ARIZONA GEOLOGICAL SOCIETY

CORDILLERAN
SECTION
MEETING

GEOLOGICAL
SOCIETY
OF
AMERICA

GUIDE BOOK FOR FIELD TRIP EXCURSIONS

IN SOUTHERN ARIZONA

APRIL 10-14, 1952
TUCSON, ARIZONA

THIS PAGE

INTENTIONALLY BLANK

ARIZONA
GEOLOGICAL SOCIETY

GUIDE BOOK
FOR
FIELD TRIP EXCURSIONS
IN SOUTHERN ARIZONA

GEOLOGICAL SOCIETY
OF
AMERICA

CORDILLERAN SECTION MEETING

APRIL 10-14, 1952
TUCSON, ARIZONA

WELCOME TO THE UNIVERSITY OF ARIZONA

The University of Arizona extends greetings and a cordial welcome to the members and guests of the Cordilleran Section of the Geological Society of America in its annual meeting on April 11 and 12, 1952, and to the Pacific Coast Branch of the Paleontological Society, the Seismological Society of America, and the Mineralogical Society of America, associated societies meeting on the University campus on these same dates.

The University is pleased to make available its facilities for these meetings. You are invited to visit the various divisions of the University and to become acquainted with the work being done. The College of Mines is outstanding for its instruction, experimentation, and research in geology and mineralogy, and in mining and metallurgical engineering. The college operates in close co-operation with the Arizona Bureau of Mines and the U. S. Bureau of Mines, both of which have offices on the campus, and with the College of Engineering.

Some of you may wish to visit the Arizona State Museum, which contains very outstanding collections of materials, particularly those pertaining to man's habitation of the Southwest through prehistoric time. On the first floor of the University library building is the gallery containing twenty-five outstanding paintings made available to the University by the Kress Foundation of New York City. The Laboratory of Tree Ring Research is located in the west stadium building.

It is my hope that you will have a most pleasant time and a successful series of meetings and field trips.

Richard A. Harvill
President

GREETINGS OF THE ARIZONA GEOLOGICAL SOCIETY

The Arizona Geological Society extends greetings and best wishes to the participants in the field excursions that have been arranged in connection with the meetings of the Cordilleran Section of The Geological Society of America in Tucson, Arizona, April 11 - 12, 1952, The Arizona Geological Society hopes that this brief introduction to some of the geological features of Arizona will result in a better understanding and appreciation of Arizona geology, The Society would like to emphasize that although we do have considerable geological information about certain areas in the State, there are many unsolved problems and many areas in Arizona have been studied only by reconnaissance methods, Perhaps some of the participants in our field trips will return and help us to obtain additional geological information,

President	Vice-President
Charles A, Anderson	E, D, McKee

Secretary-Treasurer
L, A, Heindl

Councilors

1952	1953	1954
S, F, Turner	B, S, Butler	Eldred D, Wilson
Roland Mulchay	L, K, Wilson	Theo, A, Dodge
John H, Feth		

ACKNOWLEDGMENTS

The Excursion Committee extends grateful thanks to the individuals and organizations that have contributed to the field excursions and to this guidebook, The Committee is greatly indebted to the University of Arizona for the provision of registration facilities and secretarial help and to the United States Geological Survey and the Arizona Bureau of Mines for many extended courtesies and helpful suggestions, Thanks are especially due to the Magma Copper Company, Ray Division of the Kennecott Copper Corporation, Phelps Dodge Corporation, Castle Dome Copper Company, Inspiration Consolidated Copper Company, and Arizona Portland Cement Company for granting permission to visit their respective mining properties, The assistance given by the Arizona Highway Patrol in traffic control is gratefully appreciated,

The successful preparation of this guidebook is credited to Mrs, Margaret I, Good of the University of Arizona Mimeographing Bureau for her tireless efforts in completing this guidebook and for her invaluable suggestions to the Guidebook Committee regarding preparation of manuscript and illustrations,

Mr, B, W, Simons of Tucson Photo-Engraving Corporation has been most cooperative in the preparation of the illustrations,

EXCURSION COMMITTEES

GENERAL

John W, Harshbarger (Chairman)	U, S, Geological Survey
Andrew F, Shride	U, S, Geological Survey
Eldred D, Wilson	Arizona Bureau of Mines
George A, Kiersch	University of Arizona

GUIDEBOOK

Andrew F, Shride (Editor)	U, S, Geological Survey
Edwin D, McKee (Asst, Editor)	University of Arizona
John W, Harshbarger (Asst, Editor)	U, S, Geological Survey

FIELD TRIP LEADERS

Trip 1 - Ground-water Problems of Queen Creek Area

L, C, Halpenny and S, F, Turner	U, S, Geological Survey

Trip 2 - Stratigraphy of Tucson Mountains

Donald F, Bryant and John F, Lance	University of Arizona

Trip 3 - Santa Catalina Mountains area

B, S, Butler and F, F, Grout	University of Arizona
Calvin S, Bromfield	U, S, Geological Survey

Trip 4 - Economic Geology - Ajo Porphyry Copper

Staff, New Cornelia Mine	Phelps Dodge Corporation

Trip 5 - Stratigraphy, Structure, and Economic Geology Typical of Southern Arizona

Eldred D, Wilson	Arizona Bureau of Mines
Hubert J, Steele	Magma Copper Company
George A, Kiersch	University of Arizona
Otis M, Clarke, Jr,	Ray Div,, Kennecott Copper Co,
Nels Peterson	U, S, Geological Survey
Andrew F, Shride	U, S, Geological Survey
John W, Harshbarger (Moderator)	U, S, Geological Survey

TRIP ARRANGEMENTS

L, C, Halpenny (Housing)	U, S, Geological Survey
John Feth (Meals)	U, S, Geological Survey

PHOTOGRAPHY

Tad Nichols	Tucson, Arizona

CARAVAN AND TRANSPORTATION

Phillip Johnson and Don Coates	U, S, Geological Survey
Stanley Day	Shell Oil Company
University Students (Flagmen)	University of Arizona

SCHEDULE

Wednesday, April 9: 4:30 - 10:00 PM

Registration for pre-meeting trips. Each of these trips is scheduled for all day Thursday, April 10.

Thursday, April 10: 8:00 AM

Trip 1 - Ground-water problems of Queen Creek area.
Trip 2 - Stratigraphy of Tucson Mountains.
Trip 3 - Santa Catalina Mountains area.
Trip 4 - Economic Geology - Ajo Porphyry Copper.

All caravans assemble at Pima Hall parking lot.

Friday, April 11:

Cordilleran Section Meetings (campus)

Saturday, April 12:

Cordilleran Section Meetings (campus)
Last registration for post-meeting excursion.

Sunday, April 13: 7:30 AM

Trip 5 - Structure, Stratigraphy, and Economic Geology typical of southern Arizona.
Caravan assembles in auto park east of Chemistry-Physics building.

6:00 PM

Caravan arrives Globe, Arizona.

Monday, April 14: 8:00 AM

Caravan assembles one mile west of Globe along U.S. Highway 60-70. Excursion will visit Castle Dome and Inspiration Copper properties and return to Globe for lunch.

1:00 PM

Caravan assembles east of Globe along U.S. Highway 60-70 for excursion to Salt River Canyon.

4:00 PM

Caravan disbands at Becker's Butte, Salt River Canyon. Road log continues to Holbrook, Arizona.

EXCURSION INSTRUCTIONS

1. In order to complete the planned field trips, it is necessary that the caravan start each morning at the announced time (Schedule, p. v). Your cooperation will be greatly appreciated.

2. A mimeographed copy of assembly instructions for the field trips will be given to each person at the time of registration. Please follow these assembly instructions.

3. Please have your car serviced at night in order to depart promptly in the morning. Be sure that you have a full tank of gas on all trips leaving Tucson, especially Trip 5 as there will be no gas available until you reach Superior.

4. A numbered placard will be given to each car driver for attachment to the rear window. This number designates position in the caravan.

5. Please do not pass another excursion car while caravan is enroute unless that car has dropped out of line.

6. If a car has dropped out of line for a particular reason, that car may resume its proper position at any subsequent stop.

7. If you have car trouble, please stop on the side of the road and allow caravan to pass. On Trip 5 a tow truck equipped for making minor repairs will be available for service at the end of the caravan.

8. Double parking will be necessary at scheduled stops. Please drive as close as possible to adjacent line and park about one foot between bumpers. Please follow instructions of flagmen at all times.

9. It is suggested that the person accompanying the car driver in the front seat keep him informed of stops, danger points, and points of interest noted in the road log. The driver will also appreciate having the road log read to him while enroute.

NOTE: The term "o'clock" as used throughout the road logs indicates the direction for observation; 12 o'clock is straight ahead, 9 o'clock is 90 degrees to the left, 3 o'clock is 90 degrees to the right.

CONTENTS

ILLUSTRATIONS

TABLES

COVER PHOTOGRAPH, - SUPERSTITION MOUNTAINS. This range consists mainly of dacitic flows; some minor units of tuffs and small intrusives are known, The legendary Lost Dutchman gold mine is supposed to be in this range, (Photograph by Tad Nichols.)

THIS PAGE

INTENTIONALLY BLANK

INTRODUCTION

Edwin D. McKee
University of Arizona

General Statement

The geology of southern Arizona consists of features typical of the Basin-and-Range Province. Rugged, linear mountain ranges with northwest-southeast trends are separated by broad, flat valleys. The mountains, although composed of various rock types representing many geologic ages and deformed into varied structural patterns, nevertheless, have their outlines largely determined by uplift along major fault planes. The valleys, on the other hand, are underlain chiefly of alluvial debris eroded in the mountains and transported to the lowlands by running water, mud flows, and gravity.

The stratigraphic record in southern Arizona (Tables 1 and 2) includes rocks of both early and late Precambrian age, of nearly all the Paleozoic and both the late Mesozoic systems and of considerable but largely undetermined parts of Tertiary and later time. Early Precambrian rocks are mostly schists, and gneisses known as the Pinal Schist and several granitic units. Late Precambrian is represented by little-altered limestones, mudstones, orthoquartzites and conglomerates of the Apache group.

Paleozoic deposits of southern Arizona are composed largely of normal marine limestones and reworked detrital sediments of shelf seas that extended northward from a Sonora geosyncline. The deposits are of moderate thickness and represent all but the Ordovician and Silurian periods over much of this area. Along the eastern border of the state, rocks of Ordovician age also are present.

Sediments of Triassic and Jurassic age are absent in southern Arizona and those of Early and Late Cretaceous, in contrast to most of the Paleozoic, are partly marine but largely continental. They consist of much graywacke and subgraywacke accumulated in very great thickness in narrow, rapidly sinking troughs. Cenozoic deposits are entirely continental and largely of valley-fill type.

Igneous rocks of the southern Arizona region are extremely varied both in age and type (Table 3). They include granites of two principal ages--Precambrian and post-Paleozoic--and great masses of diabase of uncertain age; some is at least as young as late Paleozoic. Hypabyssal rocks and volcanic flows and eruptive materials are largely of Cretaceous and Tertiary to Recent age and include dacites, andesites, basalts and many others. Large volumes of tuff and agglomerate are characteristic and flows, especially basaltic, cover wide areas. In general, the acid and intermediate types are earliest and the basaltic latest.

Generalizations concerning structures in southern Arizona ranges have little value because of the wide variation represented. Northwest-southeast trends of the mountains indicate a consistent pattern of late uplift, but earlier structures are of many types. Large thrust faults are a feature of many ranges and complexity of structure resulting from the activity of more than one period is common. In some ranges folding is significant; in others high-angle faults are prominent features.

Geomorphic processes imposed upon the products of structural deformation are of a type characteristic of arid and semi-arid regions. They include many bed-rock surfaces and a sharply defined cliff-slope topography in the mountains, broad pediment surfaces at mountain bases, and steep-walled arroyas or flat-bottomed playas in the valley centers.

The following table is a compilation of data on the sedimentary rocks of southeastern and east-central Arizona covered by field trips logged in this guidebook. The principal stratigraphic units are presented from youngest to oldest in descending order. Descriptions are, of necessity, generalized and thicknesses approximately average for the areas concerned.

TABLE 1. - GENERALIZED STRATIGRAPHIC SECTION OF SOUTHERN ARIZONA

Quaternary and Recent Alluvium.
- Distribution: Valleys between all ranges in southern Arizona.
- Thickness: Maximum is hundreds of feet, accurate boundary differentiation from earlier deposits not possible in most areas.
- Character: Gravels, sands, clays from bordering ranges deposited as fans, lake or playa deposits. Unconsolidated.
- Fauna: Mammal bones uncommon.

Gila Conglomerate.
- Age: Pleistocene and Pliocene.
- Type: Gila River, east of Ariz.-N. Mex. line, Gilbert (1875).
- Distribution: Valleys of S.E. Ariz. along and tributary to Gila River, westward at least as far as Tucson and Superior.

Whitetail Conglomerate.
- Age: Tertiary (pre-Gila conglomerate).
- Type: Whitetail Gulch and Whitetail Spring near Globe, Ransome (1903).
- Distribution: Valleys in vicinity of Ray, Superior, Miami, and Globe, north to Salt River.
- Thickness: Maximum of 1000 ft. (±).
- Character: Alluvial fan deposits, mostly well consolidated, including gravels, sands and clays. Separated from Gila conglomerate by dacite flows. Beds affected structurally.
- Fauna: None known.

Sonoita Group.
- Age: Upper Cretaceous (Late).
- Type: Sonoita flats near Patagonia, Stoyanow (1936).
- Formations: (descending) Fort Crittenden, Fort Buchanan.
- Thickness: Probably thickest in extreme S.E. Ariz., 4000 Ft. at Santa Rita Mts.; Upper Cretaceous deposits at Christmas 3000 ft.
- Character: Beds of conglomerate, hard gray and yellow sandstones, shales of various colors. Near Christmas, Upper Cretaceous rocks include many andesitic flows and pyroclastic materials in addition to detrital sediments, but their relation to Sonoita group is not known.
- Fauna: Plant remains, dinosaur bones, mollusks.

Bisbee Group.

Age: Lower Cretaceous (Comanche series).

Type: Bisbee, Dumble (1902). Designated as group by Ransome (1904). Revised by Stoyanow (1949).

Formations: (descending) Cintura fm., Mural limestone, Lowell fm., Morita fm., Glance conglomerate.

Thickness: 4600 ft. (≠) at Bisbee. Probably originally much more for Lower Cretaceous deposits 21,000 ft. in S.W. N. Mex. and 16,000 ft. in Huachuca Mts.

Distribution: Marine deposits confined to S.E. Ariz. (Bisbee, Patagonia); Lower Cretaceous (?) continental deposits occur across southern Arizona, referred to in Tucson Mts. as Recreation red beds and Amole arkose.

Character: Arkosic, poorly-sorted basal conglomerate; red to brown shaly mudstones, cyclic beds of sandstone, shale and limestone, massive gray limestones. Continental deposits to N. W. contain red arkose, gray shaly mudstone, gray limestone, much volcanic material.

Fauna and flora: Large, varied marine fauna (mostly mollusks) at Bisbee. Fresh water mollusks and plants in continental deposits.

Snyder Hill Formation.

Age: Middle Permian (Leonard). Correlated with Kaibab fm. of northern Ariz. and San Andreas limestone of N. Mex.

Type: Snyder Hill, west of Tucson, Stoyanow (1936).

Thickness: 1200 ft. Thins northward from S.E. Ariz. Not recognized north of Tucson Mts.

Character: Dominantly thick-bedded, massive, light gray to black limestone; thin, dolomitic beds, mostly near top; fine-grained sandstone in lower part.

Fauna: Many brachiopods and mollusks, horn corals, crinoids, bryozoans, sponges, echinoids.

Undifferentiated Permian Formations.

Age: Between Upper Pennsylvanian deposits (included in Naco) and Middle Permian (Leonard age) beds of Snyder Hill fm. In similar stratigraphic position in east-central Arizona are the Supai fm. of red sandstone and mudstone, and the overlying white, quartzitic Coconino sandstone.

Thickness: Estimated 2000 ft.

Distribution: S.E. Ariz. north to vicinity of Tucson.

Character: (descending) Thin-, flat-bedded orthoquartzite; gray, massive limestone; an alternating sequence of black shaly mudstones and other detrital sediments, locally containing many gypsum beds.

Fauna: Gastropods, pelecypods and a few brachiopods in limestone.

Naco Limestone.

Age: Pennsylvanian; as originally defined also included Permian.

Type: Naco Hills near Bisbee, Ransome (1904).

Thickness: 2500 ft. in S.E. Ariz. to 500 ft. in east-central Ariz.

Character: Relatively thin-bedded cyclic deposits, mostly limestone in southern Ariz., progressively more detrital beds northward.

Fauna: Many brachiopods, fusulinids, corals, crinoids, echinoids.

Paradise Formation,

Age: Upper Mississippian.

Type: Chiricahua Mountains, Stoyanow (1926).

Thickness: 135 ft.; restricted to extreme southeastern part of Arizona.

Character: Limestone, thin- to thick-bedded, crystalline; alternating with sandstones and shales.

Fauna: Small brachiopods, trilobites, many Archimedes.

Escabrosa Limestone.

Age: Lower Mississippian. Correlated with Redwall limestone of northern Ariz.

Type: Escabrosa Ridge near Bisbee, Ransome (1904).

Thickness: 700 ft. in S.E. Ariz.; 350 ft. in Globe area; 50 ft. in east-central Ariz.

Character: Thick-bedded, light gray limestone, mostly crystalline, locally crinoidal, forms massive cliffs.

Fauna: Brachiopods, corals, crinoids, blastoids, bryozoans.

Martin Limestone.

Age: Upper Devonian.

Type: Mount Martin near Bisbee, Ransome (1904).

Subdivisions: North of Santa Rita Mts., Martin limestone is restricted by Stoyanow who recognized additional Devonian formations, i.e. Picacho de Calera below, "Lower Ouray" above.

Thickness: 350 ft. in S.E. Ariz. to 50 ft. in east-central Ariz.

Character: Dark gray, hard, moderately thick-bedded limestone; includes some calcareous shale.

Fauna: Brachiopods (common), fish teeth, stromatoporoids.

Abrigo Limestone.

Age: Cambrian.

Type: Abrigo Canyon near Bisbee, Ransome (1904).

Subdivisions: Abrigo restricted by Stoyanow who recognizes 3 units (geographical) above, i.e. Peppersauce Canyon sandstone, Rincon limestone, Copper Queen limestone; also new units below, i.e. Santa Catalina fm., Cochise fm. The last two are of Middle Cambrian age; the others Upper Cambrian.

Thickness: 800 ft. throughout S.E. Ariz. north to Santa Catalina Mts. Much thinner between Santa Catalinas and Globe. Absent from vicinity of Globe northward.

Character: Upward transition from sandstone to shale to limestone. Middle Cambrian beds mostly green and brown shale, some quartzitic sandstone; Upper Cambrian mostly thin-bedded limestone, shale near base, intraformational conglomerates.

Fauna: Numerous trilobite zones, brachiopods common.

Bolsa Quartzite; Troy Quartzite.

Age: Middle Cambrian (base of Paleozoic).

Type: Bolsa Canyon near Bisbee, Ransome (1904); Troy Mtn. near Ray, Ransome (1915).

Thickness: 450 ft. throughout most of S.E. and east-central Ariz., extremely variable due to unconformities.

Character: Resistant, coarse-grained, cross-bedded quartzite; locally conglomeratic; color variable but much purple and brown.

Fauna: Few brachiopods near top, abundant trails.

Apache Group.

Age: Late Precambrian (probably equals Unkar-Chuar of Grand Canyon).

Type: Globe quad., Ransome (1903). Redefined, Ransome (1915). Redefined, Darton (1932).

Formations: (descending) Mescal limestone, Dripping Spring quartzite, Barnes conglomerate, Pioneer shale, Scanlan conglomerate. Locally basalt overlies the Mescal.

Thickness: 1400 feet. Confined to region of east-central Ariz. (between Little Dragoon Mts. and Mogollon Rim).

Character: Much arkosic quartzite; siliceous mudstone; conglomerate beds with conspicuous well-rounded gravels; limestone typically thin-bedded, cherty and dolomitic, locally contains algal structures, massive. Intruded by diabase in many places.

Pinal Schist.

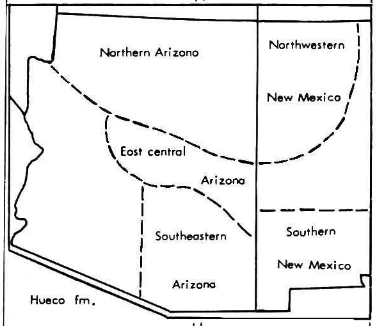
Age: Early Precambrian (may equal Yavapai schist of central Ariz. and Vishnu schist of Grand Canyon).

Type: Pinal Mts., Ransome (1903).

Character: Dominantly quartz-sericite and quartz muscovite schists, light to dark gray or greenish gray. Intruded by various granitic and other igneous bodies.

TABLE 2. - NOMENCLATURE OF SEDIMENTARY ROCKS IN SOUTHEASTERN ARIZONA AND ADJACENT AREAS.

(Approximate correlations only)

SYSTEM		SOUTHEASTERN ARIZONA	SOUTHEASTERN ARIZONA	EAST CENTRAL ARIZONA	NORTHERN ARIZONA	NORTHWESTERN NEW MEXICO	SOUTHERN NEW MEXICO	
		Ransome 1904, 1919 Darton 1925 Brown 1939	Stoyanow 1936, 1942, 1949	Darton 1925 Wilson 1939 Huddle and Dobrovolny 1945	Noble 1922 McKee 1938, 1945 Baker, Dane and Reeside 1936	Baker, Dane and Reeside 1936 C. T. Smith 1951 Simpson 1950	El Paso Area Adkins 1932 Nelson 1940	Silver City Spencer and Page 1935
QUATERNARY		Alluvium		Alluvium	Alluvium	Alluvium	Alluvium	Alluvium
TERTIARY		Gila congl. Whitetail congl.		Gila congl. Whitetail congl.	Gravels and basalt flows Bidahochi fm. Chuska ss. Tohatchi sh.	Gravels and bas lt flows Santa Fe fm. San Jose fm. Wasatch fm. Nacimiento fm.	Gravels and sands	Gravels and bas lt flows
CRETACEOUS	Upper	Undif. continental beds	Unnamed Sonoita gp. [Fort Crittenden fm. Fort Buchanan fm.	[Pinkard fm.	Mesa Verde fm. Mancos sh. Dakota ss.	Ojo Alamo ss. McDermott fm. Kirtland sh. Fruitland fm. Pictured Cliffs ss. Lewis sh. Cliff House ss. Menefee fm. Mesa Verde fm. Mancos sh. Dakota s.s.	Eagle Ford group	Colorado sh. Beartooth qtzite.
	Lower	Undif. continental beds (includes Amole arkose and Recreation red beds) Bisbee gp. [Cintura fm. Mural ls. Morita fm. Glance congl.	Patagonia gp. Molly Gibson fm. Bisbee gp. [Cintura fm. Mural fm. Lowell fm. Morita fm. Glance congl.				Buda fm. Grayson fm. Georgetown equiv. [Main Street fm. Pow Paw - Weno Ft. Worth - Denton Duck Creek fm. Kiamichi fm. Goodland fm.	
JURASSIC					Cow Springs s.s. [Morrison fm. Summerville fm. Entrada ss. Carmel fm. Navajo ss. Kayenta fm. Wingate ss.	Morrison fm. Red Mesa fm. Todilto gyp. Entrada s.s. Wingate ss.		
TRIASSIC					Chinle fm. Shinarump congl. Moenkopi fm.	Chinle fm. Santa Rosa fm.		
PERMIAN		Snyder Hill fm. Unnamed ls., sh., marl, gyp.	Chiricahua ls. Snyder Hill fm. Fossiliferous ls. and qtzite. Manzano fauna beds Gypsum beds	Kaibab ls. Coconino ss. Supai fm.	Kaibab fm. Toroweap fm. Coconino ss. Hermit sh. Supai fm. Cutler fm. Rico fm.	San Andres fm. [Limestone memb. Glorieta ss. Yeso fm. [San Yzidro memb. Meseta Blanco memb. Abo fm.	Hueco fm.	Abo red beds
PENN		Naco ls.	Galiuro ls. Naco ls.	Naco ls. Tule Spring ls.	Bird Spring fm. Hermosa fm.	Madero ls. Bursum fm. Sandia fm.	Magdalena fm.	Magdalena gp. [Syrena fm. Oswaldo fm.
MISS	Up.	Unnamed ss.	Paradise fm.				Helms fm.	
	Lo.	Escabrosa ls.	Escabrosa ls.	Redwall ls. Modoc ls.	Redwall ls.			Lake Valley ls.
DEV		Martin fm.	Lower Ouray fm. Martin ls. Picacho de Calero fm.	Martin ls. Morenci sh.	Temple Butte ls.		Canutillo sh.	Percha sh.
SIL							Fusselman ls.	Fusselman ls.
ORD				Longfellow ls.			Montoya ls. El Paso ls.	Montoya ls. El Paso ls.
CAMBRIAN	Upper	Abrigo fm. [Upper Middle Lower	Peppersauce Canyon ss. Rincon ls. Copper Queen ls. Abrigo fm.	Coronado qtzite.			Bliss ss.	Bliss ss.
	Middle	Troy qtzite Bolsa qtzite.	Southern Belle qtzite. Santa Catalina fm. Troy qtzite. Cochise fm. Pima ss. Bolsa qtzite.	Troy qtzite.	Tonto gp. [Muav ls. Bright Angel sh. Tapeats ss.			
	Lo.							
PRECAMBRIAN	Younger	Apache gp. [Mescal ls. Dripping Spring qtzite Barnes congl. Pioneer sh. Scanlan congl.	Apache gp. [Mescal ls. Dripping Spring qtzite. Barnes congl. Pioneer sh. Scanlan congl.	Apache gp. [Mescal ls. Dripping Spring qtzite. Barnes congl. Pioneer sh. Scanlan congl.	Grand Canyon ser. [Chuar group Unkar group		Lanoria qtzite.	
	Older	Granite and Pinal sch.	Granite and Pinal sch.	Mazatzal qtzite. Maverick sh. Deadman qtzite. Yavapai gp. [Alder ser. Red Rock rhy. Yeager greenstone	Vishnu sch.	Granite and schist	Granite, schist and gneiss	Schist, greenstone and granite

Compiled by Geo. A. Kiersch

IGNEOUS ROCKS BETWEEN TUCSON AND HOLBROOK, ARIZONA

Eldred D. Wilson
Arizona Bureau of Mines

The accompanying chart (Table 3) has been adapted from published and unpublished information, mainly regarding isolated areas, as noted in the list of references.

Because these rocks are of uncertain age in many of the areas, the correlations must be regarded as tentative; they are based to a large extent upon unsatisfactory indirect evidence such as lithologic similarity, intensity of deformation, alteration, or mineralization, sequence, and unconformities. Thus, for example, the diabase, although lithologically similar in a general way throughout the region, is of different ages at various localities, as interpreted by the following authors:

> Darton (1925, p. 36, 254-255): Large sills Precambrian; overlapped by Middle Cambrian Troy quartzite in Mescal Mountains and invading lower portion of Troy in some other places. Small bodies post-Pennsylvanian.
>
> Cooper (1950, p. 31): Sills earlier than Middle Cambrian Bolsa quartzite in Little Dragoon Mountains.
>
> Short and Ettlinger (1926, p. 181) and Harshman (in Short _et al_., 1943, pp. 38-39): Invades lower portion of Troy in Superior area.
>
> Shride (this guidebook): Large sills pre-Devonian in Salt River area of Gila County.
>
> Ransome (1919, pp. 53-56): Late Paleozoic or early Mesozoic in Ray-Miami area; sills invade the Troy, and small bodies penetrate the Pennsylvanian beds.
>
> Peterson (this guidebook): Late Cretaceous and early Tertiary in Miami-Globe areas.
>
> Butler and Hernon (in Moore _et al_., 1949): Probably of two ages, Younger Precambrian and Cretaceous.

Descriptions of occurrence, distribution, and petrography of igneous rocks within this region were derived from the following sources: Brown (1939, p. 697-759), Butler, B.S. (unpublished data), Campbell (1904), Cooper (1950, p. 31), Creasey (1950, pp. 63-84), Darton (1925), Gregory (1917), Harrell and Eckel (1939, pp. 51-52), Jenkins and Wilson (1920), Kiersch (1951, pp. 67-83), Kuhn (1952, pp. 56-65), Peterson (1938), Peterson (this guidebook), Ransome (1919), Ross (1925), Schwartz (1945), Short and Ettlinger (1926), Short et al. (1943), Shride (this guidebook), Steele and Rubley (1947), Wilson, E.D. (unpublished data).

	SANTA CATALINA MTS.	TUCSON MTS.	TORTILLITA MTS.	BLACK HILLS (SAN MANUEL-TIGER)	GALIURO MTS.	DRIPPING SPRING MTS.	TORTILLA MTS., RAY-SUPERIOR	MIAMI-GLOBE PINAL MTS.	GLOBE-SALT RIVER
TERTIARY OR QUATERNARY		Basalt, 700 feet, and porphyritic basalt dikes.		Basaltic dikes			Basalt dikes, small plugs, and flows,		Volcanic rocks, mainly basalt, 200 feet, (Between Salt River and Holbrook are volcanic rocks, mainly basalt, cinders, and tuff. Dikes, necks, and plugs, mainly of basic composition, north of Santo Fe Railway.)
TERTIARY	Basalt, rhyolite, and tuff; rhyolitic and basaltic dikes	Dacite porphyry and rhyolite porphyry masses and dikes; latite prophyry dikes and sills. Rhyolite, and tuff, 2,440 feet.	Dikes and minor intrusive masses. Volcanic rocks, mainly andesitic.	Rhyolitic dikes Basalt, andesite, and latite flows and breccias.	Volcanic rocks, basaltic.	Dacite flows with minor tuffaceous beds, northwesternmost part of range. andesite,	Rhyolite porphyry plugs, rhyolite flows, and perlitic sills. Tuff, more than 1,000 feet maximum. Dacite flow, more than 1,200 feet, with minor tuffaceous beds; wide-spread between Gila and Salt Rivers.	Dacite and tuff	mainly Dacite and tuff
LARAMIDE (LATE CRETACEOUS TO EARLY TERTIARY)	Catalina granite batholith central core of range. Rincon granite masses east of Tucson. Leatherwood quartz diorite masses and sills. Diabase dikes and sills.	Granite and quartz monzonite stocks; latite-porphyry dikes and sills.		Diabase dikes Monzonite porphyry masses.	Diabase dikes Granodiorite masses.	Acidic porphyries and aplite dikes, 79 mine area. Quartz diorite porphyry dikes sills, and small intrusive bodies, especially Troy vicinity. Granodiorite masses, Troy vicinity; dikes, 79 mine area. Quartz diorite masses and dikes, northeast of Kelvin. Diabase sills and dikes.	Quartz diorite porphyry dikes, sills, and small masses widely distributed. Quartz monzonite porphyry masses and dikes, Ray vicinity (Granite Mtn. and Teapot Mtn. porphyries); dikes, Magma Mine; intrusive mass at Silver King. Quartz diorite masses and dikes, northwest of Kelvin, south of Ray, and northwest of Silver King (2 miles north of Superior Diabase sills and dikes.	Schultz granite batholith; Lost Gulch quartz monzonite; Granodiarite at Gold Gulch; Willow Springs granodiorite. Diabase sills and dikes.	Diabase dikes and small sills.
UPPER CRETACEOUS	Andesite flows	Andesitic flows and tuffs, 2,000-5,000 feet.			Andesite, rhyolite, latite, and dacite, breccia, sandstone, and shale.	Andesitic to basaltic flows and pyroclastic material, southeast portion of range, vicinity of Christmas; basaltic, and dacitic minor intrusive bodies, 79 mine area.			interbedded with tuff, conglomerate,
YOUNGER PRECAMBRIAN	Diabase dikes and sills.			Diabase sills, vicinity of Camp Grant Wash.	Diabase sills in western part of range, vicinity of Aravaipa Creek.	Diabase sills. Basalt flow, 25-100 feet, overlying the Mescal limestone.	Diabase sills. Basalt flow, 25-100 feet, overlying the Mescal limestone.	Diabase sills. Basalt flows 25-100 feet, overlying the Mescal limestone.	Diabase sills. Basalt flows 25-100 feet, overlying the Mescal limestone.
OLDER PRECAMBRIAN	Oracle granite, in northwest part of range and Oracle vicinity.		Oracle granite large masses.	Quartz monzonite (Oracle granite) large masses with associated aplite dikes.	large masses Granitic masses in western part of range, Creek.		Ruin granite extensive masses throughout range southwest from Ray; small masses northwest of Ray.	Madera diorite. Solitude granite Ruin granite	north of Copper

TABLE 3. - TENTATIVE CORRELATION OF IGNEOUS ROCKS IN AREAS BETWEEN TUCSON AND HOLBROOK, ARIZONA.

GROUND WATER PROBLEMS OF QUEEN CREEK

TRIP 1, ROAD LOG

Thursday, April 10, 1952

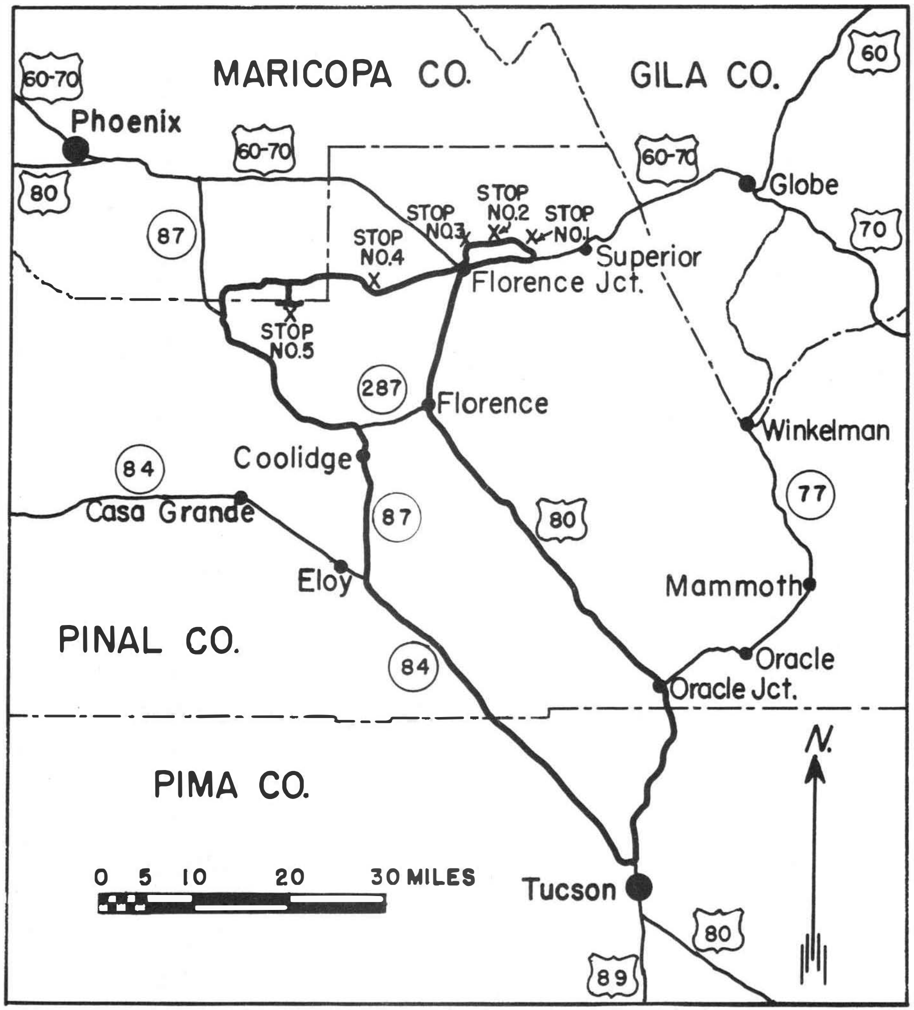
Leaders: L. C. Halpenny and S. F. Turner
Driving distance: Part 1, 81.7 miles; Part 2, 45.9 miles; Part 3, 103.5 miles; Total, 231.1 miles.

General Statement

Part 1 is from Tucson to Florence Junction on U.S. Highway 80.

Part 2 is a loop from Florence Junction east along U.S. Highway 60-70 to the upper reaches of Queen Creek, thence down the creek along a dirt road to Florence Junction, thence across the Queen Creek desert to the town of Queen Creek. Some of the travel is along ungraded desert trails.

Part 3 is from the town of Queen Creek west to State Highway 84, southeast to Tucson.



Index map for road log of ground-water field trip

FIGURE 1.

Part 1 - Tucson to Florence Junction:

0.0	0.0	Intersection of U.S. Highway 80 with State Highway 84. Follow Highway 80.
2.3	2.3	Cross Rillito Creek. The creek is tributary to the Santa Cruz River and furnishes a large part of the recharge for groundwater withdrawals in the Cortaro-Marana area, along State Highway 84. The creek drains the south front of the Santa Catalina Mountains which can be seen at 2 o'clock. An average of about 25,000 acre-feet of water is recharged annually to the Santa Cruz Basin from Rillito Creek.
2.1	4.4	Beginning of frost-free belt along foothills of Santa Catalina Mountains. Grapefruit, oranges, and lemons are raised here on a limited scale. Irrigation is from wells that are about 500 feet deep. The static water level is about 350 feet.
7.1	11.5	Cross Canon del Oro, a creek that is tributary to the Santa Cruz River and that drains the north side of the Santa Catalina Mountains. This stream also contributes substantial recharge to the ground-water reservoir of the Santa Cruz Basin. Average annual recharge is about 8,000 acre-feet. Depth to water is about 100 feet.
10.2	21.7	SLOW for Oracle Junction, at intersection of State Highway 77 with U.S. Highway 80. Continue north on U.S. Highway 80. Tortillita Mountains at 10 o'clock. Depth to water at Oracle Junction, 250 feet.
13.1	34.8	Owlhead Station on left. Picacho Peak at 10 o'clock; Picacho Mountains at 11 o'clock; Tortilla Mountains 2 o'clock; Black Hills 3 o'clock.
11.6	46.4	Tom Mix Wash.
12.4	58.8	Chuck Wagon Station on left, depth to water, 310 feet. San Tan Mountains, 10 o'clock; Gold Mine Mountains, 11 o'clock; Superstition Mountains, 1:30 o'clock; Pinal Mountains, 3 o'clock.
3.1	61.9	Gila Buttes at 3 o'clock. The Gila River flows eastward between the buttes, a proposed damsite.
2.2	64.1	Intersection of State Highway 287 (from west) with U.S. Highway 80. Town of Florence. SLOW for school zone at south side of town.
0.5	64.6	Coffee shop on right. Rest stop here or at service stations ahead.
0.3	64.9	TURN RIGHT on U.S. 80. Shell station on right, Standard station on left.
0.5	65.4	TURN LEFT on U.S. 80. Arizona State Penitentiary at 2 o'clock.
0.5	65.9	Leaving Florence. Entering upstream end of San Carlos Irrigation Project, which irrigates partly with water of the Gila River stored behind Coolidge

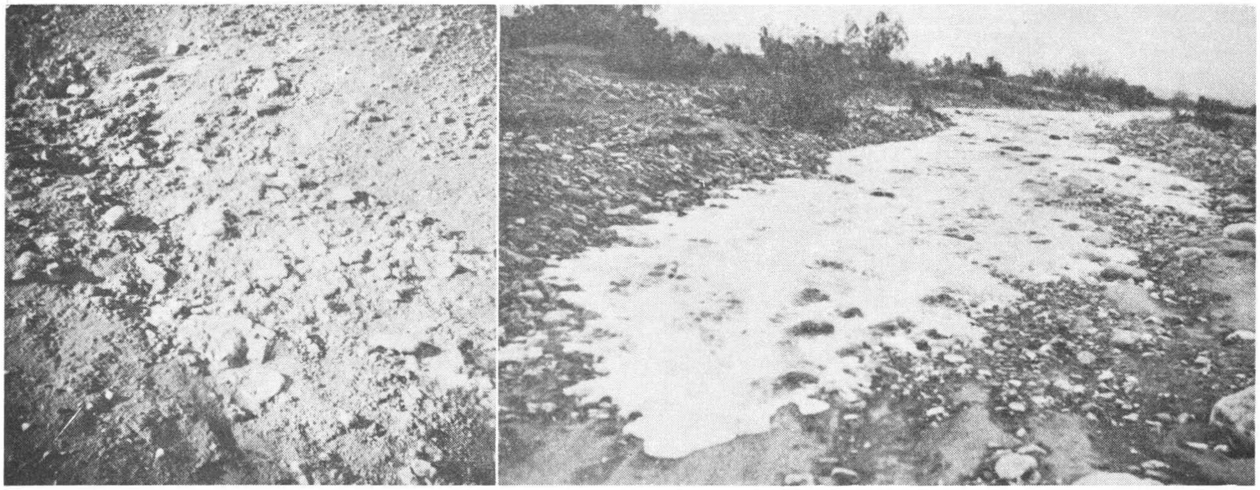
		Dam in San Carlos Reservoir, about 75 miles upstream (east). Wells are used to supplement the surface-water supply. Depth to water here about 75 feet.
0.9	66.8	SLOW for narrow bridge over Gila River. The fields immediately south of the bridge are irrigated entirely with ground water. Formerly many salt cedar and other phreatophytes grew in the bed of the Gila River here, but in recent years overpumping of the ground-water reservoir has lowered the water table and killed most of the plants.
0.3	67.1	Hunt Highway begins on left. Continue on U.S. Highway 80.
0.4	67.5	SLOW for railroad crossing.
0.5	68.0	Former Prisoner of War Camp on left.
11.7	79.7	SLOW for railroad crossing. Two wells are located along the right of way. The well 1.2 miles to the west furnishes water for the town of Superior through a pipe line along the railroad. The well 1.5 miles to the east, 460 feet to water, furnishes water for the Magma Mine at Superior. Both wells were drilled after prospecting the area for deep alluvium by using electrical resistivity geophysical methods.
2.0	81.7	SLOW for stop sign at intersection with U.S. Highway 60-70 at Florence Junction. End of Part 1.

Part 2 - Florence Junction to town of Queen Creek.

0.0	0.0	Intersection of U.S. Highway 80 with U.S. Highway 60-70. TURN RIGHT on 60-70.
2.1	2.1	SLOW for railroad crossing. At the crossing the depth to bedrock (volcanics) is 60 feet; 1/2 mile southwest along the railroad, 70 feet; 1 mile southwest, 650 feet.
3.6	5.7	Outcrop of Pinal schist in cut on left side of road.
0.9	6.6	View of Queen Creek Valley to north (9-10 o'clock). Smoke from smelter of Magma Copper Co. at Superior at 12 o'clock.
0.7	7.3	Picket Post Mountain at 12 o'clock. Volcanic tuffs and flows.
2.4	9.7	Faults in road cut, both sides of road.
0.6	10.3	SLOW for Queen Creek bridge and left turn ahead.
0.1	10.4	TURN LEFT on gravel road along Queen Creek. This is the old stage coach road from Yuma to the Silver King Mine.
0.6	11.0	Weaver's Needle in Superstition Mountains at 12 o'clock; named for Pauline Weaver the explorer.

1,0	12,0	Note coarse alluvium in wash, The alluvium is about 15 to 25 feet thick here,
1,2	13,2	STOP 1 (20 minutes), Test pit dug by Magma Copper Co, when prospecting for a water supply, Continue west on gravel road, crossing railroad,
0,1	13,3	SLOW to cross Queen Creek (no bridge),
0,3	13,6	SLOW for village of Pinal, Several hundred people lived here when the Silver King Mine was in operation,
2,9	16,5	ROAD FORK; take right fork,
1,0	17,5	Gaging station on Queen Creek,
0,1	17,6	STOP 2 (20 minutes), Cable for gaging station, Whitlow damsite (proposed Army flood-control dam), Road follows bed of creek here,
0,9	18,5	U,S, Geological Survey makes periodic water-level measurements in well to left,
1,5	20,0	Black Point damsite (proposed by Soil Conservation Service as flood-control dam),
0,8	20.8	Parapet hill at 3 o'clock, Local residents tell story that rock parapet on hill was used as an ambush for a stagecoach holdup,
0,8	21,6	STOP 3 (20 minutes), Junction with abandoned segment of U,S, Highway 60-70, Park in cleared area to left of dirt road, 100 feet from intersection with paved road, Former site of Queen Creek gaging station is at abandoned concrete bridge over the creek, Turn left on abandoned highway,
2,2	23,8	LUNCH STOP (45 minutes) at Texaco service station at intersection of old highway with U,S, 60-70, Check your gasoline and oil here or at the Shell station 0,1 mile east, Continue northwest on U,S, Highway 60-70,
0,6	24,4	U,S,G,S, observation well, Depth to water is over 400 feet here,
0,4	24,8	SLOW for left turn through gate on trail across Queen Creek desert, Occupants of last car will close gate, Trail follows power line to mile 26,7,
1,9	26,7	Gate in fence, Note paloverde trees,
0,2	26,9	Earth stock reservoir on left,
0,8	27,7	ROAD FORK, Follow right-hand branch, Note patches of caliche,
0,3	28,0	Cross Sonoqui Wash, Queen Creek has deposited sufficient alluvial material to raise the base level slightly above the surrounding terrain so that side channels of Sonoqui Wash head almost at the banks of Queen Creek,

1.9	29.9	Gate in fence. Take right fork beyond gate.
0.1	30.0	Cholla cactus and paloverde trees. Some saguaro cactus.
1.1	31.1	Stock-water reservoir. Follow left-hand fork of road.
1.8	32.9	Telephone line. Turn right (north) along trail paralleling line.
0.6	33.5	Abandoned trail crosses at right angle. Continue north along telephone line.
0.8	34.3	South edge of channel of Queen Creek. The creek is braided here and flows in several channels.
0.1	34.4	STOP 4 (20 minutes). Park on high ground between the two main channels of Queen Creek.
0.3	34.7	North edge of channel of Queen Creek. Road forks to west, continue north along telephone line.
0.4	35.1	Road forks to southwest; continue north along telephone line.
0.2	35.3	Gate in north-south section-line fence. Continue along telephone line.
0.1	35.4	Gate in east-west section-line fence. Road fork on left; continue north along telephone line.
0.8	36.2	Road fork on left. Continue straight ahead along telephone line.
0.1	36.3	Road fork to left, follow left-hand fork and leave telephone line.
0.1	36.4	Abandoned ranch headquarters; dry well. The water table declined below the bottom of the well, present depth about 275 feet.
0.4	36.8	Road fork, take left-hand branch toward the west.
0.2	37.0	Gate, continue west along fence.
0.6	37.6	Fork; take left, southwest from section-line fence. Road trends southwest and then south.
1.2	38.8	Gate, BAD BUMP in road. Turn sharp right (west) along graded section-line road. Eastern limit of irrigated area.
0.3	39.1	Gate, continue west.
0.7	39.8	Cross section-line road, continue west.
2.0	41.8	Pass under power line, continue west.
1.1	42.9	Cotton gin on right, beginning of pavement, continue west.

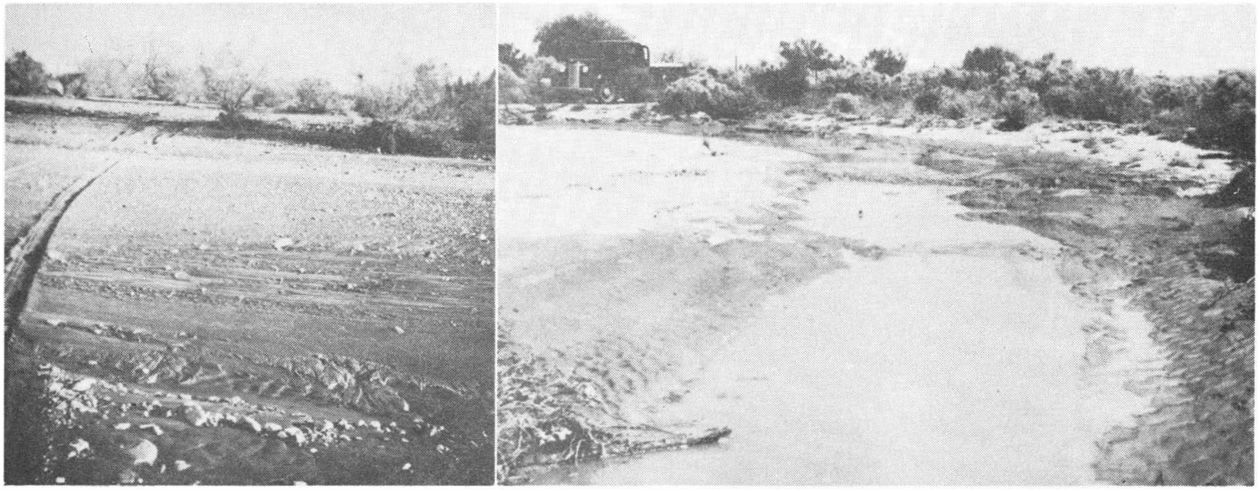


MILE 27.7, PART 2

Caliche at side of road. This material prevents recharge by infiltration of rainfall on the desert floor.

MILE 29.5, PART 2

Front of small flood in Queen Creek. Note coarse alluvium, which will absorb large quantities of water as recharge to the ground-water reservoir.



MILE 34.4, PART 2

Main channel of Queen Creek after flood on 1-1-52. Note sandy character of alluvium.

MILE 8.1, PART 2

Pools remaining after flood, lower end of Queen Creek. The alluvium is silt and clay and will absorb little water as recharge to the ground-water reservoir.

FIGURE 2. - EXAMPLES OF RECHARGE CONDITIONS IN THE QUEEN CREEK AREA

2,4	45,3	SLOW for railroad crossing.
0,7	46,0	SLOW entering town of Queen Creek. Depth to water, 185 feet. In 1940 this community consisted of a store, one house, and a few shacks for migrant laborers. Turn left (south) at Queen Creek. End of Part 2.

Part 3 - Town of Queen Creek to Tucson.

0,0	0,0	Crossroads at Queen Creek. Proceed south on section-line road.
0,5	0,5	STOP 5 (20 minutes). Park on both sides of road, north side of wood bridge over Queen Creek. Note vegetation choking the channel. Turn around and return to town of Queen Creek.
0,5	1,0	SLOW for left turn (west) on section-line road.
0,8	1,8	Cross Queen Creek (dip, no bridge).
0,2	2,0	Pavement ends at section corner. Continue west on gravel road. Crossroads are at 1-mile intervals.
2,0	4,0	SLOW for left turn (south) on section-line road. Note concrete-lined canal on north side of road before making turn. Canals are lined to conserve irrigation water.
0,1	4,1	Cross Sonoqui Wash at road dip.
0,9	5,0	SLOW for right turn (west) on section-line road.
2,0	7,0	Pavement begins. Continue west.
1,1	8,1	Cross Roosevelt Water Conservation District irrigation canal. Queen Creek flows south along east side of canal. You are entering an area where irrigation water is available from the Salt River system of storage reservoirs and canals. Continue west on paved road.
3,0	11,1	SLOW for stop sign and left turn (south) on paved road.
2,0	13,1	Entering Gila River Indian Reservation; leaving Salt River Valley area. Queen Creek spreads out in a semi-playa; only extreme floods enter the Gila River, about 4 miles west.
0,9	14,0	Dip at north channel of Queen Creek.
0,9	14,9	Dip at south channel of Queen Creek.
0,8	15,7	SLOW for railroad crossing of main line SPRR and stop sign at intersection with State Highway 87. Turn left (southeast) onto highway.

8,3	24.0	SLOW for crossing of Sacoton Dam. San Tan Mountains at 9 o'clock. This is a diversion dam on the Gila River, where water discharged from San Carlos Reservoir is diverted into canols on the San Carlos project. Pumping in this area has lowered the water table sufficiently to cause areas of formerly thriving phreatophytes to sicken and become stunted,
1,9	25,9	Highway curves southeast at intersection of paved road from southwest. Sacaton Mountains at 1 o'clock,
10,4	36,3	Casa Grande National Monument at 3 o'clock.
0,7	37,0	SLOW for intersection with State Highway 287, Highway 87 turns right (south). Continue on 87,
1,1	38,1	SLOW, entering Coolidge. Continue south.
8,0	46.1	"Eleven-mile corner"; deep oil-test hole. Valley fill materials to 3,380 feet, then volcanic series.
10,1	56,2	SLOW for intersection with Highway 84 at 3 o'clock. Continue on 84,
0,6	56,8	Overpass at SPRR crossing. Note large farmed areo to south; irrigated with ground water. This is the lower end of the Santa Cruz Basin,
1,3	58,1	SLOW for villoge of Picacho,
1,6	59,7	Earth crack across railroad and highway; note patch in pavement and trace of crack on both sides of road. Crack developed in 1951; origin not yet satisfoctorily established,
1,7	61,4	Earth crack across railroad and highway; occurred in 1949,
21,7	83,1	Village of Marano; in large formed area irrigated with ground water from lower Santa Cruz Basin,
5,0	88,1	Cement plant at 3 o'clock at village of Rillito. Limestone is quarried from Paleozoic outcrop about 2 miles west,
8,1	96,2	Cross Canon del Oro
1,2	97,4	Cross Rillito Creek,
4,7	102,1	SLOW for left turn across overpass beyond intersection with truck bypass,
0,1	102,2	Overpass,
1,3	103,5	Junction of State Highway 84 with U.S. Highway 80, in northwest part of Tucson, at point of origin of field trip. End of Part 3. End of trip,

GROUND WATER IN THE QUEEN CREEK AREA, ARIZONA*

S. F. Turner and L. C. Halpenny
Ground Water Branch, U. S. Geological Survey

Queen Creek and its surrounding alluvial basin are typical of many areas in Arizona where large supplies of ground water have been developed. Within a linear distance of 25 miles all the principal features of the hydrologic cycle as it commonly exists in Arizona are apparent: Rainfall in the upland areas produces runoff in a normally dry wash; downstream from the place where the wash passes from bedrock to alluvium, surface-water losses by infiltration become accretions to the ground-water reservoir; a downward gradient of the water table, from the zone where recharge begins to the zone where discharge occurs, causes slow movement of ground water in that direction; pumping brings the ground water to the land surface, where it is transpired or evaporated, and the cycle is completed. The only feature of the hydrologic cycle that is extensively developed in other parts of the region but is limited in the Queen Creek area is the use of ground water by nonbeneficial natural vegetation. In a small area in the upper reaches of Queen Creek (mile 17.0, part 2 of road log) mesquite and baccharis transpire ground water. In the lower reaches the water table is too deep for these plants to exist.

The Queen Creek area lies east of Phoenix, in the eastern part of the great structural basin that is commonly known as the Salt River Valley area. Queen Creek heads in the Pinal Mountains 4 miles east of Superior, at an altitude of 4,500 feet. The principal tributary is Whitlow Creek, which enters Queen Creek three-quarters of a mile above an abandoned gaging station which was constructed near the point where the creek leaves all the mountains. The drainage area of Queen Creek at that station is 191 square miles. The drainage area downstream from this station is 30 square miles, and the mean precipitation is about 10 inches. The mean precipitation of the area above the station is about 20 inches. Below the gaging station the creek receives little or no inflow, as it has built a channel confined by natural levees slightly above the level of the adjacent alluvial plain. The creek flows west to the Roosevelt Canal (Fig. 3) and thence southwest along the eastern side of the canal toward the Gila River. Only when the flow is extremely large does any water reach the river, most of it being dissipated on a playa-like area on the Gila River Indian Reservation, about 5 miles above the junction with the Gila River.

The upland areas, where most of the runoff originates, are underlain mostly by volcanic rocks and some schist and granite. The alluvium underlying the desert floor consists of a heterogeneous mixture of boulders, gravel, sand, silt, and clay, grading from very coarse grained materials near the mountain front to very fine grained materials in the vicinity of the playa. Except along the creek, a zone of caliche a few feet below the land surface retards or prevents recharge from rainfall on the desert floor. A pediment cut on basement rock underlies the alluvium for a width of about a mile along the mountain front. At the edge of this pediment the depth to bedrock increases from about 100 feet to more than 600 feet in less than half a mile.

---

*Publication authorized by the Director, U. S. Geological Survey.

Floods of 4,000 to 15,000 second-feet are not infrequent, and floods of 70,000 second-feet can be expected. In the dry period 1942-50 few floods reached the lower end of Queen Creek. Near the town of Queen Creek the channel has become so choked with vegetation that when a large flood occurs the water will overflow the channel more readily than in the past. Now that adjacent lands, formerly used only for grazing, are under cultivation, flood damage will be many times as great as in the past. In 1940 and 1941, floods in Queen Creek washed out the Roosevelt Canal in several places and spread westward across farmed lands nearly to Chandler.

Ground water is present in the alluvium downstream from the abandoned gaging station, and small supplies of ground water occur in the gravel along the creek in the upland areas. The depth to ground water is 410 feet at the point where the creek crosses U.S. Highway 80, and it decreases to 125 feet in a few places along the Roosevelt Canal. Queen Creek is influent throughout its length, except that in times of abundant runoff the water table rises to the stream level in the upper reaches. The accompanying map (Fig. 3) shows the direction of movement of ground water in the area by means of contours on the water table. Two sets of contours are shown, one representing conditions for the spring of 1950 and the other for the spring of 1939. Recharge to the ground-water reservoir is almost entirely by downward percolation of water from Queen Creek. Some of these flows are from melting of winter snow, carry very little silt, and infiltrate freely. Flows from torrential summer storms carry more silt and consequently infiltrate more slowly. A paper by Babcock and Cushing (1942) contains a description of the work done by the Geological Survey in determining recharge quantitatively. The accompanying page of graphs (Fig. 4) of water-level fluctuations illustrates how slowly the water table reacts to periods of recharge. The second graph illustrates conditions at an observation well along U.S. Highway 80 about a mile southeast of Queen Creek (at mile 24.4 Trip 1). Exceptionally heavy flows occurred in Queen Creek during the spring of 1941, but no rise in water level in the well was apparent for almost a year. During the following years little runoff occurred, but the water level in the well continued to rise until the spring of 1946.

Although the alluvium in the basin may be more than 2,000 feet thick, and although large quantities of ground water are stored, the specific yield and permeability generally decrease with depth. This means that, for each succeeding foot unwatered, less water will be yielded and the drawdown in a well at a given yield will be greater. Thus, in many areas it soon will be uneconomical to pump for irrigation even at the present high prices for farm crops.

Ground water has been pumped for irrigation in the Queen Creek area since about 1915. In 1939, 31,900 acre-feet was pumped for irrigation east of the Roosevelt Canal. The Roosevelt Water Conservation District pumped 69,500 acre-feet, making the total for the area 101,400 acre-feet. By 1950* this had increased to 295,000 acre-feet, most of the increase occurring after 1946. By the spring of 1952 about 90,000 acres was being irrigated, of which about 58,000 acres lay east of the Roosevelt Canal and was irrigated solely with ground water. In 1940 most of the land irrigated with ground water was adjacent to the canal, where the water table is nearest the land surface. As new lands were irrigated, the farmed area expanded eastward into areas where the water table is progressively deeper. By 1951, farmers were pumping in areas where the static water level was as much as 325 feet below the land surface, at least 10 sections of land were irrigated with water lifted more than 225 feet.

*Pumpage figures for 1951 not available at time manuscript prepared.

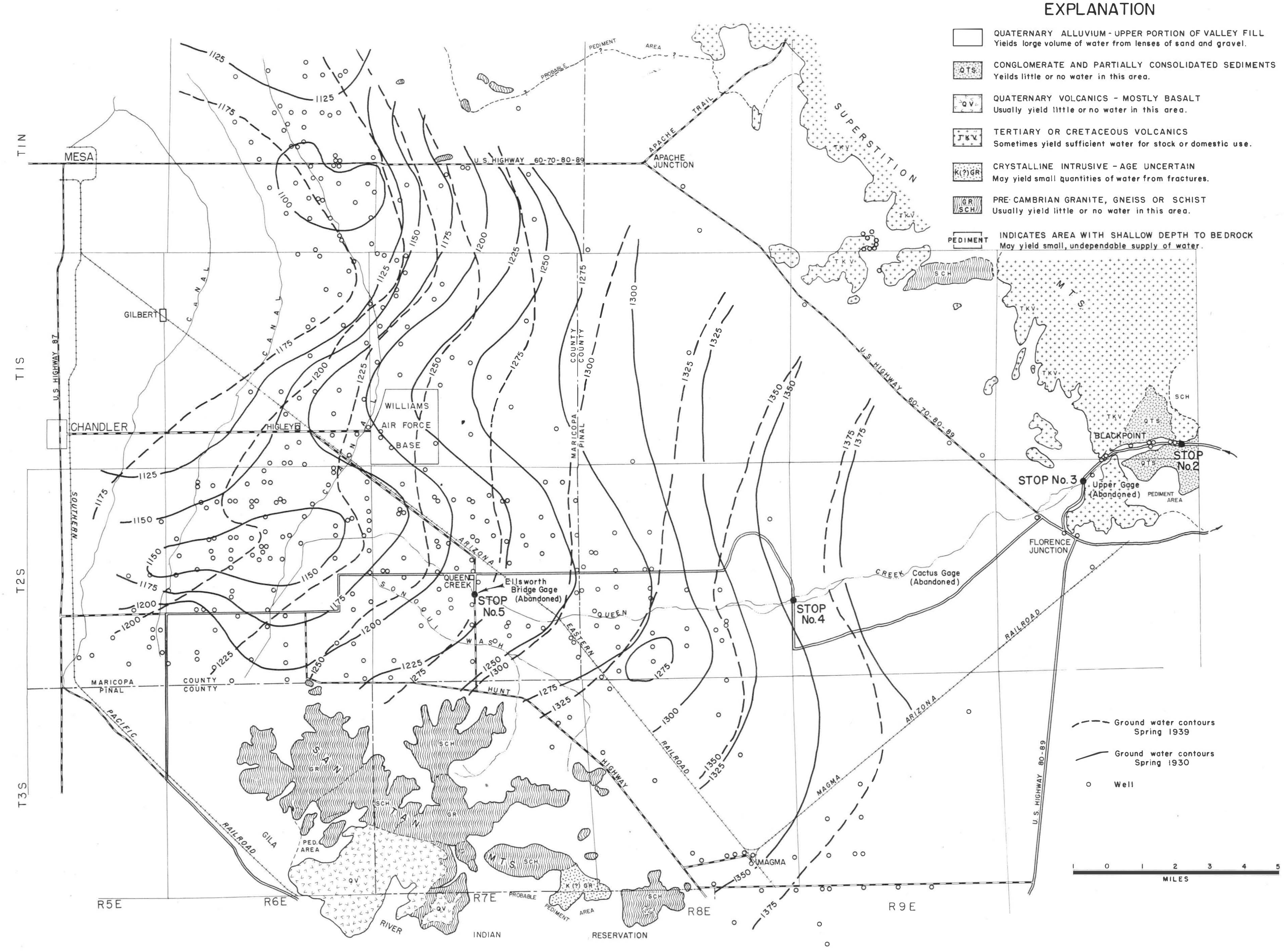


Figure 3.- Map of Queen Creek Area, Maricopa and Pinal Counties, Arizona.

As pumpage increased after the initial development, withdrawals soon exceeded recharge. The accompanying article by Babcock and Cushing (1942) notes that in the period February 12, 1940, to March 18, 1941, about 32,200 acre-feet of recharge occurred. This was a wetter-than-average period, but the recharge was small compared with the 295,000 acre-feet pumped in 1950. The withdrawals in excess of recharge had to come from ground-water storage within the basin, and as a result water levels in wells began to decline. The regional pattern of the decline is made apparent by comparing the 1939 and 1950 water-table contours on the accompanying map (Fig. 3). Locally, the amount of decline is shown by the hydrographs of water-level fluctuations in individual wells (Fig. 4). In the westernmost well graphed, the decline in the 12 years 1939-51 was 53 feet. Farther east, 1 mile north of the town of Queen Creek, the decline was 54 feet. Near the eastern limit of development (2 miles west of mile 33.2) the decline was 25 feet.

In 1951 the Queen Creek area was declared "critical" under the Arizona ground-water code of 1948, in an effort to retard depletion of ground-water supplies. After this designation was applied no new irrigation wells could be drilled or new lands irrigated from wells except those approved prior to the date the area was declared "critical." This, of course, has retarded the previously increasing rate of overdevelopment, but by the time the area was declared critical overdevelopment of ground water had already reached serious proportions. If all pumping in the area were to stop many years would be required for the water withdrawn from storage since 1940 to be replaced.

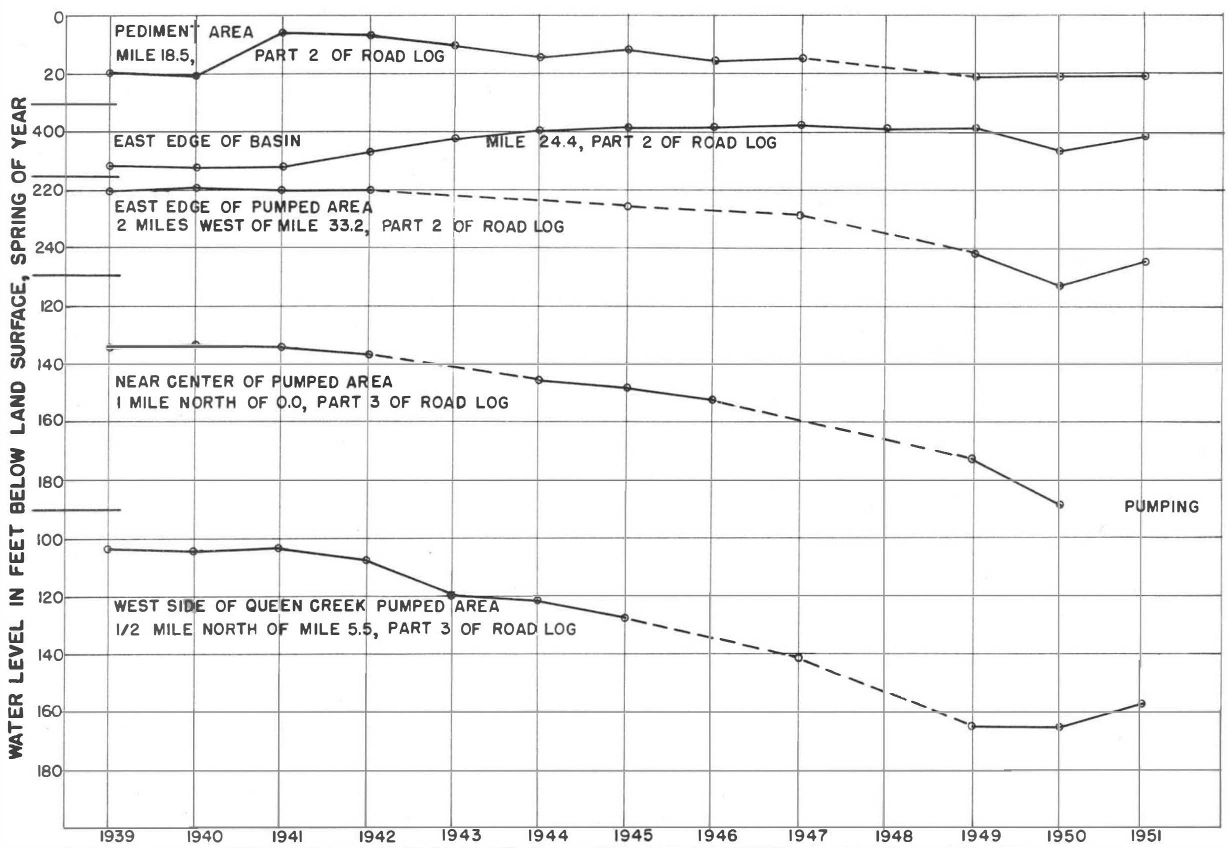


FIGURE 4. — HYDROGRAPHS OF TYPICAL WATER-LEVEL FLUCTUATIONS IN QUEEN CREEK AREA

THIS PAGE

INTENTIONALLY BLANK

RECHARGE TO GROUND-WATER FROM FLOODS IN A TYPICAL DESERT WASH, PINAL COUNTY, ARIZONA*

H. M. Babcock and E. M. Cushing
Ground Water Branch, U. S. Geological Survey

Statement of the problem

Queen Creek, considered in this paper, is a typical large desert wash. It rises in the Pinal Mountains near the mining town of Superior and enters the outwash-plain at Black Point about three miles north of Florence Junction (Fig. 3). Thence it passes over the desert in a southwesterly direction toward Chandler, spreads over the lowlands, and disappears. The flow of the stream consists almost entirely of storm-water and is of the quick, flashy type common to the deserts of the Southwest. In ordinary years the stream is dry most of the time. Formerly the flood-waters spread over the floor of the desert and did no harm. Now, however, they invade highly cultivated lands that are irrigated with water from Salt River or from wells, and cause serious damage to both crops and canals. The damage could be prevented by storing the storm-waters in a reservoir formed by a dam at or above Black Point.

The purpose of the investigation was to determine the probable effect of control by this reservoir on normal ground-water recharge from the stream in the desert stretch, the size of the stream which should be released from the reservoir to give maximum recharge, and the practicability of water-spreading operations to increase the normal recharge. The investigation comprised a part of the studies of the ground-water resources of Arizona that are being undertaken by the Geological Survey of the United States Department of the Interior in cooperation with the Arizona State Water Commissioner and Corps of Engineers of the United States Army. These studies are under the general direction of S. F. Turner. The field-work in the Queen Creek area was started August 5, 1939, and was done by H. M. Babcock and E. M. Cushing under the direction of L. C. Halpenny; the geology was studied by R. B. Morrison.

Geology

In the mountains Queen Creek flows over relatively impermeable schists, granites, and volcanic rocks and loses no appreciable amount of water to deep underground storage.

Older alluvium

About a mile west of Black Point the creek passes from the mountains to the alluvial slope of the desert plain. Near the mountains its present flood-plain is entrenched about 70 feet below the surface of its old alluvial fan. This fan coalesces with those of neighboring washes to form a piedmont plain. A well-defined terrace borders the flood-plain which

---

*Published with the approval of the Director, U. S. Geological Survey.
Reprinted from Transactions of 1942 of the American Geophysical Union.

at Black Point is about 55 feet below the piedmont plain. Westward from Black Point the scarps separating the three surfaces (piedmont plain, stream-terrace, and present flood-plain) become lower until the surfaces converge into a nearly level plain.

West from Black Point for two or three miles the piedmont plain is underlain by a rock-cut pediment that is only partly buried beneath relatively shallow alluvial fill. A little farther west, however, the water-level in wells changes from about 60 feet to over 400 feet below the land surface, suggesting the presence of a buried fault-scarp and thicker deposits of alluvium to the west.

The piedmont and terrace deposits are similar in lithology and are grouped together as older alluvium. Both are moderately well to poorly sorted and contain aggregates of small boulders, cobbles, sand, and silt. Westward this material is finer, though not appreciably better sorted. The deposits appear to have been deposited under conditions such as exist at the present time.

Caliche cementation in the upper six to ten feet of gravel underlying the piedmont plain retards the penetration of water from the surface into the gravel except where streams have cut below the caliche. Caliche is not well developed on the stream-terrace and is usually absent in the flood-plain.

Recent alluvium

Recent stream-deposits of gravel, sand, and silt cover the older alluvium in the present flood-plain. The torrential flash-floods ordinarily carry a heavy bed-load in the upper reaches but this is rapidly dropped as the stream-gradient decreases westward. As a result, a flood-plain with many shifting and interlacing channels has been produced and the sediments become finer outward from the mountains. The degree of sorting varies considerably with the floods that deposit the sediments, but in general it is not high. The most poorly-sorted sediments appear to be laid down during the larger flash-floods. During periods of steady flow of relatively clear water (such as sometimes occur after floods caused by winter rains) the channel-materials are reworked, becoming better sorted and consequently more permeable.

In the first few miles of the desert section, the flood-plain is relatively constant in width, but westward from there it widens. In the upper reaches the bed of the creek is composed of sand, gravel, and boulders. Farther down it is composed principally of sand, although the smaller channel beds are silty. The flood-plain outside of the present channels is covered by one to several feet of silt, usually underlain by coarse deposits that represent earlier channel-deposits. Still farther down the silt-mantle thickens and contains little sand or gravel.

Ground-water recharge

Queen Creek is influent throughout its entire course below the Black Point Dam site. Minor floods disappear within a short distance. Larger floods cross the area with gradually diminishing losses as the channel-deposits and older alluvium become finer, and the part of the flow that is not absorbed spreads out over the relatively impermeable silt-covered plain at the lower end of the creek and is lost by evaporation and transpiration.

Two gaging-stations have been maintained in connection with the Queen Creek investigation--the upper station about three-fourths of a mile below Black Point and the lower one at the county highway bridge, about 20 miles below Black Point. An intermediate staff-gage designated the Cactus gage also was maintained for a time. In the discussion that follows, the upstream station is designated as the Upper Gaging-Station and the downstream station as the Ellsworth Bridge Gaging-Station. The Upper Station was established in August 1939, and the Ellsworth Bridge Station somewhat later. The first year of their operation was exceptionally dry and the second year exceptionally wet. This afforded an opportunity for comparison of the rate of seepage-loss under these two extreme types of climate. Table 4 gives a summary of losses between the two gaging-stations from 17 floods that occurred between February 12, 1940, and March 12-18, 1941. During the two years floods with peak-discharge, ranging from a few second-feet to 13,000 second-feet, were recorded at the upper station (one second-foot equals 448.83 gallons a minute). Altogether during the period 64,300 acre-feet of water passed the Upper Gaging-Station while 32,100 acre-feet passed the Ellsworth Bridge Gaging-Station, showing that about one-half of the total runoff was recharged to ground-water (one acre-foot equals 325,851 gallons).

In order to compute the rate of infiltration between the gaging-stations, the areas wetted by floods of different magnitudes were estimated. This was done by running traverses across the flood-plain at intervals of one-half mile and estimating the aggregate widths of the channels wetted by flows of 10, 25, 100, 1,000 and 2,000 second-feet, and by a very large flood on August 6, 1939. From these data the arithmetical average of widths wetted by each flow and the number of acres wetted by flows of various magnitude were estimated. The areas wetted were plotted against the discharge in second-feet for each hour of flow.

The computed average rate of infiltration over the wetted area for the different floods varied from 0.14 to 2.09 feet per day and averaged 1.08 feet per day (see Table 4). The rate of infiltration for the summer-type flash-floods was less and showed a wider range than those for the winter-type floods. This is attributed to the fact that floods of the summer type are of shorter duration and on the average carry more silt than those of the winter type. During water-spreading operations in the upper Santa Ana River, California, Muckel and Mitchelson (1937, p. 16) demonstrated that the rate of infiltration decreased appreciably with the application of dirty or silt-laden water. The wide range in the computed rate of infiltration for the summer-type floods on Queen Creek may have been due largely to inability to measure these floods accurately.

The unusually heavy rainfall during the winter of 1940-41 aided the growth of a large amount of heavy vegetation in the drainage-basin of Queen Creek. This vegetation decreased the silt-load carried by Queen Creek, which probably caused the rate of infiltration to increase during the winter and spring.

Runs of seepage-measurements

Due to the unusually heavy rainfall, water flowed continuously past the Upper Gaging-Station and was comparatively clear a considerable part of the time from January 24 to April 24, 1941. On two occasions during this period about 500 second-feet of fairly clear water, that passed the Upper Gaging-Station, caused no flow at the Ellsworth Bridge Gaging-

TABLE 4. - SUMMARY OF LOSSES FROM FLOODS ON QUEEN CREEK

Observations at Upper Gaging-Station (U.G.-S.) and Ellsworth Bridge Gaging-Station (E.B.G.-S)

Date	Peak-flow at		Total discharge at		Total loss	Length of flow at		Rate of loss
	U.G.-S.	E.B.G.-S.	U.G.-S.	E.B.G.-S.		U.G.-S.	E.B.G.-S.	
	sec-ft	sec-ft	ac-ft	ac-ft	ac-ft	hr	hr	ft/day
Feb. 12, 1940	170	30	68,8	11,5	57,3	20	12	0,73
July 24-25, 1940	170	28	25,6	4,9	20,7	14	8	0,71
Aug. 3-4, 1940	700	214	58,4	45,0	13,4	16	16	0,14
Oct. 5, 1940	650	365	152	65,7	86,3	12	9	1,03
Oct. 27, 1940	994	395	244	149	95	25	26	0,46
Nov. 18-19, 1940	3,730	2,500	1,880	1,260	620	33	33	1,16
Dec. 11, 1940	1,790	795	309	144	165	18	18	1,17
Dec. 12, 1940	4,710	3,250	1,340	1,060	280	15	15	0,86
Dec. 24, 1940	8,020	4,340	2,680	1,830	850	28	24	1,31
Dec. 30, 1940 to Jan. 2, 1941	9,880	5,700	12,000	8,500	3,500	140	134	1,37
Jan. 12-13, 1941	5,990	3,300	2,700	1,380	1,320	48	37	1,62
Jan. 24-25, 1941	800	535	569	146	423	27	24	1,37
Jan. 28, 1941	3,340	1,160	1,270	321	949	47	31	1,74
Feb. 7-8, 1941	3,080	1,370	1,900	628	1,272	43	34	2,09
Feb. 24-25, 1941	4,240	3,220	3,090	2,360	730	54	54	0.75
Mar. 1-2, 1941	4,020	2,380	1,480	832	647	21	16	1,78
Mar. 12-18, 1941	7,420	5,420	15,600	9,320	6,280	138	126	1,71

Station. The rate of infiltration on these two occasions was computed as about three feet a day. Eleven runs of seepage-measurements were made during this period between January 24 and March 29. In these runs the discharge of the creek was measured at several selected points in turn, the stream-gager moving in a downstream direction. The difference in discharge between any two of these points represented approximately the amount of water lost by infiltration in the intervening reach. The distance between the gaging-points was measured and the area wetted in each of these reaches was computed. From these data the average rate of loss in depth of water in feet a day over the wetted area was computed.

A comparison of the rates of infiltration over the wetted area between the gaging-stations during floods with the rates determined from the seepage-measurements during moderate to low flows of comparatively clear water is instructive. The average for the floods over the entire stretch was only about one foot a day, while the average for the clear water in the individual parts of the stretch during the seepage-runs was more than four feet a day. The smaller rate of infiltration during the floods was due in part to the large silt-load, carried during the early stages of the flood, and in part to the spreading of the flood-water during large flows upon silty, rather impermeable material in areas outside the channels.

In the seepage-measurements it was noted that the rate of infiltration progressively decreased in a downstream direction as the material in the channel-bottom became progressively finer. It was also observed that during continuous flows of clear water after floods, the rate of infiltration increased with time. For a 2.1-mile stretch between the Upper Gaging-Station and the highway bridge it was 6.18 feet a day on January 29, 6.53 feet a day on January 30, and 6.82 feet a day on January 31, 1941. On March 23, 1941, several days after a large flood, the rate of infiltration for the same reach was 5.98 feet a day, and on March 25, 6.84 feet a day. In each case the water was clear at the Upper Gaging-Station but became progressively muddier downstream, showing that the clear water had sufficient velocity to transport the fine material, leaving the coarser and more permeable material. It is believed that a controlled steady flow of fairly clear water would soon wash out most of the fine material, and that under control the flow at the Upper Gaging-Station could be reduced sufficiently to prevent any water from flowing past the Ellsworth Bridge Gaging-Station and being lost on the silt-covered areas below.

Rise in water-levels

Wells in the desert plain near Queen Creek showed considerable rise in water-level during the early spring of 1941 as a result of recharge from the winter and spring runoff, whereas wells at a considerable distance from the creek showed very little rise.

Infiltration from pools

The rate of decline in water-levels was measured in pools that remained in the channels after floods in an effort to check the coefficients of infiltration determined from stream-gaging. The rate of lowering ranged from a maximum of 2.76 feet a day to a minimum of 0.16 foot a day, the initial rate averaging 0.91 foot a day. This is fairly close to the average coefficient of infiltration of 1.08 feet a day computed from the flood-measurements.

Evaporation-losses from bed of creek

Following a flood in the comparatively dry fall of 1939, several small containers filled with stream-bed material and a water-evaporation pan of the Colorado sunken-pan type were installed in the bed of the creek. The loss in moisture from the containers was approximately equal to the loss from the evaporation pan for the first 36 hours after the flood, but subsequently it decreased rapidly. This indicates that the amount of water required to satisfy the deficiency of moisture in the stream-bed before water could penetrate to the underground reservoir was not very large.

Conclusions

The principal recharge to ground-water in the desert region of the Southwest is from occasional flash-floods in the mountain streams and washes. Recharge occurs by infiltration into the stream-beds where they cross the desert plains. In the lowermost reaches of these streams and washes, as in Queen Creek, the flood-water generally spreads over the surface of silt-covered playas and is lost by evaporation. In the two years of record about half of the flow of Queen Creek at the mouth of its canyon was recharged to ground-water. It might be possible, however, by the construction of a flood-control dam to put practically all the water into ground-water storage. A dam at or above Black Point would release flood-water of comparatively low silt-content at a nearly uniform rate and would extend the flow over a much longer period than now. It is believed that with all floods controlled and only small flows released there would be little tendency for the bottom of the Queen Creek Channel to become sealed with silt. In fact, with the release of clear water, the channel would be cleaned of a part of the fine materials that are now present.

The investigation indicates that the largest discharge that could be released from the Upper Gaging-Station with no flow past the Ellsworth Bridge Gaging-Station is about 500 second-feet, if most of the silt has settled out before the water leaves the reservoir. It seems probable, however, that this could be increased to as much as 1,000 second-feet by the installation and operation of artificial spreading-devices in the channels of Queen Creek.

In Arizona, as in most other parts of the Southwest, the greater part of the surface-water resources that it is practicable to develop, and a large part of the ground-water resources are utilized. At the present rate of development the limit of the ground-water supplies will soon be reached. It should be possible to extend this limit in some localities by artificial recharge of water, as has been done with considerable success in southern California, thus utilizing water that otherwise would be wasted by evaporation on the desert.

PALEOZOIC AND CRETACEOUS STRATIGRAPHY OF THE TUCSON MOUNTAINS

TRIP 2, ROAD LOG

Thursday, April 10, 1952

Leaders: Donald L, Bryant and John F, Lance
Driving distance: Total logged distance 54,2 miles

General Statement

The route of Trip 2 follows the Santa Cruz River for a short distance north of Tucson, crosses by way of Picture Rocks Pass (Stop 1) to the west side of the Tucson Mountains, proceeds southward along the western margin of these mountains, and returns to the Santa Cruz Valley across a pass at the southern end, The structure, stratigraphy, and general geographic setting of the Tucson Mountains can be seen at the stops and from various other points along the route, The Tucson Mountains consist of a series of tilted fault blocks composed largely of Cretaceous sedimentary and volcanic and Cenozoic volcanic rocks, Older rocks, ranging in age from Precambrian to Permian, are preserved on both sides of the range as erosional remnants of a thrust sheet of pre-block fault age, A Paleozoic section, typical of much of southeastern Arizona, can be examined in two of these klippen at Stops 2, 3, and 5, The general setting and some of the volcanic rocks of the mountains are to be seen at Stop 1, and at Stop 4 details of some of the Cretaceous continental sediments can be examined,

0.0	0,0	Prince Road and Casa Grande highway (State 84), This intersection is 1,2 miles north of the overpass on Highway 84, The overpass is about 4,5 miles from the University of Arizona campus, and about 4,3 miles from the center of downtown Tucson,
3,2	3,2	Dairy farm on left, Tortillita Mountains ahead, Catalina Mountains on right, Tucson Mountains on left, The road follows the valley of the Santa Cruz river, which flows (when water is available) northward from Mexico,
0,6	3,8	Cross Rillito Creek,
1,1	4,9	Cross Canon del Oro, Picacho Peak, a famous landmark near Casa Grande, is visible ahead to left of road, The double peak is composed of Cenozoic volcanic rocks,
2,7	7,6	Cortaro, Turn left, CAUTIOUSLY, Tall black metal smokestack with white tip marks intersection, Ahead is Picture Rocks Pass through Tucson Mountains, North of the pass is Safford Peak, a volcanic neck, Granitic and arkosic rocks form Amole peak, south of the pass,
0,9	8,5	Dead end, Turn right, End of pavement,
0,1	8,6	El Paso Natural Gas Company pipeline crossing,

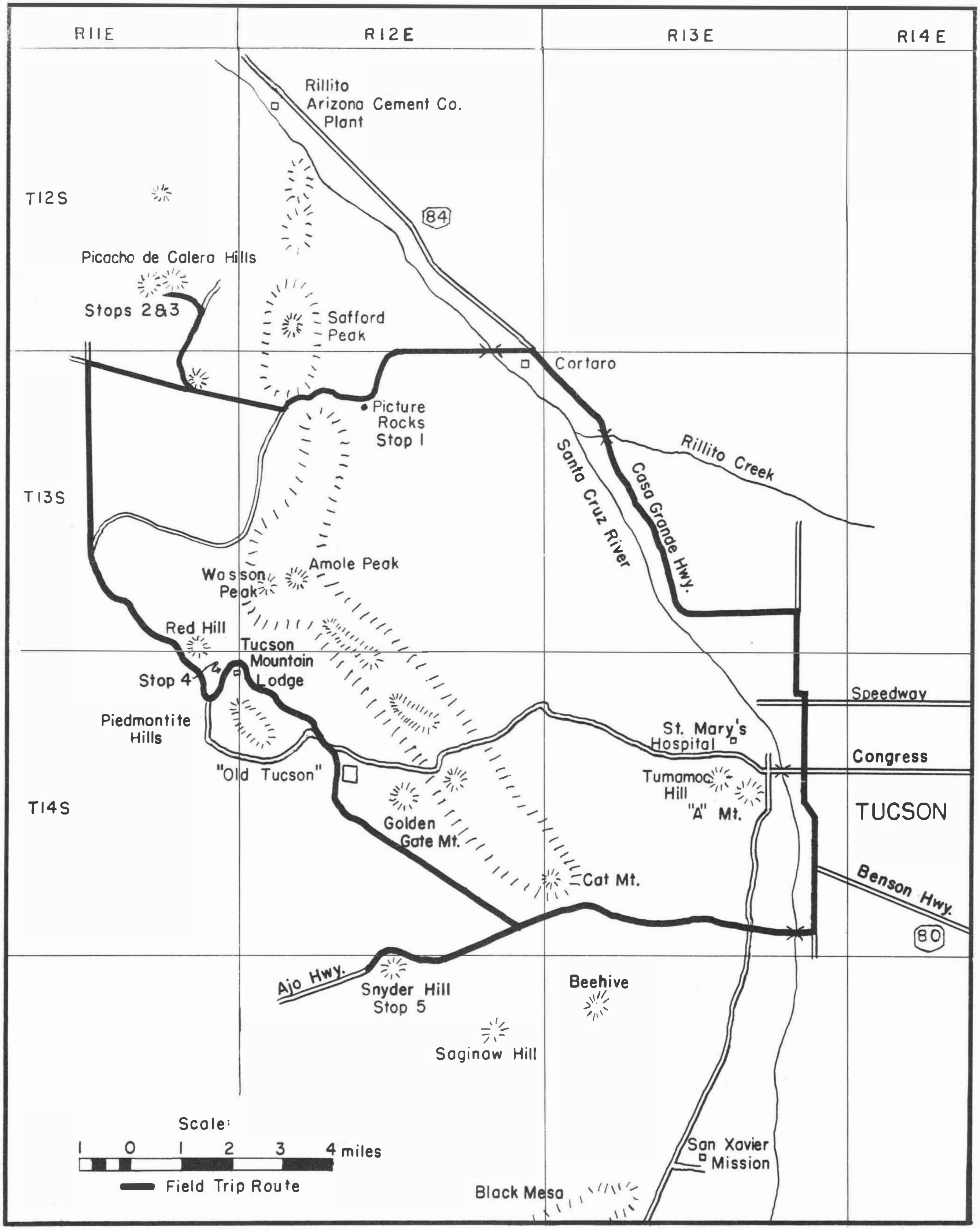


FIGURE 5.— ROAD LOG INDEX MAP, TRIP 2. TUCSON MOUNTAINS.

0.3	8.9	Turn left on Picture Rocks road.
1.0	9.9	Turn left to Picture Rocks for STOP 1. This site affords a good view of a part of the Santa Cruz Valley and the Santa Catalina Mountains to the east. Safford Peak and tilted lava flows of Cretoceous and Tertiary age are seen to the north in the Tucson Mountains, and the granitic Amole and Wasson Peaks are to the south. Dominating the local desert vegetation in this area are the giant saguaros. Other varieties of cactus represented are several types of cholla, the barrel, hedgehog, and prickly pear. Shrubs include the paloverde, creosote bush and ironwood trees. The petroglyphs from which Picture Rocks received their name have largely been removed and now adorn many Tucson fireplaces.
0.2	10.1	Continue west on Picture Rocks road.
0.7	10.8	Summit of Picture Rocks Pass. Enter Tucson Mountain Park. The road west of the pass winds through one of the finest stands of saguaros in the state.
0.1	10.9	Amole peak at 9 o'clock.
1.4	12.3	Note eastward dip of volcanic rocks to right of road.
0.5	12.8	Turn right at Avra Valley sign. Silver Bell Mountains at 12 o'clock on skyline. Picacho de Calero Hills (Twin Peaks) at 1 o'clock.
1.5	14.3	Mohican Ranch gate. Across the Avra Valley at about 12 o'clock, are the Silver Bell Mountains on skyline. South along the skyline are the Waterman, Roskruge, and Coyote Ranges. These mountains, with the Quinlans and the Baboquivaris farther south, form the western side of the Avra-Altar Valley which extends into Mexico. Usage varies, but in general the southern part of this depression is called the Altar, and the northern part, including the area visited on this trip, the Avra Valley.
0.6	14.9	Turn right past large saguaro cactus. This land is the property of Allen R. Wade, of Tucson, who has kindly given permission to pass across it.
2.0	16.9	Turn left at large paloverde tree just before road crosses small arroyo. The general structure of the Picacho de Calero Hills (Figs. 6 and 7) can be seen from various points along this road. Precambrian Pinal schist forms the western flank of the smaller hill to the west. The top of this hill, and much of the east side is formed from Cambrian Bolsa quartzite, and the Cambrian Cochise, Abrigo, and Rincon formations crop out in the saddle between the hills and on the lower western slope of the larger (east) hill. The Middle Cambrian Cochise and the Upper Cambrian Abrigo formations are separated by a 12-foot thick quartzite bed which is near the lowest point in the saddle. The Cambrian strata dip steeply to the east, as do the overlying Devonian, Mississippian, and Pennsylvanian beds. Granite is exposed on the south slope below the saddle.

0,5	17,4	Turn left on graded road. This road is on the property of the Arizona Portland Cement Company, and through their generosity it is possible for us to visit this locality. Travel along this road is prohibited without permission because of blasting operations and heavy trucking.
0,7	18.1	STOP 2. Floor of quarry in saddle. The Arizona Portland Cement Company is gradually removing both the Pennsylvanian limestone of the eastern hill and the shale of this quarry and hauling it to the cement plant near the Casa Grande highway to the east. Shales of the Cochise and Abrigo formations are exposed on the floor of the quarry; a quartzite between the two formations forms the prominent spur which divides the quarry into two parts. Alternating siltstones, sandstones, and limestones of the Cochise formation are exposed at the base of the western hill. The underlying Bolsa quartzite crops out farther up the hill. Numerous fucoids are in the Cochise at the foot of the hill and phosphatic-shelled brachiopods occur at certain horizons in the blue and green siltstones within the quarry. Some brachiopods and trilobite fragments are in the Abrigo exposed in the quarry, but at present the best collecting locality for brachiopods and trilobites appears to be on the slope of the eastern hill just above the quarry. Above the Abrigo formation is a forty-foot unit of pink coarse-grained limestone, the Rincon limestone, containing abundant fragments of the trilobite Asaphiscus. Overlying the Rincon is the Devonian Picacho de Calera formation, consisting of about 75 feet of gray limestane and dolomite and containing stromatoparoids, a few small goniatites, and in a thin sandstone layer at the top, fish teeth. Above this is the Martin limestone, here about 275 feet thick, containing Upper Devonian fossils. A good collecting locality is in the dark limestone just above and to the north of the large water tank. The overlying 600 feet of Escabrosa limestone, which contains a few zones of Lower Mississippian corals and brachiopods, will not be examined at this stop. The upper part of this formation will be seen at Stop 3. Leave quarry and return along cement company road to east.
0.7	18.8	STOP 3. The contact between the Mississippian Escabrose and the Pennsylvanian Naco formations is exposed on the hill north of the road. Some fossils occur in the upper part of the Escabrose, and numerous corals, fusulinids, and brachiopods are in the lower part of the naco formation above. Watch for the cholla cactus in this area. These are the notorious "jumping cholla." They bite!
0.5	19.3	Turn right at paloverde tree.
2.0	21.3	Turn right at large saguaro cactus.
1.9	23.2	Turn left at Pitt's Ranch road.
2.8	26.0	Marana Air Base visible to right of road in Avra Valley.
0.1	26.1	Intersection. Continue straight.

0.1	26.2	Tucson Mountain Park Road enters from left. Continue straight ahead. Low hills to left of road consist of Cretaceous Amole arkose overlying Naco limestone.
1.8	28.0	Sierrita Mountains at 2 o'clock. High peak on skyline is Baboquivari, a volcanic neck and famous landmark of southeastern Arizona. It is in the Baboquivari Mountains about 20 miles from the Mexican border.
0.3	28.3	Recreation redbeds of Cretaceous age in hill on left.
1.6	29.9	At crest of hill note view of Avra-Altar Valley on right, and Santa Cruz Valley on left. Santa Rita Mountains, southeast of Tucson and on the east side of the Santa Cruz Valley, at 10 o'clock. Sierrita Mountains, south of the Tucson Mountains and between the two valleys, at 11 o'clock. Note exceptionally good view of the pediment surrounding the Sierritas. The small group of hills on pediment to left of Sierritas proper contain the San Xavier and Mineral Hill mining districts. On west side of Altar Valley, Baboquivari Mountains appear at 1 o'clock, with Quinlan and Coyote Mountains to the north. Note lava flow on flanks of Roskruge Mountains, at 2:30 o'clock.
0.7	30.6	Turn left toward park headquarters.
0.6	31.2	STOP 4. Tucson Mountain Lodge and Tucson Mountain Park Headquarters to right of road. A desert zoological and botanical garden, which will include geological displays, is being developed here by William H. Carr, under a grant from Charles Lathrop Pack Foundation of New York. A short hike down into Kings Canyon, on left of road, will be made to see the Cretaceous Recreation redbeds, consisting of red and purple siltstones and sandstones dipping about 25° northeast. The redbeds are unfossiliferous, but ripple marks and other sedimentary structures are common. The area abounds in specimens of "Tucson meteorites," which are weathered magnetite pebbles from contact zones adjacent to intrusives into the Amole arkose, exposed to the east.
0.1	31.3	Take right fork in road. Amole arkose forms hills to left of road.
0.3	31.6	Ranger station on left. Piedmontite Hills, ahead on right, consist of Cretaceous volcanic rocks faulted against Amole arkose. Fossils from the Amole in these hills are reported by Reeside (McKee, 1951, p. 496) to be of probable Lower Cretaceous age.
0.6	32.2	Golden Gate Peak, composed of Tertiary volcanic rocks, at 12 o'clock. Peak at 11 o'clock is on crest of range just south of Gates Pass. The crest of the Tucson Mountains from here south to the Ajo road is formed from the Cat Mountain rhyolite flows, of Tertiary age, tilted to the northeast and overlying Cretaceous volcanic and sedimentary rocks.
0.7	34.2	Gates Pass road enters from left. Continue straight.

0,3	34,5	Continue straight, Road to left leads to Old Tucson, a former movie set used in filming many horse operas, and now maintained as a recreational area,
1,2	35,7	Intersection, Continue straight,
0,6	36,3	At 12 o'clock is Cat Mountain, composed of Tertiary rhyolite flows, Hills to right and left of road are of Amole arkose,
0,2	36,5	Santa Rita Mountains on skyline to left, Sharp peak at 11 o'clock is Beehive, a Tertiary volcanic neck in the southern part of the Tucson Mountains, At 1 o'clock is Black Mesa, consisting of flat-lying basalt flows of presumed Quaternary age, San Xavier mining district at 2 o'clock,
0,5	37,0	Cattle guard, Leave Tucson Mountain Park,
2,7	39,7	Ajo road, Turn right,
3,1	42,8	Turn left toward west side of Snyder Hill at pipeline crossing,
0,3	43,1	STOP 5, Snyder Hill, a klippe composed of 226 feet of limestone and dolomite, is typical of the upper part of the Permian section of southern Arizona (Figs, 8 and 9), Although collecting is difficult, fossils are abundant in many zones,
0,3	43,4	Turn right toward Tucson on Ajo road,
3,1	46,5	"Old Tucson" road enters from left, Continue straight,
3,4	49,9	Exposures of white rock about 100 yards to right of road represents an agglomerate in the Cat Mountain rhyolite sequence, This material has been quarried for building stone in the past, and was used in constructing the old Business Administration building on the University of Arizona campus,
1,0	50,9	Turn left on Mission Road, Tumamoc Hill and "A" Mountain (Sentinel Butte) are ahead, from left to right, These are composed of Tertiary or Quaternary volcanic rocks, principally basalt and tuff,
3,3	54,2	Congress Street, Turn right for downtown Tucson, or return to University of Arizona campus by continuing straight ahead to Speedway, right on Speedway to Park Avenue, right on Park to the Third Street entrance of campus,

PALEOZOIC AND CRETACEOUS STRATIGRAPHY OF THE TUCSON MOUNTAINS

Donald L, Bryant
University of Arizona

Introduction

The Tucson Mountains comprise a northwesterly-trending range about twenty-five miles long with a maximum width of ten miles. The easternmost outliers mark the western edge of the city of Tucson. These mountains rise abruptly from the surrounding valley floors which have an elevation of 2000 feet at the north end and about 2500 feet at the south end. Amole (A mo' lee) Peak, which is 4500 feet above sea level, is the highest peak in the range, extending from Amole Peak south to Cat Mountain just north of the Ajo (Ah'ho) highway (Fig. 5), maintains an elevation of nearly 4000 feet.

Little has been written about the geology of the Tucson Mountains. A few early papers of a reconnaissance nature discuss limited portions of the area; others describe local features of petrology and petrography. Some papers of more general nature refer to the Tucson Mountain area incidental to discussions of some other subject. Most of these papers are included in the references at the end of this guidebook. The only comprehensive report is "Tucson Mountains, an Arizona Basin Range type," by W. Horatio Brown (1939). The structure of the range as summarized below and the details of the Cretaceous stratigraphy are taken directly from Brown's paper.

STRUCTURE

Brown (1939, p. 701, 748-755) considers the Tucson Mountains to consist structurally of three principal parts: (1) a basement block of Cretaceous and Paleozoic rocks; (2) a series of tilted Tertiary volcanic rocks; and (3) a series of nearly flat-lying Tertiary or Quaternary basaltic rocks.

The basement block consists of a series of non-marine Cretaceous strata overridden from the west by a thrust sheet of marine Paleozoic sedimentary rocks. Remnants of this overthrust sheet remain as scattered limestone klippen on the flanks of the range and in outlying buttes. They are in low hills on the east side, and below the lava escarpment on the west side, south of Amole Peak. Snyder Hill, the Picacho de Calera Hills (called Twin Peaks on the Cortaro, Arizona quadrangle), and an unnamed hill north of Picacho de Calera are outlying blocks of the overthrust sheet. Before or during the thrusting, the underlying Cretaceous rocks were folded into a shallow syncline and the whole complex was intruded by granitic and quartz monzonitic stocks, and associated dikes and sills. After the thrusting and intrusion, there was a long period of erosion which resulted in peneplanation and almost complete removal of the overriding sheet.

Tertiary volcanics in considerable quantity accumulated on the erosion surface that developed after thrusting. The entire area was then broken by high-angle faults; blocks were tilted toward the northeast and later eroded to form the present long dip slopes of the mountains. The result is a range with gentle slopes facing northeastward and strong escarpments facing southwestward.

The final event in the constructional history of the Tucson Mountains was the extrusion of Tertiary or Quaternary tuffs and basaltic flows, remnants of which now form Tumamoc Hill, "A" Mountain and the flat-topped hills near the San Xavier (San Za veer') Mission.

STRATIGRAPHY

General

The Precambrian Pinal schist and stratified rocks representing parts of all Paleozoic systems except the Ordovician and Silurian crop out in many places in south central Arizona. In the Tucson Mountains numerous small klippen formed of these rocks, principally the ones of Pennsylvanian and Permian age, are scattered along both sides of the range. Only in the outlying Picacho de Calera Hills, however, is there a relatively unbroken sequence ranging in age from the Precambrian Pinal schist through the Pennsylvanian. The thickest unit of Permian rocks in the vicinity of Tucson occurs in another outlier, Snyder Hill (Fig. 5).

Marine Cretaceous rocks are known in southern Arizona only in the Bisbee region (Comanchean Bisbee group) and in the Patagonia Mountains (Stoyanow, 1949). Non-marine Cretaceous strata of great thickness occur in many parts of southern Arizona, however, and represent deposits of Upper as well as Lower Cretaceous age (Stoyanow, 1949, p. 58; McKee, 1951, p. 494, 497).

In the Tucson Mountain area, Brown (1939, p. 713) divides the Cretaceous non-marine rocks into three units: (1) a lower volcanic member; (2) the Recreation red beds; and (3) the Amole arkose. About 300 feet above its base, the Amole arkose contains a fresh-water molluscan fauna of probable Lower Cretaceous age.

Rocks of the Tucson Mountains that are younger than Cretaceous include Tertiary and Quaternary volcanics, lake beds, conglomerate and alluvium.

Precambrian

Pinal schist

Precambrian Pinal schist is exposed on the western face of the west hill at Picacho de Calera (Fig. 6). It consists of grayish green quartz sericite schist with a satiny sheen. The lithology of the unit and its position unconformably below the Middle Cambrian Bolsa quartzite leave no question as to its equivalence with more extensive units of Pinal schist exposed in many other parts of southern Arizona. The field trip party will not have time to visit this outcrop.

Cambrian

General

Many of the names of the principal stratigraphic units recognized in southern Arizona are those applied by Ransome during early detailed studies at Bisbee (Ransome, 1904). Some of these units have since been subdivided and some new unit names have been added to the column.

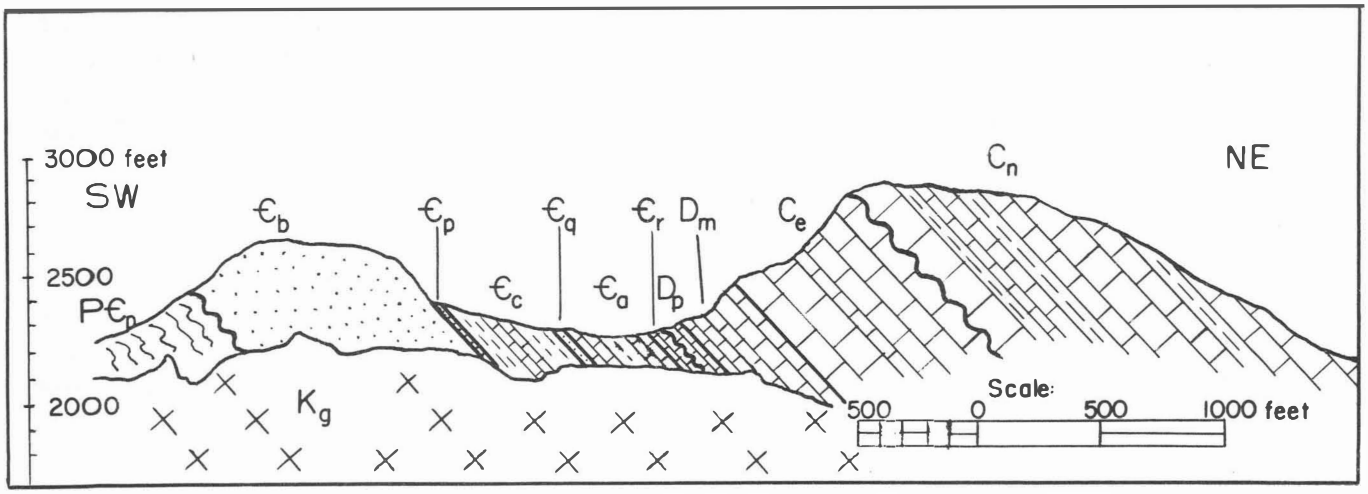


FIGURE 6. STRUCTURE SECTION THROUGH THE PICACHO DE CALERA HILLS

P€p, Pinal schist; €b, Bolsa quartzite; €p, Pima sandstone; €c, Cochise formation; €q quartzite; €a, Abrigo formation; €r, Rincon limestone; Dp, Picacho de Calera formation; Dm, Martin limestone; Ce, Escabrosa limestone; Cn, Naco formation; Kg, Cretaceous (?) granite.

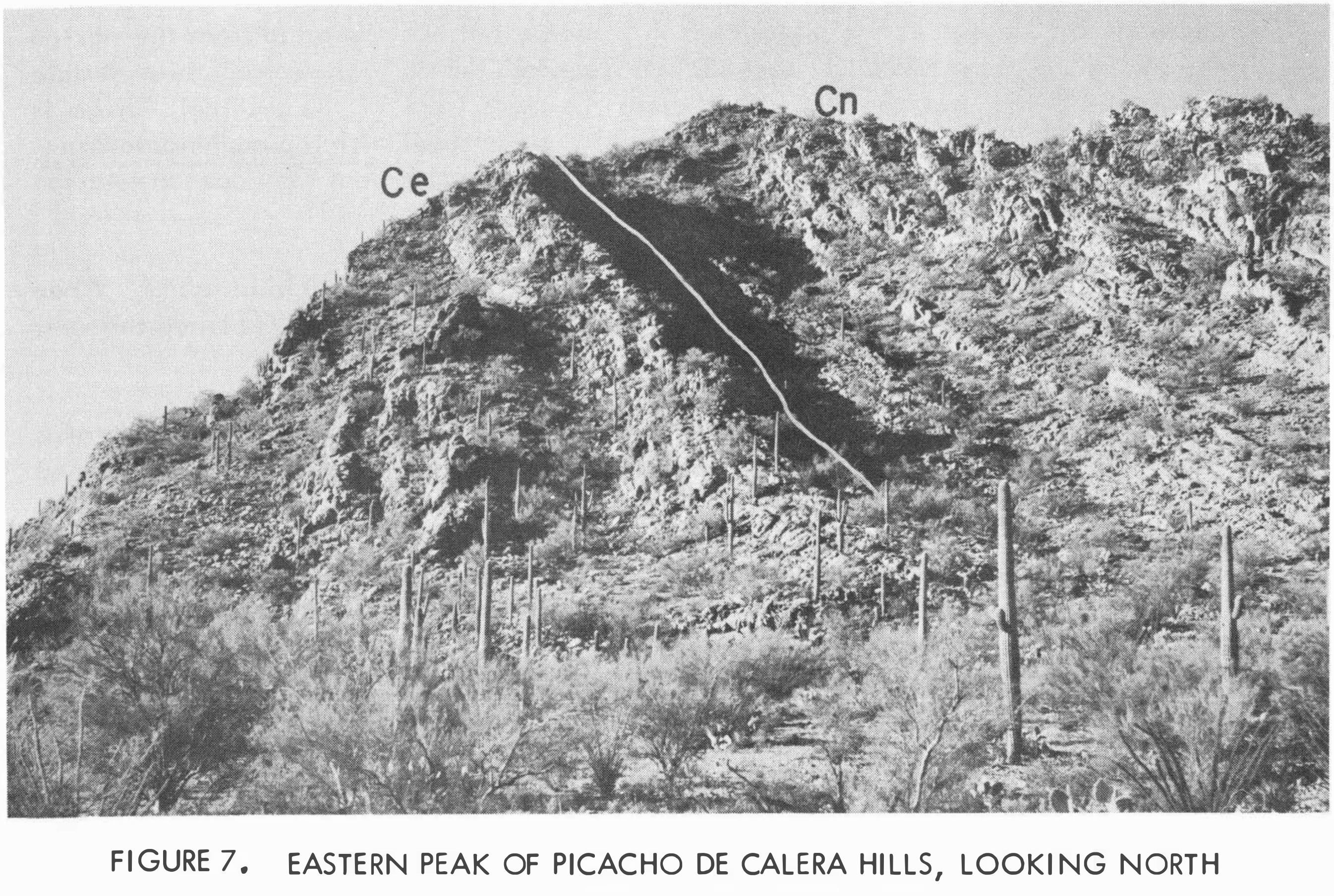


FIGURE 7. EASTERN PEAK OF PICACHO DE CALERA HILLS, LOOKING NORTH

Ce, Escabrosa limestone; Cn, Naco formation.

The Bolsa quartzite and the Abrigo limestone were named by Ransome. The Bolsa quartzite is now generally accepted as originally defined (Ransome, 1904, p. 28) but the Abrigo limestone has been subdivided by Stoyanow (1936, p. 466-471) into Middle and Upper Cambrian units, each consisting of two or more formations. Most of these divisions are shown on the Cambrian Correlation chart prepared by the Cambrian Correlation Committee (Cambrian subcommittee, 1944, Howell, chairman).

Bolsa quartzite (Middle Cambrian)

The Middle Cambrian Bolsa quartzite is exposed in numerous southern Arizona localities. It has the same characteristics in all its outcrops. It is a light brown to purple, fine-grained to coarsely conglomeratic orthoquartzite, commonly strongly cross-bedded, and 500 feet or more in thickness.

The Bolsa quartzite crops out on the top and upper east slope of the western hill at Picacho de Calera, where it has a thickness of 700 feet (Fig. 6). It rests unconformably on the Pinal schist and is conformably overlain by the Pima sandstone, four feet thick, at the base of the Middle Cambrian Cochise formation. No diagnostic fossils are known from the Bolsa quartzite but it contains numerous worm trails.

Cochise formation (Middle Cambrian)

The Cochise formation is of wide areal extent in southern Arizona. It was formerly considered part of the Abrigo limestone of Ransome but was separated from the Abrigo limestone by Stoyanow (1936, p. 466-481) because the Cochise formation contains Middle Cambrian trilobites and brachiopods, whereas the upper part of the original Abrigo is characterized by the presence of the Upper Cambrian guide fossil, Tricrepicephalus texanus. The Cochise typically has a greater percentage of clastic sediment than does the Abrigo (restricted).

The basal four feet of the Cochise formation has a distinctive trilobite fauna. When Stoyanow (1936, p. 466) subdivided the Cambrian of southern Arizona, he named this unit the Pima sandstone.

At Picacho de Calera, the Cochise formation crops out in the saddle between the hills (Fig. 6). It consists of light brown to gray, highly micaeous, thin-bedded siltstones and sandstones in units up to ten or twelve feet thick, separated by foot-thick, bluish gray, gnarly limestones. The Cochise lies conformably above the Bolsa quartzite and below a similar quartzite, twelve feet thick, which in turn is conformably below the Abrigo formation. The latter quartzite is stratigraphically in the same position as the Southern Belle quartzite which lies between the Middle and Upper Cambrian units in Peppersauce Canyon in the Santa Catalina Mountains (Stoyanow, 1936, p. 476).

The Cochise formation is about 300 feet thick in the Picacho de Calera Hills. The lower part contains abundant worm trails. In siltstone of the upper and middle parts small phosphatic brachiopods are present and in the limestones some trilobite fragments occur.

Abrigo formation (Upper Cambrian)

The Abrigo formation, as restricted by Stoyanow (1936, p. 467), is limited to that part of Ransome's Abrigo which contains Tricepicephalus texanus and which lies below Upper Cambrian units that contain Billingsella coloradoensis. The division between the Abrigo and Cochise formations is difficult to recognize in many places because these formations are quite similar lithologically and well-preserved fossils are not common in them.

The Abrigo characteristically is a bluish gray limestone, in many places cherty and dolomitic. It occurs as relatively thin, gnarly beds separated by thin beds of micaceous, shaly siltstones and fine-grained sandstones. The siltstone and sandstone make up only a small percentage of the formation. The formation ranges from 200 to 400 feet thick and is present in most areas in southern Arizona where Cambrian rocks are exposed.

The Abrigo formation in the Picacho de Calera Hills crops out in the saddle east of the Cochise formation, with the twelve-foot quartzite unit mentioned above, lying between them. The Abrigo here is reported by Brown (1939, p. 711) to be 400 feet thick, but in the saddle area the thickness is slightly less than 300 feet. Lithologically it is similar to the typical Abrigo of other southern Arizona sections and resembles the Cochise formation below it. The fauna of the Abrigo consists of small phosphatic brachiopods and fragments of trilobites of Upper Cambrian age.

Rincon limestone (Upper Cambrian)

The Rincon limestone is one of the topmost Cambrian units of southern Arizona. Stoyanow (1936, p. 469) considers it equivalent to the Copper Queen limestone which he separated from the original Abrigo of Ransome on the basis of fauna and lithology. The Rincon limestone is the top unit of the Cambrian section near Colossal Cave (the type section), in the Whetstone Mountains and in the Picacho de Calera Hills. In each of these localities it is typically a pink, coarse-grained limestone with abundant trilobite fragments and specimens of Billingsella coloradoensis. Of equivalent age and containing an equiva-fauna, but lithologically distinct, are the Copper Queen limestone of the Bisbee district and the Peppersauce sandstone of the Peppersauce Canyon sequence in the Santa Catalina Mountains. The thickness of these units ranges from 20 feet for the Peppersauce, about 40 feet as an average for the Rincon, to about 80 feet for the Copper Queen limestone.

The lower contact of the Rincon limestone in the Picacho de Calera Hills is gradational from the Abrigo, and the upper contact is the disconformity below the Devonian Picacho de Calera formation. The Rincon limestone is composed of 40 feet of thick-bedded, massive, coarse-grained, pink limestone containing abundant fragments of trilobites.

Devonian

General

The Devonian rocks in most outcrops of southern Arizona are medium to dark gray limestones, most of which weather yellow or brown, and which contain a few thin beds of shale and sandstone. In the type locality near Bisbee, where they have a thickness of 325 feet, these rocks were named the Martin limestone by Ransome (1904, p. 32).

In the Picacho de Calera Hills, the Devonian strata are about 350 feet thick. The upper 275 feet of this series contain the characteristic Martin (Upper Devonian) fauna and are of typical Martin lithology. The lower 75 feet, however, includes 25 feet of dark gray dolomite near the top; two thin beds of yellow sandstone, one at the top and one at the base; and 40 feet of bluish gray limestone. On the basis of lithology and because of fish teeth in the top sandstone bed, Stoyanow (1936, p. 488) separated this lower unit from the Martin limestone and designated it the Picacho de Calera formation.

Picacho de Calera formation (Upper Devonian)

The Picacho de Calera formation rests on the Upper Cambrian Rincon limestone with apparent conformity, but as is true in all south-central Arizona localities, Ordovician and Silurian rocks are missing. Fossils in this formation include the fish teeth in sandstone, mentioned above, stromatoporoids and small algal structures in the bluish gray limestone and small goniatites in yellow limestone near the middle. The top of the Picacho de Calera formation is considered to be at the top of the sandstone that contains fish teeth.

Martin limestone (Upper Devonian)

The Martin limestone conformably overlies the Picacho de Calera formation. The base of the Martin is the base of the gray limestone immediately above the yellow sandstone containing fish teeth in the Picacho de Calera formation.

The Martin limestone is about 275 feet thick. The lowermost 100 feet consist of dark gray, brown-weathering limestone that is cherty in the lower portion. It is separated by 25 feet of brown, calcareous sandstone from the upper 150 feet of massive, gray limestone. Fossils are relatively scarce in the Martin although some brachiopods, particularly Atrypa reticularis, are numerous in the lower part.

The upper contact of the Martin is gradational upward into the Lower Mississippian Escabrosa limestone. It is marked, in general, by a change from fine-grained dark gray limestone to very light gray, coarsely crystalline limestone containing abundant crinoid stems.

Mississippian

Escabrosa limestone (Lower Mississippian)

In the Picacho de Calera Hills the Escabrosa limestone is dominantly medium to dark gray, coarsely crystalline limestone. As noted above, the contact with the underlying Martin limestone is gradational. The change from the dark gray limestone of the Martin to the very light gray, coarsely crystalline Escabrosa limestone which has abundant crinoid stems, is typical of the contact in many parts of southern Arizona. It is a feature of the type section (Ransome, 1904, p. 42).

The Escabrosa limestone is about 600 feet thick and forms the westward-facing cliff of the east hill (Fig. 6; fig. 7) at Picacho de Calera. There are a few fossiliferous zones with abundant horn corals and Spirifers in the Escabrosa, but it is characteristically less fossiliferous than the overlying Naca formation.

Pennsylvanian

Naco formation

The Naco formation is composed of deposits laid down in southern Arizona during much of Pennsylvanian time. The Naco of the type locality at Bisbee as originally described (Ransome, 1904, p. 44) also included rocks of Permian age that occur in the upper part of a thick limestone sequence. In most parts of southern Arizona the Naco includes a considerable amount of detrital sediment and from a distance many outcrops have a characteristically banded appearance due to the alternation of limestone and siltstone beds in units from three to fifteen feet thick.

In the type locality at Bisbee, the Naco rests on the Lower Mississippian Escabrosa limestone with apparent conformity, but as rocks of Late Mississippian age are missing in the section a large hiatus must be represented. Conglomerate is present at the base of the Naco in some areas but is absent in others. Nowhere in southern Arizona has evidence of an unconformity between the Naco formation and overlying deposits of Permian age yet been recognized.

The Naco formation in the Picacho de Calera Hills forms the crest of the east hill and the long dip slope extending out under the alluvium to the east (Fig. 6; fig. 7). The erosional surface that here marks the contact between the Lower Mississippian Escabrosa limestone and the Naco formation is difficult to locate because of lithologic similarities between the two formation. It occurs where the massive, uniformly bedded limestone of the Escabrosa ends and the thin-bedded, variegated limestone, with intercalated thin beds of siltstone of the Naco begins.

The Naco at Picacho de Calera Hills is more than 1000 feet thick. It is moderately fossiliferous with a large variety of forms, including many of the characteristic Pennsylvanian species. Not far above the basal contact a zone with abundant fusulinids occurs and other fusulinid zones are at intervals throughout the formation. Brachiopods and corals are also common.

Permian

General

In the 3000 feet of limestone originally described as the Naco limestone at Bisbee (Ransome, 1904, p. 44), approximately the upper half is now known to be of Permian age. In areas farther north in southern Arizona detrital sediments, instead of limestones, comprise the lower part of the Permian deposits and most of the massive limestones are in the upper part of the sequence only. Various rock units of Permian age have been recognized through their faunas (Stoyanow, 1936, p. 530; 1942, p. 1274) and numerous local names have been given these, mostly without detailed description of the strata involved and without clear designation of the type locality. The result is that the present status of the nomenclature of Permian rocks in southern Arizona is unsatisfactory.

Snyder Hill formation

Snyder Hill is a small outlier (Fig. 8) of limestone and dolomite southwest of the Tucson Mountains proper. The beds here are 224 feet thick and contain a characteristic Permian fauna, Stoyanow (1936, p. 530) named the Snyder Hill formation from this locality, using it as the type. At present, most of the thick, massive limestone units in the upper part of the Permian sequence of southern Arizona are assigned to this formation. Similar units are exposed in various ranges and are readily recognized by lithologic character and abundant fossils. The strata that are correlated with the Snyder Hill formation are 600 to 800 feet thick in sections where post-Permian erosion has not removed large parts. They are in the upper part of the Permian sequence.

The Snyder Hill formation at Snyder Hill consists of 118 feet of very fossiliferous limestone overlain by 108 feet of dolomite (Feth, 1948, Fig. 7 and p. 98). The massive limestone is dark gray and fine grained with abundant chert concretions or nodules, mostly in bands and in many places containing fossils (Fig. 9). The overlying dolomite is more thin-bedded. Its beds are varicolored, and composed of grains that on freshly broken surfaces show the bright sparkle typical of dolomite. Fossils are scarce but quartz geodes and calcite blebs are common, and probably represent replacements of organic remains.

Cretaceous

General

The Cretaceous rocks of southern Arizona include marine strata of Lower Cretaceous age (Stoyanow, 1949; McKee, 1951, p. 494) and non-marine strata of both Lower and Upper Cretaceous age (Stoyanow, 1949, p. 58; McKee, 1951, p. 494, 497).

In the Tucson Mountains, Brown (1939, p. 713) recognized three units of Cretaceous rocks: (1) a lower unnamed volcanic member; (2) the Recreation red beds; and (3) the Amole arkose at the top. These rocks crop out at the surface over a large part of the Tucson Mountain area, particularly in the central portion. They form the underlying mass over which the Paleozoic strata were thrust. The Cretaceous rocks have a minimum thickness of 5000 feet and are probably more than 8000 feet thick.

Fossils have been found in the Cretaceous sequence of the Tucson Mountains only in the Amole arkose. These fossils are long-ranging freshwater mollusks that were tentatively placed in the Upper Cretaceous by Brown (1939, p. 719) but a later, more extensive collection has been designated as probable Lower Cretaceous by Reeside (McKee, 1951, p. 495).

Volcanic member

The volcanic member of the Cretaceous series in the Tucson Mountains consists of andesite and dacite flows interbedded with tuffs and arkoses. The base of the unit is not known but the thickness is estimated at not less than 2000 feet and possibly more than 5000 feet. In the Recreation area the volcanic member is overlain by the Recreation red beds, but the contact is a fault. It seems certain, however, that the volcanics are older than the red beds because conglomerates in the Recreation red beds contain gravels that apparently were derived from flow rocks of the volcanic member. The outcrop of the volcanic member which forms the Piedmontite Hills is a thin but representative exposure.

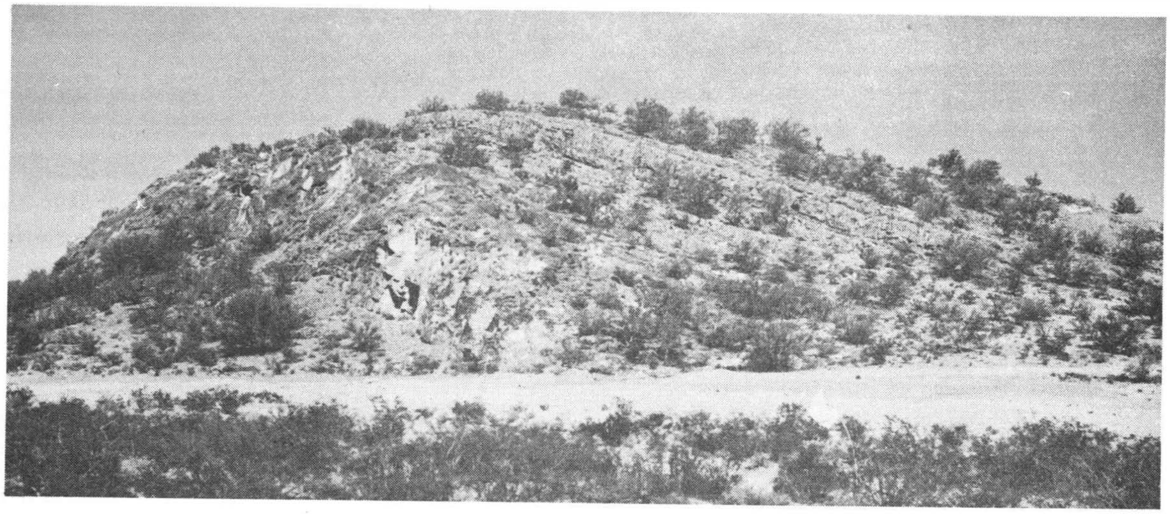
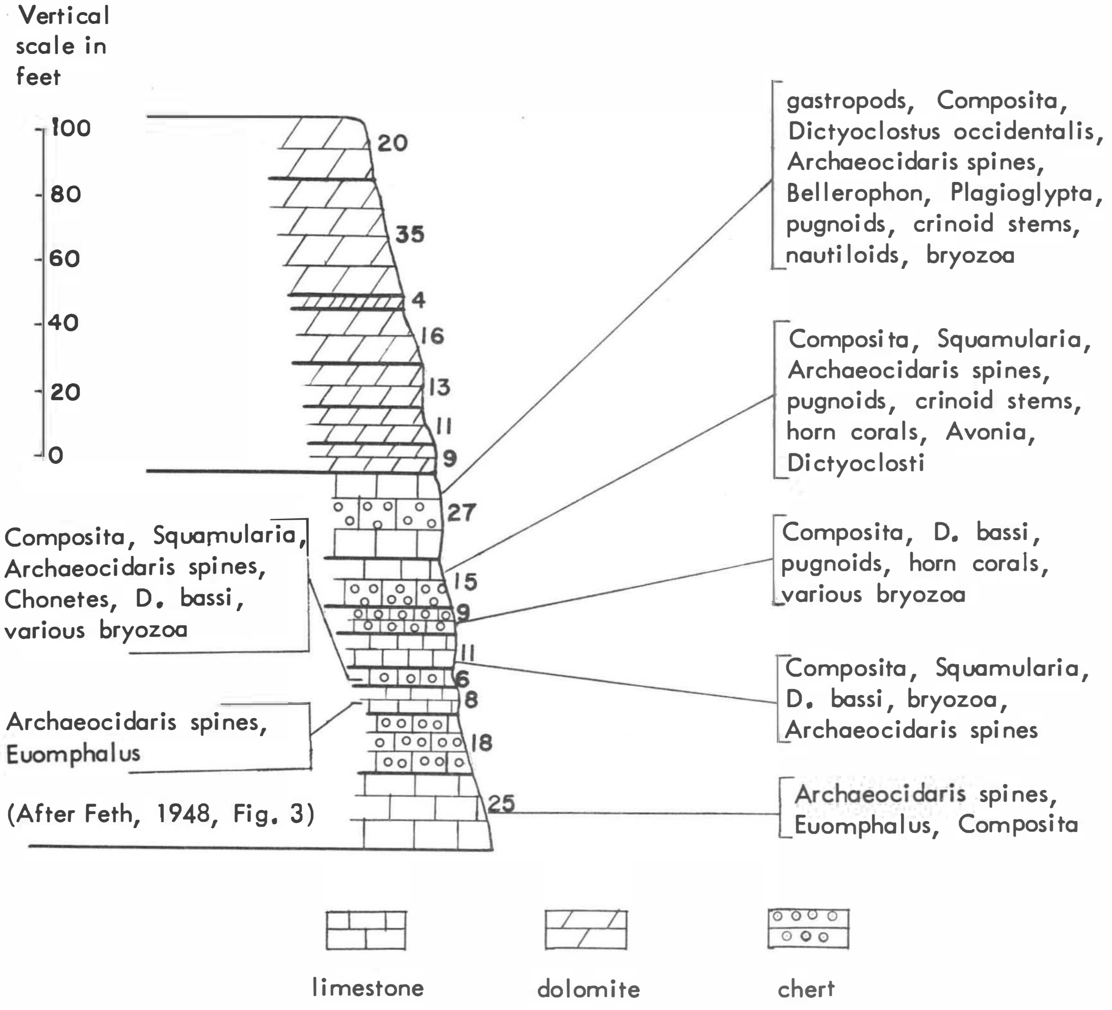


FIGURE 8. - SNYDER HILL, TYPE LOCALITY OF PERMIAN SNYDER HILL FORMATION, LOOKING NORTHEAST Limestone facies of the formation below; dolomitic facies above.



gastropods, Composita, Dictyoclostus occidentalis, Archaeocidaris spines, Bellerophon, Plagioglypta, pugnoids, crinoid stems, nautiloids, bryozoa

Composita, Squamularia, Archaeocidaris spines, pugnoids, crinoid stems, horn corals, Avonia, Dictyoclosti

Composita, D. bassi, pugnoids, horn corals, various bryozoa

Composita, Squamularia, D. bassi, bryozoa, Archaeocidaris spines

Archaeocidaris spines, Euomphalus, Composita

Composita, Squamularia, Archaeocidaris spines, Chonetes, D. bassi, various bryozoa

Archaeocidaris spines, Euomphalus

(After Feth, 1948, Fig. 3)

FIGURE 9. - COLUMNAR SECTION OF THE SNYDER HILL FORMATION AT SNYDER HILL

Recreation red beds

The Recreation red beds consist of a series of dominantly brick red to maroon arkoses. The areal extent of the red beds is much less than that of the other Cretaceous units. These sediments are largely confined to the Red Hill area west of the main range, but a few patches occur in the foothills east of Amole Peak. The bright red color of the outcrops, as shown at Red Hill and in the Tucson Mountain Lodge area, is in striking contrast to the dull, drab colors of the surrounding rocks.

The only contact of the Recreation red beds with presumed underlying rocks is the fault contact with the volcanic member mentioned before. Elsewhere the lower part of the red beds is buried under alluvium. At the top of the sequence the Recreation red beds grade into the Amole arkose through a transition zone of alternating gray arkoses typical of the Amole and red beds of the Recreation type. The total thickness of the Recreation red beds is at least 1300 feet.

Amole arkose

The topmost of the Cretaceous units in the Tucson Mountains, the Amole arkose, comprises a series of fine to coarse-grained, pink and gray arkoses, with thin beds of gray, silvery shales and dark gray limestone. The formation is characterized by numerous and repeated changes of rock type.

The Amole arkose crops out in extensive areas west of the main range and to a lesser extent east of Amole Peak. The total original thickness is unknown as the top is either eroded or cut off by thrust faulting, but a minimum thickness of nearly 2500 feet has been measured. The basal contact, as mentioned above, is gradational upward from the underlying Recreation red beds.

Metamorphism has affected large areas of the Amole arkose. Arkose beds have been extensively silicified and epidotized with resultant obscuring of bedding planes. Many of the shales are altered to dense hornfels, and limestones are changed to calc-silicate rocks with abundant development of epidote and lesser amounts of garnet.

Fossils are scarce in the Cretaceous strata of the Tucson Mountains but a few freshwater gastropods and pelecypods have been found. As previously mentioned these are Cretaceous forms, probably Lower Cretaceous.

As the Amole arkose is the topmost Cretaceous unit, present faunal evidence seems to indicate that all the Cretaceous rocks in the Tucson Mountains are of Lower Cretaceous age. The area subsequently was subjected to a long period of erosion; later, Tertiary volcanism resulted in the spreading of lavas and tuffs over the old erosion surface.

SANTA CATALINA MOUNTAINS METAMORPHIC AREA

TRIP 3 ROAD LOG

Thursday, April 10, 1952

Leaders: B. S. Butler, F. F. Grout, and C. S. Bromfield
Driving distance: Logged distance 34.3 miles. Total driving distance 80 miles.

General Statement

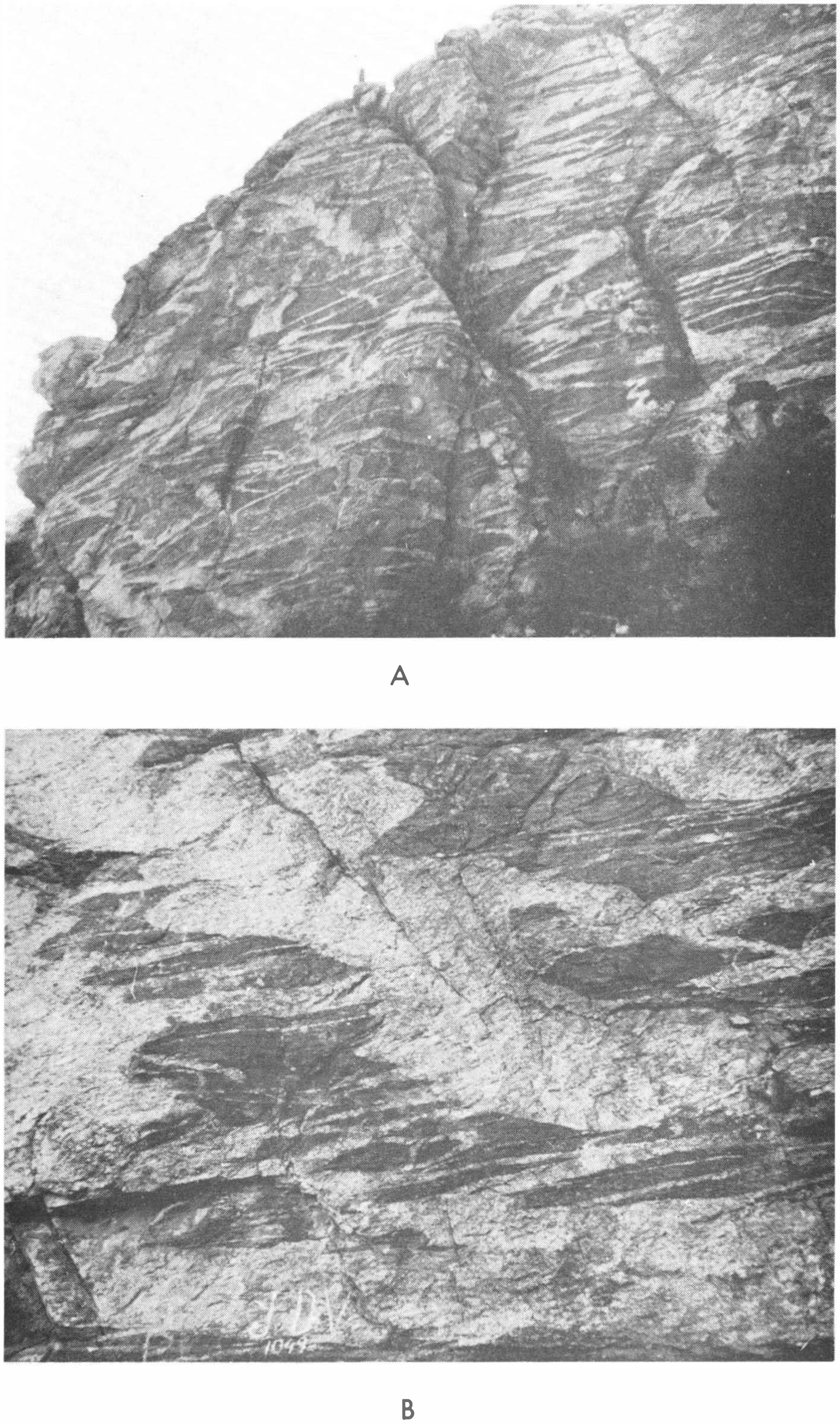
The field trip route ascends the Santa Catalina Mountains via the General Hitchcock Highway. The group will view exposures of a metamorphic-granitic complex which suggests to some the operation of granitization processes. Observations will be made of typical banded gneisses of the forerange (Stops 1 and 2), of a local example of gradation from banded gneiss into granitic gneiss (Stop 4), of typical granitic gneisses (Stop 3 and 6), and of a sharp contact between granitic gneisses and the late Precambrian Apache group (Stop 7).

The starting point of the road log is the stop sign at the intersection of Speedway and Wilmot Road. To reach this intersection go north two blocks from the University campus to Speedway, turn east (right) and proceed 5.7 miles. The route and all Stops are indicated on the geologic map (Fig. 12). The caravan will disband after the last stop and individual parties may return to Tucson immediately, or, if they prefer, remain to view additional outcrops along the return route.

0.0	0.0	ZERO POINT. Stop sign, intersection of Speedway and Wilmot Road.
0.2	0.2	At 12 o'clock, Santa Catalina Mountains. At 9 o'clock, Tanque Verde and Rincon Mountains.
0.2	0.4	Junction with unpaved road. Continue Right on pavement. Road drops off terrace on Quaternary gravels to Pantano Wash bottomland.
0.7	1.1	Bridge over Pantano Wash.
0.1	1.2	Road leaves Pantano Wash bottomland and rises onto Quaternary terrace gravels.
0.2	1.4	Junction on left, side road to University Indian Ruins. Ruins are of adobe-pueblo type, and were occupied from approximately 1300-1450 A.D. by Salado-Hohokam people.
0.2	1.6	Junction on left Sabino Canyon Road. Continue straight. Sabino Canyon is a favorite picnic area for residents of Tucson. Banded gneisses are excellently exposured there.
0.5	2.1	The Santa Catalina Mountains parallel the road on left. The Rincon and Tanque Verde Mountains extend from 12-2 o'clock.

0,3	2,4	Junction with Wrightstown road TAKE LEFT FORK,
0,5	2,9	Road drops from Quaternary surface gravels to Rillito Wash bottomland,
0,1	3,0	Bridge over Rillito Wash,
0,7	3,7	Mount Lemmon (9185 feet), highest point of the Santa Catalina Mountains, at 9 o'clock, Route reaches an elevation of slightly over 8000 feet,
0,3	4.0	Junction with Tanque Verde Road, TURN LEFT on General Hitchcock Highway. Tanque Verde Road crosses low saddle between the Santa Catalina and Rincon Mountains,
0,2	4,2	Entering saguaro cactus belt, The Saguaro National Monument, an area in which these giant cactus grow in great abundance, lies on the west slope of the Rincons a short drive from Tucson,
0,5	4,7	At 9-11 o'clock, note southerly dip of gneisses along front of forerange, At 10 o'clock is Cathedral Rock (8400 feet), high point of the forerange; at 10:30 is Mount Lemmon,
0.4	5,1	Low hills on right, near road, are of older Tertiary alluvium, These gravels are at least early Pliocene and probably pre-Pliocene in age, They are displaced by thrust faulting along the base of the mountains, Next 3 road-cuts are in these rocks,
0,2	5,3	Road cut in older Tertiary gravels,
1,0	6.3	Road cut in older Tertiary gravels, Note gentle southwest dips,
0,2	6,5	Road cut in older Tertiary gravels, which dip 40° - 45° to the southwest, Caravan will slow to 10 m.p.h, to allow observation,
0,9	7,4	At 2 o'clock, Agua Caliente Hill, Gneisses have quaquaversal dips in Rincon Mountains which are at 2:30 o'clock, At 3 o'clock, Tanque Verde Mountains, where gneisses have anticlinal form,
0,6	8,0	Crossroad; cattleguard,
0.7	8,7	In this vicinity road crosses low-angle thrust fault that parallels southern mountain face, Trace of thrust is obscured by later alluvium in this area,
0,2	8,9	Junction on right, stay on pavement, On entering mountains, note banded gneisses, typical of forerange types, Light bands are pegmatitic and granitic, Darker bands represent relict host rocks, now largely porphyroblastic gneisses,
0,1	9,0	STOP 1, CAUTION-WATCH TRAFFIC, Caravan will stop briefly for orientation and to observe banded gneisses in road cuts,

0.4	9.4	On left, crosscutting mass of granitic gneiss. Note fault.
0.1	9.5	Note low-angle fault on left.
0.1	9.6	Note steep fault on left.
0.4	10.0	Entering the Coronado National Forest. Sign on right.
0.9	10.9	Note the uniform southerly dip of the banded gneisses. As the anticlinal forerange is crossed the foliation will gradually flatten, and as the north side of the forerange is crossed will dip to the north.
0.8	11.7	Entering Molina Canyon. Excellent section of banded gneisses exposed at 3 o'clock on canyon walls. Light colored pegmatite bands of sill-like habit predominate.
1.2	12.9	STOP 2. CAUTION-WATCH TRAFFIC. Group will examine and discuss origin of banded gneisses along road cuts. Note excellent exposure on canyon wall at 3 o'clock. Note irregular and ptygmatic crosscutting bodies of pegmatite. This will be the last stop in the banded gneiss.
1.2	14.1	Observe banded gneisses in road cuts. The anticlinal forerange has been crossed and here the foliation of the gneisses dips north.
0.2	14.3	Molina Basin. This is one of a series of basins that parallel the south front of the mountains and separate the forerange of the Santa Catalina Mountains from the main range. The chain of basins marks the general line of separation between the banded gneisses of the forerange and the granitic gneisses of the main range.
0.2	14.5	The caravan has now crossed the forerange of the Santa Catalina Mountains and the road will begin the ascent to the main crest. Note during next 4 to 5 miles the decrease in abundance of dark bands of relict host rocks.
1.1	15.6	In road cut on right, dark feldspathized host rocks are folded and enclosed in granitic gneiss.
0.3	15.9	STOP 3. Group will observe interesting intersecting foliations, superficially resembling crossbedding, exposed in the gneiss of the road cut.
0.1	16.0	Road entering Federal Prison Camp Area. Observe signs. NO PARKING ALLOWED IN AREA.
0.3	16.3	REDUCE SPEED TO 20 MPH.
0.3	16.6	Side road; leaving Prison Camp area.
0.9	17.5	In view to left note basin area which separates forerange from main mountain mass.
0.4	17.9	Dark relict bands of host rocks in road cut.



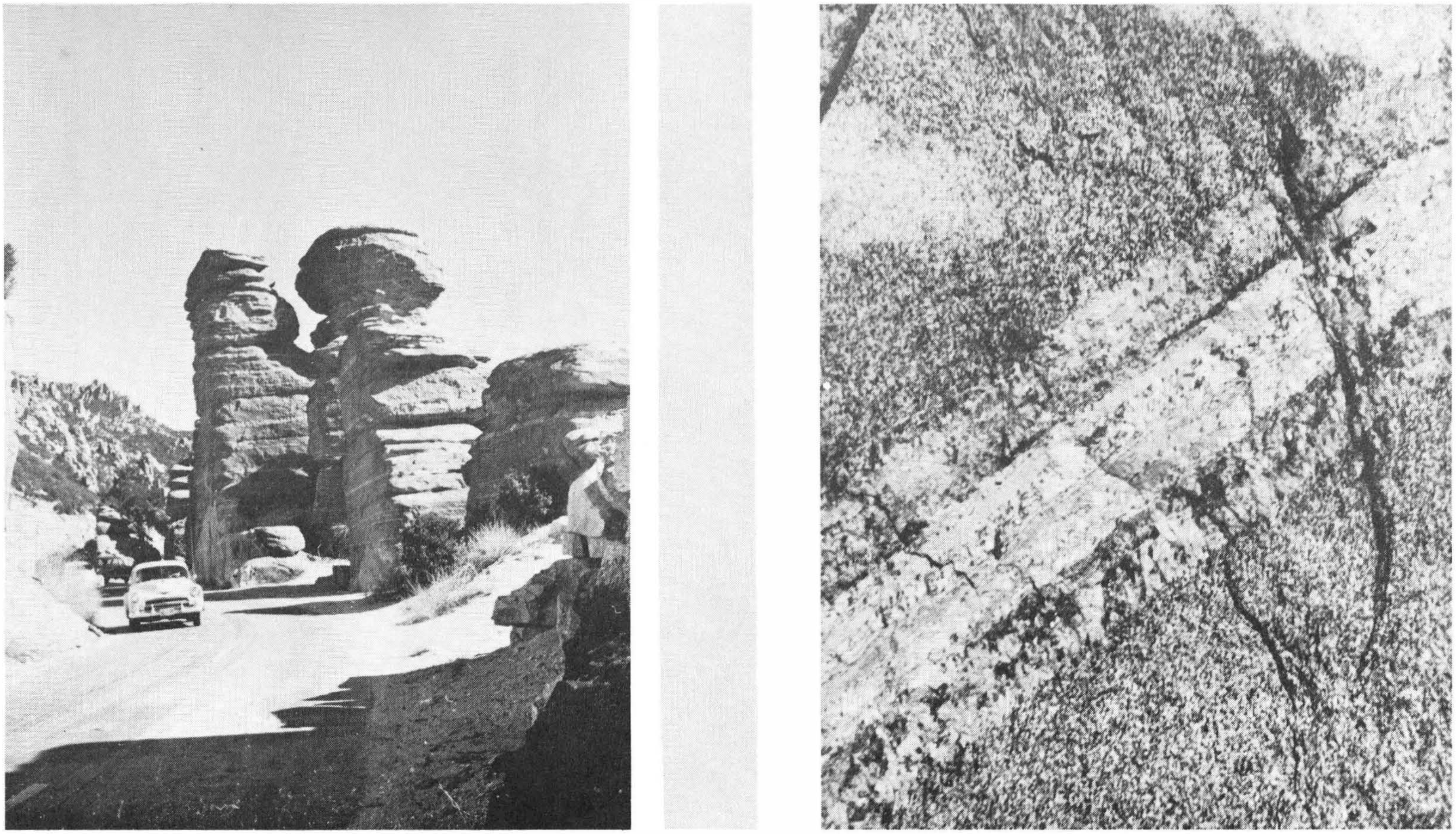
A

B

FIGURE 10. INJECTION GNEISS OF THE SANTA CATALINA FORERANGE

A. Typical injection gneiss of the forerange. Dark bands are oligoclase-biotite gneiss and represent feldspathized host; light bands are pegmatitic. Photograph taken near Stop 2.

B. Detail of a part of the lower left hand corner of Figure 10-A.



A

B

FIGURE 11. GRANITIC GNEISS AND GRANITE OF THE MAIN RANGE.

A. Granitic gneiss of the main range from the vicinity of Stop 6. The gneisses weather to picturesque castellated forms. Note narrow pegmatitic sills which parallel the foliation.

B. Granite with zoned pagmatite dike near Palisades Ranger Station, mile 29.2. Dike is about 1 1/2 feet across.

0,1	18,0	STOP 4, At the road cut, the group can observe rocks that present a transition from the banded gneisses of the forerange to the granitic gneisses of the main range, Dark bands are still apparent, but less distinct,
0,2	18,2	Road entering Bear Canyon, The upper portion of the canyon wall to the left is granite gneiss containing no relict bands of feldspathized host rocks; the lower portions of the canyon wall carry a few relicts of host rocks, Pegmatite bands more abundant in lower wall of canyon than in upper wall, The banded gneisses of the forerange appear to pass beneath the granitic gneisses of the main range; other sections to the west suggest the same relations,
0,9	19,1	Local relicts of host rocks in road cut,
0,2	19,3	Last of dark bands, Rocks from this point on are all light colored granitic gneisses and granites,
1,4	20,7	STOP 5, Bear Canyon Picnic Area, Lunch period,
0,5	21,2	Rocks here are more granitic in texture, but have some foliation,
0,1	21,3	Road leaves Bear Canyon and climbs onto ridge dominated by granitic gneisses, Pegmatites are less abundant,
1,7	23,0	Note thin sills of pegmatite in granite gneisses,
0,2	23,2	STOP 6, General Hitchcock Point, Panoramic view of the Tucson valley, Discussion of geographic setting of Santa Catalina elements and of the surrounding mountain ranges, Typical granitic gneiss of main range exposed here,
0,2	23,4	Sycamore Canyon at 9 o'clock,
0,7	24,1	Granitic gneisses weathering to picturesque forms,
1,1	25,2	Foliation less pronounced, though still definitely gneissic,
0,2	25,4	Junction on left with side road to Willow Canyon summer home area,
0,9	26,3	Junction on left with road to Rose Canyon,
0,4	26,7	At 3 o'clock, San Pedro Valley on northeast side of Santa Catalina Mountains, Rocks on northeast slope include Paleozoic and Cretaceous strata, Granites of next 1,2 miles exhibit little foliation,
1,2	27,9	Junction on left with side road,
0,4	28,3	On right, sedimentary rocks surrounded by granite,
0,1	28,4	STOP 7, Sharp contact between granitic rocks and the later Precambrian Apache Group, Probably an intrusive contact,

0,1	28,5	On right, contact of sedimentary rocks with granite.
0,1	28,6	Junction on right with side road,
0,4	29,0	Junction on left, road to Palisades Ranger Station and Camp Lawton.
0,2	29,2	In road cut on right, zoned pegmatite dikes in granite.
0,5	29,7	Road cut in sedimentary rocks,
0,4	30,1	Junction on right and left with side roads,
0,9	31,0	For the next 1,5 miles the road cuts are in rocks of the late Precambrian Apache group. The structure of the rocks is complex,
0,5	31,5	Junction on right, road to Bear Wallow,
0,1	31,6	In road cut on right, contorted Apache group sediments.
0,1	31,7	In road cut on right, Cambrian sediments show recumbent isoclinal folds.
0,3	32,0	Soldier Camp. Original camp was established in an attempt to capture the notorious Apache, Geronimo,
0,3	32,3	Pegmatitic granite intruded into rocks of the Apache group. Road is now on the north side of the main crest and near the north margin of the complex.
0,5	32,8	Pegmatitic granite in road cut,
0,3	33,1	Dark green rock cut is Leatherwood quartz diorite. It is cut by pegmatitic dikes. The diorite elsewhere intrudes rocks of Cretaceous age.
0,2	33,3	Junction on left with road to Loma Linda summer home area,
0,1	33,4	Road cut in Leatherwood quartz diorite,
0,2	33,6	San Pedro Valley at 3 o'clock. The slopes of the mountains between here and the valley in large part expose Paleozoic sediments. Dissected alluvial fans at the base of the mountains are composed of gravels correlated by some geologists with Gila conglomerate of Pliocene to Pleistocene age.
0,1	33,7	Leatherwood quartz diorite in road cut is traversed by numerous pegmatite dikes.
0,3	34,0	Junction on right with road to Oracle.
0,2	34,2	Junction on right with side road. Rock is Leatherwood quartz diorite. Mount Lemmon at 1 o'clock, named after Professor Lemmon, an Englishman who studied the plants and animal life of the region in the 1890's.
0,1	34,3	Entering Summerhaven Recreation Area. Elevation 7800 feet. Gas is available at Mount Lemmon Store on right. Area is a favorite summer retreat for heat-harassed residents of Tucson. Caravan disbands here. Tucson can best be reached by retracing the route.

THIS PAGE

INTENTIONALLY BLANK

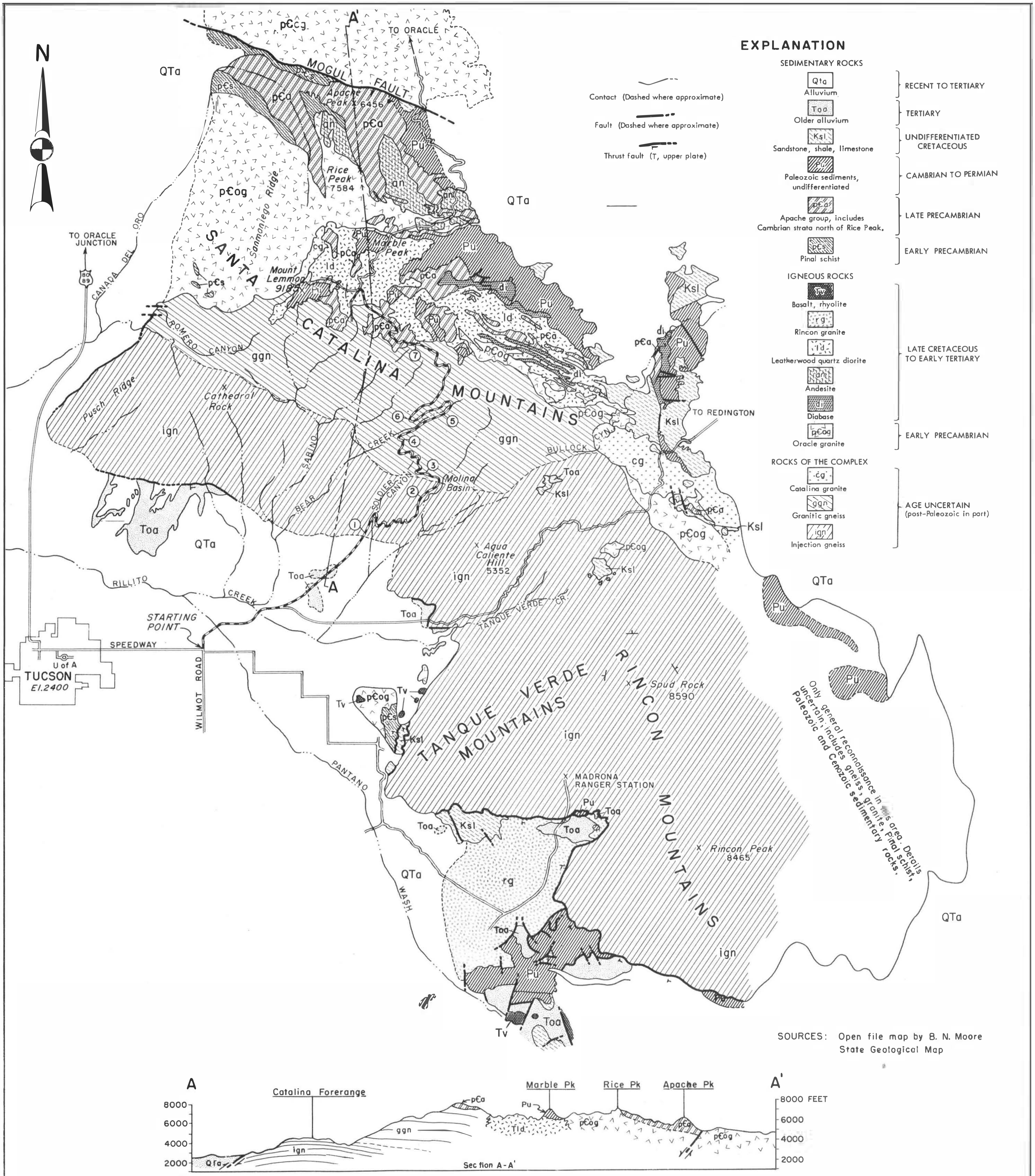


FIGURE - 12 GENERALIZED GEOLOGIC MAP AND SECTION OF THE SANTA CATALINA - RINCON MOUNTAINS

SOME GEOLOGIC FEATURES OF THE SANTA CATALINA MOUNTAINS*

Calvin S. Bromfield
Mineral Deposits Branch, U.S. Geological Survey

Introduction

The Santa Catalina Mountains extend for 20 miles in a northwest direction and outline a part of the northern boundary of the valley in which the city of Tucson lies. To the southeast the range is connected by a low pass to the Rincon and Tanque Verde Mountains. These mountains extend for 20 miles in a southerly direction and form a part of the eastern margin of the valley of Tucson. The Santa Catalina, Tanque Verde, and Rincon Mountain mass is on the western boundary of what Ransome, (1916, pp. 133-135) termed the Mountain Region, an area of rugged ranges separated by broad irregular basins filled with fluviatile and lacustrine deposits.

The Santa Catalina Mountains rise abruptly from their pediment to form a forerange behind which is the higher main crest. A disconnected series of basins that parallel the mountain front separate the forerange from the main mass. The rocks of the forerange and the south slope of the main range are cut by several deep southward draining canyons. The Santa Catalina Mountains reach a maximum altitude of 9185 feet at Mount Lemmon; the city of Tucson in the valley below lies at an altitude of 2400 feet.

The Santa Catalina, Tanque Verde, and Rincon Mountains present some geologic features which are unusual among the basin ranges of southeastern Arizona. The major part of these mountains are made up of a complex of granites, granitic gneisses, and injection gneisses. Similar rocks in other regions have been described variously as composite gneisses, permeation gneisses, migmatites, and granitized rocks. This description is confined largely to features of the Santa Catalina Mountains.

Previous Work

Little has been published on the granitic rocks and the surrounding envelope of gneissic rocks, which are the dominant rock types of the Santa Catalina Mountains. Blake (1908a, p. 379; 1908b, p. 45) mentioned the "Archaeozoic" gneisses and schists of the Santa Catalina Mountains and remarked on their superficial resemblance, from a distance, to bedded sedimentary rocks. C. F. Tolman of the U.S. Geological Survey worked in the Tucson quadrangle in 1911 and 1912, but he never published the results of his work. Ransome (1916, pp. 144-145), however, in discussing the sedimentary section of the Santa Catalina Mountains stated:

> "The central feature of the range, as worked out by Mr. Tolman, is a great post-Carboniferous intrusive mass of siliceous muscovite granite modified to a gneissic rock near its margins, surrounded by a zone of intense contact metamorphism in which rocks of widely different kinds have been conspicuously affected."

---

* Publication authorized by the Director, U.S. Geological Survey

B. N. Moore studied the geology of the Tucson quadrangle at intervals from 1930 to 1938 but resigned from the U.S. Geological Survey before the study was completed. W. M. Davis (1931) published a paper on a physiographic interpretation of the late structural history of the Santa Catalina Mountains as a basin range type. The most detailed work on the complex rocks is a study by Hernon (1932) of the pegmatitic rocks of the Santa Catalina-Rincon Mountains. A synopsis of the geology of the Tucson quadrangle, as condensed from the work of several geologists is on file at the Arizona Bureau of Mines (Moore, et al., 1949).

General Geologic Setting

A variety of sedimentary and igneous rocks flank the granitic-metamorphic complex on the north and northeast slopes of the Santa Catalina Mountains. Samaniego Ridge, the prominent north-trending ridge that extends along the northwest face of the mountains (Fig. 12), is composed of early Precambrian (?) Oracle granite. To the east of Samaniego Ridge the rocks include early Precambrian Pinal schist, late Precambrian Apache group, Paleozoic clastics and limestones, and a thick Cretaceous sequence of dominantly detrital rocks. The sedimentary rocks are intruded and, to some extent, separated from the granitic-metamorphic complex of the main mountain mass by a large post-Cretaceous igneous mass known as the Leatherwood quartz diorite, which forms much of the northern margin of the complex (Fig. 12).

Alluvial fan deposits of late Tertiary to Recent age encircle the mountains. Older Tertiary alluvial deposits are found in places, as near the southern and western base of the Rincon Mountains, and in scattered outcrops near the southern base of the Santa Catalina Mountains. These older Tertiary alluvial deposits, generally red siltstones, sandstones and conglomerates, underlie the younger gravels with angular unconformity. The older deposits appear to be unrelated to present physiographic features, and are displaced by late faults which are genetically related to the uplift of the Santa Catalina Mountains. The age of the older deposits is uncertain, but they are at least early Pliocene and probably are pre-Pliocene in age.

The structure of the Santa Catalina Mountains is complex. The southern margin of the range and the western margin of the Rincon Mountains are outlined by the trace of a thrust fault (Moore, et al., 1949, pp. 16-17). Along the southern face of the Santa Catalina Mountains the fault dips 15° to 40° to the south, and the earlier Tertiary alluvial deposits are thrust over gneisses.

Along the northwestern end of the Santa Catalina Mountains is a northeast striking high-angle fault which dips westward. A northwest-trending, southwesterly dipping normal fault, known locally as the Mogul fault (Fig. 12), crosses a part of the northeastern side of the Santa Catalina Mountains. The latest movement along this fault displaces the late Tertiary to Pleistocene alluvial fan deposits bordering the northeast flank of the range.

Probably late in the history of the area, the mountains were faulted and broadly domed up to their present level (Moore, et al., p. 17). The fault along the western base, as well as a number of other faults, may have formed at this time.

On physiographic evidence W. M. Davis (1931) interpreted the late structural history of the Santa Catalina Mountains as involving an uplift along the southern and western margins; later there was an upbending along the northern margin and depression along the southern base.

Granitic-metamorphic complex

General Statement

The dominating geologic feature of the Santa Catalina Mountains is a complex of granites and gneisses. The granites are in and near the higher portions of the mountains and grade outwards to the south, east, and west into granitic gneisses, which in turn grade into injection gneisses in the forerange.

The dividing line between the injection gneisses and the granitic gneisses follows in general the irregular chain of basins extending from Romero Canyon on the west to Bullock Canyon on the east, and is parallel to the southern mountain front. The line of demarcation is by no means a definite boundary, for there is gradual transition from the injection gneisses to the granitic gneisses.

Deeply incised southerly trending canyons expose thick sections of these interesting rocks. The several rock types are well exposed along the field trip route which ascends the mountains along parts of several of these canyons.

Injection Gneisses of the Forerange

The injection gneisses of the forerange include a variety of rocks that have developed from an intimate and extensive invasion of an original schistose host by emanations of granitic composition. Numerous alternating dark and light colored bands representing respectively the metamorphosed host and the "injected" granitic material are characteristic of the forerange gneisses. The nature of the original host is obscured by the feldspathization that has been imposed on it. The rocks that have resulted from this "injection metamorphism" range from dark slightly feldspathized argillite, phyllite, or biotite schist containing only a few small scattered augen of oligoclase in the less altered host, to augen gneiss in more extensively feldspathized host. The augen gneisses develop by increase in size and number of oligoclase augen and a coarsening of the biotitic groundmass. The more or less dark augen gneisses become lighter in color with increase in feldspar and quartz and corresponding decrease in biotite. Granoblastic gneisses of granitic composition are present, and along with the augen gneiss are the most abundant and widespread types in the forerange. In places one or the other type may predominate. The textures of the injection gneisses which range from porphyroblastic to granoblastic have been modified by cataclastic action.

The various gneisses and feldspathized schists of the forerange are banded by numerous pegmatite bodies. The pegmatites range in size from narrow, incipient streaks, which appear to have formed along planes of foliation, to bodies 20 or more feet thick. Most of the pegmatites are sill-like and parallel the foliation of the host rocks, maintaining nearly constant thicknesses over considerable distances. Others cut across the foliation of the host rock and have irregular shapes; some are ptygmatic in form.

The mineralogy of the pegmatitic bodies is simple; albite, quartz, orthoclase, and oligoclase are the principal minerals. Anhedral to subhedral orthoclase crystals, some more than 12 inches long, are enclosed in a finer-grained aggregate of quartz, oligoclase, and local large albite crystals. Myrmekite and graphic intergrowths of orthoclase and quartz occur in places. Garnet and magnetite are minor constituents.

Granitic Gneisses and Granites of the Main Range

North of the dividing line that separates the injection gneisses of the forerange and the granitic gneisses of the main range the rocks are noticeably more granitic in composition and lighter in color, pegmatitic bodies are less abundant, and the dark colored bands characteristic of the forerange gneisses are largely absent. The dominant rock is a granitic gneiss.

The minerals of the granitic gneisses include feldspar, quartz, biotite, and muscovite, along with minor accessories. Feldspar augen are commonly of oligoclase and orthoclase. Orthoclase locally replaces oligoclase augen along cleavages. There is some myrmekite, and garnet is a common accessory. The rocks are richer in muscovite, poorer in biotite, and apparently somewhat richer in orthoclase than the injection gneisses of the forerange. The pegmatites which make up so large a part of the injection gneisses are insignificant quantitatively in the granitic gneisses and are thin, few being more than 2 feet thick. Most of the pegmatites are sill-like.

In places along and near the crest of the range, the granitic gneisses grade into almost massive granites. The term Catalina granite has been applied to some of these rocks (Moore, et al., 1949, p. 12), and others are undifferentiated on existent maps of the complex. The grain size ranges from coarse to fine. The mineral composition of the granite is similar to that of the granitic gneisses; the essential difference between them is in their relative textures.

Structure of the Complex

In general the large-scale structures defined by the main trends of the foliation of the gneisses are broad and open. Evidence suggests that the foliation in part is inherited from an original foliation or bedding of the host rocks. Along the southern front of the Santa Catalina forerange, the foliation of the injection gneisses in general dips at low angles to the south. East of Sabino Canyon these rocks form an anticline with a northwesterly trending axis; west of Sabino Canyon, though in part still anticlinal, the structure is less well known. At the western end of the forerange, as seen on the northwestern face of Pusch Ridge, the foliation of the gneisses outlines an asymmetrical anticline with a gentle south limb and a steeply dipping to overturned north limb. This fold can be seen from the Tucson-Oracle Junction highway.

In places small-scale, recumbent, isoclinal folds, shown in the foliation of the injection gneisses convey the impression that pre-metamorphic structure of the invaded host rocks may have been very complex. Pegmatitic bodies in places parallel the small-scale folds, but also commonly transect these structures.

The foliation of the granitic gneisses of the main crest, in general, dips at low angles to the north, parallel to the foliation of the injection gneisses of the forerange which appear to pass underneath the granitic gneisses.

Some problems of the complex

Origin of the Complex

Several different interpretations on the origin of the complex of gneisses and granites have been advanced. Hernon (1932, p. 62) considered the injection gneisses of the fore-range to have resulted from metasomatic processes. The early phases of the transformation were dominated by sodic solutions which resulted in the production of oligoclase-biotite gneisses from original pelitic hosts. A later phase was dominated by potash-silica solutions which altered part of the oligoclase-biotite gneisses to pegmatites. Hernon concluded that the various pegmatitic bodies in the injection gneisses, though in part emplaced by dilation, were largely the result of the metasomatic processes.

Moore, et al., (1949, p. 13) state that "in the advanced stages (of replacement) the gneiss, irrespective of the character of the original rock, tends to consist dominantly of feldspar, quartz, and mica, " and state (1949, p. 16) that the variety of gneissic rocks is "thought to have been produced through the permeation of stratified rocks of different kinds by granitic material." Thus it has been intimated that the granitic gneisses may represent a more advanced stage in granitization of the injection gneisses. Tolman (Hernon, 1932, p. 12), however, has interpreted the more homogeneous granitic gneisses of the main range as a laccolithic mass of sheared granite.

Age of the Complex

The age of the injection metamorphism of the rocks of the Santa Catalina Mountains is not definitely known. Blake (1908b, p. 47) assumed an older Precambrian age for the gneissic rocks. Tolman (Ransome, 1916, pp. 144-145) interpreted the age of the granites and the surrounding belt of rocks, which he considered as formed by intense "contact metamorphism", as post-Carboniferous. Hernon (1932, p. 25) thinks the possibility of an age younger than Precambrian is worthy of recognition, and Moore, et al., (1949, p. 12) indicate the age as post-Cretaceous or early Tertiary and state that the various granitic and gneissic rocks cut and grade into rocks as young as a dacite that is regarded as Tertiary in age. Until further studies are made the relative ages of the various granites of the Santa Catalinas and related metamorphic rocks must be regarded as uncertain.

Age of the Host Rocks

Another problem posed by the metamorphic complex is the age and nature of the original host rocks. The transition from granite to injection gneiss is clearly exposed, but the transition from injection gneiss to an original host that can be correlated with rocks of known age is nowhere definitely exposed. At a few places, as 2 miles southeast of the Madrona Ranger Station (Fig. 12), slightly feldspathized phyllites outcrop; but exposures are limited and the rocks have not been correlated with any rocks of known age. A few narrow quartzite relicts are found locally in the injection gneisses of the forerange. These relicts suggest that the original host was composed, in part at least, of sedimentary rocks.

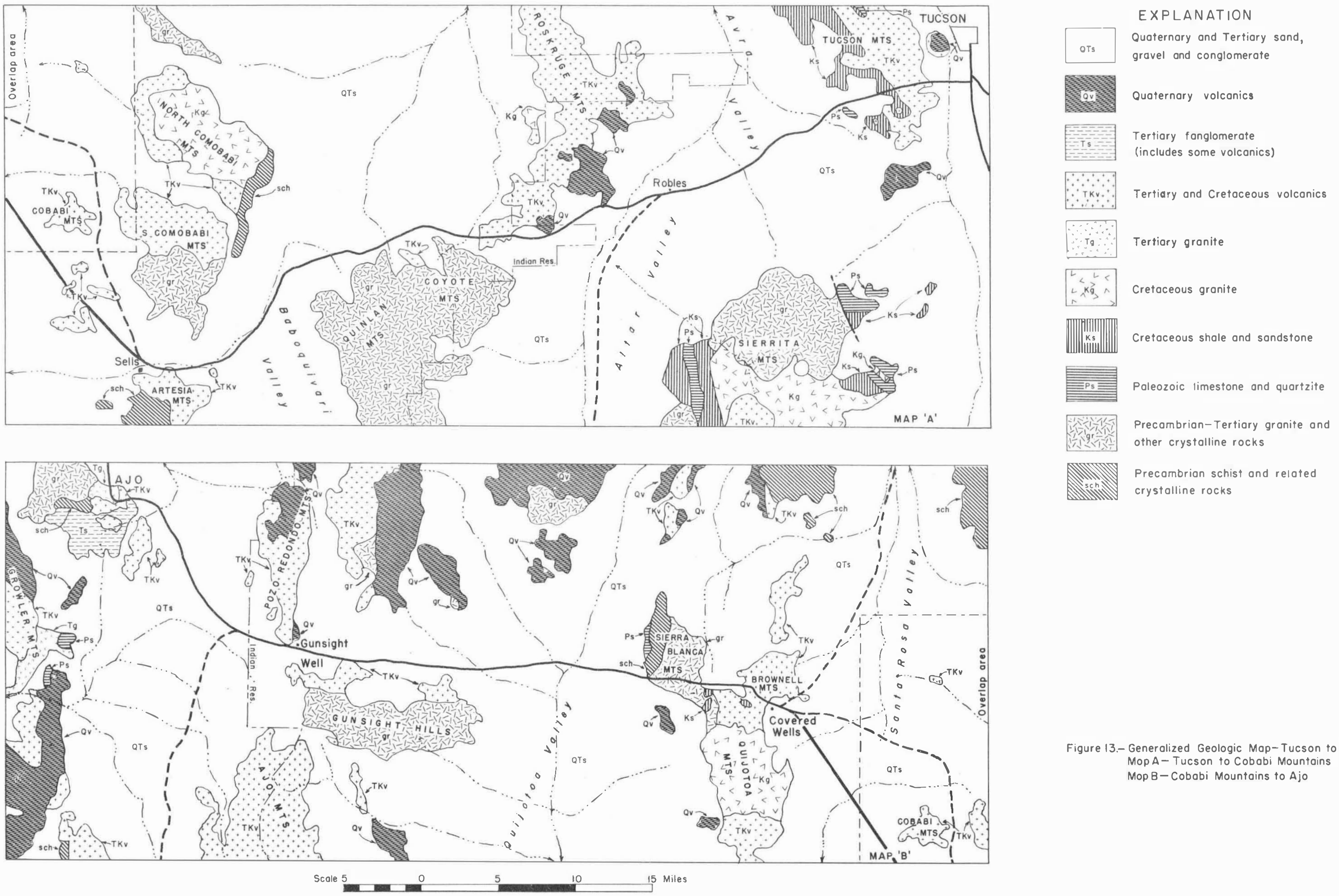


Figure 13.– Generalized Geologic Map– Tucson to Ajo
Map A – Tucson to Cobabi Mountains
Map B – Cobabi Mountains to Ajo

ECONOMIC GEOLOGY-AJO PORPHYRY COPPER

TRIP 4

Thursday, April 10, 1952

Leaders: Staff, New Cornelia Mine.
Driving Distance: Tucson to Ajo, 134 miles.

General Statement

The excursion to Ajo is by bus, therefore a road log is not included; instead, strip maps (Fig. 13) showing general geology along the route are furnished. By noting landmarks shown on the maps, the excursionist will be able to orient himself.

The Tucson-Ajo region is a part of the Sonoran Desert subdivision of the Basin and Range Province. Here it is characterized by relatively narrow, sharply eroded mountain ranges of north-northwest trend alternating with broad detrital-floored plains or valleys. As interpreted, the ranges represent tilted fault blocks or horsts, the internal structure of which is locally complicated by folding, thrust faulting, and by Tertiary, Laramide and earlier igneous intrusions.

Of particular geologic interest are the following features. The Tucson Mountains immediately west of Tucson, are a Basin and Range mountain type, and are described by Bryant in this guidebook (see field trip 2). The northern portion of the Sierrita Mountains, 10 miles south of the route, consists of Paleozoic and Cretaceous rocks intruded by granite which forms the high mass and the sloping pediment. On the eastern flank of the Sierritas is the San Xavier zinc-lead mine.

The Altar-Avra Valley, west of the Tucson Mountains, is a broad alluvium-filled basin typical of the Sonoran Desert. The Roskruge Mountains are composed of Tertiary-Cretaceous volcanic rocks, and are presumably separated by a fault of great magnitude from the Coyote-Quinlan-Baboquivari Mountains to the southwest. The northern portion of the latter mountain group consists of granites; within the granite area are small outcrops of Paleozoic sediments. Baboquivari Peak (altitude 7,730 feet), a volcanic plug visible from the Avra Valley and from the vicinity of Sells, is a prominent landmark to the south of the Quinlan Mountains.

The Comobabi Mountains consists of metamorphic rocks ranging from Precambrian to Tertiary in age, intruded by granite and overlain by Tertiary-Cretaceous volcanics. The Artesia, Cobabi, Quijotoa, Pozo Redondo, and Ajo Mountains are composed briefly of Tertiary-Cretaceous volcanics; the volcanics of the Artesia Mountains, immediately south of Sells, are underlain by schist; Tertiary-Cretaceous intrusives are prevalent in the Cobabi and Quijotoa Mountains. The Cobabi Mountains are the site of recent exploratory drilling for low-grade copper deposits. The Quijotoa area, in the early days, was the scene of extensive small-scale gold placering operations.

The Sierra Blanca is composed of granite, schist, and metamorphosed Paleozoic limestone. The Gunsight Hills are chiefly of granite, locally overlain by Tertiary-Cretaceous volcanics.

GEOLOGY OF THE NEW CORNELIA MINE, AJO, ARIZONA

(Abstracted from James Gilluly, The Ajo Mining District, Arizona: U.S. Geological Survey, Prof. Paper 209, 1946.)

Introduction

Ajo is located in the Sonoran Desert in Arizona, with arid climate and low humidity. A great variety of rocks ranging from Precambrian to Recent in age are exposed in the Ajo 15-minute quadrangle. The New Cornelia mine, operated by Phelps Dodge Corporation, is in a porphyry copper type of deposit. For the purposes of this guidebook, only the geology of the pit and adjacent area will be described.

Geology

Three main formations are exposed in the pit: 1) the Concentrator volcanics of Cretaceous (?) age; 2) Cornelia quartz monzonite of Tertiary (?) age; 3) Locomotive fanglomerate of middle (?) Tertiary age (Fig. 14).

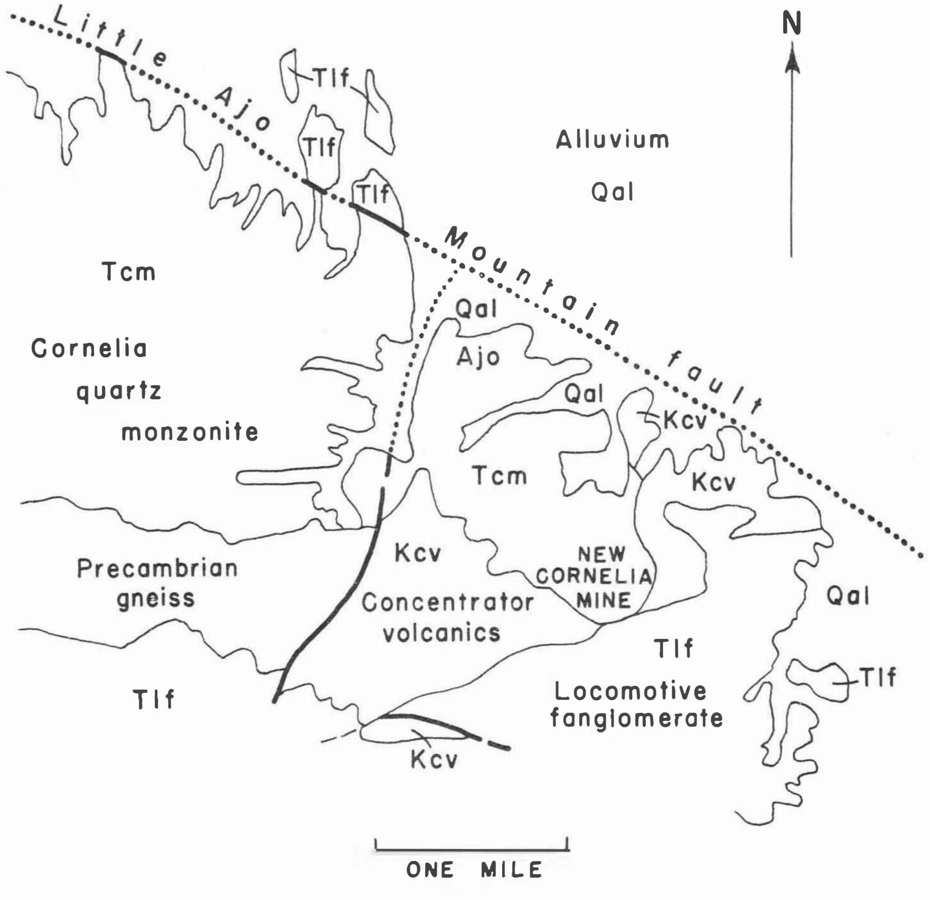


FIGURE 14 — Geologic map of New Cornelia Mine (after Gilluly).

The Concentrator volcanics include chiefly rhyolitic and andesitic pyroclastic rocks and flows that have been albitized to keratophyres and quartz keratophyres. Some of the quartz is primary phenocrystic quartz, but much may have been introduced by later hydrothermal solutions. In the vicinity of the pit, rock alteration is sufficiently intense to mask the original characters of the rocks. The colors of the Concentrator volcanics range from white to light gray to red and brown.

The Concentrator volcanics are intruded by the stock of Cornelia quartz monzonite which makes up the higher part of the Little Ajo Mountains. A small offshoot to the east, probably the displaced apex of this stock, contains the ore deposit of the New Cornelia mine. A quartz dioritic border facies is present along the eastern and southwestern margin of the pit, where it is intrusive into the Concentrator volcanics. Coarse orthoclase is common in the quartz monzonite, and the definite association with pegmatite veins suggests that the corase orthoclase formed late in the magmatic history.

The Locomotive fanglomerate is exposed in the south wall of the New Cornelia pit where it rests on an irregular erosional surface carved from the Concentrator volcanics and Cornelia quartz monzonite. The fanglomerate is composed of materials that are extremely variable in composition and size. Sorting is poor; boulders rest in a matrix of cobbles, pebbles and silt. Thick bedding is characteristic. The attitude of the beds is easily recognized in the south wall of the pit; the fanglomerate strikes easterly and dips steeply to the south.

The northeast margin of the Little Ajo Mountains is bounded by a fault (Fig. 14), and much of the trace of the fault is buried by alluvium. The displacement on this fault may exceed 10,000 feet; the entire mountain block has been elevated and steeply tilted about 50° southward from this fault. Movement along the fault is younger than the Locomotive fanglomerate, and the steep dips of the fanglomerate along the south wall of the pit are an expression of the south tilt.

New Cornelia Ore Body

General Character

The New Cornelia mine exploits a large body of disseminated copper ore by open-cut methods. Most of the ore is in the normal Cornelia quartz monzonite, but some is contained in the dioritic border facies and Concentrator volcanics. The ore body was formed prior to the deposition of the Locomotive fanglomerate. The shape of the ore body is roughly elliptical, trending north-northwest, and is well outlined by the pit.

The primary ore consists chiefly of chalcopyrite with some bornite and a little pyrite. The gangue consists of quartz and orthoclase, and the sulfides are distributed in veinlets and discrete grains through the altered quartz monzonite. The rock is so highly impregnated with orthoclase as to be practically pegmatized along two main north-northwest trending zones; the richest ore accompanies this most intensely altered rock. Chlorite and sericite that have replaced plagioclase are widespread, but the rock contains so much orthoclase and quartz that it is hard and resembles fresh rock physically, contrasting markedly with the soft, chalky-appearing ores of most porphyry copper deposits.

Fracturing of the Cornelia quartz monzonite in the New Cornelia ore body was extremely intimate. Attempts to work out a systematic arrangement of the fracture pattern were fruitless. For the most part, the rock is "crackled" rather than sheared. The crackling or brecciation which affects the quartz monzonite and adjacent Concentrator volcanics cover only a small area, and must have had a highly localized source.

Sequence of Mineralization

Whatever the cause of brecciation, it continued through much of the period of mineralization. Solutions penetrating the brecciated ground deposited a long series of minerals, partly by replacement of monzonite and partly by filling in fractures. The earliest phase was the introduction of pegmatite of replacement origin. The pegmatite consists of very coarse microcline, subordinate orthoclase, quartz, biotite, and much chlorite. The pegmatite blends at its contacts with the host monzonite. The area of coarse pegmatization is central to a large area where the groundmass of the monzonite is largely replaced by fine-grained pink orthoclase. Silicification of the quartz monzonite is intense near the pegmatite. The original mafic minerals in the quartz monzonite have largely altered to chlorite.

Magnetite closely followed the pegmatization and was localized near the pegmatites. Sulfides began to form after magnetite, and pyrite is the oldest of the sulfides. Chalcopyrite appears to have begun to form before bornite, but this is not certain. Where pyrite, chalcopyrite, and bornite occur together, it seems that the chalcopyrite is older than the bornite in its replacing relations to pyrite.

Albitization is essentially complete in the area of the ore body, both in the pegmatized areas as well as around them. Sericitization tends to be less conspicuous in the pegmatized zones, perhaps because of the dominance of potash feldspar over the more susceptible plagioclase. However, sericite is present nearly everywhere. Sericite continued late in the mineralizing epoch for it veins chalcopyrite and probably replaces chlorite.

Oxidation and Enrichment

Oxidation of the primary sulfide ore has produced two contrasting products. The oxidation that occurred during Recent geologic time produced carbonate ore above the groundwater table; the carbonate ore passed directly into primary sulfide at depth. This carbonate ore covered much of the original exposures of the ore body and was successfully treated by leaching, starting in 1915, and has long been mined out. As primary sulfide ore was exposed, it was mined for the concentrator; thus no stripping of leached capping was needed before large scale mining of sulfide ore. The grade of the carbonate ore was essentially identical with that of the underlying sulfide ore, proving that the carbonate ore was developed by oxidation of the sulfide ore essentially in place, and that oxidation was related to the Recent erosion surface. There was practically no tendency toward the formation of a supergene enrichment zone such as comprises much of the commercial ore of most disseminated copper deposits.

In sharp contrast, beneath the Locomotive fanglomerate to the south of the pit, there is a zone of leached capping above a blanket of chalcocite ore. The chalcocite blanket and leached zone dip steeply south, essentially parallel to the base of the Locomotive fanglomerate, proving that the leaching and enrichment occurred prior to the deposition of the Locomotive fanglomerate and subsequent southward tilting. The chalcocite ore locally contains as much as 10 percent of copper, and furnished most of the shipping ore in the early periods of mining. The top of this chalcocite zone in places is 450 feet below the base of the Locomotive fanglomerate, and elsewhere was exposed at the surface prior to the deposition of the fanglomerate. Some oxide copper is present in the leached zone, mostly native copper or cuprite; carbonate minerals are subordinate.

Whether the factors that determined the marked differences in weathering of the ore body in pre-Locomotive and in Recent time were mainly climatic or mineralogic is not known. If the material weathered and eroded in Recent time, climatic differences would provide the answer. But as most of the pre-Locomotive topography and much of the ore body have been removed by erosion, it cannot be shown that the primary mineralization was uniform.

The apparent localization of notable leaching and supergene enrichment in the Recent cycle in the area where pyrite is relatively more abundant suggests that the proportion of pyrite may be the controlling factor. This corresponds with the general experience in other areas and with experimental work as it is commonly interpreted. If this hypothesis is adopted, one must conclude that proportionally more pyrite was present in the rocks where the pre-Locomotive enrichment took place along the south margin of the pit.

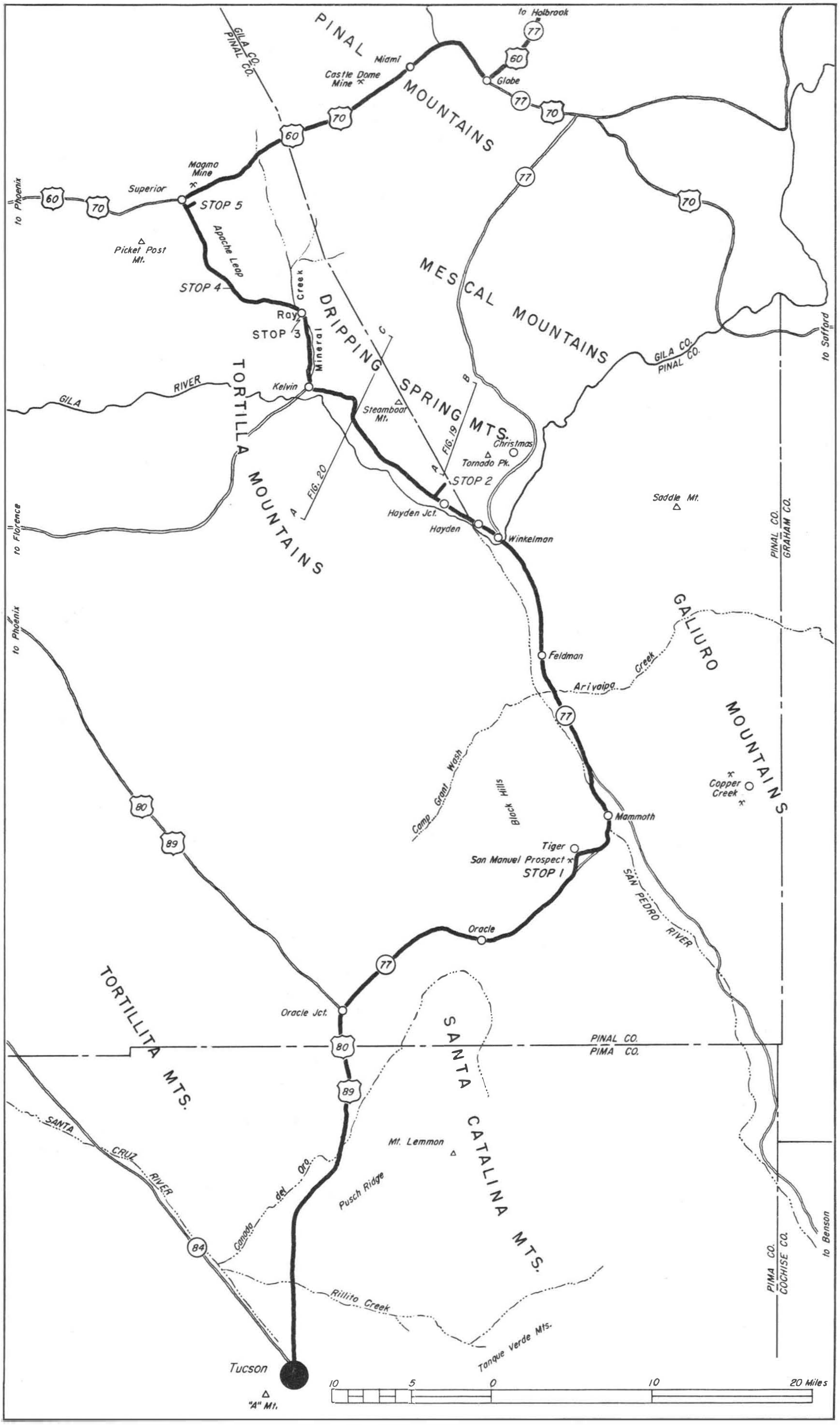


FIGURE 15.-ROAD LOG INDEX MAP, TRIP 5, FIRST DAY

STRATIGRAPHY, STRUCTURE, AND ECONOMIC GEOLOGY TYPICAL OF SOUTHERN ARIZONA

TRIP 5, ROAD LOG

First Day--Sunday, April 13, 1952

Leaders: H. J. Steele, G. A. Kiersch, O. M. Clark, Jr., E. D. Wilson
and J. W. Harshbarger
Driving Distance: 145 miles. Logged distance: 137.3 miles.

General Statement

This trip begins at Tucson in the Santa Cruz valley, follows along the western and northern edges of the Santa Catalina Mountains and enters the San Pedro drainage basin near Oracle. The route traverses the San Pedro and Gila valleys to Kelvin, then follows the valley of Mineral Creek, along the southwestern base of the Dripping Spring Mountains, to Ray. West of Ray the route crosses a spur of the Tortilla range, beyond which it parallels a westward facing escarpment to Superior. It then swings eastward and crosses the mountains to Miami and Globe.

The party will observe (1) typical outcrops of Precambrian, Paleozoic, Tertiary, and Quaternary rocks of the region; (2) faulting and folding, particularly that of Laramide to post-Pliocene age; (3) typical Basin-Range physiography; and (4) the geologic setting of three of the major mining districts of southern Arizona. There will be five stops. Stop 1 is at the new San Manuel copper prospect, where a brief discussion of the geologic features of the ore body will be given. Stop 2, west of Hayden, will be to observe stratigraphy and structure typical of the area between Winkelman and Ray. Stop 3 is to view the geology of the Ray open pit and the regional setting of this mineral district. Stop 4, near Walnut Creek, is an area of thrust faulting and Tertiary igneous activity. At Superior, Stop 5, stratigraphic units and structure typical of the area will be viewed, and a discussion of some of the problems of the Magma mine will be presented.

0.0	0.0	Intersection of U. S. Highway 80 & 89 (Stone Avenue) with Speedway Blvd. Follow Highway 80 & 89 northward.
0.2	0.2	TURN LEFT, follow Highway 80 & 89. Directly ahead are the Tucson Mountains (Brown, 1939). At 10 o'clock are Tumamoc hill and "A" Mountain (Sentinel Peak) composed of Quaternary or late Tertiary, flat-lying basalts. At 1 o'clock is Amole Mountain, a latitic intrusive of post-Cretaceous age. Between Tumamoc hill and Amole Mountain are tilted Tertiary rhyolite and andesite flows, which include tuff beds. At 2 o'clock, near the north end of the range, is Safford Peak, a volcanic neck of dacite. Many of the low outlying hills along the east front of the range are klippen of Paleozoic limestone, mostly of Permian age. For a discussion of the Tucson Mountains see the paper by D. L. Bryant, "Paleozoic and Cretaceous Stratigraphy of the Tucson Mountains", in this guidebook.
0.3	0.5	Follow right on Highway 80 & 89.

1,5	2,0	Intersection of State Highway 84 with U,S, Highway 80 and 89. Continue straight ahead on route 80 & 89,
0,3	2,3	At 1-2 o'clock are the Santa Catalina Mountains, These mountains form a triangular block roughly twenty miles on each side, They are bounded on the northeast by a long bajada (alluvial slope) to the valley of the San Pedro river and on the east by the San Pedro valley, A thrust fault is exposed along the southern base of the mountains, The Santa Catalina Mountains are believed to have been faulted and uplifted in Tertiary time,
2,1	4,4	Rillito Creek Bridge,
0,2	4,6	Valley fill gravels in road cuts are part of the dissected alluvial fans which are locally referred to as the "Catalina Foothills",
2,4	7,0	Note on the western end of the "Catalinas", the gneissic structure of the rocks dipping toward the Tucson valley,
0,6	7,6	At 11 o'clock are the Tortillita Mountains, composed essentially of Oracle (?) granite, schist and gneiss correlated with the gneisses of the Santa Catalina Mountains, remnants of Paleozoic limestone, and Cretaceous and Tertiary volcanics, The Tortillita Mountains apparently are formed as a block upthrown with respect to the northwest part of the Santa Catalina Mts,
2,7	10,3	Approximate point of intersection of two major faults, The southern fault bounds the Tucson valley side, and the northeastward trending fault bounds the west side of the Santa Catalina Mountains,
1,5	11,8	At 1 o'clock is Pusch Ridge, the western-most part of the "Catalinas," An asymmetrical anticline is well exposed along the northern side of Pusch Ridge where one limb dips steeply northward, and the other limb dips gently southward, Examples of large scale exfoliation of gneissic rock are abundant,
1,8	13,6	Canada del Oro ("Canyon of Gold") bridge, The setting for Harold Bell Wright's novel, "Mine with the Iron Door" is near the headwaters of the Canada del Oro, Promotion schemes for large scale gold placer operations along the Canada have been attempted, but little actual placering was ever accomplished, At 2 o'clock is Mount Lemmon (9150 feet), winter sports and summer recreation area for southern Arizonians,
0,3	13,9	At 9 o'clock, note the three levels of alluvial fans at the base of mountains, Terraces, carved in the fans, exposing cross-sections for study, The highest fans are the youngest,
2,5	16,4	At 3 o'clock is the Canada del Oro section of the Santa Catalina Mountains, Folding exhibited in gneiss on the left side of the canyon, Eastward from the canyon gneiss grades into granite of post-Paleozoic age,

0,2	16,6	At 1 o'clock is a northwesterly-trending spur of the Santa Catalina Mountains. The contact between the Precambrian Oracle granite on the north and the gneissic granite on the south roughly parallels the canyon located on the north side of the ridge,
0,2	16,8	PICTURE POINT. Fig. 16.
0,4	17,2	At 9 o'clock are the Tortillita Mountains,
0,5	17,7	At 12 o'clock are high-level depositional terraces of Pleistocene-Recent gravels,
1,6	19,3	At 3 o'clock note banding of the metamorphic rocks,
2,0	21,3	At 12 o'clock are the Tortilla Mountains. The caravan route circles the east side of the mountains and crosses the range at a point west of Ray.
2,5	23,8	Oracle Junction, intersection U.S. Highway 80 & 89 with State Highway 77. TURN RIGHT and follow route 77.
3,2	27,0	At 9 o'clock are the Tortilla Mountains,
1,1	28,1	At 1 o'clock is Samaniego Ridge. (See Fig. 12). Canada del Oro heads on the western slope of this ridge. Eastward lies Oracle Ridge; it highest point, Marble Peak, is capped by Carboniferous rocks,
1,6	29,7	At 1 o'clock on the skyline is a low ridge composed of Oracle granite. The town of Oracle is situated near the saddle on the north end. The Mogul fault, a major structure of the northern Santa Catalinas, traverses the ridge 3 miles southward from Oracle. Precambrian, Paleozoic, and Cretaceous rocks crop out south of the Mogul fault, Oracle granite on the north,
1,4	31,1	At 10 o'clock are the Pinal Mountains,
0,6	31,7	At 3 o'clock is the head of Canada del Oro, a beheaded stream that formerly drained eastward to the San Pedro River as a tributary of Tucson Wash. After uplift during the Tertiary, a tributary of the Santa Cruz River worked eastward and captured the Canada del Oro, diverting its flow westward into Rillito Creek. Near the northern edge of the mountains, the stream flow changes abruptly from a northeastward to a westward direction.
0,5	32,2	At 2 o'clock is a pediment developed on the Oracle granite.
0,7	32,9	The boulder-like masses are of Oracle granite.
2,4	35,3	Oracle, Arizona, elevation 4,470 feet, a summer resort and center for many dude ranches. Many examples of granite weathering under a semi-arid environment are seen,
0,3	35,6	TURN LEFT, follow pavement and state route 77.

0.6	36.2	At 12 o'clock are the Galiuro Mountains of mesa-like outline. The upper portion consists mainly of Tertiary lava flows, tuff, ash, and conglomerate that dip gently eastward; underlying Paleozoic and Precambrian Apache group rocks have been locally invaded by acid intrusives (Darton, 1925). San Pedro valley is in foreground.
0.4	36.6	Road cut on Oracle granite. Tourmaline-bearing aplite dikes cut the granite. At 12 o'clock, Stanley Butte is in the far distance. It is a rhyolite porphyry mass north of the Arivaipa mining district.
0.6	37.2	Cattleguard.
0.5	37.7	At 11 o'clock the light-colored outcrop is an aplitic dike.
0.2	37.9	Several aplite dikes are exposed in road cuts.
0.6	38.5	Cattleguard. Note the contact between Oracle granite and overlying granitic alluvium. B. S. Butler has suggested that two ages of alluvium are present in this area. The older granitic alluvium is composed essentially of Oracle granite fragments. The younger alluvium consists of lava debris, with only minor amounts of granitic material. North and west of the San Manuel prospect in the Black Hills, Tertiary lavas are underlain by granitic alluvium and overlain by volcanic debris. The underlying granitic alluvium appears to be equivalent to the Whitetail conglomerate of the Superior-Ray area (Ransome, 1903), and the younger volcanic debris is the equivalent of the Gila conglomerate (Gilbert, 1875). Tertiary lavas are absent along the route (State Highway 77). Both the older granitic alluvium (Whitetail equivalent) and the overlying Gila conglomerate are exposed in road cuts.
0.7	39.2	Road cuts are in granitic alluvium. Road cuts within the next half-mile expose the Gila conglomerate. Many of the plants of this area, particularly the California poppy, have been studied for trace elements (Lovering, *et al.*, 1950).
0.4	39.6	At 11 o'clock, the dark-stained area is the southernmost part of the Black Hills. These hills consist of Oracle granite and sedimentary rocks of the Apache group in the northern part; Tertiary volcanics form the southern part.
0.2	39.8	At 11:30 o'clock is the No. 1 shaft of the San Manuel prospect.
0.1	39.9	At 12:30 o'clock are the dissected fans along the valley floor of the San Pedro river.
1.2	41.1	Cattleguard. Gila conglomerate in road cuts.
0.1	41.2	Gila conglomerate, in road cuts, is displaced by faults.
0.3	41.5	Andesite porphyry dikes are exposed in road cut.

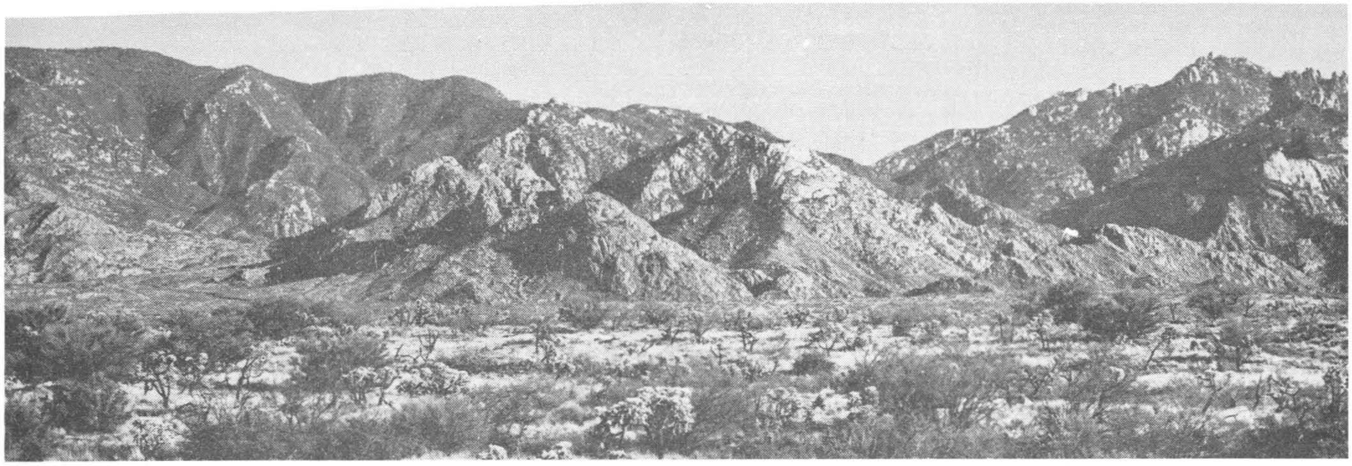


FIGURE 16. - NORTHWEST FACE OF THE SANTA CATALINA MOUNTAINS. Looking east from mile 16.8 Rugged ridge in middleground is between Romero and Montrose Canyons (Fig. 12). Timbered area on left is Samaniego Ridge composed of Precambrian Oracle granite. Rugged ridge and peak on right are composed of gneiss. There is a major fault along the base of the mountain front.

FIGURE 17. - GALIURO MOUNTAINS, LOOKING NORTHEAST FROM VICINITY OF SAN MANUEL. Picture from mile 48.1. The Galiuro mountains are composed of granites and Apache group sediments capped by a thick succession of Cretaceous and Tertiary lavas. San Pedro Valley in foreground.

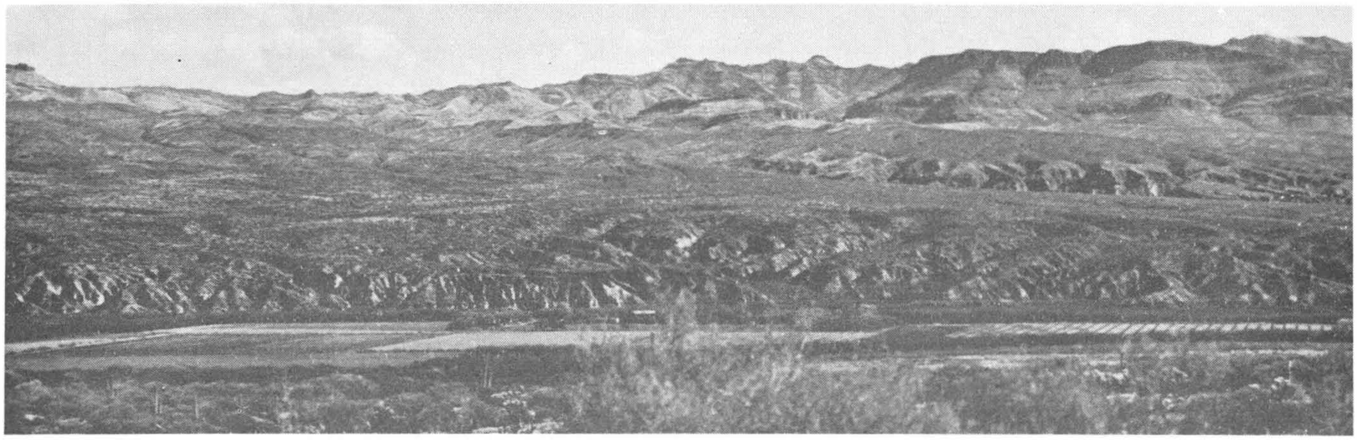


FIGURE 18. - DISSECTED PLAYA DEPOSITS IN SAN PEDRO VALLEY. View east from mile 48.1. The playa deposits, in the foreground are gypsiferous and diatomaceous beds of Pliocene and Pleistocene age. In background is lava-capped, southern extension of Galiuro Mountains.

0,2	41,7	Dirt road to left, keep on pavement,
0,2	41,9	Intersection of State Highway 77 and road to San Manuel property, Turn left off pavement,
0,5	42,4	Tilted beds of Gila conglomerate are well exposed in road cut,
0,4	42,8	At 12 o'clock is Red Hill, a strongly pyritized, fine-grained siliceous intrusive, In foreground is Shaft No, 1, San Manuel prospect,
0,2	43,0	At 11 o'clock, Tucson Wash, a major drainage channel of the area, At 12 o'clock is Shaft No, 2, San Manuel prospect,
1,1	44,1	Road junction, just short of No, 1 Shaft, TURN RIGHT,
0,6	44,7	TURN SHARP LEFT in wash,
0,2	44,9	Road to left, KEEP STRAIGHT AHEAD,
0,05	44,95	TURN SHARP LEFT at road junction,
0,15	45,1	Three-way junction, KEEP STRAIGHT AHEAD,
0,05	45,15	STOP 1 (40 minutes), Walk up old road, Discussion of San Manuel prospect will be by H, J, Steele, After stop follow loop to return to incoming road,
0,15	45,3	TURN SHARP RIGHT and follow incoming road,
0,2	45,5	Junction in wash (mileage 44,7 above), TURN SHARP LEFT toward pavement,
0,1	45,6	Junction with State Highway 77, TURN LEFT,
0,3	45,9	San Manuel fault, Footwall monzonite porphyry is exposed in right-hand road cut, Gila conglomerate crops out beyond this point,
0,1	46,0	Bridge, Water in wash is from pumping operations at the San Manuel No, 1 Shaft,
0,4	46,4	The Mammoth-Saint Anthony mine road intersects Highway 77 on left, Keep ahead on pavement,
1,7	48,1	PICTURE POINT, Figures 17 and 18,
0,1	48,2	At 12 o'clock in bottom of valley are Tertiary, gypsiferous, lake beds,
0,6	48,8	Cattleguard,
0,5	49,3	Mammoth, Arizona, Town is named after the Mammoth clain, Mammoth-Saint Anthony mine, Tiger, Arizona,

0,1	49,4	Road junction to Copper Creek mining district is on the right, Keep straight ahead on the paved State Route 77,
0,9	50,3	At 10 o'clock, note the two distinct units in the Tertiary sediments, The older, fine-grained lake sediments are separated from the overlying coarse gravel by an erosion surface,
0,3	50,6	Tucson Wash,
0,5	51,1	Bridge over the San Pedro River, which heads in Sonora, Mexico, and flows into the Gila River at Winkelman, The route follows down the San Pedro valley to Kelvin,
0,6	51,7	Road junction on right to Benson,
1,9	53,6	Gypsiferous clays of Pliocene (?) age are well exposed in numerous road cuts,
1,9	55,5	Gypsiferous clays are exposed in road cuts, Gypsum is mined in similar beds about 1 mile east of Feldman, (6 miles ahead),
0,8	56,3	At 12 o'clock eastward dipping sedimentary rocks are of Precambrian Apache group,
0,8	57,1	At 1:30 o'clock, Brandenberg Peak,
0,4	57,5	At 10 o'clock, Mescal limestone and Dripping Spring quartzite outcrop,
2,1	59,6	Aravaipa Creek, At 9 o'clock resistant walls of canyon are of Mescal limestone,
0,6	60,2	Road junction on right to Aravaipa Canyon, Keep straight ahead,
0,2	60,4	At 1 o'clock, Saddle Mountain, At 2-3 o'clock, Devonian, Mississippian and Pennsylvanian limestones appear in distance,
0,9	61,3	Bridge,
0,6	61,9	Road junction on right to gypsum quarry located 1 mile east, Feldman, on the left,
1,2	63,1	At 12 o'clock, Dripping Spring Mountains, The Pinal Mountains are in the background,
0,3	63,4	At 11 o'clock, the small hill consists of Cretaceous (?) volcanics,
1,9	65,3	At 11 o'clock, Teapot Mountain near Ray, Arizona,
0,2	65,5	Cattleguard,
2,2	67,7	At 10 o'clock, Cretaceous (?) andesites,

THIS PAGE

INTENTIONALLY BLANK

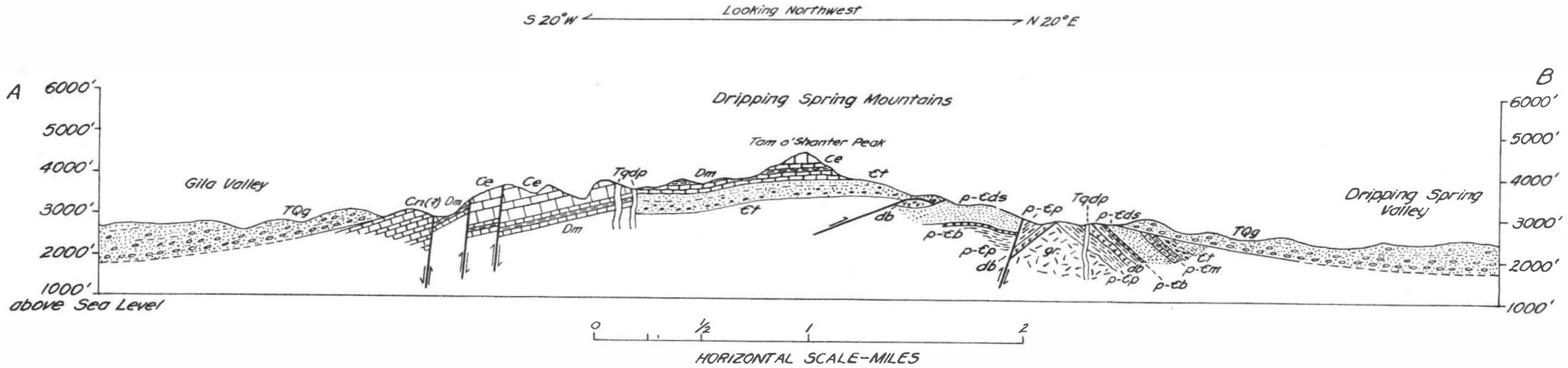


FIGURE 19:-CROSS SECTION (A-B) THROUGH DRIPPING SPRING MOUNTAINS AT TAM O'SHANTER PEAK. SEE ROAD LOG MAP (FIGURE 15) AND FIGURE 29 FOR LINE OF CROSS SECTION.

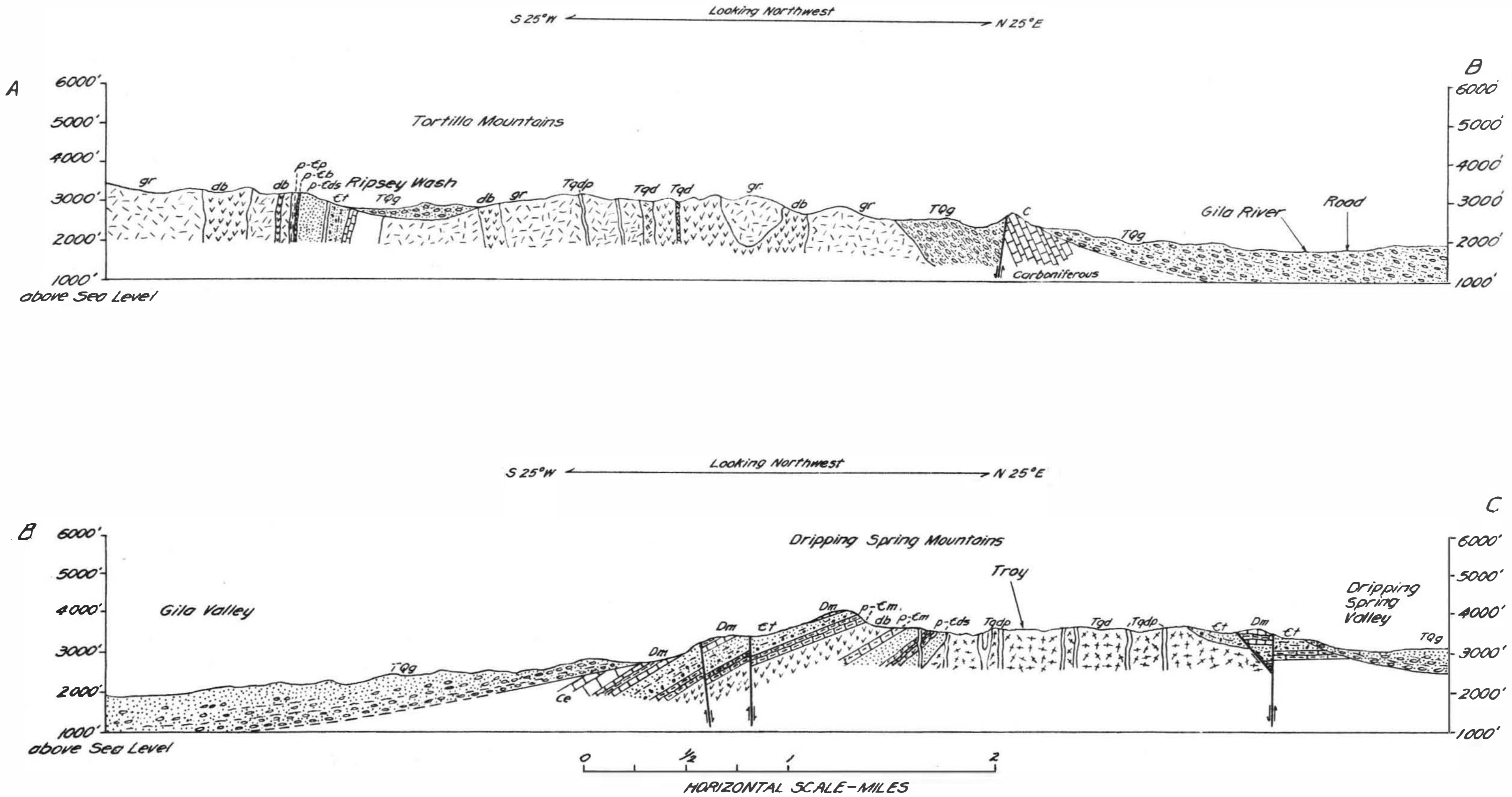


FIGURE 20:-CROSS SECTION THROUGH THE EASTERN PART OF THE TORTILLA MOUNTAINS (A-B) AND THE DRIPPING SPRING MOUNTAINS (B-C). SEE ROAD LOG MAP (FIGURE 15) FOR THE LINE OF CROSS SECTION.

SYMBOLS

Fault, high angle showing relative movement

Fault, low angle overthrust

After F.L. Ransome (1923) with modification of figure 19 by G.A. Kiersch

EXPLANATION

LATE TERTIARY-QUATERNARY

Pliocene-Pleistocene

TQg

GILA CONGLOMERATE

Largely coarse fluvatile conglomerates, weakly to firmly cemented with some tuffaceous beds.

UNCONFORMITY

EARLY TERTIARY(?)

Tqdp

QUARTZ DIORITE PORPHYRY

Dikes and small intrusive masses.

Tgd

GRANODIORITE

Intrusive mass in Troy Basin.

Tqd

QUARTZ DIORITE

Dikes and comparatively small intrusive masses.

MESOZOIC(?)

db

DIABASE

Medium-grained, ophitic diabase as regular sills with cross-cutting connections. Intruded especially in Mescal limestone.

PALEOZOIC

Penn-sylvanian

Cn

NACO LIMESTONE

Gray to blue-gray, thin-to thick-bedded limestone. Thin chert conglomerate at base, ledge-and cliff-former.

DISCONFORMITY

Miss-issippian

Ce

ESCABROSA LIMESTONE

Gray, thick-to massive-bedded limestone; parts thin-bedded; prominent cliff-former.

Devonian

Dm

MARTIN LIMESTONE

Yellowish to dark gray, thin-bedded limestone. Some arenaceous beds in lower part. Ledge- and slope-former.

UNCONFORMITY

Cambrian

Ɛt

TROY QUARTZITE

Cross-bedded, pebbly quartzite; chiefly thick-bedded with thin, argillaceous beds in upper part. Cliff-former.

UNCONFORMITY

YOUNGER PRECAMBRIAN

Apache group

p-Ɛm

MESCAL LIMESTONE

White to buff, thin-bedded limestone; abundant chert; included as mapped an overlying flow of basalt.

p-Ɛds

DRIPPING SPRING QUARTZITE

Banded dark red and gray, fine-grained ripple-marked quartzite. Cliff-former.

p-Ɛb

BARNES CONGLOMERATE

Coarse, well-rounded quartzose pebbles in arkosic matrix.

p-Ɛp

PIONEER SHALE

Dark reddish-brown arenaceous shale grading into arkosic quartzite at base. Includes as mapped, underlying thin Scanlan conglomerate.

UNCONFORMITY

OLDER PRECAMBRIAN

gr

GRANITE

Generally coarsely porphyritic; batholithic mass exposed Tortilla range.

0.4	68.1	At 3 o'clock, Saddle Mountain, a prominent landmark of this area. The Saddle Mountain mining district to the northwest has been described by Ross (1925).
0.7	68.8	Cattleguard.
0.1	68.9	At 11 o'clock, south side of Tornado Peak, type locality for the Tornado limestone (Ransome, 1923) of Mississippian and Pennsylvanian ages. These Carboniferous beds have subsequently been separated into the Escabrosa (Mississippian) and Naco (Pennsylvanian) formations.
1.6	70.5	At 12 o'clock is the stack of the Hayden Copper smelter.
0.2	70.7	At 11 o'clock, the road winding up the side of the limestone slopes leads to the 79 mine.
0.3	71.0	Gila River Bridge.
0.2	71.2	Road junction, State Route 77 and Ray road. TURN LEFT to Ray. The Christmas mine at Christmas, Arizona, 8.9 miles from Winkelman on State Route 77.
0.3	71.5	On left, Hayden-Winkelman golf course. Beyond is the southern limit of the tailings pond of the Hayden concentrator, Kennecott Copper Corp.
0.9	72.4	At 2-3 o'clock, Kennecott concentrator and the copper smelter, American Smelting and Refining Company at Hayden, Arizona. In distance, the fault-line scarp forms the western boundary of the Dripping Spring Mountains. The massive, thick-bedded Escabrosa limestone is the prominent cliff-former. The overlying, thin- to thick-bedded Naco limestone is the cliff- and ledge-forming unit that caps the range. The fault blocks of this range have a regional southward dip.
0.1	72.5	On left, Hayden depot of the Arizona Eastern Railroad, now a branch line of the Southern Pacific Railroad Company. Overhead flume transports tailings from the concentrator to the tailings pond.
0.1	72.6	Road junction on right is to Hayden. Keep left.
0.2	72.8	At 10 o'clock are the Tortilla Mountains, consisting of complexly faulted Precambrian crystallines and later Precambrian and Paleozoic sediments. Gila conglomerate is exposed in all the road cuts.
1.4	74.2	Railroad crossing.
0.4	74.6	Hayden Junction.
0.5	75.1	Road junction, TURN RIGHT toward Tornado Peak.

0,8	75,9	STOP 2 (20minutes), Discussion of the salient geologic features of the Gila valley, Tortilla and Dripping Spring Mountains will be by George A, Kiersch, Caravan returns to the Winkelman-Ray highway,
0,8	76,7	Intersection with highway, TURN RIGHT,
0,5	77,2	Cattleguard,
0,1	77,3	Railroad crossing,
0,3	77,6	At 9 o'clock are complexly folded and faulted granitic rocks and Precambrian and Paleozoic sedimentary rocks of the Tortilla Mountains,
1,6	79,2	At 11 o'clock, an extension of the Tortilla Mountains, The granitic rocks and the Precambrian and Paleozoic sedimentary rocks are repeated due to faulting,
1,6	80,8	At 12 o'clock, Teapot Mountain near Ray,
0,4	81,2	At 12 o'clock is a cliff of Gila conglomerate, The general thickness of this formation increases toward Kelvin,
2,1	83,3	At 9 o'clock are dip slopes of the steeply inclined beds of Gila conglomerate,
2,5	85,8	At 2 o'clock, Tam O'Shanter Peak, See cross section, Fig, 19, Tornado Peak is the rounded, low peak to the south on the skyline,
0,2	86,0	At 12 o'clock, Troy Mountain, type locality for the Cambrian Troy quartzite (Ransome, 1923), The overlying Paleozoic formations are the Martin, Escabrosa, and Naco limestones that crop out in the adjacent cliffs,
2,1	88,1	At 2 o'clock, massive cliffs of Escabrosa limestone, overlain by thin- to thick beds of Naco limestone,
2,2	90,3	Cattleguard,
0,1	90,4	Bridge, This area is underlain by granitic rocks which are concealed locally by a thin veneer of alluvium,
0,3	90,7	Tailings dump from early day operation of mines in this vicinity,
0,4	91,1	Ray Junction, The hill to left of Ray Junction is underlain by Precambrian granite and is intruded by diabase, The extensively leached outcrops have attracted considerable attention from prespectors, The area was explored by churn drilling in 1949-50,
0,6	91,7	At 12 o'clock are Precambrian granitic rocks,
0,1	91,8	Kelvin, Arizona,

0.4	92.2	At 12 o'clock, erosional spires are composed of Gila conglomerate.
0.1	92.3	At 9 o'clock, diabase and granite outcrops.
0.7	93.0	Bridge over Mineral Creek. Note the size of boulders overlying the gravel beds.
0.1	93.1	At 1 o'clock, folded and faulted Paleozoic rocks of the Dripping Spring range.
0.1	93.2	Gila conglomerate.
0.1	93.3	Road cut in granite. Gila conglomerate crops out on both sides of the Mineral Creek valley. Note the varied sizes and composition of the gravel, degree of rounding, type of stratification, and amount of cementation.
2.0	95.3	At 2 o'clock, diabase, overlain by Troy quartzite. Upper outcrops consist of Martin limestone, and Escabrosa limestone.
0.3	95.6	At 2 o'clock, across Mineral Creek, is Dripping Spring quartzite.
0.3	95.9	Ray golf course.
0.2	96.1	At 12 o'clock is a high angle reverse fault, trending nearly parallel with the road. The fault separates Dripping Spring quartzite on the right, Pinal schist on the left.
0.2	96.3	At 9 o'clock, Dripping Spring quartzite.
0.2	96.5	Bridge over Mineral Creek.
0.1	96.6	At 7 o'clock, high angle reverse fault. Pinal schist is in hanging wall to the left (west), Dripping Spring quartzite in footwall to the right (east).
0.5	97.1	Kennecott Copper Corporation mine offices.
0.4	97.5	TURN SHARP LEFT, THEN RIGHT, instead of continuing through Ray.
0.2	97.7	TURN SHARP LEFT and enter Ray pit. Recess log. STOP 3. Discussion of geologic features of the Ray copper deposit will be by O.M. Clarke, Jr. and of regional geology by E. D. Wilson. Road log discontinued through the mine area and resumed at junction with Ray-Superior Highway, at mileage point 98.2
0.2	97.9	Bridge over Mineral Creek. (This point is not on route through open pit.)

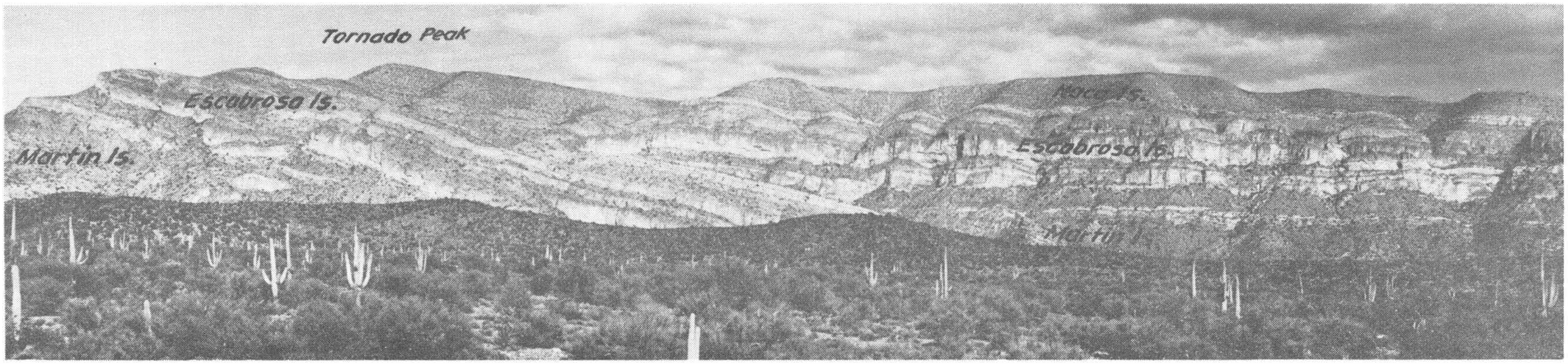


FIGURE 21. - PANORAMIC VIEW OF DRIPPING SPRING MOUNTAINS TOWARD TORNADO PEAK. Picture from Stop 2. The slope- and ledge-forming Martin limestone is overlain in succession by the massive Escabrosa limestone and the ledge-forming Naco limestone. A fault separates the rocks on the right from those on the left.

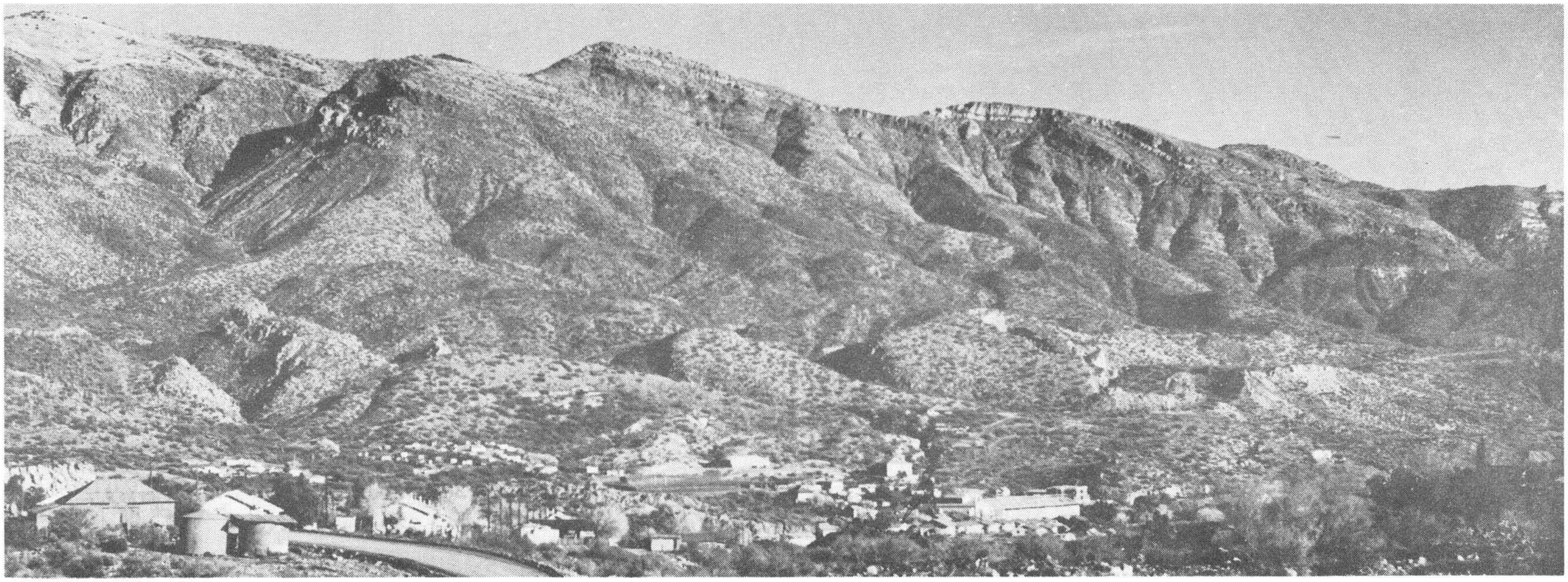


FIGURE 22. - DRIPPING SPRING MOUNTAINS FROM RAY-SUPERIOR HIGHWAY. View is east across Mineral Creek from mile 99.1. Ray in foreground. Low hills sloping toward observer are of Tertiary dacite. That portion of the Dripping Spring Range in this view includes Pinal schist, Apache group sediments, diabase, and Paleozoic strata, intricately faulted.

0,3	98,2	Road junction, Ray-Superior Highway and road from open pit, On leaving the pit the caravan will TURN LEFT and resume log from this point, At 12 o'clock, after re-entering the Ray-Superior road, Tertiary dacite caps the ridge and is underlain by Tertiary Whitetail conglomerate, At 11 o'clock is Teapot Mountain, Here the cliff-forming dacite is underlain by approximately 800 feet of Whitetail conglomerate (slope), which rests on a basement of Pinal schist,
0,15	98,35	On right is housing project for personnel of the Ray Mines, TURN SHARP LEFT, THEN SHARP RIGHT,
0,15	98,5	Note subsidence areas, due to block0caving method of ore extraction, in use at the Ray mine since 1910, Contorted Pinal schist is in the foreground,
0,6	99,1	PICTURE POINT, Fig, 22
0,4	99,5	Pinal schist in road cut,
0,2	99,7	Enter Copper Canyon,
0,3	100,0	Pinal schist in road cuts,
1,1	101,1	At 9 o'clock, quartz monzonite porphyry in road cut,
0,2	101,3	Road junction on left to Copper Butte, Continue on main road,
0,2	101,5	Pinal schist in road cuts,
0,2	101,7	At 11 o'clock, Hells Peak, a rhyolite plug,
0,2	101,9	Walnut Creek,
0,2	102,1	At 1 o'clock, Pinal schist and rocks of the Apache group are brought in contact with Naco limestone by the Walnut fault, In this area the fault is a steep reverse fault; to the northeast it is a low-angle thrust fault, (Wilson, this Guidebook),
0,5	102,6	At 4 o'clock, Teapot Mountain, Reddish material near the base is mineralized Pinal schist, Whitetail conglomerated capped by dacite overlies the schist,
0,3	102,9	STOP 4, Discussion of structure and rocks of the northern end of the Tortilla Mountains will be by E, D, Wilson,
0,1	103,0	At 12 o'clock, underneath power line, is travertine along Walnut fault zone, The travertine rests on Pinal schist,
0,2	103,2	At 3 o'clock, Pinal schist in road cut, At 9 o'clock, travertine,

0,4	103,6	At 3 o'clock, fault blocks of Troy quartzite are exposed,
0,1	103,7	At 9 o'clock, silica breccia masses associated with a reverse fault, These breccias closely resembly masses associated with some major faults in the Dripping Spring range,
0,3	104,0	PICTURE POINT, Fig, 24
0,2	104,2	CAUTION-SHIFT TO LOWER GEAR, This is the "Hump" or divide on the Ray-Superior highway, At 3 o'clock, reddish beds of Martin limestone in road cut, At 9 o'clock, Escabrosa limestone, At 11 o'clock, Picketpost Mountain, At 11:15 o'clock, Weaver's Needle in far distance, At 12 o'clock, smoke from copper smelter of Magma Copper Corporation at Superior,
0,1	104,3	At 3 o'clock, Dripping Spring quartzite in road cut,
0,1	104,4	At 3 o'clock, diabase in road cut,
0,1	104,5	Enter Crook National Forest, Dripping Spring quartzite in road cut,
0,1	104,6	At 3 o'clock, Barnes conglomerate overlying Pioneer shale in road cut, On skyline is Escabrosa limestone,
0,3	104,9	At 3 o'clock, Pioneer shale in road cut on the new highway,
0,4	105,3	At 3 o'clock, Apache group and overlying limestones,
0,9	106,2	At 3 o'clock, silica breccia pipes, Caravan route here parallels the Concentrator fault, The western, or hanging wall side, has moved downward with respect to the eastern side,
0,3	106,5	At 9 o'clock, dacite hill,
0,7	107,2	Dacite in road cut, Concentrator fault parallels highway on right side,
0,2	107,4	At 12 o'clock, dacite in foreground, Picketpost Mountain in the distance,
0,4	107,8	At 10:30 o'clock, on skyline is Weaver's Needle, a prominent spire rising above the general level of the Tertiary volcanics that form the Superstition Mountains,
0,1	107,9	At 3 o'clock, diabase,
0,4	108,3	At 11:30 o'clock, the Concentrator fault cuts through low saddle, Troy quartzite and the Martin Escabroso limestones are exposed along the escarpment,
0,6	108,9	At 9 o'clock, Escabrosa limestone overlain by dacite,

0,1	109,0	A mosaic of small fault blocks is associated with the major Concentrator fault zone in this area. Rocks of Precambrian, Paleozoic and Tertiary age are exposed within individual fault blocks.
1,0	110,0	At 3 o'clock, diabase crops out at base of the slope.
0,6	110,6	At 11 o'clock is Picketpost Mountain which consists of Tertiary flows and interbedded tuffs, intruded by a rhyolitic porphyry mass that is well exposed on the northern face. High grade perlite deposits are present along the eastern base of the mountain. The quarries are visible from the Superior-Florence Junction highway. This mountain was named from a nearby military post, established to protect the mines in the eighteen-seventies. The mountain served as a lookout.
0,2	110,8	Road junction on right, Belmot road to Grand Pacific mine.
0,6	111,4	At 3 o'clock, diabase and Dripping Spring quartzite in road cut.
0,6	112,0	Road junction on right to Cross Canyon, where the diabase cuts lower Troy quartzite beds.
0,4	112,4	At 2 o'clock, Queen Creek mine. Production was principally from mineralized beds at the base of the Martin limestone.
0,3	112,7	Road junction with new portion of U.S. Highway. TURN SHARP RIGHT.
0,2	112,9	STOP 5. Discussion of geology and mineralization and problems of Magma mine area.
0,2	113,1	Caravan returns to road junction U.S. Highway 60-70. TURN SHARP RIGHT. Continue up Queen Creek Canyon.
0,3	113,4	Troy quartzite in road cut.
0,1	113,5	Base of Martin limestone, note mineralized zone near the contact with Troy quartzite.
0,1	113,6	Contact between the Martin limestone and overlying Escabrosa limestone.
0,2	113,8	Bridge across Queen Creek. Escabrosa limestone crops out on right side of road.
0,3	114,1	Basal beds of the Naco formation.
1,0	115,1	Angular unconformity between the Naco formation and the dacite.
0,2	115,3	Claypool tunnel.
0,3	115,6	Eastern shaft of Magma Mine is on right, immediately below the road.

FIGURE 23, - HELLS PEAK, A LATE TERTIARY RHYOLITE PLUG, View southwest, This plug of glassy rhyolite, more than 1000 feet in diameter, penetrates Gila (?) conglomerate and tuff beds, Cliffs of tuff on right and left of canyon,

FIGURE 24, - HUMP GULCH REVERSE FAULT, VIEW TO WEST AT MILE 104,0, Diabase (db) separated from Martin limestone (Dm) by reverse fault, Ledges in left middleground are Escabrosa limestone (Ce),

FIGURE 25, - PICKETPOST MOUNTAIN, View southeast from U,S, Highway 60-70, Pinal schist, in lower right foreground, is overlain by tuffs (the light-colored bluffs), Dark capping consists of flows of acidic composition,

0,3	115,9	Note the flow structure in the dacite along the new road cuts, Tuff beds occur with the flows, especially near the top and base of the section,
2,9	118,8	Observe the synclineal structure in the dacite along Devils Canyon,
0,2	119,0	Bridge across Devils Canyon,
0,3	119,3	Typical weathered and jointed outcrops of dacite,
1,8	121,1	At 12 o'clock, outcrop of Schultze granite on skyline,
0,8	121,9	Contact between dacite and the Schultze granite, near Pinal Ranch,
1,2	123,1	Typical weathered outcrop of Schultze granite,
0,9	124,0	At 10 o'clock, Castle Dome Copper Co, open pit mining operation,
0,9	124,9	Bridge over Pinto Creek,
1,3	126,2	Road junction to Castle Dome Copper mine, Keep right on main highway, U,S, 60-70,
0,2	126,4	At 2 o'clock, Pinal Mountains, The higher wooded peaks consist of Pinal schist and Madera diorite, The lower rounded hills consist of Schultze granite, The white outcrop on left is the Solitude granite,
1,3	127,7	At 10 o'clock near road, roof pendant of Pinal schist in the Schultze granite,
1,4	129,1	Normal contact between the Pinal schist and Schultze granite along hillside on left,
0,3	129,4	Bridge over Bloody Tanks Wash, Pinal schist in road cuts,
0,8	130,2	City limits of Miami, Arizona, SLOW, sharp turn to right ahead,
0,2	130,5	Bridge, Road crosses over the Miami fault,

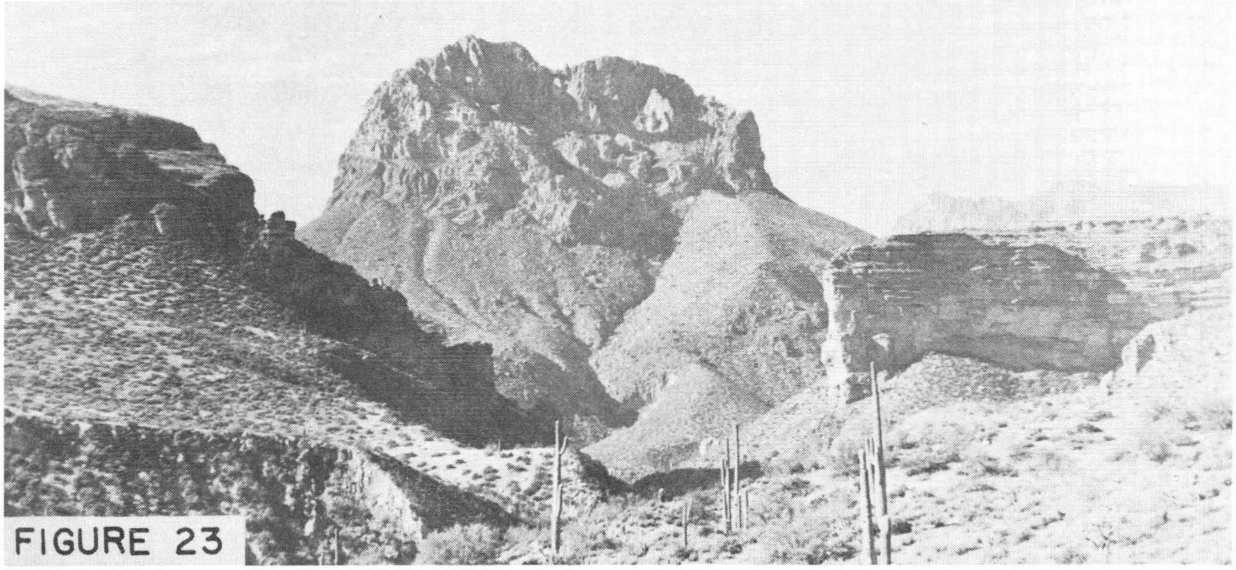


FIGURE 23


FIGURE 24

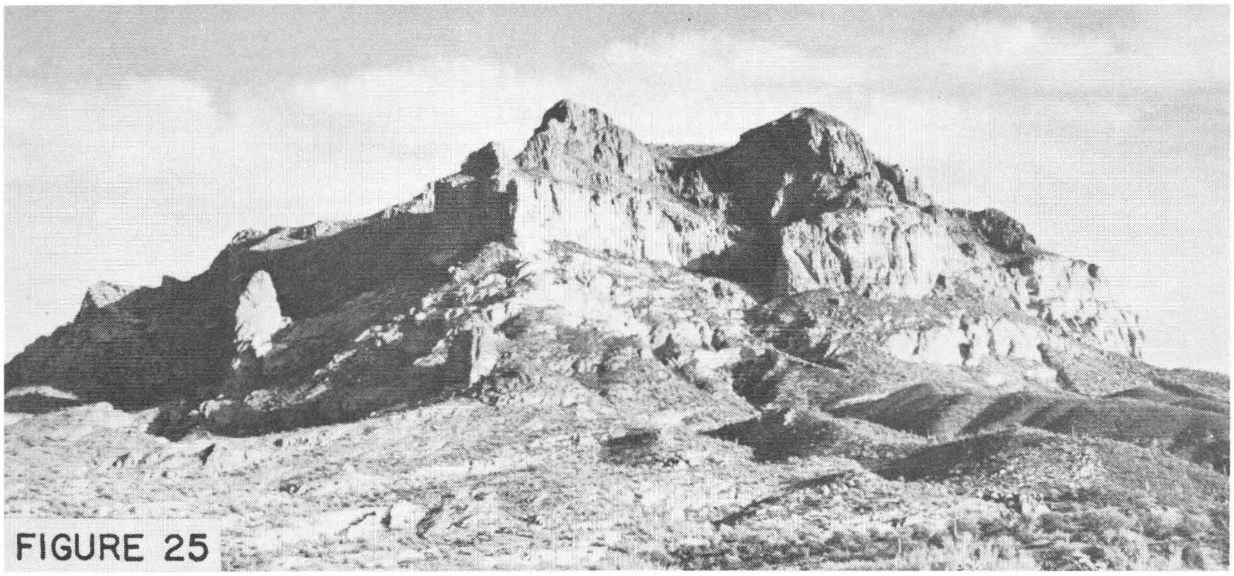


FIGURE 25

0,2	130,7	At 11 o'clock, main shaft of Miami Copper Company on skyline,
0,7	131,4	At 12 o'clock, large sand bank is part of tailings pond,
0,4	131,8	At 11 o'clock on skyline, International Smelter,
1,1	132,9	Claypool, Arizona, KEEP TO LEFT,
0,9	133,8	Railroad crossing, At 8 o'clock, Sleeping Beauty Peak and Copper Cities mine,
0,2	134,0	Road junction, Apache Trail and U,S, Highway 60-70, Gila conglomerate in road cuts, Small fault planes can be seen in the conglomerate,
0,6	134,6	At 12 o'clock, the rounded knobby outcrop is dacite,
0,7	135,3	View of Old Dominion mine, At 11 o'clock, Buffalo Ridge, which consists of Troy quartzite underlain by a diabase sill, The sill was intruded between the Troy quartzite and the underlying Mescal limestone,
0,9	136,2	At 3 o'clock, Mine Rescue Station, old slag dump on left side of road,
0,1	136,3	City limits of Globe,
1,0	137,3	Gila County Court House, left side of main square,

END OF LOG, FIRST DAY, FIELD TRIP 5,

SAN MANUEL COPPER DEPOSIT

H. J. Steele
Magma Copper Company

General Geology

Introduction

At San Manuel the mineralized outcrop, chief copper mineral of which is chrysocolla, is a triangular area with a northeast-southwest base of 380 feet and with the apex of the triangle 400 feet to the southeast. Northwest of the base is Red Hill, so called because of the prominent gossan coloration. With a few exceptions, conglomerate and alluvium cover the rest of the property. The elevation varies from 2900 feet to 3500 feet above sea level. The area slopes gently to the northeast, with the exception of a small rugged and precipitous portion around the south side of Red Hill, and is cut by numerous dry washes with northeasterly courses toward the San Pedro River.

Rocks

Relatively few rock types occur as surface exposures or are encountered in drilling. These formations were mapped by G. M. Schwartz of the United States Geological Survey, and the logging of all drill holes has conformed to his classification(1945, 1949). The rocks are quartz monzonite, monzonite porphyry, diabase, rhyolite and rhyolite breccia, Gila conglomerate and recent alluvium.

The quartz monzonite in the drilled area is granitoid in texture, and shows varying degrees of hydrothermal alteration. Quartz is abundant; the feldspar and biotite are extremely altered in most places. Rutile is common, and the rock in general is sericitized and kaolinized.

The monzonite porphyry has a fine groundmass composed largely of a mosaic of quartz and feldspars. There is an abundance of biotite but less quartz than in the quartz monzonite. The feldspar phenocrysts are much altered in most areas, and much of the biotite is bleached or chloritized. Secondary quartz flooding is fairly common, especially in the ore zone.

Alteration products in both the quartz monzonite and monzonite porphry, as reported by G. M. Schwartz from thin section examination, include the following minerals: the hydromicas, allophane, epidote, leucoxene, montmorillonite, dickite, chlorite, potash clays, and calcite.

Diabase occurs as occasional small dikes cutting both the quartz monzonite and monzonite porphyry. The rock is considerably altered, grades from fine to coarse diabasic texture, and is mineralized with chalcopyrite and pyrite, or in the oxidized zone with chrysocolla and iron oxides.

The rhyolite, which is unmineralized and which cuts the diabase and the monzonites, is light grey to light cream in color, fine-grained, with a few small quartz and feldspar phenocrysts in a finely crystalline groundmass.

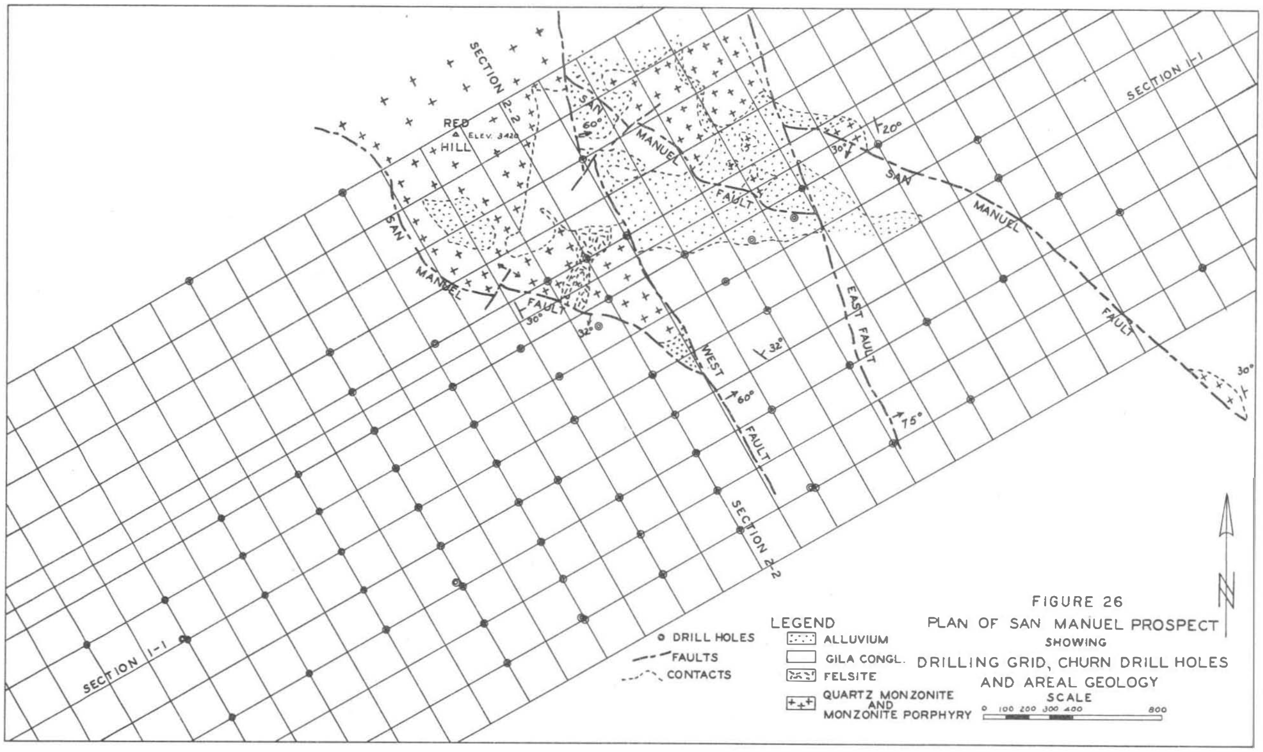


FIGURE 26. - PLAN OF SAN MANUEL PROSPECT.

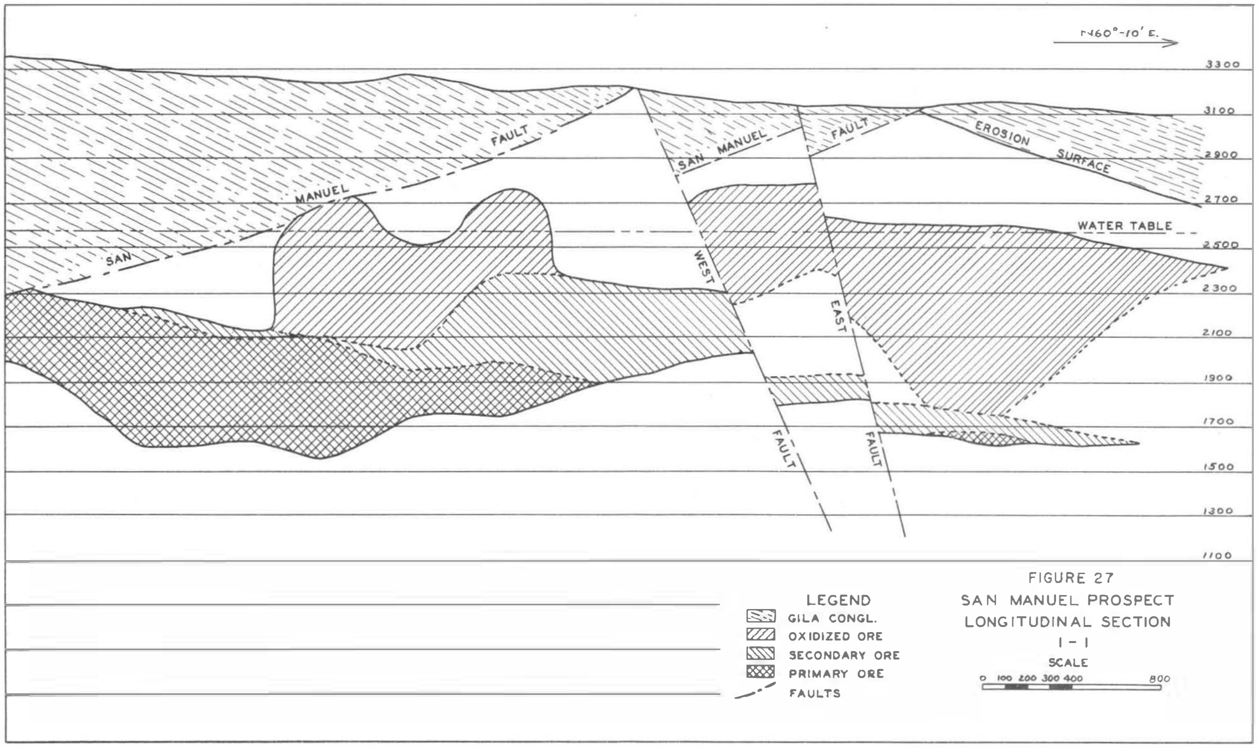


FIGURE 27. - SAN MANUEL PROSPECT, LONGITUDINAL SECTION.

The diabase is not common, and felsite, though more abundant than diabase, is relatively unimportant in the overall rock distribution.

The Gila conglomerate consists of alluvial material interbedded with lava flows, breccias, and tuffs. The coarse conglomerate of San Manuel is composed of boulders of acid and basic volcanics cemented with clay. A phase of the Gila conglomerate, designated as granitic conglomerate and composed largely of fragments of relatively unaltered quartz monzonite, has been encountered in drilling to the southwest.

Structure

The structure at San Manuel is interpreted largely through drilling results plus the information gained in sinking No. 2 shaft and drifting on the 1285 level.

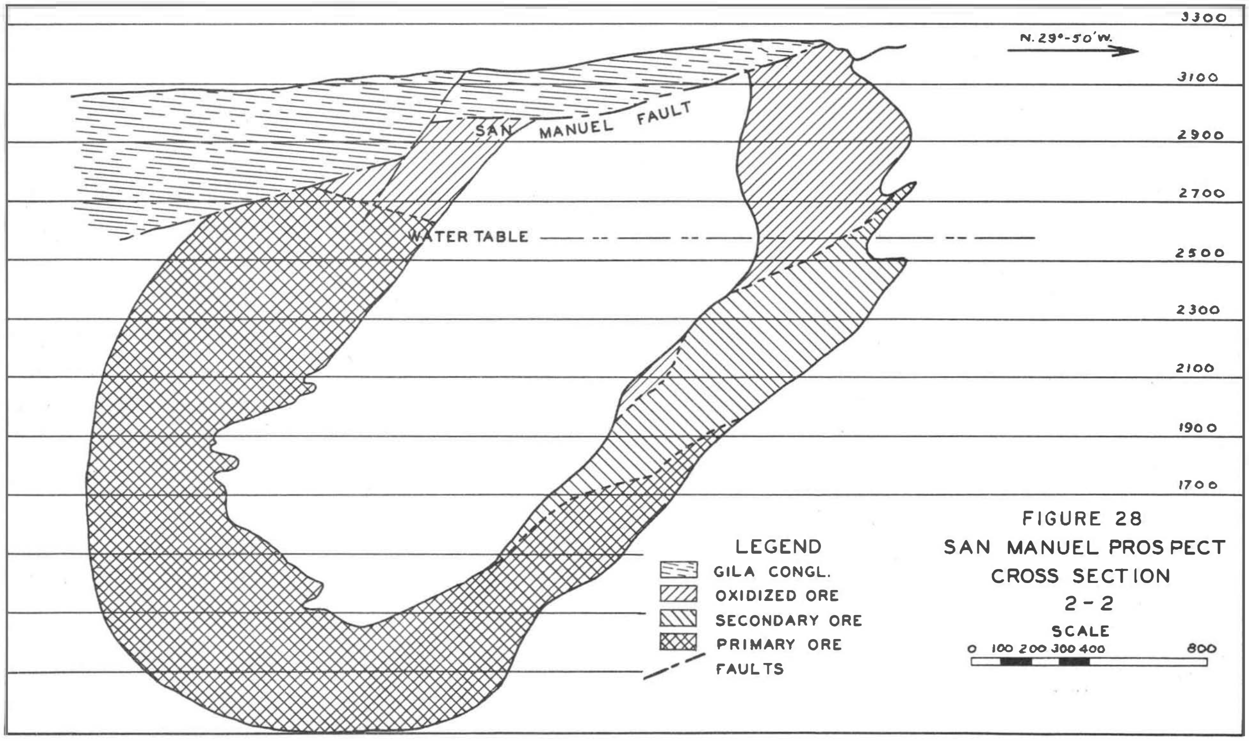


FIGURE 28
SAN MANUEL PROSPECT
CROSS SECTION
2 - 2

The Gila conglomerate, which covers the major part of the San Manuel deposit, strikes northwest and dips northeast at 20° to 45°. The San Manuel fault, striking northwest, more or less parallel to the strike of the conglomerate, and dipping southwest at 25° to 35°, forms the contact between the monzonite and the conglomerate. The San Manuel fault is in turn cut by two faults that dip 60° to 70° northeast and strike northwest. The most westerly of these faults is designated as the West fault, and the most easterly as the East fault. This step faulting of the conglomerate has been substantiated by drilling to the northeast. Minor outcrops of hematite-stained, altered monzonite porphyry occur at intervals along the surface exposure of the most northeasterly segment of the San Manuel fault. Drilling northeast of these exposures indicates that the contact of the conglomerate with the old erosion surface dips northeasterly at 20° to 25°. The indicated vertical displacement of the West fault is in the neighborhood of 400 feet, and of the East fault, 200 feet. The East fault has been considered to be the southward extension of the Mammoth fault.

The outcrop area, as shown in Figure 26, is bounded on the southwest by the San Manuel fault and on the northeast by the West fault. The base or northern limit of the ore body is controlled by decreasing copper mineralization, and is therefore, an assay boundary.

The regularity of the San Manuel fault in both strike and dip is unusual. It is difficult to visualize a low angle normal fault of such magnitude so persistent in attitude. The most feasible explanation, with the limited data at hand, can best be presented by this possible sequence of events:

1. Intrusion of the monzonite, and mineralization of the intrusive masses.
2. Oxidation and secondary enrichment.
3. Tilting to the east or northeast, as indicated by the older Cretaceous (?) volcanic series north of San Manuel.
4. Oxidation and slight enrichment.
5. Deposition of the Gila conglomerate (Events 4 and 5 may be contemporaneous).
6. San Manuel fault formed, dipping 60° to 65° to the southwest.
7. Regional tilt of 25° to 35° to the northeast and development of the fault system, which strikes northwest, and dips to the east.

The San Manuel ore body insofar as it has been explored by churn drilling and underground work is, because of the irregularities inherent in a deposit of disseminated mineralization, difficult to describe as to size and shape.

It must be remembered that the shape as shown in plan or section is due to an arbitrary grade cutoff; in other words the following is a description of a continuous mass of mineralized rock, containing sufficient copper to be considered ore, within a much larger mineralized mass of lower copper content. There are no physical walls or boundaries and by visual inspection the difference between ore and waste is not usually apparent.

The explored ore zone extends 5400 feet in a northeasterly-southwesterly direction and 3000 feet in a northwesterly-southeasterly direction (Figs. 27 and 28).

For purposes of description reference will be made to the southwest one-third, central one-third, and northeast one-third of the ore body.

The southwest one-third of the ore zone is a tabular mass, averaging 400 feet in thickness, striking N. 60° E. and dipping southeast at about 55°. This dip persists downward for about 2400 feet at which point there is a pronounced flattening.

The central one-third has the same attitudes as the southwest one-third. In this area, however, the down dip flattening continues until the ore zone becomes horizontal and then rolls upward in a U shape.

In the northeastern one-third of the deposit the strikes and dips of the limbs of the central U-shaped portion converge to the east.

The strong pyritic mineralization below the outlined ore body has not been bottomed by any drilling to date. The upper portion of the hanging wall rock is very lightly mineralized; alteration and mineralization increase to depth until the zone of better copper mineralization is encountered.

Mineralogy

In the oxidized zone the chief ore mineral is chrysocolla; cuprite occurs locally; malachite and azurite are rare. The chrysocolla is generally in joints and fracture planes.

Chalcocite is the predominant copper mineral in the secondary zone. Residual primary chalcopyrite, developed chiefly as intergrowths with the secondary minerals, and secondary chalcopyrite, also occur. Some native copper and minor amounts of bornite and covellite are found. There is very conclusive evidence of one or more stages of partial oxidation of the secondary zone in parts of the ore body. This may be due to variations of the water table and regional tilting.

Chalcopyrite and minor amounts of chalcocite are the chief copper minerals of the primary zone. The proportion of chalcopyrite to pyrite determines the footwall of the ore body. Slight oxidation is found relatively deep in the primary zone, and is throught to coincide with fault planes. The sulphide minerals are well disseminated throughout the monzonite, as well as occurring as veinlets. Chalcopyrite and chalcocite are common as films on pyrite. Molybdenite is in sufficient amount to be of economic importance. Gold and silver are in small quantities throughout the deposit. Rutile is fairly abundant throughout, and is thought to be an alteration product of biotite.

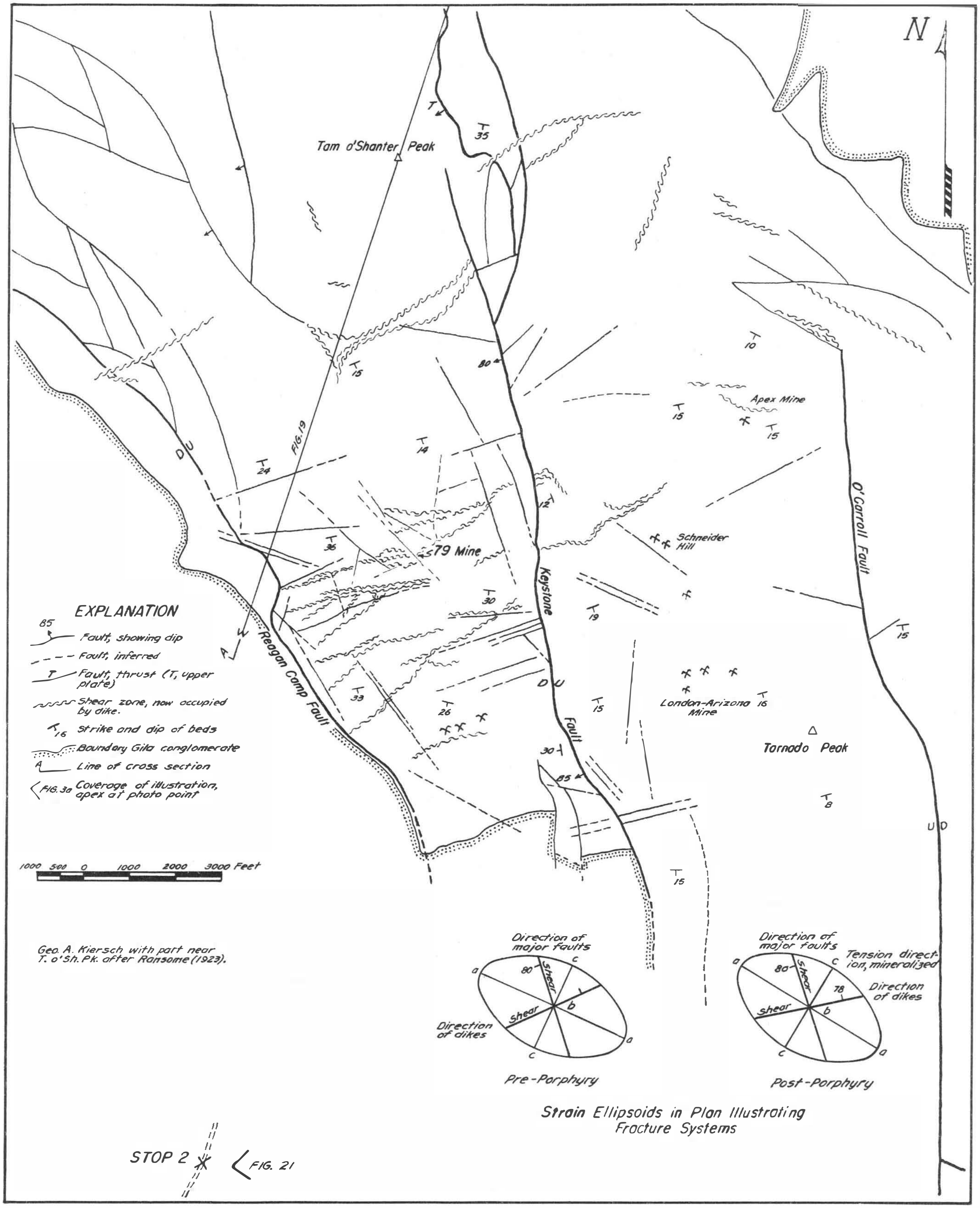


FIGURE 29.-STRUCTURAL PATTERN, TORNADO-TAM O'SHANTER PEAKS AREA.

GEOLOGY OF THE TORNADO-TAM O'SHANTER PEAKS AREA DRIPPING SPRING MOUNTAINS, ARIZONA

George A. Kiersch
University of Arizona

Introduction

The Dripping Spring Mountains, have been formed, in part, as an anticlinal uplift. The mountains are from 3 to 4 miles wide and extend northwestward, more than 20 miles, from Winkelman to a point north of Ray. North of Ray the range coalesces with the Tortilla Mountains. The Dripping Spring Mountains are bounded on the northeast by the debris-filled valley of Dripping Spring Wash and on the southwest by that of the Gila River.

Ransome (1923) considered the Dripping Spring Mountains to be an outstanding example of an area thoroughly dislocated by an irregular network of normal faults. Faulting in the southern or Tornado-Tam O'Shanter Peaks section of the range is more systematic than elsewhere in the range.

Some of the earliest geological work in the Dripping Spring Mountains was that of Ransome (1919, 1923). Subsequently, a description of mining operations in the southern part, within the Banner mining district, was made by Ross (1925a) and the stratigraphic section that crops out north of Tornado Peak was measured by Peterson (1945). A study of the area, particularly the 79 mine, was made in 1946-47 by the writer (Kiersch, 1949, 1951a).

Thanks are due to Dr. E. D. Wilson, Arizona Bureau of Mines, for suggestions regarding this paper.

Sedimentary Rocks

Strata of the Tornado-Tam O'Shanter Peaks area range from Precambrian to Tertiary in age and represent much of the sequence shown in Table 2 of this Guidebook. In general, in the belt east of Keystone fault, younger rocks occur to the south and older to the north.

The Barnes conglomerate, Dripping Spring quartzite, and Mescal limestone of younger Precambrian age crop out in isolated fault blocks in the northern part of the area. The Mescal limestone is 140 feet thick in this area and is intruded in numerous places by diabase.

The Middle Cambrian Troy quartzite overlies the Mescal limestone, and consists of thin to thick, cross-laminated, pebbly beds of orthoquartzite and is approximately 400 feet thick. The Troy is overlain by 225 feet of undifferentiated shale and quartzite, probably of Middle Cambrian age.

The Upper Devonian Martin limestone, which overlies the Cambrian sequence, consists of thin limestone beds with some shale, and has a maximum thickness of 328 feet. Lower Mississippian Escabrosa limestone is next in succession. It is a massive, cliff-forming limestone and has a maximum thickness of 581 feet. The youngest Paleozoic formation of this area is the Pennsylvanian Naco limestone. It consists of thin limestone beds with abundant chert, and is 385 feet thick on Tornado Peak. To the west and south, however, it is considerably thicker. The entire Paleozoic section appears conformable in this area, although at least three disconformities are recognized.

Isolated remnants of the Pliocene-Pleistocene Gila conglomerate crop out within the limits of the Dripping Spring Mountains and occur as extensive valley fill along its outer boundaries.

Igneous Rocks

Diabase has intruded the Mescal limestone in the form of a sill and has extended as small stringers and irregular apopyhses into the Troy quartzite. The diabase has a maximum thickness of 400 feet in several outcrops. The total thickness of the sill is unknown as its lower contact is not exposed. At Steamboat Mountain (Fig. 15), Ransome (1923) observed diabase dikes cutting Carboniferous rocks and believed the diabase to be younger than Pennsylvanian in age. Short, et al. (1943) considered the diabase at Superior to be of post-Middle Cambrian and pre-Upper Devonian age.

In the southern and central part of the Tornado-Tam O'Shanter Peaks area andesite and basalt locally overlie the Naco limestone, and basic sills and dikes invade the pre-Pennsylvanian rocks. Similar volcanic rocks that crop out to the south near Christmas were regarded by Ross (1925) as Upper Cretaceous in age. The Tornado-Tam O'Shanter Peaks section probably was once covered by intermediate to basic flows and pyroclastic rocks that later were removed by erosion.

The Dripping Spring Mountains were subjected to deformation, presumably during the Laramide interval. This mountain-making disturbance apparently was accompanied in its later stages by intrusion of acidic dikes, sills and plugs, which may have been apophyses of the central Arizona batholith (Ettlinger, 1928). Porphyritic bodies of rhyolite, granite, granodiorite, monzonite, quartz diorite and diorite intruded the shear zones.

Structure

Folding and Low-Angle Faulting

The Tornado-Tam O'Shanter Peaks section of the Dripping Spring Mountains reflect systematic structural deformation in which an anticlinal uplifted block was complexly faulted (Fig. 19).

The belt east of Keystone fault is a block dipping about 15° southward, and is broken by minor faults. West of Keystone fault, faulting has broken the strata into numerous blocks that dip 30° to 40° to the south. Compressional stresses are evidenced by bedding-plane faults and by a thrust fault north of Tam O'Shanter Peak. Bedding-plane faults at the London-Arizona mine may have helped to prepare the basal Martin limestone beds as a favorable host for ore solutions.

High-Angle Faulting

The high-angle faults are classified as of pre-ore and post-ore age. Those of pre-ore age have been important in localizing mineral deposition. Some of those of post-ore age have displaced ore bodies, but others have only influenced the topography.

Pre-ore Faults

The main pre-ore breaks are the O'Carroll, Keystone, and Reagan camp faults, which strike in a northwesterly direction (Fig. 29). Most of the pre-ore faults are normal and dip steeply to the west. The largest displacement is more than 2,000 feet on the Keystone fault.

Associated with the main faults are shear zones which in general strike N. 60° to 70° E. (Fig. 29). The principal zones of shearing are between the Reagan Camp and Keystone faults; a few shear zones appear east of the latter. Field evidence indicates that vertical movement along the shear zones is small. Granitic magma invaded many of the shear zones, probably soon after the earliest pre-ore faulting. Most of these granitic dikes dip steeply northward.

After emplacement of the dikes, movement recurred along the major north-south faults. The resulting stresses fractured the dikes with a general shearing that strikes N. 70° to 85° E. and tension fissures that strike about N. 55° E. (see strain ellipsoid, Fig. 29). Contemporaneous with the shearing or slightly later, faults striking N. 70° E. were formed. Displacement on these faults is essentially vertical; on most of them, the south block has been moved upward relative to the north block.

Post-Ore Faults

The major post-ore faults strike N. 35° to 45° W. and displace numerous granitic dikes in the area. Additional post-ore movement along some of the pre-ore faults of N. 70° E. strike apparently also occurred. At the 79 mine, the main post-ore faulting took place prior to deposition of the Gila conglomerate.

Minor faulting and probably some tilting occurred after deposition of the Gila conglomerate. Along the southwest boundary of the Dripping Spring Mountains, the conglomerate is cut by many small faults and dips about 30° west.

Ore Deposits

The ore deposits within the Tornado-Tam O'Shanter Peaks area are mainly of the replacement type. Sulphides replaced shaly limestone beds in the Martin and Naco strata, the granitic dikes and the quartz latite porphyry plug. In the igneous rocks the sulphides commonly occur as veinlets and as disseminated grains.

79 Mine

The 79 mine has been the largest single metal producer in the Tornado-Tam O'Shanter Peak area of the Dripping Spring Mountains. Ore worth approximately $4,000,000 has been produced since 1919. Lead is the principal metal. Early production consisted of lead-carbonate ore from bed-replacement deposits. Since 1940 the major production has been from lead-zinc sulphide ore occurring as replacement veins in a rhyolite porphyry dike.

Ore solutions apparently penetrated upward along major faults and shear zones. The ores were deposited in northeast-trending fractures within a shattered dike of rhyolite porphyry and in favorable beds of impure Naco limestone, Hypogene mineralization took place in a definite but interrupted, three-stage sequence, Early pyrite was shattered and veined by sphalerite, "argentiferous" galena and chalcopyrite, Late quartz cuts all earlier sulfides, The bed replacement and upper parts of the North dike vein replacement ore bodies have been extensively altered by olidation and supergene enrichment,

Curtin or Humphrey Mine
(Wilson 1951)

Naco limestone is intruded by a system of porphyry dikes that locally form sills, Ore deposits are irregular replacements in the Naco limestone; they occur mainly on the north or hanging wall side of a main dike and on the footwall side of the sills, The lead-zinc ore has been altered by oxidation and supergene enrichment,

Sequence of Events

A brief resume of the geologic history of the Tornado-Tam O'Shanter Peaks area is as follows:

(1) During late Precambrian time, rocks of the Apache group (Table 2) were laid down on the bevelled surface of older Precambrian Pinal schist and granite,

(2) After a period of erosion, Paleozoic rocks of several periods were deposited, beginning with the Troy quartzite of Middle Cambrian time (Table 2), At least two and possibly three disconformities were developed in this sequence of Paleozoic formations, Sedimentation may have continued after the Naco limestone deposition, but Permian and Mesozoic sediments have not been recognized in this area,

(3) Diabase may have been intruded at two widely separated intervals, The first was a Precambrian-early Paleozoic invasion that occurred principally as sills and caused some upwarping, The second was a small-scale, post-Pennsylvanian invasion that developed largely as dikes,

(4) Deformation of the Precambrian and Paleozoic strata was initiated probably during Laramide (late Cretaceous) time and the Dripping Spring Mountains were formed as an anticline,

(5) Volcanic outpourings, apparently in Late Cretaceous time probably blanketed much of the southern portion of the range,

(6) Granitic dikes invaded many of the existing shear zones and subsequent movement fractured the dike system, Ore solutions closely followed this second period of faulting in some parts of the range,

(7) The main post-ore faulting is believed to have occurred in Middle to Late Tertiary time, Oxidation of certain exposed ore bodies was accelerated as a result of this deformation,

(8) Deposition of the Gila conglomerate probably began in late Pliocene time and continued through the Pleistocene,

(9) Recent faulting has tilted the Gila conglomerate beds and accelerated erosion locally,

STRUCTURAL CONTROL OF ORE DEPOSITION AT RAY, ARIZONA

Otis M. Clarke, Jr.
Ray Division, Kennecott Copper Corporation

Introduction

The first copper mining at Ray was started in 1880, although silver prospectors had been active prior to this. Large scale mining was begun in 1911 after more than 350 churn drill holes had been drilled and sampled. The ore was mined underground in parallel shrinkage stopes and the pillars later recovered by cavings. This system was gradually changed to the block caving system such as is being used at the present time in the No. 2 Mine. Seventy-five million tons of ore have been mined by underground methods; this ore averaged about one and a half percent of copper.

The open pit at Ray was started in 1947. Forty million tons of stripping and, to date, five million tons of ore have been mined from the pit. Both the pit and the mine are in operation. Exploratory diamond drilling was started in 1921 and was resumed in 1946. More than 250 diamond drill holes have been drilled.

The general geology of the Ray district was described by Ransome (1919,1923). Spurr and Cox made an excellent report on the mining geology to the Ray Consolidated Copper Company during its first drilling campaign. C. L. Hoyt (1938), present Chief Engineer at Ray, described effects of faulting on the supergene ore body. These reports have formed the basis of the present article.

General Statement

The location of the supergene ore body at Ray is controlled by the primary mineralization and by faulting. Faults have partly controlled the oxidation, leaching, and reprecipitation of copper and have displaced the ore body. Structure also controlled the location of hypogene copper mineralization.

Rocks of the District

As shown by Table 5, the basal rock in the Ray area is Pinal schist, which has been intruded by older Precambrian granite and diorite. It is overlain successively by rocks of the younger Precambrian Apache group, by Middle Cambrian Troy quartzite, and by limestones of Devonian, Mississippian, and Pennsylvanian ages. These rocks were intruded, presumably during late Cretaceous-early Tertiary (Laramide) time, by diabase, quartz diorite, quartz monzonite (Granite Mountain and Teapot Mountain porphyries), and quartz-diorite porphyry. Next younger are the Tertiary Whitetail conglomerate, Tertiary dacite and tuff, and Tertiary-Quaternary Gila conglomerate.

Rocks of the Mine Area

At the Ray ore body, the Paleozoic strata and beds of the Apache group were removed by pre-Whitetail erosion; in the immediate vicinity, Whitetail conglomerate, dacite, and Gila conglomerate rest directly upon the older Precambrian rocks.

Most of the ore mined has occurred in the Pinal schist, which here represents metamorphosed sediments together with minor amounts of meta-rhyolite and basic intrusives.

Diabase is conspicuous in the Ray pit as a large wedge-shaped mass of which the footwall dips about 45 degrees E., and the hanging wall 15-30 degrees E. The diabase body east of Mineral Creek is more irregular in outline and displaced by faulting. Dikes and sills of diabase cut the mineralized area. Diabase was the most favorable host rock for hypogene copper deposition, but not all diabase is highly mineralized.

A mass of quartz diorite, weakly mineralized, crops out south of Ray. The Granite Mountain porphyry, of quartz-monzonitic composition, occurs as a series of wide dikes and large masses southwest of Ray; as irregular dikes and "fingers" throughout the mines; and as a plug cutting diabase and schist near the center of the ore zone. This porphyry is mineralized similarly to the schist.

The Teapot Mountain porphyry is coarsely crystalline to almost pegmatitic in texture and contains large, well-formed phenocrysts of feldspar. This rock, which forms a series of outcrops north of the ore body, may be post-mineral.

Structure

The Ray fault, which strikes north-northwesterly along Mineral Creek and parallel to the main mountain ranges, divides the area. The amount of movement on this fault, as described by Spurr (1916), was perhaps 1,000 or 2,000 feet; Ransome (1919), on the other hand, regarded the displacement as less than 100 feet in places and not more than several hundred feet anywhere. Spurr's interpretation seems preferable as judged by differences in ore deposition on opposite sides of the Ray fault. East of the fault little supergene ore has been found, but hypogene mineralization extends rather deep.

Folding has affected the schist locally, and pre-mineral faulting resulted in intense crushing of all rocks. Mineralized northeast fractures of steep dip occur throughout the area, but few of them can be traced for more than a few hundred feet. The crushing continued during hypogene mineralization.

The largest of the northeast fractures is the Sun fault, which crosses the ore body in the western part of No. 2 mine, splits into two branches, and flattens at depth (Fig. 30). In its eastern portion, the footwall branch reverses in dip.

The Emperor fault is a post-mineral thrust which, in the pit, shows a roll and a change of direction (Fig. 30, sec. A-A'). The western portion of the fault strikes N. 60° E. and dips 30° NW.; the eastern portion strikes southward and dips 15° - 30° E. Striations show two sets of movements, one southward and one westward. Measured displacement of porphyry and diabase amounts to less than 1,000 feet.

The North End and West End faults limit copper ore on the north and west, respectively.

The Consuelo and Bishop faults, which are post-mineral breaks of northwest trend, cut the ore in the No. 2 mine.

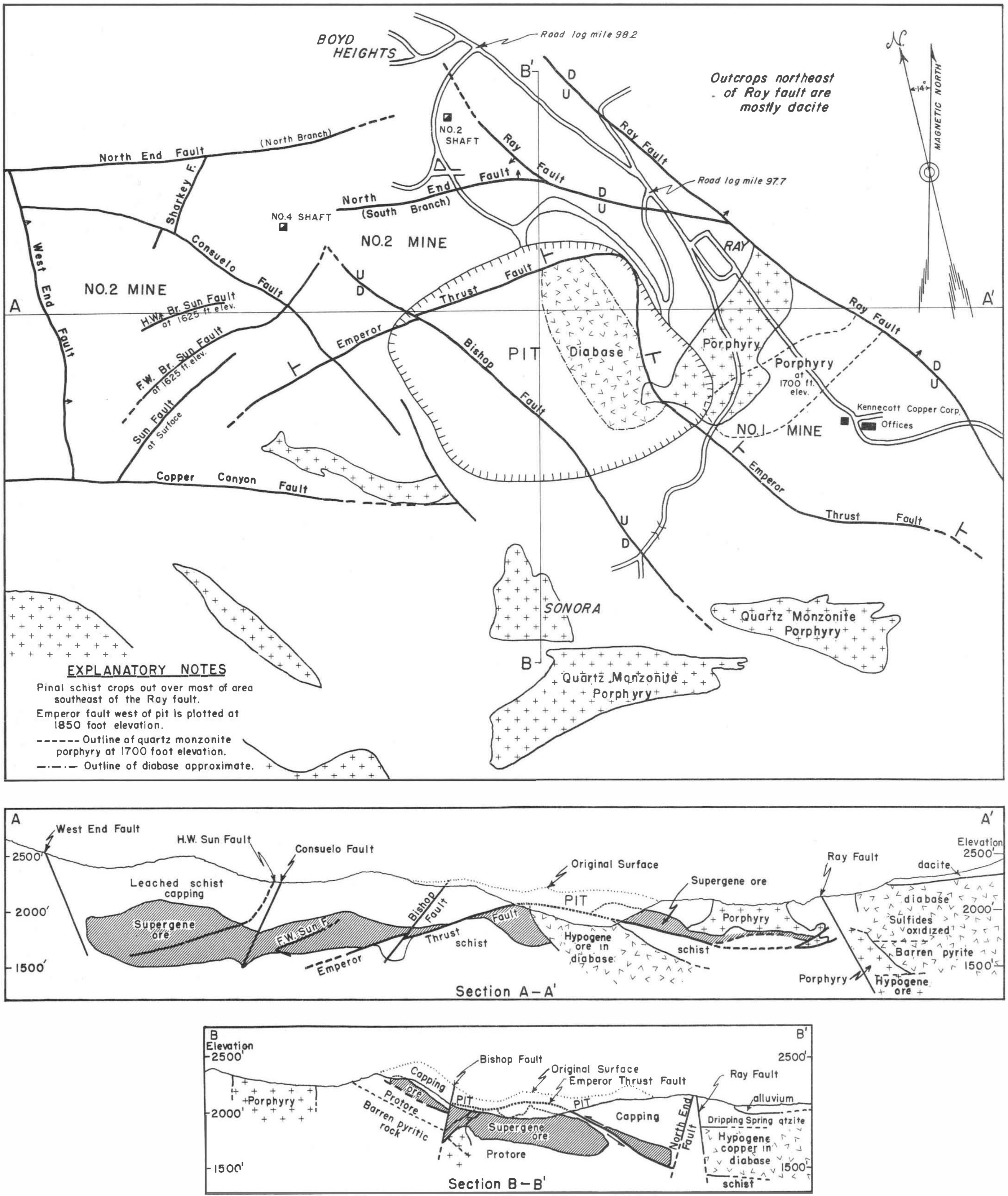


FIGURE 30.- SKETCH MAP AND SECTIONS, RAY ARIZONA AREA

Hypogene Mineralization

General Features

Hypogene copper ore occurs in diabase and amphibolite schist in the central zone of the mineralized area. The copper occurs as chalcopyrite in pyrite-quartz veinlets which criss-cross the entire mineralized area. Ore is deepest near the center of the diabase mass west of the Ray fault. East of the fault copper is distributed erratically, and some copper is under a barren pyrite zone.

The better grade hypogene ore is surrounded by schist and porphyry of low copper content. This protore contains approximately 0.2 percent copper, probably as chalcopyrite mixed with pyrite, although chalcopyrite rarely is identified in specimens containing less than 0.3 percent copper. Schist protore extends in a thick north-dipping zone from the pit area west along the southern part of No. 2 mine, to and along the Sun fault. Protore also extends south from the pit to the area south of No. 1 mine. Protore is not found in the bottom of the mine or on the north side. Its northern extent is obscured by supergene chalcocite.

Barren pyritic rock, similar in appearance to protore but lacking copper, is below and beyond the edges of the protore. There is a transition zone between typical protore and barren pyritic rock. Pyrite in general diminishes away from the ore body.

Molybdenite veinlets occur in the higher grade portions of the copper zone, in schist, porphyry, and diabase, and extend deeper than the protore. A little molybdenite occurs in the central zone, extending beyond the area of better grade hypogene copper ore.

Primary Structural Control

The quartz monzonite porphyry, the last rock intruded before mineralization, is regarded as the source of the copper. Crushed host rocks appear to have caused a disseminated type of ore body to form, rather than a vein type, as at the Magma mine. The center of mineralization occurs near the Ray fault where the diabase came up. Movement on the Ray fault, although mainly of post-mineral age, appears to have been in part pre-mineral.

Oxidation, Leaching, and Secondary Enrichment

Most of the ore mined has been supergene, derived from the schist protore by oxidation and leaching which resulted in migration of copper downward and replacement of pyrite with chalcocite. The leached schist or capping, in part, has been eroded away.

There were two stages of secondary enrichment. Much of the ore body was enriched prior to eruption of the Tertiary dacite. Leaching was resumed when late faulting and erosion again exposed the ore. The process is still going on.

Effect of Structure on Supergene Ore

The last fault movement raised and tilted the ore body northward. In the southern end of the ore, above water table, copper is being leached and moved downward. Oxidation and leaching are stronger along faults and fractures where air and water can penetrate.

Residual masses of chalcocite ore occur in the capping away from fractures. These residual masses are protected from leaching by impervious barriers of gouge. Perched water tables also have protected ore, but in places the bottom of the zone of oxidation is irregular and extends to the bottom of the ore body along faults.

The distribution of the supergene ore was influenced by existing fault zones, which either were channelways for movement of solutions or included impermiable barriers of gouge. The Emperor thrust fault with its thick blanket of gouge is the most important of the barrier faults. It controlled distribution of ore in the eastern part of No. 2 mine and in much of No. 1 mine. Ore solutions crossed the Emperor fault only in the vicinity of the Bishop fault, which displaced the Emperor fault. Minor fractures associated with the Bishop fault also cut the fault gouge, allowing passage of solutions. The breaks associated with the Bishop fault are responsible for the localization of the schist ore that is being mined in the western part of the pit.

The northeast-trending pre-mineral Sun fault contains impervious gouge which partly localized the ore in the western part of No. 2 mine. The West End fault blocked migration of copper to the west, but this fault is west of the hypogene mineralization; therefore the grade of ore drops sharply in the western part of the mine area.

The northwest Consuelo fault served as a channelway and caused ore to extend along a northwest trough. Farther northward it served as a barrier. The Consuelo fault displaced the north-south Sharkey fault, which localized a small ore body north of the Consuelo fault.

The North End faults also are barriers, but little of the copper bearing solutions reached them. They appear to be of pre-mineral age, and the rock north of them is mostly unaltered.

Native Copper and Cuprite

Native copper and cuprite crystals occur in the pit at Ray. The largest and best specimens have been obtained in the schist just west of the diabase. The supergene copper solutions were blocked by the diabase and formed rich ore by replacing all the pyrite in the schist. Native copper and cuprite occur also in the eastern part of the pit, in schist and in a diabase sill above the main diabase mass. Much of the cuprite formed as veins of hairlike chalcotrichite. Chalcotrichite has not been found west of the diabase.

Native copper and cuprite are found only in areas where replacement of pyrite by chalcocite was complete. In the oxidation and leaching, sulfuric acid and ferric sulfate appear to have been insufficient to dissolve all the copper. Much of it was reprecipitated as native metal or as cuprite. Where chalcocite containing residual pyrite has undergone leaching, almost all the copper has gone into solution as copper sulfate.

Gold and Silver

Only a trace of gold is found in the ore at Ray. It appears to be rather uniformly distributed and unaffected by secondary enrichment. The diabase may contain more gold than the schist, but it is in quantities too small for accurate determination. Silver occurs with the copper, but in small amounts and erratically distributed. It, like copper, is concentrated by secondary enrichment. The ratio of silver to copper is higher in hypogene diabase ore than supergene schist ore. Native silver, associated with native copper, has been found in the pit.

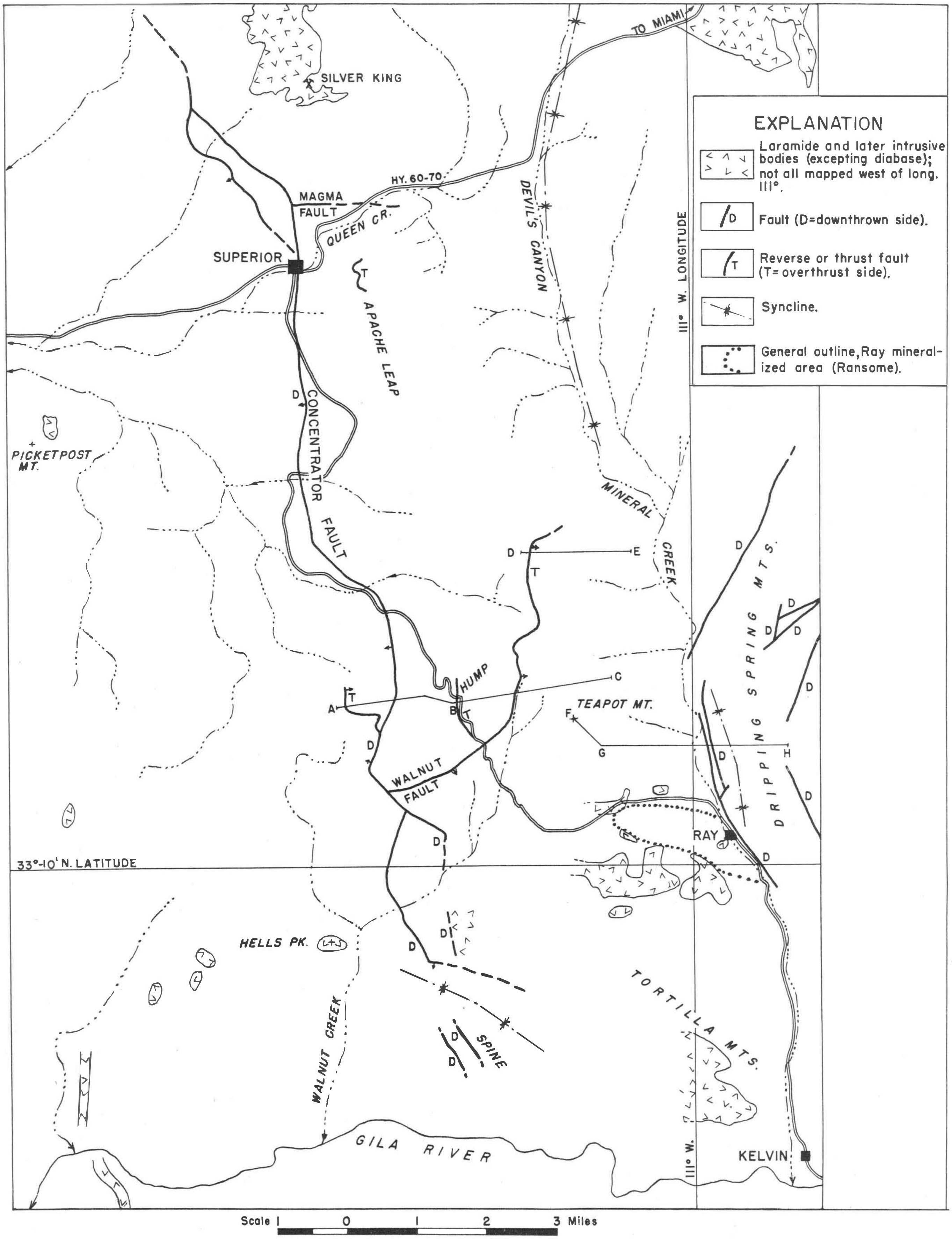


FIGURE 31.- General structure features, Ray-Superior area.

GENERAL GEOLOGY BETWEEN RAY AND SUPERIOR, ARIZONA

Eldred D. Wilson*
Arizona Bureau of Mines

Introduction

The area between Ray and Superior displays spectacular features of deformation, igneous activity, erosion, and sedimentation, which developed during Laramide and subsequent time. Here, as elsewhere in the Southwest, the Tertiary-late Cretaceous history remains partially obscure, with complexities that have not received detailed regional study.

In addition, the area is of interest, because it adjoins two mining districts, less than 10 miles apart, which during 1911-51 produced metals valued at more than $506,500,000. Of this total, approximately 65.5 per cent came from Ray, and 34.4 per cent from Superior.

Sources of Information

The following summary is based upon preliminary field studies made for the Arizona Bureau of Mines, supplemented by basic data from Ransome (1919), Hoyt (1938), Clarke (this Guidebook), Short and Ettlinger (1926), Short et al. (1943), and Steele (this Guidebook) regarding the Ray and Superior districts. Appreciative acknowledgment is made to Dr. B. S. Butler for active collaboration in part of the field work, and to Prof. E. D. McKee for identification of fossils.

Topography

Ray is in the southward-trending narrow valley of Mineral Creek, between the Dripping Spring Range on the east and the Tortilla Range on the West. A few miles north of Ray, these ranges converge into a complex mountainous tract which, continuing north and northwest beyond Superior, is separated from the Castle Dome-Miami area on the northeast by the drainage of Pinto Creek.

An outstanding topographic feature is the ridge which crosses Gila River near Kelvin, overlooks Mineral Creek from the west, and extends north-northwestward for more than 20 miles. Its crest northward from Teapot Mountain (Fig. 34) broadens into a rough dacite plateau of which the western scarp, Apache Leap, overlooks Superior.

The western portion of the Ray-Superior area has been extensively dissected into ridges, peaks, and mesas of irregular pattern.

Deep canyons mark the drainage systems of Mineral, Walnut, and Queen Creeks, the general positions of which are indicated on Figure 31.

Structure

General Statement

This general region underwent folding and faulting, with associated igneous invasion, principally during Older Precambrian, Laramide (Late Cretaceous - Early Tertiary), and subsequent times Additional vulcanism, apparently accompanied by only mild structural disturbances, occurred during Younger Precambrian, Upper Cretaceous, and Quaternary, as indicated in Table 3 of this Guidebook. Regional uplift and depression took place at

---

*Geologist, Arizona Bureau of Mines, University of Arizona

ROCKS

The principal formations in the Ray-Superior area are as follows (see also Table 3):

Table 5. Formations in the Ray-Superior area

Age	Formation	Character and Distribution	Thickness in feet
Quaternary	Alluvium	Unconsolidated gravel, sand, and clay.	
Unconformity			
Quaternary or Tertiary	Basalt	Flows covering small areas, mainly west of Superior; dikes and small plugs in late fault zones.	
Unconformity			
Middle Tertiary to Late Tertiary	Rhyolite	Porphyritic to glassy necks, as in Hells Peak and part of Picketpost Mt.; flows and perlitic sills, mainly west of Superior.	
	Tuff	Rhyolitic to dacitic tuff, stratified and cross bedded, locally containing large boulders of older rocks; in general contemporaneous with the rhyolitic necks. Occurs only west of Concentrator fault; extensive in southwestern part of area.	0-1,000
	Gila (?) conglomerate	Loosely to firmly consolidated gravel, boulders, sand, and silt; fragments rounded to angular. In valley of Mineral Creek; west of Concentrator fault and in southwestern part of area. Includes some tuff and lenticular flows of basalt.	0-1,050
	Unconfarmity		
	Dacite	Flows; minor tuff especially at top and base; thin vitrophyre near base. Widespread, north from Teapot Mountain and southwest from Superior	0-1,250
	Unconformity		
	Whitetail conglomerate	Generally consolidated, weakly stratified gravel and boulders, angular to poorly rounded, locally with sand and silt. In pre-dacite local depressions; thickest south and east of Walnut fault.	0-1,000
	Unconformity		
Laramide	Quartz diorite porphyry	Dikes, sills, and small masses, widely distributed.	

Age	Formation	Character and Distribution	Thickness in feet
Laramide	Quartz monzonite porphyry	Masses and dikes, Ray vicinity; dikes, Magma mine.	
	Quartz diorite	Masses and dikes, northwest of Kelvin.	
	Diabase	Sills, dikes. Probably of two ages.	
Pennsylvanian and possibly some Permian	Naco limestone	Medium-bedded gray limestone, in places cherty, with some shale beds. Extensive under Apache Leap.	1,390
Disconformity			
Mississippian	Escabrosa limestone	Medium to thick-bedded, cliff-forming light-gray to white limestone. Extensive west of Apache Leap.	420
Disconformity			
Devonian	Martin limestone	Thin-bedded, slope-forming limestone with paper shale near top. Extensive west of Apache Leap.	340
Disconformity			
Middle Cambrian	Troy Quartzite	Cross-bedded, pebbly quartzite, cliff forming. Extensive north of Walnut fault.	425
Disconformity			
Younger Precambrian (Apache group)	Basalt	Vesicular basalt.	0-220
	Mescal limestone	Thin-bedded limestone with thin chert bands. Widespread north of Walnut fault; also north of Teapot Mt.	225
	Dripping Spring quartzite	Banded arkosic quartzite, beds few inches to 2 ft. thick	820
	Barnes conglomerate	Mainly quartzite pebbles in arkosic cement.	15
	Pioneer shale	Dark purplish brown shale, quartzitic at base.	230
	Scanlan conglomerate	Quartz and quartzite pebbles in sandy to shaly cement.	0-15
Unconformity			
Older Precambrian	Madera diorite	Small masses north of Ray.	
	Ruin granite	Masses southwest of Ray.	
	Pinal schist	Fine-grained light-gray sericitic schist. Ray area; south and east of Walnut fault; west of Concentrator fault.	

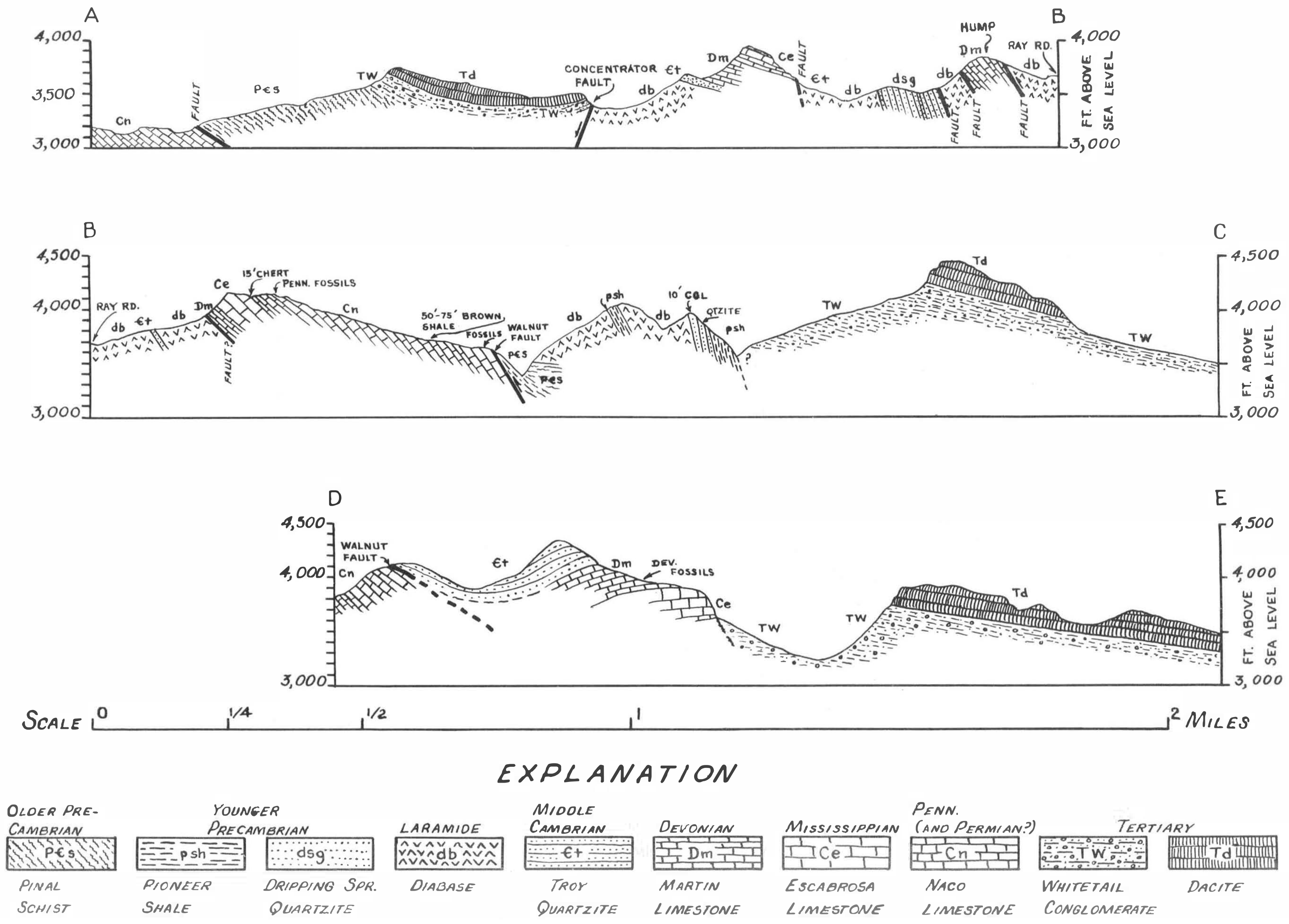


FIGURE 32.- CROSS SECTIONS ALONG LINES A-B, B-C, AND D-E OF FIGURE 31.

intervals between the periods of major unrest, as evidenced by disconformities (Table 5).

Older Precambrian folding and faulting (Anderson, 1951), with associated igneous invasion ascribed to the Mazatzal Revolution (Wilson, 1939), affected an extensive region of which the Ray-Superior area forms a small part.

In east-central Arizona, particularly between the Plateau and the Dragoon Mountains, basalt of Younger Precambrian age flowed on top of the Mescal limestone, and diabase invaded the Apache group along bedding-plane faults or bedding slips. The diabase in part antedates the Middle Cambrian Troy formation (Darton, 1925, p. 36, 254-255; Cooper, 1950, p. 31), but in some localities diabase intrudes Pennsylvanian beds and presumably is of Laramide age.

Superimposed upon the earlier structures, Laramide shear faults of general east-west and north-south trends, accompanied by northeast and northwest tension breaks, developed parallel to Older Precambrian structures. Some of the intrusives, Laramide as well as Older Precambrian, show northeasterly alinement (Peterson, this Guidebook); others occupy zones of shear faults. The Laramide folds mostly trend northwest to northward, locally transverse to the Precambrian folds. Faults and folds affecting the Tertiary formations follow in general the Laramide trends. Thus, the structure appears to reflect ancient heritages. Many of the faults seem to represent old zones of intermittent displacement. Breaks initially of shear or tension type may have become normal faults upon release of compressional stresses.

In the Ray-Superior area, the main recognized structural features (Fig. 31) from east to west include the following: Synclines and faults along Mineral Creek; Walnut overturn and reverse fault; Elm thrust fault; east-west faults; Hump Gulch reverse fault; Concentrator fault zone; Spine syncline; and thrust fault west of the Concentrator fault.

Synclines and Faults along Mineral Creek

East of Apache Leap, the dacite is flexed into a broad, shallow syncline of which the axis trends south-southeast along Devil's Canyon of Upper Mineral Creek. Where crossed by the Superior-Miami highway, the western limb of this syncline dips 15 or 20 degrees, and the eastern limb dips somewhat more gently.

In the western limb, under Apache Leap, Paleozoic and Younger Precambrian beds strike generally northward, with arcuate variations reflected by the mountain front, and dip 30 to 50 degrees eastward (Fig. 37). East of Superior they dip as much as 25 degrees more steeply than the overlying dacite, which fact suggests that the Laramide folding (Wilson, 1950, p. 88-89) here was accentuated by post-dacite compression.

About 3 miles north of Ray a fault, which trends northeasterly across Mineral Creek, brings dacite on the northwest against older rocks of the Dripping Spring Range (Ransome, 1919, 1923).

Ransome (1919, p. 128-130) observed that the attitude of the Whitetail, dacite, and Gila formations north of Ray (Fig. 33) is generally synclinal. The western limb of the syncline is displaced by a zone of step faults, collectively termed the Ray fault, which parallels Mineral Creek. As interpreted by Spurr (1916) and by Clarke (this Guidebook), the country east of Mineral Creek has dropped perhaps from 1,000 to 2,000 feet along the Ray fault; Ransome, however, concluded that the synclinal folding with minor step faulting could account for the difference in elevation between the dacite west and east of Mineral Creek.

About a mile south of Ray, Pinal schist on the west has been thrust up over Dripping

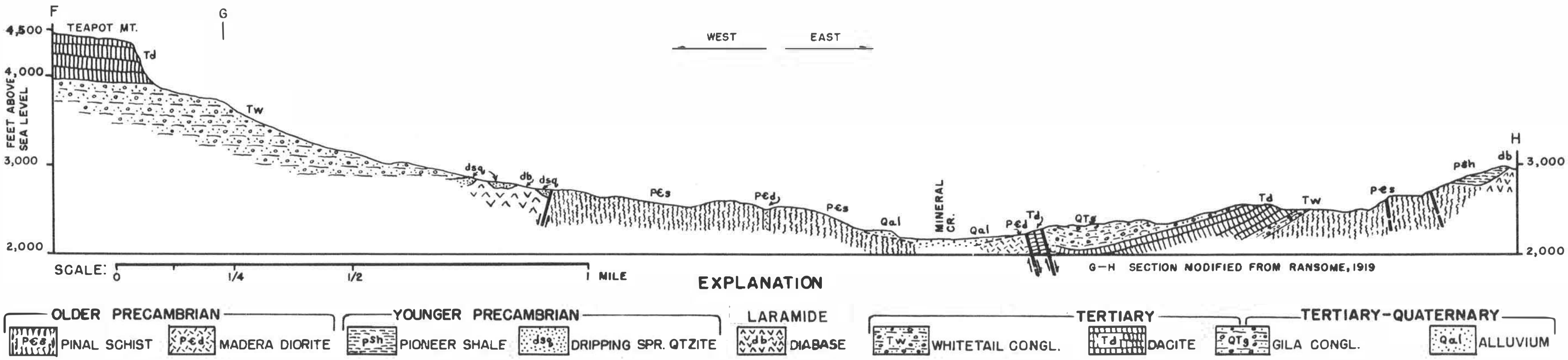


FIGURE 33.- CROSS SECTION ALONG F-G-H OF FIGURE 31.

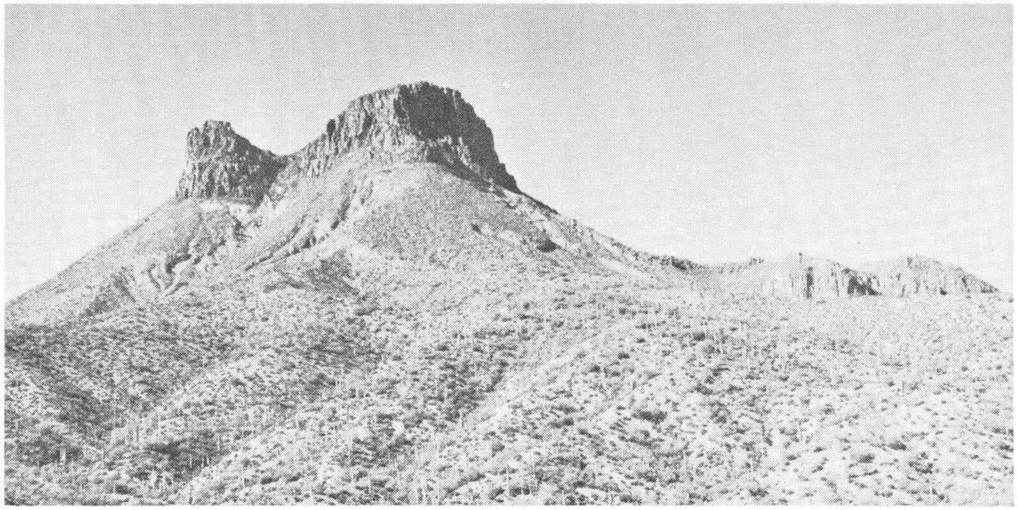


FIGURE 34. - TEAPOT MOUNTAIN FROM SOUTHWEST. Upper cliff of dacite is underlain by Whitetail conglomerate, 800 or more feet thick. Pinal schist in foreground.

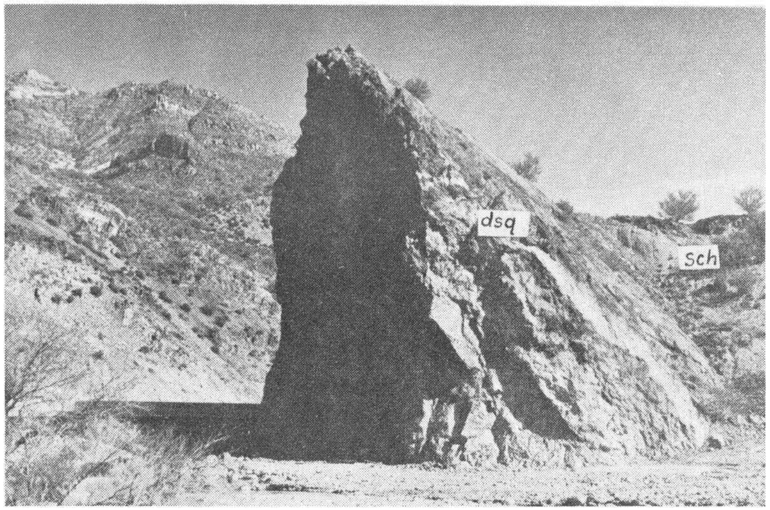


FIGURE 35. - THRUST FAULT ON WEST SIDE OF MINERAL CREEK, HALF MILE SOUTH OF RAY. Pinal schist (sch), on extreme right, is thrust over Dripping Spring quartzite (dsq). Dripping Spring Range in background.

Spring quartzite on the east, As described by Ransome (1919), the fault dips 45 degrees southwest (Fig, 35) and possibly continues southward between Dripping Spring quartzite and overlying Gila conglomerate,

In the Ray mine area a low-angle thrust, the Emperor fault, has effected post-mineral displacement (Clarke, this Guidebook).

Possibly the Emperor fault and the aforementioned thrust south of Ray represent renewed movement upon breaks which originated with the Laramide folding (Kiersch, 1951, and this Guidebook) of the Dripping Spring Range,

Walnut Overturn and Reverse Fault

On the main ridge, two miles north of Teapot Mountain, the Cambrian, Devonian, and Mississippian beds (Fig, 32, section D-E) lie upside down, This feature was recognized originally by B, S, Butler, As the Mississippian beds of the section are overlapped by Tertiary Whitetail conglomerate on the east, the deformation presumably was Laramide,

Separating the overturned lower Paleozoic from Naco limestone on the west (Fig, 32, section D-E) is the Walnut reverse fault, This fault extends (Fig, 31) south-southwestward along upper Walnut Canyon and across the Ray-Superior highway (Fig, 36), It disappears at the Concentrator fault, the western or downthrown side of which here consists of Late Tertiary tuff,

The zone of the Walnut fault in places is occupied by a dike of fine-grained diabase,

Where crossed by section B-C (Fig, 32), the Walnut fault dips 60 degrees east and brings Pinal schist against stratigraphically high Naco limestone that dips 50 degrees eastward, On the east side 4,100 feet of Paleozoic and Apache rocks plus an unknown thickness of Pinal schist are missing, Hence the vertical displacement totals more than 4,100 feet and may greatly exceed that amount,

On the upthrown side, throughout a large area south and southeast of the Walnut fault, the Paleozoic and Apache beds were largely removed by erosion, Into valleys or tectonic depressions within the deeply eroded area, Whitetail conglomerate was deposited,

Elm Thrust Fault

In upper Elm Canyon east of Superior, a thrust fault appears in Naco limestone below the dacite, As mapped by Harshman (Short et al,, 1943, p, 55), this fault dips 35 degrees northeast, approximately with the bedding of the limestone, A post-ore normal fault has dropped the western portion of the thrust relative to the eastern portion,

The Elm thrust may be contemporaneous with the Walnut overturn and reverse fault,

East-West Faults

Many faults of general east-west strike and steep dip cut pre-dacite rocks but tend to be obscure except in mine workings, Within the Magma and Belmant mine areas (Short et al,, 1943), they have effected displacements, partly vertical and partly horizontal, ranging up to 500 or more feet, Notable displacement along the east-west faults antedated ore deposition and presumably was of the some general age as the folding and overthrusting; additional, later movement is evident locally, The principal mineralized veins at Superior occur within fault fissures of the east-west system,

Hump Gulch Reverse Fault

A reverse fault brings diabase against Devonian Martin limestone along the wouthward-trending gulch which the Ray-Superior route follows between the Walnut foult and the Hump

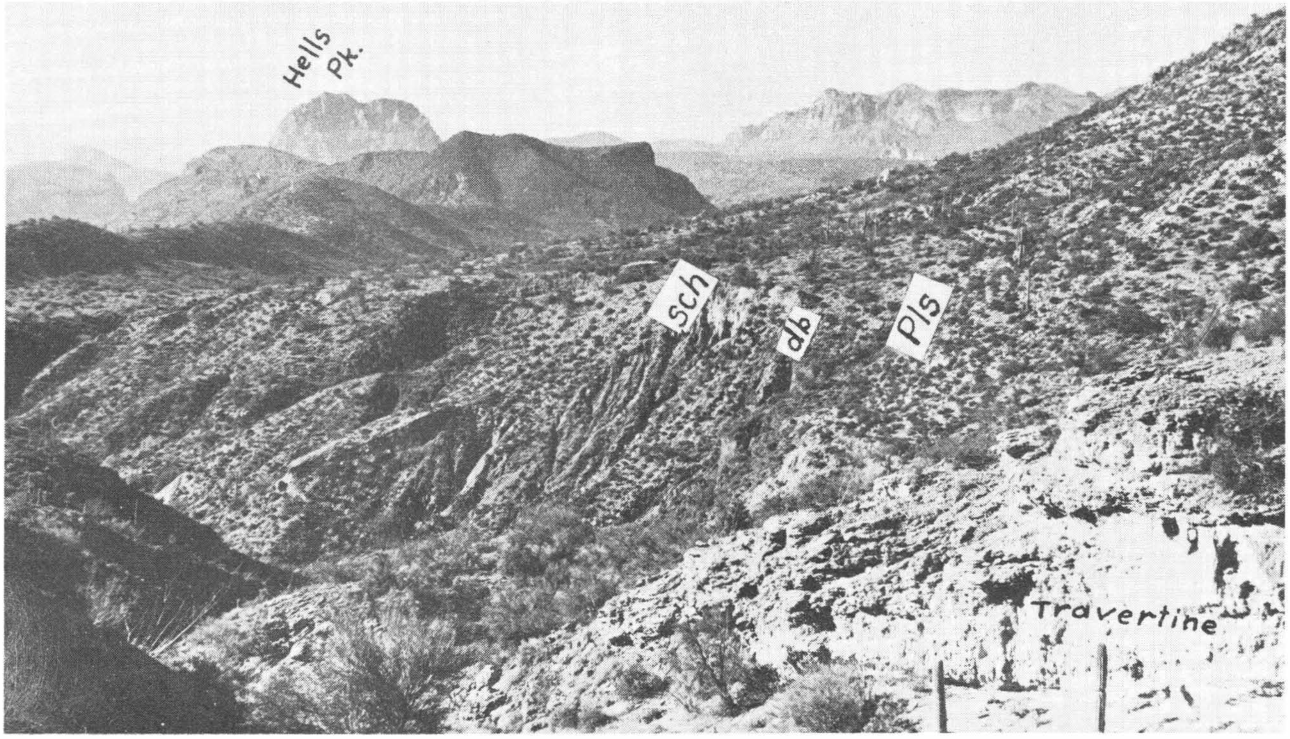


FIGURE 36. - LOOKING SOUTHWESTWARD ACROSS WALNUT FAULT FROM MILE 103.0. Pinal schist (sch) in left middleground is separated from Paleozoic limestone (Pls) on right by Walnut reverse fault. Diabase (db) occupies fault zone. Travertine in right foreground.

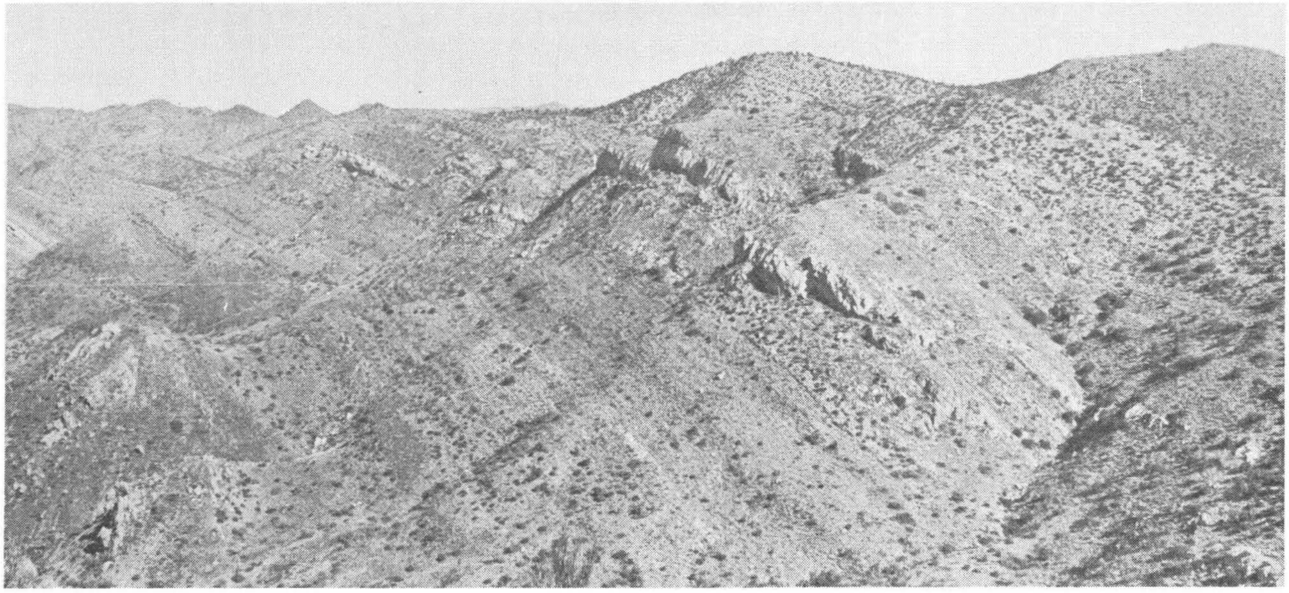


FIGURE 37. - VIEW OF MAIN RIDGE NORTHEAST OF THE HUMP. View northeast from line of section B-C, Fig. 31. Escabrosa limestone in cliffs is underlain by Martin limestone, Troy quartzite, Apache group, and diabase. Naco limestone forms slope above Escabrosa. Ridge on extreme upper right consists of tilted Apache beds and diabase, east of Walnut fault.

(Fig. 31). Boldly outcropping masses of silica breccia, hydrothermal in origin, locally mark the zone of this fault. The general relations are shown in Fig. 24 and section B-C of Fig. 32.

Concentrator Fault Zone

The Concentrator fault zone has been mapped for a length of some 15 miles and evidently extends far beyond the limits indicated on Fig. 31. Its main break follows a zig-zag course of about N. 15 degrees W., dips 60 to 70 degrees west, and effects a vertical displacement, relatively downward to the west, of 2,000 feet or more. The zone as a whole forms links and branches of complex pattern throughout a broad belt.

The Concentrator fault cuts post-Gila (?) tuff. Near Superior, it apparently effected considerable displacement prior to deposition of the Gila conglomerate (Short _et al_., 1943).

Spine Syncline

In the southern part of the Ray-Superior area (Fig. 31), the older rocks and also the Whitetail conglomerate, dacite, and lower portion of the post-Gila (?) tuff are folded into a narrow northwestward-trending syncline. The southwestern limb of this fold forms the Spine, a sharp ridge which rises 1,400 feet above the Gila River. The northeastern limb, south of Copper Butte, is cut by the Concentrator fault. As shown by a recent churn-drill hole, this syncline has depressed the pre-Whitetail surface of the schist to an elevation of 700 feet, and the lower limit of complete oxidation to 100 feet above sea level. The fold becomes obscure southeastward on a surface of crystalline rocks, and northwestward it passes beneath younger tuff. In alinement with the fold northwestward is Hells Peak, a plug of glassy rhyolite more than 1,000 feet in diameter (Fig. 23, 36), which penetrate Gila (?) conglomerate and the lower tuff beds.

Thrust Fault West of Concentrator Fault

West of the Concentrator fault, 6 miles south of Superior, Pinal schist is thrust over Naco limestone (Fig. 32, sec. A-B). The thrust fault, locally marked by gouge and breccia 10 feet thick and dipping 35 to 45 degrees eastward, is exposed for a length of a mile. It is concealed by dacite on the northwest and cut off by the Concentrator fault, originally was continuous with the Walnut overturn and Walnut reverse fault. The possible extent of the thrust fault, as for example beneath other areas of Pinal schist west of the Concentrator fault, remains unknown.

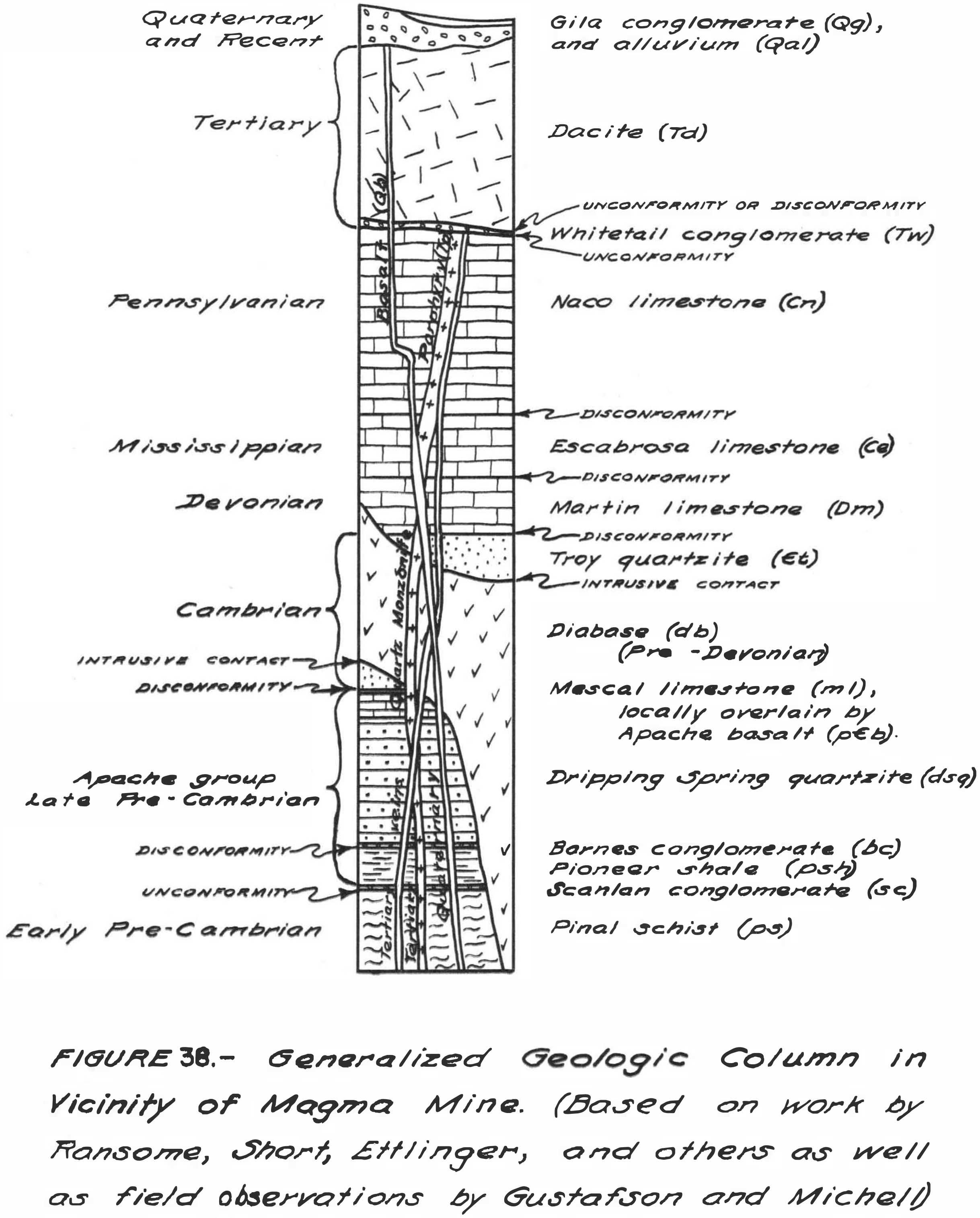


FIGURE 38.- Generalized Geologic Column in Vicinity of Magma Mine. (Based on work by Ransome, Short, Ettlinger, and others as well as field observations by Gustafson and Michell)

SUPERIOR AREA

H, J, Steele
Magma Copper Company

Introduction

The Superior mining area, in northeastern Pinal County, Arizona is 65 miles east of Phoenix and 20 miles west of Miami, via U,S, Highway 60-70,

Superior is at an elevation of 2,800 feet, and the steep dacite-capped escarpment immediately east of the town rises abruptly to an elevation of 4,800,

Mining activity has been carried on continuously since the discovery of the Magma vein in 1874 and of the Silver King ore body in 1875, The bulk of production has been from the Silver King, Lake Superior and Arizona (now owned by Magma Copper Company), and the Magma, which is the only mine now operating,

Rock Types

The rocks exposed in the area consist of Precambrian Pinal schist unconformably overlain by easterly dipping Apache group of younger Precambrian sediments, Cambrian quartzite, and Paleozoic limestone, which are in turn overlain by Tertiary dacite flows,

The schist and pre-Devonian sediments are cut by diabase sills, and the entire series is cut by quartz-monzonite porphyry dikes, The youngest igneous rock is Quaternary basalt occurring as dikes (Fig, 38),

Pinal Schist

The Pinal schist, of early Precambrian age, is a light grey, fine-grained, highly sericitic rock with finely developed schistocity, Veinlets of quartz are common, and in places in the Magma mine the rock is almost entirely quartz, The schist is, in part at least, of sedimentary origin,

Apache Group Rocks

The Scanlan conglomerate is the basal member of the Apache group, but exposures are not abundant in the area, The conglomerate is 2 to 15 feet thick where exposed, and has not been recognized in the Magma mine, The Pioneer shale is next in succession and it consists of moderately hard dark purplish brown arkosic shale, In places it grades into hard arkosic quartz, The maximum thickness known in the Magma mine is 350 feet, The overlying Barnes conglomerate is about 15 feet thick and is composed of vitreous quartzite pebbles with some milky quartz pebbles in a coarse sandy, arkosic matrix, This distinctive bed is a good horizon marker in the Magma mine,

The next formation is the Dripping Spring quartzite, The quartzite is buff to yellow and brown, strongly banded, and has an average thickness of 820 feet, It is highly arkosic with 20 to 40 percent feldspar and toward the top grades into Mescal limestone; limestone or shaly beds alternating with normal quartzite. Underground in the Magma mine it is difficult to differentiate the Dripping Spring from the Troy quartzite unless the Barnes conglomerate is present.

The uppermost formation of the Apache group is the Mescal limestone. This formation is a thin-bedded buff to grey limestone with many chert bands parallel to the bedding, and is about 225 feet thick. The basalt flows, which in places overlie the limestone, have a total maximum thickness of 220 feet although they are not always present. Until recently the Mescal limestone was not recognized in the Magma mine. Exploration east on the 3,400 level cut 165 feet of Mescal and 70 feet of the basalt. The limestone in this exposure was light yellow to green presumably due to the presence of tremolite. Asbestos seams up to 3 inches thick are common.

Paleozoic Rocks

The Troy quartzite, of Middle-Cambrian age, and about 400 feet thick, lies unconformably on the Mescal limestone. It characteristically consists of cross-bedded pebbly quartzite. Overlying the Troy quartzite is the upper Devonian Martin limestone, 350 to 425 feet thick. The Martin is yellowish to buff in color and tends to form a debris-covered slope between the cliff-forming Troy quartzite and the white Escabrosa limestone. No angular unconformity has been recognized between the Troy and Martin, but a disconformity is evident in an exposure immediately south of Superior. The lower part of the Martin is a favorable host rock for replacement ore in the vicinity of mineralized cross breaks, as is the L. S. and A. and Queen Creek mines. Exploration within this same zone is being carried on in the Magma mine.

The Escabrosa limestone, of Lower Mississippian age, averages about 420 feet in thickness. It is white to light grey and forms priminent massive cliffs. The Naco limestone, of Lower Pennsylvanian age, is a thin-bedded white, light-grey, or light-pink limestone. Near the top of the formation a prominent yellow chert bed forms a smoll cliff which is an excellent marker bed. The exposed thickness of the Naco in the Queen Creek canyon is about 1,200 feet.

Tertiary Rocks

The Whitetail conglomerate is the oldest rock of Tertiary age in the area. The conglomerate consists of coarse debris and silt, accumulated probably in Middle Tertiary time on the pre-docite erosion surface. A maximum thickness of 100 feet is exposed in Queen Creek Canyon. The dacite conglomerate overlies the Tertiary dacite and is similar to the Gila conglomerate of Pliocene age. It was deposited upon an irregular surface and has a considerable range in thickness.

Igneous Rocks

Diabase and Quartz Diorite

Diabase sills have intruded the Pinal Schist, Apache group, and Troy quartzite. In the Magma mine a total thickness of 3,100 feet of diabase sills have been cut by mine workings. The diabase has not intruded the Martin limestone in the mine area. A stock of quartz diorite intrudes Naco limestone and is unconformably overlain by Tertiary dacite, north of Magma and near the Silver King.

Quartz-Monzonite Porphyries

The Silver King quartz-monzonite porphyry, an elliptical mass 2,500 feet from east to west and 1,200 feet wide, was intruded into the southeastern part of the quartz-diorite stock. The Silver King ore body is within the porphyry, which shows predominately sericitic alteration and a progressive increase in quartz toward the zone of mineralization. The Magma quartz-monzonite porphyry, which is pre-ore, occupies the Magma vein fault from the outcrop to the 1,200 level and below this level occurs in many places in either the north or south wall of the vein.

Dacite and Basalt

A thick series of dacite flows, tuffs, and agglomerates overlies the Paleozoic and older rocks as well as the Silver King quartz diorite stock and Whitetail conglomerate. In Queen Creek Canyon the thickness is 1,200 feet. The youngest igneous rock in the district occurs as small basalt intrusive bodies and flows later than the post-dacite faults. In the Magma mine it occurs as dikes from one or two feet up to 30 feet in thickness which cut the ore bodies.

Magma Mine

The Paleozoic and Apache beds at the Magma mine strike northerly and dip 30 to 35 degrees eastward. The Magma vein and the smaller parallel Koerner vein, some 900 to 1,000 feet south of the Magma vein, are faults with the fault zone material replaced by the ore minerals. The veins strike slightly north of east.

The Magma vein cuts the Paleozoic series, from the base of the dacite, as well as the Apache group, schist, and the intrusive quartz monzonite porphyry and diabase sills. The bottom of oxidation insofar as explored is parallel to the dip of the beds, and the attitude of the diabase sills is roughly conformable to that of the sediments.

The Magma vein, from the surface to the 800 level, dips 70 degrees to 80 degrees northward. From the 800 level it steepens to vertical, and below the 1,200 level it dips south at 70 degrees to 75 degrees.

Structure

The displacement of the wall rock by the Magma vein fault is about 400 feet downward and 400 feet westward on the south or hanging wall side. The two major post-ore faults are: 1. The Main fault striking north-south and dipping at 45 degrees west (Fig. 39). The surface trace of this fault is along the face of the escarpment east of the mine yard. The displacement on the hanging wall of this fault is down about 1,300 feet and south about 1,350 feet. 2. The Concentrator fault striking N. 40 degrees W., dipping 60 degrees southwest, and converging southward with the Main fault (Fig. 39). The amount of displacement on the Concentrator fault is uncertain, but it is known to have brought dacite into contact with Pioneer shale (Fig. 40) on 2,800 level.

Faulting of a minor degree within the stoping area falls into three general classes, based on the effect on the vein.

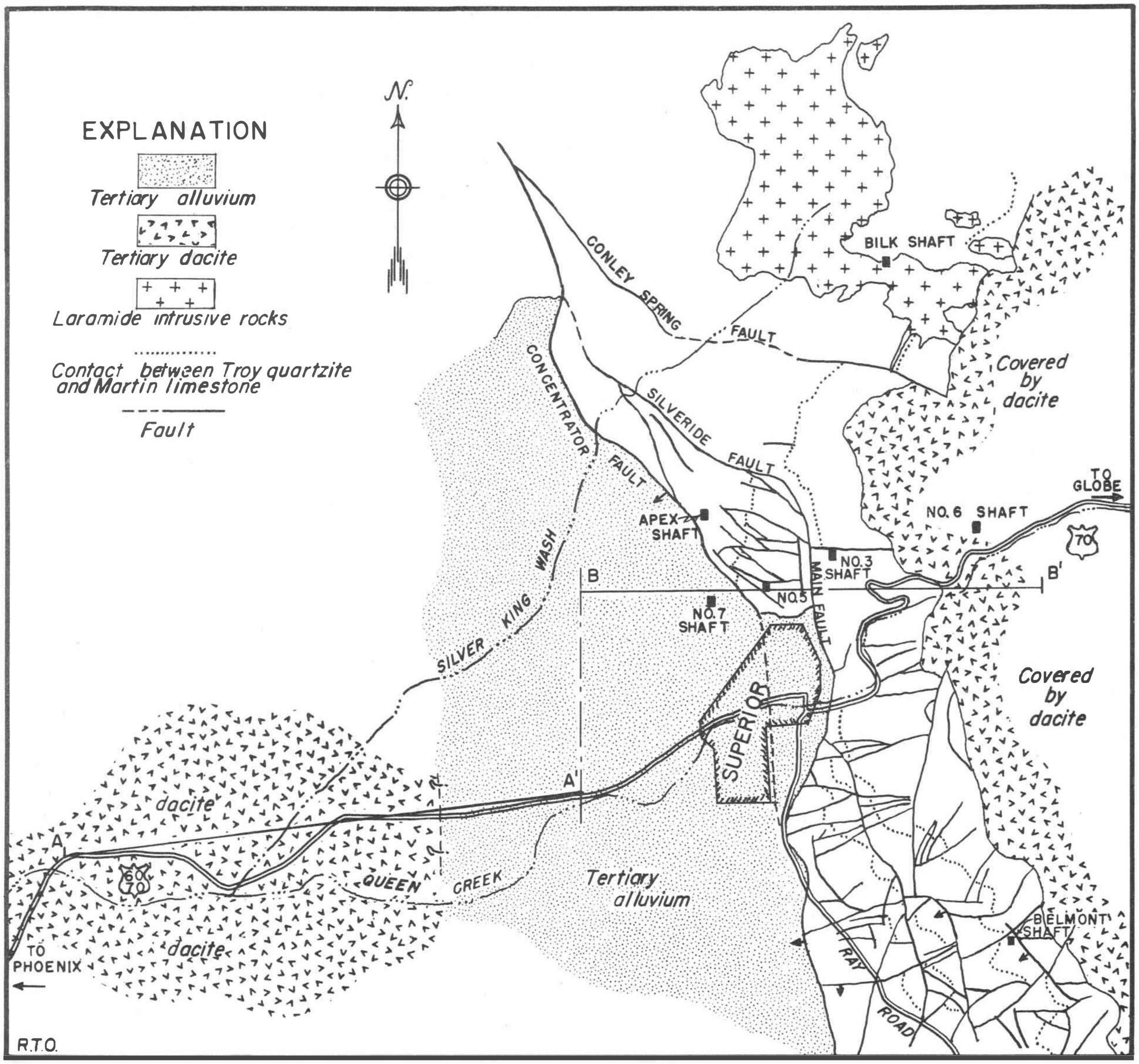


FIGURE 39. – GENERALIZED MAP SHOWING FAULT PATTERN, SUPERIOR AREA

SCALE: 0 2,000 4,000 8,000 FEET

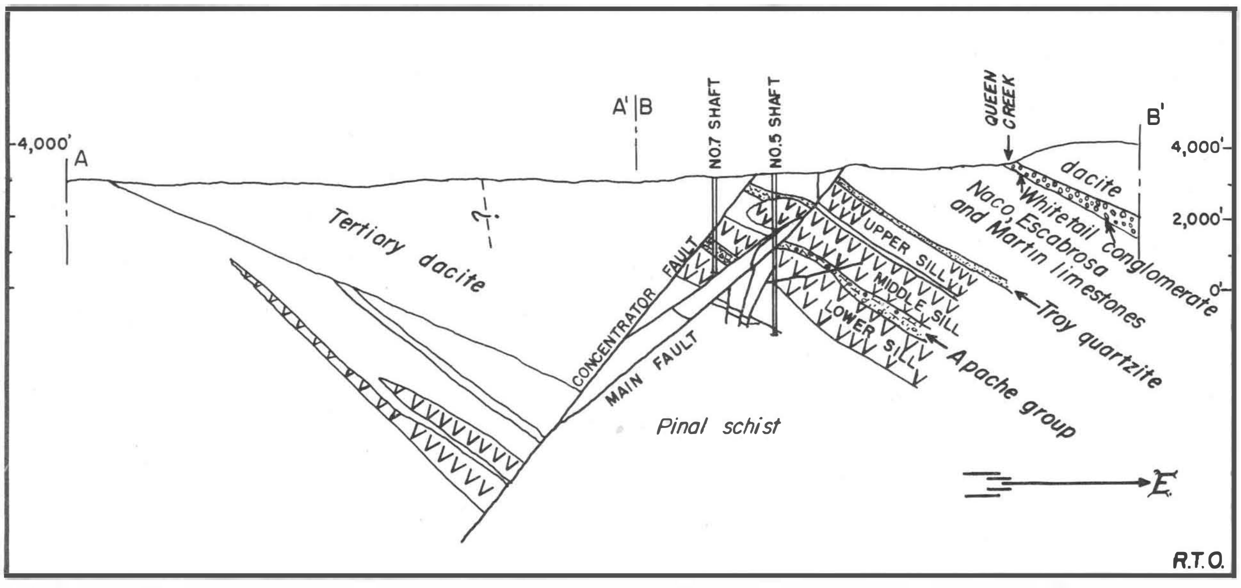


FIGURE 40.– COMPOSITE CROSS SECTION THROUGH SUPERIOR AREA

SCALE: 0 2,000 4,000 8,000 FEET

1. Flat faults--low angle reverse faults striking nearly parallel to the vein and dipping from 0 to 15 degrees south. These are thought to be pre-ore breaks along which, in most cases, there has been post-ore displacement up to 30 feet on the dip. Those flat faults with no evidence of post-ore movement have the effect of an abrupt roll and thinning of the vein. In some cases the mineralization is much leaner in grade above the fault, indicating a damming effect on the ore solutions.

2. Strike faults, locally known as slicer faults, are of reverse type and usually dip steeply north. The maximum displacement on them is about 30 to 40 feet.

3. Cross faulting in the vein with displacement up to 150 feet horizontally. These faults may strike either northwest or northeast and dip steeply either east or west. The structure as described can be considered typical of the district.

Ore Bodies

The Magma vein averages 12 to 15 feet wide. It has been explored, and stoping operations have been carried on, from the surface to the 4,600 level. Exploration by diamond drilling but no drifting, had been done from the 4,800 level. The vein has been explored on strike for 9,000 feet.

In the upper East country, a zinc ore body is being mined, but the bulk of the copper ore has occurred in the central and west portion of the vein. The copper ore minerals are chalcopyrite, bornite, enargite, and some chalcocite and tennantite.

The vein walls are clearly defined, but the wall rock, especially in the schist, is not strong. Rock alteration does not continue far into the walls and the mineralization in general is confined within the vein walls.

The bottom of the Martin limestone, as mentioned under rock description, is a favorable zone for replacement mineralization. This zone has been mined to some extent in the zinc ore body and is being explored to the east on lower levels. Appreciable mineralization extends along this zone north or south from the vein for more than 200 feet in places. The mineralization where explored is massive pyrite and chalcopyrite with bornite.

Stoping is almost entirely by square set with waste fill following ore extraction as ground conditions dictate. A waste raise system from the surface provides the bulk of the stope-fill material.

Rock Temperatures

One of the major production problems at Magma is the high rock temperature. There is an increase in rock temperature of 1.27 degrees per 100 feet of depth between the 2,550 level, where rock temperature is 129 degrees F., to 4,600 level, where a series of temperatures taken in a diamond drill hole averaged 155 degrees F. Air conditioning for stopes and development headings is accomplished by circulating chilled water from a surface cooling tower and from Carrier refrigeration units located underground, through coils located at strategic points in the mine. The air supply, drawn through the coil units by fans, is carried to working places available through mine openings and by flexible vent tubing or 24" spiral weld steel pipe.

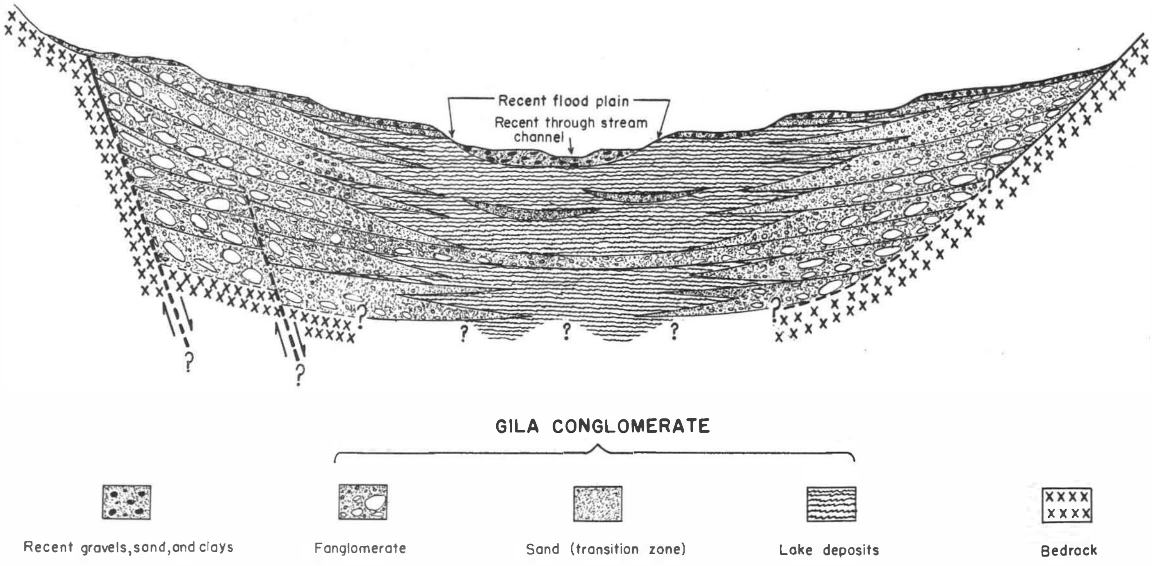
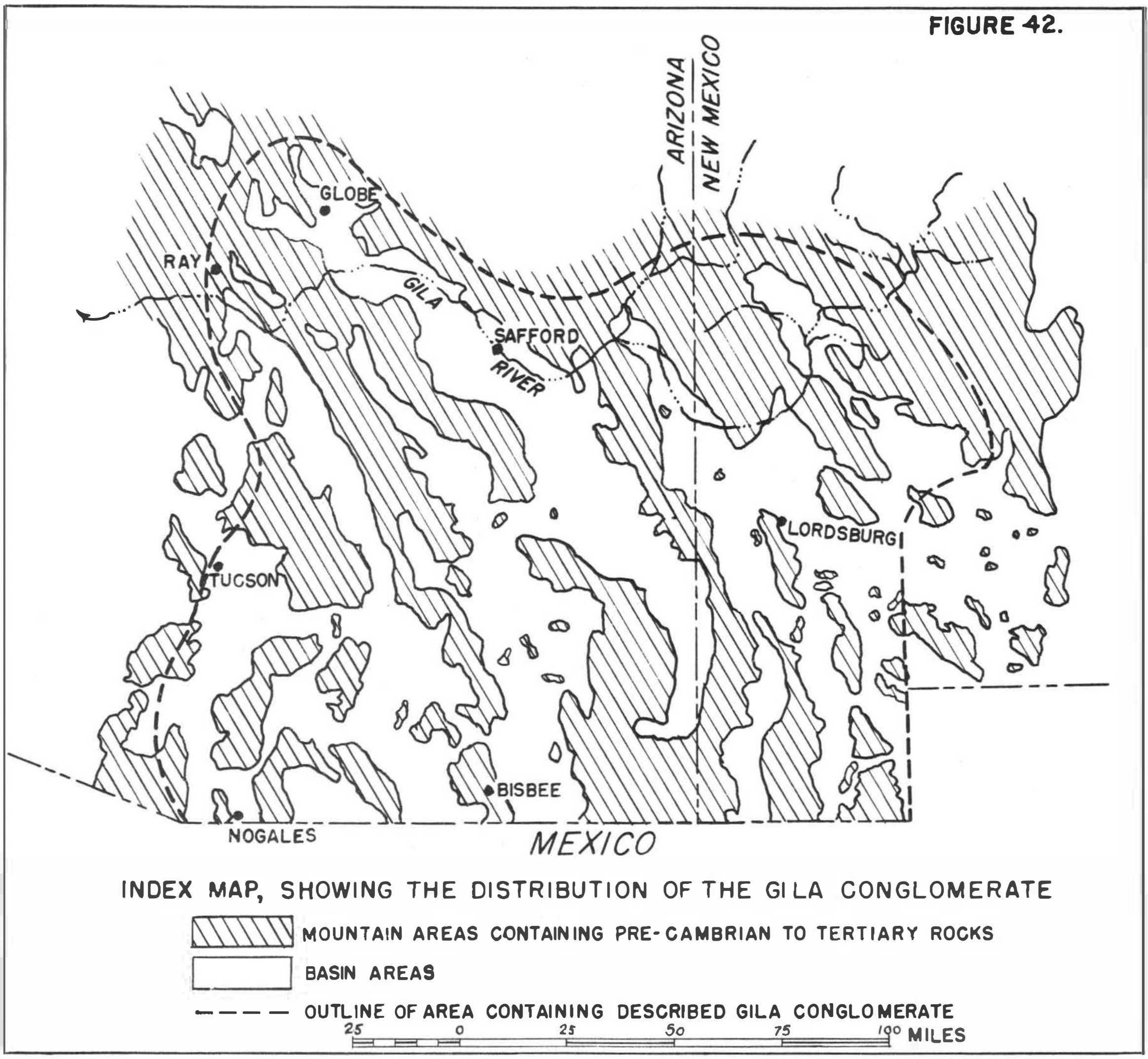


FIGURE 41. - HYPOTHETICAL CROSS SECTION OF A BASIN SHOWING GILA CONGLOMERATE BOTH DEPOSITIONAL AND FAULT CONTACT WITH OLDER ROCKS. NOT TO SCALE.

FIGURE 42.



GILA CONGLOMERATE

L, A, Heindl
Tucson, Arizona

The field trips sponsored by the Arizona Geological Society will pass through extensive areas of eroded and terraced alluvial material, Much of it is called the Gila conglomerate, the genesis and history of which are controversial, The following paper reviews published material on the Gila conglomerate and outlines some of the major problems concerning the formation as it is described in the literature,

Use of the term "Gila conglomerate"

The term "Gila conglomerate", as it is currently used, is applied to poorly- to well-consolidated alluvial materials that are deposited in the structural valleys of the Gila River and some of its tributaries, These sediments appear to have been deposited under conditions similar to those existing today, The term does not include conglomerate deposits of early Tertiary age nor does it include terrace and stream deposits that are obviously of Recent age,

Originally the term "Gila conglomerate" was applied by Gilbert (1875) to the coarse fluviatile conglomerates along that part of the Gila River east of the Arizona-New Mexico border, He tentatively assigned these conglomerates to the Pleistocene age, The term was extended progressively westward to the vicinity of Ray, Arizona by Ransome (1904; 1919) on the basis of physical continuity and lithologic similarity, The formation was redefined, also by Ransome, to include lacustrine deposits because the conglomerates locally grade laterally and vertically into silt, Meinzer (1913) called beds in the vicinity of Willcox, Arizona, "Gila conglomerate", and Schrader (1915) applied the term as far south as Nogales, In New Mexico the name was applied to beds in southwest corner of the state (Schwennesen, 1918) and in the vicinity of Silver City (Paige, 1916), Darton (1925) suggests the name "Gila conglomerate" for deposits near the Vekol Mountains, northwest of Tucson, and at Peach Springs, Arizona, in the Colorado Plateau area, Distribution of the Gila conglomerate is shown on Fig, 42,

In studying the ground-water resources of the Safford and San Simon Valleys, Schwennesen (1917; 1919) postulated that the finer material near the axis of the valleys was younger than the coarser material near the basin margins and that the finer material overlay the coarser with angular unconformity, Part of the same area was restudied by Knechtel, who opposed Schwennesen's ideas and reaffirmed Ransome's thesis of gradation from coarse-textured marginal fanglomerate to fine-grained central playa deposits (1936; 1938),

Gilbert and Ransome described only the very coarse alluvial material of areas immediately adjacent to the Gila River, Knechtel later noted that deposits along the Gila River are interbedded with deposits of alluvial materials laid down by streams tributary to the Gila, He therefore extended the name "Gila conglomerate" to the alluvial and lacustrine deposits within the structural basins occupied by tributary streams, Knechtel noted that the beds of the Gila conglomerate are essentially horizontal in these basins,

Ransome (1919), Bryan (1926), Peterson (1938), Schrader (1915), Schwartz (1945) and others, apply the term "Gila conglomerate" to beds that dip at low to high angles and that match, except for structural attitude, earlier descriptions of the Gila conglomerate,

Age of the Gila conglomerate

The age of the Gila conglomerate, as determined by a few vertebrate fossils from essentially horizontal lake beds south of Benson, is late Pliocene to early Pleistocene (Gidley, 1922; 1926; Gazin, 1942). No conspicuous change that might be ascribed to environment separates the early Pleistocene from the late Pliocene deposits. As the fauna described are from surface exposures, and as drill data show a continuation of 1,200 to 1,600 feet of similar sediments below these exposures it is possible that deposition of Gila conglomerate began before late Pliocene time.

Description of the Gila conglomerate

The Gila conglomerate, as generally recognized, includes deposits representing three different environments: (1) Fanglomerate along the basin margins, (2) playa deposits in the centers of the valleys, and (3) deposits laid down in the transition zone between the coarse fanglomerate and the fine-grained playa deposits. (See Fig. 41). Locally, basalt flows are intercalated with the sediments.

Some of the fanglomerates have initial dips as great as 10 degrees and contain boulders as much as 12 feet in diameter, indicating local sources. Some boulders are rounded, particularly those of granitic origin; others are angular, as in the case of some volcanic rocks. The fanglomerate zone is typified by cobble and pebble conglomerates with interbedded layers of pebbly sandstone. The width of zone of fanglomeratic deposits ranges from narrow to wide, depending on local depositional or structural conditions.

The playa deposits include sediments that range from corase sand to clay; fine-grained sand and silt predominate. Locally there are extensive gypsum deposits, thin units of fresh-water limestone, tuffaceous and diatomaceous beds. Some of the gypsum deposits are worked commercially.

In most places the transition zone between the fanglomerates and the central playa deposits is less than 200 yards in width. The change locally is so abrupt that faulting, as an explanation for the change, can be dismissed only by tracing the gradation step by step. In some areas where the sediment is almost wholly granitic the transition zone is as much as a mile wide.

The thickness of the Gila conglomerate has been variously estimated from a minimum of not less than 1,000 feet (Schwennesen, 1919) to a maximum of 8,000 feet (Ransome, 1919). The great thicknesses are explained by faulting contemporaneous with deposition, so that eroded materials from upthrown blocks were deposited on the downthrown blocks. In no estimate is a bottom boundary given and, where great thicknesses are estimated, beds may be duplicated by faulting.

Several authors have pointed out that the base of the Gila conglomerate has not been identified in the centers of any structural valleys. Locally, along the margins of the basins, conglomerate that appears continuous with Gila conglomerate overlaps rocks ranging in are from Precambrian through late Cretaceous. In many areas the Gila conglomerate is exposed in fault contact with early Tertiary and older rocks.

In most Arizona valleys where the Gila conglomerate is recognized, it is eroded to form a series of graded surfaces, each sloping gently toward the center of the valley. In general, three main terraces, separated by distinct steepenings of slope, can be distinguished. Some of these terraces are covered by veneers of younger alluvium up to 100 feet thick.

Problems of the Gila conglomerate

Some of the problems connected with the Gila conglomerate are those concerned with: (1) The definition of the Gila conglomerate; (2) the depositional and structural history of the alluvial deposits within the basins; and (3) ground-water resources of the basins.

What is the Gila conglomerate?

The term Gila conglomerate is used to describe alluvial deposits in an area of at least 30,000 square miles (Fig. 42). This area is crossed by seven roughly parallel mountain ranges separated by seven broad irregular troughs. The mountain ranges are generally assumed to be uplifted blocks and the intermontane troughs to be down-faulted blocks filled with alluvium of local derivation. The textural similarity of the conglomerates and the common presence of lake beds in the centers of the troughs point to deposition under similar environments. Fossil evidence from the upper lakebed members shows that some of the like deposits in the several basins were contemporaneous. The question is whether textural similarity and contemporaneity of the upper members is sufficient evidence to place the deposits of the several basins in a single unit. A single unit implies areal continuity, which has not been demonstrated either on the surface or at depth. The passes between the troughs contain alluvial deposits but these are not known to be Gila conglomerate nor are the passes known to be underlain by Gila conglomerate. In addition, the basic assumption that the development of the ranges and troughs follows a single structural pattern or was contemporaneous throughout the region has not been incontrovertably established.

It may be suggested that the use of the term "Gila conglomerate", through its application to several basins, to a variety of deposits (including lake beds), and to more than a single cycle of deposition, has inhibited understanding of the depositional and structural history of the basin deposits in this area.

Problems of late Tertiary history

Among the conglomerates within the basins are stratigraphic units that are more tightly cemented, that are composed of material whose local source is not clearly demonstrable, and that dip at high angles as a result of structural deformation. The term "Gila conglomerate" is usually applied to alluvium both in fault contact and in depositional contact with these deformed beds. The more steeply dipping conglomerates have been separated from the Gila conglomerate by Ross (1925) and Knechtel (1936). Other authors have included in the Gila conglomerate similar deformed beds which are in angular discordance with the flat-lying beds commonly assigned to the Gila.

The problem of whether the deformation of these beds was contemporaneous with or followed the latest deformation of the mountains has great significance in interpretation of the Tertiary history of Arizona. The latest deformation, resulting in mountain masses from which the Gila conglomerate might be derived, is assumed to be of late Miocene or early Pliocene age (Knechtel, 1936; McKee, 1951.) A single period of techtonism over a large area, resulting in an angular unconformity between the deformed beds and later deposited flat-lying beds, is implied. The application of this concept to large areas has recently been questioned by Gilluly (1949).

The Whitetail conglomerate described by Ransome (1919) in the vicinity of Ray is separated from the Gila conglomerate by 3,000 feet of pre-Gila dacite flows. Except for dacite fragments in the Gila conglomerate, it is impossible to differentiate the two formations (Ransome, 1919). Some of the tilted beds assigned to the Gila conglomerate may be correlatable with the Whitetail conglomerate.

It is suggested that steeply dipping conglomeratic beds reflect local structural deformation, and that the steeply dipping beds in a single basin are contemporaneous with comparatively flat-lying beds both within the same basin and with those in other basins. These areas of deformed beds may be the key areas for study of the structural history of this area.

Ground-water problems

Water supply in the conglomerate-filled basins is derived mainly from ground water, most of it recent channel deposits. The increased use of water for agricultural and municipal use in these basins in recent years makes it necessary to consider the Gila conglomerate as an auxiliary source of ground water. The capacity of the Gila conglomerate to store and transmit water, and the structural relations both within the Gila conglomerate and between the Gila conglomerate and adjacent formations are problems now being investigated.

Locally the Gila conglomerate includes important aquifers. Relatively few wells in the fanglomerate are successful even where drilled to depths of 500 and 600 feet. The water has not been tapped everywhere within the fanglomerate because drilling has not in all places gone deep enough. In contrast, playa lake beds of the Gila conglomerate include important artesian aquifers consisting of tongues of permeable sands and gravels extending basinward into the impermeable deposits of quiet-water deposition. Infiltration from runoff in desert washes is greatest in the fanglomerate zone, and recharge of the artesian aquifers is by lateral movement from the fanglomerates along the margins of the basins to the permeable sediments of the central parts of the basins.

Extensive lake deposits, containing locally important aquifers at depth, occur in nearly all the basins. The extent of the lake beds, their continuity and their relations to other deposits in a basin are factors of considerable importance in evaluating the ground-water resources of the basins in southern Arizona.

TRIP 5, ROAD LOG (CONTINUED)

Second Day--Monday Forenoon, April 14, 1952

Leaders: Nels P, Peterson and E, F, Reed
Driving Distance: 38,6 miles, Log distance 38,6 miles

General Statement

This portion of Trip 5 traverses the Globe-Miami-Castle Dome mineral belt, The major portion of the rocks seen will consist of Precambrian granitic and metamorphic rocks, and Tertiary gravels, Only a few isolated blocks of Paleozoic sediments will be observed in this complexly faulted area,

Porphyry copper deposits, the main features of interest in this region, will be observed and discussed, Included in the excursion and discussion are the Catle Dome copper deposit, which was developed in the early part of World War II; the Inspiration Consolidated Copper Company ore body, where open pit mining operations have been initiated in the subsidence area produced by block-caving mining methods; and the Miami copper deposit subsidence area which will be viewed from the townsite of Inspiration, The caravan will return to Globe for lunch and afterwards will proceed north from Globe to the Salt River Canyon,

0,0	0,0	Gila County Court House (at stop light, Proceed toward Miami to assembly point at mile 1,0,
0,8	0,8	Bridge across Pinal Creek,
0,2	1,0	Old slag dump on right, Caravan assembles along side of road,
0,3	1,3	At 2 o'clock, rounded knobby outcrops of dacite,
0,5	1,8	At 2 o'clock, light-colored outcrop is a block of Mississippian limestone, Gila conglomerate in road cuts,
0,3	2,1	Observe small faults in Gila conglomerate in road cuts,
0,9	3,0	At 10 o'clock, Copper Cities Mines development; this porphyry copper deposit is being stripped preparatory to open pit operation, Sleeping Beauty Mountain on skyline,
0,4	3,4	Road junction on right, Apache Trail,
0,3	3,7	Tailings pond and waste dump,
0,8	4,5	At 1 o'clock International Smelter on top of hill,
0,5	5,0	Road junction to Inspiration Consolidated Copper Company Mines,
0,9	5,9	At 1 o'clock main shaft of Miami Copper Company mine, Bridge across Bloody Tanks Wash,

1,0	6,9	At 3 o'clock Miami fault, Pinal schist in footwall, Gila conglomerate in hanging wall,
0,8	7,7	At 11 o'clock the hills are of Schultze granite,
0,3	8,0	Contact between Pinal schist and Schultze granite along hillside on right, Bridge across Bloody Tanks Wash,
1,7	9,7	Roof pendant of Pinal schist in the Schultze granite on right side of road,
1,5	11,2	Cattle guard, road junction to Caţle Dome Copper Company, TURN SHARP RIGHT. Schultze granite in road cuts,
0,8	12,0	At 10 o'clock, Mazatzal Mountains in far distance,
0,4	12,4	At 1 o'clock, Needle Mountain, composed of Gila conglomerate underlain by Pinal schist,
0,4	12,8	At 12 o'clock, on skyline, dacite flow,
0,1	12,9	Cattle guard,
0,2	13,1	Fault contact between Pinal schist and Schultze granite, Road parallels fault for several hundred yards,
0,2	13,3	At 9 o'clock, Lost Gulch quartz monzonite in road cut,
0,3	13,6	Aplite dikes in the quartz monzonite probably offshoots from the Schultze granite,
0,1	13,7	Willow Spring granite in road cut,
0,3	14,0	Contact between Willow Spring granite and Lost Gulch quartz monzonite,
0,05	14,05	Castle Dome guard station, Water entering reservoir on left is pumped from the Old Dominion Mine at Globe,
0,05	14,1	At 1 o'clock, dacite flow on skyline, Jewel Hill, at 12 o'clock, is capped by Escabrosa limestone which is underlain by Martin limestone, At a lower level the brown Dripping Spring quartzite is faulted against the Martin and is underlain by diabase,
0,3	14,4	First view of Castle Dome Mine,
0,1	14,5	Contact between the diabase and Schultze granite, Porphyry dikes occur in the diabase, At 12 o'clock, Jewel Hill fault, the easterly marginal fault of the Castle Dome horst,
0,3	14,8	Road junction, continue straight ahead, Small hills near road are of granite porphyry,

0.5	15.3	Guard station and main office of Castle Dome Copper Company. Please stay in line and follow instructions given by flagmen.
0.6	15.9	STOP 1. (45 minutes.) Park cars along old ore dump road. Discussion of Castle Dome copper deposit by Nels Peterson.
0.6	16.5	Main office of Castle Dome Copper Company.
0.5	17.0	Road junction, take left fork.
2.4	19.4	Pinal Mountains at 12 o'clock. The higher wooded peaks consist of Pinal schist and Madera diorite. The lower rounded hills are of Schultze granite. The whitish outcrop on left is the Solitude granite.
1.4	20.8	Road junction with U.S. Highway 60-70; TURN LEFT. Outcrops of Schultze granite along road.
0.2	21.0	Pinal Mountains at 10 o'clock.
1.3	22.3	Roof pendant of Pinal schist in the Schultze granite at 10 o'clock.
1.4	23.7	Contact between the Schultze granite and the Pinal schist along hillside on left.
0.3	24.0	Bridge across Bloody Tanks Wash. Pinal schist in road cuts.
0.9	24.9	City limits of Miami, Arizona. SLOW, main road bears sharp right.
0.1	25.0	Road junction to Inspiration Consolidated Copper Company Mines. TURN SHARP LEFT. Bullion Plaza School on left. Miami fault crosses road at junction.
0.05	25.05	Turn sharp left.
0.05	25.1	Road junction, bear right. Entering Live Oak Gulch.
0.1	25.2	First view of Inspiration Copper Company ore body.
0.2	25.4	Schultze granite crops out along right side of road.
0.2	25.6	Sulphide Tunnel, supply yard for underground workings of the Inspiration Mine.
0.1	25.7	Railroad crossing.
0.2	25.9	Road junction bear left. Cross Live Oak Gulch.
0.2	26.1	Road junction, continue straight ahead.
0.6	26.7	At 3 o'clock, close-up view of surface cave and ore body.

0,2	26,9	STOP 2, (30 minutes), Park cars along west side of open pit, Discussion of Inspiration ore body by Nels P, Peterson and E, F, Reed,
0,2	27,1	Top of hill, SHIFT INTO LOW GEAR: STEEP GRADE AHEAD.
0,2	27,3	Bridge, Gila conglomerate on left overlies the ore body,
0,6	27,9	Top of hill, Gila conglomerate on right, At 12 o'clock, Pinal schist capped by dacite,
0,2	28,1	View of Live Oak shaft, Mosaic of outcrops of Gila conglomerate, dacite and Pinal schist in this area,
0,2	28,3	Hoist house, Live Oak shaft,
0,05	28,35	Railroad crossing, stay on outside of fence, Dacite on left side of road,
0,05	28,4	Contact between dacite and Pinal schist,
0,1	28,5	Road junction, bear right; Pinal schist,
0,5	29,0	Webster Gulch Bridge, bear right; Pinal schist,
0,4	29,4	View of the main shaft and general office of Inspiration Consolidated Copper Company,
0,2	29,6	Bridge across Webster Gulch,
0,1	29,7	Ore storage bins for the leaching plant,
0,1	29,8	At 10 o'clock, copper leaching vats,
0,3	30,1	View of International Smelter, At 3 o'clock, Miami Copper Company ore body and town of Miami,
0,3	30,4	Town of Inspiration,
0,1	30,5	Road junction to residential area, bear right,
0,1	30,6	STOP 3, (10-20 minutes), This stop is along east side of subsidence area, Discussion of Miami Copper Company ore body by E, F, Reed,
0,2	30,8	Road junction, TURN SHARP RIGHT,
0,6	31,4	Roadjunction, continue straight ahead,
0,1	31,5	At 12 o'clock, Inspiration Consolidated Copper Company mill,

0,2	31,7	Road junction, bear right, Crossing Miami fault; Gila conglomerate on east side of fault,
0,5	32,2	At 12 o'clock, International Smelter,
0,8	33,0	SLOW, sharp curves ahead, tailings pond,
0,5	33,5	Bridge across Bloody Tanks Wash,
0,1	33,6	Road junction, U,S, Highway 60-70, TURN LEFT,
1,4	35,0	Railroad crossing, At 8 o'clock, Sleeping Beauty Peak and Copper Cities Mine,
0,2	35,2	Road junction, Apache Trail, Gila conglomerate in road cuts,
0,7	35,9	At 12 o'clock, rounded knobby outcrop of dacite,
0,7	36,6	View of Old Dominion Mine, Buffalo Ridge on the left, of Troy quartzite that overlies a diabase sill intruded between the quartzite and the Mescal limestone,
0,9	37,5	Mine rescue station at 3 o'clock,
0,1	37,6	City limits of Globe, Ariz,
1,0	38,6	Pinal County Court House, LUNCH STOP,

THIS PAGE

INTENTIONALLY BLANK

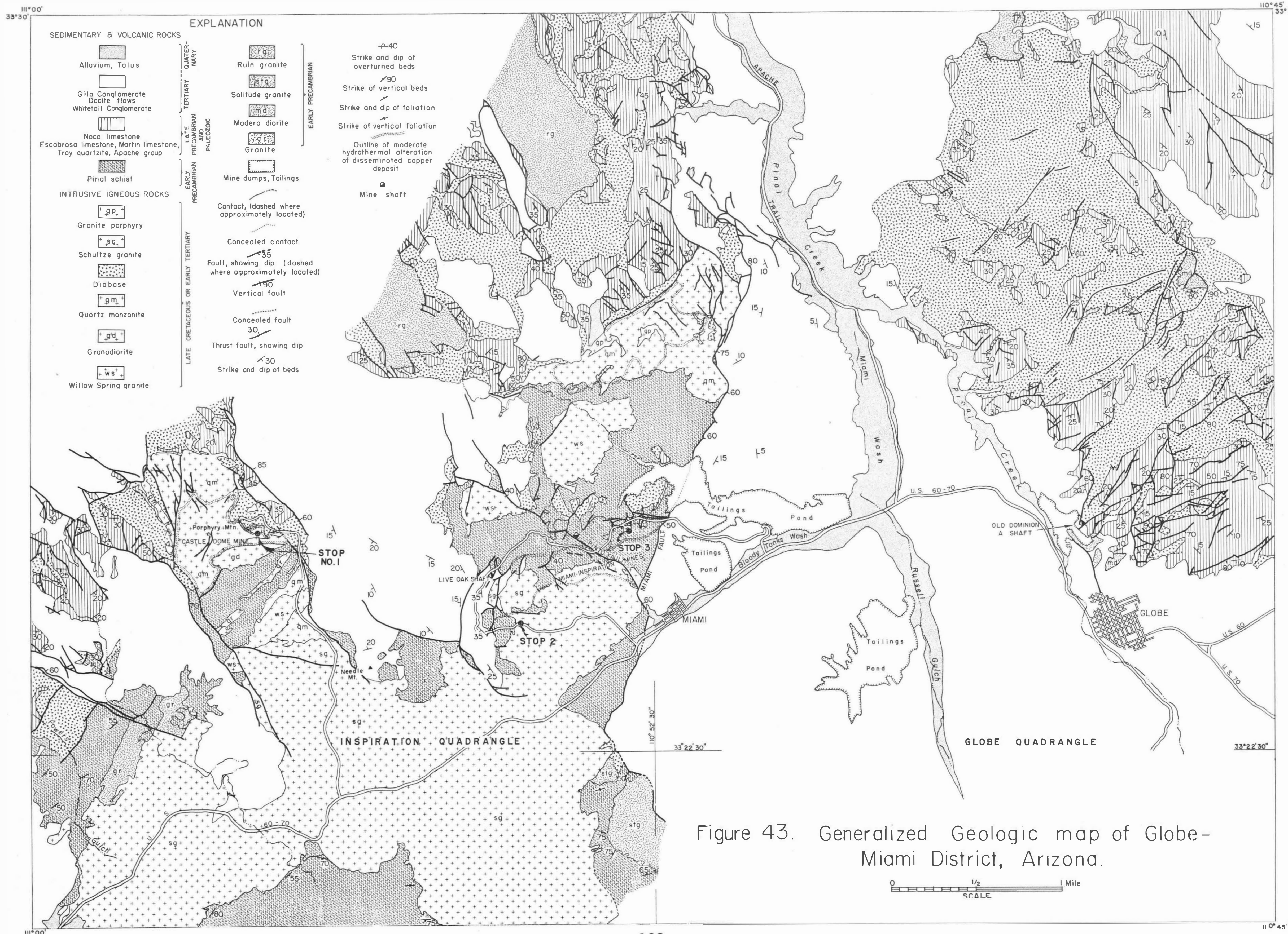


Figure 43. Generalized Geologic map of Globe-Miami District, Arizona.

STRUCTURAL HISTORY OF THE GLOBE-MIAMI DISTRICT*

Nels P. Peterson
Mineral Deposits Branch, U.S. Geological Survey

The stratigraphy of the Globe-Miami district is essentially the same as that of the nearby Pioneer and Mineral Creek districts. The same stratigraphic units are represented in all three districts, but the units may differ slightly in character and thickness. The three areas differ mainly in structure and in history of igneous intrusions. The Pioneer district may well be on the southwestward continuation of a deeply rooted structural zone that was the locus of igneous intrusions and mineralization in the Globe-Miami district.

The decipherable structural history of the Globe-Miami area began during the Mazatzal revolution in early Precambrian time after a long period of sedimentation. The earliest structural lines were produced by a northwest-southeast compression that folded and recrystallized the early sediments into approximately their present form. These metamorphosed sediments make up the Pinal schist. The general strike of the bedding and foliation in the schist is about N. 50° E., and the dips are steep northwest or southeast. During the later stages of the revolution, several intrusions of igneous magma took place, some before the complete metamorphism of the sediments. These intrusions are represented by the Madera diorite, a medium-grained granite, Ruin granite, and possibly Solitude granite.

Toward the end of the Mazatzal revolution, the topography of the region must have been characterized by extremely rugged mountains made up of folded and faulted blocks of Pinal schist and included bodies of igneous rocks. There followed a long period of erosion during which the region was worn down to an almost featureless peneplain sparsely strewn with detritus.

Late Precambrian time was initiated by the advance of the sea over the base-leveled terrain, forming a broad shallow basin in which the sedimentary sequence of the Apache group was deposited. The only regional disturbance during Apache time resulted in the formation of the Barnes conglomerate, which separates the Pioneer formation from the Dripping Spring quartzite.

The end of Precambrian time is not marked by any appreciably structural disturbance. It is represented by an erosional disconformity, but the sedimentary strata were not faulted or recognizably warped during their emergence from the sea. The only evidence of igneous activity is one or more thin flows of basalt that overlie the Mescal limestone.

During the period of erosion that followed eruption of the basalt and withdrawal of the sea, the basalt flows and Mescal limestone were completely removed from a large part of the district. In some places, channels were cut through the Barnes conglomerate, exposing the Pioneer formation; but there was no apparent deformation of the strata.

Similarly, the interval following deposition of the Cambrian Troy quartzite was one of relative quiet, although the hiatus represented by the disconformity at the top of the Troy

---

* Publication authorized by the Director, U.S. Geological Survey.

includes part of Upper Cambrian, Ordovician, Silurian, and Lower Devonian time. In a large part of the district, erosion completely removed the Troy quartzite and also some of the underlying rocks of the Apache group, but no faults formed during this interval have been recognized.

The remainder of the Paleozoic era also was a time of great stability. Devonian and Carboniferous rocks were deposited conformably on Cambrian rocks and the late Precambrian Apache group. There is no apparent break between the Devonian and Carboniferous systems. The absence of upper Mississippian strata and the presence of thin lenses of chert conglomerate indicate a disconformity between the Mississippian and Pennsylvanian series, but intervening erosion must have been slight.

Thus from late Precambrian time, when the formations of the Apache group were being deposited, through the Paleozoic era, structural forces were practically inactive; and the sedimentary formations succeeded one another conformably. The recognizable erosional disconformities resulted from alternating uplift and subsidence of the land or sea level so regional in scope that no detectable angular unconformities were formed between the several sedimentary systems.

There are no sedimentary formations representing the interval between Pennsylvanian and early Tertiary time, but sedimentation probably continued at least through the Paleozoic era. At least the later part of this long interval of time was one of widespread igneous activity, extensive faulting, and erosion. All the intrusions of the district except those that are clearly of early Precambrian age could have occurred during this interval. For lack of more restrictive age criteria, they tentatively have been assigned to the late Cretaceous or early Tertiary orogeny.

Among the earliest intrusions assigned to this period are the Willow Spring granite, the granodiorite in Gold Gulch, and the Lost Gulch monzonite (Fig. 43). These as well as some of the early Precambrian intrusions show a tendency toward northeasterly elongation and alinement. Their spatial relations suggests a controlling, northeast-trending zone of weakness that developed during the early Precambrian revolution.

Considerable crustal adjustment must have accompanied and followed these early igneous intrusions. The zone in which they occurred and the region north of it undoubtedly were well dissected by faults before the widespread diabase intrusions began. The displacement on most of these faults was small or moderate, but on many of them much additional displacement resulted from the diabase intrusions.

The diabase was injected at relatively shallow depths, with probably no more than the thickness of the Paleozoic formations separating some of the largest masses from the surface. Space for the large volumes of intruded magma was provided by dilation of the crust, with consequent rupture and displacement of the intruded rocks. The diabase magma formed dikes and sills by forcing its way into faults and between the sedimentary beds. Some blocks of strata were pushed apart, others were lifted and tilted, and some were dislodged and completely enveloped by diabase.

As a result of the diabase intrusions, many of the old faults became igneous contacts between diabase and older rocks. After the diabase intrusion but before the period of copper mineralization, the old faults on some of these contacts were reopened, and additional displacement took place. Although the displacements probably were small, the faults formed during this interval are of great economic importance because many of them became channels for mineralizing solutions.

The relative elevation of the Pinal Mountains south of the district must have begun soon after the diabase intrusion. This was accomplished partly by broad folding of the sedimentary strata that overlie the crystalline rocks of the area and partly by a major fault on the north side of the range. Although the fault has not been seen, the structural relationships require its existence and suggest that its general strike south of the Globe-Miami district is approximately east-northeast parallel with the zone of igneous intrusions.

The next important event to affect the structure of the district was the intrusion of the batholith of Schultze granite which underlies most of the southwestern part. Later pulses of the same magma formed lobes of granite porphyry at several places along the margins of the main mass. The magma also formed dikes and small masses where it invaded the surrounding formations.

The extensive copper mineralization of the district followed soon after the Schultze granite and granite porphyry intrusions. It appears to have been the culminating event of this long period of igneous activity. The Miami-Inspiration deposit formed along the north contact of a lobe of granite porphyry and the other large disseminated deposits are closely associated with outlying intrusions of granite porphyry. It is noteworthy that, although the pre-mineral faults have great diversity in strike, only faults and fracture zones having northeast strikes were mineralized by hypogene solutions. The disseminated deposits also show prominent northeasterly trends. All the mineral deposits of economic importance are confined to a northeast-trending zone that was the locus of numerous igneous intrusions.

Undoubtedly erosion occurred at various intervals during the Mesozoic era, and it continued for some time after the period of mineralization. In the vicinity of the Miami-Inspiration ore bodies, the cover of sedimentary rocks was completely removed, and the mineralized schist and granite porphyry were exposed to weathering agent. The greater part of the detritus was transported away from the district, but a little of it accumulated in low-lying areas forming the Whitetail conglomerate. While erosion was going on in the Miami-Inspiration area, there was a basin of deposition in the vicinity of Porphyry Mountain to the west, so that while the Miami-Inspiration deposit was exposed and undergoing supergene enrichment, the cover over the Castle Dome deposit was being increased and thus protected the deposit from oxidation.

Erosion was interrupted by an explosive ejection of dacitic tuff and the outpouring of a great sheet of dacite lava that covered much of the region, north and west of the Pinal Mts.

Faulting on a large scale resumed after the dacite eruption and was more or less continuous into Pleistocene time. The faulting was mainly of the normal type; but at the southwest end of the Old Dominion mine, a block of early Precambrian Madera diorite was thrust over the dacite along a low-angle, south-dipping fault.

Erosion also resumed after the dacite eruption and began wearing away elevated blocks. The dacite was completely removed from some areas, and debris from the underlying formations began to accumulate in the low areas as broad coalescing alluvial fans, which compose the major part of the Gila conglomerate. As time went on, these deposits of coarse bouldery detritus, gravel, sand, and silt were built up to thickness that exceed 4,000 feet.

The thickest accumulation of the conglomerate was in the mass that crops out in the broad valley between Globe and Miami. This large outcrop coincides approximately with a roughly triangular block bounded by normal faults along which the block has been relatively depressed. At the time of its greatest extent, the Gila conglomerate probably mantled the entire district and lapped considerably higher up the slope of the Pinal Mountains to the south than it does now.

Deposition of Gila conglomerate ceased with a period of regional uplift and local faulting. A new drainage system tributary to the Salt River basin developed, and the Gila conglomerate began wearing away. One of the highest blocks in the district at this time and probably among the first to be stripped of its cover of lava and sedimentary formations was the Castle Dome horst block on Porphyry Mountain. The mineralized quartz monzonite was uncovered for the first time, and weathering agents began the work of enrichment that was largely responsible for the formation of the Castle Dome ore body.

The quartz monzonite in the Lost Gulch area had been mineralized at the same time as that on Porphyry Mountain. At least a part of the Lost Gulch mass had been unroofed before the dacite eruption, and undoubtedly the mineralized rock had undergone some weathering, but whether any part of the present chalcocite ore body was formed at that time is uncertain. Here too, the quartz monzonite outcrop is in a relatively elevated block, which probably was stripped of its cover of dacite and Gila conglomerate at about the same time that the quartz monzonite on Porphyry Mountain was uncovered. At least the major part of the enrichment that produced the Copper Cities ore body was nearly contemporaneous with the enrichment at Castle Dome and is related to the present erosion cycle.

The mineralized schist and granite porphyry in the Miami-Inspiration area was covered by only dacite and Gila conglomerate after they had been exposed in pre-dacite time, nevertheless, they remained largely covered until very recent time. The western end of the ore body is still buried beneath dacite and conglomerate, and small remnants of these formations overlie the eastern part in several places. The chalcocite ore body produced by enrichment during the pre-dacite exposure has been but little modified by recent supergene action.

Throughout the northern part of the district, where the outcrops are mainly of late Precambrian and Paleozoic sedimentary formations and included bodies of diabase, the beds have a general gentle to moderate southwesterly dip. The dominant structural feature, however, is a complex network of normal faults (Fig. 43). Although there is a great diversity in strike and dip of the faults, two principal trends are apparent - one striking northeast, the other northwest. The northwest-trending faults are by far the most prominent. Their general effect has been to successively step down the blocks to the east so that formations of similar age are repeated many times along a traverse from southwest to northeast.

In the southern part of the Globe Hills area east of Pinal Creek, the beds dip south to southeast, and northeast-trending faults are most prominent. Most of them are relatively old, and many, like the Old Dominion fault, are mineralized. The north or northwest faults are generally younger than the dacite and commonly displace the mineralized faults.

In the igneous zone through the central part of the district, faults are less numerous, Most of them trend north or northwest and involve dacite or Gila conglomerate,

In the Pinal Mountain area to the south, the outcrops are almost entirely of Pinal schist and Madera diorite, and very few faults have been recognized,

In general, the faults in the district having the greatest displacement involve dacite and Gila conglomerate, Among themare the marginal faults of the Castle Dome horst and the Miami fault, which drop the Gila conglomerate of the Globe Valley mass into contact with the older rocks to the west and limits the Miami-Inspiration ore body at the west end,

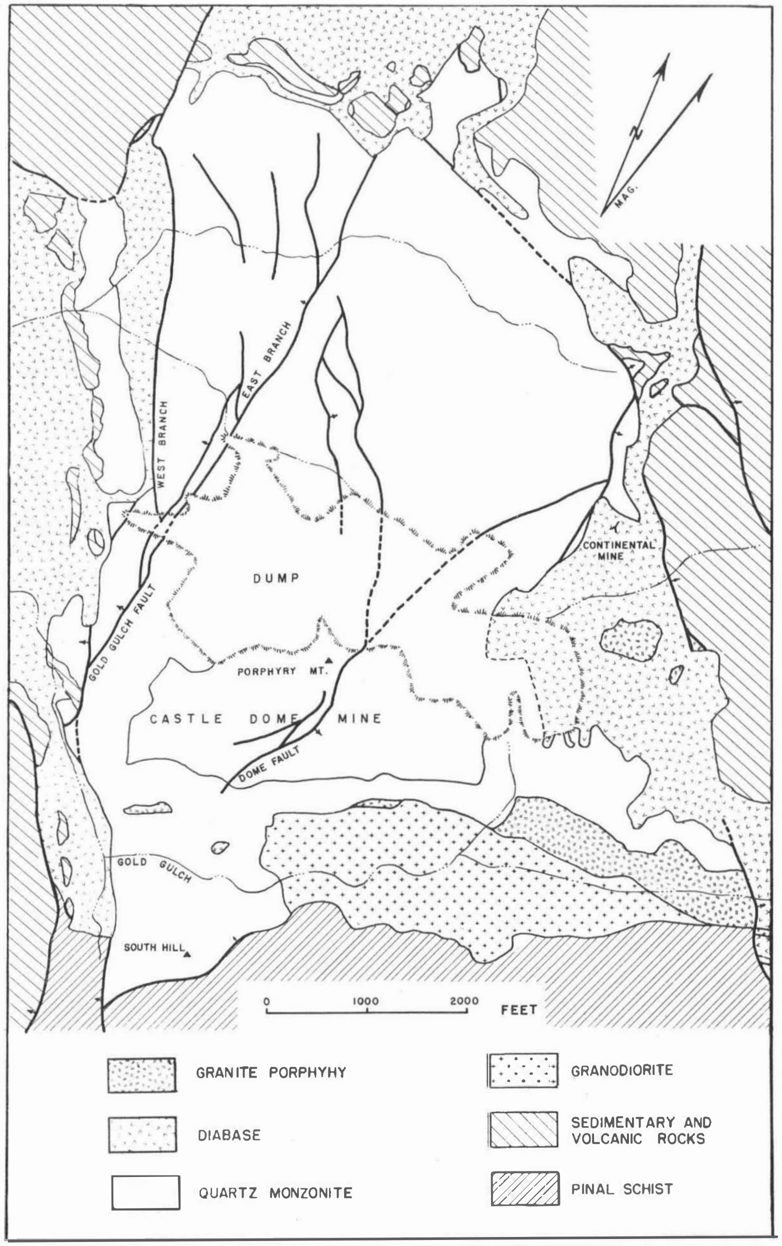


FIGURE 44. - GENERALIZED GEOLOGIC MAP OF THE CENTRAL PART OF THE CASTLE DOME AREA, ARIZONA.

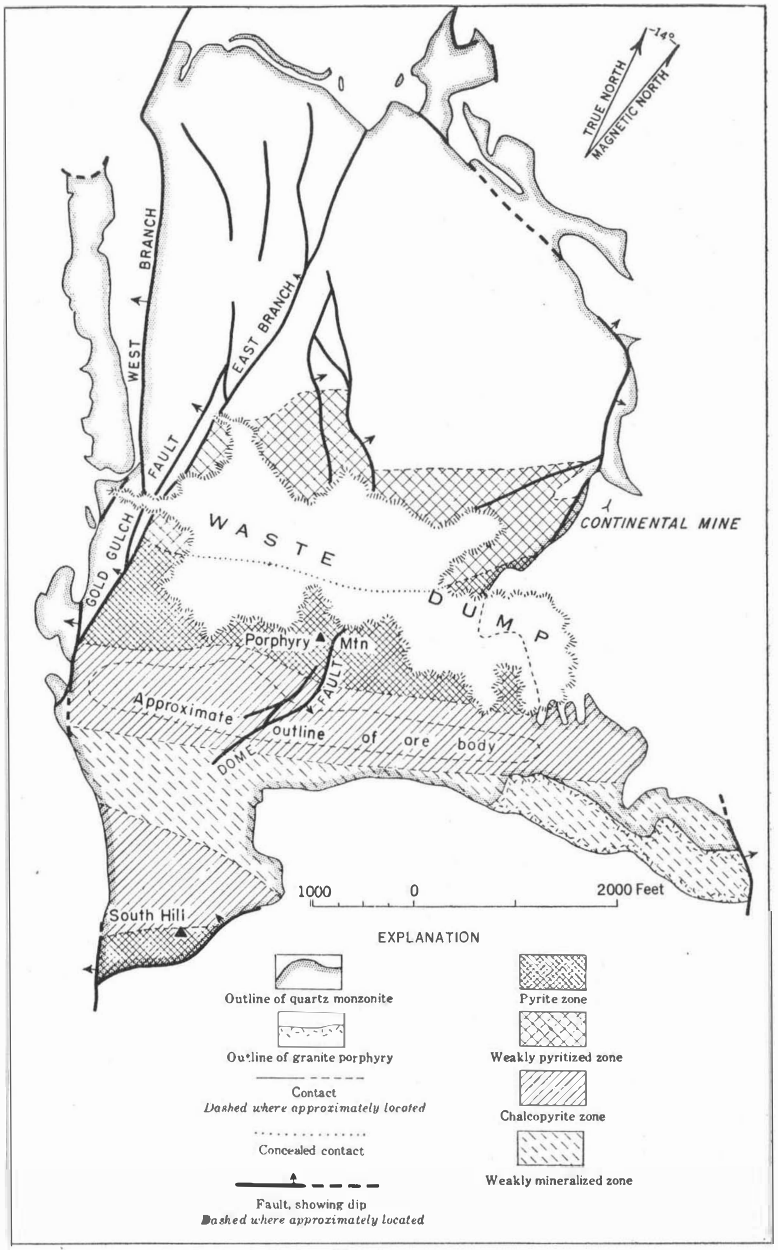


FIGURE 45. - OUTLINE OF QUARTZ MONZONITE, CASTLE DOME DEPOSIT, SHOWING GENERALIZED PATTERN OF MINERALIZATION ZONES. (From Peterson et al, U.S. Geol. Survey Bull. 971, 1951)

CASTLE DOME COPPER DEPOSIT*

N, P, Peterson
Mineral Deposits Branch, U,S, Geological Survey

The rocks most closely associated with the Castle Dome copper deposit are a quartz monzonite that has been correlated with Ransome's Lost Gulch monzonite, a granite porphyry that probably is related to the Schultze granite, and some thin diabase sills intruded into the quartz monzonite in the vicinity of the mine, Although the granite porphyry is mineralized, it was only slightly affected by supergene enrichment and contains no ore bodies, The outcrop of the quartz monzonite mass measures about 1 1/2 miles from south to north by about 1 mile from east to west (Fig, 44), Porphyry Mountain is in the south-central part of the outcrop,

The dominant structure is a horst trending about north-northwest, Within it is the quartz monzonite, The horst is bounded on the east and west sides by steeply dipping normal fault systems along which the quartz monzonite was brought into fault contact with pre-Cam brian Apache group and Paleozoic rocks that formed the roof of the quartz monzonite intrusion, Diabase was later intruded along these marginal faults and now generally separates the quartz monzonite from the relatively depressed blocks in which the sedimentary rocks are exposed, The latest movement on the marginal faults involved dacite and Gila conglomerate, A fault, occupied along part of its extent by diabase, crosses the horst near the northern edge of the quartz monzonite, and along it the block to the south was relatively elevated,

The hypogene copper mineralization is confined almost entirely to the granite porphyry and the southern half of the quartz monzonite body, Where it extends beyond the limits of these rocks it is usually very weak,

The principal hypogene sulfides are pyrite, chalcopyrite, and molybdenite, They occur mainly in and associated with a set of narrow, closely spaced, generally parallel quartz veins that strike about N, 75° E, and dip steeply southward, The only other hypogene sulfides, sphalerite and galena, represent a decidely later phase of mineralization and occur in a few veins along faults and major fractures that generally cut across the earlier copper-bearing veins, The gangue minerals are mainly the same as the constituents of the host rock, together with introduced quartz, clay, sericite, and a little barite,

The distribution and relative proportions of the hypogene sulfide minerals show a distinct zoning pattern (Fig, 45), In one zone that passes through the summit of Porphyry Mountain and extends across the quartz monzonite in a direction parallel to the strike of the veins, the mineralization is mainly pyrite and quartz with very little chalcopyrite, Northward, the mineralization in the high-pyrite zone gradually fades out with no apparent change in character, Adjacent to this zone on the south, and parallel to it, is a zone in which there is less pyrite and more chalcopyrite, The copper content in the form of hypogene minerals in this zone was about 0,3 percent, Molybdenite is most abundant along the southern margin of the high-pyrite zone and in the northern part of the chalcopyrite zone,

---

* Publication authorized by the Director, U,S, Geological Survey,

The hydrothermal alteration of the host rock consists of three phases: a weak propylitic phase, a clay phase, and a quartz-sericite phase. The areal distribution of the various phases and their relative intensities are clearly related to the zoning pattern of the hypogene metallization.

Very weak alteration of the propylitic type, in which biotite and plagioclase are partly replaced by sericite, epidote, clinozoisite, chlorite, calcite, and a little pyrite, occurs in an outer zone, where metallization also is weak. It extends somewhat beyond where metallization and alteration can be recognized in the field.

This zone of feeble alteration surrounds an area of stronger alteration, where most of the plagioclase and a little of the orthoclase and biotite are replaced by a mixture of montmorillonite-type clay, hydrous mica, and sericite. The clay alteration is most intense in the high-pyrite and chalcopyrite zones and diminishes gradually toward the north and south, where more fresh plagioclase together with alteration products of the propylitic phase is evident.

The quartz-sericite phase of alteration is related to numerous small quartz-pyrite veins along which the wall rock is replaced by quartz, sericite, and a little pyrite and adularia. Each quartz-pyrite vein is bordered by a glistening white zone in which the wall rock has been mostly replaced by quartz and sericite. This type of alteration is general throughout the mineralized area but is most intense in the high-pyrite zone, where pyrite veins are largest and most numerous. In some places, the altered zones along the veins coalesce, and the rock is completely replaced. The quartz-sericite zone might be considered as forming an innermost zone of alteration coinciding with the zone of high-pyrite metallization, although actually it is superimposed on the clay and propylitic phases wherever pyrite veins occur in them.

Several thin diabase sills from a foot to 10 feet thick crop out along the southern edge of the chalcopyrite zone and dip at low angles toward the north or northwest through the chalcopyrite zones. The copper content of the sills is usually at least double that of the zone in which they occur, and the quartz monzonite adjacent to one or both sides of the sills is substantially richer in copper than average grade. The stronger copper metallization associated with these sills was an important contributing factor in the formation of the ore body.

Supergene enrichment also was an important factor in the formation of the ore body, although the enrichment cycle is in an early stage of development, as is shown by the incomplete replacement of the hypogene sulfides by chalcocite and covellite and by the comparatively shallow depth to which enrichment has penetrated. In general supergene enrichment has affected only the upper part of the ore body. It is relatively deep in the southern part but becomes progressively shallower and weaker toward the north. The leached capping averages about 80 feet in thickness. The boundary between capping and the top of the ore conforms closely with the present topography. The bottom surface of the secondary sulfide zone is much more irregular and apparently was not influenced by the ground-water level, which is well below the ore body and about at the level of Gold Gulch south of the mine. In the upper part of the secondary sulfide zone, most of the chalcopyrite has been replaced by chalcocite and covellite; but even there, pyrite was not replaced except to a minor extent in a few places. The amount of replaced hypogene sulfide decreases progressively with depth. In many places, particularly near the footwall and in the western part of the ore body, unenriched hypogene ore is being mined. It is ore mainly because of the richer hypogene metallization associated with the diabase sills.

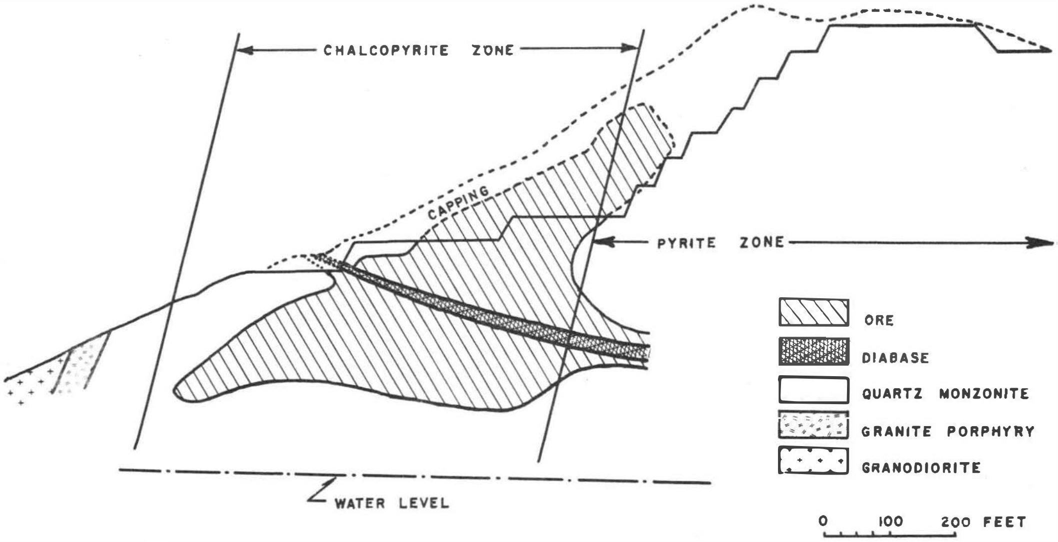


FIGURE 46.-TYPICAL CROSS SECTION OF THE CASTLE DOME ORE BODY

The ore body, which is largely mined out, ranged in length from about 2,000 feet on the upper levels to about 3,800 feet on the lowest mine level. In cross section, it was roughly triangular in shape with one vertex of the triangle at the apex of the body (Fig. 46). The upper or south side was the boundary between capping and the top of the secondary sulfide zone. It dipped southward roughly parallel to the south slope of Porphyry Mountain. The north or footwall side coincided approximately with the north limit of the chalcopyrite zone.

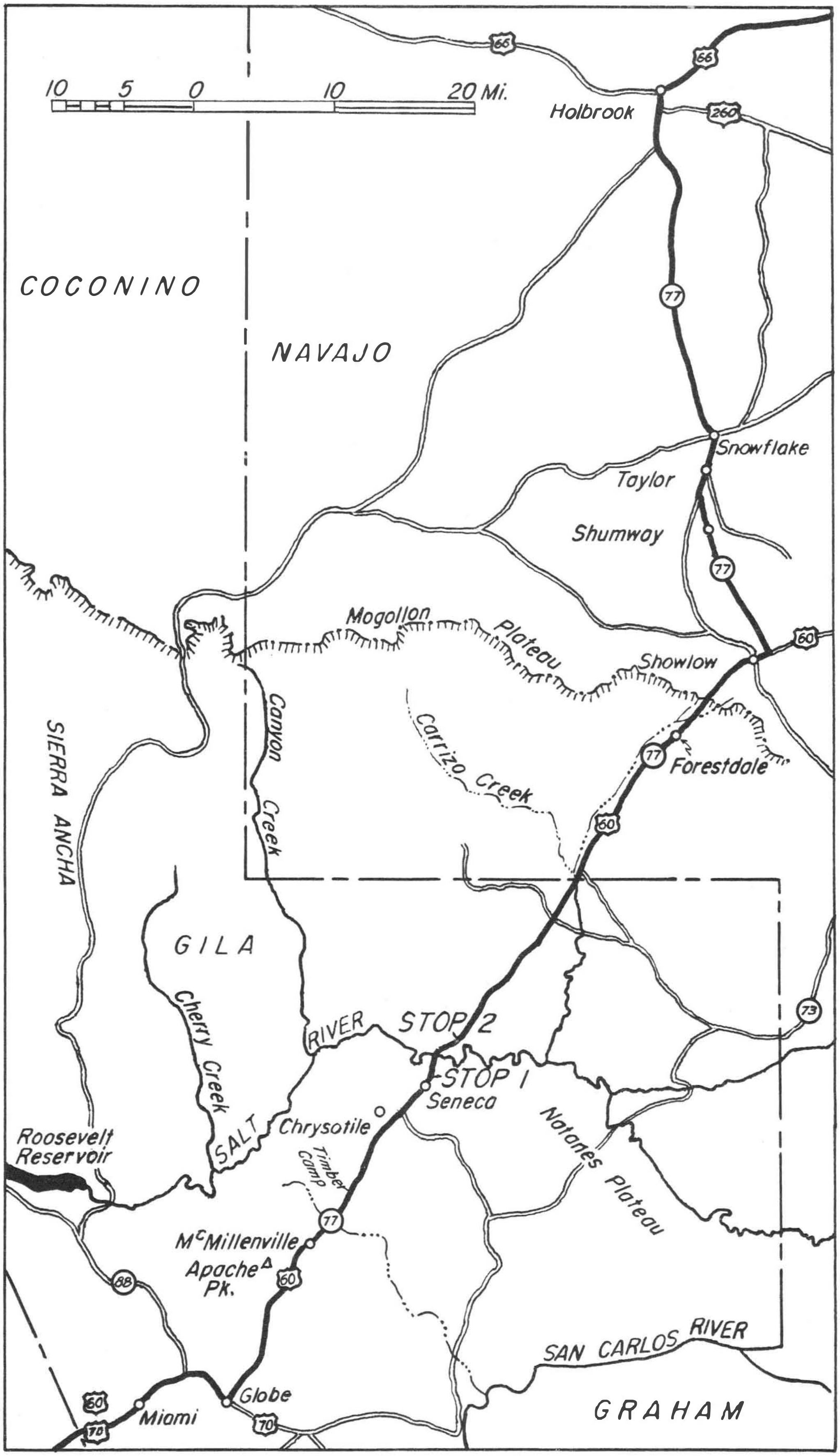


FIGURE 47.- ROAD LOG INDEX MAP, TRIP 5, SECOND DAY

TRIP 5, ROAD LOG (CONTINUED)

Second Day--Monday Afternoon, April 14, 1952

Leaders: A, F, Shride, E, D, McKee, and J, W, Harshbarger
Driving Distance: Log distance to Becker's Butte 46,6 miles, to Holbrook 138,6 miles,

General Statement

This portion of Trip 5 continues northward out of the Laramide intrusion and mineralized belt of the Ray, Superior, Globe-Miami region, The area of complex faulting is left and the structurally flat-lying, relatively undisturbed Plateau region is entered about 20 miles out of Globe, At the Salt River Canyon the great diabase intrusions, so extensive in east-central Arizona are well exposed; in crossing the canyon, one of the two main areas of asbestos mining will be traversed, Immediately north of the canyon sections of the Martin limestone (Devonian) and Redwall limestone (Mississippian) can be observed, Those who chose to continue north to Holbrook may observe sections of the Naco limestone (Pennsylvanian), the Supai formation (Pennsylvanian-Permian), and high Tertiary gravels and basalts,

0,0	0.0	Junction U,S, Highways 60 and 70, Asbestos mill at 1 o'clock, TURN LEFT on Highway 60,
0,2	0,2	Gila conglomerate in road cuts,
1,0	1,2	Diabase in road cut on right,
0,2	1,4	Troy quartzite in road cut,
0,2	1,6	Dacite in road cut and hill to west (left),
0,2	1,8	Troy quartzite in road cut,
0,2	2,0	At 10 o'clock, Apache Mountains in distance, Tertiary gravels are exposed in road cuts for next 5 miles,
0,9	2,9	Bridge,
0,5	3,4	Through next interval of 1,7 miles Highway 60 is on pediment cut on Tertiary gravels, At 10 o'clock, on hills, are outcrops of quartzite of the Apache group; dumps represent old copper prospects, At 12 o'clock are Apache Mountains, which consist mainly of Apache group sediments and diabase,
2,0	5,4	Bridge,
0,4	5,8	Cattleguard on boundary of Crook National Forest, Route continues over Tertiary gravels,
1,3	7,1	Dripping Spring quartzite in road cuts of next 0,3 miles, There are many high angle faults in this general area,

0.4	7.5	Diabase in roadcuts next 2.4 mile interval is representative of sills in the vicinity of Globe, Miami, Ray and Superior. Note reddish coarse-grained variety of the diabase at mileage 7.6
1.8	9.3	At 1 o'clock, Dripping Spring quartzite on top of hill.
0.6	9.9	Conglomerate on left (west), as roadcut is entered, is the Barnes conglomerate at base of Dripping Spring quartzite.
0.1	10.0	Diabase on left.
0.1	10.1	Dripping Spring quartzite.
0.4	10.5	Diabase in road cuts for next 2.2 mile interval.
0.1	10.6	Peaks at 2 o'clock capped by Dripping Spring quartzite.
0.2	10.8	Cattleguard at crest of Apache Mountains.
1.9	12.7	Precambrian granite. In this area, and as well as is known, between here and the Salt River the Apache group rests unconformably on this granite.
0.2	12.9	Diabase.
0.8	13.7	Precambrian granite.
0.2	13.9	Mostly diabase, next 3.6 mile interval.
0.7	14.6	At 12 o'clock, planar surface is remnant of pediment cut on diabase.
0.3	14.9	At 1 o'clock, small mesas are of Quaternary basalt, which caps and protects underlying Tertiary gravels from erosion.
1.0	15.9	At 12 o'clock, conical peak prominent in distance is Haystack Butte. This peak is underlain by a thick, possibly laccolithic, portion of a diabase sill.
0.3	16.2	Note contact in road cut between two diabase sills. Commonly the contact between two diabase sills is irregular in areas where the diabase intrudes granite. In areas where the diabase is dominantly concordant to sediments the contact between sills is commonly planar. Such contacts are probably the result of invasion of a younger sill along the contact between sediments and an older sill.
0.2	16.4	Ghost town, 200 yards to left, is old bonanza silver camp of McMillanville.
0.6	17.0	At 12 o'clock, high ridge on skyline is composed of Precambrian granite probably capped by Dripping Spring quartzite.
0.5	17.5	At 12 o'clock, conical peak is Jackson Butte. Road cuts of next 3.3 miles expose mostly Tertiary or Quaternary gravels; exceptions are noted below.

0,6	18,1	Light-colored outcrops on right and left sides of road are Tertiary tuffs, which are overlain by basalt, An attempt was made in 1946 to quarry this tuff for building block and light-weight aggregate,
0,3	18,4	Quaternary (?) basalt in road cuts,
0,2	18,6	Cattleguard, Valley fill in this area is cut by numerous faults,
0,6	19,2	Bridge across Seven Mile Wash, Road cut at south end of bridge is Quaternary (?) basalt,
0,5	19,7	At 11:30 o'clock, conical peak on skyline is Jackson Butte, Topographically the southern border of the Colorado Plateau coincides with the Mogollon Rim, approximately 40 miles to the north; most geologists consider the Mogollon Rim to be the approximate boundary between the Colorado Plateau and the Basin-Range types of structure, However, in this area Jackson Butte is approximately at the southern margin of the area of plateau structure,
1,1	20,8	Precambrian granite in most road cuts of next 2,7 miles, Note large (as much as 3 1/2 inches in diameter) feldspar phenocrysts,
1,2	22,0	In road cut, diabase intruded into granite,
0,5	23,3	Aplitic facies of granite,
0,2	23,5	Diabase,
0,2	23,7	Precambrian granite,
1,1	24,8	Diabase intruded into granite,
0,2	25,0	Diabase,
0,8	25,8	Precambrian granite,
1,0	26,8	Diabase,
0,7	27,5	Plateau surface traversed for next 2 miles is the top of the Timber Camp Mountains, Note the abrupt increase in number and change in types of vegetation that results from a rise of a few hundred feet and a change in exposure, The Timber Camp Mountains are underlain by flat-lying sediments of the Apache group, both intruded by sills of diabase, Ledges on hills to west probably are of Dripping Spring quartzite,
2,1	29,6	Troy quartzite,
0,1	29,7	Conglomerate lenses in the Troy quartzite,
0,6	30,3	Route along Highway 60, for next 3,7 miles, is over poorly exposed Troy quartzite and diabase intrusive sills,

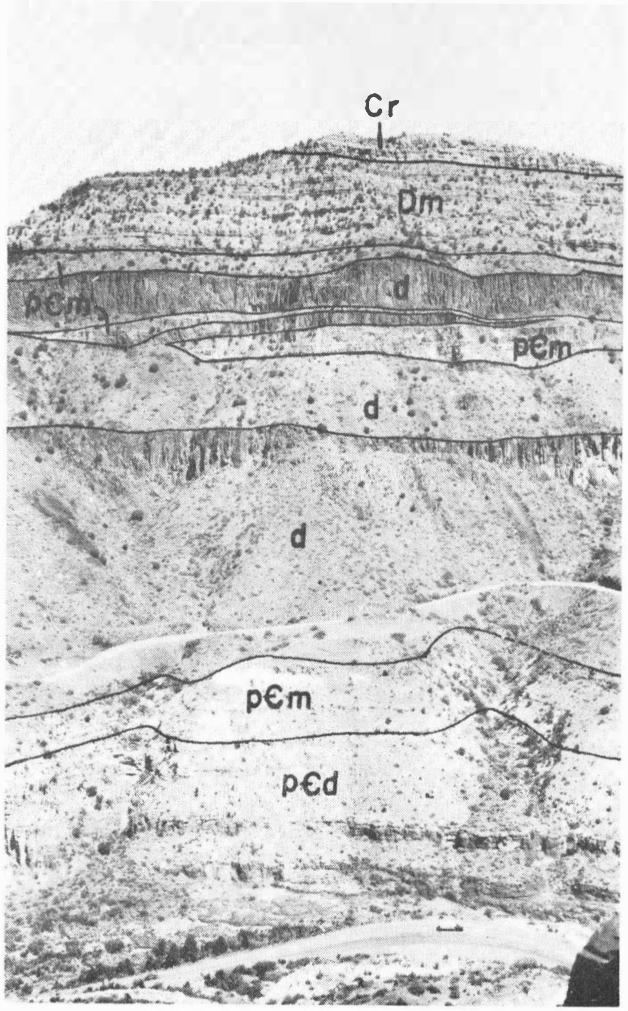


FIGURE 48. -NORTH WALL OF SALT RIVER CANYON. Highway 60 in foreground. Shows structure and dilation by diabase sills typical of region. (Cr) Redwall limestone, (Dm) Martin limestone, (pЄm) Mescal limestone, (pЄd) Dripping Spring quartzite, (d) diabase.

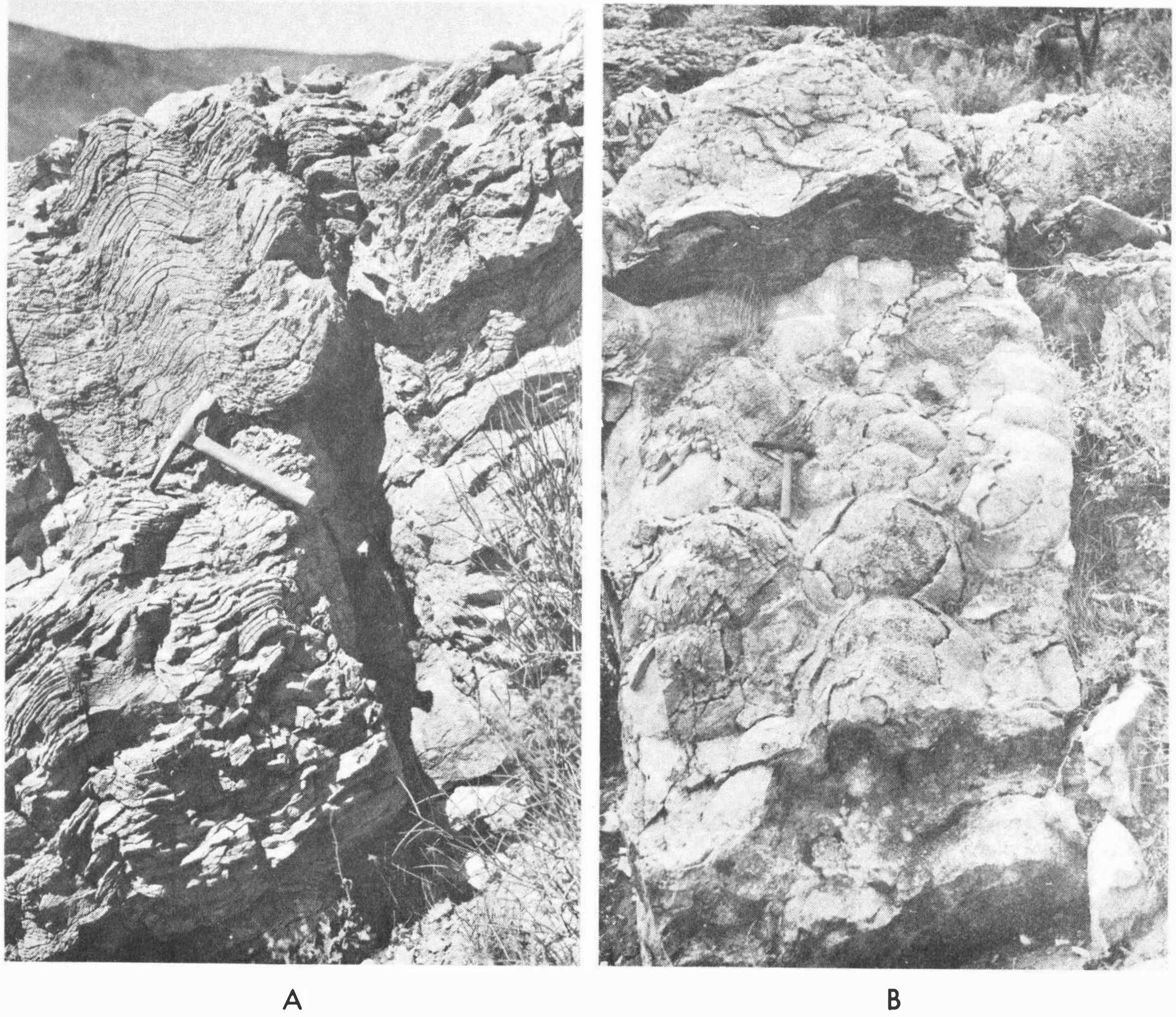


FIGURE 49. - ALGAL STRUCTURES IN UPPER MEMBER OF THE MESCAL LIMESTONE. A. - Cross-section view. B. - View of upper surface.

1,3	31,6	White Mountains at 12 o'clock on far skyline,
0,8	32,4	Gravel road to left terminates, 3 miles distant, at Chrysotile, site of largest underground asbestos mine in the United States. The chrysotile asbestos of east-central Arizona is unique in the Americas because of its low magnetite content,
0,2	32,6	Mountain range at 9 o'clock on skyline is the Sierra Ancha. The upper portion of the Sierra Ancha is composed of flat-lying Apache group sediments and Troy quartzite. The lower portion of the Sierra Ancha is dominated by thick sills of diabase which intrude the Apache group,
0.2	32,8	Mountains in far distance at 8 o'clock are Four Peaks of the Mazatzal Range. The Mazatzal Mountains are composed mainly of older Precambrian sediments, rhyolites, and granitic to basic intrusives,
1,0	33,8	Quartzite typical of the lower Troy of this area. Note pebbly lenses and cross-bedding. Here the Troy quartzite is coarse-grained and non-arkosic. This is in contrast to the arkosic, fine-grained Dripping Spring quartzite, which is cross-bedded but on a smaller scale, and typically appears banded from a distance,
1,0	34.8	Cattleguard, entering San Carlos Indian Reservation. Diabase, with the minor noted exceptions noted below, through the next 12.9 mile interval. Through this interval 2 and perhaps 3 sills are traversed. The contacts between the sills are not readily seen at road level. The broad basin through the interval 25.9-28.0 is typical of the topographic expression of sills of plateau areas.
0,4	35,2	Mesa on skyline ahead is capped by Martin limestone (Middle Devonian). Diabase sill immediately underlying the Martin limestone includes "slivers" of upper formations of the Apache group. Unconformity at base of Martin limestone bevels both sediments and this sill. Therefore sills in this area are pre-Middle Devonian,
1,0	36,2	Seneca,
0,5	36,7	Road junction on left leads to main asbestos-bearing area of Salt River region,
0,3	37.0	Siltstones and shales comprise top 60-80 feet of Mescal limestone in this area, providing the upper portion of the Mescal is not missing due to pre-Troy or pre-Martin erosion,
0,5	37.5	Siltstones and shales of upper portion of Mescal limestone.

0,8	38,3	Five-foot wide diabase dike on right hand side of road (inconspicuous from car), This dike cuts vertically through this sill and through an upper sill into which the sill being traversed is intruded, Thus there are a minimum of 3 separate diabase intrusions exposed along the slope traversed by this portion of the route, The dike is truncated by the unconformity at the base of the Devonian limestone,
0,3	38,6	At 10 o'clock, 2 miles distant, prominent peak on skyline is "72" Mesa, This peak is capped by Troy quartzite and underlain by a discordant diabase sill, one of the few examples in this area of a thick sill intrusive into Troy quartzite, This sill probably was intruded along a thrust fault, There are numerous examples of minor diabase intrusions into Troy quartzite, Therefore, the diabase of the area is post Middle Cambrian,
0,4	39,0	Those returning to Globe may stop at parking area on left and walk 200 feet along west side of hill ahead, and 30 feet higher than road, to a small asbestos deposit, All dumps seen in the canyon are from chrysotile asbestos mining operation,
0,1	39,1	STOP 1, TURN LEFT into parkway and WALK 200 feet along trail toward canyon, Enroute, note algal limestone, Discussion of stratigraphy, diabase intrusions and structure of area by A, F, Shride, After stop, caravan will continue down canyon,
0,4	39,5	Thin "sliver" of Mescal limestone in diabase, Upper massive beds represent algal (or upper) member; flat-bedded limestone represents lower member,
0,3	39,8	Spheroidal weathering of diabase and weathering of diabase to "pebbly" soil especially well exhibited in this and next road cuts,
0,1	39,9	Parking area for scenic view up the Salt River Canyon, CARAVAN WILL NOT STOP HERE,
1,6	41,5	Lower member of Mescal limestone, Note thin (8-12 inch) persistent diabase sills, The massive bed at road level approximately 1/2 way through the first road cut is one of the most favorable beds in the district for the localization of asbestos deposits, It is not appreciably mineralized in this exposure,
0,4	41,9	Dripping Spring quartzite,
0,3	42,2	Bridge across the Salt River,
0,1	42,3	At 9 o'clock note typical banding in cliff of Dripping Spring quartzite, BE PREPARED TO LOOK IN THIS DIRECTION-FIELD OF VIEW IS LIMITED, Road junction on left with road down canyon, The first 7 miles of this road parallels the canyon and offers an excellent opportunity to view the sills and various varieties of the diabase,

0,1	42,4	Diabase sill; lower contact is approximately 20 feet stratigraphically above base of Mescal limestone,
0,3	42,7	Lower member of Mescal limestone,
0,1	42,8	Diabase,
0,7	43,5	Massive cliff on skyline at 12 o'clock is of Redwall limestone,
2,4	45,9	Unconformity between Martin limestone (Devonian) and diabase, Note weathering of diabase and lack of chill border,
0,7	46,6	STOP 2, Becker's Butte lookout parking area, Peak on skyline to southeast is Becker's Butte, which is capped by Redwall limestone, Base of uppermost massive cliffs is approximate contact between Redwall and Martin limestones, This contact also can be seen across tributary canyon to east from this stop,

END OF FIELD TRIP

This is the last formal stop of this field trip, For those participants leaving Arizona via the northern route the road log is continued to Holbrook, Informal stops, enroute to Holbrook, can be arranged with J, W, Harshbarger at this stop,

FROM STOP 2

To	Holbrook 92 miles		Flagstaff,	183 miles
	Gallup via Holbrook,	189 miles	Phoenix,	137 miles
	Gallup via St, Johns,	185 miles	Tucson,	171 miles
	Albuquerque via Highway 66,	324 miles	El Paso via Globe,	373 miles
	Albuquerque via Highway 60,	325 miles	El Paso via Socorro,	447 miles

---

0,4	47,0	Contact between the Martin limestone (Upper Devonian) and Redwall limestone (Mississippian),
0,4	47,4	Contact between the Redwall limestone and Naco formation (Pennsylvanian),
1,1	48,5	Limestone and mudstone cyclic deposits in Naco formation, observe similar cycles in road cuts ahead,
4,8	53,3	Outcrops of Naco formation in road cut and on skyline at 1 o'clock,
0,2	53,5	Tertiary gravels crop out in road cuts and also form the low hills in the foreground,
4,2	57,7	Excellent outcrop of Tertiary gravels displaying well-rounded pebbles, cobbles, and boulders in a matrix of sand and silt,

0,3	58,0	Exposure of red beds in road cut is the first of a series of outcrops of the Supai formation (Permo-Pennsylvanian),
1,2	59,2	The escarpment in the distance is the famed Mogollon Rim, which consists mainly of Permian strata,
1,6	60,8	Road junction to Cibeque on left,
0,4	61,2	At 10 o'clock, conspicuous promontory formed mostly of Supai strata,
1,0	62,2	Parallel-bedded siltstone and claystone of Supai formation in roadcuts,
2,5	64,7	Bridge across Carrizo Creek, Fossiliferous limestone in Naco formation below level of bridge and red beds of Supai formation above bridge, Tertiary basalt on skyline,
2,7	67,4	Road junction to White River and Fort Apache on right,
1,0	68,4	Red beds of siltstone and mudstone in Supai formation,
0,7	69,1	At 2 o'clock, Apache limestone member of Supai formation on skyline, Basalt lies on red Supai formation in cliffs on both sides of the road,
1,2	70,3	Corduroy Creek Canyon, Walls of canyon are formed from red sandstone and mudstone of Supai formation, overlain by massive yellow to gray thin-bedded limestone (Apache member), locally scoured and channels filled with Tertiary gravels, and covered locally with basalt, Hills in distance consist mostly of Supai formation, Outcrop on right side of road is made up of travertine beds overlain by basalt and underlain by Tertiary gravels,
2,5	72,8	Bridge across Cedar Canyon, walls formed of Tertiary basalt, hills to left formed of Supai formation,
4,8	77,6	Bridge across Corduroy Creek, walls formed of Tertiary basalt.
1,3	78,9	Small lumber mill on right side of road,
2,8	81,7	Forestdale,
0,2	81,9	Yellowish outcrops in road cuts for next 2 miles are sandy limestone of the Kaibab formation (Permian), Tertiary gravels form thin mantle,
4,4	86,3	Sitgreaves National Forest,
0,6	86,9	Cretaceous claystone in road cut,
3,4	90,3	Entering Showlow,
0,7	91,0	Showlow, named from the turn of a card,

0.2	91.2	Road junction to McNary on right, continue straight ahead.
0.5	91.7	Road junction U. S. Highway 77, U. S. Highway 60. Follow left fork toward Holbrook; right fork leads to Springerville.
0.7	92.4	Route traverses a wide basalt-capped mesa with a cover of pinon and juniper.
10.0	102.4	From 12 to 3 o'clock sides of valley, comprising reddish shale and white sandstone, are believed to be Upper Triassic sediments; Quaternary basalt forms the capping rock.
1.0	103.4	Sandstone in road cut, basal unit of the Upper Triassic sequence.
0.5	103.9	Bridge. Basalt at 10 o'clock.
1.8	105.7	Low mesa in foreground contains a coarse-grained sandstone believed to be Shinarump conglomerate or basal member of Chinle formation (Upper Triassic).
0.2	105.9	Chinle formation in road cut.
1.4	107.3	Taylor
1.0	108.3	Red beds in road cuts are in the Moenkopi formation (Triassic).
1.7	110.0	Cross Apache railroad.
0.6	110.6	Snowflake.
0.8	111.4	Bridge across Silver Creek. At 12:30 o'clock, walls in narrow canyon are formed by the Coconino sandstone (Permian).
0.8	112.2	Contact between Coconino sandstone and overlying Moenkopi formation. Kaibab limestone is absent in this area.
0.4	112.6	Yellowish-red thin-bedded siltstone in road cuts is the basal unit of the Moenkopi formation.
3.7	116.3	Bridge. Coconino sandstone crops out in wash.
6.8	123.1	Lower massive sandstone of the Moenkopi formation forms the mesas in foreground.
0.4	123.5	At 1:30 o'clock, dark hill in distance is Woodruff Butte. The butte is formed from a basaltic cap on the Chinle formation, which is underlain by Moenkopi formation and Coconino sandstone. Indian ruins are present on butte.

5,6	129,1	Coconino sandstone in wash,
1,8	130,9	Road junction to Woodruff on right,
2,1	133,0	At 12 to 1 o'clock in the far distance the bright-colored rocks of the Chinle formation form a part of the Painted Desert, The black knobs are volcanic necks in the Hopi Buttes country,
0,5	133,5	At 1:30 o'clock, Shinarump conglomerate forms the cap of small mesa, which is underlain by Moenkopi formation,
1,1	134,6	Coconino sandstone on both sides of road,
1,0	135,6	Moenkopi Butte at 2 o'clock, capped with Shinarump conglomerate,
0,9	136,5	Lower Moenkopi formation (Wupatki member) in road cut,
1,0	137,5	Coconino sandstone near road,
0,4	137,9	Road junction to Petrified Forest and St, Johns on right,
0,3	138,2	Bridge across Little Colorado River,
0,4	138,6	Main square, Holbrook, Caravan disbands here, Follow U,S, Highway 66 west to Flagstaff and California, Follow U,S, Highway 66 east to Gallup and Albuquerque,

PENNSYLVANIAN-PERMIAN FACIES OF THE SUPAI FORMATION IN CENTRAL ARIZONA

R. L. Jackson
The California Company

Introduction

The red beds of the Supai formation have considerable areal extent in northern Arizona. Many of the colorful canyons of central and northern Arizona are carved into the Supai.

In the course of this study, which was begun in 1950, detailed stratigraphic sections were measured along the Mogollon Plateau in central Arizona. Sections were measured in Munds and Beaver Creek Canyons along a southwesterly line, and along the Mogollon Rim from Pine, Ariz., eastward to Promontory Butte. Cross bedded units in the Supai were studied and mechanical analyses of representative rock samples were made. Careful consideration was given to the faunal and facies development from west to east. The stratigraphic sections of the Supai formation measured by E. D. McKee (1950, personal communication) to the west of the area studied, and the section measured by S. S. Winters (1951, p. 10-16) at Fort Apache, Ariz., to the east, were walked over and reviewed by the writer. Previous investigations of the Supai formation were summarized by the writer in an earlier publication (Jackson, 1951, p. 84-91).

Stratigraphic relationships

Fig. 50 represents a generalized section of the Supai formation from Spring Mountains, Nev., to Fort Apache, Ariz. The facies changes in the members of the Supai are readily apparent, although some of the relationships laterally across this area are open to question.

Supai strata in the area studied are essentially flat-lying. Gentle northerly dips up to a maximum of five degrees have been measured. The formation consists of alternating beds of very fine-grained sandstone, siltstone, mudstone, limestone, and claystone. The lithologic units of the Supai reflect the environment of a stable to mildly unstable depositional shelf, and the Supai formation is considered to be deltaic (Hughes, 1949) in origin. As a result of the study of cross-lamination surfaces in the Supai formation of northern Arizona, McKee (1940, p. 822) indicates that the probable direction in which the sediment was transported was toward the south. Cross bedding studies by the writer indicate a southeasterly direction of deposition.

A series of eight measured stratigraphic sections was made in the area studied. Attention was given to the relations of rock units to faunal zones, of marine to non-marine facies, of cyclic sedimentation, and of sedimentation in relation to transgression and regression. A section at Fossil Creek was measured along a traverse different from that followed by Huddle and Dobrovolny (1945) as the new location appeared to contain a better exposed sequence of Pennsylvanian and Permian rocks. Correlation and comparison of the Fossil Creek section with the Oak Creek Canyon section of E. D. McKee to the west, and the composite section of Winters at Fort Apache to the east is shown in Figure 51.

McKee divides the Supai formation in Oak Creek Canyon into three distinct members. Member A consists of the cliff-forming upper sandstones; member B is composed of ledge-slope forming siltstones and sandstones; member C is a massive cliff and ledge formed by the lower sandstones.

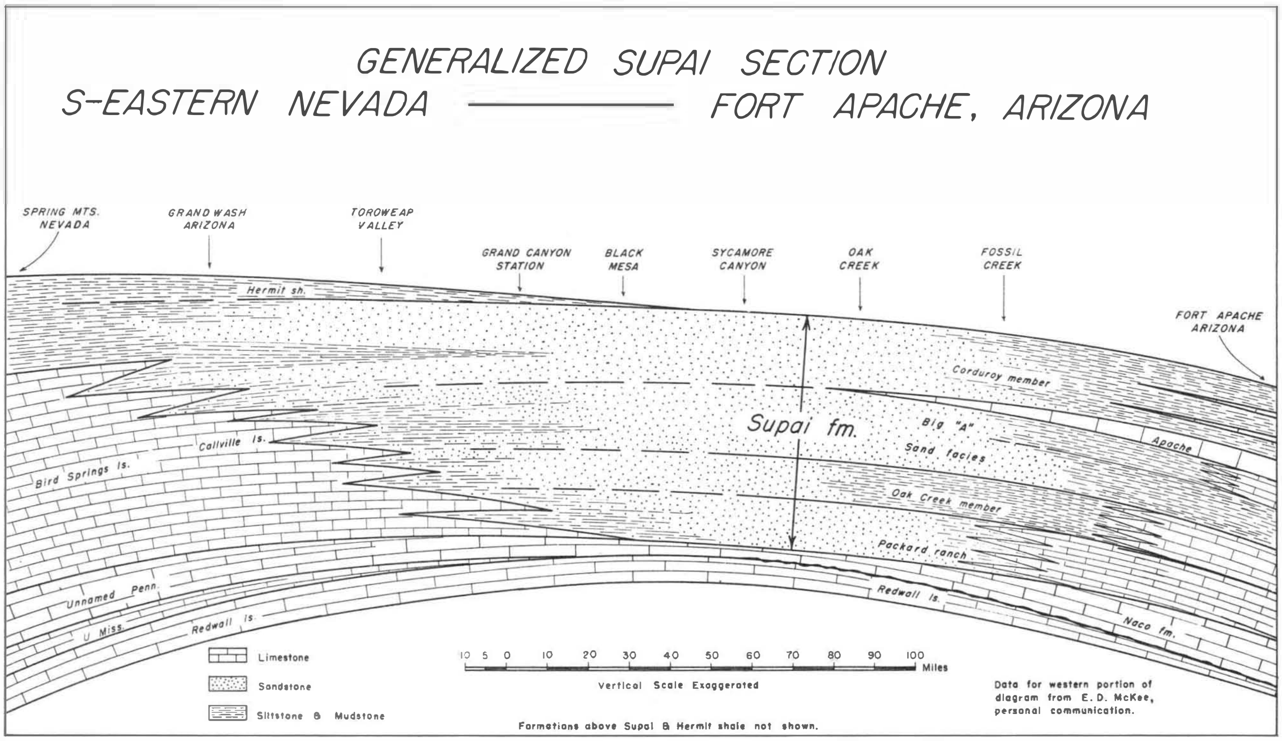


FIGURE 50. - GENERALIZED SUPAI SECTION, SOUTHEASTERN NEVADA TO FORT APACHE, ARIZONA.

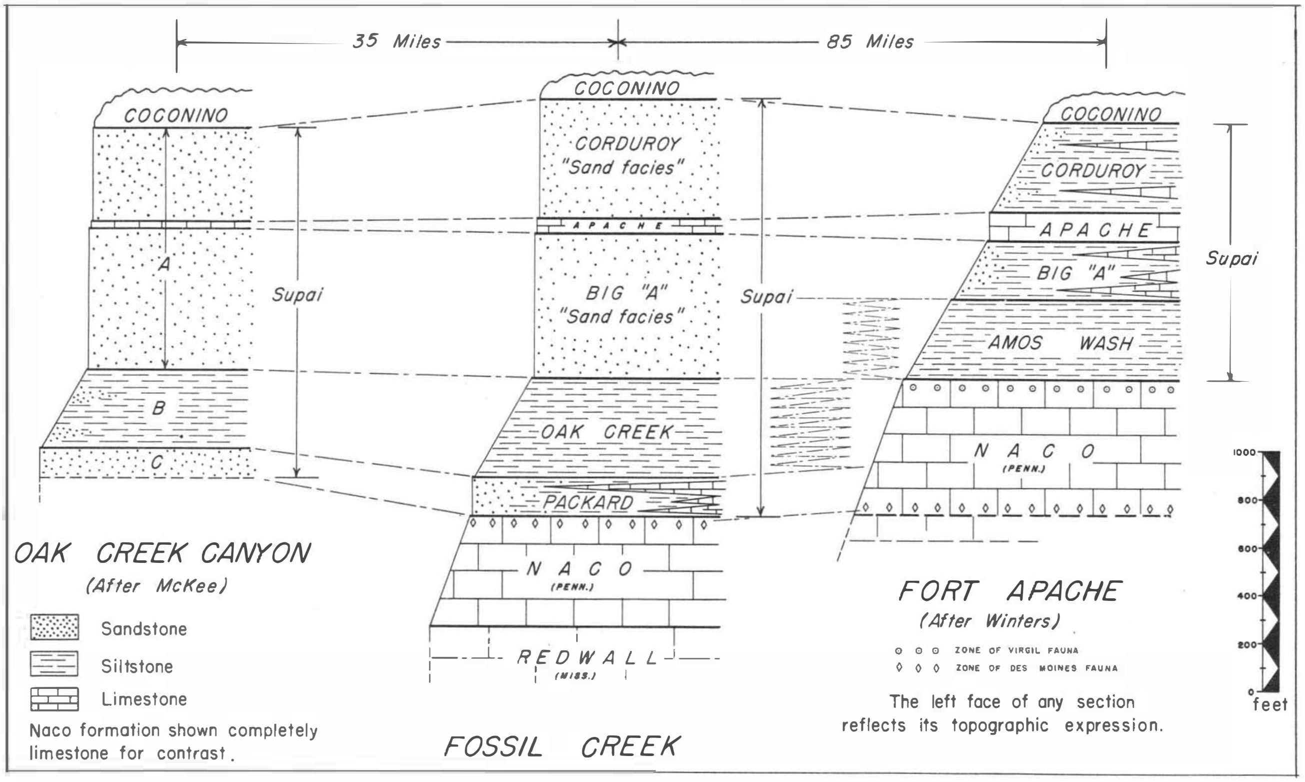


FIGURE 51. - CORRELATION OF COLUMNAR SECTIONS OF THE SUPAI FORMATION.

Winters recognizes four members in the Supai formation in the Fort Apache area farther east. These are the Corduroy, Fort Apache limestone of Stoyanow (1936, p. 533), Big "A", and Amos Wash members (Fig. 51), named for the localities where described. The Corduroy and Fort Apache limestone members and the three members of McKee are recognized in the area studied by the writer.

At the Fossil Creek locality, Winters' Corduroy member is represented by a sandstone facies. In the same area, the Fort Apache limestone member is much thinner than it is farther east, but remains a limestone facies. The thinning of the Fort Apache limestone continues northwestward through the Oak Creek Canyon locality but at Sycamore Canyon, still farther to the west, the member is missing (Fig. 50). The Big "A" and Amos Wash members of Winters are represented by an undifferentiated sand facies at Fossil Creek, probably the result of lateral gradation such as that in the Corduroy member above. The weak ledge-slope topographic expression of the underlying member at Fossil Creek has optimum development at Oak Creek; the term Oak Creek member is retained for the Fossil Creek section. The Packard ranch member has optimum expression and development at Sycamore Canyon, and is recognizable both at Oak Creek Canyon and at Fossil Creek, although not at Fort Apache. Winters found a clear separation of the Amos Wash member and the Naco limestone in the Fort Apache area.

Pennsylvanian-Permian relationships

Huddle and Dobrovolny (1945) place the contact of the Pennsylvanian Naco limestone and the overlying Supai formation above a sequence of gray limestone and shale beds, and below a sequence of beds consisting of sandstone, shale, and some limestone. In Winters' opinion, this is an arbitrary division which unnaturally divides a continuous sequence of similar lithology and faunal assemblage. Winters' raises the Pennsylvanian-Permian boundary 410 feet above that proposed by Huddle and Dobrovolny. The uppermost bed of Winters' Naco is a gray, thin-bedded limestone, ripple-marked and fossiliferous. This limestone is overlain by gray and reddish brown claystone beds which grade upward into non-calcareous siltstone and sandstone beds.

Through the identification of fusulinids, Winters establishes a Virgil (latest Pennsylvanian) age for the upper Naco. This is especially interesting upon consideration of the fauna found farther west. The highest fossiliferous stratigraphic unit of the Naco limestone at Fossil Creek yields fossils of Des Moines age (Fig. 51). Both this zone and that represented by the Fort Apache limestone above serve as approximate time planes from Fossil Creek to Fort Apache. The lithologic assemblages between these zones clearly indicate conditions of off-lap or regression during late Pennsylvanian-early Permian time.

Whether transgressive or regressive deposits form in any area normally depends upon relative rates of sinking and sedimentation. Thus, the regressive deposits of Pennsylvanian-Permian age in the Fossil Creek-Fort Apache area indicate a dominance of sedimentation over basin sinking.

The Packard ranch member of the Supai formation, arenaceous at the type locality, becomes more calcareous eastward. Huddle and Dobrovolny acknowledge that the Naco and Supai formations may interfinger insome parts of Arizona. A means of establishing correlation between contemporary facies, regardless of their lithologic differences is the intertonguing of distinct facies as seen in the outcrop (Dunbar, 1941, p, 313-332). It is suggested here that the Packard ranch member is an example of this intertonguing. The Packard ranch member is not represented at Fort Apache (Fig, 51); the Amos Wash member of Winters contain no limestones. From the foregoing it appears that the Packard ranch member of Oak Creek and Fossil Creek intertongues with the Naco of Winters. It is evident, therefore, that the Packard ranch member of the Supai formation is of Pennsylvanian age. It is further suggested that the siltstone interval of the Oak Creek member at Fossil Creek is represented by the limestone facies of Winters' upper Naco at Fort Apache. The off-lap facies change of sandstone to siltstone to limestone within the limiting Fort Apache and Des Moines time planes is a factor favoring this suggestion.

Summary and Conclusions

The Supai formation of central Arizona is an advancing continental deltaic deposit of Pennsylvanian-Permian age which has caused a regression of the Pennsylvanian sea due to sedimentation exceeding subsidence in the area.

Subdivision of the Supai formation in central Arizona into members of considerable areal extent can be made. The Packard ranch and Oak Creek members as outlined in this paper are equivalent to the upper part of the Naco formation as described by Winters, and are considered Pennsylvanian in age.

Author's note

The highways (US60--Arizona 77) on which the field trip traverses, passes east of the principal area of study for this paper. The facies expression of the Supai formation more nearly approximates the stratigraphic section measured by Mr. S. S. Winters, which may be examined in Figure 51.

Excellent fossil collecting may be attained by turning off the highway (US 60--Ariz. 77) right, toward Fort Apache, Arizona, to connect with state route 73; thence south to the crossing of White River, a total distance of about 30 miles. The collecting locality is just 100 yards short of the bridge corssing White River. The writer visited this locality and collected a prolific Des Moines (Pennsylvanian faunae from the Naco formation which outcrops here.

REFERENCES CITED

Anderson, C. A. (1951) Older Precambrian structure in Arizona, Geol. Soc. Am., Bull., vol. 62, p. 1331-1346.

Babcock, H. M. and Cushing, E. M. (1942) Recharge to ground water from floods in a typical desert wash, Pinal County, Arizona. Am. Geophys. Union, Tr., vol. 77, p. 239-240.

Baker, A. A., Dane, C. H., and Reeside, J. B., Jr. (1936) Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado, U.S. Geol. Survey, Prof. Paper 183, 66 pages.

Blake, W. P. (1908a) Notes upon the structure of the Santa Catalina gneiss, Science, new ser., vol. 28, p. 379-380.

_____ (1908b) Geological sketch of the region of Tucson, Arizona, in MacDougal, D.T., Botanical features of North American deserts, Carnegie Inst. Washington, Pub. 99, p. 45-68.

Brown, W. H. (1939) Tucson Mountains, An Arizona Basin Range Type, Geol. Soc. Am., Bull., vo. 50., p. 697-760.

Bryan, Kirk (1922) Erosion and sedimentation in the Papago country, Arizona, U.S. Geol. Survey, Bull. 730-B, p. 19-90.

_____ (1925) The Papago country, Arizona, U.S. Geol. Survey Water-Supply Paper 499, 436 pages.

_____ (1926) San Pedro Valley, Arizona, and the geographic cycle (Abstract), Geol. Soc. Am., Bull., vol. 37, p. 169-170.

Campbell, M. R. (1904) The Deer Creek coal field, Arizona, U.S. Geol. Survey, Bull. 225, p. 240-258.

Cooper, J. R. (1950) Johnson Camp area, Cochise County, Arizona, Univ. Ariz., Ariz. Bur. Mines Bull. 156, p. 30-39.

Creasey, S. C. (1950) Geology of the St. Anthony (Mammoth) area, Pinal County, Arizona, Univ. Ariz., Ariz. Bur. Mines Bull. 156, p. 63-84.

Darton, N. H. (1925) A resume of Arizona geology, Univ. Ariz., Ariz. Bur. Mines Bull. 119, 298 pages.

_____ (1932) Algonkian strata of Arizona and western Texas (Abstract), Wash. Acad. Sci. Jour., vol. 22, p. 319.

Davis, W. M. (1931) The Santa Catalina Mountains, Arizona, Am. Jour. Sci., 5th ser., vol. 22, p. 289-317.

Dumble, E. T. (1902) Notes on the geology of southeastern Arizona, Am. Inst. Min. Eng., Tr., vol. 31, p. 696-715.

Dunbar, C. O. (1941) Permian faunas; a study in facies, Geol. Soc. Am., Bull., vol. 52, 313-331.

Ettlinger, I. A. (1928) Ore deposits support hypothesis of a Central Arizona batholith, Am. Inst. Min. Eng., Tech. Pub. 63, 23 pages.

Feth, J. H. (1948) Permian stratigraphy and structure, northern Canelo Hills, Arizona, Am. Assoc. Petro. Geol., Bull., vol. 32, p. 82-108.

Gazin, C. L. (1942) The late Cenozoic vertebrate faunas from the San Pedro Valley, Arizona, U.S. Nat. Mus. Proc., vol. 92, no. 3155, p. 475-518.

Gidley, J. W. (1922) Preliminary report on fossil vertebrates of the San Pedro Valley, Arizona, with descriptions of new species of Rodentia and Lagomorpha, U.S. Geol. Survey, Prof. Paper 131, p. 119-131.

Gidley, J. W. (1926) Fossil Proboscidea and Edentata of the San Pedro Valley, Arizona, U.S. Geol. Survey, Prof. Paper 140, p. 83-95.

Gilbert, G. K. (1875) Report on the geology of portions of New Mexico and Arizona, U.S. Geog. and Geol. Surveys W. 100th Mer., Rept., vol. 3, Geology, p. 503-567.

Gilluly, James (1946) The Ajo mining district, Arizona, U.S. Geol. Survey, Prof. Paper 209, 112 pages.

______ (1949) Distribution of mountain building in geologic time, Geol. Soc. Am., Bull., vol. 60., p. 561-590.

Gregory, H. E. (1917) Geology of the Navajo country - a reconnaissance of parts of Arizona, New Mexico, and Utah, U.S. Geol. Survey, Prof. Paper 93, 161 pages.

Guild, F. N. (1905 Petrography of the Tucson Mountains, Pima County, Arizona, Am. Journ. Sci., 4th ser., vol. 20, p. 313-318.

Harrell, M. A., and Eckel, E. B. (1939) Ground-water resources of the Holbrook region, Arizona, U.S. Geol. Survey, Water-Supply Paper 836-B, p. 19-105.

Hernon, R. M. (1932) Pegmatitic rocks of the Catalina-Rincon Mountains, Arizona, M. Sc. thesis, Univ. Ariz. (unpublished).

Howell, B. F., et al. (1944) Correlation of the Cambrian formations of North America, Geol. Soc. Am., Bull., vol. 55, p. 993-1003.

Hoyt, C. L. (1938) Ray district, Univ. Ariz., Ariz. Bur. Mines Bull. 145, p. 80-86.

Huddle, J. W. and Dobrovolny, Ernest (1945) Late Paleozoic stratigraphy of central and northeastern Arizona, U.S. Geol. Survey, Oil and Gas Invest., Prelim. Chart 10.

Hughes, P. W. (1949) History of the Supai formation in Black Mesa, Yavapai County, Arizona, Plateau, vol. 22, p. 32-36.

Jackson, R. L. (1951) Stratigraphic relationships of the Supai formation of central Arizona, Plateau, vol. 24, p. 84-91.

Jenkins, O. P., and Wilson, E. D. (1920) A geological reconnaissance of the Tucson and Amole Mountains, Univ. Ariz., Ariz. Bur. Mines, Bull. 106, p. 5-18.

Kiersch, G. A. (1949) Structural control and mineralization at the Seventy Nine mine, Gila County, Arizona, Econ. Geol., vol. 44, p. 24-39.

______ (1951) Seventy Nine mine area, In Arizona zinc and lead deposits, Univ. Ariz., Ariz. Bur. Mines Bull. 158, p. 67-81.

Knechtel, M. M. (1936) Geologic relations of the Gila conglomerate in southeastern Arizona, Am. Jour. Sci., 5th series, vol. 31, p. 81-92.

______ (1938) Geology and ground-water resources of the valley of Gila River and San Simon Creek, Graham County, Ariz., U.S. Geol. Survey, Water-Supply Paper 796-F, p. iv, 181-222.

Kuhn, T. H. (1951) Bunker Hill district, Univ. Ariz., Ariz. Bur. Mines Bull. 158, p. 56-65.

McKee, E. D. (1938) The environment and history of the Toroweap and Kaibab formations of northern Arizona and southern Utah, Carnegie Inst. Washington, Pub. 492, 268 pages.

______ (1940) Three types of cross-lamination in Paleozoic rocks of northern Arizona, Am. Jour. Sci., vol. 238, p. 811-824.

______ (1945) Cambrian history of the Grand Canyon region, Carnegie Inst. Washington, Pub. 563, 232 pages.

______ (1951) Sedimentary basins of Arizona and adjoining areas, Geol. Soc. Am., Bull., vol. 62, p. 481-505.

Meinzer, O. E., and Kelton, F. C. (1913) Geology and water resources of Sulphur Spring Valley, Arizona, U.S. Geol. Survey, Water-Supply Paper 320, p. 9-213.

Mitchelson, A. T. and Muckel, D. C. (1937) Spreading water for storage underground, U.S. Dept. Agriculture, Tech. Bull. 578., p. 16.

Moore, B. N., Tolman, C. F., (with contributions by Butler, B. S. and Hernon, R. M.) (1949) Geology of the Tucson Quadrangle, Arizona, U.S. Geol. Survey, Open File Report, on file Ariz. Bur. Mines, Tucson.

Nelson, L. A. (1940) Paleozoic stratigraphy of Franklin Mountains, west Texas, Am. Assoc. Petrol. Geol., Bull., vol. 24, p. 157-172.

Noble, L. F. (1922) A section of the Paleozoic formations of the Grand Canyon at Bass Trail, U.S. Geol. Survey, Prof. Paper 131-B, p. 23-73.

Paige, Sidney (1916) Silver City Folio, U.S. Geol. Survey, Geol. Atlas, no. 199, 19 pages.

Peterson, N. P. (1938) Geology and ore deposits of the Mammoth mining camp area, Pinal County, Arizona, Univ. Ariz., Ariz. Bur. Mines Bull. 144, 63 pages.

______ (1948) Geology of the Castle Dome copper deposit, Arizona, Am. Inst. Min. Eng., Tr., vol. 178, p. 195-205.

______, Gilbert, C. M., and Quick, G. L. (1951) Geology and ore deposits of the Castle Dome area, Gila County, Arizona, U.S. Geol. Survey, Bull. 971, 134 pages.

Ransome, F. L. (1903) Geology of the Globe copper district, Arizona, U.S. Geol. Survey, Prof. Paper 12, 168 pages.

______ (1904a) Globe Folio, U.S. Geol. Survey, Geol. Atlas, no. 111, 17 pages.

______ (1904b) The geology and ore deposits of the Bisbee quadrangle, Arizona, U.S. Geol. Survey, Prof. Paper 21, 168 pages.

______ (1915) The Paleozoic section of the Ray quadrangle, Arizona, Wash. Acad. Sci. Jour., vo. 5, no. 11, p. 380-388.

______ (1916) Some Paleozoic sections in Arizona and their correlation, U.S. Geol. Survey, Prof. Paper 98-K, p. 133-166.

______ (1919) The copper deposits of Ray and Miami, Arizona, U.S. Geol. Survey, Prof. Paper 115, 192 pages.

______ (1923) Ray Folio, U.S. Geol. Survey, Geol. Atlas, no. 217, 24 pages.

Ross, C.P. (1925a) Ore deposits of the Saddle Mountain and Banner mining districts, Arizona, U.S. Geol. Survey, Bull. 771, 72 pages.

______ (1925b) Geology and ore deposits of the Aravaipa and Stanley Mining districts, Graham County, Arizona, U.S. Geol. Survey, Bull. 763, 120 pages.

Schrader, F. C. (1915) Mineral deposits of the Santa Rita and Patagonia mountains, Arizona, with contributions by J. M. Hill, U.S. Geol. Survey, Bull. 582, 373 pages.

Schwartz, G. M. (1945) Geology of the San Manuel area, Pinal County, Arizona, U.S. Geol. Survey, Strategic Minerals Invest., Prelim. Maps 3-180.

______ (1949) Oxidation and enrichment in the San Manuel copper deposit, Arizona, Econ. Geol. vol. 44, p. 253-277.

Schwennesen, A. T. (1917) Ground water in the San Simon Valley, Arizona and New Mexico, U.S. Geol. Survey, Water-Supply Paper 425, p. 1-35.

______ (1918) Ground water in the Animas, Playas, Hachita, and San Luis basins, New Mexico, U.S. Geol. Survey, Water-Supply Paper 422, 152 pages.

______ (1919) Geology and water resources of the Gila and San Carlos Valleys in the San Carlos Indian Reservation, Arizona, U.S. Geol. Survey, Water-Supply Paper 450, p. 1-27.

Short, M. N., and Ettlinger, I. A. (1926) Ore deposition and enrichment at the Magma mine, Superior, Arizona, Am. Inst. Min. Eng., Tr., vol. 74, p. 174-222.

______, Galbraith, F. W., Harshman, E. N., Kuhn T. H., and Wilson, Eldred D. (1943) Geology and ore deposits of the Superior mining area, Arizona, Univ. Ariz., Ariz. Bur. Mines, Bull. 151, 159 pages.

Simpson, G. G. (1950) Cenozoic formations and vertebrate faunas, in Guidebook for 4th field conference of the Soc. Vert. Paleont. in N.W. New Mexico, p. 74-85.

Smith, C, T, (1951) Nomenclature chart in Guidebook of the south and west sides of the San Juan basin, New Mexico and Arizona, New Mexico Geol, Soc,

Spencer, A, C,, and Paige, Sidney (1935) Geology of the Santa Rita mining area, New Mexico, U, S, Geol, Survey, Bull, 859, 78 pages,

Spurr, J, E, (1916) The relation of ore deposition to faulting, Econ, Geol, vol, 11, p, 601-622,

Steele, H, J,, and Rubley, G, R, (1948) San Manuel prospect, Am, Inst, Min, Eng,, Tr,, vol, 178, p, 181-194,

Stoyanow, A, A, (1926) Notes on recent stratigraphic work in Arizona, Am, Jour, Sci,, 5th ser,, vol, 12, 311-324,

______ (1936) Correlation of Arizona Paleozoic formations, Geol, Soc, Am,, Bull,, vol, 47, p, 459-540,

______ (1942) Paleozoic paleogeography of Arizona, Geol, Soc, Am,, Bull,, vol, 53, p, 1255-1282,

______ (1949) Lower Cretaceous stratigraphy in southeastern Arizona, Geol, Soc, Am,, Mem, 38, 169 pages,

Tolman, C, F, (1909) The geology of the vicinity of the Tumamoc Hills, Ariz,, in Spalding, V, M,, Distribution and movement of desert plants, Carnegie Inst, Washington, Pub, 113, p, 67-82,

Wilson, E, D, (1928) Asbestos deposits of Arizona, Univ, Ariz, Ariz, Bur, Mines Bull, 126, 100 pages,

______ (1939) Precambrian Mazatzal revolution in central Arizona, Geol, Soc, Am,, Bull,, vol, 50, p, 1113-1164,

______ (1950) Superior area, Univ, Ariz,, Ariz, Bur, Mines, Bull, 156, p, 84-98,

______ (1951) Curtin or Humphrey mine, Univ, Ariz,, Ariz, Bur, Mines, Bull, 158, p, 82-83,

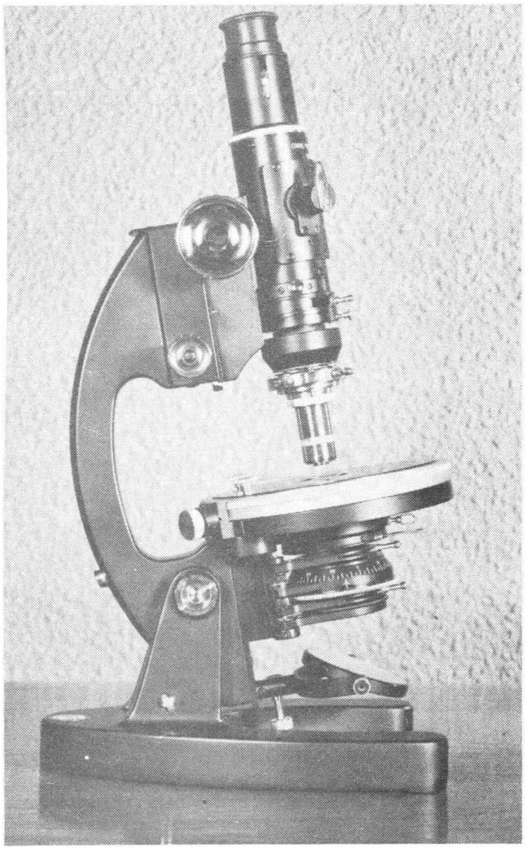
Winters, S, S, (1951) Permian stratigraphy in eastern Arizona, Plateau, vol, 24, p, 10-16,

ANACONDA

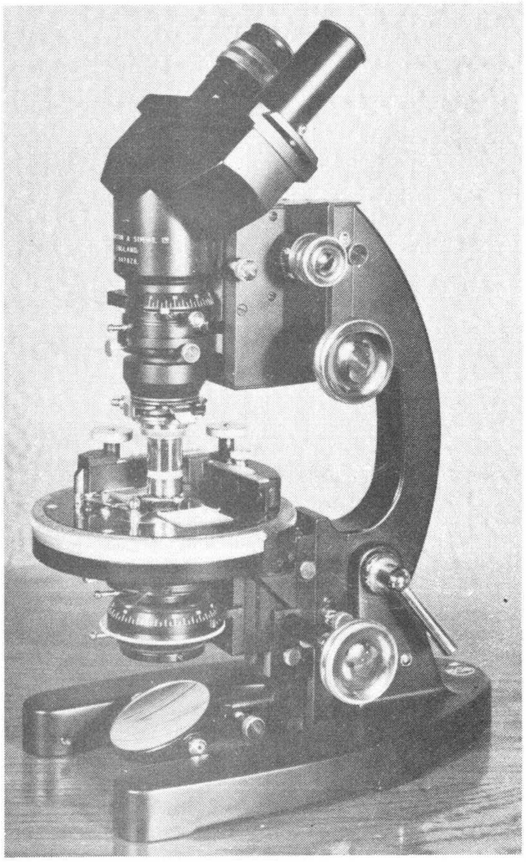
COPPER

MINING

COMPANY



Cooke M7110 Research Model



Cooke M7250 Universal Model

COOKE POLARIZING MICROSCOPES

EXCLUSIVE ADVANTAGES

All models supplied with full-size condensers and extra large Polaroid polarizers supplying full field of illumination at all magnifications without resort to swing-out lenses.

All models supplied with patented trip-in Bertrand Lenses and Bertrand Diaphragms, centerable, giving crisp interference figures for an area covering 0.05mm on the specimen without refocusing.

Improved accessory equipment:

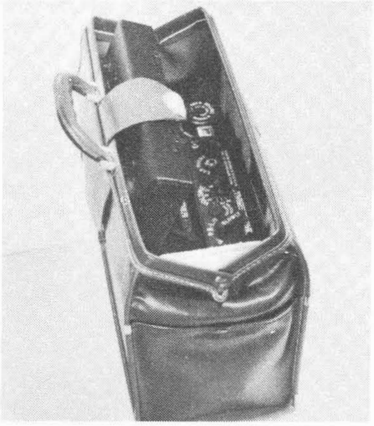
1. Objective mounts permitting individual rotation to best extinction position.
2. Slotted objectives permitting measurements with graduated quartz wedge, and other compensators, over the interference figure.
3. Greatly improved universal stage.
4. Binocular bodies supplied for all work not requiring the Bertrand Lens. (Binocular body can be immediately interchanged with straight body with Bertrand Lens without disturbing fine focus)

Send for brochures on;
Cooke Polarizing microscopes
Cooke Stereoscopic Microscopes
Cooke Metallurgical Microscopes
Cooke Metallographic Apparatus
Cooke Universal Stage
Cooke Polarizing Microprojector
Vickers Projection Microscope

THE R.Y. FERNER COMPANY, INC.
110 Pleasant Street, MALDEN 48, MASSACHUSETTS
Offices: Chicago - Denver - San Francisco
In Canada: Cooke, Troughton and Simms, Ltd.
61 College Street, Toronto

(Supplied in the United States with service and replacement stock facilities maintained)

WALKIE-RECORDALL
• ON THE SPOT •
BATTERY RECORDER



THE ELECTRONIC SECRETARY

Records All Conversation—Any Time . . . Any Place

No Heavy Load . . No Bulk . . No Wires . . No Reels

No Connecting To Electric Socket

IT'S ALL IN THE BAG

Total Weight 9 lbs. (Model CCB)

Simply Turn a Concealed Knob and

RECORD

HANDS BUSY?

LET MILES WALKIE-RECORDALL TAKE YOUR NOTES

IN THE FIELD—IN THE LAB OR UNDERGROUND

While Walking Riding or Flying

RECORDS: Interviews, conferences, reports, 1-man inventory, market research, sales training, 2-way phone, etc.
SENSITIVITY RANGE: Up to 40 ft. radius from microphone (concealed in bag). Records reports whispered into the microphone WHILE ON TRAINS, PLANES OR CARS.
UNINTERRUPTED CONTINUITY: Up to 90 min. (Model CC), & up to 4 hrs. (Model CC4), on each side of endless film band.
COST OF PERMANENT RECORDING, incl. batt.: 4¢ to 6¢ per hr.
PERMANENT, FUTURE PLAYBACK: No extra cost.
COST OF "A" & "B" BATTERIES (STANDARD): 1¢ per hr.
LIFE OF BATTERIES: 100 & 350 working hrs., respectively.
INDEXED RECORDINGS: Playback any part within split sec. up to 6 sec. Identify, File. Mail first-class for 3¢.
SAME UNIT records and plays back instantly and permanently.
CONTROLS: Fast "Forward Go-Back", "Start-Stop" & "Speed".

MILES REPRODUCER CO., INC.
812 BROADWAY NEW YORK 3. N Y

1946	1947	1948	1949	1950	1951	1952
Villa de Seris	Rio Chico Moradillas Tayoltita	Moradillas Tayoltita Contra Estaca	Moradillas Tayoltita Contra Estaca	Moradillas Tayoltita Contra Estaca Namiquipa	Moradillas Tayoltita Contra Estaca Namiquipa Guazapares Matehuala	Moradillas Tayoltita Contra Estaca Guazapares Matehuala Tacubaya YOUR MINE ?

HADRILCO

635 N. 3rd Ave., Tucson

Ph. 2-4112

THIS PAGE

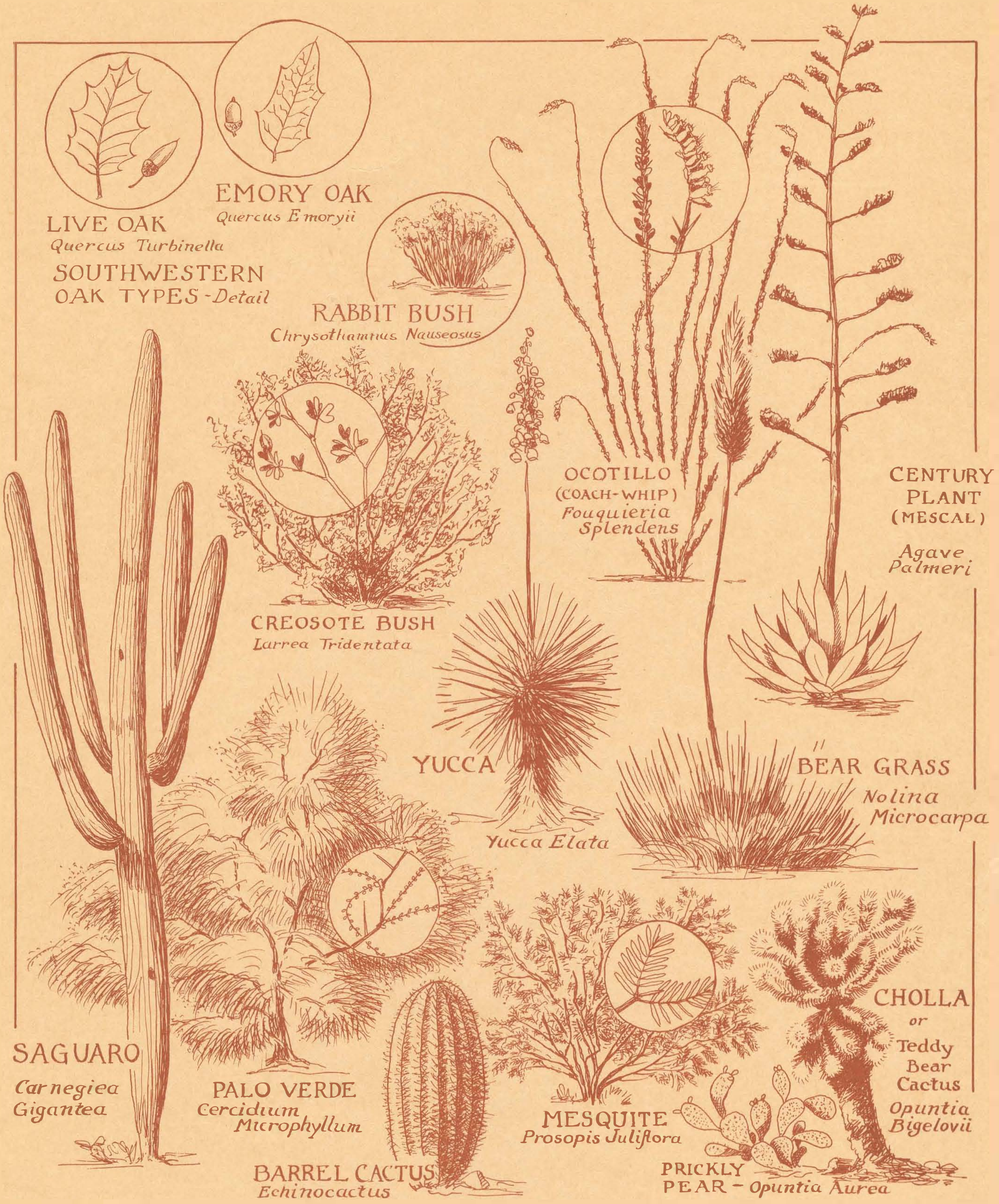
INTENTIONALLY BLANK

ERRATA

Page 14	Fig. 2, caption under lower right-hand photograph should read: MILES 8.1, PART 3
Page 18	Fourth line from bottom of second paragraph: "Trip 1" should read "Part 3."
Page 18	Third paragraph, 4th line: "at a given yield" should be deleted.
Page 18	Fourth paragraph, last line: "from a static level" should be inserted before "more."
Page 19	Fig. 3 in Explanation: "Ground water contours Spring 1930" should read "Ground water contours Spring 1950."
Page 43	NOTE: Banded gneisses of the Trip 3 road log are the equivalent of injection gneisses of the article on page 51.
Page 49	Mileage point 33.1, first sentence, should read: "Dark green rock in road cut is Leatherwood quartz diorite."
Page 55	The following paragraph was omitted at the end of this article: Blake (1909, p. 47) assumed, as was customary in 1908, that the age of the metamorphic terrane was Precambrian. Hernon (1932, p. 18) concluded that the dominantly pelitic nature of the host is equally compatible with the theory of derivation from the Pinal schist of Precambrian age or from the Cretaceous rocks. The Apache group, which is dominantly quartzitic, and the Paleozoic rocks, which are mostly quartzites and limestones, were considered as least likely hosts. This interesting problem awaits more detailed studies.
Page 90	Substitute "oxidation" for "olidation" in the last sentence of first paragraph.
Page 97	Second paragraph, last line should read: "Of this total, approximately 65.6 percent came from Ray, and 34.4 percent from Superior."
Page 103	Second line from bottom, last word should read: "southward."
Page 105	Next-to-last paragraph, last phrase should read: "which penetrates Gila (?) conglomerate and the lower tuff beds.
Page 105	Last paragraph, 4th line on should read: "It is concealed by dacite on the northwest and cut off by the Concentrator fault on the southeast." "Presumably this thrust fault, now downthrown by the Concentrator fault, originally was continuous with the Walnut overturn and Walnut reverse fault."
Page 108	Fourth paragraph, 2nd line, 10th word should read: "prominent."
Page 112	Caption, Fig. 41, should read: "Hypothetical cross section of a basin showing Gila conglomerate both in depositional and in fault contacts with older rocks."
Page 125	Fourth paragraph, 4th line, 10th word, should read: "agents."

THIS PAGE

INTENTIONALLY BLANK



~ Some typical plants of Southern Arizona