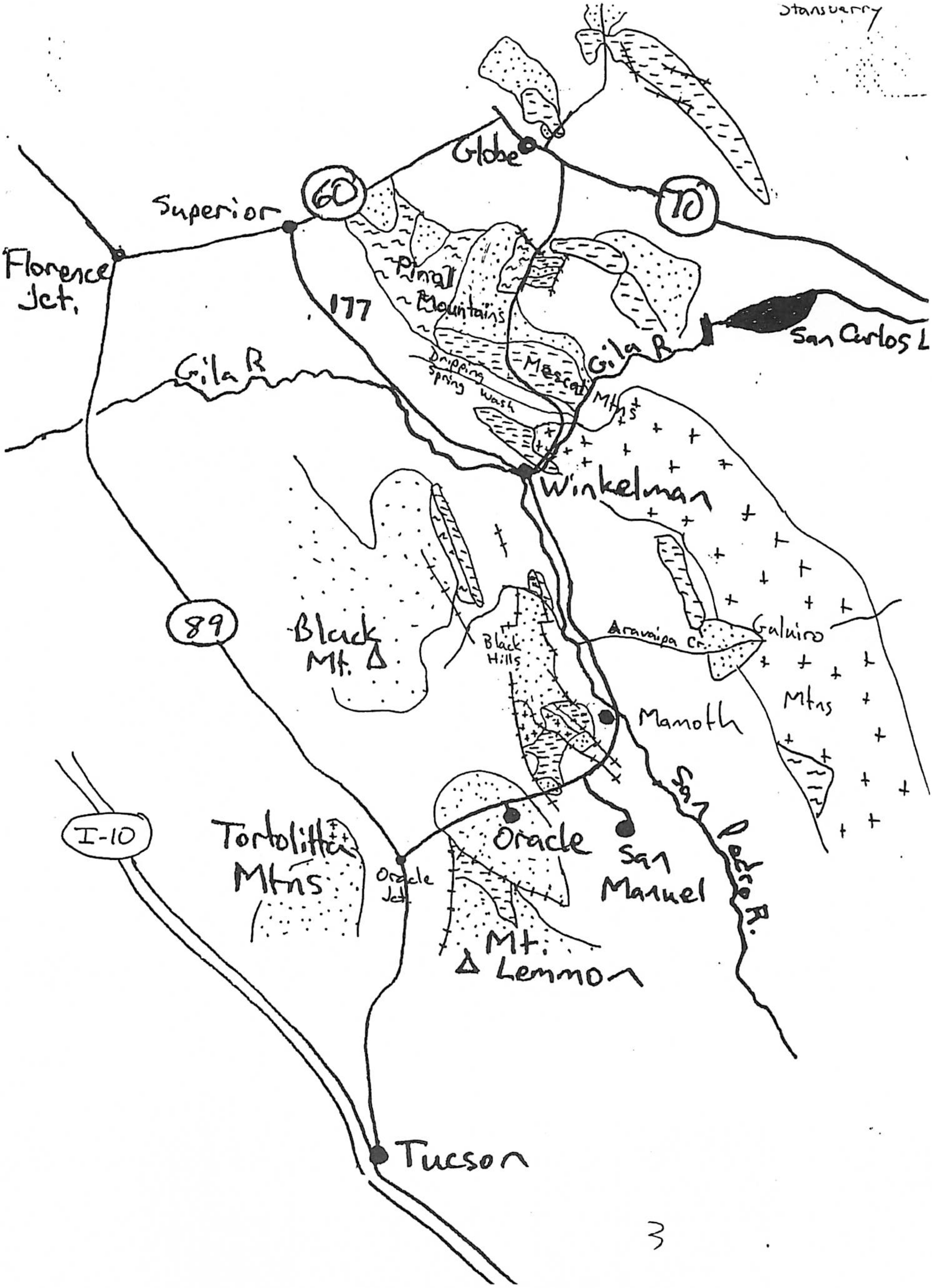
Stansberry

Highway 77: Oracle Jct. to Globe

Key to geologic map

symbol	description / units
—⊕—	highway
═	I-10
∼	river
┼┼┼	fault
⁙	Intrusive Igneous Oracle Granite (1.4 Ga) Diabase, Mescal Mtns North of Globe Pinal Mtns Granite Galiuro Mtns Tertiary intrusives
+ +	Volcanic Galiuro Mtns Tertiary Andesite Cretaceous Andesite Gila River Canyon Cretaceous Andesite
~ ~	Metamorphic Pinal Schist

Stansberry


Globe
60
70
Superior
Florence Jct.
177
Pinal Mountains
San Carlos L
Gila R
Gila R
Mescal Mtns
Dripping Spring Wash
Winkelman
89
Black Mt.
Black Hills
Aravaipa Cr.
Galuiro Mtns
Mamoth
San Pedro R.
I-10
Tortolitta Mtns
Oracle Jct.
Oracle
San Manuel
Mt. Lemmon
Tucson

Key cont'd - Highway 77 Oracle Jct. to Globe

▤ Sedimentary

- Black Hills
  - Cretaceous Shales, Quartzite, Limestone
- Camp Grant Wash & northward
  - Apache Group, Precambrian
  - Paleozoic limestone
- Gila River Canyon
  - Naco Limestone, Pennsylvanian
- Mescal Mountains
  - Naco Limetone
  - Bolsa Quartzite, Cambrian
  - Martin Shale, Devonian
  - Escabrosa Limestone, Mississippian
  - Mescal Limestone / Apache, P.C.
  - Dripping Spgs. Quartzite
  - Pioneer Shale
  - Barnes Conglomerate

Spring 1992 Field Trip Experience

Hard rocks between Oracle and Globe along US 77, conducted by Jim Head (West)

We will be able to see rocks from nearly the entire sedimentary section on the way to Globe. The units visible fromm Route 77 and a sedimentary sequence are shown below. These compliment the geologic sketch map in John Stansberry's section. The rocks represented along the route are listed by age in the table and are marked by an asterisk in the sedimentary section. John will handle the sedimentary rocks and I'll discuss the igneous and metamorphic rocks. There will be considerable overlap. The hard rocks you should notice (in order of appearence) are

1)Oracle granite (1.55Ga), near Oracle. Note color and presence of zenoliths.
2)Fault contact of Precambrian granite and Cenozoic gravels, past San Manuel turnoff. Note that this granite differs from the Oracle granite.
3)Tertiary volcanics, west side of road, north of Aravaipa Creek.
4)Contact between Cretaceous volcanics and the Naco limestone, north of the big anticlinal arch.
5)Older Precambrian granite in contact with the Pinal Schist (1.6Ga) at Pinal Pass. Note dikes in the granite.
6)Younger Precambrian diabase and Tertiary dacite boulders north of Globe.

Table 5. Ages and geologic names of rock units encountered along State Highway 77

AGES	ROCK REPRESENTATIVES
CENOZOIC	
Quaternary	Not named sands, silts, clays, gravels and volcanics
Tertiary	Not named sedimentary and volcanic rocks; Dacite; Andesite; Bidahochi Formation; Not named high elevation gravels
MESOZOIC	
Cretaceous	Not named sedimentary rocks and, locally, volcanic rocks
Jurassic	Not present
Triassic	Wingate Sandstone; Chinle Formation; Moenkopi Formation
PALEOZOIC	
Permian	Kaibab Formation; Coconino Sandstone; Supai Formation
Pennsylvanian	Possibly basal Supai Formation; Naco Limestone
Mississippian	Redwall Limestone and Escabrosa Limestone
Devonian	Martin Formation
Silurian	None
Ordovician	None
Cambrian	Bolsa Quartzite
PRECAMBRIAN	
Younger	Diabase; Troy Quartzite; Apache Group: Mescal Limestone, Dripping Spring Quartzite, Barnes Conglomerate, Pioneer Shale
Older	Granitic rocks locally named, e.g., Oracle Granite; Pinal Schist

Mount Glove-Douglas ①

Keith
et al.
(1980)
in GSA
Memoir
153

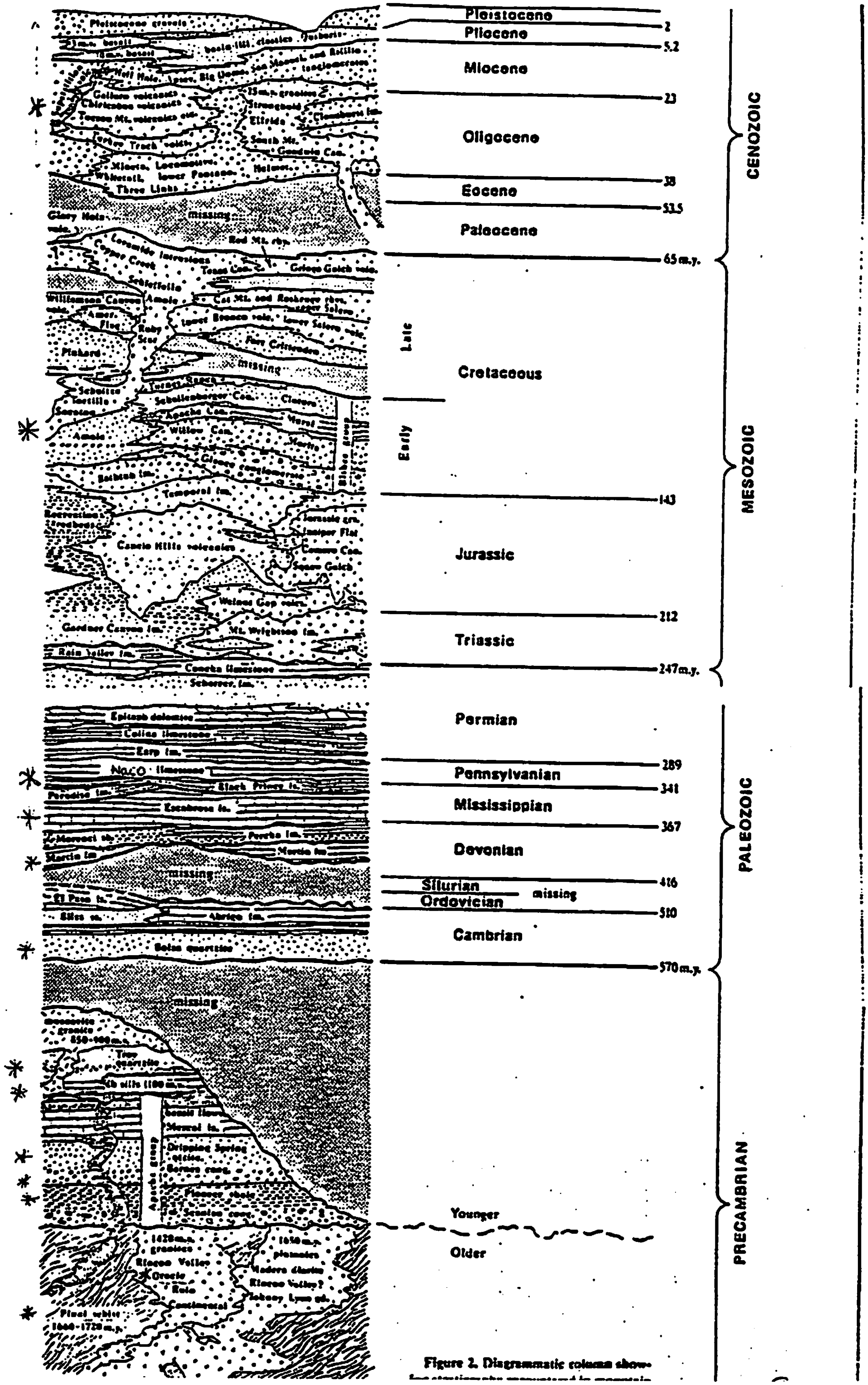
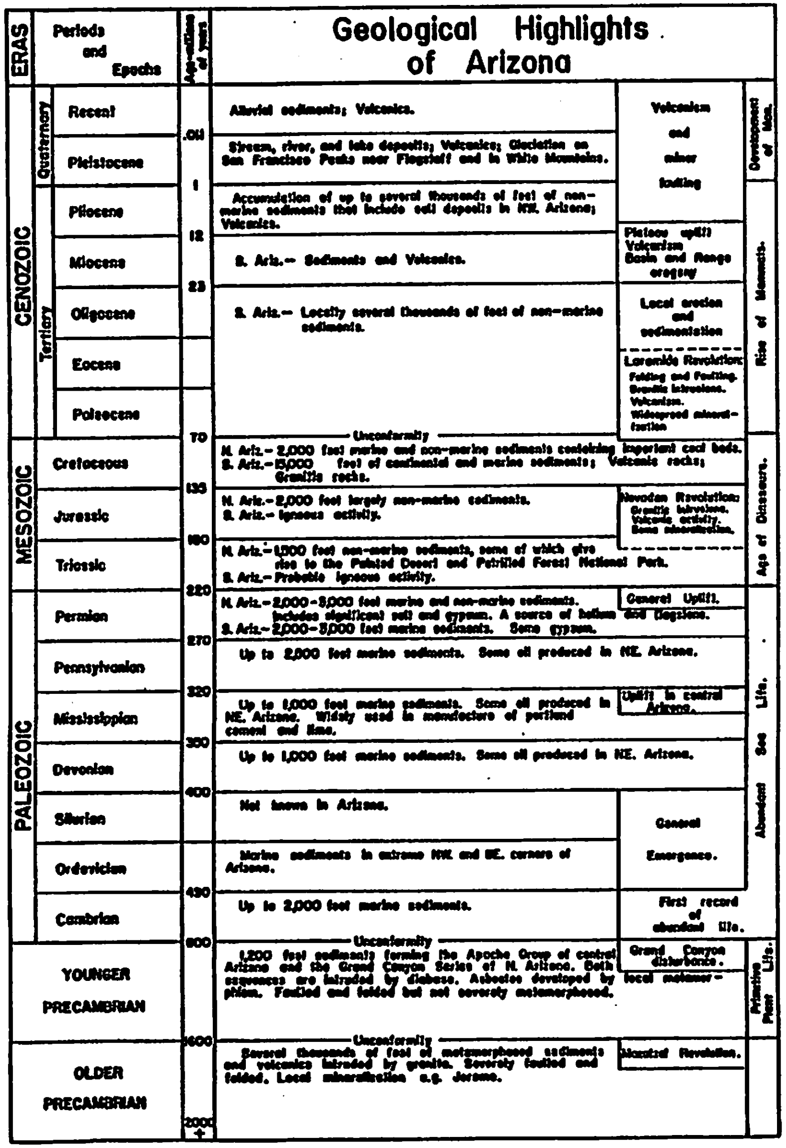


Figure 2. Diagrammatic column show-

GEOLOGY OF THE SAN MANUEL ORE BODY
A CLASSIC PORPHYRY COPPER DEPOSIT
by Don Musselwhite

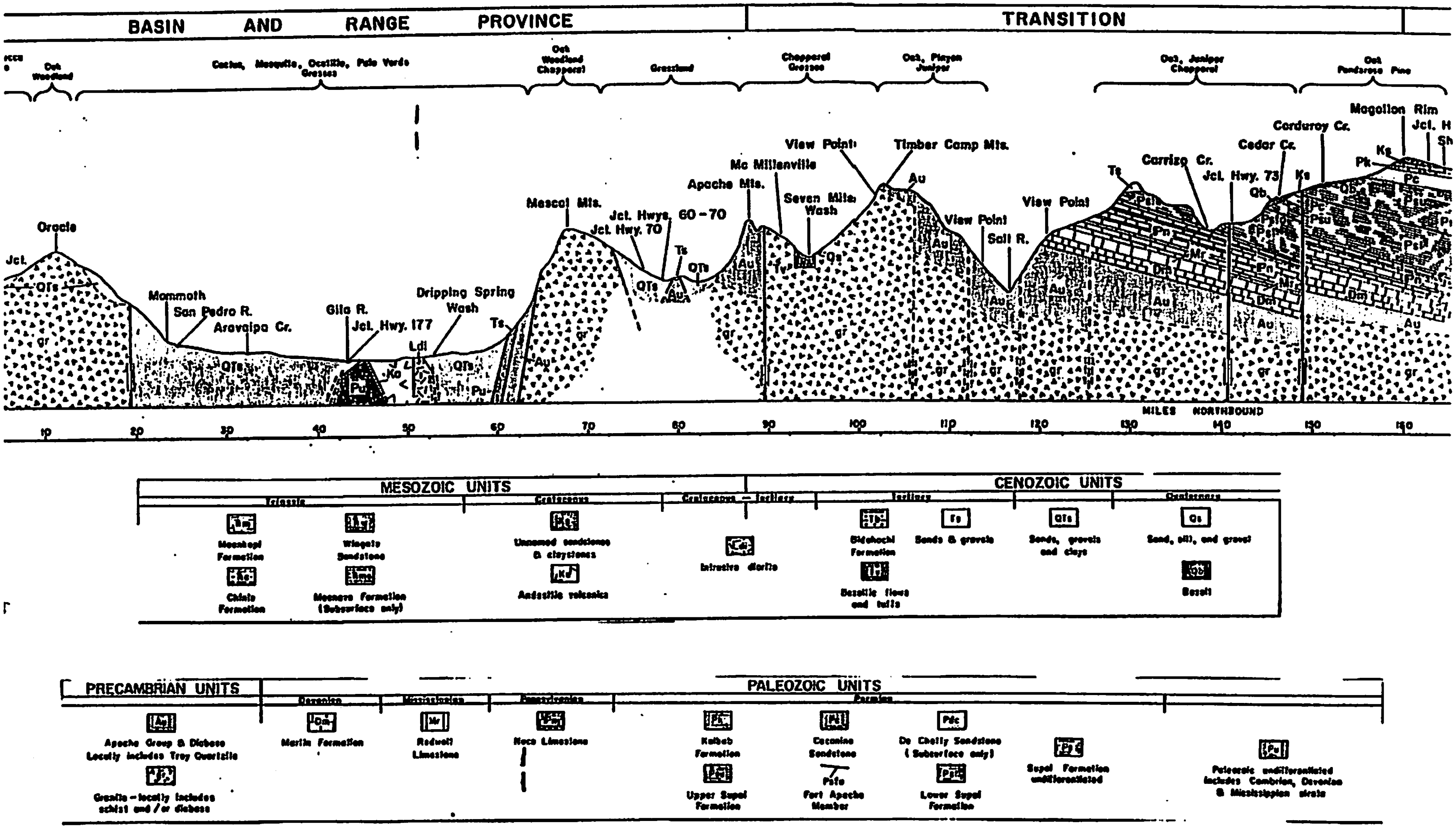


ERAS		Periods and Epochs	Age-millions of years	Geological Highlights of Arizona		
CENOZOIC	Quaternary	Recent	.011	Alluvial sediments; Volcanics.	Volcanism and minor faulting	Development of Man.
		Pleistocene	1	Stream, river, and lake deposits; Volcanics; Glaciation on San Francisco Peaks near Flagstaff and in White Mountains.		
	Tertiary	Pliocene	12	Accumulation of up to several thousands of feet of non-marine sediments that include salt deposits in NW. Arizona; Volcanics.		Rise of Mammals.
		Miocene	23	S. Ariz.— Sediments and Volcanics.	Plateau uplift Volcanism Basin and Range orogeny	
		Oligocene		S. Ariz.— Locally several thousands of feet of non-marine sediments.	Local erosion and sedimentation	
		Eocene			Laramide Revolution: Folding and Faulting. Granitic intrusions. Volcanism. Widespread mineralization	
		Paleocene	70			
MESOZOIC		Cretaceous	135	——— Unconformity ——— N. Ariz.— 2,000 feet marine and non-marine sediments containing important coal beds. S. Ariz.— 15,000 feet of continental and marine sediments; Volcanic rocks; Granitic rocks.		Age of Dinosaurs.
		Jurassic	180	N. Ariz.— 2,000 feet largely non-marine sediments. S. Ariz.— Igneous activity.	Nevadan Revolution: Granitic intrusions. Volcanic activity. Some mineralization.	
		Triassic	220	N. Ariz.— 1,000 feet non-marine sediments, some of which give rise to the Painted Desert and Petrified Forest National Park. S. Ariz.— Probable igneous activity.		
PALEOZOIC		Permian	270	N. Ariz.— 2,000–3,000 feet marine and non-marine sediments. Includes significant salt and gypsum. A source of helium and flagstone. S. Ariz.— 2,000–3,000 feet marine sediments. Some gypsum.	General Uplift.	Abundant Sea Life.
		Pennsylvanian	320	Up to 2,000 feet marine sediments. Some oil produced in NE. Arizona.		
		Mississippian	350	Up to 1,000 feet marine sediments. Some oil produced in NE. Arizona. Widely used in manufacture of portland cement and lime.	Uplift in central Arizona.	
		Devonian	400	Up to 1,000 feet marine sediments. Some oil produced in NE. Arizona.		
		Silurian		Not known in Arizona.	General Emergence.	
		Ordovician	490	Marine sediments in extreme NW. and NE. corners of Arizona.		
		Cambrian	600	Up to 2,000 feet marine sediments.	First record of abundant life.	
YOUNGER PRECAMBRIAN			1600	——— Unconformity ——— 1,200 feet sediments forming the Apache Group of central Arizona and the Grand Canyon Series of N. Arizona. Both sequences are intruded by diabase. Asbestos developed by local metamorphism. Faulted and folded but not severely metamorphosed.	Grand Canyon disturbance.	Primitive Plant Life.
OLDER PRECAMBRIAN			2000 +	——— Unconformity ——— Several thousands of feet of metamorphosed sediments and volcanics intruded by granite. Severely faulted and folded. Local mineralization e.g. Jerome.	Mazatzal Revolution.	

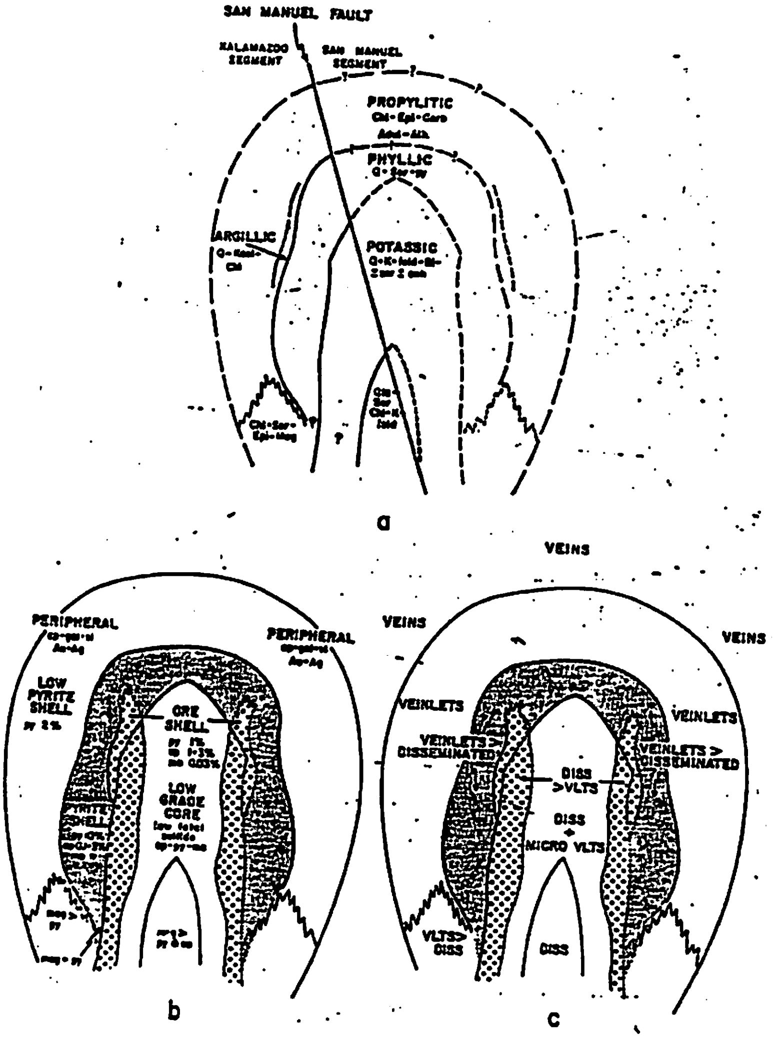
Geologic History

A summary of geologic events in the area includes:

- Precambrian quartz monzonite mass (the Oracle Granite);
- Intrusion by monzonite porphyry;
- Intrusion of both by diabase;
- Fracturing associated with regional compression;
- San Manuel ore body formed—its genesis related to the monzonite porphyry intrusion;
- Erosional cycle—oxidation begins;
- Cloudburst Formation deposited with concomitant intrusion of andesite dikes into the older rocks;
- Intrusion of rhyolite into the Cloudburst volcanics and all older rocks;
- Regional tilting of 20°–25° NE. and chloritic alteration;
- Erosional cycle—oxidation renewed;
- Gila(?) Conglomerate deposited;
- San Manuel fault developed;
- Further tilting to the northeast with development of N. 25° W. system of normal faults and renewed oxidation;
- Further faulting along N. 60° E. trend offsetting N. 25° W. system;
- Quaternary deposits.



Profile and section along Arizona Highway 77 showing principal rock units, geographic features, and vegetative types. View looking westerly.



Concentric alteration and mineralization zones from the type area of San Manuel-Kalamzoo, Arizona. (a) alteration zones (b) zones of mineralization (c) occurrences of sulphides.

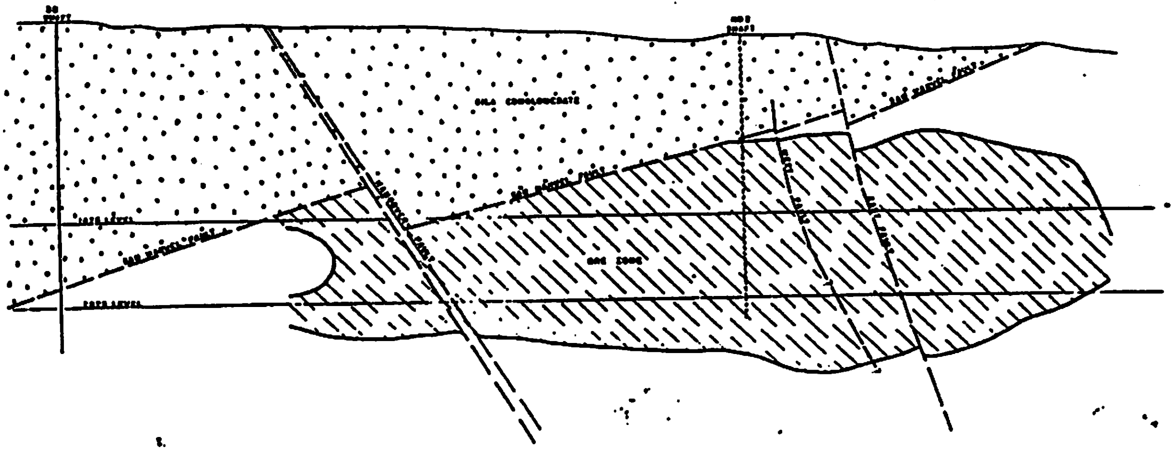
SUMMARY

The San Manuel ore body is a disseminated copper deposit with ore mineralization localized in quartz monzonite, monzonite porphyry, and diabase. Deposition of ore is believed to be but one event in the igneous history of the area. The igneous epoch opened with intrusion of monzonite porphyry, which was followed by diabase intrusion and regional compression that intensely fractured the rocks. Invasion by hydrothermal solutions of varying composition produced intense although variable alteration; primary ore minerals (chalcopyrite and molybdenite) were deposited at a time when potash content of the invading solutions was high. The broad zone of contact between quartz monzonite and monzonite prophyry rock was the most favorable zone for deposition of chalcopyrite; the quartz monzonite appears to have been a slightly better host rock. Ore localization is related to rock permeability, which varies with closeness of fracturing and density of the host rock. There is no evidence that chemical control played any significant part in ore localization.

Since its formation, the deposit has been intruded by minor dikes of andesite and rhyolite and has undergone at least three epochs of oxidation and enrichment. Oxidation was deep and pervasive, but enrichment was limited, and the ore body being mined today owes its economic significance mainly to primary mineralization.

With the attainment of full production in 1958, San Manuel took rank among the major copper mines in the western hemisphere. In 1961, as the world's largest underground operation, the mine ranked fourth in tonnage and sixth in metallic copper production among the hemisphere's major producers.

With a substantial reserve of sulfide tonnage remaining, the mine should continue as a first rank producer of copper for several decades.



SECTION B'—B

-Idealized longitudinal section looking northwest.

The El Capitan Catastrophic Landslide

With your most catastrophic hosts

☞ Will Grundy and Mark Lemmon ☜

Vitally catastrophic statistics

Volume of rock:	4×10^7 m^3	Time of emplacement:	Pleistocene (?)
Max vertical drop:	1300 m	Max horizontal travel:	6800 m
Deposit thickness:	5 - 35 m	Width of deposits:	1500 m
Max exposed length:	3800 m		

Catastrophic references:

Howard, K.A. (1973) Avalanche Mode of Motion: Implications From Lunar Examples. *Science* 180, 1052-1055.

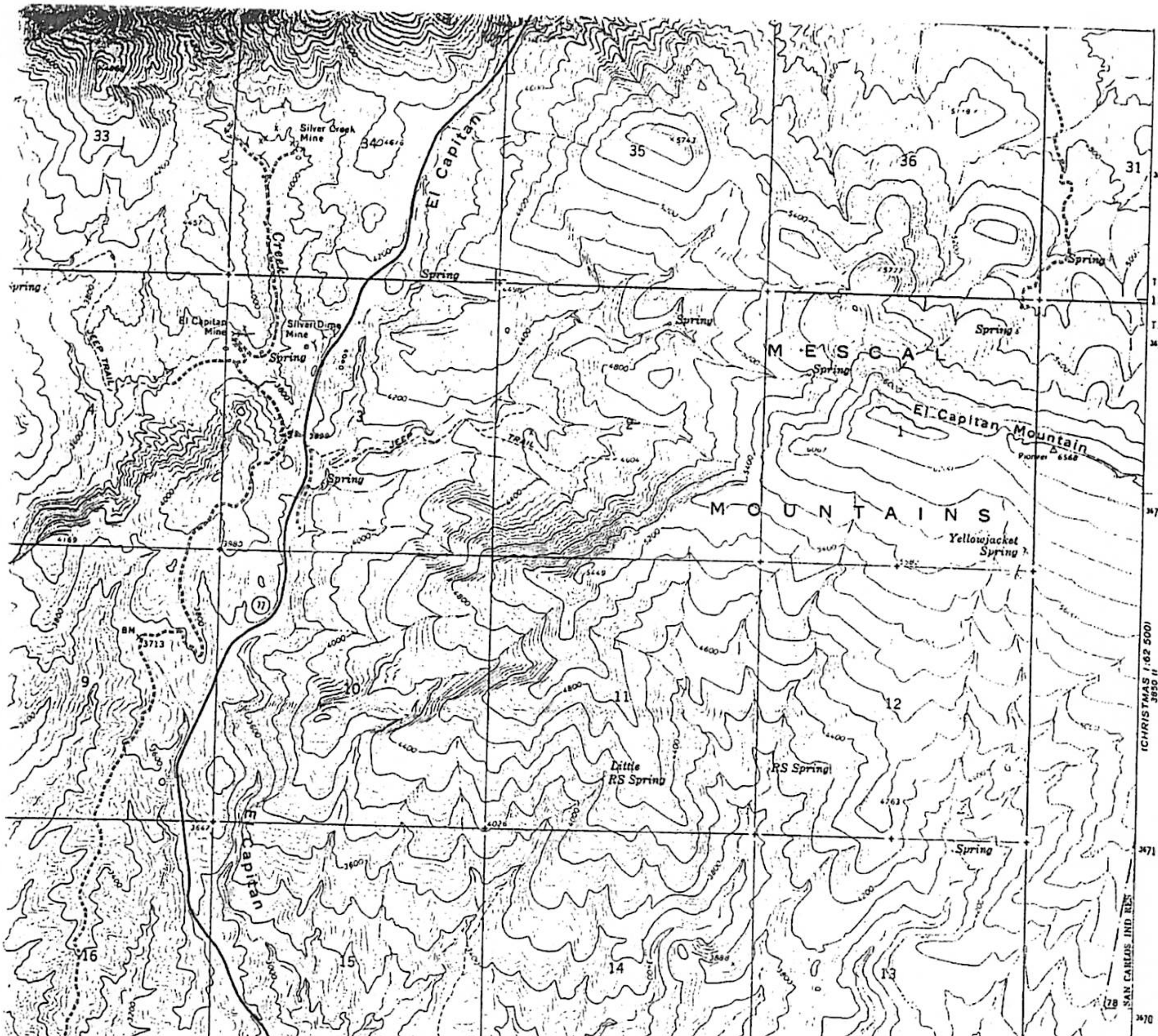
Hsü, K.J. (1975) Catastrophic Debris Streams (Sturzstroms) Generated by Rockfalls. *G.S.A. Bull.* 86, 129-140.

Krieger, M.H. (1977) Large Landslides, Composed of Megabreccia, Interbedded in Miocene Basin Deposits, Southeastern Arizona. Geological Survey Professional Paper 1008, Washington D.C.

★Melosh, Sir H.J. (1986) The Physics of Very Large Landslides. *Acta Mechanica* 64, 89-99.

Shreve, R.L. (1968) Leakage and Fluidization in Air-Layer Lubricated Avalanches. *G.S.A. Bull.* 79, 653-658.

Yarnold, J.C., and J.P. Lombard (1989) A Facies Model for Large Rock-Avalanche Deposits Formed in Dry Climates. in Conglomerates in Basin Analysis: A Symposium Dedicated to A.O. Woodford: Pacific Section S.E.P.M. 62, 9-31.


33
Silver Creek Mine
34
35
36
31
El Capitan
Creek
Spring
El Capitan Mine
Silver Dime Mine
JEEP TRAIL
T 2 S
12'30"
T 3 S
MESCAL
El Capitan Mountain
Pioneer 6568
MOUNTAINS
Yellowjacket Spring
BM 3713
9
10
11
12
Little RS Spring
RS Spring
El Capitan
Canyon
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(CHRISTMAS 1:62 500)
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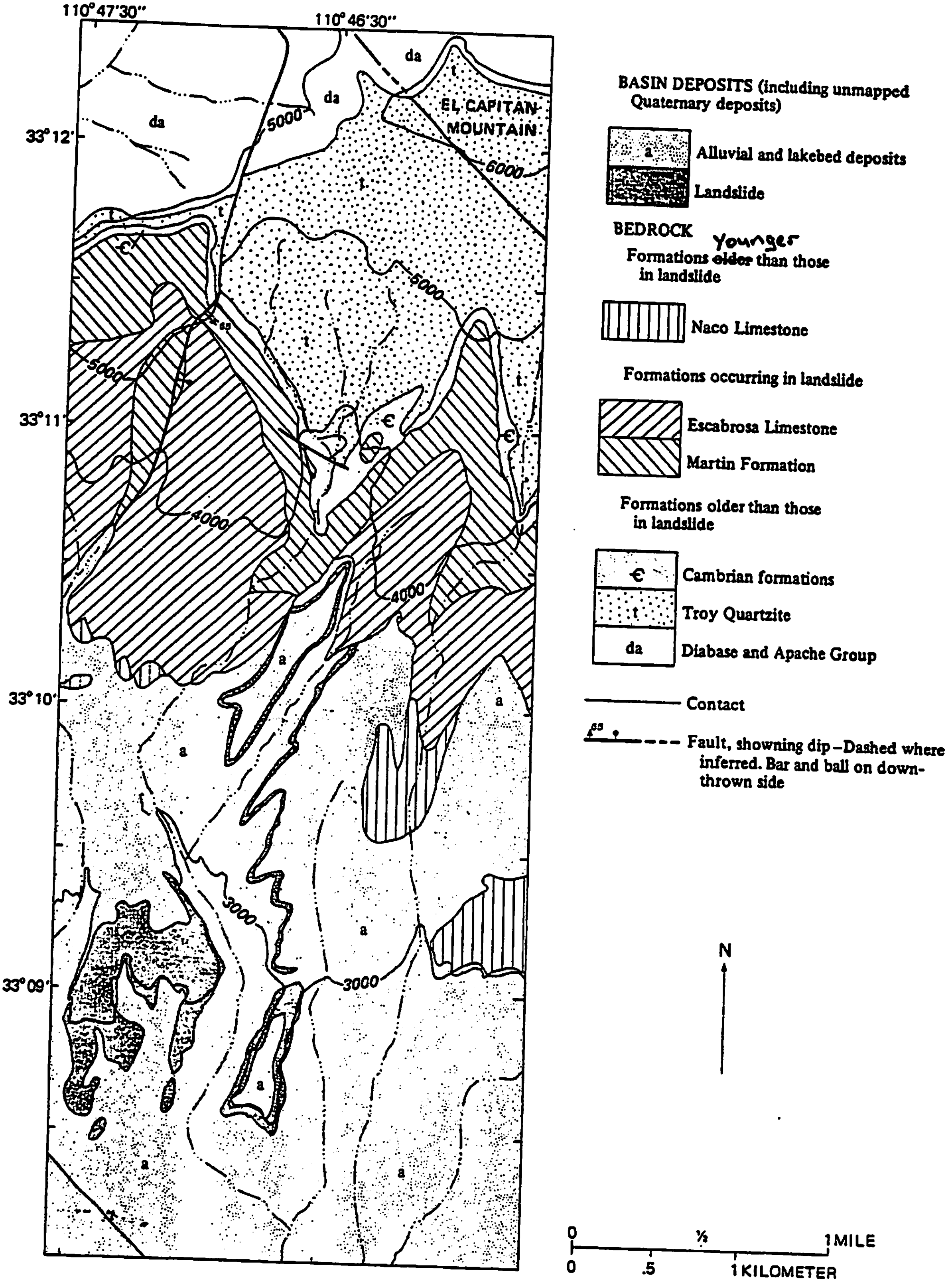


FIGURE 27.—El Capitan landslide and its source area on El Capitan Mountain. Reduced from geologic map of El Capitan Mountain quadrangle (Cornwall and Krieger, 1977).

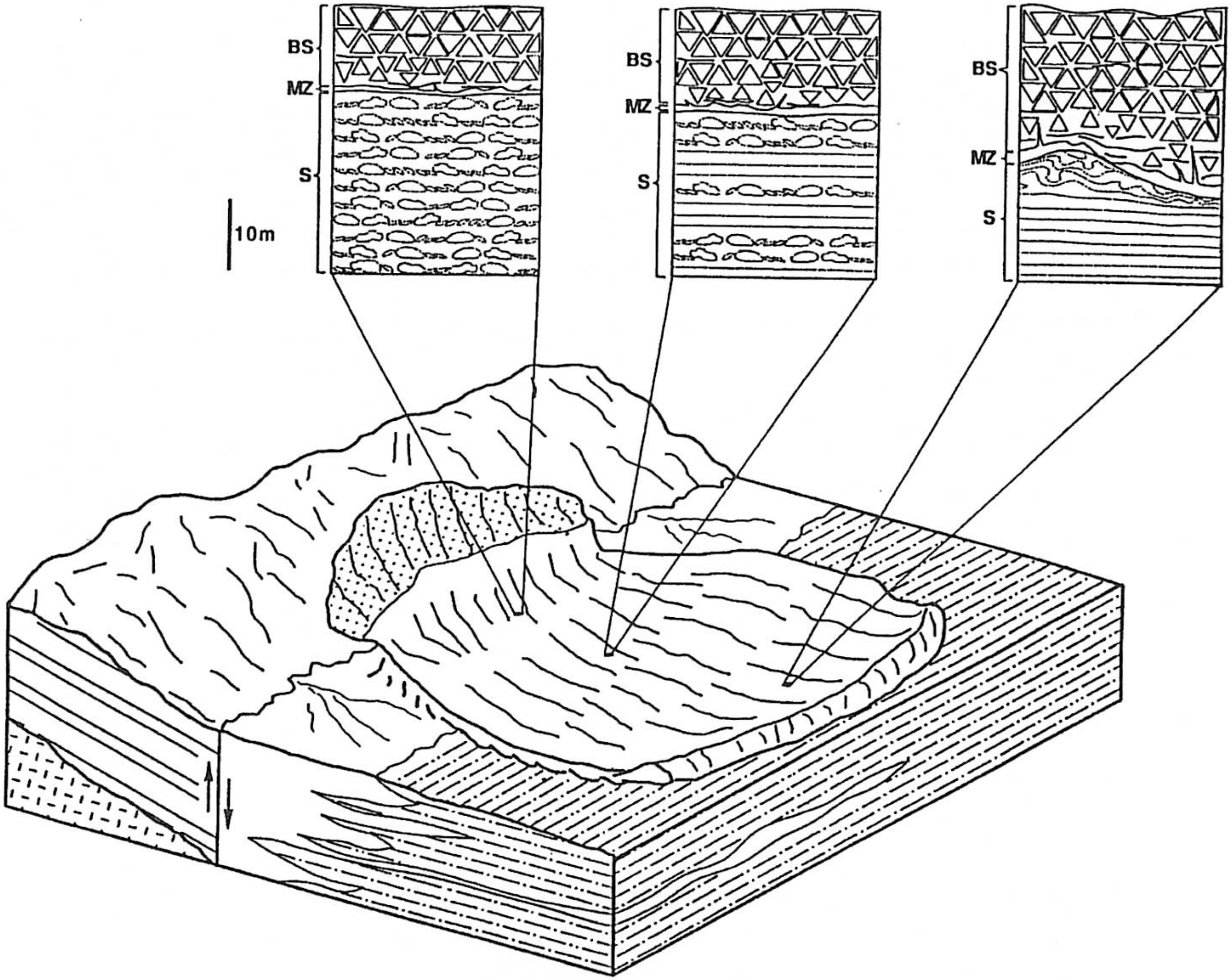


Figure 17. Idealized morphology (not to scale) of large dry-climate rock-avalanche deposit showing internal features and associated substrate lithofacies in proximal, medial, and distal portions. Abbreviations are the same as in Figure 15. Approximate vertical scale is indicated for zonal stratigraphic columns.

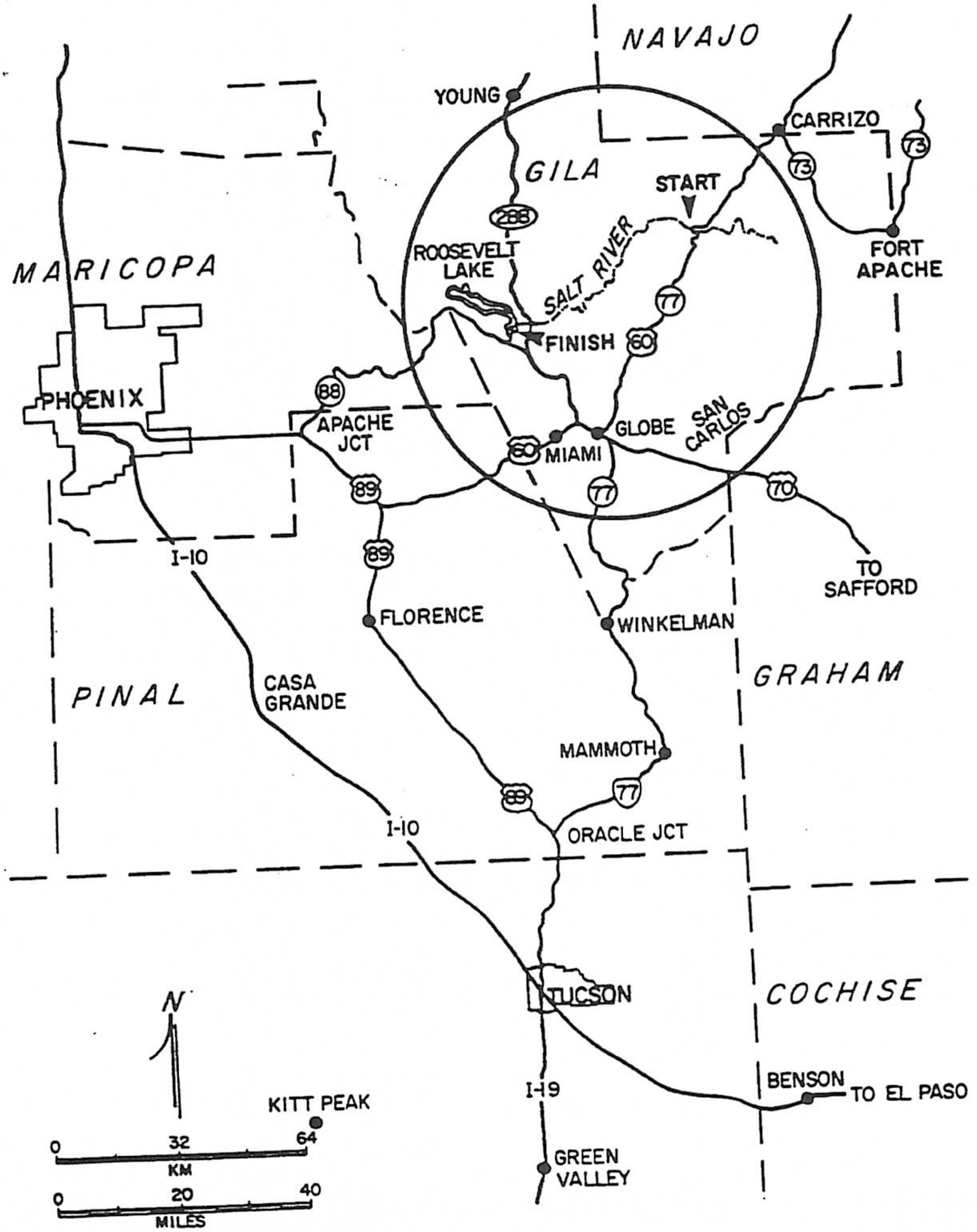
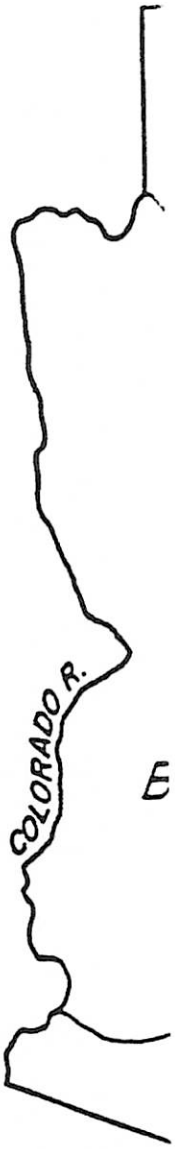


FIGURE 1. Location map of the Salt River Canyon area

15

serious attention from geologists. Existing geologic maps of the Can-



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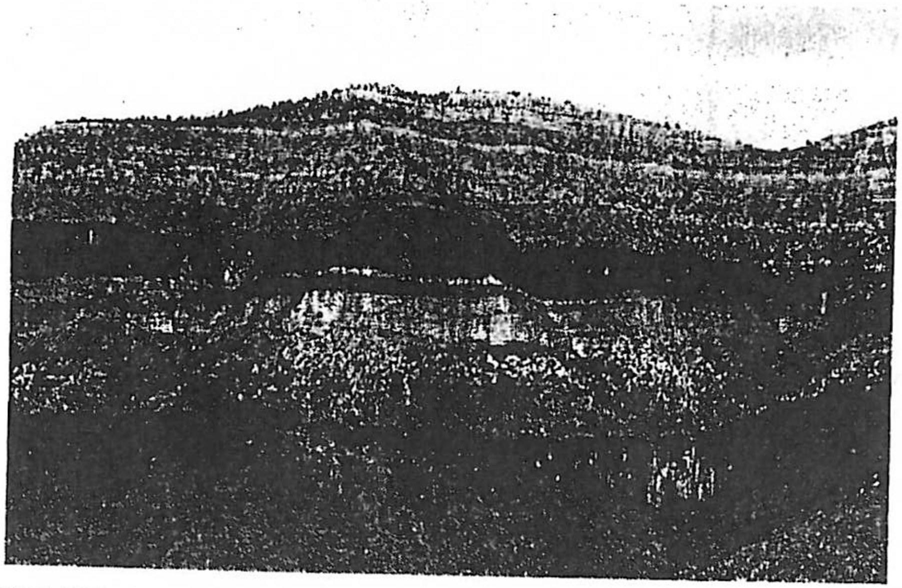

FIGURE 11. Diabase sills (dark-gray), which intrude upper Proterozoic strata. View is north to cliffs at east end of traverse. Mescal Limestone is white cliff former at center of photo; light-gray strata near top of cliff above uppermost sill are Devonian. Above and below the lowermost cliff-forming sill is slope-forming diabase.

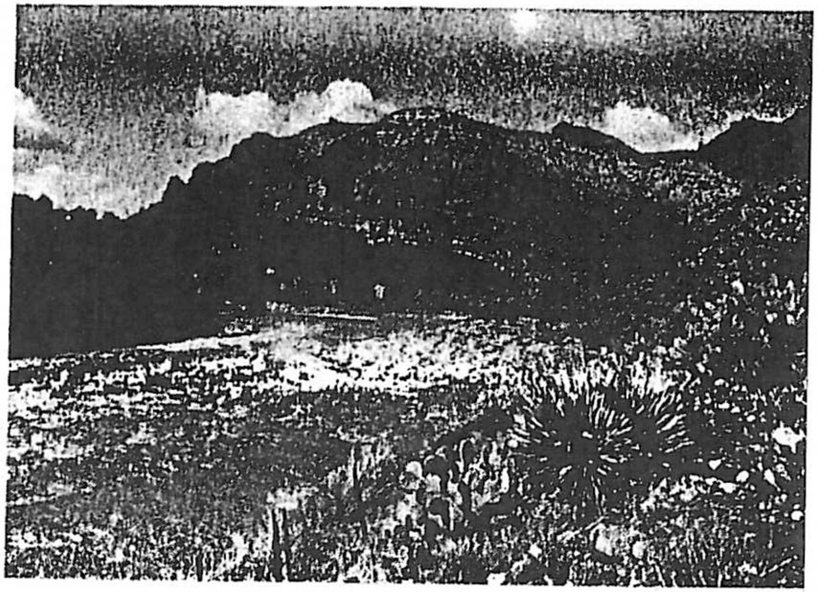

FIGURE 12. North-northwest-directed view of Mule Hoof mor at the raft-launching site at MP 59.3. Dark-gray rock near rive is diabase, and this is overlain by Dripping Spring Quartzi Mescal Limestone (light-gray).

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MP 52.9 ***Sluice Box Rapid*** (2–3).

MP 50.8 ***Mescal Falls*** (7–9).

MP 49.7 to MP 49.4 *Inflation Fault and Diabase Dike*. The displacement on this fault at river left is caused by "differential intrusio the upper Proterozoic sequence. The fault strikes approximately N. 30° E. To the east of the fault is a thick sill of dia to the west is relatively undisturbed and unintruded Dripping Spring Quartzite. Separation of marker beds along the fault ind that the total displacement on the fault is the same as the thickness of the sill. A complementary inflation fault occurs Walnut Canyon at milepoint 48.6.

Shride (1967) long ago recognized and interpreted the provocative displacement patterns of faults of this type. One of Sh diagrams, reproduced as Figure 15, shows "effects of sill inflations on displacement along a pre-existing fault." The or displacement produced by early faulting (Fig. 15) may be dramatically altered when a diabase sill is emplaced into strata o side of the fault only (Fig. 15).

The inflation faults were not generally conduits for magma flow. Rather, the faults accommodated vertical motions (Fig Each fault served as a partition between compartments of inflation on either side. In some cases the magma used the fault zo an access to feed stratigraphically higher sills (Fig. 16). Where the diabase dilated a pre-existing fault, complex displac rocks (Hayes and Drewes, 1968; Drewes and Finnell, 1968; Finnell, 1970; Drewes, 1971). The Cretaceous rocks in southern Arizona, unlike the Paleozoic and Triassic (?)-Jurassic rocks, were flat lying and undeformed prior to Laramide tectonism and thus serve as an important guide to the style and kinematics of Laramide deformation (Davis, 1979).

The principal Laramide deformation of Arizona was strong northeast-southwest compressional deformation. Monoclines developed in the Colorado Plateau (Kelley, 1955a, 1955b). To the south, deformation belts of folding and thrust and reverse faulting were produced (Gilluly, 1956; Sabins, 1957; Cooper and Silver, 1964; Drewes, 1978; Davis, 1979). The regional structural framework of which the folded and faulted strata were a part is not known for certain. Drewes (1978) has interpreted the Laramide geologic framework in the context of low-angle, northeast-directed overthrusting. Davis (1979) considered the deformation style akin to Wyoming-type basement-cored uplifts. A highly speculative interpretation that has emerged recently is that all of southern Arizona, at a depth of about 10,000 to 15,000 ft, is underlain by a system of flat faults that separate Precambrian basement above from a repeated sequence of Cretaceous and older rock below. This interpretation has been offered by the Anshutz Corporation as a working hypothesis for exploration for hydrocarbons in southern and western Arizona (Keith, 1980). In effect, the model suggests that a break-out zone of thrusting may cross part of the Transition Zone in the Salt River region, perhaps camouflaged by the effects of Basin and Range faulting. Alternatively, the inferred thrust zone may root underneath the Colorado Plateau tectonic province, in which case the Basin and Range–Colorado Plateau boundary zone would be in an upper-plate position (Otton, 1981).

Following major crustal shortening, but still during Laramide time, the Basin and Range province of southern Arizona was invaded by abundant plutons of granitic and quartz monzonitic composition, many of which are copper rich. According to Rehrig and Heidrick (1972), the Laramide intrusions were formed at a time of crustal extension and differential uplift achieved under the influence of weak lateral compression.

A net effect of Laramide tectonism was northeast tilting of Cretaceous strata in the Transition Zone and along the southern boundary of the Colorado Plateau (Peirce and others, 1979). Tilting was a response to uplift in the region of the Transition Zone and of a yet undefined portion of the Basin and Range province. The gently tilted strata were subjected to Paleocene-Eocene erosion, beveling rocks in the region along a continuous surface. It was on this surface in slight angular unconformity with Cretaceous strata that the Eocene-Oligocene rim gravels were deposited along the southern edge of the Colorado Plateau (Peirce and others, 1979). This clastic sequence, now preserved in remnant patches at high elevations on the southern edge of the Colorado Plateau, was a product of northeasterly transport and deposition on a concave-upward surface, which is now largely removed from the Mogollon Rim. Clasts within the rim gravels conclusively disclose that Precambrian crystalline rocks were exposed as major bedrock sources during the time of deposition of these gravels. In fact, Peirce and others (1979) have shown that Precambrian bedrock was exposed within 30 mi of the site(s) of deposition of some of the rim gravels. Furthermore, 50- to 60-m.y.-old Laramide volcanic rocks are represented as clasts in the rim gravels. Large boulders in the rim gravels disclose high stream gradients (Peirce and others, 1979).

"Later in Oligocene(?) time, a generally unrecognized tectonic event induced erosion and downcutting that outlined an ancestral Col-

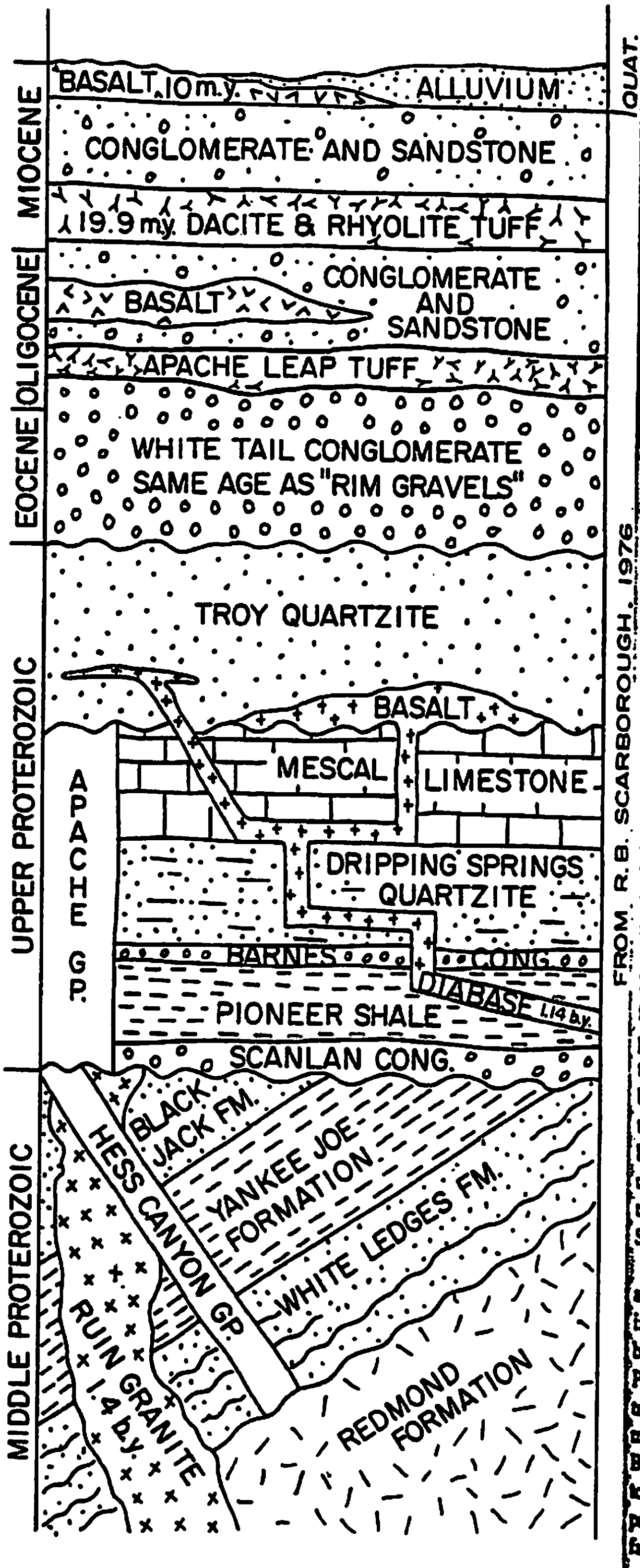

FIGURE 8. Composite geologic column for the Salt River Canyo region

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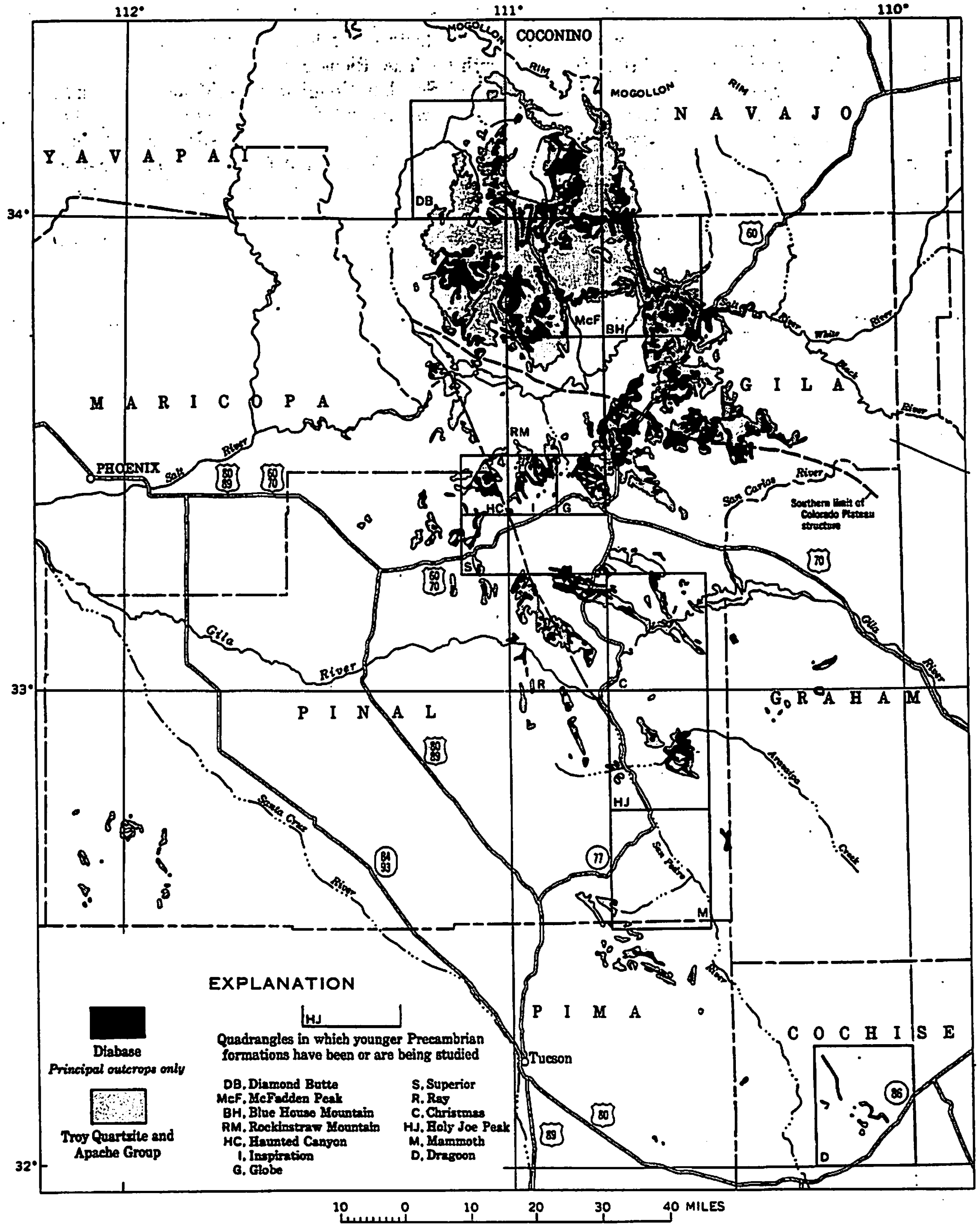

FIGURE 3.—Outcrops of younger Precambrian strata and coextensive diabase intrusions in southeastern Arizona. Modified from county geologic maps published by Arizona Bureau of Mines, 1958–60.

Quartzite and Mescal Limestone of the Apache Group, and the diabase, which intrudes all the Precambrian units (Figs. 10b and 14b). Within this segment, products of the inferred rifting of the North American continent are exposed, including major diabasic intrusions and intrusion-related mineralization. Furthermore, the effects of probably Laramide deformation are revealed in beautifully exposed monoclines and in a complexly reactivated ancient fault zone, the Canyon Creek fault (Fig. 18b).

The second segment (II, Fig. 9) cuts into middle Proterozoic rocks, namely the Redmond Formation, the White Ledges, Yankee Joe, and Blackjack Canyon Formations of the Hess Canyon Group, and the Ruin Granite (Figs. 18b, 26b, 28b, 37b, 38b, and 40b). The lithologies of the Hess Canyon Group and the volcanic Redmond Formation are typical of the 1.6- to 1.7-b.y.-old dominantly metasedimentary sequence. The northeast-trending Precambrian structural grain of folding so typical of Arizona is well displayed by the rocks along this segment of the river. Side canyons offer excellent exposures of folds, cleavages, and transposition structures. Additionally, the presence of the Ruin Granite provides an opportunity for a close look at part of the 1.42-b.y.-old anorogenic granite suite.

The third segment (III, Fig. 9) of the river (Figs. 38b and 40b) is dominated by Tertiary conglomerate and other clastic rocks, rhyolitic volcanic rocks, basalt flows, and Quaternary gravels. These rocks afford insight into mid-Tertiary and Basin and Range events of faulting, intrusion, and extrusion, as well as the geomorphic development of the region through which the Salt River flows.

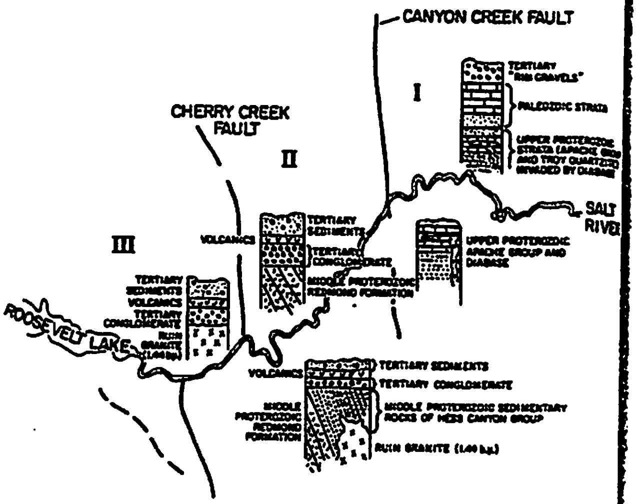

FIGURE 9. Schematic diagram portraying the geologic sections e countered along different segments (I, II, and III) of the Salt Riv Canyon

TABLE 2. Geological Column, Salt River Canyon

AGE		NAME	DESCRIPTION
CENOZOIC	QUATERNARY	Alluvium	River gravels, sands, and occasional silts.
	QUATERNARY	Terrace deposits	Gravels and sands stranded on benches cut by the Salt River as it downcut through the Tra- sition Zone. Some of these terraces may be older than Pleistocene, but detailed work is needed to distinguish the ages.
	UPPER TERTIARY	Basalt	This 10-m.y.-old basalt covers many of the plateaus in this region, including Black Mes on the north side of the Salt River. It is seen at river level in Redmond Flat as a columnar joint flow.
	LOWER MIOCENE	Dacite and Rhyolite Tuffs	Felsic water-laid and air-laid tuffs, which are intercalated with Tertiary sediment According to Peterson (1962), the top of the Whitetail Conglomerate is defined by the appearance of these dacitic tuffs. Age is 19.9 m.y. (Damon and Bikerman, 1964).
	MID-TERTIARY	Basalts	Undated basalt flows and occasional hypabyssal intrusions; sometimes deposited on dacite, usually upon sediments.
	OLIGOCENE TO MIOCENE	Teritary sediment-ary rocks	These sediments consist of conglomerates, siltstones, and sandstones. There are occasion interbeds of volcanic and volcaniclastic rocks.
	OLIGOCENE	Apache Leap Tuff	A prominent cliff-forming rhyodacitic tuff within the Tertiary sediments. The Apach Leap completely blanketed the lower stretches of the Salt River region, and may hav a source at the ignimbrite vent just upstream from Redmond Flat.
	EOCENE TO OLIGOCENE	"Whitetail Conglom-erate"	Generally referred to as "Whitetail Conglomerate," these old gravels are "poorly t firmly consolidated gravels and conglomerate...derived from uplifted area of Ce- tral Arizona, and consist of pebbles, cobbles and boulders representing all the older rocks of th region." (Moore, 1968, p. 60)

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TABLE 2. Geological Column, Salt River Canyon *(Continued)*

AGE		NAME		DESCRIPTION
		PALEOZOIC AND MESOZOIC		Not seen in part of canyon that was traversed.
		"APACHE GROUP" DIABASE 1.14 ±.04 b.y.		Coarse- to fine-grained ophitic to subophitic olivine diabase in sills. Weathers light olive gray to yellow-brown, typically a slope former. Chill margins of multiple intrusions and some differentiation are noted in the diabase. The diabase preferentially intrudes Apache Group rocks, especially the Mescal Limestone, but also intrudes the Troy Quartzite. Successive levels of sills are interconnected by dikes. Extensive thermal metamorphism is noted in the country rock. Asbestos mineralization is common at the Diabase-Mescal contact. The sills and dikes vary in thickness from inches to more than one thousand feet. The thickness of the Apache Group has been doubled as a result of sill intrusion. (Shride, 1967)
UPPER PROTEROZOIC		TROY QUARTZITE 0–1,200 ft	Quartzite Member 0–500 ft	Light-gray to grayish-pink medium-grained orthoquartzite with hematite-coated grains cemented by quartz overgrowths. Bedding is generally 2–30 in and is cross stratified. The quartzite is a steep ledgy slope former. (Shride, 1967)
			Chediski Sandstone 0–700 ft	Light-gray to pinkish-gray sericite sandstone. Coarse grained with pebbles of jasper, rhyolite, and quartzite. Thin bedded to massive, it is a ledge and cliff former in its more massive units. Cross stratification can be seen in the more thinly bedded units. (Shride, 1967)
			Arkose Member 0–450 ft	A basal conglomerate with weathered, rounded clasts from the underlying basalt flows. Dominantly a pale-brown to red, fine- to medium-grained arkose, firmly cemented. Large-scale (10–100 ft) cross-stratification; interbedded with silty seams. A cliff former with rounded ledges. (Shride, 1967)
	APACHE GROUP		Basalt Flows 0–375 ft	Grayish-red to brown, porphyritic, vesicular hematitic basalt. Intergranular texture of laths of plagioclase and apatite. Abundant alteration minerals are present: chlorite, serpentine, and albite. The basalt overlies the Argillite member of the Mescal Limestone and also separates the Algal and Argillite members of the Mescal. (Shride, 1967)
		MESCAL LIMESTONE 250–420 ft	Argillite Member 0–100 ft	A yellow-brown, siliceous, dense argillite with intraformational chert breccias and conglomerates. Some thermal alteration minerals, micas and amphiboles, can be found in close proximity to the basalt flows. (Shride, 1967)
			Basalt Flow 0–110 ft	"Hematitic and vesicular" basalts. See entry above under Basalt Flows. (Shride, 1967, p. 26)
			Algal Member 40–130 ft	The Algal member is composed of two units. The upper is a grayish-red to yellowish- brown crystalline dolomite with lenses of chert. The lower is an algal unit. The upper dolomite is a slope former. The algal unit is a pale-red to reddish-brown dolomitized stromatolitic *(Collenia frequens)* limestone, typically thick bedded (6 ft) and is a cliff former. (Shride, 1967)
			Lower Member 150–270 ft	A coarse-grained arkosic to feldspathic sandstone forms the basal member of the Mescal a cliff former 5–6 ft thick. Above this is a thick dolomite sequence. Yellow-brown to grayish-red, thick- to thin-bedded crystalline limestone with abundant lenses of chert dominate the lower Mescal. Forms both ledges and slopes. (Shride, 1967)
		DRIPPING SPRING 550–700 ft	Siltstone Member 200–370 ft	A fine-grained grayish-orange to yellow-brown siltstone with intercalated thin-bedded bedded arkose comprises the upper member of the Dripping Spring Quartzite. The siltstone is comprised of clay- and silt-sized material, dominantly feldspathic and micaceous with some fine-grained pyrite. Forms slopes with intermittent ledges. (Shride, 1967)
			Arkose Member 200–350 ft	A fine- to medium-grained, pale-brown to orange arkosic quartzite, massively bedded. A prominent cliff and ledge former. When bedding is revealed by weathering, prominent cross-stratification may be seen. (Shride, 1967)
			Barnes Conglomerate 0–40 ft	A gray-red basal arkosic conglomerate member of the Dripping Spring Fm. Well-rounded granules, pebbles, and cobbles of vitreous quartzite, jasper, and some volcanic rocks in a poorly sorted, very coarse arkosic matrix. Bedding thickness is variable, typically a ledge and cliff former 5–30 ft thick. Contact is gradational with upper member of the Pioneer Shale (Shride, 1967)

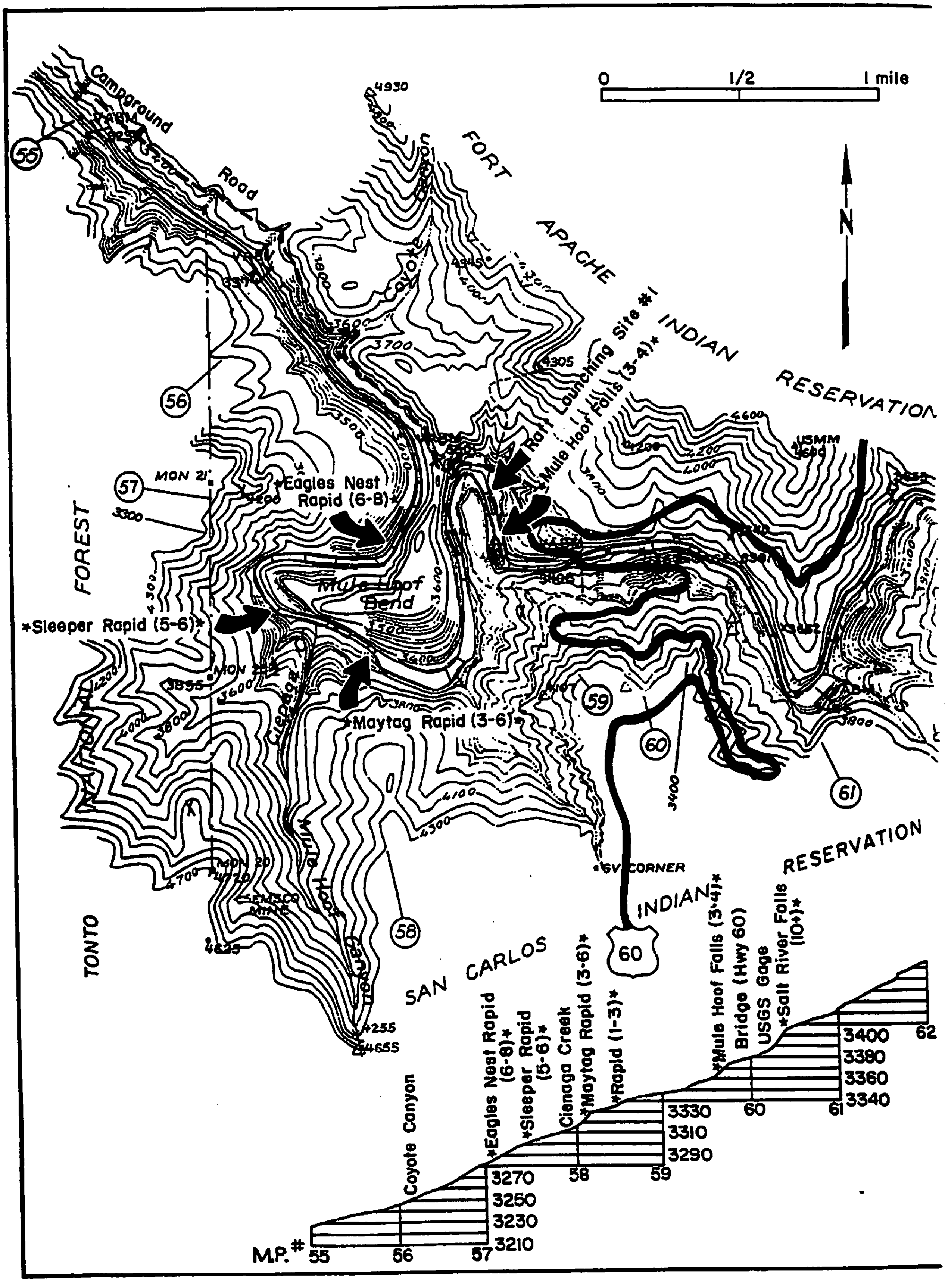


FIGURE 10a. Topographic map of the Mule Hoof Bend area.

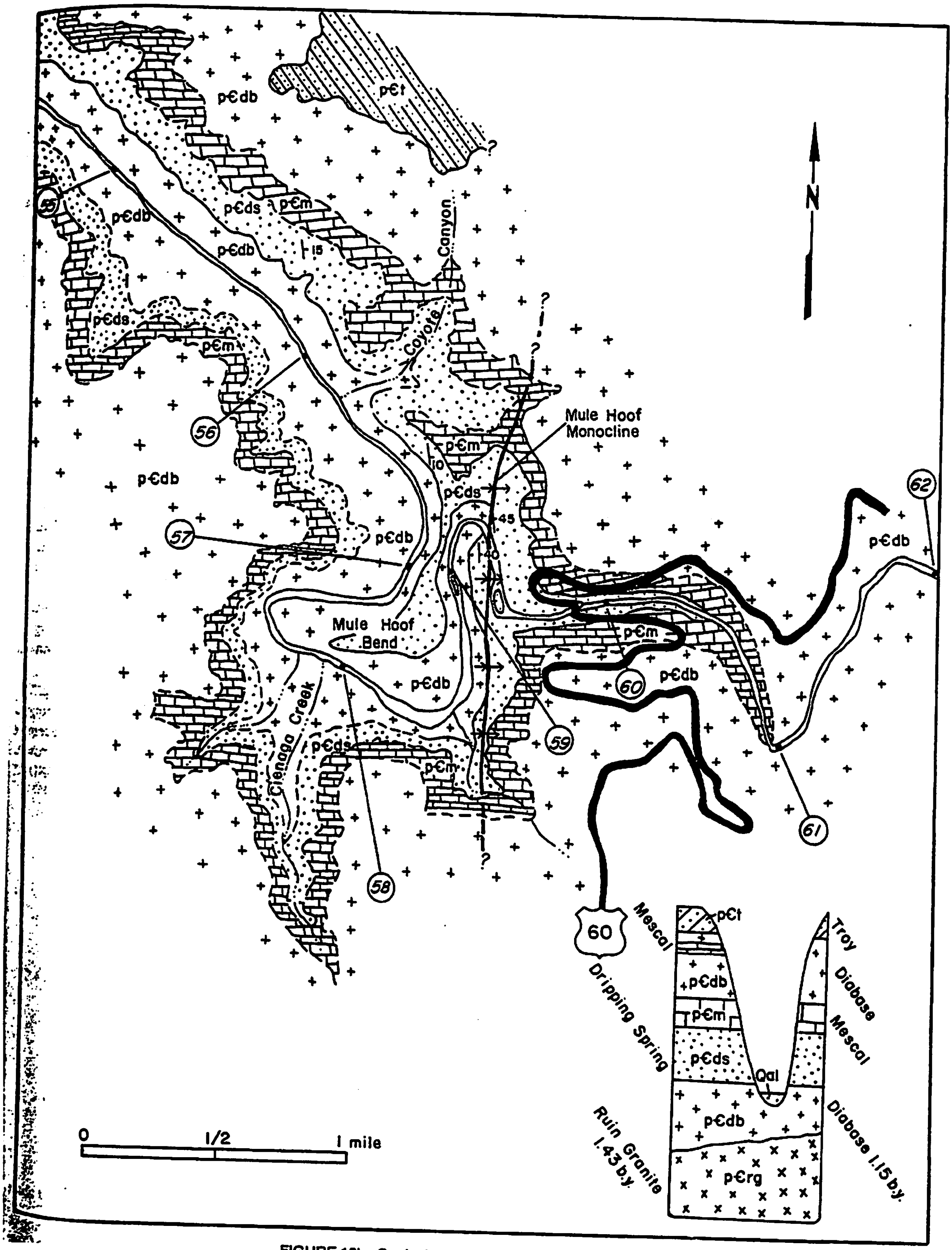


FIGURE 10b. Geologic map of the Mule Hoof Bend area.

augite (a) A common mineral of the clinopyroxene group: $(Ca,Na)(Mg,Fe^{+2},Al)(Si,Al)_2O_6$. It may contain titanium and ferric iron. Augite is usually black, greenish black, or dark green, and commonly occurs as an essential constituent in many basic igneous rocks and in certain metamorphic rocks. Dana (1892) confined the name "augite" to clinopyroxenes containing appreciable $(Al,Fe)_2O_3$, but petrologists have applied it to members of the system $(Mg,Fe,Ca)SiO_3$. Cf: *pigeonite*. (b) A term often used as a syn. of *pyroxene*.—Syn: *basaltine*.

asbestiform Said of a mineral that is fibrous, i.e. that is like asbestos.

asbestine adj. Pertaining to or having the characteristics of asbestos.—n. A variety of talc; specif. *agalite*.

asbestos (a) A commercial term applied to a group of highly fibrous silicate minerals that readily separate into long, thin, strong fibers of sufficient flexibility to be woven, are heat resistant and chemically inert, and possess a high electric insulation, and therefore are suitable for uses (as in yarn, cloth, paper, paint, brake linings, tiles, insulation, cement, fillers, and filters) where incombustible, nonconducting, or chemically resistant material is required. (b) A mineral of the asbestos group, principally chrysotile (best adapted for spinning) and certain fibrous varieties of amphibole (esp. tremolite, actinolite, and crocidolite). (c) A term strictly applied to the fibrous variety of actinolite.—Syn: *asbestus; amianthus; earth flax; mountain flax*.

biotite (a) A widely distributed and important rock-forming mineral of the mica group: $K(Mg,Fe^{+2})_3(Al,Fe^{+3})Si_3O_{10}(OH)_2$. It is generally black, dark brown, or dark green, and forms a constituent of crystalline rocks (either as an original crystal in igneous rocks of all kinds or a product of metamorphic origin in gneisses and schists) or a detrital constituent of sandstones and other sedimentary rocks. Biotite is useful in the potassium-argon method of age determination. (b) A general term to designate all ferromagnesian micas.—Syn: *black mica; iron mica; magnesia mica*.

biotitite An igneous rock almost entirely composed of biotite. Cf: *granitite*. Syn: *glimmerite*.

chrysotile A white, gray, or greenish mineral of the serpentine group: $Mg_3Si_2O_5(OH)_4$. It is a highly fibrous, silky variety of *serpentine*, and constitutes an important type of asbestos. Not to be confused with *chrysolite*. Cf: *antigorite*. Syn: *serpentine asbestos; clinochrysotile*.

diabase (a) In the U.S., an intrusive rock whose main components are labradorite and pyroxene and which is characterized by ophitic texture. As originally applied by Brongniart in 1807, the term corresponded to what is now recognized as *diorite*. Syn: *dolerite*. (b) In British usage, an intrusive igneous rock of the composition of diabase as defined in the U.S. but which has been highly altered by the decomposition of feldspars and mafic minerals.

diabasic (a) A syn. of *ophitic*. Kemp (1900, p.158-159) considered that "diabasic" applied to textures in which there was a predominance of plagioclase, with augite filling the interstices, while "ophitic" indicated a predominance of augite over plagioclase. (b) Composed of or resembling diabase.

diablastic Pertaining to a texture in metamorphic rock that consists of intricately intergrown and interpenetrating constituents with usually rodlike shapes (Becke, 1903).

For the purposes of this report, the term "diabase" is used to describe mafic intrusive rocks of approximate basaltic composition and having ophitic, subophitic, and intersertal textures. Closely related albite-rich rocks are discussed as differentiation products of the normal diabase.

epicontinental Pertaining to the continental shelf.

homocline A general term for a rock unit in which the strata have the same dip, e.g. one limb of a fold, a tilted fault block, a monocline, or an isocline. Cf: *monocline*. Adj: *homoclinal*.

hornblende (a) The commonest mineral of the amphibole group: $Ca_2Na(Mg,Fe^{+2})_4(Al,Fe^{+3},Ti)(Al,Si_8O_{22}(O,OH)_2$. It has a variable composition, and may contain potassium and appreciable fluorine. Hornblende is commonly black, dark green, or brown, and occurs in distinct monoclinic crystals or in columnar, fibrous, or granular forms. It is a primary constituent in many acid and intermediate igneous rocks (granites, syenites, diorites, andesites) and less commonly in basic igneous rocks, and it is a common metamorphic mineral in gneisses and schists. Symbol: Ho. (b) A term sometimes used (esp. by the Germans) to designate the *amphibole* group of minerals. The term "Hornblende" is an old German name for any dark, prismatic crystal found with metallic ores but containing no valuable metal (the word "Blende" indicates "a deceiver").—Obsolete syn: *hornstone*.

hornblende andesite *hungarite*.

hornblende-hornfels facies Rocks formed in the middle grades of thermal (contact) metamorphism at temperatures between 350°C and 550°C and at low pressures not exceeding about 2500 bars (Turner and Verhoogen, 1960, p.511). It is part of the *hornfels facies*. Cf: *pyroxene-hornfels facies; albite-epidote-hornfels facies*.

hornblendite An igneous rock composed almost entirely of hornblende. The term has been equated incorrectly by some authors with the metamorphic rock amphibolite.

monocline A unit of strata that dips or flexes from the horizontal in one direction only, and is not part of an anticline or syncline. It is generally a large feature of gentle dip. Cf: *homocline; flexure*. Adj: *monoclinal*. Obs. syn: *unicline*.

ophite A general term for diabases which have retained their ophitic structure although the pyroxene is altered to uralite. The term was originated by Palasson in 1819.

ophitic Said of the holocrystalline, hypidiomorphic-granular texture of an igneous rock (esp. diabase) in which lath-shaped plagioclase crystals are partially or completely included in pyroxene crystals (typically augite). Also, said of a rock exhibiting ophitic texture (e.g. ophite) or, rarely, of a similar texture involving other pairs of minerals. The term *diabasic*, although generally considered synonymous, was distinguished from "ophitic" by Kemp (1900, p.158-159) who considered the latter as having an excess of augite over plagioclase, while the former had a predominance of plagioclase, with augite filling the interstices. Cf: *poikilitic; poikilophitic*. Nonpreferred syn: *basiophitic; granitotrachytic*. Syn: *doleritic; gabbroid*.

olivine (a) An olive-green, grayish-green, or brown orthorhombic mineral: $(Mg,Fe)_2SiO_4$. It comprises the isomorphous solid-solution series forsterite-fayalite. Olivine is a common rock-forming mineral of basic, ultrabasic, and low-silica igneous rocks (gabbro, basalt, peridotite, dunite); it crystallizes early from a magma, weathers readily at the Earth's surface, and metamorphoses to serpentine. (b) A name applied to a group of minerals forming the isomorphous system $(Mg,Fe,Mn,Ca)_2SiO_4$, including forsterite, fayalite, tephroite, and a hypothetical calcium orthosilicate. Also, any member of this system.—See also: *peridot; chrysolite*. Syn: *olivinoid*.

olivine basalt A group of basalts that contain olivine in addition to their other components; considered by some petrographers as a less-preferred syn. of *alkali olivine basalt*.

Paleozoic An era of geologic time, from the end of the Precambrian to the beginning of the Mesozoic. Obs syn: *Primary*.

pegmatite An exceptionally coarse-grained (most grains one cm or more in diameter) igneous rock, with interlocking crystals, usually found as irregular dikes, lenses, or veins, esp. at the margins of batholiths. Although pegmatites having gross compositions similar to other rock types are known, their composition is generally that of granite; the composition may be simple or complex and may include rare minerals rich in such elements as lithium, boron, fluorine, niobium, tantalum, uranium, and rare earths. Pegmatites represent the last and most hydrous portion of a magma to crystallize and hence contain high concentrations of minerals present only in trace amounts in granitic rocks. The first use of the term "pegmatite" is attributed to Hauy (1822) who used it as a syn. of *graphic granite*. Cf: *pegmatoid; symplectite*. See also: *pegmatitic*. Syn: *giant granite*.

pelite (a) A sediment or sedimentary rock composed of the finest detritus (clay- or mud-size particles): e.g. a mudstone, or a calcareous sediment composed of clay, minute particles of quartz, or rock *flour*. The term is equivalent to the Latin-derived term, *lutite*. (b) A fine-grained sedimentary rock composed of more or less hydrated aluminum silicates with which are mingled other small particles of various minerals (Twenhofel, 1937, p.90); an aluminous sediment. (c) A term regarded by Tyrrell (1921, p.501-502) as the metamorphic derivative of lutite, such as the metamorphosed product of a siltstone or mudstone. "As commonly used, a pelite means an aluminous sediment metamorphosed, but if used systematically, it means a fine-grained sediment metamorphosed" (Bayly, 1968, p.230).—Etymol: Greek *pelos*, "clay mud". See also: *psammite; psephite*. Syn: *pelyte*.

pelitic (a) Pertaining to or characteristic of pelite; esp. said of a sedimentary rock composed of clay, such as a "pelitic tuff" representing a consolidated volcanic ash consisting of clay-size particles. (b) Said of a metamorphic rock derived from a pelite; e.g. a "pelitic gneiss", a "pelitic hornfels", or a "pelitic schist", derived by metamorphism of an argillaceous or of a fine-grained aluminous sediment.—Cf: *argillaceous; lutaceous*.

plagioclase (a) A group of triclinic feldspars of general formula: $(Na,Ca)Al(Si,Al)Si_2O_8$. At high temperatures it forms a complete solid-solution series from Ab ($NaAlSi_3O_8$) to An ($CaAl_2Si_2O_8$). The plagioclase series is arbitrarily subdivided and named according to increasing mole fraction of the An component: albite (An 0-10), oligoclase (An 10-30), andesine (An 30-50), labradorite (An 50-70), bytownite (An 70-90), and anorthite (An 90-100). The Al/Si ratio varies with increasing An content from 1:3 to 1:1. Plagioclases are one of the commonest rock-forming minerals, have characteristic twinning, and commonly display zoning. (b) A mineral of the plagioclase group; e.g. albite, anorthite, peristerite, and aventurine feldspar.—The term was introduced by Breithaupt (1847, p.490) who applied it to all feldspars having an oblique angle between the two main cleavages. Cf: *alkali feldspar; orthoclase*. Syn: *sodium-calcium feldspar*.

pluton (a) An igneous *intrusion*. (b) A body of rock formed by metasomatic replacement. —The term originally signified only deep-seated or plutonic bodies of granitoid texture. See also: *plutonism*.

plutonian Var. of *plutonic*.

plutonic (a) Pertaining to igneous rocks formed at great depth. See also: *plutonic rock*. Cf: *hypabyssal*. (b) Pertaining to rocks formed by any process at great depth. —Syn: *abyssal; plutonian; deep-seated; hypogene*.

Poikilitic An old term for the Permian and the Triassic.

poikilitic Said of the texture of an igneous rock in which small crystals of one mineral (e.g. plagioclase) are irregularly scattered without common orientation in a larger crystal of another mineral (e.g. pyroxene); also, said of the enclosed crystal. The larger crystal is typically anhedral and exhibits optical and crystallographic continuity; in hand specimen, this texture produces lustrous patches (*luster mottling*) due to reflection from cleavage planes. Originally spelled *poecilitic*. Cf: *ophitic; endoblastic*. Nonrecommended syn: *semipegmatitic*.

Proterozoic (a) The more recent division of the Precambrian. Cf: *Archeozoic*. Syn: *Algonkian; Agnotozoic*. (b) The entire *Precambrian*.

salic [petrology] Said of certain light-colored silica-, or magnesium-rich minerals present in the norm of igneous rocks; e.g. quartz, feldspars, feldspathoids. Also, applied to rocks having one or more of these minerals as major components of the norm. Etymol: a mnemonic term derived from silicon + aluminum + *ic*. Cf: *femic; mafic; felsic*.

SERPENTINE $Mg_3Si_2O_5(OH)_4$

Monoclinic — prismatic $\frac{2}{m}$

Environment: A secondary mineral, resulting from a hot-water alteration of magnesium silicates.

Crystal description: Crystals unknown, except as the parallel fibers called chrysotile asbestos. Also massive, sometimes with a botryoidal surface as if it had been amorphous when formed.

Physical properties: White, green, brown yellow, red, black. *Luster* silky, waxy to greasy; *hardness* 2–5; *gravity* 2.2–2.6; *cleavage* none to fibrous. Translucent to opaque; yellowish varieties often fluorescent cream-yellow.

Composition: Basic magnesium silicate (43.0% MgO, 44.1% SiO_2, 12.9% H_2O, plus some iron and possibly nickel).

Distinguishing characteristics: A very common mineral, and one that should always be suspected in a rock with a greasy feel. Usually relatively soft and dark greenish. White varieties are not common and typically are associated with other serpentines. The serpentine asbestos varieties are softer and more flexible than the amphibole asbestoses. The blackening and the water released in the closed tube also distinguish it from amphibole asbestos. Ease with which the green massive material can be scratched distinguishes it from nephrite jade; it is harder than chlorite, however.

Occurrence: Since serpentine seems frequently to form by the alteration of primary magnesium silicates taking up the water originally present in the magma, they are found wherever dark-colored magnesium silicate rocks occur. Great serpentine formations, as in the California Coast Ranges, give it rock status as well as mineralogical identity. Readily identifiable in highway cuts by the shiny, greenish, slickensided surfaces.

Serpentinization seems commonly to invade mineralized areas, altering quite unrelated minerals to serpentine. In this way we find at the famous Tilly Foster Mine (Brewster, New York) that serpentine is pseudomorphous after numerous minerals, and also forms botryoidal coatings and films ranging from white to black. Large masses of serpentine result from the alteration of the dark intrusives, as at: Hoboken, New Jersey; Staten I., New York; Eden Mills, Vermont; Thetford and Asbestos, Quebec. Veins of fibrous asbestos cut through such bodies; there are quarries or mines for chrysotile asbestos in those regions, near Coalinga, California, and in Arizona.

Varieties:

Fibrous and silky:	chrysotile
Columnar:	picrolite
Waxy:	retinalite
Platy:	antigorite
Micaceous:	marmolite
Massive and mottled:	ophiolite
Translucent light green:	williamsite

Interesting facts: Chrysotile is considered the best asbestos. Serpentine marbles make the popular verd antique. Closely related nickel-rich serpentines are important ores of the metal (garnierite) and are mined in New Caledonia. Commonly used in decorative carvings.

subophitic Said of the ophitic texture of an igneous rock in which the feldspar crystals are approximately the same size as the pyroxene and are only partially included by them.

uralite A green, generally fibrous or acicular variety of secondary amphibole (hornblende or actinolite) occurring in altered rocks and pseudomorphous after pyroxene (such as augite).

uralite diabase *uralitite*.

uralitite A term suggested for a diabase that contains augite altered to uralite. Syn: *uralite diabase*.

uralitization The development of amphibole from pyroxene; specif. a late-magmatic or metamorphic process of replacement whereby uralite results from alteration of primary pyroxene. Also, the alteration of an igneous rock in which pyroxene is changed to amphibole; e.g. the alteration of gabbro to greenstone by pressure metamorphism.

uralolite A mineral: $CaBe_3(PO_4)_2(OH)_2.4H_2O$.

Ural-type glacier *drift glacier*.

uramphite A bottle-green to pale-green mineral: $(NH_4)(UO_2)(PO_4).3H_2O$.

uraninite A black, velvety-brownish, steel-gray, or greenish-black, strongly radioactive, octahedral or cubic mineral, essentially UO_2, but usually partly oxidized. It is the chief ore of

The Springerville Volcanic Field: an example of Plio-Pleistocene monogenetic volcanism in Arizona.

4/23/92
Randy Tufts

By turns hot embers from her entrails fly,
And flakes of mountain flame that arch the
sky.—VIRGIL's Aeneid

Some of the world's most active volcanoes are near the centers of ancient civilization in the Mediterranean region: Mount Etna in Sicily and Vesuvius on the shore of the Bay of Naples. Thus it is not strange that classic literature contains many references to volcanoes and that many myths and legends are associated with them. This wealth of folklore is an important source of information on the activity of volcanoes in ancient times.

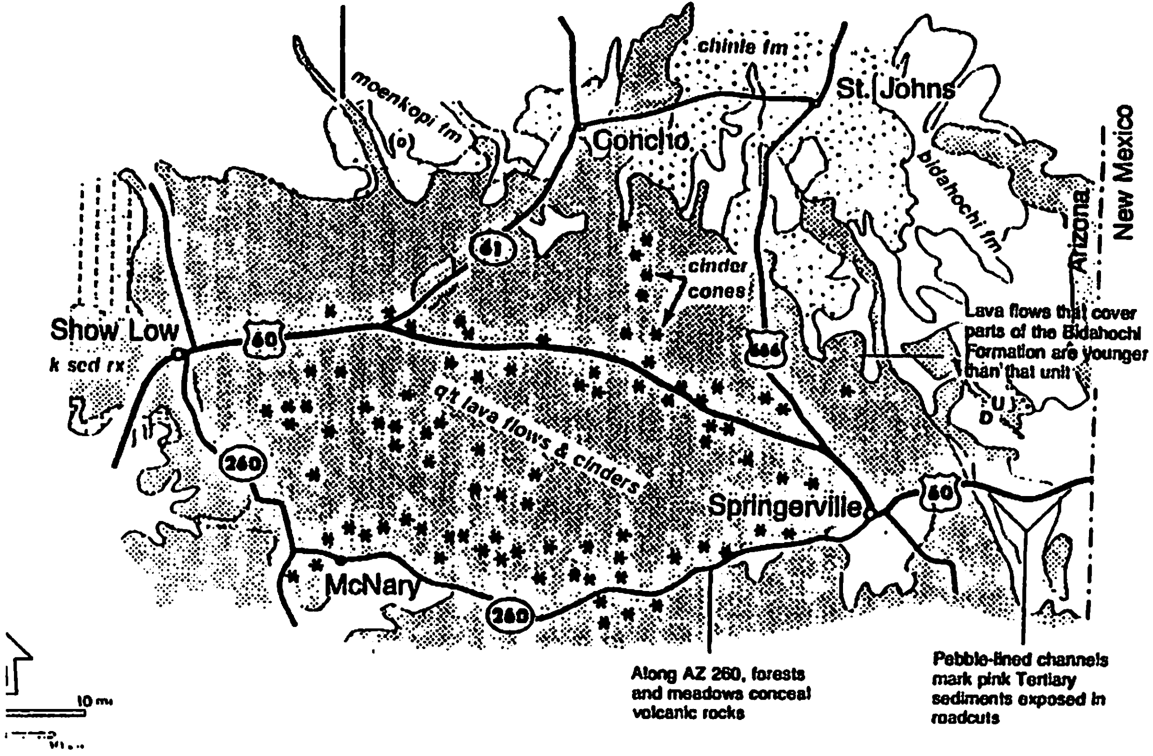
In Greek mythology Hephaestus is the god of fire, and the name, meaning "burning," "shining," or "flaming," probably originally referred to the brilliance of lightning. In Roman mythology Hephaestus was identified with Vulcan, one of the three children of Jupiter and Juno. Vulcan was the god of fire, especially terrestrial fire, volcanic eruptions, and the glow of the hearth and forge. Vulcan was the blacksmith of the gods. His forge at Olympus was equipped with anvils and all the implements of the trade. Vulcan made the arrows for Apollo and Diana, the shield of Achilles, and the invincible breast-plate of Hercules. He was toolmaker to the gods, utilizing the power of his forge for their welfare. His wife, according to the *Odyssey*, was Venus. (See Gayley 1911, p. 26.)

Poets have identified Vulcan's workshop with various active volcanoes in the belief that the smoking mountain was the chimney of Vulcan's forge. The explosions in the eruption of a volcano were believed to be Vulcan pounding on his anvil, while the fire and smoke came from the forge. It was here that Vulcan made the thunderbolts which Jove threw about so recklessly. Most frequently in ancient writings Vulcan's forge was located on the island of Vulcano, one of the Lipari or Aeolian Islands in the Tyrrhenian Sea, off the coast of Sicily (see Ch. 8). In fact, the name *volcano* is derived from the Latin name Vulcanus or Volcanus, applied to the island in ancient times because it was believed to be the location of the forge of Vulcan. From this association, the name *volcano* has been applied to all mountains which give off "smoke and fire" throughout the world.

There is a legend that, during the reign of Romulus, a temple to Vulcan was built in Rome, and a festival called Vulcanalia was held on August 23 of each year, the ceremony consisting of a sacrifice to Vulcan for the purpose of averting all mishaps that might arise from the use of fire or light.

After Bullard. 1984

US 60
New Mexico to Show Low



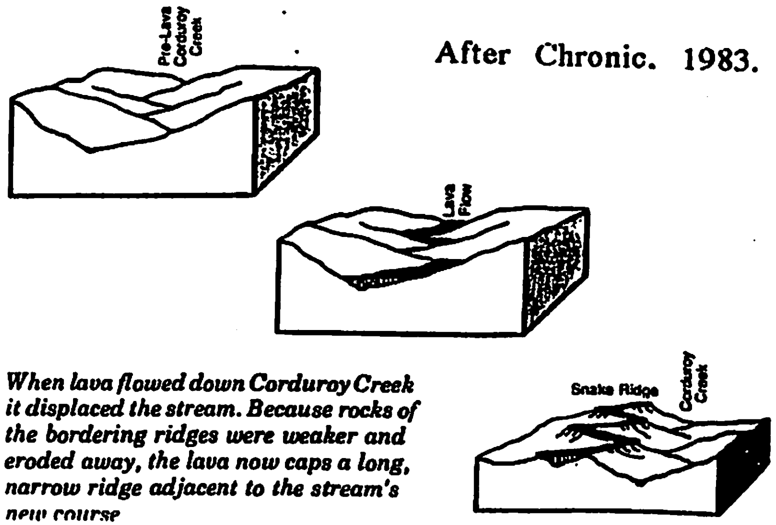
Long, narrow basalt-capped ridges result when lava flows down stream valleys. Valley walls have since eroded away

Lava flows that cover parts of the Bidahochi Formation are younger than that unit

Along AZ 260, forests and meadows conceal volcanic rocks

Pebble-lined channels mark pink Tertiary sediments exposed in roadcuts

After Chronic. 1983.



When lava flowed down Corduroy Creek it displaced the stream. Because rocks of the bordering ridges were weaker and eroded away, the lava now caps a long, narrow ridge adjacent to the stream's new course

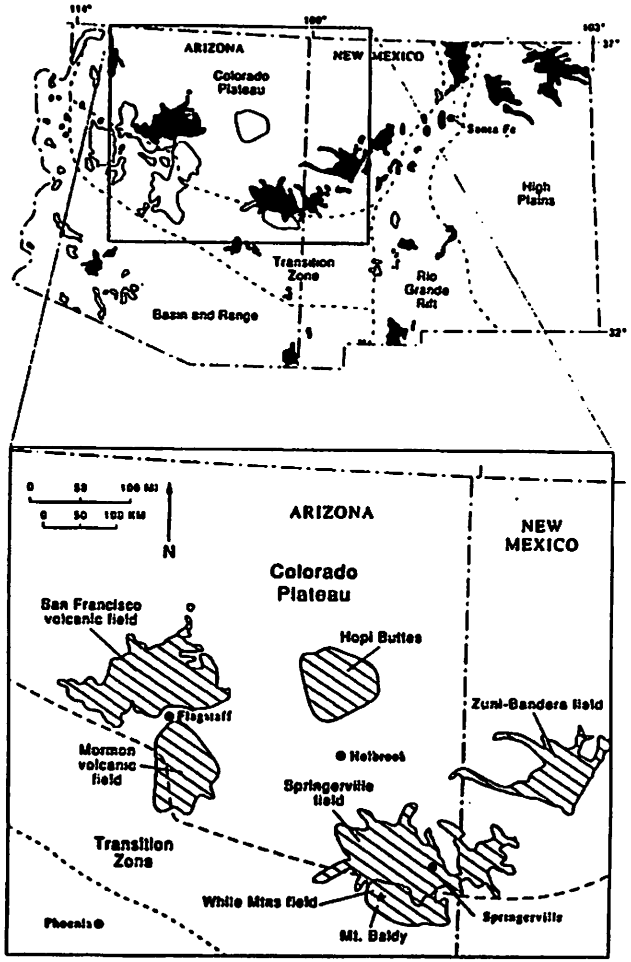


FIGURE 1—Distribution of late Cenozoic basaltic fields in Arizona and New Mexico (from Luedke and Smith, 1978). Dark areas, volcanic rocks of Pliocene to Holocene age (mostly younger than 5 Ma); unshaded outlined areas, volcanic rocks of Miocene or older age (6–16+ Ma). Enlarged area shows volcanic fields visited on Excursion 5A.

After Ulrich et al. 1989

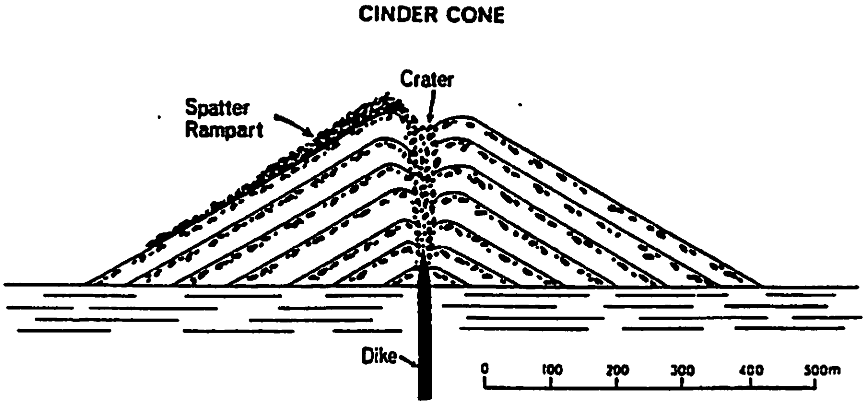


Fig. 5.4 Schematic diagram of a cinder cone. Bedding of cinders at the flank of the cone is at the angle of repose (30°). A small welded spatter rampart is on the left side of the diagram.

After Smiley et al. 1984

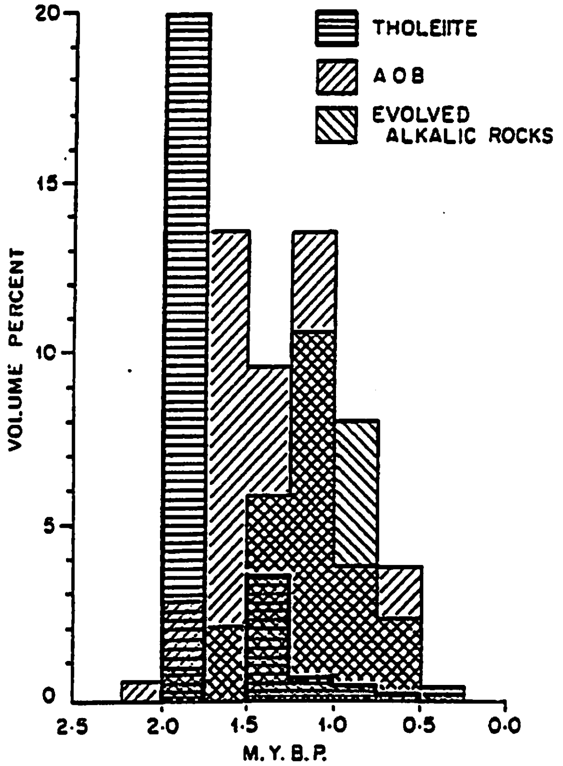
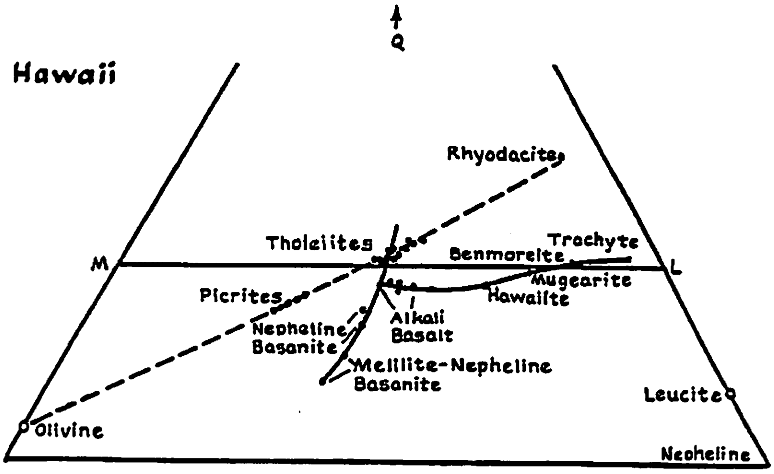


FIGURE D2—Estimated volume effusion rates for three rock types through time, viewed in 250,000 yr intervals. AOB = alkali olivine basalt (sensu stricto). Hawaiite, mugearite, and benmoreite are classified as evolved alkalic rocks. The peak in evolved alkalic rocks production, 0.5 Ma later than that for alkali olivine basalt, coupled with the eruptive recurrence interval of 4400 yrs, suggests these data represent the entire life cycle of the Springerville volcanic field.

After Condit et al. 1989

Fig. 7-14. Von Wolff diagram for the rocks of Hawaii. Compositions are plotted in terms of the normative components "L" (leucocratic minerals, feldspar, and feldspathoids), "M" (mafic minerals, pyroxene, olivine, and iron oxides), and "Q" normative quartz above the line LM and normative Ne and Lc below). Note the trend of tholeiitic compositions directly away from olivine along the dashed line) and the course of mildly alkaline rocks close to the line of silica saturation, LM. (Adapted from G. A. Macdonald, 1968, *Geol. Soc. Amer. Mem. 116*, 477–522.)



After McBirney, 1984

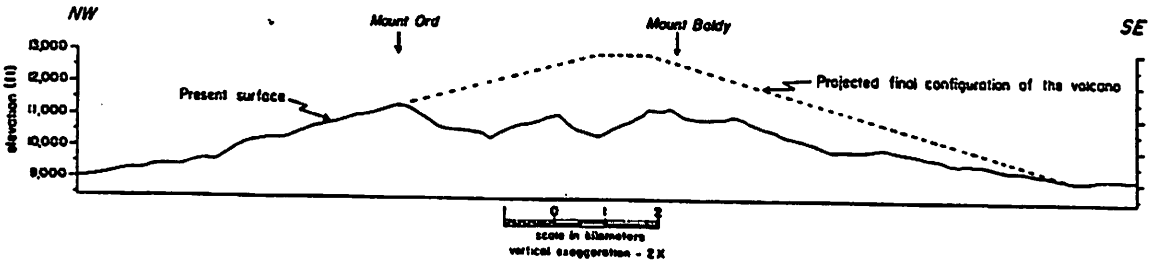


Figure 9.—Topographic profile across the White Mountains showing the possible final configuration of the volcano.

After Merrill and Pewe, 1977

SUMMARY OF CHARACTERISTCS OF ARIZONA'S PLIO-PLEISTOCENE VOLCANIC FIELDS

d Location	Area sq km	Altitude m	Tallest Cones	Volcano types and numbers	Rock Types	Nodules	⁸⁷Sr/⁸⁶Sr	Ages Ma	References
0°N 0°W	830	1300	200m	Scoria cones—250	Alkali basalt Hawaiite; Bas. andesite Ankaramite Quartz basalt	Lherzolite Garnet Lherzolite Pyroxenite Gabbro	0.7029- 0.7041	7.0—Holocene	Best, 1970 Best and Brimhall, 1974 Best and others, 1980 Leeman, 1974
cisco 0°N 0°W	5000+	2000	330m	Scoria cones—500+ Maar tuff ring—5 Composite—4	Alkalic Basalt Benmoreite-trachyte Calc-Alkalic Andesite—latite Dacite—rhyolite	Pyroxenite Gabbro	0.7026 0.7050	6.0—Holocene	Damon and others, 1974 Leeman, 1970 Moore and others, 1976 Smiley, 1958 Tanaka and others, 1986 Wolfe, 1984 Wolfe and others, 1983
ville- Low 0°N 0°W	3000+	2000	300m	Scoria cones—400+ Maar—1	Basalt Hawaiite—mugearite Benmoreite	Gabbro	0.7036 0.7053	2.1—0.3	Condit, 1984 Crumpler and others, 1986 Laughlin and others, 1976 Laughlin and others, 1971 Leeman, 1970
los 15°N 5°W	50	1000	eroded	Cones—5 Maar-tuff ring—1	Basalt	Lherzolite Pyroxenite	0.7035	4.2—1.0	Frey and Prinz, 1978 Leeman, 1970 Shafiqullah and others, 1980 Wilshire and Shervais, 1975
ardino imo) 0°N 5°W	850	1300	150m	Scoria cones—135 Maar craters—5	Basalt Hawaiite	Lherzolite Pyroxenite Gabbro	0.7029- 0.7034	3.2—0.3	Evans and Nash, 1979 Kempton and others, 1982 Lynch, 1978 Menzies, 1983 Menzies and others, 1985
ma 35°N 15°W	300	700	20m	Lava cones—5	Basalt	None reported	0.7034	None dated	Lynch, unpublished Paz-Moreno, 1984
Plain 50°N 0°W	750+	160	75m	Lava cones—20	Basalt	None reported	0.7035	3.2—2.0	Leeman, 1970 Lynch, unpublished Shafiqullah and others, 1980
50°N 0°W	1500	200	150m	Scoria Cones—425 Maar/tuff ring—13 Composite—1	Basalt—hawaiite Hawaiite—trachyte	Lherzolite (rare) Pyroxenite Gabbro	0.7030- 0.7042	1.7—0.12 +Holocene	Donnelly, 1974 Gutmann, 1972 Lynch, 1981
andera 50°N 0°W	2500+	1500	100m	Scoria cones—74	Alkali basalt Tholeiitic basalt	Lherzolite	0.7027- 0.7034	3.8—0.2 +Holocene	Ander and others, 1981 Leeman, 1970

atitude and longitude of the approximate center of each field

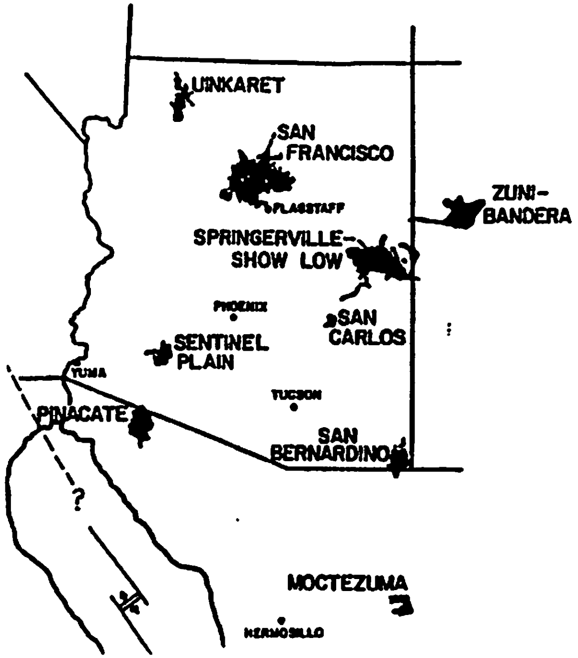
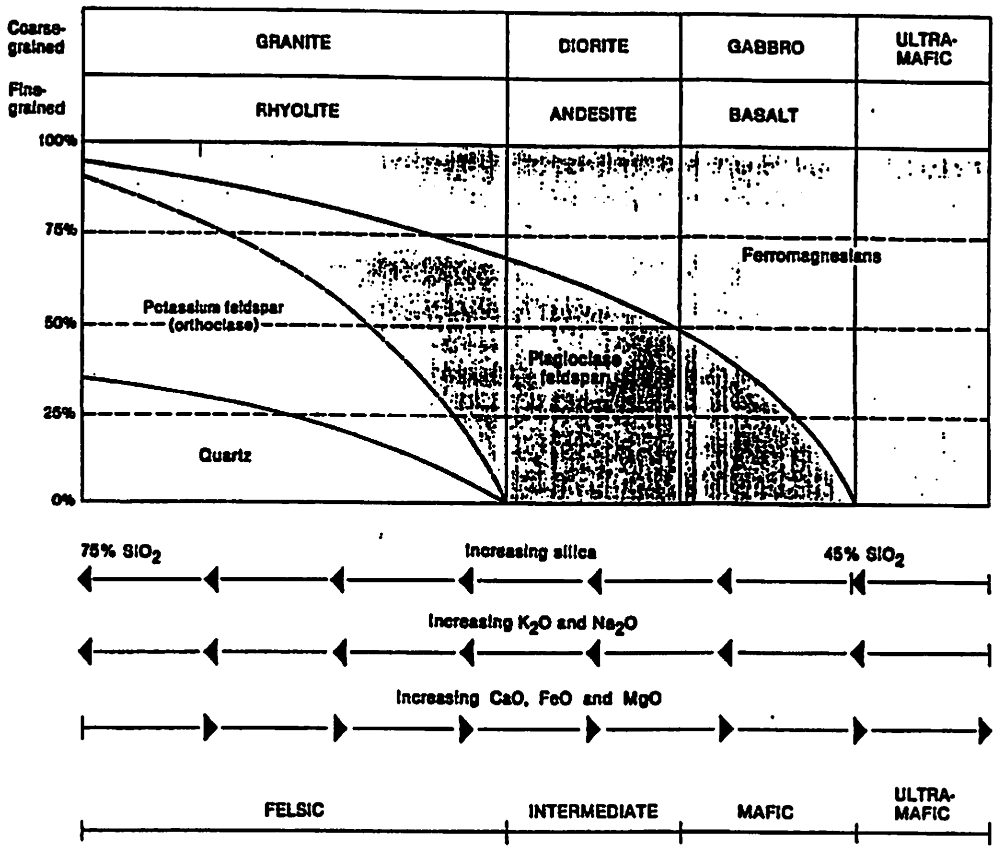


Figure 1. Fields of Plio-Pleistocene age volcanoes in the Arizona region. Uinkaret, San Francisco, Zuni-Bandera and Pinacate are potentially active. Occurrences of Pliocene basaltic rock that are older than 3 Ma, lack easily recognizable constructional landforms and are omitted. The general characteristics of each field are summarized in table 1.

After Lynch. 1989

Figure 4.10 Classification chart for the most common igneous rocks. Rock names based on special textures are not shown.



After Hess. 1989.

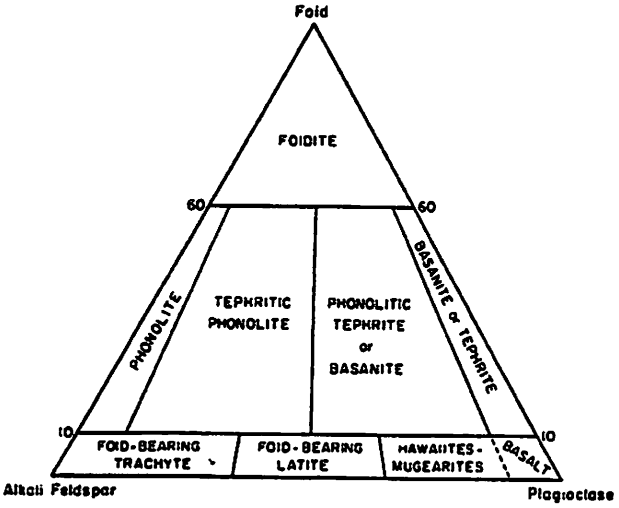


Figure A.6. Root names for SiO_2-undersaturated volcanic felsic rocks.

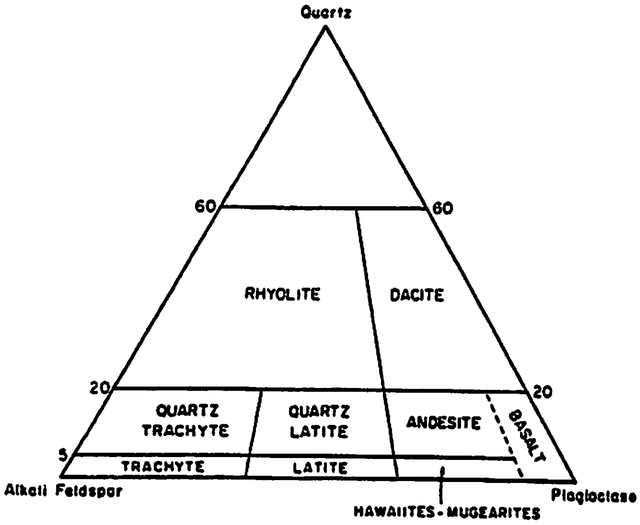
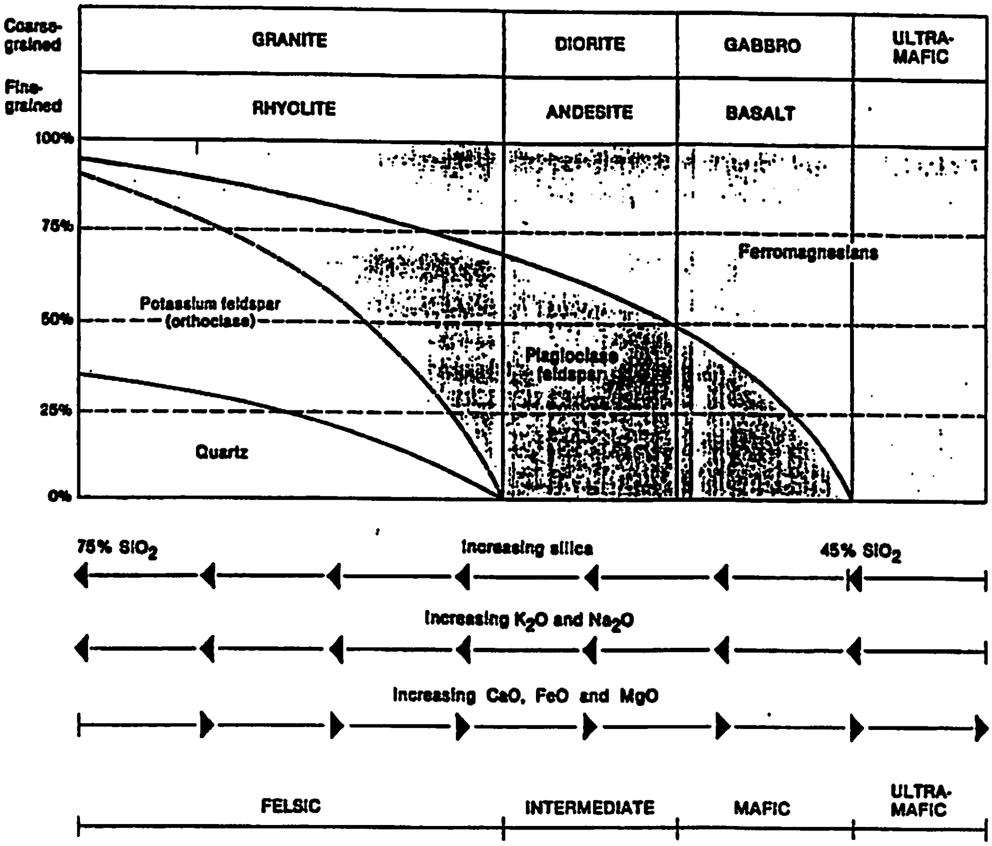


Figure A.5. Root names for volcanic rocks corresponding to plutonic granitoid rocks.

After Plummer. 1988

Figure 4.10 Classification chart for the most common igneous rocks. Rock names based on special textures are not shown.



After Hess. 1989.

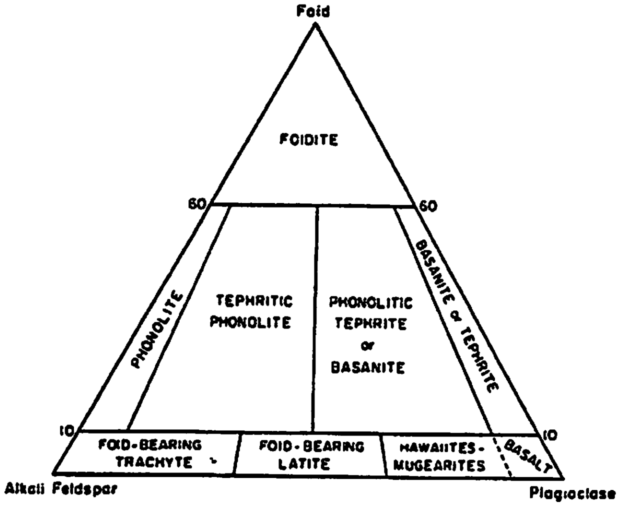


Figure A.6. Root names for SiO_2-undersaturated volcanic felsic rocks.

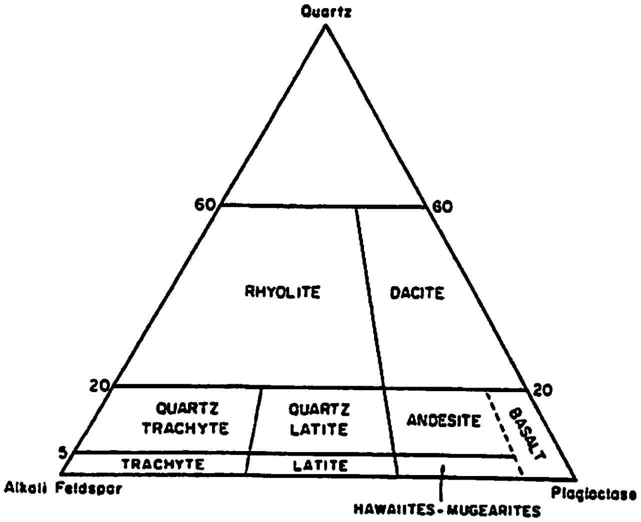
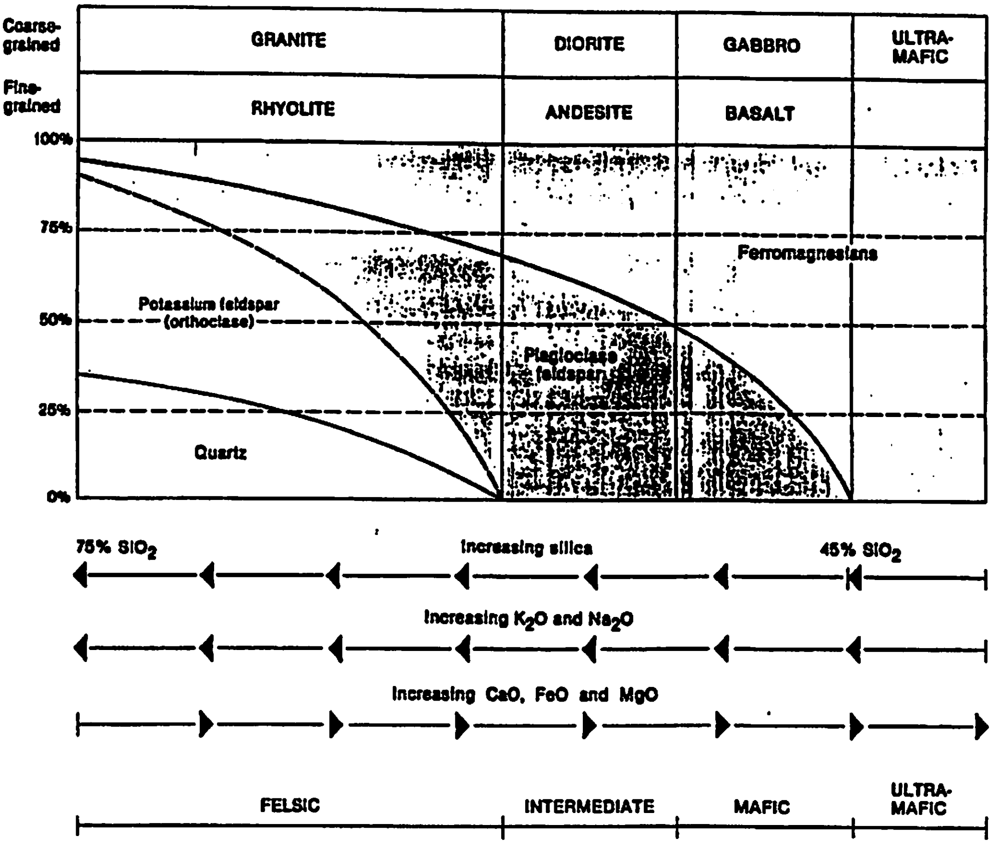


Figure A.5. Root names for volcanic rocks corresponding to plutonic granitoid rocks.

After Plummer. 1988

Figure 4.10 Classification chart for the most common igneous rocks. Rock names based on special textures are not shown.



After Hess. 1989.

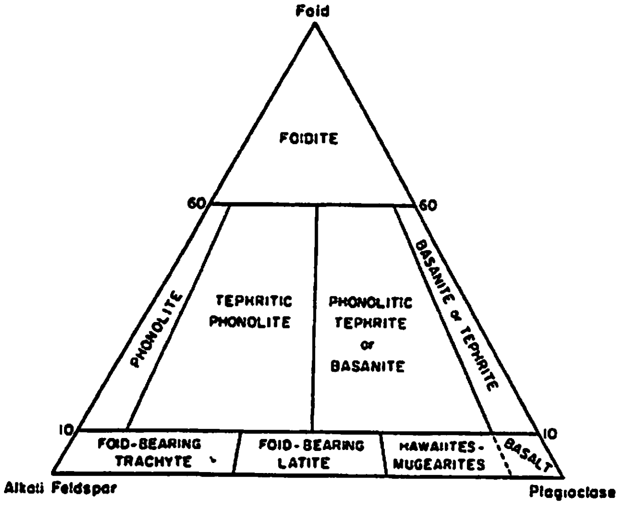


Figure A.6. Root names for SiO_2-undersaturated volcanic felsic rocks.

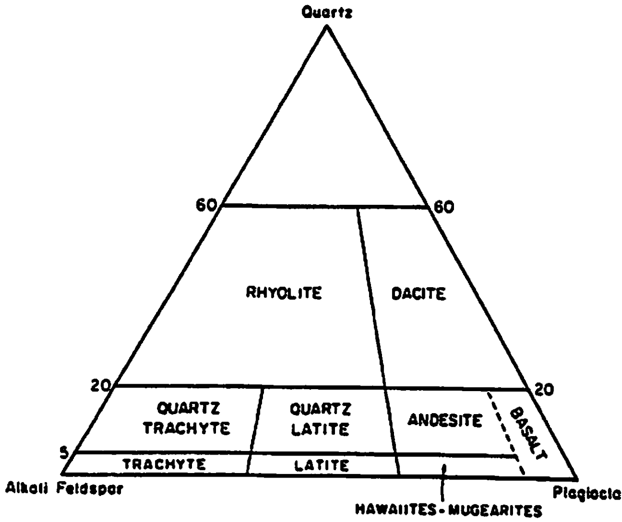
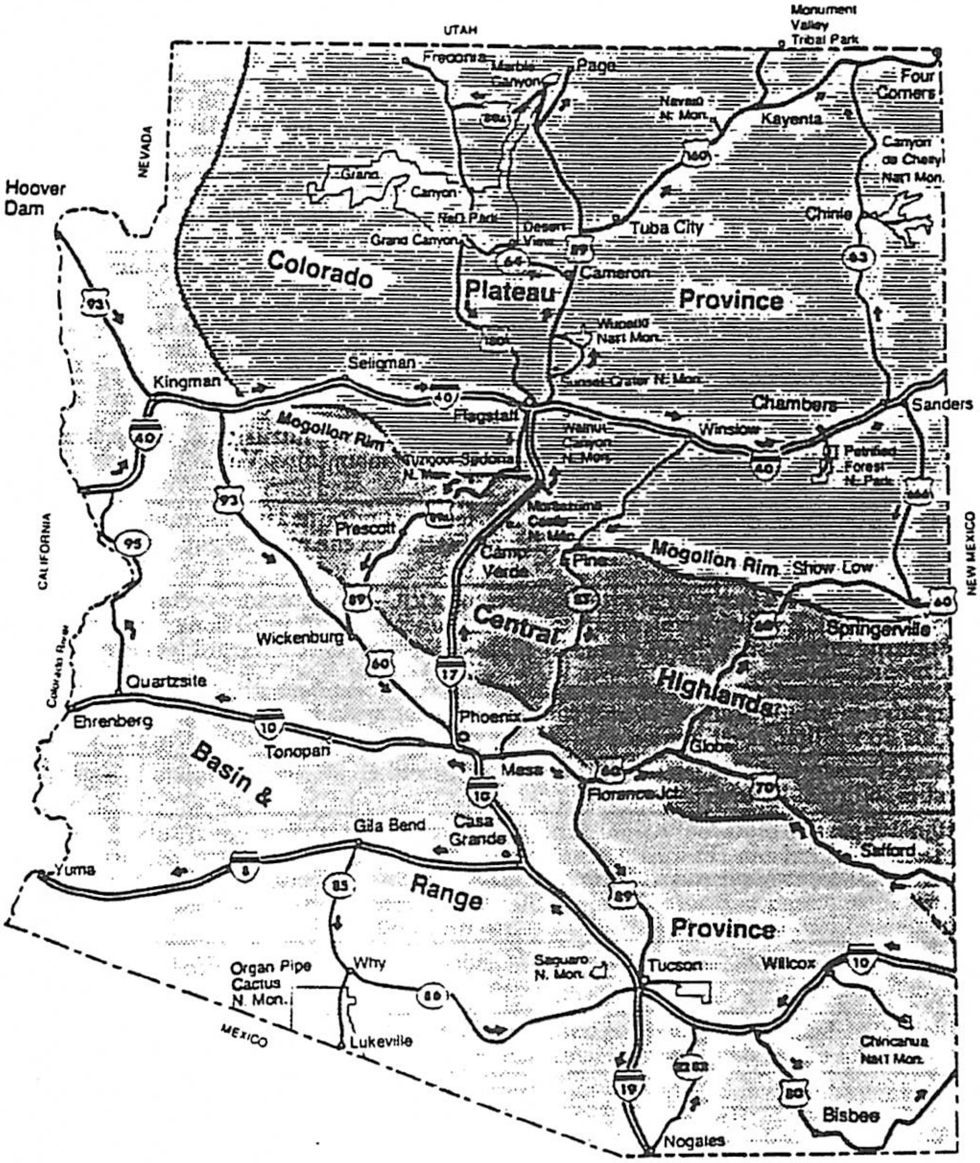


Figure A.5. Root names for volcanic rocks corresponding to plutonic granitoid rocks.

After Plummer. 1988

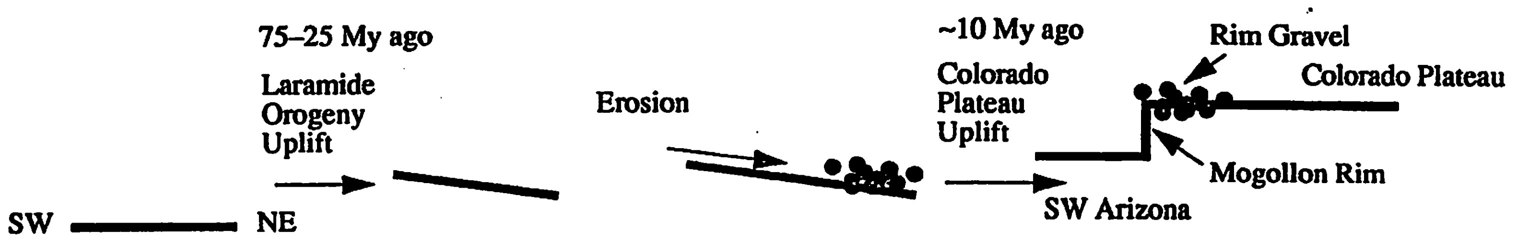


After Chronic. 1983.

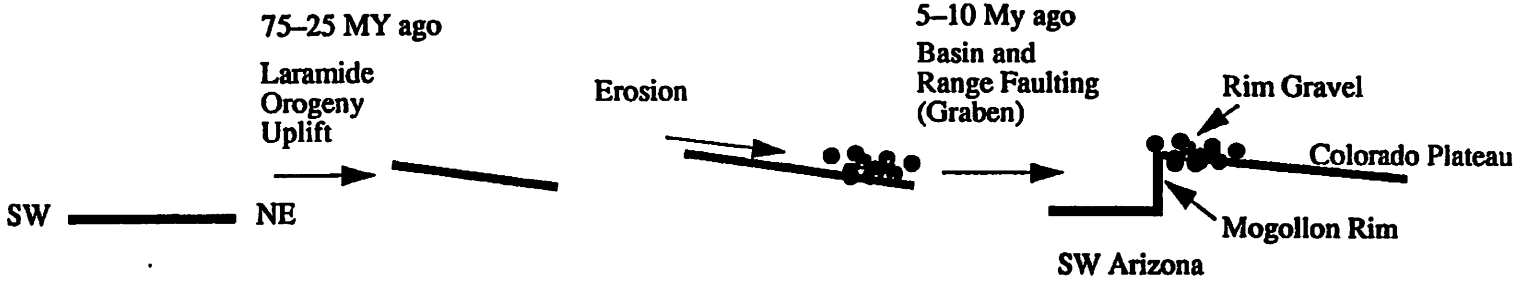
Problem: Why is there gravel on top of the hill, which is from rocks older than the ones it sits on? All of the water flows from the North, now, but they're older than anything in that direction, and are more similar to the rocks far below. In fact, there's even bits of basalt otherwise found only to the South.

Answer: The hill used to go farther South, the gravel rolled downhill, then the old hill went away.

Model 1
(Originally
Pre-Plate-Tectonics)



Model 2



Issues remaining:

- Modern dating of some rim gravels yields 30-50 My.
- Stratigraphy is more complicated then pictured here.
- Perhaps an additional (pre- basin-and-range) faulting episode.
- Colorado River.
- Up to 80 km of scarp erosion.

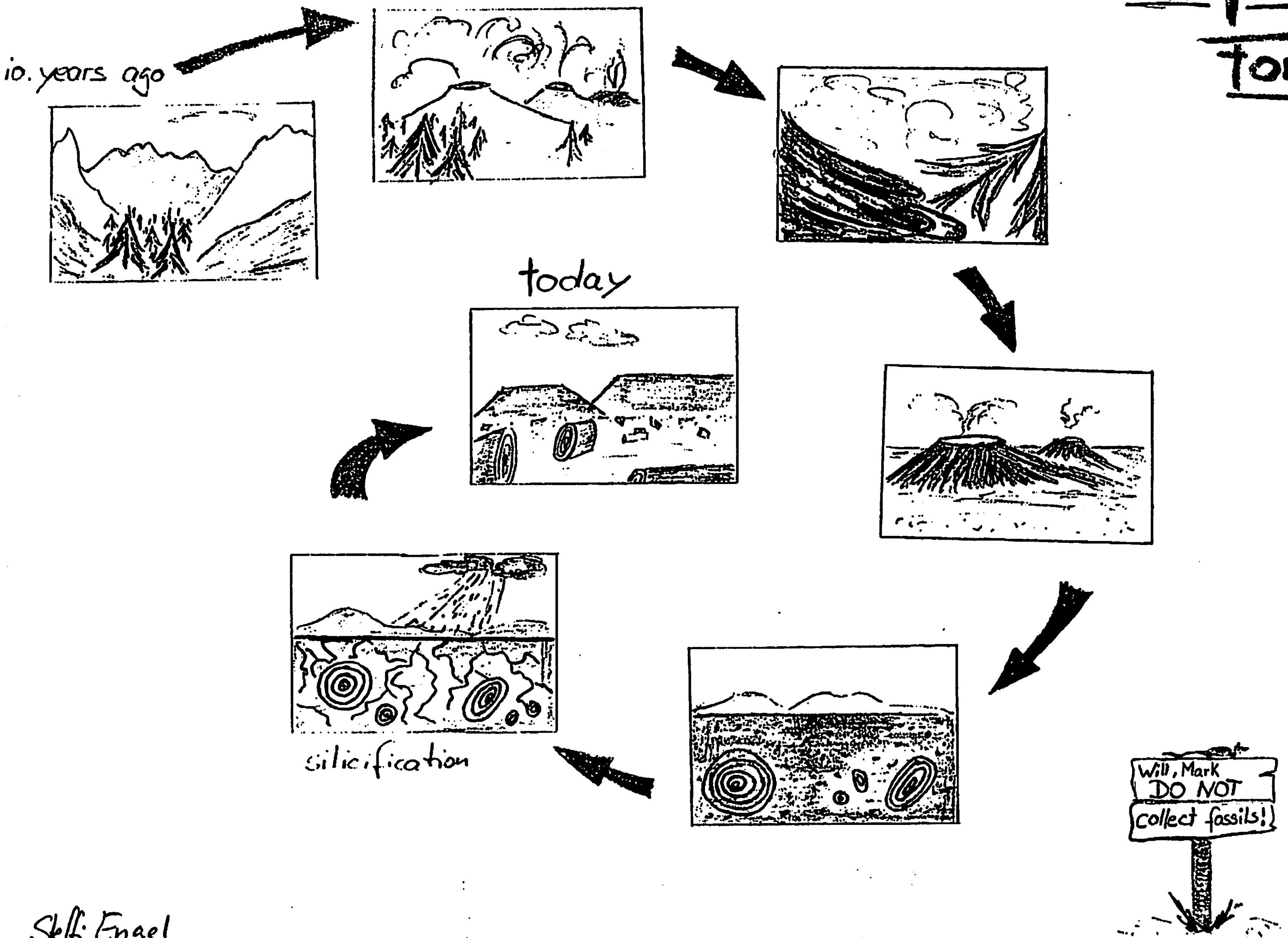
PTYS 597a

PLANETARY FIELD GEOLOGY PRACTICUM

Field Trip 24–26 April 1992

Day 2
Show Low to Canyon de Chelly

Petrified Forest



Steffi Engel

4/24 - 4/26 (1992.

①

Planetary Field Geology Practicum
The Chinle Formation of the Painted Desert
Bill Bottke, Moderator

(1*)

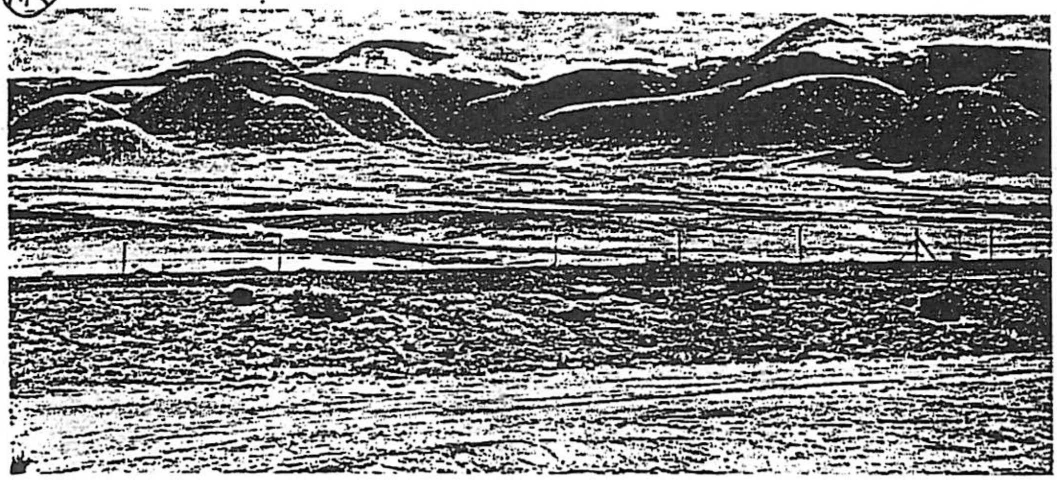


Figure 11–2. Petrified Forest Member of the Chinle Formation, north of Cameron.

The Basics:

The Chinle Formation of the late Triassic age is composed of various rocks of continental origin, including claystone, sandstone, limestone, siltstone, and conglomerate. It extends over most of the Colorado Plateau province, where it varies in thickness from 200 ft to 1700 ft (typical depth of 1000 ft). It is not uncommon to see the exposed layers of this formation where erosional processes are significant. The mixtures of the depositional conglomerate lead to many colors (blue, gray, red, yellow, white, green) which give the painted desert its name.

The Chinle Formation rests uncomfortably on the underlying strata, where in most of the Colorado Plateau it overlies the Moenkopi Formation of the Early and Middle Triassic age. It is divided into a lower (bentonitic) part and an upper (red-beds) part. The lower part of the Chinle Formation is considered to be a continental deposit laid down in streams and lakes and on flood plains (this interpretation os based predominantly on the types of sedimentary structures and fossils). The upper part is likely a lake bed deposit, due to the grain size and composition of the depositional features. Fossils in these regions are much scarcer, but contact between the two units is gradational and difficult to find in some areas.

35

(1*) GEOLOGY OF ARIZONA (NATIONS)

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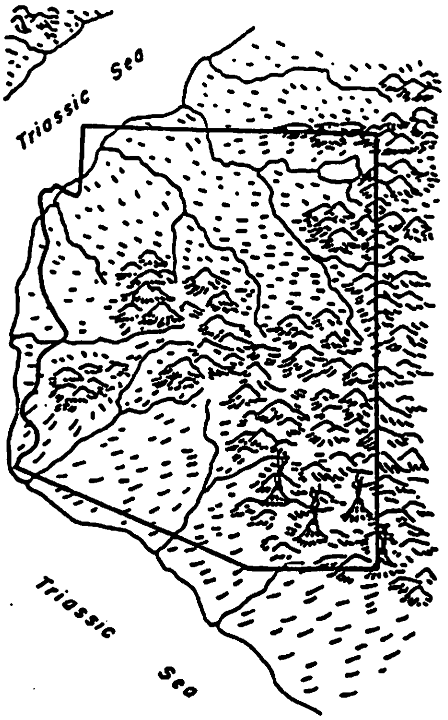


Figure 11-1. Paleogeographic map of Arizona during Triassic time. Reproduced from Wilson, 1962. A résumé of the geology of Arizona; Arizona Bureau of Mines, Bulletin 171.

Origins of the Chinle:

The Triassic period (230 - 180 M.Y. ago) was a time of general emergence above sea level, following the late Permian withdrawal of the middle Permian shallow seas that covered most of Arizona. As high mountain ranges rose in central Arizona, all of central and southern Arizona was uplifted (Mogollon Highland) and deeply eroded with erosional debris spread northward in early Triassic times by sluggish streams to be deposited as mud and sand on the low costal plain of a shallow sea that extended northward and westward into Utah and Nevada. Occasional volcanoes deposited fine volcanic ash into these flow features which mixed with the other debris and clay. Stream directions, as indicated by the orientation of the cross strata, were mostly N-NE, indicating a source area to the south of the Colorado plateau. This source, the Mogollon highland, was predominantly a volcanic terrain, as indicated by the abundance of volcanic debris in the lower Chinle. Fossil-bearing pebbles in conglomerate layers in the lower Chinle, on the other hand, indicate that some sedimentary rocks were exposed as well in the source region. Fallen trees were often caught up in this flow and eventually silicified, forming the "petrified trees" we see today (see Steffi's talk).

By late Triassic time the elevation of Mogollon Highland had increased enough that the slope gradient among the northward flowing rivers was allowing transportation of coarser sediments, such as sand and gravel, over the coastal plain. These gravels were spread uniformly and are now referred to the Shinarump Conglomerate. The widespread sandstone and conglomerate units of this feature are probably point-bar deposits produced by the lateral migration of meandering streams. Following this deposition, the Mogollon Highlands were evidently reduced in elevation, since the following deposition sediments were much finer in grain size. This material (volcanic ash, sand and clay) was spread over most of

2*

3

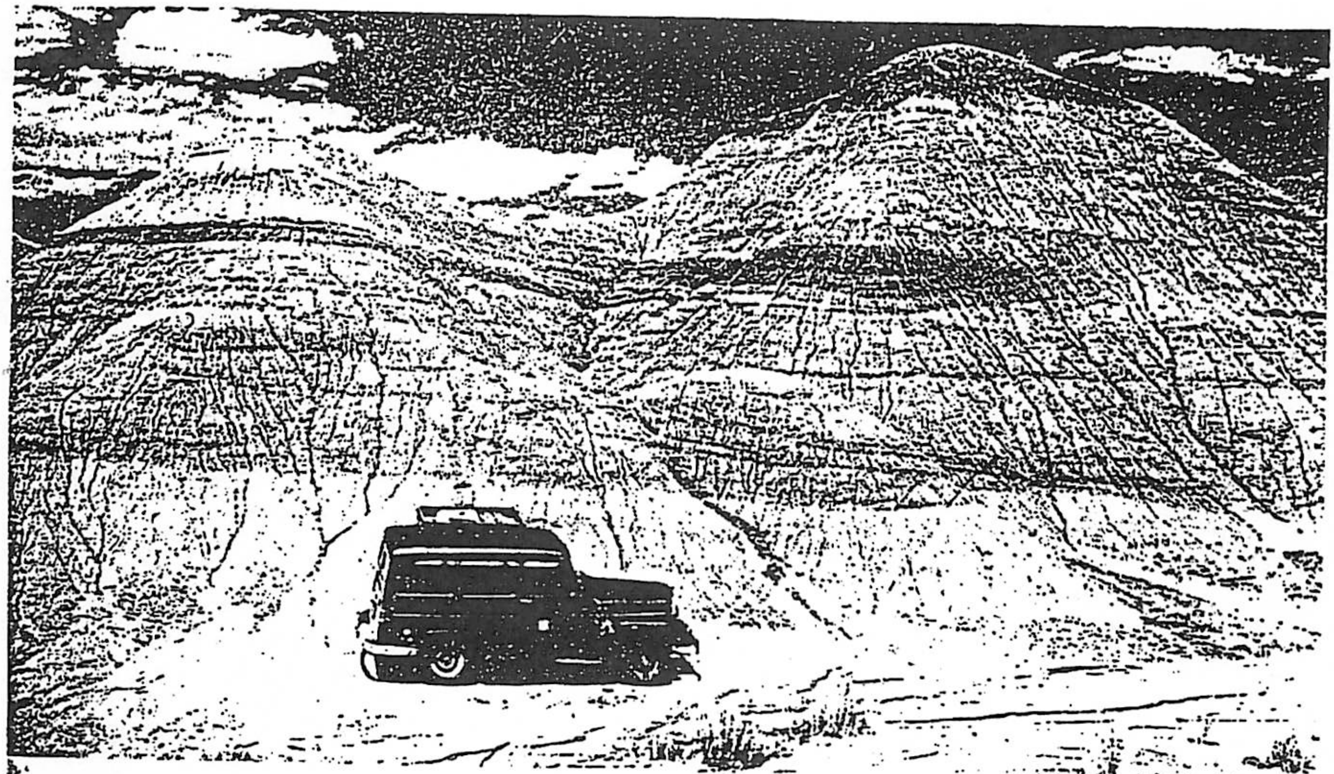


FIGURE 19.—Shallow trough sets of low-angle cross-strata in Petrified Forest Member of Chinle Formation near Cameron, Ariz.

The Lower Chinle; Composition and Characteristics:

The lower part of the Chinle formation is mainly composed of variegated bentonitic claystone (a reddish clay formed from volcanic ash), clayey sandstone, and thin widespread units and sandstone and conglomerate. Easily erodible, bentonite also swells up when its wet and shrinks when its dry, making life difficult for new plant growth as well as allowing the Chinle to form very distinctive landforms. It contains an abundant amount of fossil flora and fauna, attesting to the early violence surrounding the production of the volcanic sediments.

The Petrified Forest Member is the thickest and most wide-spread member of the lower Chinle Formation. Present throughout lower the southern part of the Colorado Plateau, it is generally 1000 ft thick and composed of brightly colored horizontally stratified claystone and clayey siltstone as well as cross-stratified clayey sandstone. These rocks contain montmorillonitic clay probably derived from the alteration of volcanic glass, and sand-sized material composed of volcanic debris. In some areas the member contains units of cross-stratified ledge-forming sandstone and conglomerate (i.e. the most conspicuous being the Sonsela Sandstone Bed, which covers a large part of NE Arizona and NW New Mexico).

④

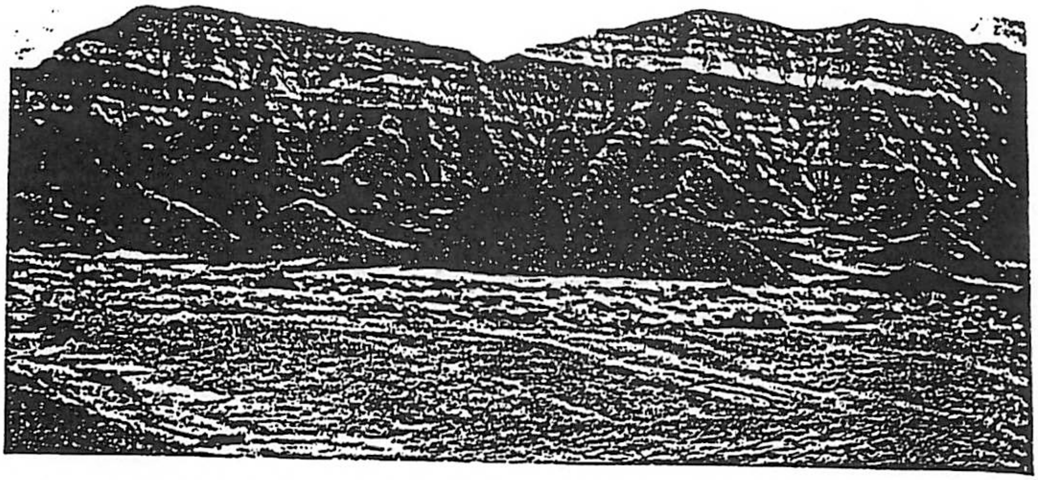


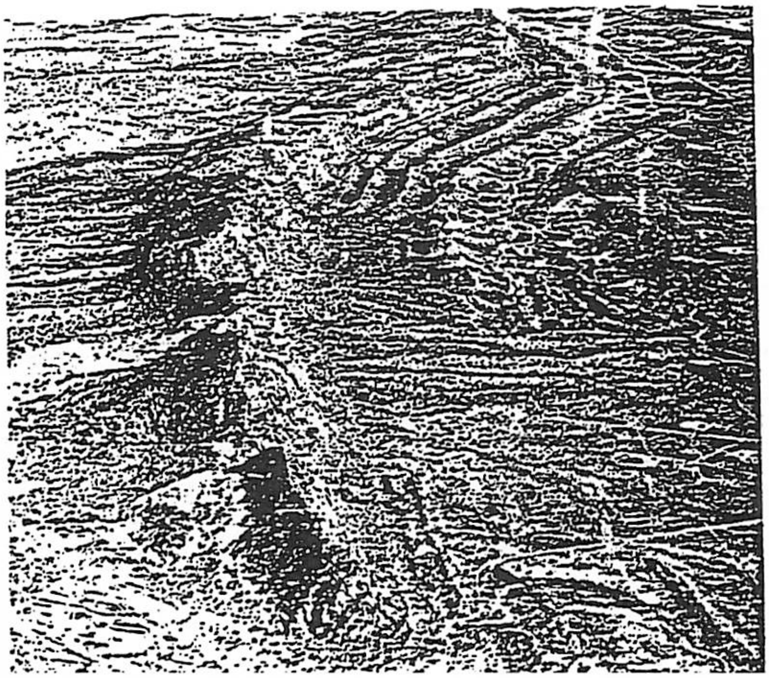
Figure 11–4. Owl Rock Member of the Chinle Formation, north of Cameron.

The Upper Chinle; Composition and Characteristics:

The upper part of the Chinle consists of reddish horizontally bedded or structureless siltstone and generally minor amounts of sandstone, limestone, and siltstone. Fossils in these regions are much scarcer, but contact between the lower and upper Chinle units is gradational and difficult to find in some areas.

The upper part of the Chinle Formation may be mostly a lake deposit, as indicated by the fine texture and even bedding of the strata and by the type of fossils. Cross stratified sandstone layers, interpreted as stream deposits, are abundant locally and are most abundant in a narrow belt extending from SW Colorado to Central Utah. This belt of sandstone is considered to mark the location of a major river system. Highlands in W. Colorado and the Mogollon Highland in S. Arizona are considered to be the major source areas during deposition of the upper part of the Chinle Formation. Granitic and metamorphic rocks and some sedimentary rocks were exposed in the W. Colorado highlands, but rocks exposed in the Mogollon Highland were mainly volcanic.

(1*)



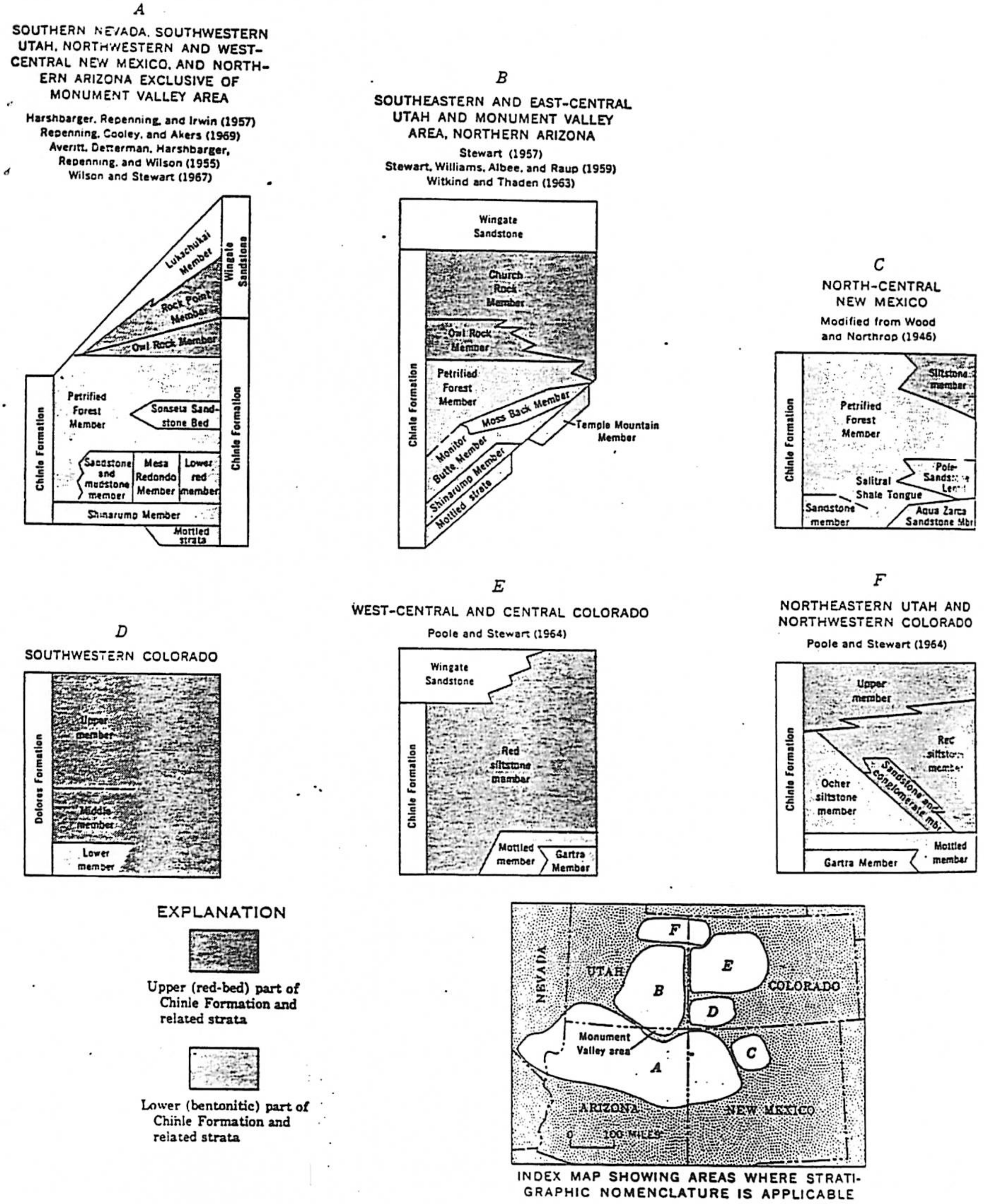


FIGURE 1. — Nomenclature of the Chinle Formation and related strata in the Colorado Plateau region.

39

Z* USGS PROFESSIONAL PAPER 557.3 GS4, NO. 690 (1972)

(2*)

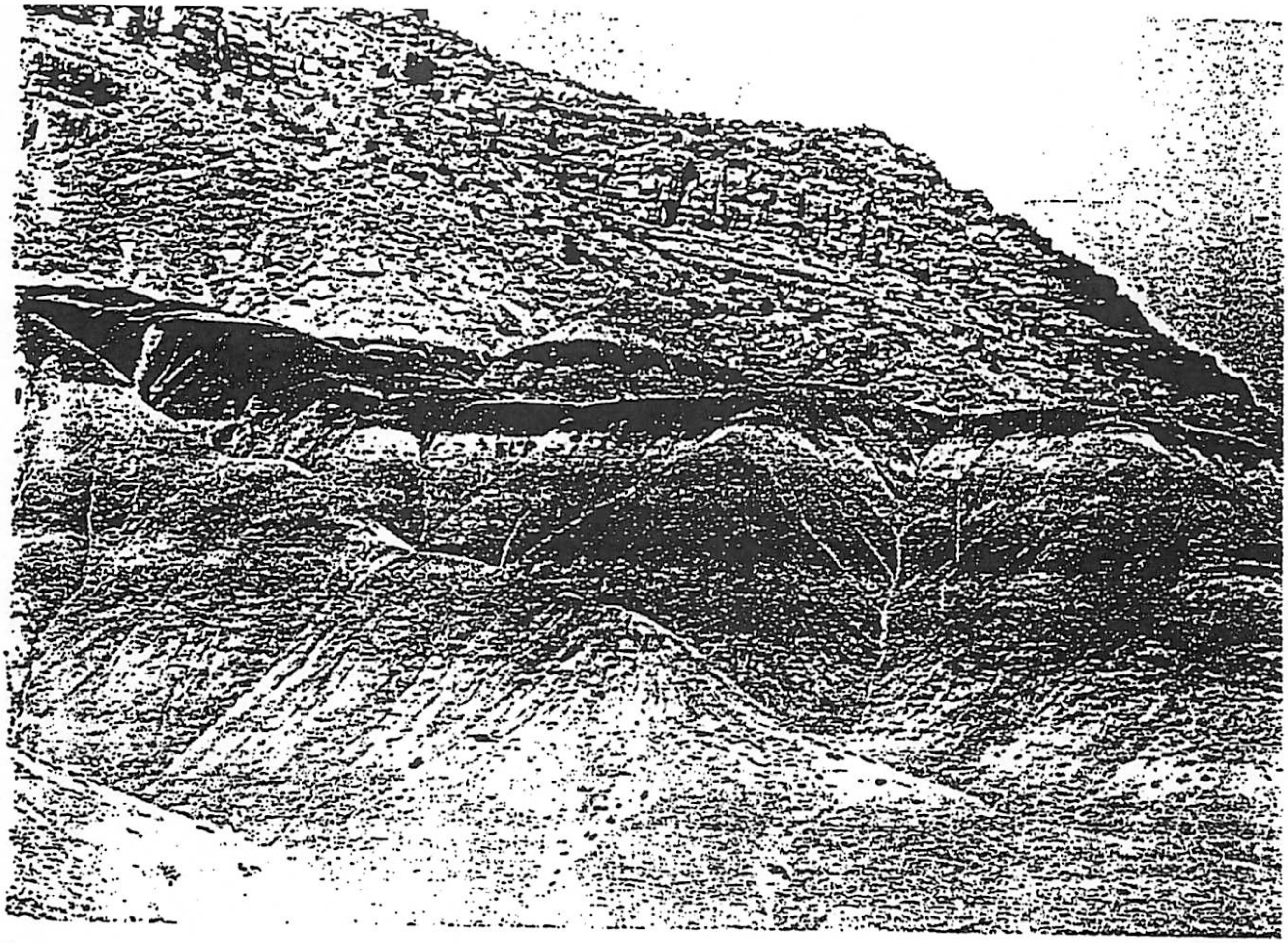


FIGURE 17. — Horizontally stratified claystone in Petrified Forest Member of Chinle Formation near abandoned town of Paria, Utah. Cliffs in background are in units of the Glen Canyon Group.

(1*)

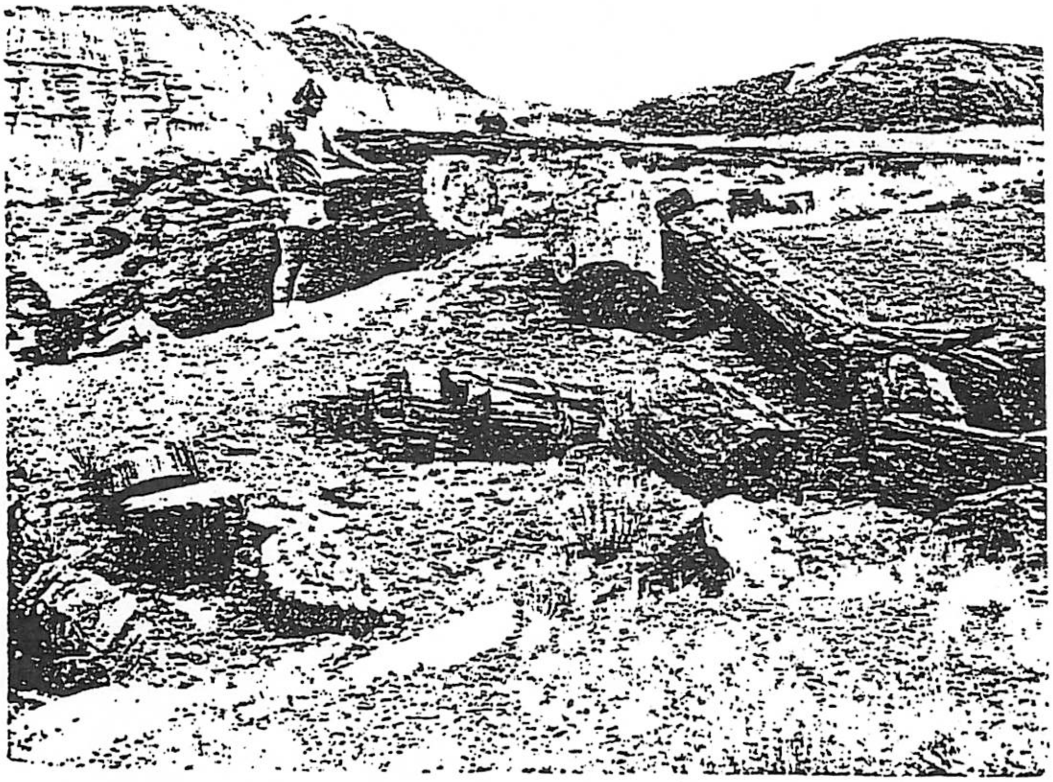
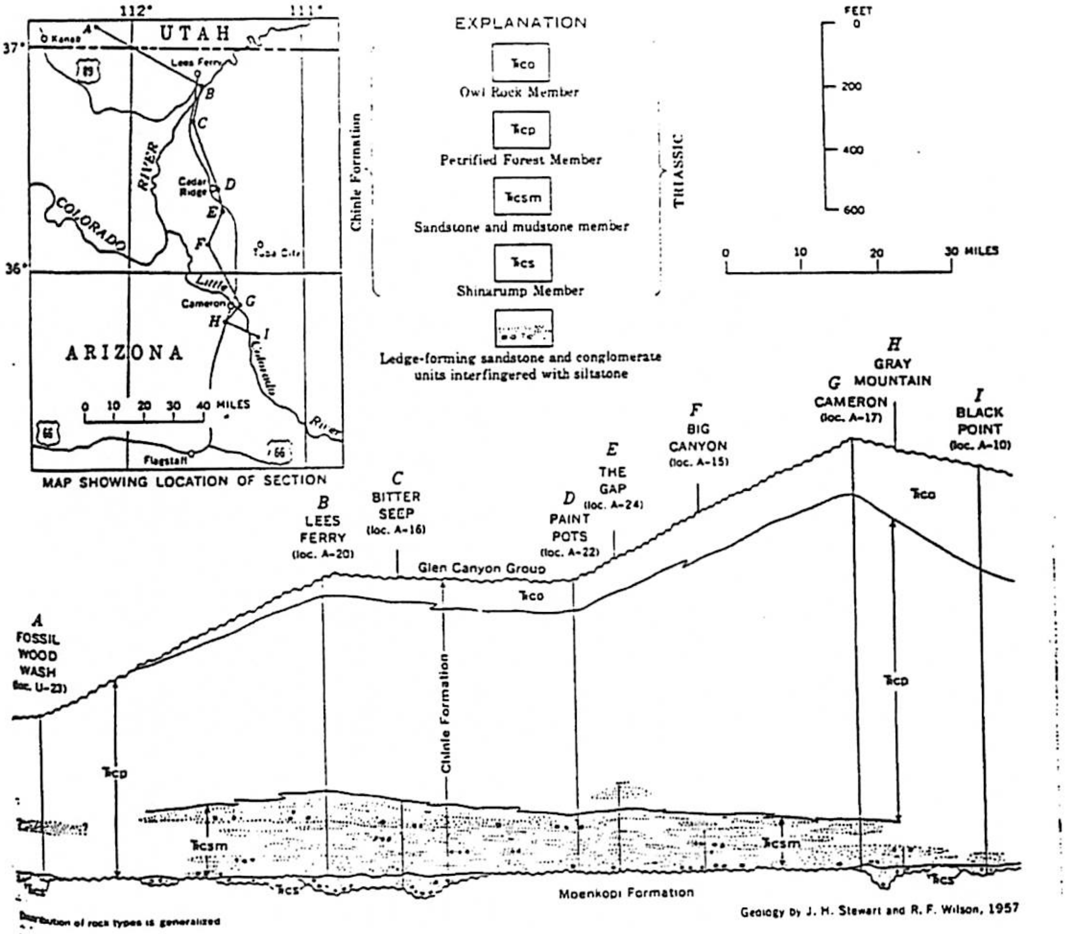


Figure 11–3. Petrified logs of *Araucarioxylon* in the Chinle Formation at Petrified Forest National

(Z*

(1



Distribution of rock types is generalized

Geology by J. H. Stewart and R. F. Wilson, 1957

FIGURE 12. — Correlation of Chinle Formation in north-central Arizona and south-central Utah.

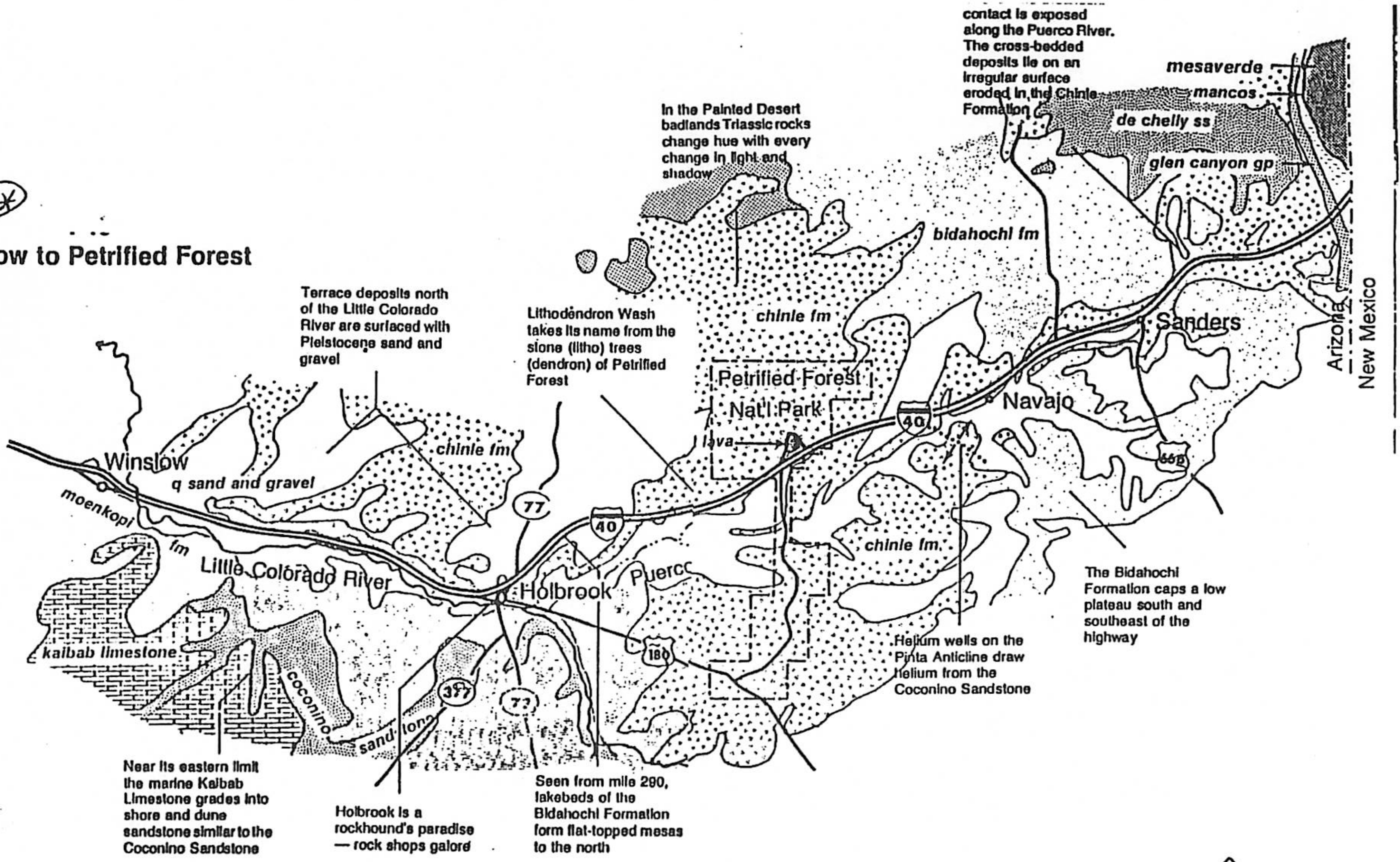
(Z*)

FIGURE 18. — Frothy weathering surface developed on claystone in Petrified Forest Member of Chinle Formation near Joseph City, Ariz.

41

3*

inslow to Petrified Forest



I-40
Petrified Forest to New Mexico

ROADSIDE GEOLOGY OF ARIZONA (CHRONIC), 1983

(8)

Planetary Field Geology Handout G.Komatsu

Formation Process of Sapping Valleys

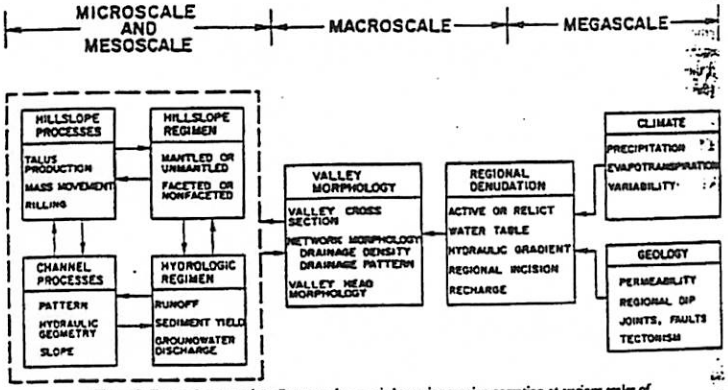


Figure 2. Factors important in valley morphogenesis by spring sapping operating at various scales of geomorphic concern. Feedback relations are indicated by arrows pointing in opposing directions. Local processes involving hillslopes and adjacent channels constitute an especially complex interrelated system (dashed lines).

Baker et al., 1990

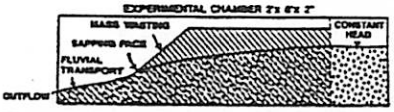
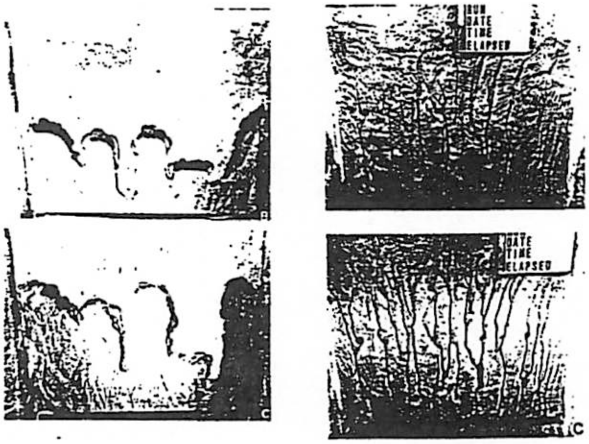


Figure 10. Longitudinal section of a two-dimensional experimental seepage chamber. Ruled lines indicate sand, circles show saturated zone. (Kochel and others, 1985.)



Howard, 1987

T. Dunne

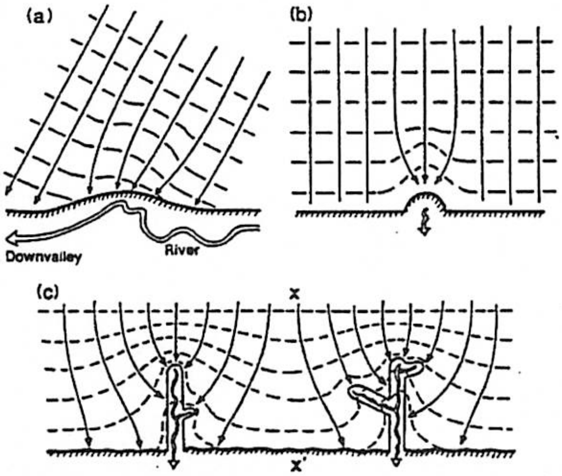
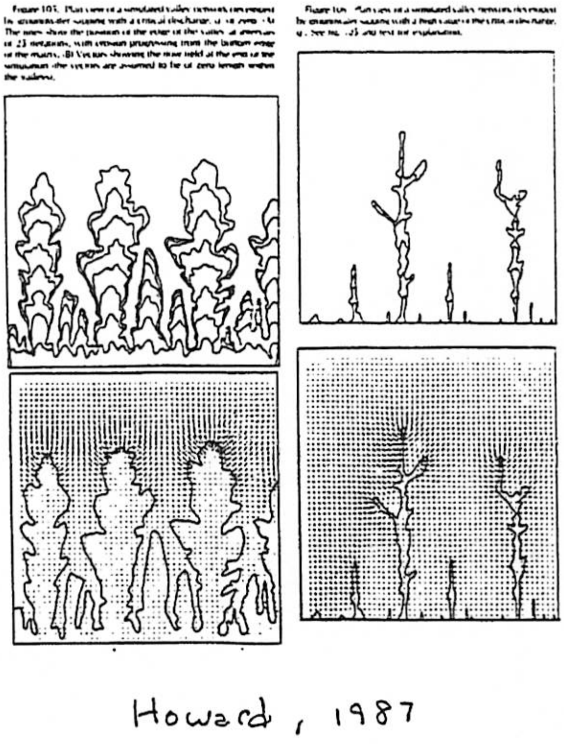


Figure 11. Plan view of the perturbations of a groundwater flow net that lead to the extension of spring heads to form a drainage network. Solid arrows are flow lines, dashes indicate equipotentials. (a) Concentration of flow at a boundary perturbed by an outside agent. (b) Concentration of flow caused by a small seepage failure localized by a lithological heterogeneity. (c) Increased convergence of flow lines around neighboring spring heads that have retreated into a land mass. Tributary valleys form as a result of secondary perturbations of the flow field due to the same geometric or hydrogeologic factors. Convergence on the spring heads leads to divergence of flow between the valleys (After Dunne, 1980.)

Dunne, 1990



Howard, 1987

Comparison, Mars and Venus

Marsian Valley Networks

1) Geologic settings

  a. cratered highland (Noachean, 3.8 - 3.9 billion years)

2) Morphology, particularly for the longitudinal valleys (Pieri, 1980, Baker, 1982)

  a. theater-shaped valley headwalls
  b. strong structural control of valley alignment and planform
  c. hanging tributary valleys
  d. long main valleys with short, stubby tributaries
  e. irregular angles of channel junction
  d. valley widths that remain nearly constant in a downstream direction

3) Origin

  a. surface runoff, particularly for the dendritic valley networks (Milton, 1973, Sagan et al., 1973)
  b. sapping (Pieri, 1980, Baker, 1982)
  c. valley glacier (Lucchitta et al., 1981, Lucchitta, 1982)

4) Implication

  a. warm, wet climate (Pollack, 1979)
  b. hydrothermal circulation (Brakenridge et al., 1985, Gulick and Baker, 1989)

Venusian Valley Networks

1) Geologic settings

  a. highland regions
  b. coronae
  c. novae

2) Morphology (Gulick et al., 1992)

  a. rectangular
  b. labyrinthic
  c. pitted or irregular

3) Origin

  a. lava sapping (Komatsu et al., 1992)

4) Implication

  a. gradual thermal erosion
  b. exotic low viscosity lavas (sulfur, carbonatite)

Sapping Features: Morphology

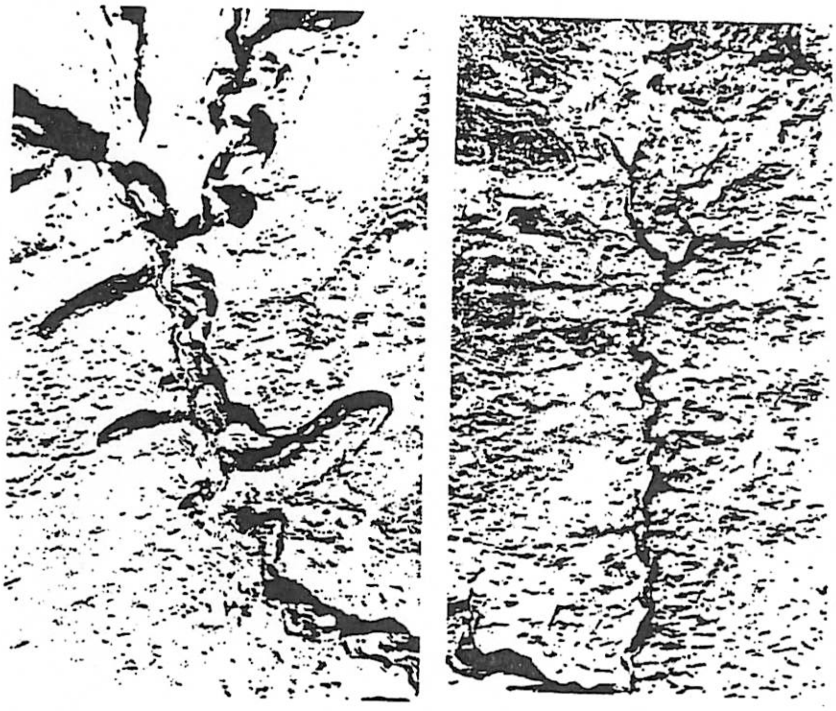
(V. Hillgren)

General Features:

1) Valleys have "theater" heads
2) Steep head walls
3) Constant valley width
4) Short tributaries
5) Size and orientation controlled by structure

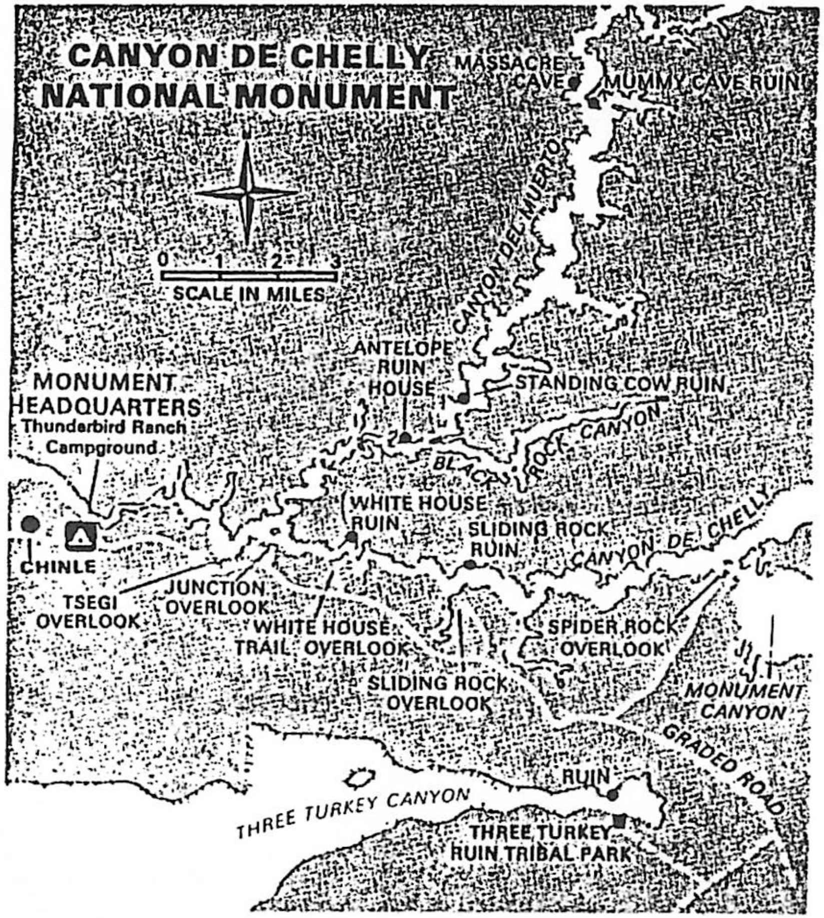
Why the Colorado Plateau?

On the Colorado Plateau there are abundant sandstones with high porosity, permeability, and weak cement. In other words, groundwater flows easily through these units.



Sapping vs. nonsapping origin
(Laity & Malin '85)

Ius Chasma, Mars
sapping? What do you think?
(Carr, '89)



Vicinity map of Canyon de Chelly National Monument (N.P.S., 1970).

Erik Asphaug and Andy Rivkin,
your helpful hosts

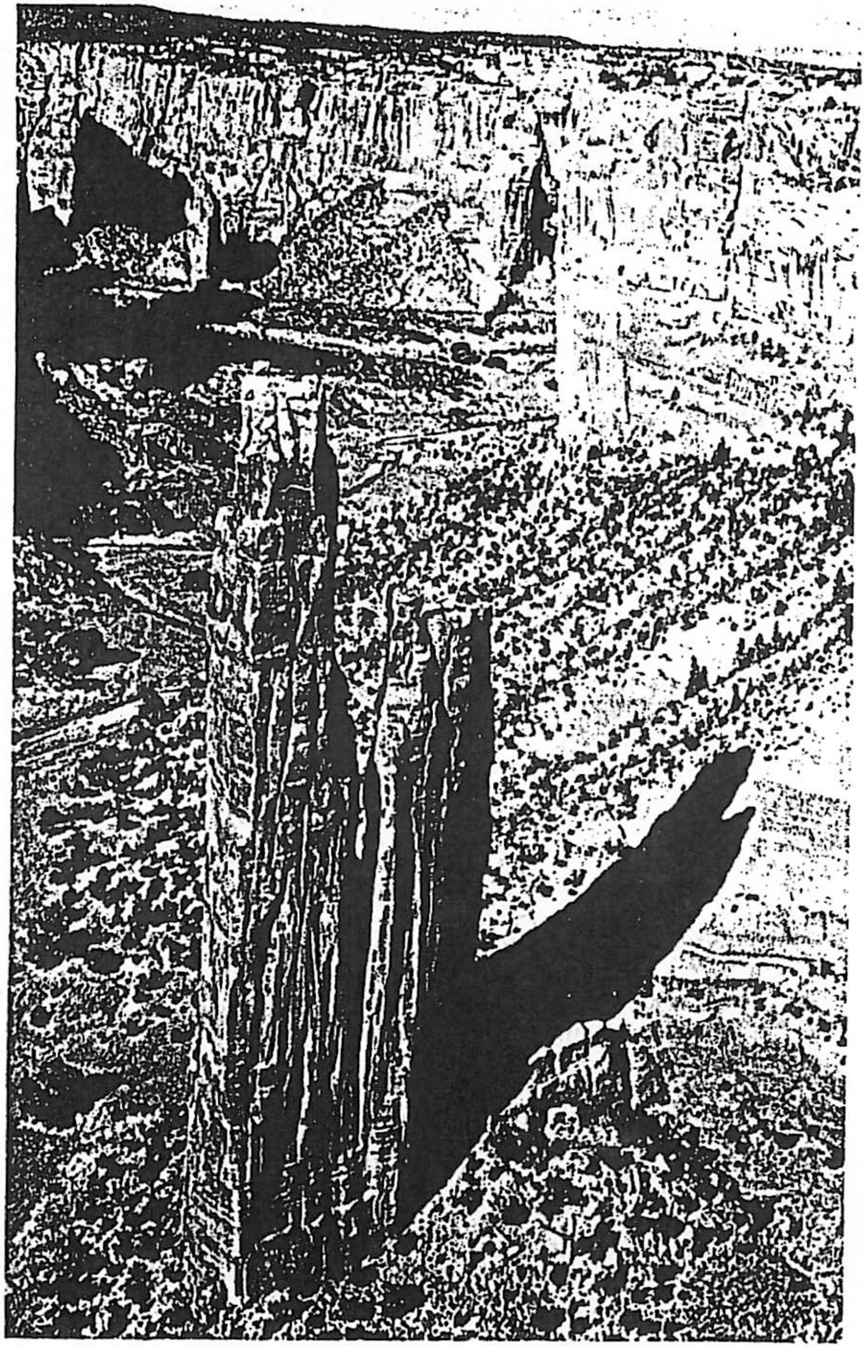


Figure 7. Canyon de Chelly and Spider Rock. Photo: S. Reynolds.

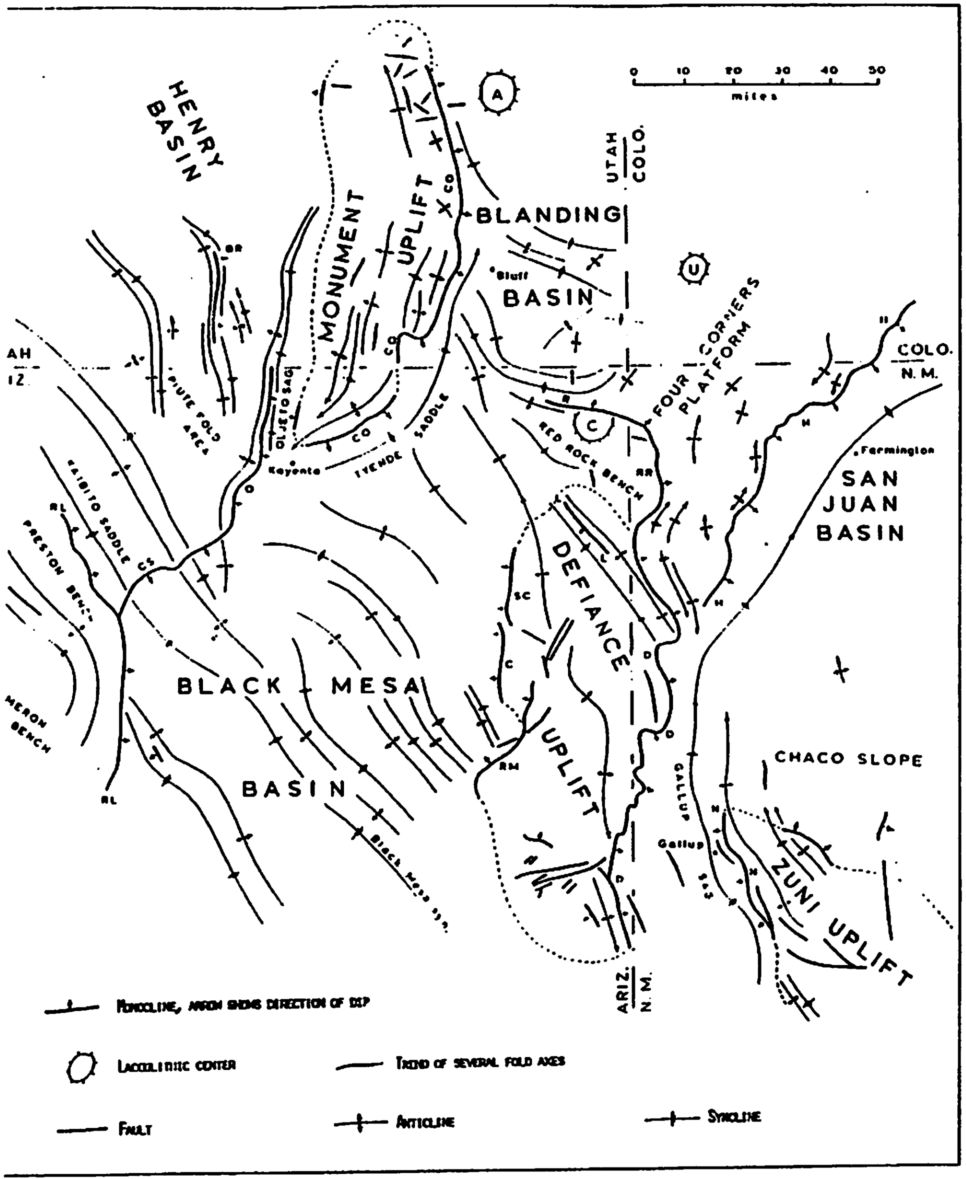


Figure 1.

eneralized tectonic map of Four Corners region of Colorado Plateau (modified from Kelley, 1955b). Abbreviations for clines are: BR, Balanced Rock; C, Chinle; CO, Comb; CS, Cow Springs; D, Defiance; H, Hogback; L, Lukachukai; N, Nutria; rgan Rock; R, Rattlesnake; RL, Red Lake; RM, Rock Mesa; RR, Red Rock; SC, Sheep Creek. Abbreviations for laccolithic ers are: A, Abajo; C, Carrizo; U, Ute. Dashed lines indicate boundaries of uplifts.

DEFIANCE UPLIFT

The Defiance uplift lies along the western part of the region, mostly in Arizona but extending locally a short distance into New Mexico. It is a north-trending uplift about 30 miles wide and 100 miles long. It is asymmetrical on the east as a result of the sharp, sinuous Defiance monocline which determines the eastern boundary. The staggared, broad crestal axes of the uplift have a maximum structural relief of 7,500 feet, some 3,000-6,000 feet of which is on the monocline. The monocline is only 1-2 miles wide between its monoclinal and synclinal bends, and dips along it range from 20°-90°. By contrast dips in the broad crestal area and along the wide, gentle western limb only very locally exceed three degrees.

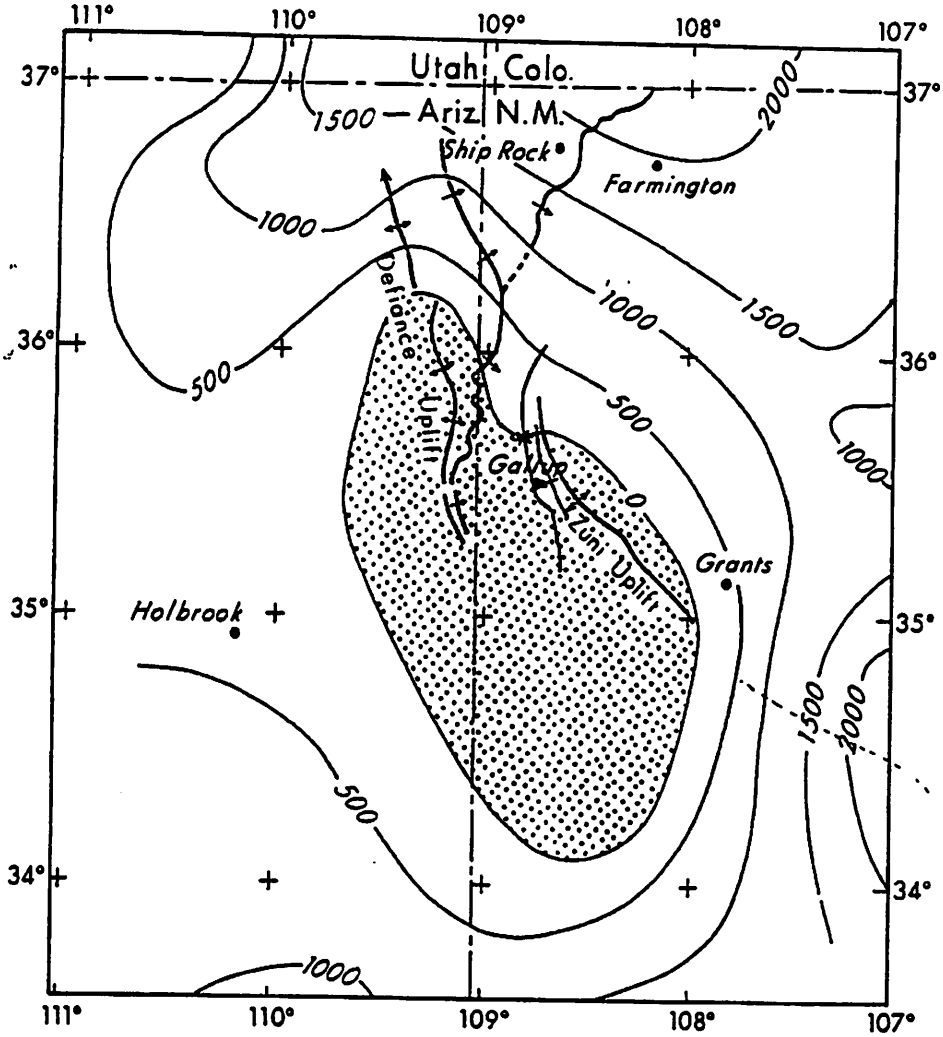
Faults are uncommon and minor, with two notable exceptions: the Tsaile graben and the Wide Ruins fault zone. The Tsaile graben in the northwestern part of the uplift is 1-2 miles wide and 15 miles long. Its northeast-trending normal faults drop Triassic Chinle one or two hundred feet between Shinarump sandstones.

Despite exposures of Precambrian rocks in the Zuni and Defiance uplifts, the deformational history of pre-Paleozoic time as well as the early and middle Paleozoic is poorly or not at all known in the region. Lower Paleozoic beds probably covered all the region only to be stripped by late Devonian time.

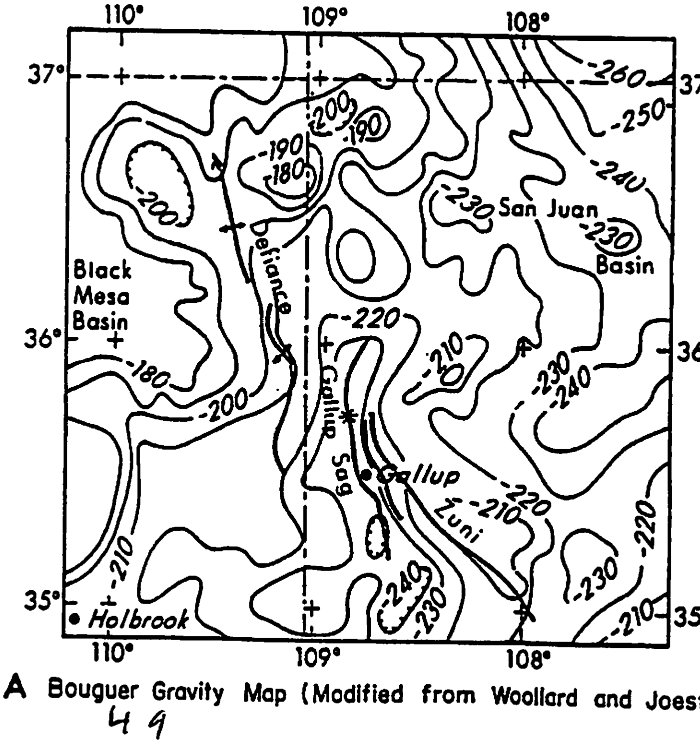
Monoclines and related structures of the Colorado Plateau developed principally during Late Cretaceous to early Tertiary (Laramide) time, whereas epeirogenic uplift of the plateau as a whole probably took place later during Tertiary time. Minor doming related to injection of laccoliths and other intrusions occurred after Laramide time and modified some of the older structures.

A compressional origin for the monoclines has been proposed by Baker (1935) and by Kelley (1955a, 1955b) on the basis of geometry of the monoclines and the regional distribution of thrust faults of similar age in surrounding regions. Earlier workers, however, thought that vertically oriented forces had produced vertical faults in the basement with draping of overlying beds to form the monoclines (Powell, 1873; Dutton, 1880). It seems likely that primary horizontal compression deep within the crust beneath the Colorado Plateau resulted in local secondary stress fields near the surface having strong vertical components, perhaps similar to a mechanism proposed by Thom (1955) for wedge uplifts in the northern Rocky Mountain region. This implies a strong crust that was able to transmit horizontal stresses over long distances without intense deformation.

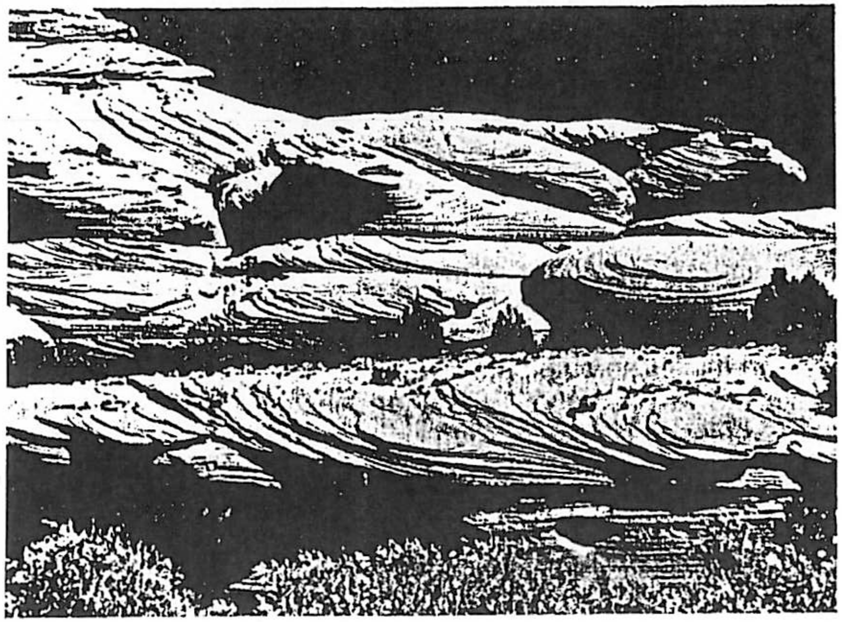
VINCENT C. KELLEY , N.MGS 1967



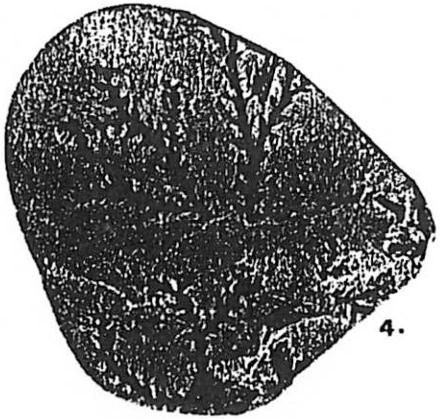
B Pennsylvania isopach and the Zuni-Defiance positive



A Bouguer Gravity Map (Modified from Woollard and Joesting, 1964)

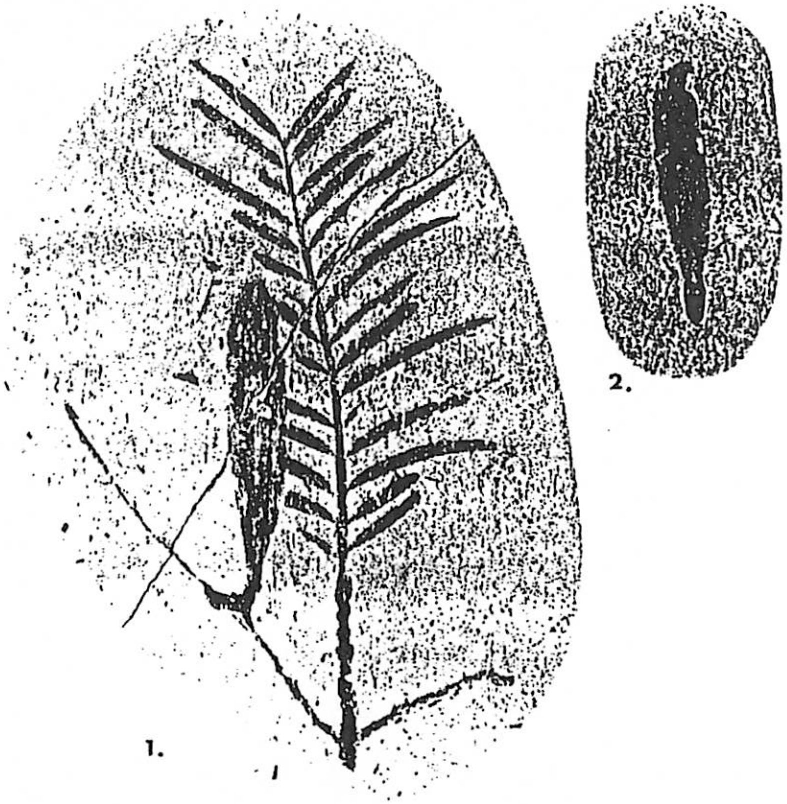


re 8. Cross-beds in De Chelly Sandstone, Canyon de Chelly. Photo: S. olds.



4.

In Canyon de Chelly, there are only three geological units visible, only two of which are encountered along the White House Trail. These units are the *Shinarump* Conglomerate, which is part of the *Chinle* Formation, the *de Chelly* Sandstone, which has its type section here in the canyon, and the *Supai* Formation, which is more sedimentary units. The latter is hidden from view even at the bottom of the trail.



1.

2.

Fossil plants from the Chinle Formation, Canyon de Chelly

DE CHELLY: De Chelly Sandstone is typically divided into a number of members. Three of these members, the White House, Hunter's Point and Oak Springs members are present in Canyon de Chelly. There is some controversy viz. the Oak Springs member, however, as most investigators don't actually consider it as related to the de Chelly formation, but a tongue from a different formation, like the Supai. The de Chelly Sandstone is Permian in age, and composes 240 meters of the 305 m depth of Canyon de Chelly.

The *White House* member is the most recently lain, dating back 260-275 million years to the Leonard Epoch of the Permian Period. Cross-bedding in this member seems to indicate an eolian origin. Paleogeographic studies suggest that this area was covered by sand dunes at the time, with the cross-bedding showing a prevailing north to northeasterly wind. A shallow sea was nearby, as the figure shows.

Going a little further back in time, we come to the *Oak Springs* member. As mentioned before, this seems to be a tongue of adjacent redbed units, perhaps the Supai. This unit and all further units are not visible from the White House Trail.

The Hunter's Point member shows evidence of an aqueous depositional environment: ripple lamination, even bedding and fine sand-sized grains. All these seem to indicate a medium-to-low energy area, such as a broad shelf. The aforementioned sea is thought to have intruded further in earlier times.

SHINARUMP: This unit is of Upper Triassic age, laid down roughly 210 million years ago. The clasts seem to be Precambrian, eroded from the Mogollon Rim. However, there also appears to be some contribution from eroded de Chelly Sandstone as well. Shinarump Conglomerate is light gray, tan and brown, and coarse grained (obviously)

SUPAI FORMATION: This is dark, poorly resistant and slope forming. It seems to have been deposited in a mudflat with shifting stream courses.

The uplift of the plateau seems to have occurred in the last 10 million years, with the canyon itself only being cut in the last few million.

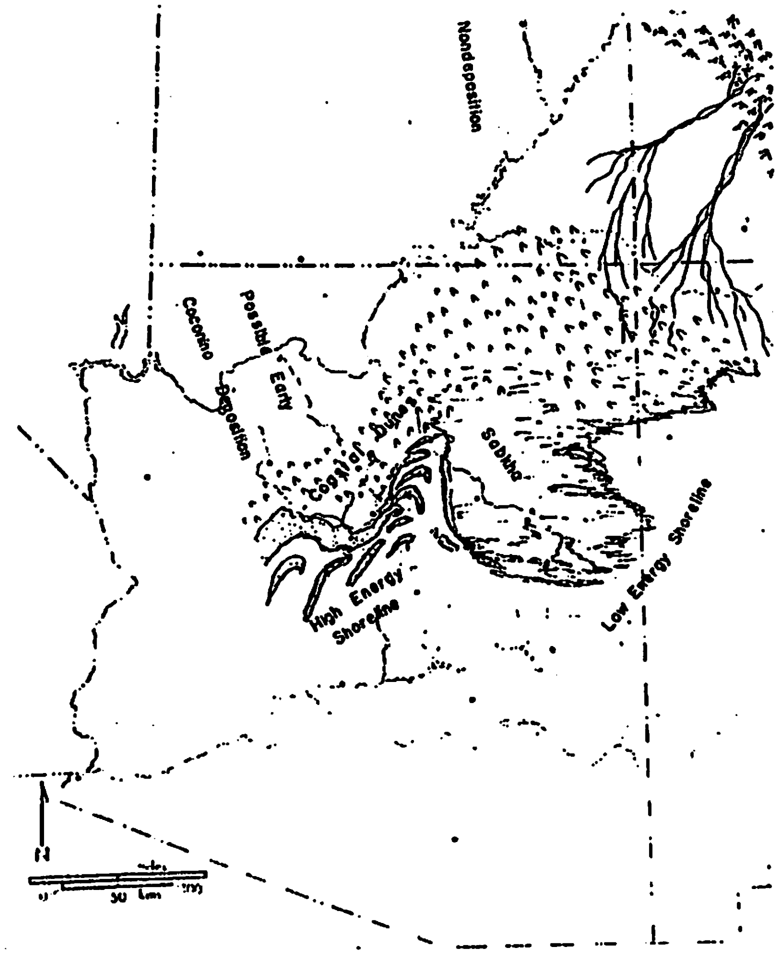
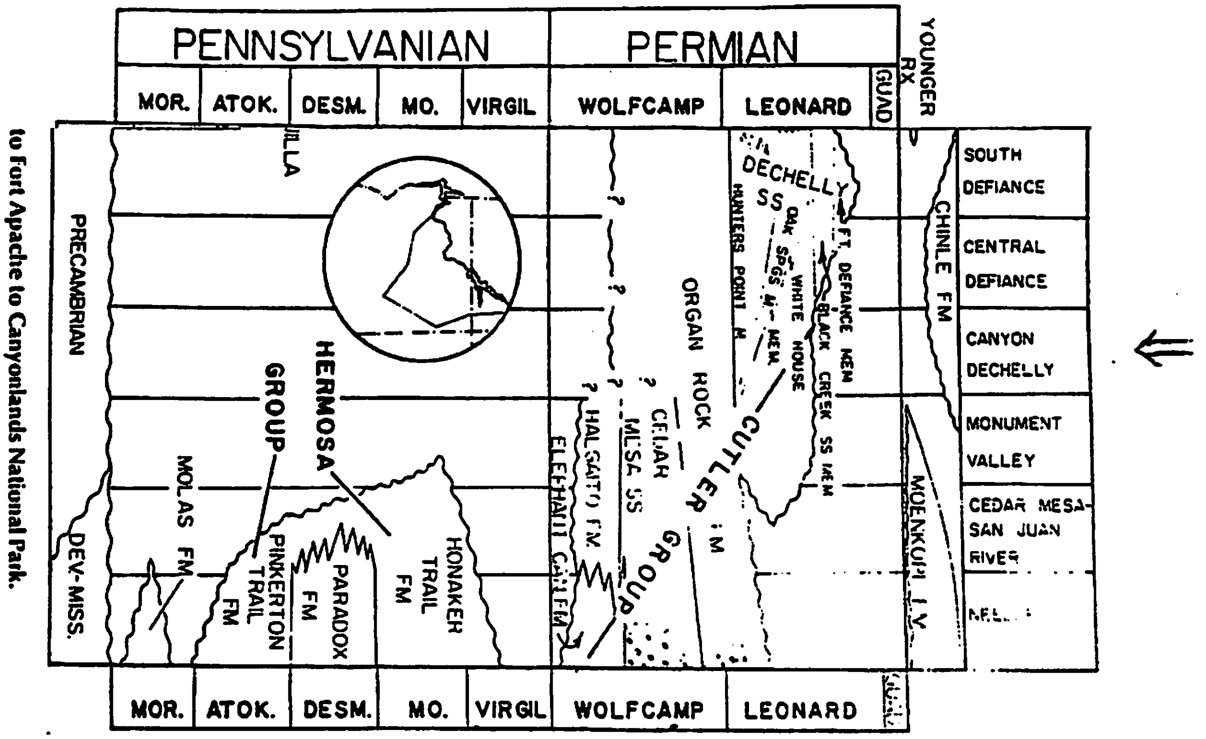


FIGURE 14—Hypothetical paleogeography during the later stages of deposition of the Schnebly Hill formation and DeChelly Sandstone.



SHINARUMP CONGLOMERATE MEMBER (of Chinle Fm.)—U. Triassic

(1) Four Corners region. (2) G. K. Gilbert, 1875, U.S. Geol. and Geog. Surv. W 100th Mer., v. 3, p. 1-187. (3) Shinarump Cliffs, S of Vermilion Cliffs, Kane Co., Utah. (4) Ylw.-wh. to buff cgl., ss., and sh.; mass. gry. x-bed, cgltic ss.; lenses of red-gry. sh. Sil. wood abund. (0-225'). (5) Recog. as basal cgl. mem. of Chinle Fm. Disconf. or unconf. on Moenkopi Fm.; conf. and gradat. with Monitor Butte Mem. of Chinle Fm. Acc. to J. H. Stewart, 1957, A.A.P.G. Bull., v. 41, p. 442-452, in Moab, Utah area, the so-called Shinarump cgl. of Baker (1933) and McKnight (1940) is a strat. higher unit at base of Chinle and is assigned to Church Rock Mem. of Chinle. The Shinarump was long regarded as a fm.

DE CHELLY SANDSTONE MEMBER (of Cutler Fm.) or DE CHELLY SANDSTONE (of Cutler Gr.)—L. Permian (Leonardian)

(1) NE Arizona, SE Utah, NW New Mexico. (2) H. E. Gregory, 1915, A.J.S., 4th, v. 40, p. 102. (3) Canyon de Chelly, Apache Co., Arizona. (4) Mass. x-bed., lt. red, buff, and br. ss. and cgl. (0-1,000'). Pale br.-red, tan, oran., even-gr. cse. x-bed. ss. with a few sh. (300'-800'). (5) Orig. a mem. of the Cutler Fm.; raised to fm. rank by J. A. Momper, 1957, Four Cor. Geol. Soc. 2d Gdbk., p. 90. In Monument Valley, overlies the Organ Rock Tongue; in places overlies Supai Fm.; overlain by Hoskinnini Mem. of Moenkopi Fm. In pt., equiv. to Supai Fm. and Coconino Ss. Prob. equiv. of White Rim Ss. in Utah and of Meseta Blanca Ss. Mem. of Yeso Fm. in New Mexico. In type area, H. W. Peirce, 1964, N.M.G.S. 18th Gdbk., p. 57-62, recog. five mems. (ascend.): Hunters Point, Oak Springs Cliffs, White House, Black Creek, and Fort Defiance (all not present at some locs.).

SUPAI FORMATION (of Aubrey Gr.)—Pennsylvanian-Permian

(1) Four Corners region to E California and SE Nevada. (2) N. H. Darton, 1910, U.S.G.S. Bull. 435, p. 21-25. (3) Supai Village, in Havasu (Cataract) Canyon, N Arizona. Supai is contraction of word "Havasupai". (4) Red ss. and sh., purp. ls. (500'-1,000'; 1,700'-1,800' along Mogollon Rim, Arizona; 3,000'(?) in Confusion Range, Utah). (5) Conf. on Naco Ls. or unconf. on Redwall Ls.; overlain disconf. or gradat. by Hermit Sh. or Rico Mem. of Cutler; or by Kaibab Ls.; or by Coconino Ss. In Grand Canyon area, the Hermit Sh. sep. Supai from Coconino. In Defiance uplift and Toadlena area, Supai interfingers with overly. De Chelly Ss. Equiv. to Cutler Gr., and to Abo and Yeso Fms.

PTYS 597a

PLANETARY FIELD GEOLOGY PRACTICUM

Field Trip 24–26 April 1992

Day 3
Canyon de Chelly to Tucson via Flagstaff

HOPI BUTTES

Ellen Howell

Where they are (1-3)

and

What they are (4)

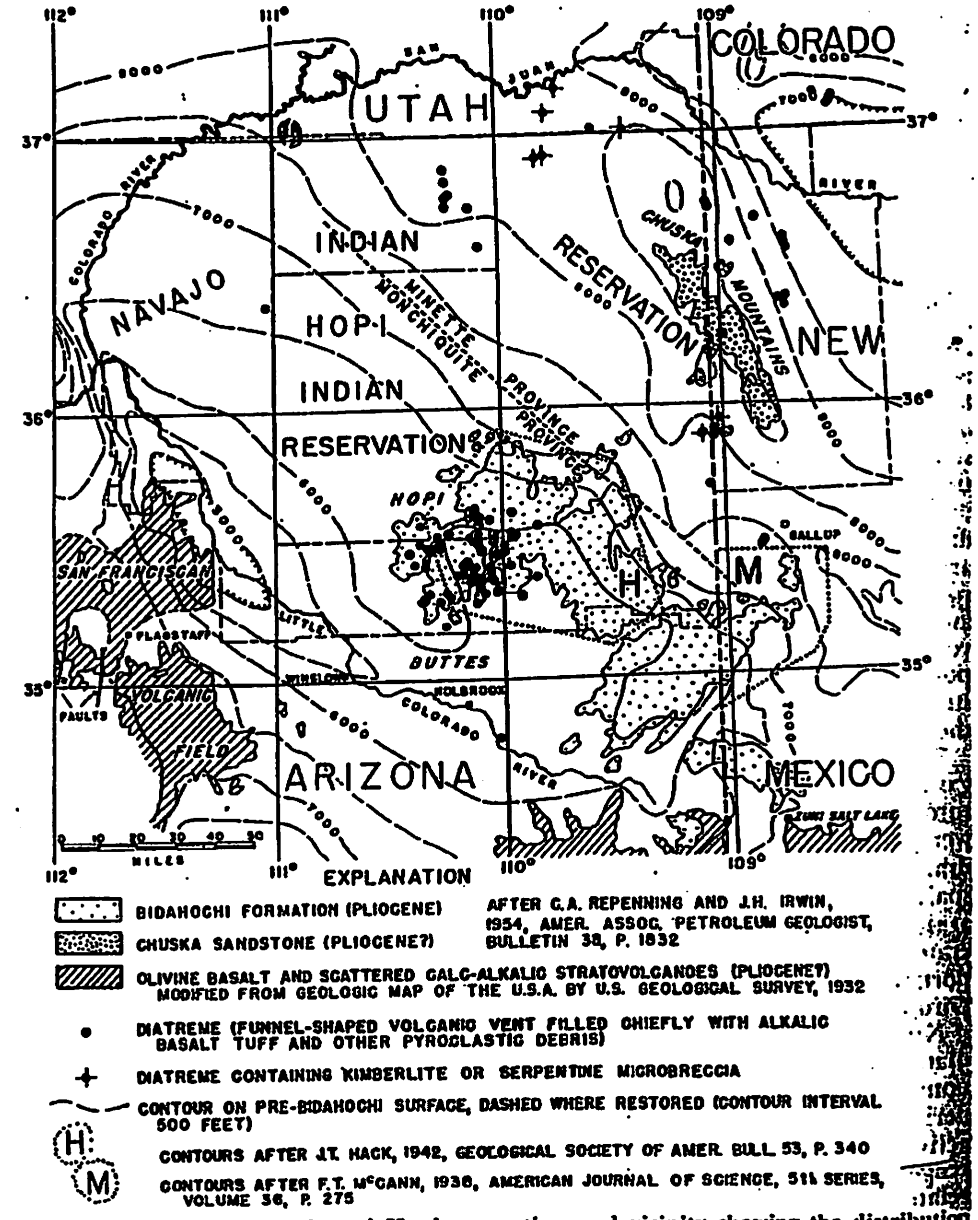


Figure 1. Index map of Navajo and Hopi reservations and vicinity showing the distribution of diatremes, sedimentary and volcanic rocks of Pliocene(?) age, and configuration of the pre-Bidahochi surface

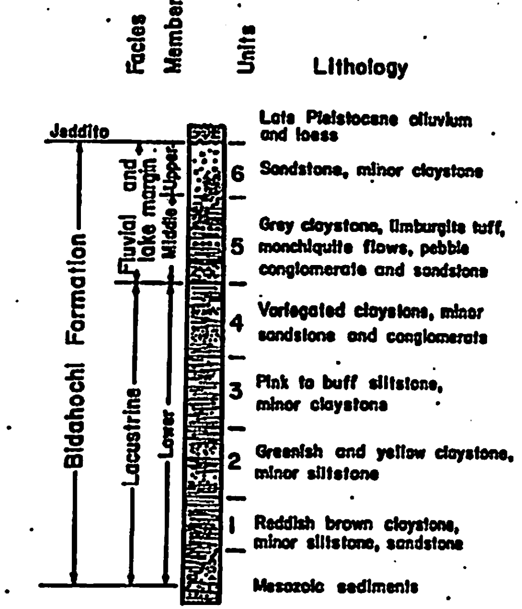


Figure 1. Bidahochi Formation. Subdivision and lithologies after Repenning and Irwin, 1954; and Shoemaker, et al., 1957.

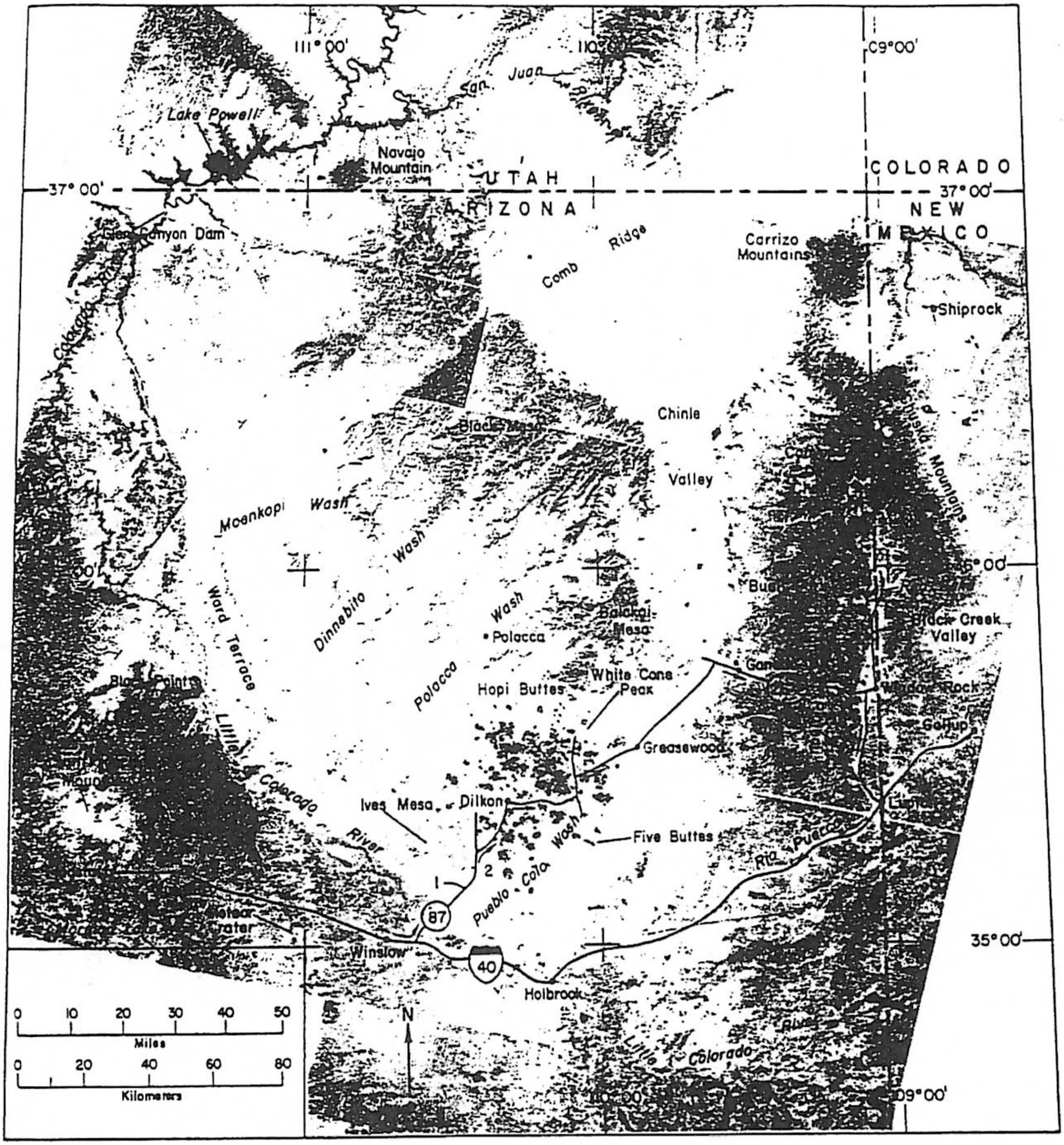


Figure 1b.—ERTS photomosaic of Black Mesa Basin and adjacent areas, northeastern Arizona, showing the route of a 2-day field trip (NASA ERTS E-1103-17323-7, 1318-17265-7, 1318-17271-5, 1319-17321-5, and 1319-17323-7).

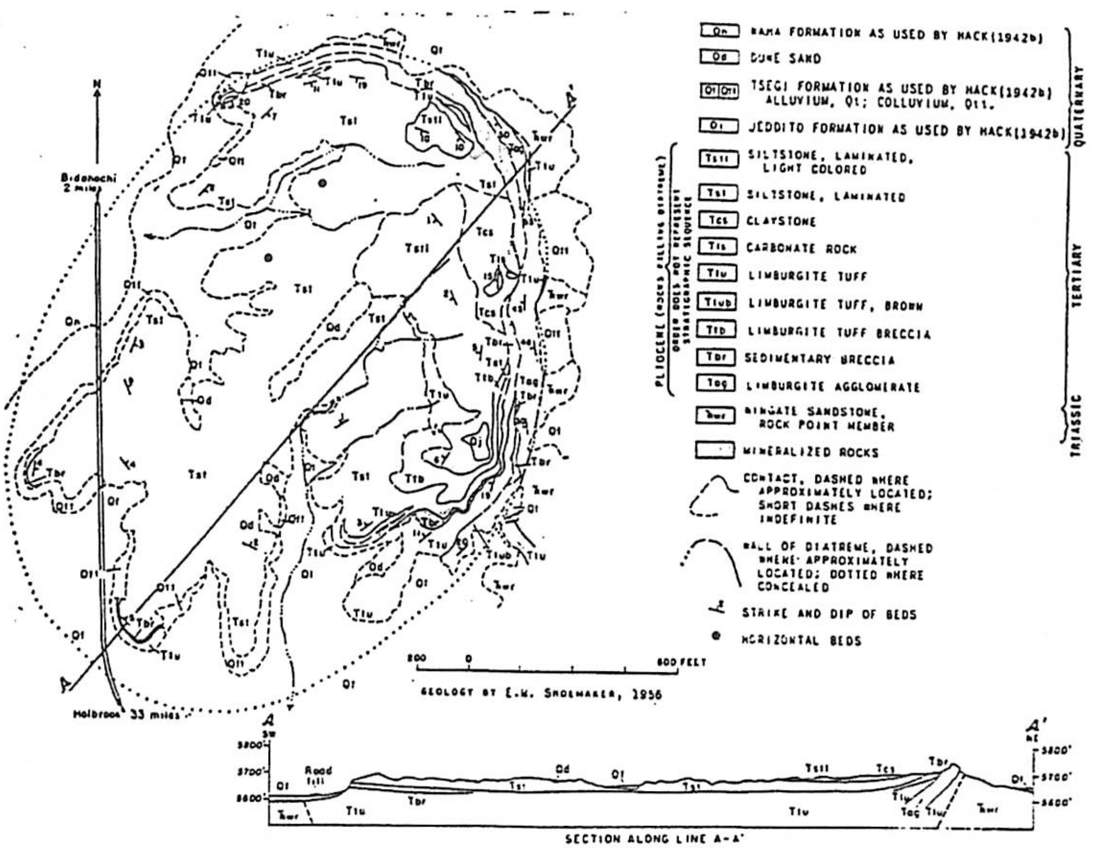


Figure 3. Geologic map and section of the diatreme at the Hoskietso claim showing distribution of mineralized rocks

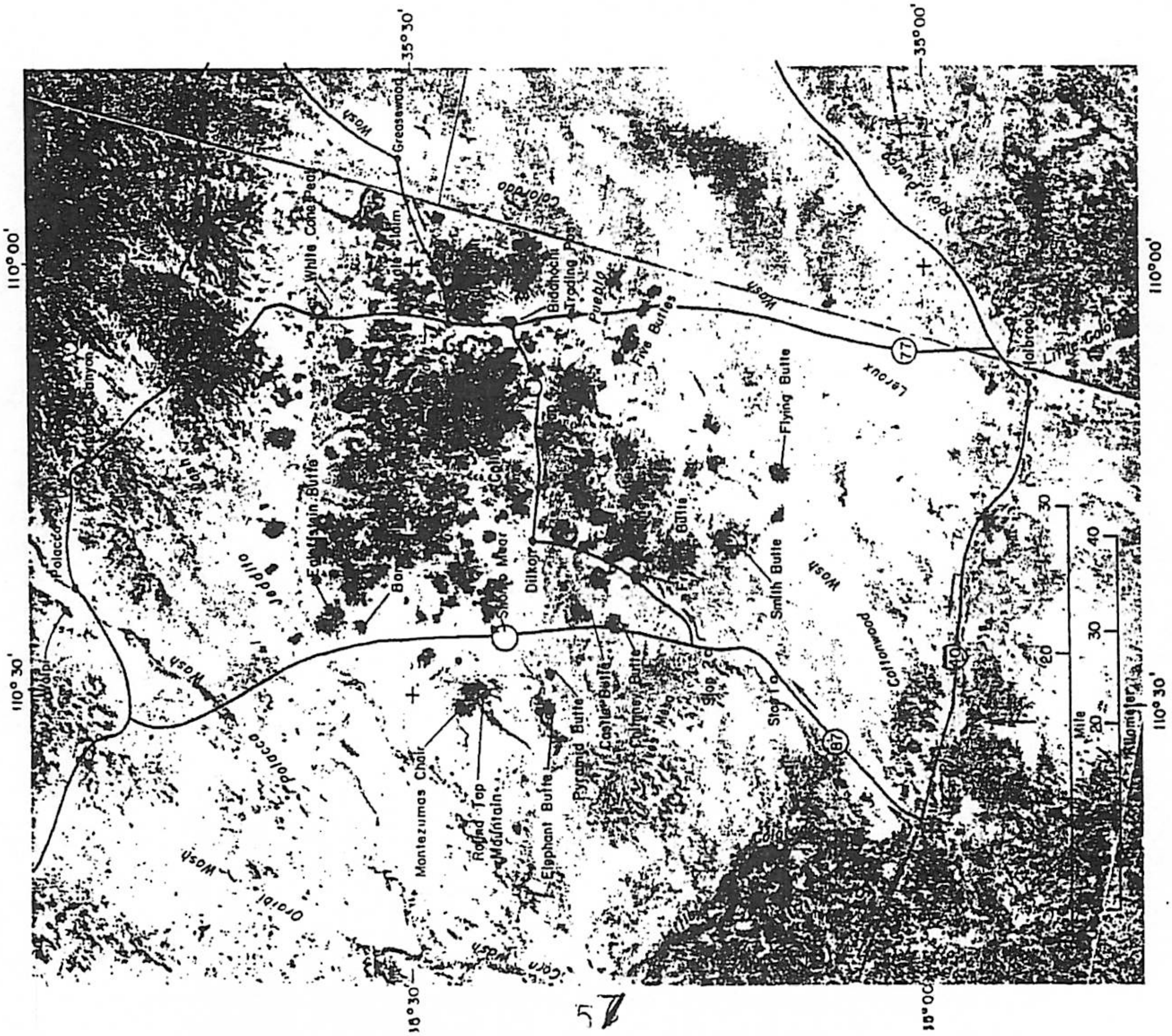
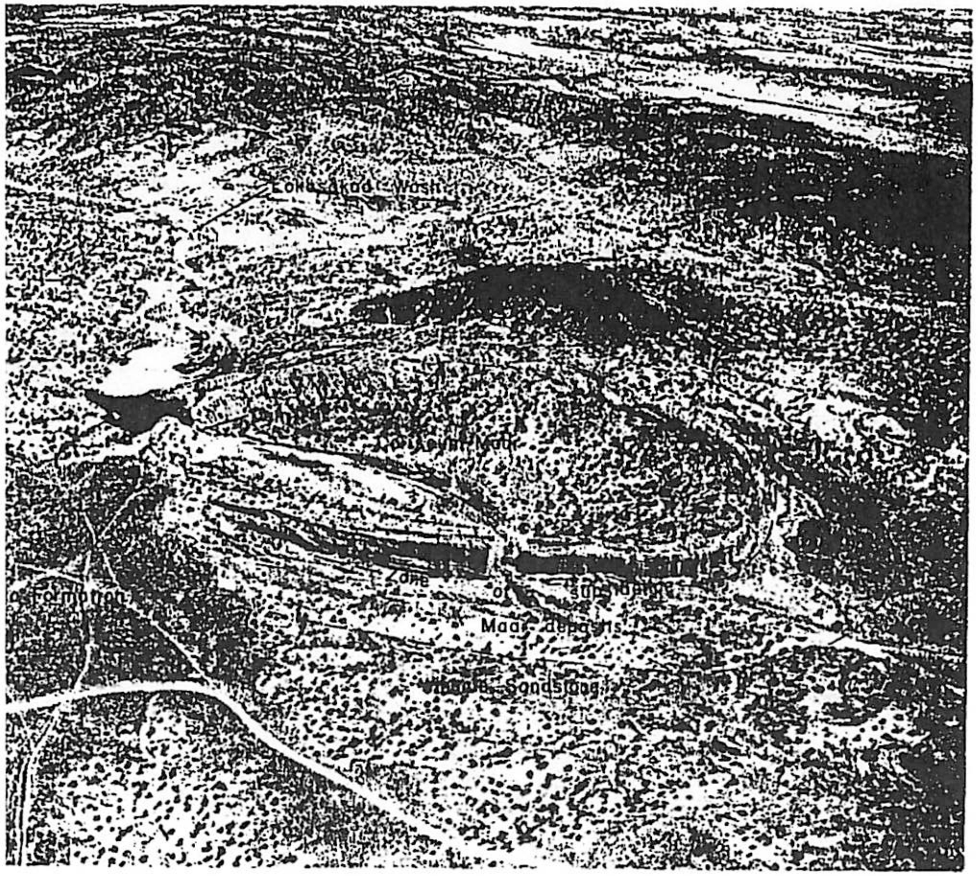


Figure 2.—ERTS photomosaic showing the Hopi Buttes volcanic field, and showing locations of features named in this report.



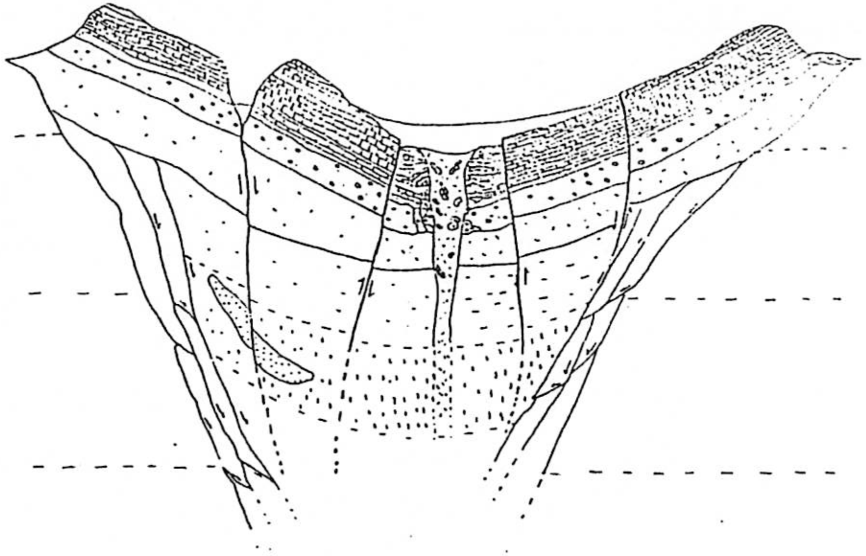


Figure 1. Schematic diagram of a diatreme after the vent has collapsed, been filled with sediments, collapsed again, and undergone erosion. Sediments filling the diatreme consist of fine-grained sandstone and siltstone interbedded with volcanic tuff. Alluvium and soil fill the uppermost portion of the vent. Inner portions of the vent are filled with volcanic tuff, breccias, and agglomerates. A collapse ring, steeply dipping beds, and outwardly dipping faults are produced from collapse of the vent.

—Aerial photograph looking north toward Coliseum maar (stop 4) asahad Wash. Part of the maar is still hidden beneath the Formation. The entire structure may have been buried by m during Jeddito time, as suggested by superposition of the The "coliseum" wall of bedded tuff breccia within the maar s a circular zone of faulting and drag folding caused by ositional subsidence within the crater. Fossil fish and bird have been found in lacustrine sediments of this maar.

K. GAKLOW P. 3 of 3

; Deadman wash.
m.y. (P. E. Damon.

d, silt, and clay with
near Rincon Basin
some interbedded
equivalent to the
and Bowles, 1976)
and others (1974)
avel, and silt on
ulders derived from

dated interbedded
rian rocks as much
Sycamore and Oak

ELD
olivine to hawaiitic
vas and pyroclastic

LOCENE)—Time of
chronologic, and
n commun., 1977)

F SUNSET CRATER
e seen or interpreted

50.000 years old or
rface is rough and

OF MERRIAM AGE
cannot be seen or

IE)—Flow surface is
nmed with spatter.
s (see Qba); locally
00 yrs (Baksi, 1974,

/ is undissected and

CENE)—Andesite of
augite, and olivine in
ypersthene may be

BRUNHES EPOCH
proximately 0.7 m.y.
e and others, 1976)
Normal or reversed
/. old. Includes most
hers. 1976)
OF BRUNHES AGE
t cannot be seen or
1
HIN THE BRUNHES
r pre-Merriam basaltic

BASALTIC TUFF AND TUFF BRECCIA (PLIOCENE)—Deposits of cinders. hydrated basaltic glass. and accessory and accidental xenoliths in Sycamore and Oak Creek Canyon areas. Age is between 4.2 and 4.9 m.y. in Volunteer Canyon (Damon and others, 1974). Locally includes older basalt flows in Sycamore and Oak Creek Canyons

Tbo OLDEST BASALTS OF SAN FRANCISCO VOLCANIC FIELD (PLIOCENE AND MIOCENE)—Informally called rim basalts; in Volunteer Canyon unit includes four flows with K-Ar ages of 3.9 to 9.0 m.y. (Damon and others, 1974)

Td DACITE DOME (PLIOCENE)—Occurs on northeast flank of San Francisco Mountain stratovolcano. Age is 2.78± 0.13 m.y. (Damon and others, 1974)

Tr RHYOLITE DOME OR FLOW (PLIOCENE)—Glassy, aphyric to porphyritic rhyolite. Associated with Sitgreaves Mountain and Kendrick Peak volcanoes and isolated domes between these centers and San Francisco Mountain stratovolcano

RHYOLITE PYROCLASTIC DEPOSITS (PLIOCENE)—Associated with Sitgreaves Mountain; predominantly air-fall deposits

ROCKS OF HOPI BUTTES VOLCANIC FIELD

BIDAHOCHI FORMATION (PLIOCENE AND MIOCENE)

Tbu Upper member—Sandstone, weakly consolidated, mostly fluvial in origin

Tbl Lower member—Calcareous mudstone, siltstone, sandstone, and minor rhyolitic ash. Mostly lacustrine in origin

Volcanic vent deposits—Includes tuff breccia, agglomerate, and lacustrine deposits in maar craters. Lava flows may cover vents and other deposits. Ages range from approximately 8.5 to 4.2 m.y. (P. E. Damon, unpub. data, 1979)

Monchiquite lava flow—Alkalic lamprophyre containing clinopyroxene, olivine, biotite, and analcite. Extends beyond its source, in some cases as much as several kilometers. Ages are 7 to 6 m.y. (P. E. Damon, unpub. data, 1979)

Dike or neck—Monchiquite similar to lava flows (Tbf); commonly includes tuff breccia. Age range is same as for vent deposits (Tbv)

Bedded monchiquite tuff—Mostly lacustrine or air-fall in origin; may extend several kilometers from the eruptive source

SEDIMENTARY ROCKS OF THE COLORADO PLATEAU

Kw WEPO FORMATION OF MESAVERDE GROUP (UPPER CRETACEOUS)—Alternating beds of olive-gray siltstone, coal, and yellowish-gray sandstone. Thickness 0–350 ft (0–107 m)

Kt TOREVA FORMATION OF MESAVERDE GROUP (UPPER CRETACEOUS)

Ktu Upper sandstone member—Yellowish-gray to grayish-orange-pink, fine-grained to very coarse grained sandstone. Thickness 0–80 ft (0–24 m)

Middle carbonaceous mudstone member—Variegated mudstone. Thickness 0–100 ft (0–30 m)

Lower sandstone member—Light-brown to pale-yellowish-gray, fine- to medium-grained sandstone. Thickness 0–120 feet (0–37 m)

Tongue of Toreva Formation—Sandstone. Intertongues with Mancos Shale. Mapped in the Padilla Mesa area. Thickness 0–250 ft (0–76 m)

Km MANCOS SHALE (UPPER CRETACEOUS)—Light- to dark-gray claystone and siltstone. Thickness 160–725 ft (50–220 m)

Upper tongue—Light- to dark-gray claystone and siltstone. Mapped in the Padilla Mesa area. Thickness 0–50 ft (0–15 m)

Kd DAKOTA SANDSTONE (UPPER CRETACEOUS)—Tan, brown, and gray sandstone, conglomeratic sandstone, and conglomerate. Thickness 0–90 ft (0–27 m). Pinches out to southeast

Jcs COW SPRINGS SANDSTONE (MIDDLE JURASSIC)—Greenish-gray to light-yellowish-gray, fine- to medium-grained, cross-stratified sandstone. Thickness 0–285 ft (0–87 m) where exposed; 470 ft (143 m) thick in well at Keams Canyon. Pinches out to southeast

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K. GARLOW
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Rt. 264 to Tuba City

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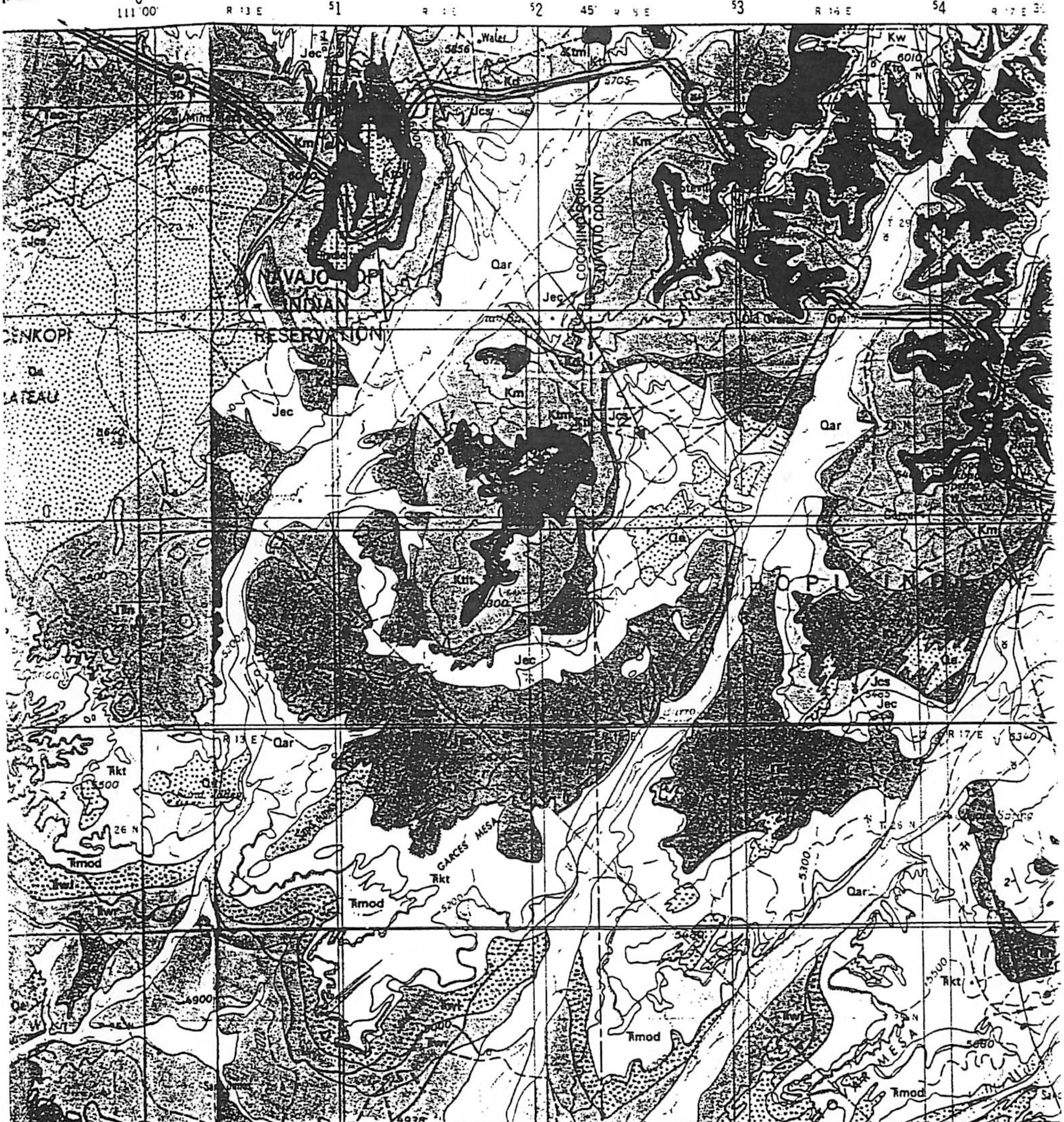

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KEVIN GAKLOW

SR 264

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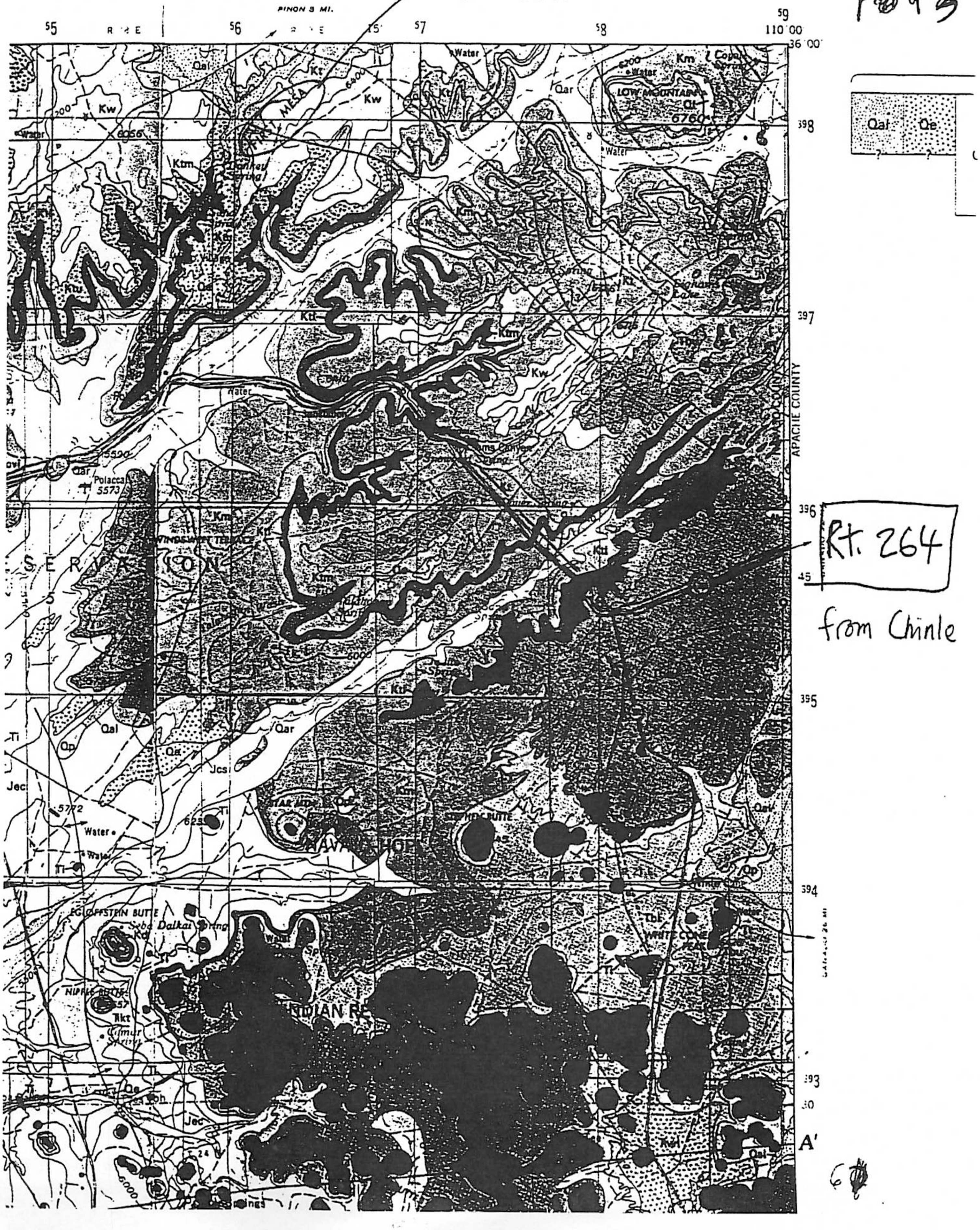
FIRST MESA



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