MESOZOIC THROUGH EARLY TERTIARY SEDIMENTATIONAL AND TECTONIC PATTERNS OF NORTHEAST SONORA AND SOUTHEAST ARIZONA*

led by:
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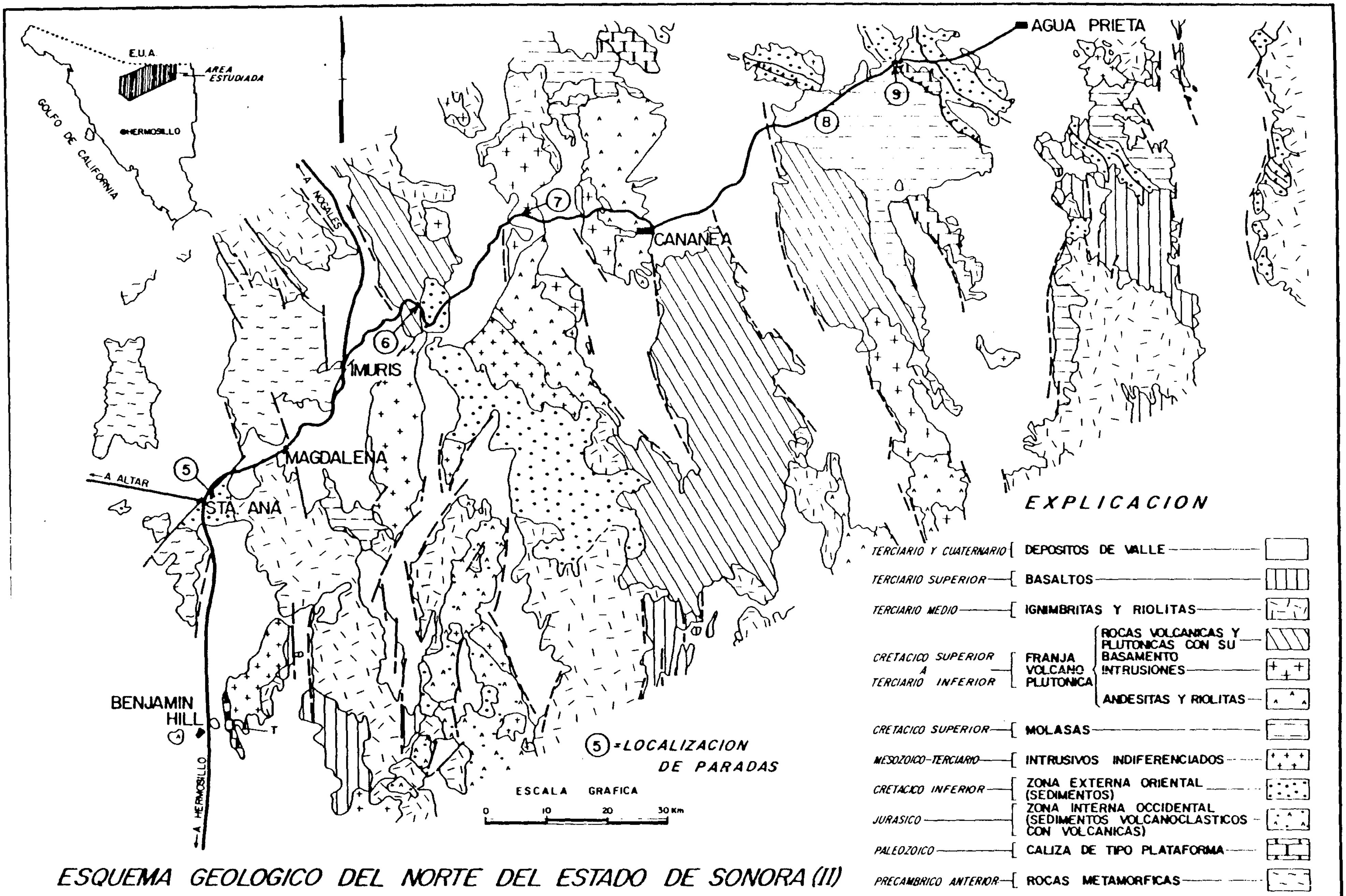
NORTHEAST SONORA LEG

Leader:

Francisco Longoria



ESQUEMA GEOLOGICO DEL NORTE DEL ESTADO DE SONORA (II)

ITINERARY FOR NORTHEAST SONORA LEG

Leader: Francisco Longoria

GEOLOGY OF THE AGUA PRIETA REGION, NE SONORA. MEXICO.

Objectives:

1) To examine the lithostratigraphy of Paleozoic and Mesozoic rocks of the Agua Prieta Region.

2) To study the structural relationship between Paleozoic rocks and Mesozoic rocks (lower Cretaceous Bisbee and upper Cretaceous Cabullona groups).

3) To visit two localities in the Agua Prieta Region whereby southwest directed thrusting in the Cabullona Basin ~~have~~ has been proposed.

ITINERARY

Saturday, March 28, 1981.

07:30 Meet at main entrance of Motel Valle Grande.

08:00 Leave Hermosillo from Motel Valle Grande.

14:00 Arrive in the Agua Prieta Region.

14:30 Sierra de Anibacachi.

On the SSW flank at the Sierra de Anibacachi we will examine the Bisbee Group. At this locality fossiliferous Morita and Mural are well exposed.

16:30 Cerro la Morita (Mina la Negrita).

Good outcrops of Paleozoic rocks assigned to the Mississippian Escabrosa through Pennsylvanian Permian Naco limestone sequence are exposed on Cerra la Morita.

Here we will focus on the structural relationship between Paleozoic and Lower Cretaceous rocks.

17:30 - 18:00 Drive to the Hotel el Greco in Agua Prieta. Have dinner. Spend the night and be ready for next morning at 07:00 hrs.

Sunday, March 29, 1981.

07:00 Leave from Hotel el Greco in Agua Prieta and drive to Sierra de Cabullona.

Be certain you are carrying all of your luggage because we will not be returning to Hotel el Greco.

8:00 Sierra de Cabullona.

Here, we will have a look at the stratigraphic sequence exposed on the SSW flank of Sierra de Cabullona. Paleozoic rocks are exposed in the lower and middle parts of the range. The Paleozoic/Upper Cretaceous contact at this locality is thought to be a thrust fault.

11:00 Leaver Sierra de Cabullona.

12:00 Cross the USA/Mexican Border at Douglas, Arizona.

GEOLOGY OF THE AGUA PRIETA REGION

by

Francisco Longoria

INTRODUCTION

The region under consideration (Figure 1) lies within the Cabullona Basin of northeast Sonora. It is located south of the towns of Agua Prieta and Naco. The region covers an area of approximately 1850 square kilometers. Physiographically, the Agua Prieta region lies within the Basin and Range Province of northeast Sonora. The rocks exposed in the area are predominantly sedimentary rocks, although volcanic and plutonic igneous rocks and metamorphic rocks, are locally abundant (Figure 2).

The Agua Prieta Area plays an important role in the paleotectonic interpretation of SE Arizona and NE Sonora. In general, the structural evolution of the region is poorly known and controversial. Pioneer field studies in the Agua Prieta region by Taliaferro (1933), Imlay (1939), and King (1934); as well as in adjacent areas by Ransome (1904) and Willson (1934) demonstrated that this region displays several structural and stratigraphic features that deserve more investigation. Recent studies by Rangin (1977) into late Cretaceous - early Tertiary tectonics of the Northern part of Sonora (Figure 2) suggested superimposed deformations and southwest directed thrusting in the Cabullona Basin. Paleontologic studies by Gamper and Longoria (1980) have shown that the Lower Cretaceous rocks of NE Sonora are predominantly open marine deposits, locally rich in planktonic foraminifera. Nevertheless, much remains to be learned about the tectonic evolution of the whole area.

The main mountain ranges in the area are: 9) Sierra de San Jose, 2) Sierra de Anibacachi, 3) Cerro de la Morita, 4) Sierra del Coloso, 5) Sierra Loma Blanca, 6) Cerro de Cabullona, and 7) Sierra de Magallanes (See Figure 2).

Paleozoic, Mesozoic and Tertiary rocks are well exposed in several of these mountain ranges and allow us an excellent view of the stratigraphic and structural relationships. During our field excursion we will concentrate our attention on the rock and structural sequences exposed at Sierra de Anibacachi, Cerro de la Morita and Cerro de Cabullona.

STRATIGRAPHY (Figure 3)

Precambrian Rocks

Two main lithostratigraphic units are recognized in the Precambrian of the Agua Prieta Region: 1) The Pinal Schist, and 2) Las Mesteñas Granite. Only small patches of these two units are found within the area covered by the field trip.

The Pinal Schist crops out in the lower part of the Sierra de Las Mesteñas, as well as in the SW flank of the Sierra de los Ajos. Both localities are a few kilometers south of Sierra de Cabullona. The Pinal Schist is also exposed on the SW flank of the Cerro de la Morita.

The Pinal Schist contains a wide variety of lithologies: phyllites, quartz gneiss, muscovite-biotite-gneiss, sericite-chlorite-quartz-schist. The base of the Pinal Schist is not exposed in the Agua Prieta Region. The upper boundary is a nonconformity.

The term Las Mesteñas Granite refers to a lithostratigraphic unit of felsic composition containing xenoliths of the Pinal Schist. The Las Mesteñas Granite is well exposed in the Sierra de Las Mesteñas. A few outcrops of the Las Mesteñas Granite can be found along the tributary creeks of the Rio Cabullona. The Las Mesteñas Granite generally is strongly weathered and forms the lower parts of the hills near Sierra de Las Mesteñas.

At several localities a polymictic conglomerate can be found. In the Cerro de la Morita area along the creek beds a conglomerate mainly composed of angular to subangular cobbles and boulders of metamorphic rocks is common. Most of the clasts found in this conglomerate are derived from the Pinal Schist. The stratigraphic age of this conglomerate is unknown.

Paleozoic Rocks

In the Agua Prieta Region the Paleozoic rocks can be assigned to the following lithologic units: Bolsa Quartzite, Abrigo Limestone, Martin Limestone, Escabrosa-Naco limestone. Paleozoic rocks are present in isolated localities and their stratigraphic relationship is still poorly understood. However, Paleozoic rocks are known from several localities: Cerro de la Morita, and Cerro de Cabullona. South of the Agua Prieta Region Paleozoic rocks are present at Cerro de Las Mesteñas and Sierra de los Ajos.

Bolsa Quartzite

The oldest Paleozoic unit known in the region of Agua Prieta is the Bolsa Quartzite. This unit is mainly composed of pure quartz sandstone and some conglomeratic sandstone. Locally the sandstones of this unit are metamorphosed and become metaquartzite.

The lower part of the Bolsa Quartzite is characterized by the presence of several thin layers of conglomeratic sandstone. These layers vary from 20 cm up to 1.0 m in thickness. The sandstone often displays cross-stratification. In general, the rocks of the Bolsa Formation weather pink to white and give the outcrops their typical pinkish appearence. The sand grains are well-rounded to subrounded and cemented by quartz, chlorite or sericite. The quartz grains vary in diameter from 0.5 to almost 2.0 cm.

Several conglomeratic sandstone layers can be observed in the middle and upper parts of the Bolsa Quartzite. These conglomeratic layers are formed of subrounded quartz grains which vary from 2.0 to 4.0 cm in diameter. The conglomeratic layers display a somewhat darker pink-reddish color.

The total thickness of the Bolsa formation in the area is unknown. The Bolsa Quartzite is found in the SW flank of the Sierra de Cabullona where it reaches a maximum thickness of about 18 meters. Small outcrops of this unit can also be observed near the Cerro de la Morita.

The Bolsa Quartzite overlies the Las Mestenas Granite. This contact is only observed at isolated outcrops in the Sierra de Las Mestenas. At this locality a basal conglomerate can be observed. The upper limit of this unit is placed at the base of the first appearance of limestone beds assigned to the Abrigo Formation.

Abrigo Formation

The Abrigo Formation is composed of an intercalation of limestone and marls. In the Agua Prieta region the Abrigo Formation is frequently covered by alluvium deposits. It always forms low relief. The limestones of the Abrigo are thin-bedded and gray in color. They are consistently interbedded with marls and calcareous shales. The lower contact, i.e., the Bolsa-Abrigo formational boundary, is difficult to see in the field because it is always covered by soil. However, this contact was observed in the Sierra de las Mestenas and corresponds to a sharp change in lithologies, from orthoquartzite of the Bolsa Quartzite to limestones and marls of the Abrigo Formation. The upper contact, i.e., the Abrigo-Martin formational boundary, is quite obvious in the field. It corresponds to a lithologic change from thin-bedded limestones and marls to thick-bedded, massive limestones. In the Sierra de Cabullona the Abrigo Formation is about 120 m thick.

Martin Formation

The sequence herein refered to the Martin Formation is composed of dark-gray limestone beds about 1.0 to 1.5 m thick. Shale layers are commonly interbedded with the limestones. The Martin Formation is exposed on the SW flank of the Sierra de Cabullona. The contact with the Abrigo Formation is placed at the change in thickness of the limestone beds, from thin-bedded limestones of the Abrigo to thick layers of the Martin. On the other hand, the upper limit, i.e., the Martin-Escabrosa boundary, is sometimes difficult to place in the field. However, for practical uses, this boundary is placed at the base of the first stratigraphic appearance of fossiliferous beds (encrinites) of the Escabrosa Limestone.

The Martin Formation is well exposed on the SW flank of the Sierra de Cabullona where it reaches a maximum thickness of about 280 m. A few invertebrate fossils where collected from this unit. Among them, small brachiopods and corals are frequently found. the Martin Formation is regarded as Devonian in age on basis of the presence of specimens of *Atrypa reticularis*.

Escabrosa-Naco Limestone

In the Agua Prieta region above the Martin Formation is a thick sequence of massive thick-bedded, gray to dark, compact limestone with some chert and occasionally thin beds of shales. This sequence could be assignated to either the Escabrosa or the Naco formations. In the field it is extremely difficult to place the boundary between these two units. Consequently, during the field work the term Escabrosa-Naco Limestone was used to include both units. According to Ramsome (1904, p. 45) both units have several features in common. Ransome (op. cit.) based the distinction between the Escabrosa and the Naco on paleontological criteria.

The unit herein referred to the Escabrosa-Naco Linestone is well exposed on the SW flank of the Sierra de Cabullona. Also the Escabrosa-Naco can be observed in the Sierra de la Morita area.

The Escabrosa-Naco Limestone is approximately 185 m thick. It is assigned to the Carboniferous based on the presecence of brachiopods. Apparently, both Mississippian and Pennsylvanian faunas are present and, more or less, correspond to the Escabrosa and Naco formations respectively.

Cretaceous Rocks

Cretaceous rocks are widely exposed in the Agua Prieta region. They are by far the most abundant rock in the northern part of the area. Both Lower and Upper Cretaceous series are found. The Lower Cretaceous rocks are referred to the Bisbee Group whereas Upper Cretaceous rocks are placed in the Cabullona Group. Both groups represent abrupt changes in sedimentation and are related to the Cretaceous structural and tectonic evolution of the region.

Bisbee Group

Lower Cretaceous rocks of Upper Barremian to Middle Albian age are abundant in NE Sonora and SE Arizona. South of Cabullona several formation names have been proposed to include rocks from this time span. However, it is clear that the main subdivision of the Bisbee Group into four formations is still valid -- at least for the Agua Prieta Region. It is also worth noting that several obvious differences can be drawn between the Bisbee section in the Mule Mountain and the Bisbee Group of Agua Prieta. Continued stratigraphic studies will be required to unravel these discrepancies.

According to Ransome (1904, p. 56) the Bisbee Group is subdivided into four main units, from bottom to top: the Glance Conglomerate, the Morita Formation, the Mural Limestone, and the Cintura Formation.

In the Agua Prieta Region only the first three units have been recognized. The Cintura Formation may only represent a structural repetition of the Morita Formation. Excellent exposures of the Bisbee Group can be found at several localities. Southwest of Agua Prieta, the Bisbee Group is well exposed on the Sierra de Anibacachi.

Glance Conglomerate. The Glance Conglomerate is classically regarded as the basal part of the Bisbee Group. In the Agua Prieta region the Glance Conglomerate unconformably overlies Paleozoic rocks of the Escabrosa-Naco Limestone. Its stratigraphic relations are still doubtful. However, it is likely that the Glance unconformably underlies the Morita Formation. The Glance Conglomerate is present along the SSW edge of the Sierra de Anibacachi. where it forms low hills. Consequently, the greater part of the Glance Conglomerate is covered by soil. However, isolated patches of outcrops can be studied along small creeks between Cerro de la Morita and Sierra Anibacachi.

The Glance Conglomerate is made of pebbles and fragments of schist and limestone. In general the schist and limestone pebbles are subangular and vary in size but it is clear that they have been transported only a short distance from their source areas. In general, the Glance Conglomerate displays reddish outcrop colors.

Neither the lower nor the upper boundaries of the Glance were seen in the Agua Prieta Region. It is likely that the Glance Conglomerate represents a littoral deposit lain down along a marine shore line. However, it is also possible that the Glance-la Morita contact represents a surface of unconformity which would imply that the Glance Conglomerate may be a much younger unit and not related to the Bisbee Group.

Morita Formation. The Morita Formation is composed of thin bedded sandstones and shales with some limestone intercalations. The Morita is easy to recognize in the area because its tan to reddish color gives the outcrops their typical reddish appearance. The Morita Formation is well exposed on the SSW flank of the Sierra Anibacachi. In the Agua Prieta region Morita Formation reaches a maximum thickness of about 320 m. Its lower contact with the Glance Conglomerate is difficult to see in the field because of thick soil cover. However, the contact is interpreted to represent a surface of unconformity. The upper boundary, i.e., Morita-Mural, contact is sharp but conformable and is placed at the base of the first appearance of massive limestone beds of the Mural Limestone.

Mural Limestone. In the Agua Prieta region the Mural Limestone is characterized by massively bedded, fossiliferous, pure limestone. The Mural Limestone is here restricted to include only limestone beds. Ransome (1904, p. 65) included in the Mural Limestone the uppermost part of the Morita Formation composed of alternating sandstones, shales and limestone.

Excellent exposures of Mural Limestone are found in the Sierra de San Jose and in the Sierra de Anibacachi. At the later locality, the Mural Limestone is composed of gray-colored, massive limestone containing abundant fossil remains. The fossils include caprinids and brachiopods as well as benthonic foraminifera (orbitolinids).

The Morita-Mural contact is transitional. It was placed at the first appearance of massive beds of the Mural. The Mural Limestone reaches a maximum thickness of about 235 m.

Cabullona Group

The Cabullona Group consists of a thick sequence of mainly terrigenous sediments with minor amounts of volcanic tuff and rhyolite flows. The whole group is widely exposed in the area between La Morita and Magallanes Peak.

The Cabullona Group is strongly folded and faulted which locally makes its stratigraphic interpretation difficult. In spite of local structural complexities, four major subdivisions of the Cabullona Group (Snake Ridge formation, Camas sandstone, Packard Shale and Rhyolite tuffs and flows) can be easily recognized in the field. However, the actual boundaries of these units are difficult to place. The Cabullona Group is estimated to have a thickness of more than 6800 m. Strong lithologic changes occur within short distances in any given unit. The contacts between the different formations is often placed within transitional zones making it difficult to recognize the lower or upper part of each formation.

Structural Setting

The geology of the Agua Prieta Region plays an important role in the tectonic framework of NE Sonora and SE Arizona. Several attempts have been made to unravel the structural geology of this region (King, 1939, Imlay, 1939, Taliafero, 1933). Recently Rangin (1977) presented a structural scheme for the Agua Prieta Region whereby he (op. cit.) described at least three different phases of deformation superimposed on each other. According to Rangin (1977) the Agua Prieta Region was subjected to different deformations which can be observed at several localities.

In the Agua Prieta region the following deformational sequence can be easily recognized: 1) an Albian-Cenomanian tectonic phase, corresponding to the unconformity observed at the base of the upper Cretaceous and 2) an Upper Cretaceous-Lower Tertiary tectonic phase expressed by overthrusting of the northern ranges over the Cabullona Basin to the south.

One of the main features of the polyphase deformation is the SW thrusting in the Cabullona Basin as shown in Figure 2. As earlier noted by Taliaferro (1939, p. 36), the southwest directed thrusting in the area of Agua Prieta is exactly in the opposite direction from the thrusts in the Bisbee Quadrangle about 25 miles to the NNW of the Agua Prieta Region, where all the thrusting has a direction of movement from southwest to northeast. Evidence of both thrust movements may be observed at two localities: 1) Cerro de la Morita, in the west-central part of the Agua Prieta Region where Paleozoic rocks are well exposed; and 2) the SW flank of the Sierra de Cabullona in the ESE portion of the region. The Loma Blanca Klippen consisting of Paleozoic rocks resting on upper Cretaceous rocks of the Cabullona Group is a strong evidence for the lower Tertiary deformation.

In the Cerro de la Morita (Figure 2) Paleozoic rocks (Escabrosa-Naco Limestone) are exposed along the SW flank of the Cerro de la Morita (Figure 4). This Paleozoic sequence is involved in pre-Bisbee group deformation. The

Cerro de la Morita is an anticlinal fold overturned towards the SSW. A thin slice of Glance Conglomerate can be observed. Also, a thin sheet of Pinal Schist may be found. As previously noted by Taliaferro (1933), this evidence allows the suggestion that Cerro de la Morita is the core of the Sierra de Anibacachi anticline which has been subdivided into imbricated thrust slices and overturned towards the SSW.

The Sierra de Cabullona (Figure 2) is another opportunity to demonstrate the tectonic model of the Agua Prieta Region. At this locality, the Paleozoic sequence is apparently affected by a different episode of deformation that obviously took place before the deposition of the Bisbee Group. This deformation is characterized by northeast-directed thrusting.

LOCALITIES TO BE VISTED DURING THE GSA FIELD EXCURSION

Two main areas within the Agua Prieta Region will be visited during our Field Excursion: 1) the Cerro de la Morita and Sierra de Anibacachi southwest of Agua Prieta; and 2) the Sierra de Cabullona south-southeast of Agua Prieta.

Sierra de Anibacachi

The Sierra de Anibacachi is the northernmost range in the Agua Prieta Region (see geologic map). It is by far the largest range in this region and is alligned northwest-southeast. It is about 30 km long and approximately 6 km wide.

The Sierra de Anibacachi is predominantly comprised of Lower Cretaceous rocks (Bisbee Group). Excellent outcrops of the Bisbee Group can be studied. The Glance Conglomerate is mainly found in the lower part (valley), the Morita Formation is well exposed in the middle part of this range (Figure 2).

Field relationships show that the Anibacachi mountain range exhibits a different structural pattern from that observed in the Cerro de la Morita. The Bisbee Group exposed on the SW flank of the Sierra de Anibacachi predominantly dips homoclinally north-northeast whereas Paleozoic rocks exposed at la Morita seem to be synclinally folded towards the northeast. Two different working hypotheses may explain this difference in structural pattern: 1) Paleozoic rocks of the Agua Prieta Region were subjected to a pre-Albian-Cenomanian deformation; or 2) both the Paleozoic and the Bisbee Group rocks were subject to the same deformation and the area between the Cerro de la Morita and the Sierra de Anibacachi represents the flank of a regional thrust with a south-southwest to north-northeast transport direction. Detailed field work is required before any definitive conclusions about the tectonic development of the Agua Prieta Region can be drawn.

Cerro de la Morita

The Cerro de la Morita is a rather small physiographic mass located southwest of the Sierra de Anibacachi (see Figure 2). It consists mainly of Paleozoic Escabrosa-Naco Limestone. On its SSW flank it apparently overlies the Cabullona Group, via an overthrust fault (?). Paleozoic rocks exposed in the Cerro de la Morita seem to be folded in an overturned syncline that exhibits a southwest-northwest direction of transport.

Sierra de Cabullona

The Sierra de Cabullona mountain range displays a somewhat complex geology (Figure 2). Both Paleozoic and Lower Cretaceous rocks are present in the Sierra de Cabullona. The Sierra de Cabullona covers an approximate area of about 90 square kilometers. The Paleozoic rocks are exposed on the south-southwest flank of the Sierra de Cabullona, whereas the Lower Cretaceous (Bisbee Group) comprises the north-northeast flank of this range. Rocks assigned to the Cabullona Group are poorly exposed on the lower hills of the southwest portion of this range. The Cabullona Group is covered by basaltic lavas of Tertiary and Quaternary age.

The pre-Bisbee rocks (mainly Upper Paleozoic) of the Sierra de Cabullona show evidence of a deformation that could be related to a late Paleozoic-early Mesozoic phase of deformation. At the same time, Paleozoic and Lower Cretaceous rocks seem to be in fault contact with the Cabullona Group. It does not appear that this fault is a low angle thrust fault. This deformation would correspond to a younger phase of tectonism, perhaps related to the Laramide deformation of the southwest North American Cordillera.

References cited.

Gamper, M.A. and Longoria, J.F.

1980. Foraminiferos del grupo Bisbee del Este de Sonora. V. Convencion Soc. Geol. Mexicana. Resumenes.

Imlay, R.W.

1936. Paleogeographic studies in northeastern Sonora. Bull. Geol. Soc. Amer. 50, pp. 1723-1744.

King, E.R.

1939. Geological reconnoissance of Central Sonora. Am. Jour. Sci. 5, vol. 28, no. 164.

Rangin, C.

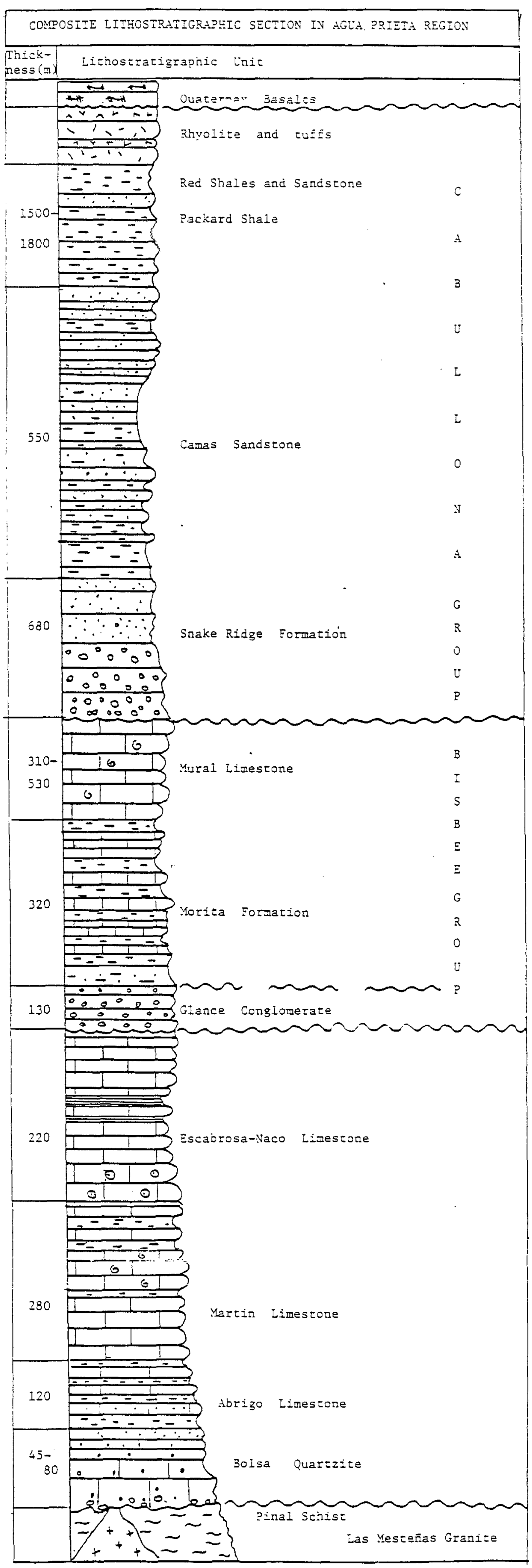
1977. Tectonicas superpuestas en Sonora Septentrional. Univ. Nal. Auton. Mexico. Inst. Geologia Revista. 1 (1), p. 44-47.

Ransome, F.C.

1904. The Geology and ore deposits of Bisbee Quadrangle, Arizona. U.S.G.S. Prof. Paper. 21, 168 pp.

Taliaferro, N.

1933. An occurrence of Upper Cretaceous sediments in northern Sonora. Mexico. Jour. Geol. XLI (1), pp. 12-87.


COMPOSITE LITHOSTRATIGRAPHIC SECTION IN AGUA PRIETA REGION
Thick-ness(m)
Lithostratigraphic Unit
Quaternary Basalts
Rhyolite and tuffs
Red Shales and Sandstone
1500-1800
Packard Shale
550
Camas Sandstone
680
Snake Ridge Formation
CABULLONA GROUP
310-530
Mural Limestone
320
Morita Formation
BISBEE GROUP
130
Glance Conglomerate
220
Escabrosa-Naco Limestone
280
Martin Limestone
120
Abrigo Limestone
45-80
Bolsa Quartzite
Pinal Schist
Las Mesteñas Granite

Univ. Nal. Autón. México, Inst. Geología, Revista, Vol. 1, Núm. 1.

Rangin, Lámina 1.

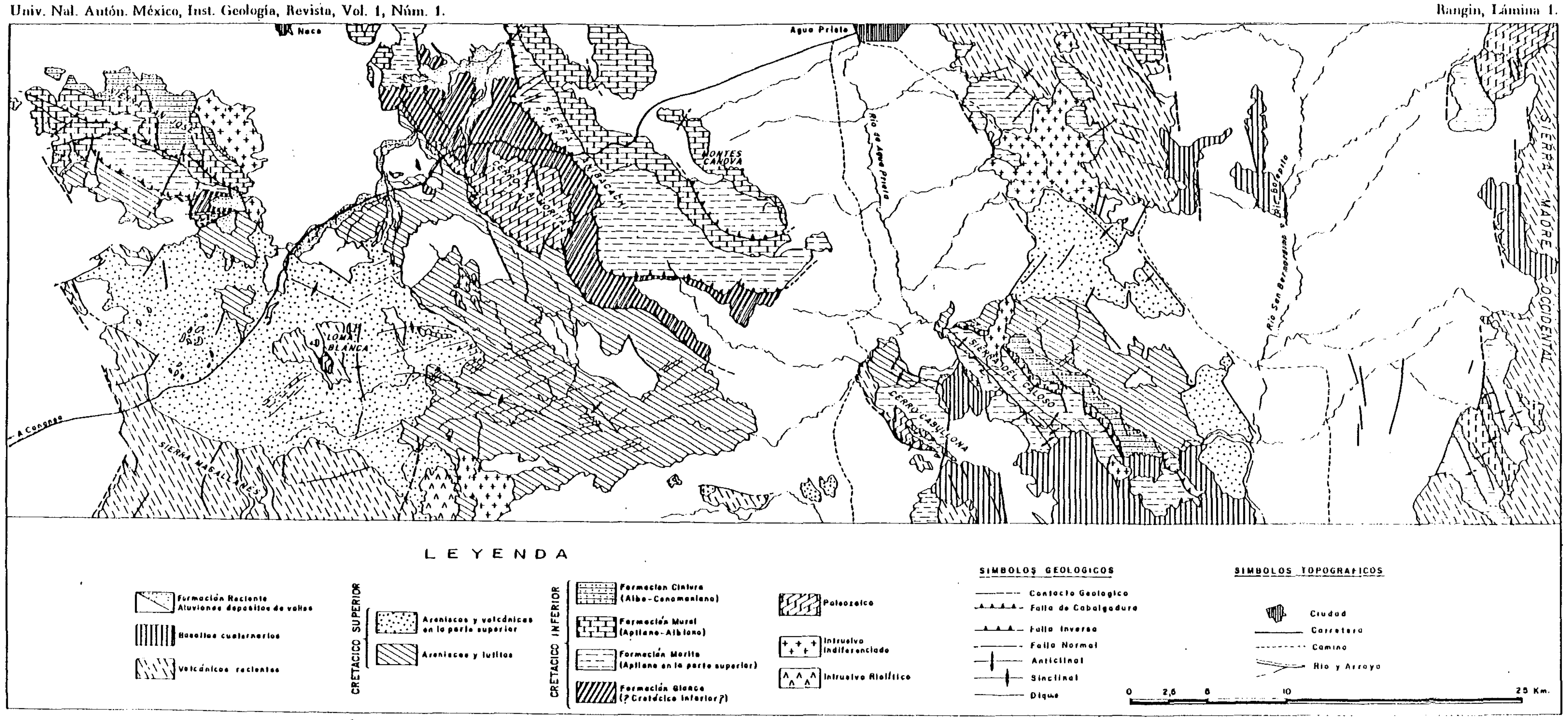


Figure 2: MAPA GEOLOGICO DE LA REGION AL SUR DE NACO Y AGUA PRIETA, SONORA

Taken from: Rangin, 1977
UNAM Inst. geol.
Revista 1(1): 44-47

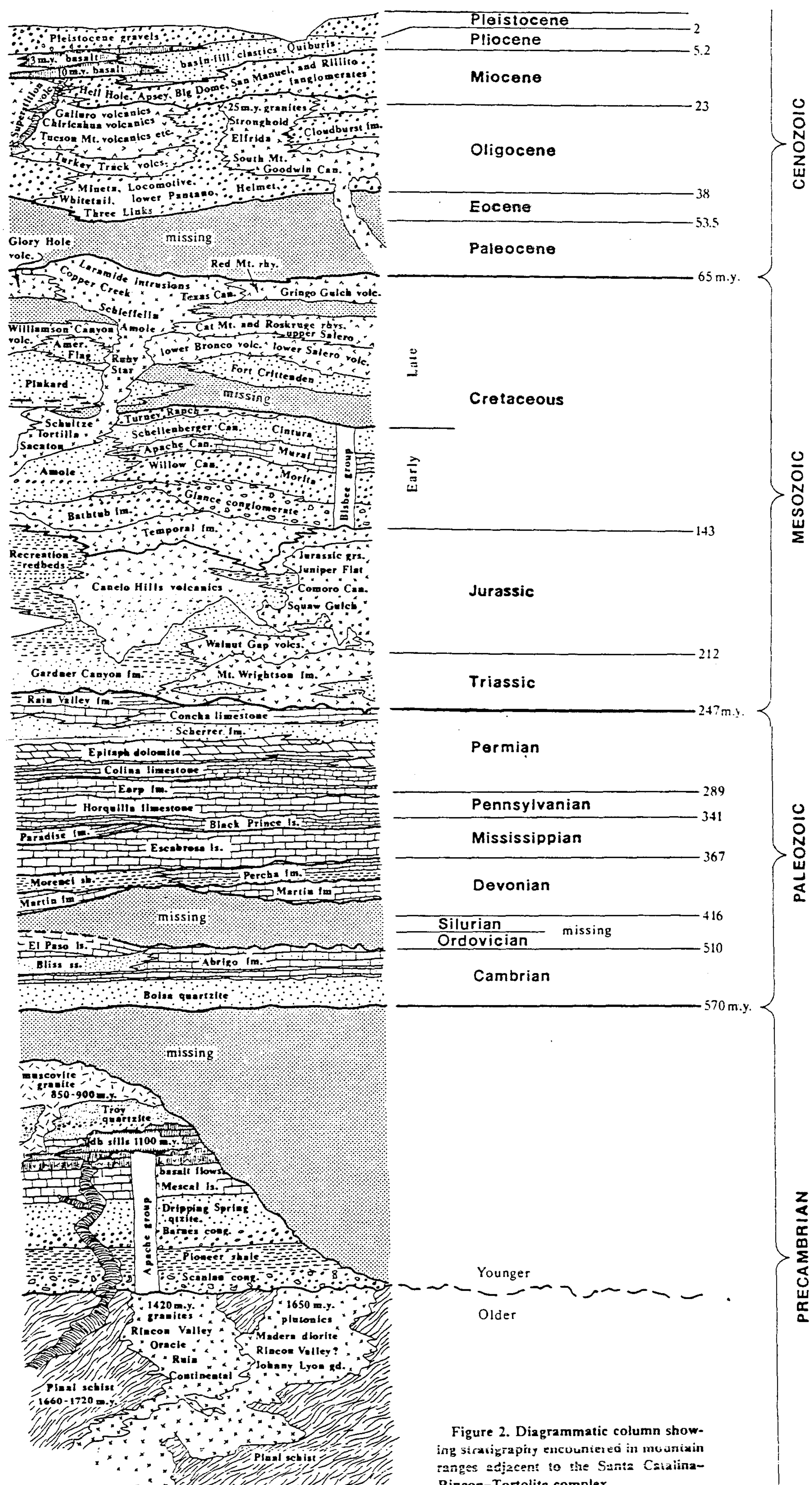


Figure 2. Diagrammatic column showing stratigraphy encountered in mountain ranges adjacent to the Santa Catalina-Rincon-Tortolita complex.

V Convencion Geologica Nacional
Sociedad Geologica Mexicana
Mexico, D.F., 16-19 Nov. 1980

BIOESTRATIGRAFIA Y FACIES SEDIMENTARIAS DEL CRETACICO INFERIOR DE SONORA

M. A. Gamper
J. F. Longoria

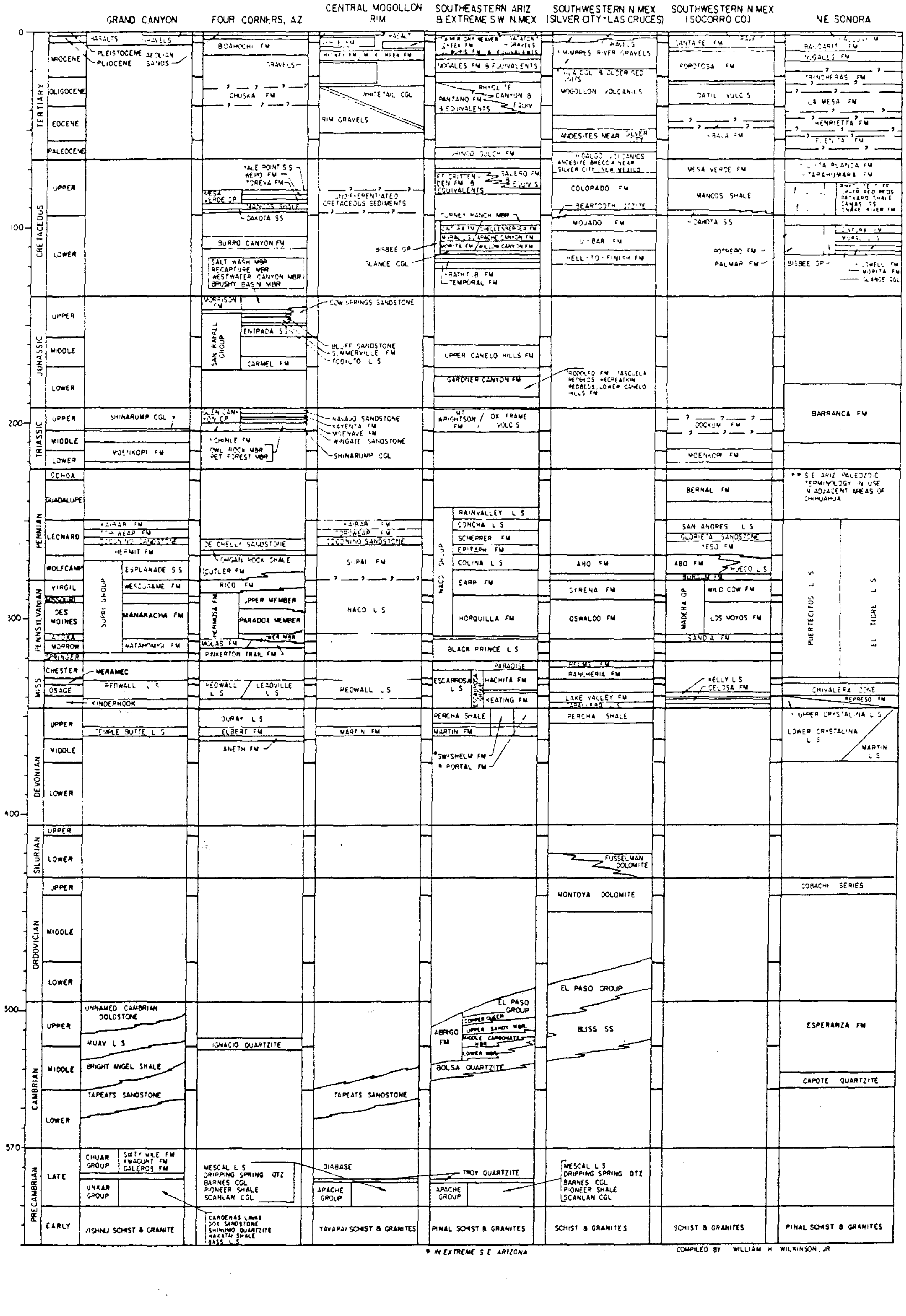
El presente trabajo muestra los resultados del estudio de varias secciones levantadas en el área comprendida entre los poblados de Sahuaripa y Naco. Las observaciones de campo permiten señalar que las rocas del Cretácico Inferior de Sonora son asignables al Grupo Bisbee. Estas rocas fueron sometidas a esfuerzos comprensivos muy intensos que ocasionan su cabalgamiento sobre el Grupo Cabullona del Cretácico Superior. Los conjuntos de foraminíferos planctónicos presentes en muestras colectadas permiten determinar que el Cretácico Inferior del noreste de Sonora representa el lapso comprendido del Aptense al Albense. Así mismo, las especies identificadas señalan la existencia de las biozonas CI–12, CI–13, CI–14 y CI–15 del esquema bioestratigráfico propuesto por Longoria en 1977. Durante ese lapso el Cretácico Inferior del noreste de Sonora experimentó cambios muy marcados en ambientes sedimentarios. La presencia de biomicritas de foraminíferos planctónicos (hedbergeloides y favusélidos) en la parte basal permite asegurar que durante ese intervalo prevalecieron ambientes de facies francamente marinas (facies pre–arrecifal). Al mismo tiempo, la existencia de boundstones de rudistas determina la facies arrecifal. Las rocas de textura packestone -grainstone de fragmentos de moluscos, atestiguan el desarrollo de bancos calcáreos. Por otra parte, la presencia de biomicritas de miliólidos determina la facies post–arrecifal. La sucesión de facies del Cretácico Inferior del noreste de Sonora muestra una marcada migración en tiempo con dirección ENE–WSW. En base a la presencia de favusélidos se postula la extensión de los mares epicontinentales de Texas y NE de México al noreste de Sonora.

SOUTHEAST ARIZONA LEG

Leaders:

Stanley B. Keith and William L. Bilodeau

STRATIGRAPHIC NOMENCLATURE CHART



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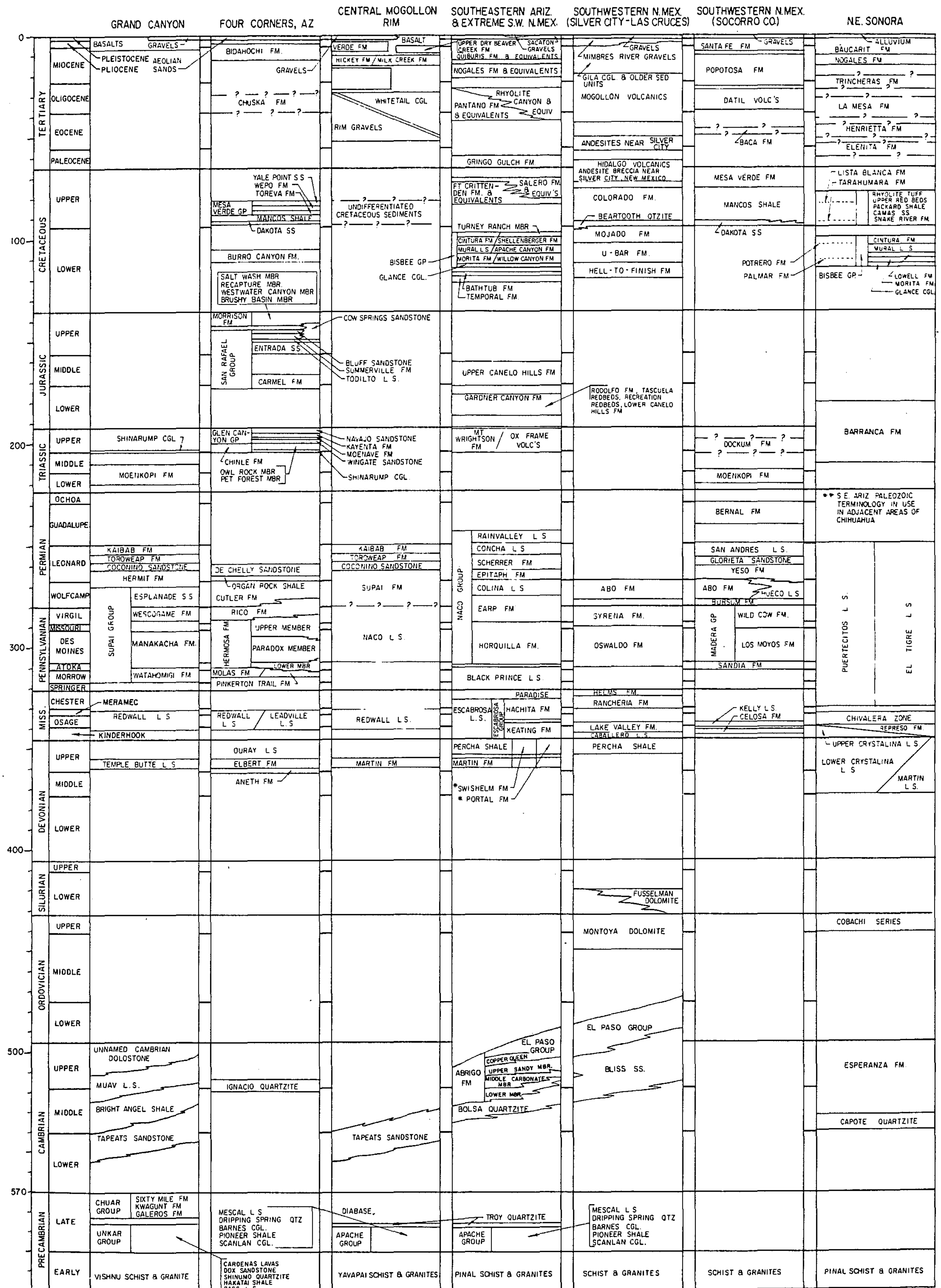

* IN EXTREME S.E ARIZONA

COMPILED BY WILLIAM H WILKINSON, JR

ARTICLES

New Mexico Geol. Soc. Guidebook, 29th Field Conf., Land of Cochise, 1978

MESOZOIC DEPOSITIONAL HISTORY OF SOUTHEASTERN ARIZONA

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INTRODUCTION

The area considered herein is roughly between Tucson and the southeastern corner of Arizona (fig. 1). It lies between the Mexican Border and latitude 32°15′ N., and between New Mexico and longitude 111°15′ W.

Interpretations of stratigraphic relations and regional correlation of Mesozoic rocks in this region are complicated by the lack of datable fossil material in most of the units and by structural complexities; since late Early Permian time, various parts of the region apparently have been subjected to about six episodes of faulting and nearly as many episodes of plutonism. Recently, however, much has been learned about these Mesozoic rocks by professors and students from universities, geologists associated with the minerals industry, and U.S. Geological Survey geologists. This paper is basically an updated version of an earlier paper (Hayes and Drewes, 1968). Although most of the conclusions reached in that paper are unchanged, some of the unnamed units referred to in that paper have been named, units probably correlative to units described in that paper have been found in additional localities, some tentative conclusions of that paper have been made more certain while others have been abandoned, and the worldwide geologic time scale has been revised. The data presented herein are largely presented in much more detail in Cooper (1971), Drewes (1971), Hayes (1970a, 1970b), and Simons (1972). We have also drawn from many older or less detailed recent reports. We obviously are heavily indebted to all of these previous workers, but are ourselves responsible for the interpretations presented here.

Our correlations (fig. 2) are based on analysis of local geologic relations, on paleontologic data of variable usefulness, on radiometric age determinations of variable reliability, on some petrologic studies, and on the assumption that major geologic events must have some degree of regional continuity. In our earlier paper we followed Holmes' (1965) time scale for most of the Mesozoic but used the more refined scale of Gill and Cobban (1966) for the Late Cretaceous. That time scale is shown on the left edge of the correlation diagram, and the time scale of Van Eysinga (1975) is shown on the right edge.

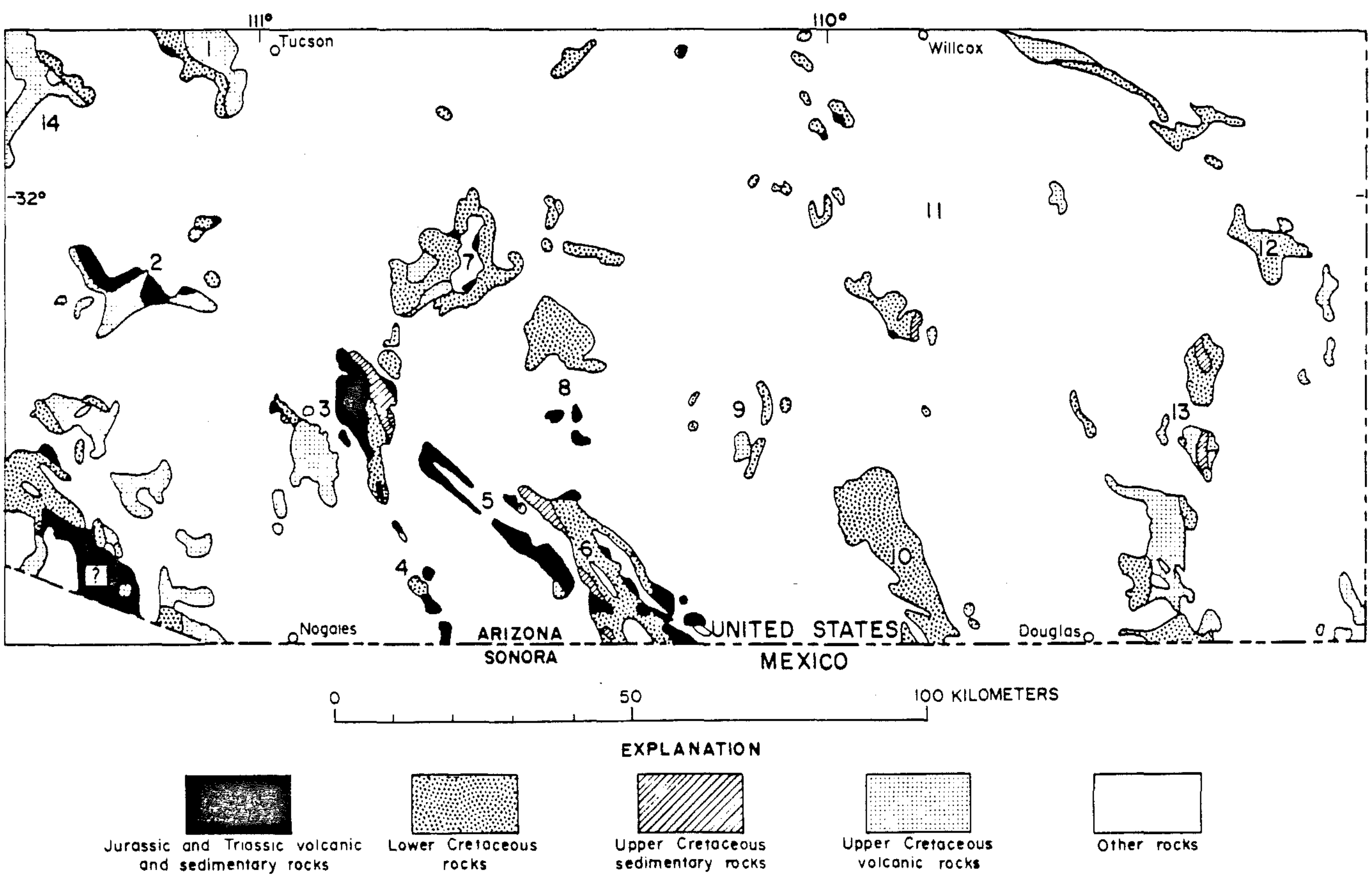

Figure 1. Map showing distribution of Mesozoic volcanic and sedimentary rocks in southeastern Arizona. (1) Tucson Mtns.; (2) Sierrita Mtns.; (3) Santa Rita Mtns.; (4) Patagonia Mtns.; (5) Canelo Hills; (6) Huachuca Mtns.; (7) Empire Mtns.; (8) Whetstone and Mustang Mtns.; (9) Tombstone Hills; (10) Mule Mtns.; (11) Dragoon Mtns. area; (12) Chiricahua Mtns.; (13) Pedregosa Mtns.; (14) Roskruge Mtns.

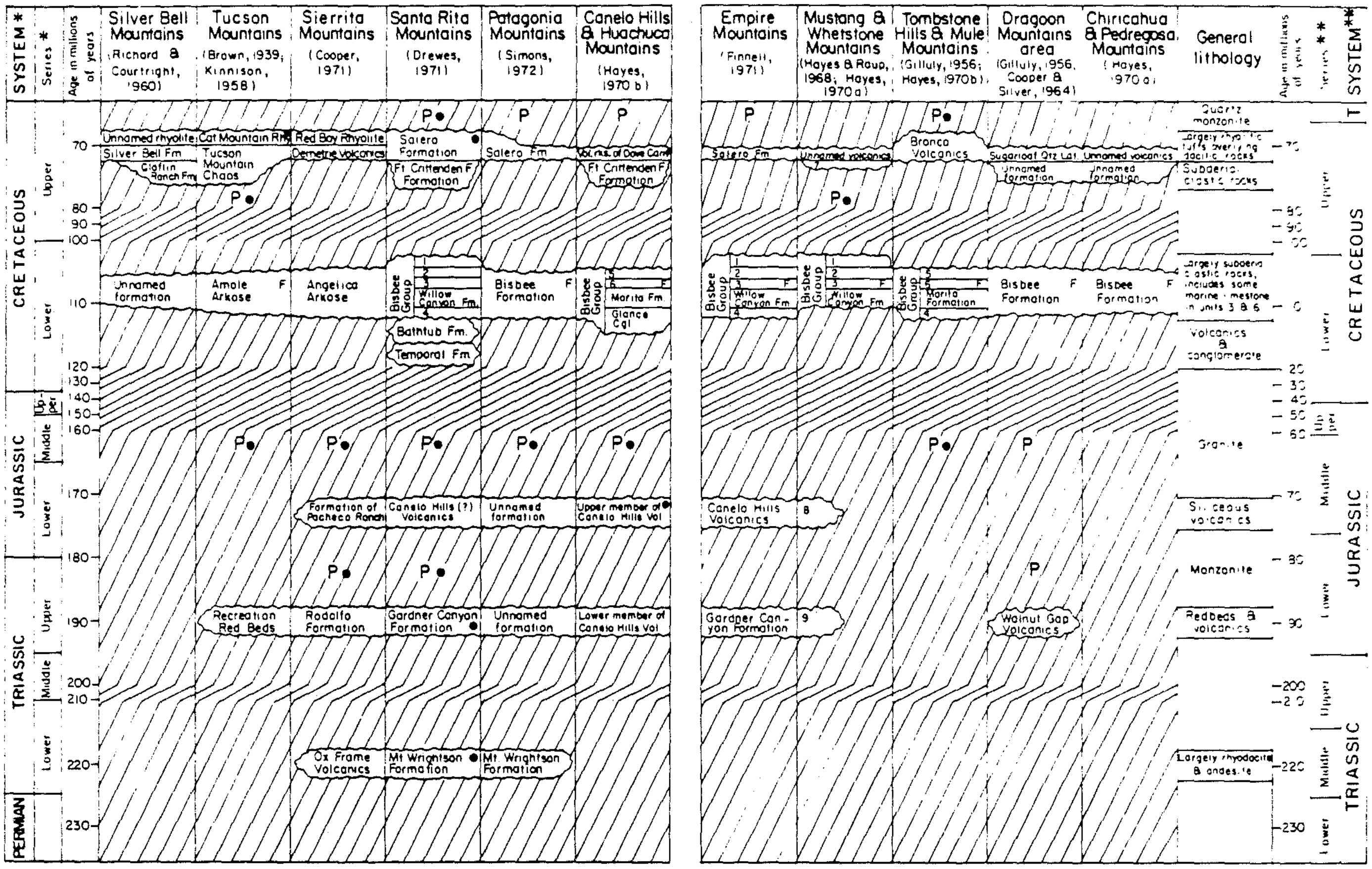

*Figure 2. Correlation chart of Mesozoic rocks in southeastern Arizona. Localities, except for Silver Bell Mountains, are shown on Figure 1. *, time scale used by Hayes and Drewes (1968); **, time scale used by Van Eysinga (1975); (P) plutonic and associated rocks; (F) fossil-bearing rocks; ●, ratiometrically dated rocks. Numbers within chart: (1) Turney Ranch Formation; (2) Schellenberger Canyon Formation; (3) Apache Canyon Formation; (4) Glance Conglomerate; (5) Cintura Formation; (6) Mural Limestone; (7) sedimentary rocks of Rose Tree Ranch; (8) rhyolite in Canelo Hills Volcanics; (9) red beds at base of Canelo Hills Volcanics. Note changes in time scale indicated by pitch of diagonal lines.*

REGIONAL SETTING

Pre-Mesozoic rocks of southeastern Arizona include Precambrian metamorphic, plutonic and sedimentary rocks that are unconformably overlain by about 1,500 m of Paleozoic marine sedimentary rocks ranging in age from Middle Cambrian to late Early Permian. The Mesozoic sequence is unconformably overlain by volcanic and sedimentary rocks of Cenozoic age.

The Mesozoic rocks have a composite maximum thickness of about 12,000 m. They include rhyolitic to andesitic volcanic rocks, sedimentary rocks largely of subaerial origin and some marine beds. Plutonic rocks were intruded in Triassic(?), Jurassic and Late Cretaceous time but are here considered only in connection with their age relation to sedimentary and volcanic rocks. The Mesozoic rocks are treated here in three major divisions separated from each other and from older and younger rocks by major unconformities: (1) Triassic and Jurassic rocks, (2) Lower Cretaceous rocks, and (3) Upper Cretaceous rocks.

Permian-Triassic Unconformity

Marine Paleozoic rocks are separated from subaerial Mesozoic rocks by a widespread unconformity. The youngest Paleozoic formation preserved anywhere beneath the unconformity is the Rainvalley Formation of Permian age in and near the Mustang Mountains, but in places much older rocks lie immediately beneath the unconformity. The oldest Mesozoic rocks inferred to overlie the Permian-Triassic unconformity are included in a volcanic sequence, at least the middle part of which is of Triassic age. The basal contact of these volcanics has not been seen, but the local relief in the Santa Rita Mountains may have been great, for a lens of cobble conglomerate in the sequence contains some clasts of Precambrian granitic rock. The oldest Mesozoic rocks actually in depositional contact with Permian rocks in known exposures are red beds of presumed Late Triassic or Early Jurassic age in the Canelo Hills. The local relief on the erosion surface there may not have been great, inasmuch as the contact irregularities are minor, no basal conglomerate is present, and the lowest chert pebbles of Paleozoic origin in conglomerates intercalated in the red beds are well rounded. On the other hand, the red beds at several places in the Canelo Hills contain exotic blocks of Permian rock interpreted by Simons and others (1966) to be landslide debris from nearby hills. In the Huachuca Mountains Triassic or Jurassic volcanics overlie normally faulted Paleozoic rocks.

MESOZOIC DEPOSITIONAL HISTORY

Triassic and Jurassic Rocks

Three major units, two of them largely consisting of volcanic rocks and the third a medial red-bed unit, make up the oldest major division of Mesozoic rocks. These rocks are most abundant in the western part of the region, mainly in relatively small, faulted areas.

The older volcanic rocks, about 3,000 m thick, are typically represented by the Mount Wrightson Formation in the Santa Rita Mountains. Most of these volcanic rocks are rhyodacite, but andesitic rocks are common in the lower and upper fourths of the formation. Minor conglomerate is intercalated in the middle of the formation, and sandstone and quartzite lenses are scattered throughout and are abundant toward the top. The rhyodacite is intensely indurated and about half of it is finely flow-laminated. The rhyodacite contains, in addition to thick lava flows, welded tuff and agglomeratic tuff facies. The andesitic rock includes some vesicular flows and local pillow lavas. The larger lenses of sandstone and quartzite have sweeping crossbedding of the eolian type; grains are well sorted, largely well rounded and mostly of foreign origin but are admixed with locally derived volcanic detritus.

Similar rocks in a slightly thinner sequence form the Ox Frame Volcanics of the Sierrita Mountains and occur at several localities in the Patagonia Mountains.

The medial red-bed unit is typified by red beds of the lower member of the Canelo Hills Volcanics (Hayes and others, 1965) in the Canelo Hills, the similar Gardner Canyon Formation in the east-central part of the Santa Rita Mountains, and the Rodolfo Formation in the Sierrita Mountains. The Gardner Canyon Formation is estimated to be 600 m thick. The red beds consist of thick-bedded to massive mudstone and siltstone in which some sandstone, conglomerate and volcanics are intercalated. The pebbles of the conglomerate are chiefly chert (derived from Paleozoic formations) and volcanic material (presumably derived from the above-described Mount Wrightson Formation and similar rocks). The volcanic rocks in the red-bed unit are generally pale reddish-purple, finely porphyritic latite, dacite or andesite tuffs, flows and breccias.

Somewhat similar and possibly equivalent units occur in the Empire Mountains, in the Mustang Mountains, in the northern end of the Santa Rita Mountains and on the west and southwest flanks of the Sierrita Mountains. The Recreation Red Beds of Brown (1939) in the Tucson Mountains probably also represent the unit. The Walnut Gap Volcanics of the Little Dragoon Mountains area (Cooper and Silver, 1964) contain red beds which are provisionally correlated with these rocks.

These possibly correlative units vary in proportions of components. Red beds are a very minor constituent of the Walnut Gap Volcanics, whereas no true volcanic rocks—only volcanic sediments—are present in the unit on the west side of the Sierritas. The rocks in the Empire and Tucson mountains are less massive than those in the Canelo Hills and in the Gardner Canyon Formation. The rocks of the northern end of the Santa Rita Mountains contain more sandstone, grit and conglomerate than siltstone.

The youngest of the major units of Triassic and Jurassic age, with a composite thickness in excess of 2,000 m, is the upper part of the Canelo Hills Volcanics. These rocks have been recognized only in the Canelo Hills and the west flank of the Huachuca Mountains. Probable equivalents occur in the Mustang Mountains, may be represented by the formation of Pacheco Ranch (Drewes and Cooper, 1973) on the west side of the Sierrita Mountains, and possibly are represented in the Patagonia, Santa Rita and Empire mountains. The upper member consists of silicic flows, tuffs and some clastic rocks. The rhyolitic lava resembles the flow-laminated volcanic rocks of the Mount Wrightson Formation, but field relations in the Canelo Hills indicate that it is younger than red beds whose clasts include flow-laminated rhyolitic rock. Radiometric dates also indicate that the upper part of the Canelo Hills Volcanics is younger than the volcanic rocks of the Mount Wrightson Formation.

Age

The Mount Wrightson Formation is considered to be older than the Gardner Canyon Formation on the basis of a lead-alpha age determination of 220 m.y. made for volcanic rock in the Mount Wrightson Formation (fig. 2) and on the fact that the Gardner Canyon Formation, which has yielded a considerably younger lead-alpha age (fig. 2), in places contains cobbles of flow-banded volcanic rock identical in appearance to that in the Mount Wrightson Formation. Furthermore, the Ox Frame Volcanics on the west side of the Sierrita Mountains, which we believe to be equivalent to the Mount Wrightson Formation, are in depositional contact with Paleozoic rocks and are overlain by beds of the Rodolfo Formation which are tentatively correlated with the Gardner Canyon Formation. The age of the Mount Wrightson Formation is further supported by the fact that monzonite that is intrusive into the formation has yielded a lead-alpha age of 184(±) m.y. The monzonite, in turn, was intruded by a granite that has been dated by the potassium-argon and lead-alpha methods as of Middle Jurassic age (fig. 2).

Red beds of the lower member of the Canelo Hills Volcanics are considered to be older than rocks of the upper member of the Canelo Hills Volcanics on the basis of field relations (Hayes and others, 1965) and of a still-younger radiometric age in the overlying volcanics that was determined by a potassium-argon date for biotite from welded tuff (fig. 2). A minimum age for the Recreation Red Beds, which we correlated with the red beds of the Canelo Hills Volcanics and the Gardner Canyon Formation, is indicated by a potassium-argon date of 150 m.y. for an andesite porphyry that has intruded the formation (Damon and others, 1967). In several areas, superposition of beds alone dates many of these rocks as post-Early Permian and pre-late Early Cretaceous; in the Santa Rita Mountains, inclusion of clasts of the Triassic Mount Wrightson Formation in the Gardner Canyon Formation show the Gardner Canyon to be Late Triassic or younger.

Jurassic-Cretaceous Unconformity

Jurassic plutonic activity was followed by pronounced uplift and deep erosion to produce the Jurassic-Cretaceous unconformity. This unconformity places Cretaceous rocks on Jurassic granite in the Santa Rita, Patagonia, Huachuca, Dragoon and Mule mountains, and on other Triassic and (or) Jurassic rocks in the Sierrita, Huachuca and Empire mountains, in the Dragoon Mountains area, and possibly in the Tucson Mountains. Relief on the unconformity is considerable in many areas; it amounts to hundreds of meters in the Mule Mountains, and is at least 300 m locally in the Santa Rita and Huachuca mountains. Arkosic conglomerate filling old canyons in those ranges is at least as coarse as the most recent piedmont gravel in the same areas.

Lower Cretaceous Rocks

During Early Cretaceous time two groups of rocks were deposited in the region: (1) an older relatively local group of volcanic and associated sedimentary rocks, and (2) a younger, widespread, thick group of sedimentary rocks, the Bisbee Group and its correlatives.

Volcanic and Associated Sedimentary Rocks

Volcanic and sedimentary rocks of the older group are the combined Temporal and Bathtub formations, each about 600 m thick, of the southeastern flank of the Santa Rita Mountains. Rocks similar in lithology and comparable in age to at least the youngest part of the sequence in the Santa Ritas occur in the Glance Conglomerate of the Bisbee Group (Hayes, 1971b) in the Huachuca Mountains. In the Santa Rita Mountains, these rocks consist of roughly equal amounts of epiclastic rock, rhyolitic tuffs and flows, and andesitic or dacitic volcanics. A minor unconformity separates the two formations there, and the basal part of each formation contains lenticular and locally very thick bodies of coarse conglomerate. Some of these conglomerates are arkoses derived wholly of detritus of Jurassic granite; others contain abundant Precambrian granitic rocks. Such deposits indicate the large amounts of local uplifting and presumably faulting that occurred between Middle Jurassic and earliest Cretaceous time.

The volcanic rocks are also highly lenticular. Some groups of andesitic flows or volcanic breccia as much as 300 m thick extend only 3 to 5 km. Most rhyolitic rock is tuff and tuff breccia, but some welded tuff and lava are present. The volcanic rocks are everywhere so intensely altered that radiometrically datable minerals are destroyed, and zircon sufficiently abundant to provide material for dating was found only in a tuff immediately overlying Jurassic granite. A Jurassic date determined thereon, while not impossible considering the large range of possible error assigned the results, is suspect because of the likelihood that the tuff flow could have picked up its zircon from granite grus over which it flowed.

In the Huachucas, this sequence of volcanic rocks and conglomerates rests unconformably on the Canelo Hills Volcanics, is apparently conformable with overlying rocks in the Bisbee Group, and thus is dated geologically as of probable Early Cretaceous age.

Bisbee Group and Correlative Rocks

Sedimentary rocks of Early Cretaceous age are widely distributed in southeastern Arizona (fig. 1) and are 3,000 m thick or more in some areas. Throughout the region they are made up largely of clastic sediments deposited in a subaerial environment, but rocks of marine origin make up a significant part of the sequence in the southeastern part of the region. Locally, thick conglomerates at the base of the sequence are dominantly fanglomerates. Most of the Lower Cretaceous strata, however, are believed to represent part of a large delta complex on the margin of a sea that existed to the southeast, mostly in Mexico. In the northwest, marine rocks are supplanted by brackish-water facies and the continental rocks are more arkosic. For the purposes of this paper is is convenient to divide the region into southeastern, northeastern, southwestern, central and northwestern areas.

Southeastern area

In the Mule Mountains and Huachuca Mountains (Hayes, 1970b), all of the Lower Cretaceous strata are assigned to the Bisbee Group, which is made up of four formations: the Glance Conglomerate at the base, the Morita Formation, the Mural Limestone, and the Cintura Formation. The Morita and Cintura Formations are made up mostly of repeated sequences of pinkish-gray, arkosic, cross-laminated sandstones that grade upward into massive grayish-red siltstones and mudstones. The Mural Limestone is a fossiliferous marine unit. The Bisbee Group is as much as 1,700 m thick in the Mule Mountains and ranges from nearly 1,800 m to about 3,000 m thick in the Huachucas.

In the Pedregosa and southern Chiricahua mountains, the Bisbee Formation is about 2,400 m thick and is divisible into four units that, except for the greater prevalence of marine rocks, are roughly comparable to the formations in the Mule Mountains (Epis, 1952).

Northwestern area

In the Dragoon (Gilluly, 1956), Little Dragoon (Cooper and Silver, 1965), and Dos Cabezas (Sabins, 1957) mountains, no significant marine units are present and the Bisbee can be treated as a formation similar in lithology to the Morita and Cintura Formations of the Mule Mountains; a distinct basal conglomerate member is generally present. The formation may be more than 4,500 m thick at one locality in the Dragoon Mountains.

Southwestern area

About 1,000 m of rocks assigned to the Bisbee Formation are present in the Patagonia Mountains (Simons, 1972). Bisbee-like rocks are also present in ranges to the west of the Patagonias.

Central area

Rocks that are correlative in large part with the Bisbee Group of the Mule Mountains are present in the Whetstone Mountains and were called the Bisbee(?) Formation by Creasey (1967). The sequence there is at least 2,000 m thick and may be hundreds of meters thicker; it was divided into four stratigraphically distinct subunits by Tyrrell (1957) and Schafroth (1968). The four units in ascending order are the Willow Canyon, Apache Canyon, Shellenberger Canyon and Turney Ranch formations. Schafroth (1968) and Hayes (1970a) correlated the Willow Canyon Formation with the Morita Formation, the Apache Canyon Formation with the Mural Limestone, and the Shellenberger Canyon Formation with the Cintura Formation; the Turney Ranch Formation was considered to be younger than the Cintura. The rocks of the Whetstone Mountains are generally similar to those in the Mule Mountains but apparently represent a more landward facies. Marine limestone is rare, but thin-bedded limestone of fresh- to brackish-water origin is relatively abundant in the Apache Canyon Formation. Much of the sandstone in the Whetstones is more arkosic than to the southeast.

The Lower Cretaceous sequence in the Empire Mountains (Finnell, 1971) and in the northern part of the Santa Rita Mountains (Drewes, 1971) is similar to that in the Whetstones, and the same subunits are recognizable. In the northern part of the Empires, the basal hundreds of meters of the sequence is in apparent onlap relations with what T. L. Finnell (oral commun., 1967) believes was a rising highland of Precambrian rock (see Bilodeau, this guidebook).

Northwestern area

Hundreds of meters of strata in the Tucson Mountains in the Amole Arkose of Brown (1939) are very similar to Lower Cretaceous strata of the Whetstone, Empire and northern Santa Rita mountains and are undoubtedly general correlatives. Rocks similar to the Amole Arkose are present in the Angelica Arkose of the Sierrita Mountains (Cooper, 1971) and in the Cocoraque Formation of the Roskruge Mountains (Heindl, 1965).

Age

Collections of marine invertebrates from the Mural Limestone in and near the Mule Mountains and reported on by T. W. Stanton (*in* Ransome, 1904), Stoyanow (1949), J. B. Reeside, Jr. (*in* Gilluly, 1956) and Douglass (1960) strongly indicate a correlation of the Mural with the Trinity Group of Texas. Fossils collected by Stoyanow (1949) and during our studies from the Mural in the Huachuca Mountains also indicate a Trinity age, as do fossils from limestones in the Bisbee Group in the Pedregosa Mountains. The entire Bisbee Group in those areas may represent much of Aptian and Albian time. Fossils reported by Tyrrell (1957) in the Whetstone Mountains and by Stoyanow (1949) in the Patagonia Mountains also suggest an Albian age. Fossils collected by Brown (1939) and Kinnison (1958) from the Amole Arkose in the Tucson Mountains are not as definitive; correlation in part, if not all, of that formation with the similar strata of the Whetstones is done on the basis of lithology.

Mid- to Late Cretaceous Unconformity

Uplift and erosion again followed deposition of the Bisbee Group and equivalent rocks. A mid- to Late Cretaceous unconformity has been described in southeastern Arizona by Darton (1925), Epis (1952) and Gilluly (1956). Such an unconformity is demonstrable in the Santa Rita, Huachuca and Pedregosa mountains and in the Canelo Hills, where sedimentary rocks of Late Cretaceous age overlie the Bisbee and contain fragments of Bisbee, gently truncate some beds at the top of the Bisbee, or truncate faults in the Bisbee. In other areas, Upper Cretaceous volcanic rocks overlie gently to isoclinally folded Lower Cretaceous rocks.

In many areas the relief of the mid- to Late Cretaceous unconformity is not large, for little of the upper part of the Bisbee, as it is known in the type section, is missing. In other areas, however, as in the Serrita Mountains, rocks of Jurassic and probably Triassic age underlie Upper Cretaceous volcanic rocks (Cooper, 1971). Similarly, at the north end of the Empire Mountains, Upper Cretaceous volcanic rocks overlie rocks assigned to the Precambrian (Finnell, 1971). Inasmuch as Upper Cretaceous basal conglomerates in many places contain clasts identifiable as having been derived from Triassic, Jurassic and even Paleozoic rocks, other areas probably exist, that are either not exposed or not yet discovered, in which Lower Cretaceous rocks had been removed before Upper Cretaceous rocks were deposited.

Upper Cretaceous Rocks

Lower Sedimentary Sequence

Sedimentary rocks of Late Cretaceous age lie with slight (and local?) angular unconformity upon the Bisbee Group and lie with probable conformity beneath latest Cretaceous volcanic rocks in a few ranges in the region. This sequence of rocks, though locally of great thickness, is not as widely distributed as are the Lower Cretaceous rocks or the Upper Cretaceous volcanic rocks.

The best known of these Upper Cretaceous sedimentary rocks are included in the Fort Crittenden Formation of the east side of the Santa Rita Mountains (Drewes, 1971). At the base of the sequence there, unconformable with the underlying Bisbee Group, is a lenticular conglomerate made up dominantly of well-rounded cobbles of lower Mesozoic volcanic and sedimentary rocks. Above this is a 160-m-thick sequence of gray shale and subordinate siltstone in which are found a varied fauna including fresh-water mollusks, fish, turtles and dinosaurs of Santonian to Maestrichtian Age (Miller, 1964). Above this fossiliferous shale unit in the Adobe Canyon area is more than 1,800 m of variable grayish-red and brown conglomerate, arkosic sandstone and subordinate shale. High in the unit are several thin rhyolitic tuff beds.

The Fort Crittenden Formation also overlies the Bisbee Group on the west side of the Huachuca Mountains. Locally conglomerates are dominant in the basal 180 m of the unit. These are overlain by a sequence, at least 210 m thick, of shale and graywacke that contains fresh-water mollusks similar to those in the shale and sandstone of the Santa Rita Mountains.

Discontinuous exposures of the Fort Crittenden Formation extend for several kilometers along the northeast side of the Canelo Hills. There conglomerates similar to those in the upper part of the Fort Crittenden Formation of the Santa Ritas overlie the shale and siltstone member. On the southwest side of the Canelo Hills, beds of sandstone, conglomerate, shale and minor tuff are overlain by Upper Cretaceous andesite breccia. These may represent the top of the Fort Crittenden Formation.

In the Rucker Canyon area of the Pedregosa and Chiricahua mountains, Epis (1952) described a sequence at least 1,200 m thick that consists dominantly of well-rounded conglomerates that rest unconformably on the Bisbee Group and appear to grade up into andesites. Those conglomerates, which are derived from the Bisbee and from Paleozoic formations, are undoubtedly roughly equivalent to the Fort Crittenden Formation.

Part of the Bisbee Formation as mapped by Gilluly (1956) between Courtland and South Pass in the Dragoon Mountains contains beds of volcanic-clast conglomerate and may also be correlative with the Fort Crittenden Formation.

Local thin conglomerate units at the base of the Tucson Mountain Chaos of Kinnison (1959) occur in a similar stratigraphic position in the Tucson Mountains and are here considered as possible equivalents to beds high in the Fort Crittenden Formation. Richard and Courtright (1960) have previously correlated the Tucson Mountain Chaos with thin conglomerate and breccia units that locally appear conformably beneath Upper Cretaceous andesites in the Empire Mountains and elsewhere in the region.

The Fort Crittenden Formation of the Huachuca and Santa Rita mountains is similar to, and was probably once coextensive with, dated Upper Cretaceous strata described by Taliaferro (1933) in the Cabullona area in Mexico, several kilometers southwest of Douglas, Arizona.

The presence of terrestrial vertebrates and fresh-water invertebrates, together with the character and distribution of the conglomerates and other sediments, suggests that the Fort Crittenden Formation and correlative strata were deposited locally in subaerial valleys cut on the Bisbee Formation or Group and older rocks after an orogenic episode. The principal drainage direction was probably southeastward toward the Late Cretaceous Mexican geosyncline.

Upper volcanic sequence

The youngest of the major units of Mesozoic rock consists of distinctive andesite to dacite breccia, rhyodacite tuff and welded tuff, and a little sedimentary rock, having a combined thickness of as much as 1,400 m. These rocks, the Salero Formation, conformably overlie the Fort Crittenden Formation in the Santa Rita Mountains (Drewes, 1971); volcanic strata in the Pedregosa Mountains (Epis, 1952) also conformably overlie rocks correlative with the Fort Crittenden Formation. In other areas, presumably old high areas between the major valleys in which the Fort Crittenden Formation and correlatives were deposited, the volcanic rocks unconformably overlie Lower Cretaceous or older rocks. Our regional correlations of these Upper Cretaceous volcanic units are basically similar to earlier correlations by Richard and Courtright (1960), although they considered the rocks to be of Tertiary age. Our chief contribution here is to briefly describe these rocks in areas not described by them (Richard and Courtright, 1960).

The Salero Formation of the Santa Rita Mountains contains a basal member of dacitic breccia and rhyodacitic welded tuff and a capping unit of sedimentary and tuffaceous rock. In ascending order, there is as much as 120 m of flows, 300 m of dacitic breccia, 360 m of rhyodacitic welded tuff and at least 650 m of sedimentary and tuffaceous rock. The dacitic breccia grades laterally into an arkose and arkosic conglomerate facies, where it overlies a rugged old erosion surface cut on granite. The fragments in the breccia are set in a matrix of pulverized dacitic material, and scattered throughout the dacitic debris are blocks of exotic material as much as 450 m across. Similar exotic blocks appear in a correlative andesitic or dacitic breccia in the Tucson Mountains, the Tucson Mountains Chaos. Similar breccias are characteristic of the Demetrie Volcanics in the Sierrita Mountains, volcanic rocks of Dove Canyon in the Canelo Hills (Simons, 1972), the lower parts of the Sugarloaf Quartz Latite and Bronco Volcanics of the Dragoon Mountains region (Gilluly, 1956), and andesites mapped by Epis (1952) in the Pedregosa Mountains. Such breccias are also present in the Empire Mountains (Finnell, 1971).

The overlying rhyodacite welded tuff of the Salero Formation is a brownish-gray to greenish-gray massive unit in which separate cooling units have not been recognized. It is a crystal tuff with abundant, commonly chloritized book biotite. Similar welded tuff forms the Cat Mountain Rhyolite of Brown (1939) in the Tucson Mountains. Nonwelded rhyolite tuff of the Red Boy Rhyolite in the Sierrita Mountains and the upper parts of the Sugarloaf Quartz Latite and Bronco Volcanics of the Dragoon Mountains region are probably equivalent. Tuff in a similar stratigraphic position also occurs in the Empire Mountains.

The lowest member of the Salero Formation seems to have few counterparts in the region. The uppermost member, however, underlies an area in the extreme southwestern part of the Santa Rita Mountains and is found in the Ruby quadrangle west of Nogales. The uppermost member consists of alternating tuffaceous sandstone, volcanic conglomerate, tuff breccia, agglomerate and some red beds, largely metamorphosed to hornfels by intrusives of late Late Cretaceous age.

Samples of these Upper Cretaceous volcanic rocks from the Tucson and Santa Rita mountains, Canelo Hills, and elsewhere have been dated using the potassium-argon method by Bikerman and Damon (1966) and by U.S. Geological Survey laboratory personnel (fig. 2). The dates obtained verify the inferred Late Cretaceous age of at least the volcanic rocks of the Salero Formation, which conformably rest on the Fort Crittenden Formation of known Late Cretaceous age.

The youngest Mesozoic rocks of the region are plutonic rocks, commonly diorite or granodiorite but including some coarse-grained quartz monzonite. Their emplacement was followed in the Paleocene and Eocene by intrusion of more quartz monzonite, granodiorite and, commonly, quartz latite porphyry, including many of the ore-associated bodies of the region.

SUMMARY

The Mesozoic history of southeastern Arizona was complex and varied. In Triassic and Early Jurassic time, the region experienced at least two periods of volcanic activity, apparently separated by a period of plutonism. A more widespread period of plutonism and uplift ensued in Middle Jurassic time. During Late Jurassic and earliest Cretaceous time, the region was subjected to erosion. After a brief period of local volcanic activity, the late Early Cretaceous sea advanced from the south and southeast and the region received deposition of a thick deltaic sequence. In early Late Cretaceous time, regional uplift and another phase of orogeny occurred. The resulting mountainous area was eroded and fluviatile sediments were deposited in valley areas tributary to the sea to the southeast. Widespread volcanic activity followed and was finally succeeded by another episode of plutonism at the end of the Cretaceous.

REFERENCES

Bikerman, Michael, and Damon, P. E., 1966, K/Ar chronology of the Tucson Mountains, Pima County, Arizona: Geol. Soc. America Bull., v. 77, p. 1225-1234.

Brown, W. H., 1939, The Tucson Mountains—An Arizona Basin Range type: Geol. Soc. America Bull., v. 50, p. 697-759.

Cooper, J. R., 1971, Mesozoic stratigraphy of the Sierrita Mountains, Pima County, Arizona: U.S. Geol. Survey Prof. Paper 658-D, 42 p.

Cooper, J. R., and Silver, L. T., 1964, Geology and ore deposits of the Dragoon quadrangle, Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 416, 196 p.

Creasey, S. C., 1967, Geologic map of the Benson quadrangle, Cochise and Pima Counties, Arizona: U.S. Geol. Survey Misc. Inv. Map I-470.

Damon, P. E., and others, 1967, Correlation and chronology of ore deposits and volcanic rocks; Annual progress report No. COO-689-76 to Research Division, United States Atomic Energy Commission: Unpublished report by Geochemical Section, Geochronology Laboratories, Tucson, Univ. Ariz., 82 p.

Darton, N. H., 1925, A résumé of Arizona geology: Arizona Univ. Bull. 119, Geol. Ser., no. 3, 298 p.

Douglass, R. C., 1960, The foraminiferal genus Orbitolina in North America: U.S. Geol. Survey Prof. Paper 333, 50 p.

Drewes, Harald, 1971, Mesozoic stratigraphy of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Survey Prof. Paper 658-C, 81 p.

Drewes, Harald, and Cooper, J. R., 1973, Reconnaissance geologic map of the west side of the Sierrita Mountains, Palo Alto Ranch quadrangle, Pima County, Arizona: U.S. Geol. Survey Misc. Field Stud. Map MF-538.

Epis, R. C., 1952, Geology of the Pedregosa Mountains, Cochise County, Arizona [Ph.D. dissertation]: Berkeley, Univ. California, 263 p.

Finnell, T. L., 1971, Preliminary geologic map of the Empire Mountains quadrangle, Pima County, Arizona: U.S. Geol. Survey Open-File Map, 2 sheets.

Gill, J. R., and Cobban, W. A., 1966, The Red Bird section of the Upper Cretaceous Pierre Shale in Wyoming: U.S. Geol. Survey Prof. Paper 393-A, 73 p.

Gilluly, James, 1956, General geology of central Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 281, 169 p.

Hayes, P. T., 1970a, Cretaceous paleogeography of southeastern Arizona and adjacent areas: U.S. Geol. Survey Prof. Paper 658-B, 42 p.

———— 1970b, Mesozoic stratigraphy of the Mule and Huachuca Mountains, Arizona: U.S. Geol. Survey Prof. Paper 658-A, 28 p.

Hayes, P. T., and Drewes, Harald, 1968, Mesozoic sedimentary and volcanic rocks of southeastern Arizona: Arizona Geol. Soc. Guidebook III, p. 49-58.

Hayes, P. T., and Raup, R. B., 1968, Geologic map of the Huachuca and Mustang Mountains, southeastern Arizona: U.S. Geol. Survey Misc. Inv. Map I-509.

Hayes, P. T., Simons, F. S., and Raup, R. B., 1965, Lower Mesozoic extrusive rocks in southeastern Arizona—The Canelo Hills Volcanics: U.S. Geol. Survey Bull. 1194-M, 9 p.

Heindl, L. A., 1965, Mesozoic formations in the Comobabi and Roskruge Mountains, Papago Indian Reservation, Arizona: U.S. Geol. Survey Bull. 1194-H, 15 p.

Holmes, Arthur, 1965, Principles of physical geology, 2d ed.: New York, The Ronald Press, 1288 p.

Kinnison, J. E., 1958, Geology and ore deposits of the southern section of the Amole mining district; Tucson Mountains, Pima County, Arizona [M.S. thesis]: Tucson, Univ. Ariz., 123 p.

———— 1959, Chaotic breccias in the Tucson Mountains, Arizona: Arizona Geol. Soc. Guidebook II, p. 48-57.

Miller, H. W., Jr., 1964, Cretaceous dinosaurian remains from southern Arizona: Jour. Palentology, v. 38, p. 378-384.

Ransome, F. L., 1904, Geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Prof. Paper 21, 168 p.

Richard, K. E., and Courtright, J. H., 1960, Some Cretaceous-Tertiary relationships in southeastern Arizona and New Mexico: Arizona Geol. Soc. Digest, v. 3, p. 1-7.

Sabins, F. F., Jr., 1957, Stratigraphic relations in Chiricahua and Dos Cabezas Mountains, Arizona: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 466-510.

Schafroth, D. W., 1968, Stratigraphy of some Cretaceous formations of southeastern Arizona: Ariz. Geol. Soc. Guidebook III, p. 59-67.

Simons, F. S., 1972, Mesozoic stratigraphy of the Patagonia Mountains and adjoining areas: U.S. Geol. Survey Prof. Paper 658-E, 23 p.

Simons, F. S., Raup, R. B., Hayes, P. T., and Drewes, Harald, 1966, Exotic blocks and coarse breccias in Mesozoic volcanic rocks of southeastern Arizona: U.S. Geol. Survey Prof. Paper 550-D, p. D12-D22.

Stoyanow, A. A., 1949, Lower Cretaceous stratigraphy in southeastern Arizona: Geol. Soc. America Mem. 38, 169 p.

Taliaferro, N. L., 1933, An occurrence of Upper Cretaceous sediments in northern Sonora, Mexico: Jour. Geology, v. 41, p. 12-37.

Tyrrell, W. W., Jr., 1957, Geology of the Whetstone Mountains area, Cochise and Pima Counties, Arizona [Ph.D. dissertation]: New Haven, Yale Univ., 171 p.

Van Eysinga, F. W. B., 1975, Geological time table, 3rd ed.: Amsterdam, Elsevier Scientific Pub. Co.

New Mexico Geol. Soc. Guidebook, 29th Field Conf., Land of Cochise, 1978

THE GLANCE CONGLOMERATE, A LOWER CRETACEOUS SYNTECTONIC DEPOSIT IN SOUTHEASTERN ARIZONA

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INTRODUCTION

The middle Mesozoic tectonic environment of southeastern Arizona is poorly understood. Although recent regional syntheses by Drewes (1978) and Titley (1976) have added to our knowledge of the Mesozoic tectonic evolution of this region, much is still unclear. Titley (1976) recognized the presence of a major pre-Laramide, northwest-trending tectonic grain in southeastern Arizona and compiled evidence, primarily of an indirect nature, for vertical tectonic movements during the middle Mesozoic. The geologic structures that define this tectonic pattern are extremely discontinuous and obscure and require further investigation and documentation. Study of clastic sedimentary rocks deposited during this episode of crustal instability greatly clarifies the nature of these structural features and of the accompanying deformation. The most instructive clastic sedimentary deposit of middle Mesozoic age in the region is the Glance Conglomerate.

The Glance Conglomerate is a Lower Cretaceous alluvial fan deposit which provides a direct sedimentary record of extensive erosion associated with pronounced vertical displacements along various exposed and inferred normal faults. These relationships are especially well displayed in the southern Mule Mountains and in the Empire Mountains. In the Santa Rita Mountains, Drewes (1971, 1972) has also related the deposition of coarse conglomerate to Early Cretaceous normal faulting. The syntectonic nature of the Glance Conglomerate makes it a valuable key to understanding the mid-Mesozoic tectonic environment of southeastern Arizona.

GEOLOGIC SETTING

Sedimentary rocks of late Early Cretaceous age are widespread in southeastern Arizona, southwestern New Mexico and northern Mexico. These rocks comprise a thick sequence, over 3500 m, of shale, sandstone, conglomerate and limestone mapped as the Bisbee Group or various local units that are correlative with the Bisbee Group. The type section for the Lower Cretaceous is located in the Mule Mountains near the town of Bisbee. Ransome (1904) divided the strata into four units, the Glance Conglomerate at the base, the Morita Formation, the Mural Limestone, and the Cintura Formation at the top. Due to marked lateral facies changes within the Bisbee Group, Lower Cretaceous rocks exposed in mountain ranges to the north and west of Bisbee do not fit well into this classification scheme.

A major portion of the Bisbee Group in the southeastern part of the region is of marine origin and of Aptian to Albian age. The Mural Limestone is a relatively thick-bedded, fossiliferous, shallow marine limestone, and both the upper Morita and lower Cintura Formations contain marine sandstone and shale. Strata both above and below the marine interval are mainly fluvial. To the west and north the proportion of limestone decreases and to the northwest the only carbonates present are thin-bedded, silty, brackish water limestones. The sandstones of the Bisbee Group become more feldspathic or arkosic to the west (Hayes, 1970b). To the southeast in Mexico, Lower Cretaceous marine rocks increase in thickness and dominate the section (Cordoba and others, 1971; Greenwood and others, 1977).

The marine facies of the Bisbee Group represents the transgression and regression of an Early Cretaceous shallow marine sea which deepened to the southeast. This marine basin had a definite northwesterly linear trend; it received clastic and carbonate sediment in northern Mexico during the Late Jurassic before transgressing northwestward into southeastern Arizona in the late Early Cretaceous (Cordoba and others, 1971; deCserna, 1971; Hayes, 1970b; Beauvais and Stump, 1976).

The basal unit of the Bisbee Group, the Glance Conglomerate, is not directly related to the transgressive facies of this marine sea. The Glance Conglomerate is predominantly a coarse fanglomerate and was deposited on alluvial fans in local basins bounded on at least one side by normal faults. This synorogenic, unfossiliferous, nonmarine deposit is related to substantial vertical tectonic movements which preceded moderately stable crustal conditions and the transgression of the late Early Cretaceous shallow marine sea from the southeast.

Deposition of the Glance Conglomerate took place in a dramatically different tectonic as well as depositional environment from that of most of the overlying strata in the Bisbee Group. Analysis of the Glance Conglomerate both regionally and in detail at two well exposed localities allows for substantial insight into the mid-Mesozoic structural evolution of southeastern Arizona.

GENERAL STRATIGRAPHY

The Glance Conglomerate was first described by Dumble (1902) in the southern Mule Mountains. Recent work on the Glance Conglomerate (Hayes, 1970, 1970b; Drewes, 1971; Bilodeau, 1977, 1978) and extensive local and quadrangle mapping by university students, professors and most recently by U.S. Geological Survey geologists, has greatly expanded the knowledge of its distribution and character. Regionally the Glance Conglomerate varies widely in thickness, composition, texture, contact relationships and possibly even in age. The widely scattered outcrop distribution of this formation is shown in Figure 1.

The Glance Conglomerate was deposited with major unconformity on rocks ranging in age from Jurassic to Precambrian. Typically the Glance Conglomerate unconformably overlies late Paleozoic limestone at one locality, yet only a short distance away rests directly on Precambrian schist or granite. Locally it may overlie limited exposures of Triassic or Jurassic volcanic rocks and redbeds or Jurassic granite. The Glance also

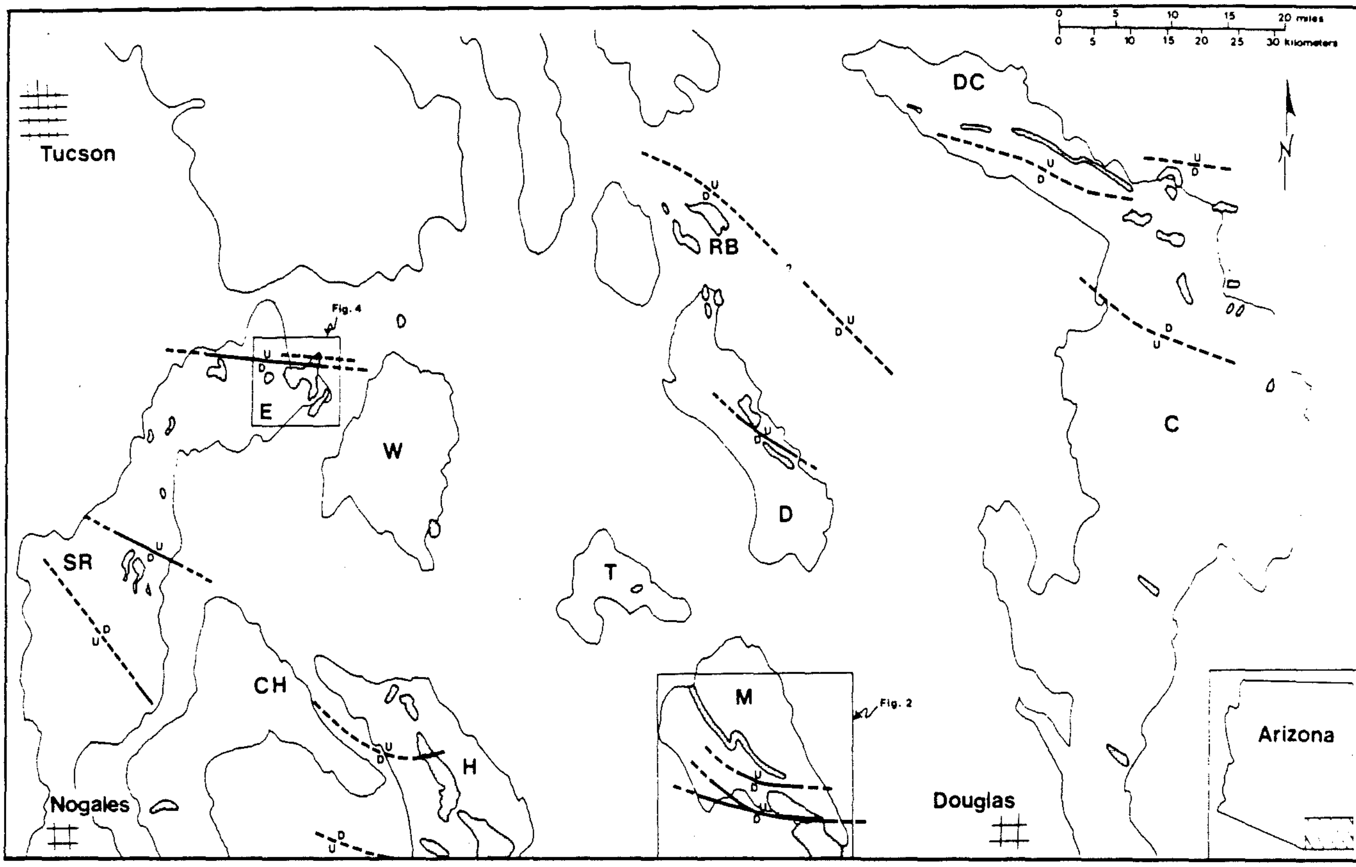

Figure 1. Distribution of Glance Conglomerate and equivalent rocks in southeastern Arizona. Also shown are the known and inferred faults associated syntectonically with these fanglomerate deposits. (SR) Santa Rita Mtns., (E) Empire Mtns., (W) Whetstone Mtns., (CH) Canelo Hills, (H) Huachuca Mtns., (T) Tombstone Hills, (M) Mule Mtns., (D) Dragoon Mtns., (RB) Red Bird Hills, (DC) Dos Cabezas Mtns., (C) Chiricahua Mtns.

ranges in thickness from less than one to over 1000 m, with large variations over short distances.

Compositionally, the Glance Conglomerate consists of poorly sorted and poorly rounded cobble to boulder conglomerate and breccia containing clasts of Paleozoic limestone and quartzite, Mesozoic volcanic rocks, Jurassic granite and Precambrian schist and granite. This assortment of clast types varies both regionally and within local outcrop areas. Where the Glance is thin (1-10 m), it is usually a monomictic conglomerate with a clast composition which reflects that of the underlying formation. Where relatively thick, it is a polymictic conglomerate with vertical variations in clast composition that define specific clast assemblages and frequently give the formation a locally consistent internal stratigraphy.

These various mappable lithofacies units are named for the composition of the most abundant clast type within the specific assemblage. Consequently, limestone, quartzite, volcanic, schist and granite-clast lithofacies are developed as well as some distinct lithofacies that contain two or more clast types. Locally the boundary between two lithofacies is sharp, although a gradational contact is much more common. The internal stratigraphy of lithofacies units consistently reflects the exposure and erosion of progressively older pre-Cretaceous formations within its source areas. The vertical sequence of clast assemblages thus presents an inverted stratigraphy of the eroded source terrane, typically involving the entire Paleozoic section and part of the Precambrian.

Texturally the Glance Conglomerate is highly variable. Textures ranging from very poorly sorted, matrix-supported, disorganized conglomerate to relatively well-sorted, though bimodal, clast-supported, well-bedded conglomerate are found. Typically the matrix-supported conglomerate contains angular to subangular clasts with a muddy matrix, is poorly sorted, poorly bedded and makes up a major part of the formation where it is relatively thick. Large boulders 1 to 2 m across are often found scattered throughout the section. Cut-and-fill channel structures are also found. Where the Glance Conglomerate is thin, the clasts are subrounded and have a clast-supported, commonly well-ordered fabric. Similar beds are frequently interbedded with the matrix-supported conglomerate layers as well as with beds and stringers of sandstone.

ENVIRONMENT OF DEPOSITION

The poorly sorted, rather disorganized nature of the matrix-supported conglomerate, plus the large boulders, the fine-grained matrix, and the cut-and-fill channels suggest that these are debris-flow deposits. The better sorted, better rounded, clast-supported conglomerates with oriented fabric are examples of fluvial traction-flow deposits (Bull, 1972; Walker, 1975). The intimate association of these two types of deposits, along with the thickness variations and lithofacies changes suggest that the Glance Conglomerate was deposited subaerially on alluvial fans along actively rising mountain fronts. Paleoflow directions from clast imbrications, channel orientations and oriented clast fabrics support this interpretation.

Glance Conglomerate of the Mule Mountains

The Glance Conglomerate in the Mule Mountains is principally exposed in two broad outcrop bands southeast of Bisbee and in one long, thin band to the north (fig. 2). The three outcrop areas are restricted to discrete structural blocks separated by faults and have characteristics unique to the Glance Conglomerate of each particular block. The thickness of the formation is significantly different on each of the structural blocks, and differences in clast composition, subjacent rock type and degree of rounding of the clasts are also notable. The two essentially west-trending faults that separate these blocks are the Dividend fault on the north and the Abrigo-Bisbee-West fault complex to the south.

The Glance Conglomerate in the Mule Mountains can be divided into three gradational lithofacies units, a schist-clast facies, a limestone-clast facies and a mixed-clast facies. This internal stratigraphy is fully developed only in the southernmost structural block, while the schist-clast facies is the only lithofacies present in the central and northern blocks.

North of the Dividend fault the Glance Conglomerate unconformably overlies either Jurassic Juniper Flat Granite or Precambrian Pinal Schist. Nowhere within this northern structural block is the Glance more than 30 m thick, and locally it is absent. Compositionally, all of the Glance Conglomerate in this block is classified as schist-clast facies even though the number of pink granitic clasts is greater than Pinal Schist clasts where the formation directly overlies Juniper Flat Granite. The clasts are mostly subrounded cobbles and pebbles composing a clast-supported framework set in a reddish-brown sandy matrix.

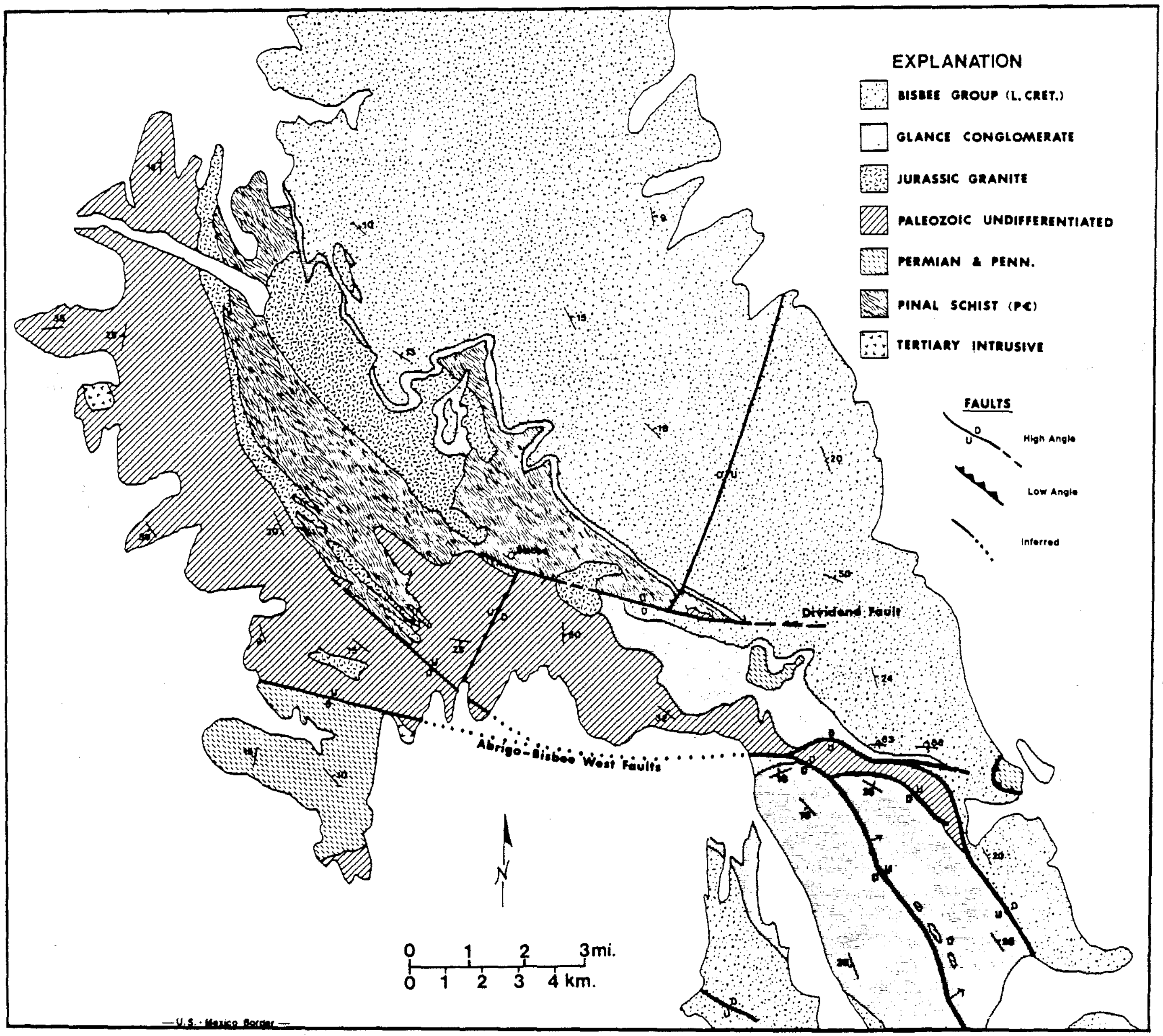

Figure 2. Geologic sketch map of the Mule Mountains (modified from Hayes and Landis, 1964).

South of the Dividend fault but north of the Abrigo-Bisbee-West faults, the Glance Conglomerate increases in thickness to 100-200 m and unconformably overlies late Paleozoic limestone. All of the Glance Conglomerate in this block also belongs to the schist-clast facies even though quartzite clasts become abundant in the lower half of the section. At the base of the section a thin limestone breccia grades up into schist-quartzite conglomerate. The Glance Conglomerate here has both matrix-supported and clast-supported zones with frequent large schist boulders.

In the southern structural block, south of the Abrigo-Bisbee-West faults, the Glance is at least 1000 m thick. This abrupt increase in thickness correlates with an increase in the diversity of clast types. Here three distinct lithofacies can be delineated. At the base of the section where the Glance rests unconformably on late Paleozoic limestone, a limestone-clast facies is developed. Minor, though locally abundant, clasts of red silicic volcanic rock, dolomite, chert and sandstone are found with the subangular to angular limestone clasts in this lithofacies. Gradationally above this unit is the mixed-clast facies where limestone clasts are of equal significance to quartzite and chert clasts. Quartzite clasts are subrounded and are derived primarily from Cambrian Bolsa Quartzite. Limestone and dolomite clasts come from a wide variety of Paleozoic formations, with cobbles from the Horquilla, Escabrosa and Martin Formations especially recognizable.

The mixed-clast facies grades vertically into schist-clast facies which is found in both structural blocks to the north. The transition zone is very thick and as is the case in the central structural block, there are abundant subrounded quartzite clasts present in the lower part of the schist-clast facies. Conglomerate beds of the schist-clast facies grade up into and interfinger laterally with sandstone and siltstone of the lower Morita Formation.

As shown in Figure 3, the lithofacies changes and the southward increase in thickness of the Glance Conglomerate clearly demonstrate that the Dividend fault and the Abrigo-Bisbee-West fault system were active during the time of Glance deposition. This interpretive cross-section has been greatly simplified, for reactivation of these faults and initiation of others during later Cretaceous and Tertiary deformation has complicated the present structural picture. Bryant and Metz (1966) were the first to note that the Dividend fault controlled much

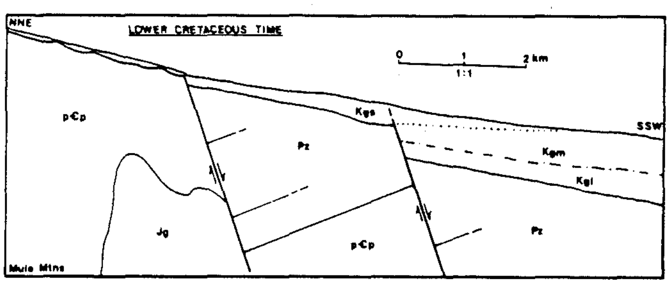

Figure 3. Schematic cross-section across the Dividend and Abrigo-Bisbee-West faults in the southern Mule Mountains showing the various lithofacies units within the Glance Conglomerate during Early Cretaceous time. (Kgs) Glance schist-clast lithofacies, (Kgm) Glance mixed-clast lithofacies, (Kgl) Glance limestone-clast lithofacies, (Pz) Paleozoic undifferentiated, (p€p) Precambrian Pinal Schist, (Jg) Jurassic Juniper Flat Granite.

of the diversity found in the Glance Conglomerate and reported it to have normal displacement down to the south of 1500 m.

Deposition of the Glance Conglomerate was by subaerial processes on alluvial fans that were built along the southern margin of a fault-block mountain range rising to the north. The complete Paleozoic section was eroded from this rising fault block and deposited in a subsiding graben-style basin to the south. The nature of the Glance Conglomerate and the low relief of the pre-Cretaceous unconformity north of the Dividend Fault suggest that a pediment was developed there before being covered by finer-grained, fluvial, lower Morita beds. Paleoflow data is in accord with this interpretation, showing consistent south to southwest flow directions.

Glance Conglomerate of the Empire Mountains

In the Empire Mountains the Glance Conglomerate is mainly exposed in the northeastern part of the mountain range. One outcrop belt runs along the east side of the range and another, somewhat less continuous band, across the northern side (fig. 4). The thickness varies from about 1000 m in northern exposures to less than 1 m or locally absent to the south. This gradual thinning southward is accompanied by lateral intertonguing of the Glance Conglomerate with overlying Willow Canyon Formation (Morita Formation equivalent).

Compositionally, the Glance Conglomerate can be separated into three lithofacies, a lower limestone-clast facies, a middle, transitional mixed-clast facies and an upper granitic-clast facies. The limestone-clast conglomerate facies consists of clast-supported subangular to subrounded cobbles and boulders of limestone, dolomite and minor chert bound in a

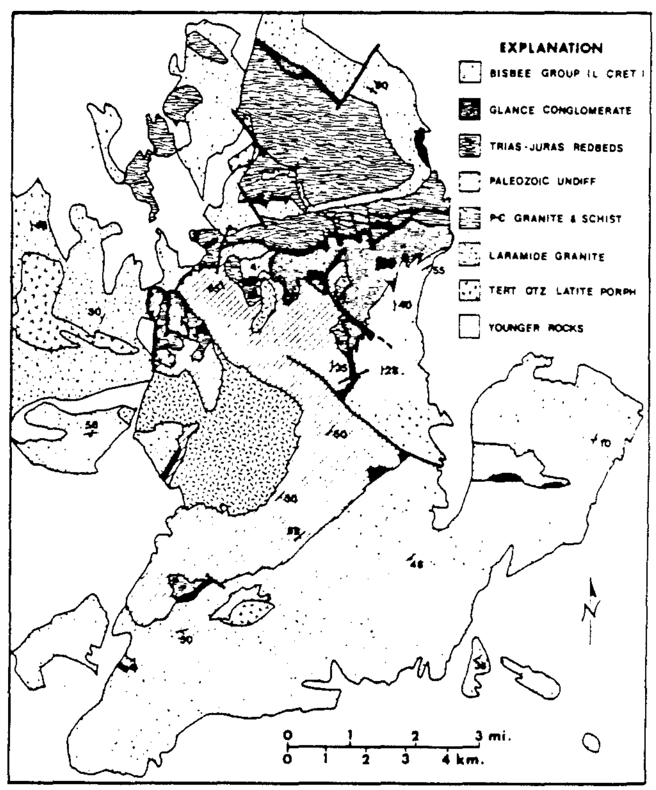

Figure 4. Geologic sketch map of the Empire Mountains (modified from Finnell, 1971).

matrix of reddish-brown to gray calcareous sandstone and siltstone. Boulders up to 3 m in diameter are common and large exotic blocks as much as 300 m long and 60 m wide of late Paleozoic limestone are found near the base of the unit. The limestone-clast facies ranges in thickness from less than 1 m to 120 m and rests unconformably upon late Paleozoic limestone or local exposures of redbeds of Triassic Gardner Canyon Formation or possible Triassic-Jurassic Canelo Hills Volcanics mapped by Finnell (1971).

The mixed-clast facies has a rather abrupt lower contact, formed by the sudden appearance of appreciable amounts of pink to light reddish-brown, angular to subangular Bolsa Quartzite fragments set in a matrix of reddish-brown sandstone and sandy mudstone. In the middle and upper sections of this facies granitic clasts become increasingly abundant. In general this mixed-clast facies is a quartzite-granite-limestone clast conglomerate and grades up into granitic-clast facies.

The granitic-clast lithofacies is restricted to the most northeastern section of the main outcrop area and scattered exposures of Glance Conglomerate further north. This facies rests either on the mixed-clast facies or unconformably on Precambrian granitic rocks. The lower part of this unit, where it overlies the mixed-clast facies, is gradational from a quartzite-granite clast conglomerate to a pure granitic-clast conglomerate composed primarily of Precambrian gneissic quartz diorite clasts set in a greenish-gray arkosic matrix. Where the granitic-clastic facies rests on Precambrian basement rocks, the composition is entirely Precambrian granitic fragments. The thickness of this facies ranges from 1 m to over 500 m.

These relationships are shown on the interpretive cross-section in Figure 5. Much local structural complexity has been simplified on this cross-section. Note that the geometry, inferred tectonic movements and syntectonic nature of the Glance Conglomerate are strikingly similar to that found in the Mule Mountains (fig. 3). The entire Paleozoic section, 2000 m of sedimentary rock, has been eroded off an uplifted northern block and the detritus deposited on alluvial fans and in a clastic basin to the south. Paleoflow determinations support this model, with consistent south to southwest flow directions. The intertonguing nature of the Glance Conglomerate and the basinal sandstones and siltstones of the Willow Canyon Formation suggest that normal faulting was active during most of the time of Willow Canyon (Morita equivalent) deposition. In the Mule Mountains, exposures suggest that normal faulting had ceased by that time, but the relationship between the Morita Formation and the Glance Conglomerate farther south is not known.

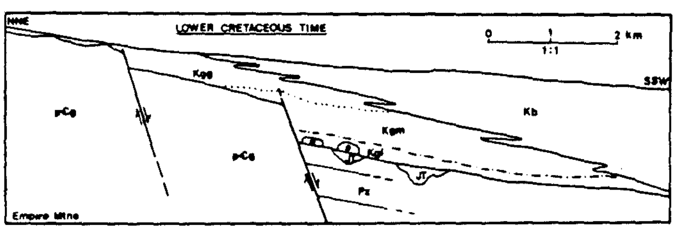

Figure 5. Schematic cross-section of the Empire Mountains in Early Cretaceous time showing Glance Conglomerate stratigraphy and syntectonic relationships. Note similiarities with Mule Mountains (fig. 3). (Kb) Bisbee Group, (Kgg) Glance granite-clast lithofacies, (Kgm) Glance mixed-clast lithofacies, (Kgl) Glance limestone-clast lithofacies, (JT) Jurassic-Triassic redbeds, (Pz) Paleozoic undifferentiated, (p€p) Precambrian granite and schists, (e) exotic landslide blocks of late Paleozoic limestone.

REGIONAL TECTONIC IMPLICATIONS

Regional studies of the Glance Conglomerate imply that similar depositional environments and syntectonic relationships as those found in the Mule and Empire mountains existed throughout southeastern Arizona during the Lower Cretaceous. The nature and contact relationships of the exposures of Lower Cretaceous fanglomerate in the Huachuca, Santa Rita, Dragoon, Dos Cabezas and Chiricahua mountains and in the Red Bird and Gunnison Hills suggest that the faults shown in Figure 1 were active during early Early Cretaceous time. Many of these faults are not exposed at present but are inferred to exist beneath Cenozoic cover in the approximate locations and orientations shown. Note that some of the inferred fault scarps faced to the northeast, whereas those related to the Glance Conglomerate exposures in the Mule and Empire mountains faced to the south-southwest. Source terranes to the southwest included exposures of Mesozoic volcanic 'rocks that gave rise to volcanic-bearing clast suites in some Glance and correlative conglomerates of the Huachuca, Santa Rita and Dos Cabezas mountains.

The regional pattern of Early Cretaceous faults suggests that southeastern Arizona was undergoing extensive vertical tectonic movements along northwest- and west-trending normal faults. Rotation of the fault blocks (shown in Figure 3) and comparison with other block-faulted regions indicate that this was also a zone of regional northeast-southwest extension. This zone of middle Mesozoic extensional deformation and syntectonic deposition extended south and southeast into Mexico to merge with the northwest-trending Chihuahua Trough, a major Mesozoic marine basin (Taliaferro, 1933; Imlay, 1939, 1944; Hayes, 1970b; Cordoba and others, 1971; Greenwood and others, 1977). The position, timing and extent of this episode of continental rifting indicates that it was a major event in the Mesozoic evolutionary development of the southern Cordillera.

ACKNOWLEDGMENTS

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REFERENCES

Beauvais, L., and Stump, T. E., 1976, Corals, molluscs, and paleogeography of Late Jurassic strata of the Cerro Pozo Serna, Sonora, Mexico: Paleogeog., Paleoclimatol., Paleoecol., v. 19, p. 275-301.

Bilodeau, W. L., 1977, Sedimentary and stratigraphic evidence for mid-Mesozoic normal faulting along major northwest-trending faults in southeastern Arizona [abs.]: Geol. Soc. America, Abs. with Programs, v. 9, p. 898.

———— 1978, The Glance Conglomerate: A mid-Mesozoic group of isolated alluvial fan complexes in southeastern Arizona [abs.]: Geol. Soc. America, Abs. with Programs, v. 10, p. 96.

Bryant, D. G., and Metz, H. E., 1966, Geology and ore deposits of the Warren mining district, *in* Titley, S. R., and Hicks, C. L. (eds.), Geology of the porphyry copper deposits, southwestern North America: Univ. of Ariz. Press, p. 189-203.

Bull, W. B., 1972, Recognition of alluvial fan deposits in the stratigraphic record, *in* Rigby, J. K., and Hamblin, W. K. (eds.), Recognition of ancient sedimentary environments: Soc. of Econ. Paleontologists and Mineralogists Spec. Pub. 16, p. 63-83.

Cordoba, D. A., Rodriguez-Torres, R., and Guerrero-Garcia, J., 1971, Mesozoic stratigraphy of the northern portion of the Chihuahua Trough, *in* Seewald, K., and Sundeen, D. (eds.), The geologic framework of the Chihuahua tectonic belt: West Texas Geol. Soc. Pub. 71-59, p. 83-97.

deCserna, Z., 1971, Mesozoic sedimentation, magmatic activity and deformation in northern Mexico, *in* Seewald, K., and Sundeen, D. (eds.), The geologic framework of the Chihuahua tectonic belt: West Texas Geol. Soc. Pub. 71-59, p. 99-117.

Drewes, H., 1971, Mesozoic stratigraphy of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Survey Prof. Paper 658-C, 81 p.

———— 1972, Structural geology of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Survey Prof. Paper 748, 35 p.

———— 1978, The Cordilleran orogenic belt between Nevada and Chihuahua: Geol. Soc. America Bull., v. 89, p. 641-657.

Dumble, E. T., 1902, Notes on the geology of southeastern Arizona: Am. Inst. Mining Engineers Trans., v. 31, p. 696-715.

Finnell, T. L., 1971, Preliminary geologic map of the Empire Mountains quadrangle, Pima County, Arizona: U.S. Geol. Survey Open-File Rep. 71-106.

Greenwood, E., Kottlowski, F. E., and Thompson, S., III, 1977, Petroleum potential and stratigraphy of Pedregosa Basin: Comparison with Permian and Orogrande Basins: Am. Assoc. Petroleum Geologists Bull., v. 61, p. 1448-1469.

Hayes, P. T., 1970a, Mesozoic stratigraphy of the Mule and Huachuca Mountains, Arizona: U.S. Geol. Survey Prof. Paper 658-A, 28 p.

———— 1970b, Cretaceous paleogeography of southern Arizona and adjacent areas: U.S. Geol. Survey Prof. Paper 658-B, 42 p.

———— and Landis, E. R., 1964, Geologic map of the southern part of the Mule Mountains, Cochise County, Arizona: U.S. Geol. Survey Misc. Inv. Map I-418.

Imlay, R. W., 1939, Paleogeographic studies in northeastern Sonora: Geol. Soc. America Bull., v. 50, p. 1723-1744.

———— 1944, Cretaceous formations of Central America and Mexico: Am. Assoc. Petroleum Geologists Bull., v. 28, p. 1077-1195.

Ransome, F. L., 1904, The geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Prof. Paper 21, 168 p.

Taliaferro, N. L., 1933, An occurrence of Upper Cretaceous sediments in northern Sonora, Mexico: Jour. Geol., v. 41, p. 12-37.

Titley, S. R., 1976, Evidence for a Mesozoic linear tectonic pattern in southeastern Arizona: Ariz. Geol. Soc. Digest, v. 10, p. 71-101.

Walker, R. G., 1975, Conglomerate: Sedimentary structures and facies models, Chap. 7, *in* Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Soc. of Econ. Paleontologists and Mineralogists, Short Course 2, p. 133-161.

ROAD LOGS

and

DISCUSSIONS

ITINERARY FOR SOUTHEAST ARIZONA LEG

Leaders: Stanley B. Keith and
William L. Bilodeau

Sunday, March 29, 1981.

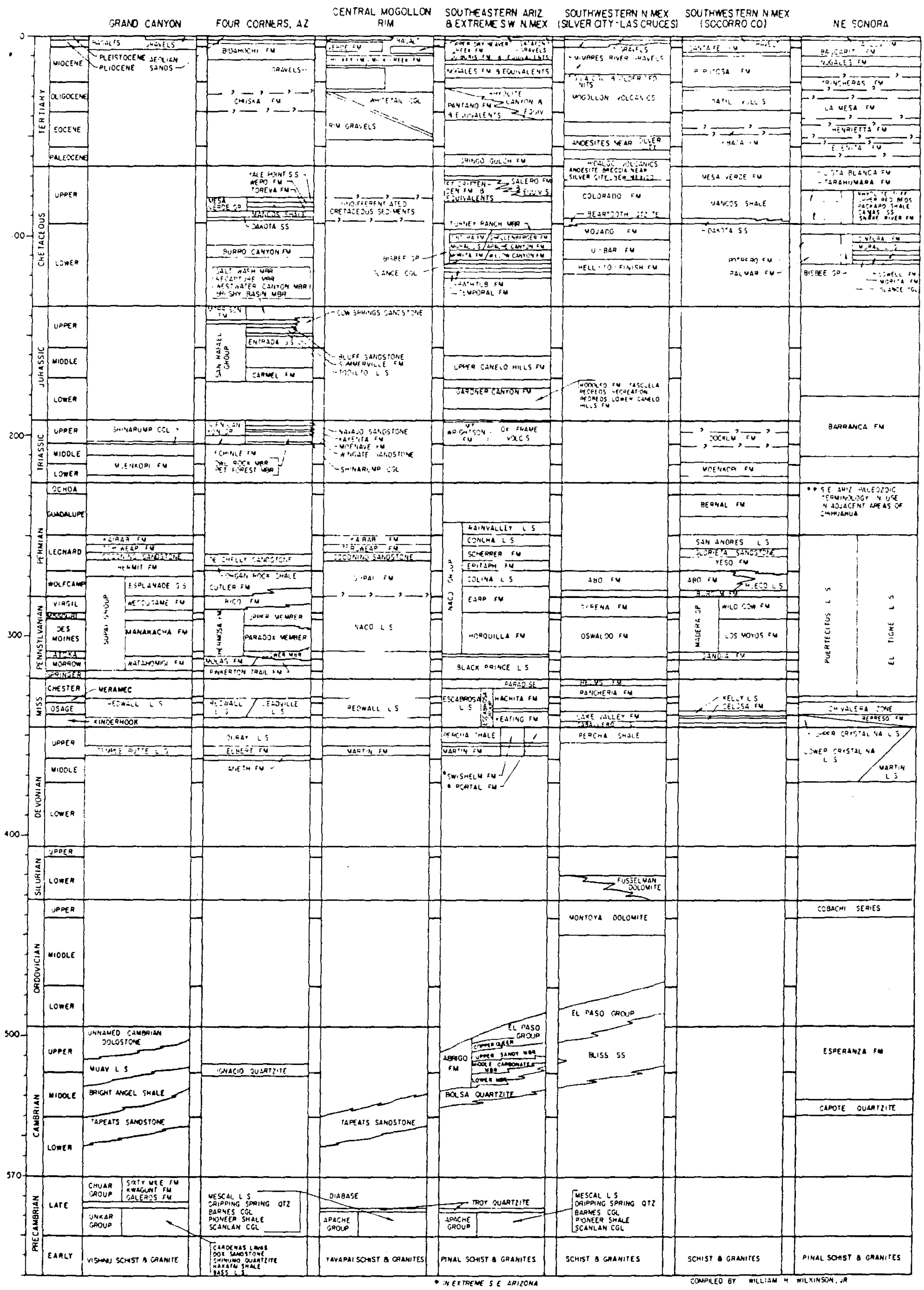
12:00-12:30	Cross the USA/Mexican border at Douglas, Arizona.	
12:40-13:05	Stop 1:	Biohermal buildup in the Mural Limestone.
13:10-13:50	Stop 2:	Structure and Tectonics of the southern Mule Mountains.
14:00-14:30	Stop 3:	Limestone facies of Glance Conglomerate.
14:45-15:00	Stop 4:	Pinal Schist facies of Glance Conglomerate and intertonguing relationships of Glance Conglomerate and Morita.
15:10-15:30	Stop 5:	Basal contact of the Glance Conglomerate.
15:35-16:10	Stop 6:	Morita-Mural section.
16:15-16:30	Stop 7:	Lavendar Pit overlook: overview of Jurassic-age porphyry copper mineralization and Dividend fault.
16:40-17:00	Stop 8:	Extension of Dividend fault structure to the northwestern Mule Mountains.
17:15-17:40	Stop 9:	Stratigraphy and structure of Government Butte.
18:00	Arrive in Tombstone. Accommodations for the evening will be at the LOOKOUT LODGE.	
19:00	Dinner at Wagonwheel restaurant in Tombstone.	

Monday, March 30, 1981.

08:00	Depart from Tombstone.	
08:10-08:40	Stop 1:	Laramide silver mineralization and polyphase fault movements at the Prompter Mine.
09:20-10:20	Stop 2:	Laramide deformation and tectonics of the Huachua Mountains.
11:10-12:10	Stop 3:	Eolian sandstones of the Mt. Wrightson Formation.

12:10-12:40	Lunch.	
12:40-13:20	Stop 4:	Conglomerates of the Temporal Formation (Glance equivalent).
13:25-14:10	Stop 5:	Conglomerates of the late Cretaceous Fort Crittenden Formation.
14:45-15:15	Stop 6:	Salero (late Cretaceous volcaniclastic unit) - Bisbee Group contact and tectonics of the northern Empire Mountains.
15:20-16:10	Stop 7:	Glance conglomerate and Mesozoic redbeds in the northern Empire Mountains.
17:00	Arrive in Tucson.	

STRATIGRAPHIC NOMENCLATURE CHART



DAY 2 (AFTERNOON)

ROADLOGS FROM DOUGLAS TO

TOMBSTONE, ARIZONA

Milepost

365 Milepost 365. Phelps Dodge Corporation's Douglas was founded in 1901 and named for the mining engineer, Dr. James Douglas, who established a smelter here for the Bisbee ores. This smelter was actually blown in by the Calumet and Arizona Company in November, 1902. The Copper Queen smelter of Phelps Dodge was located at 9:00 where the old power house and general offices are visible. Although construction was begun before the C & A, the Copper Queen smelter was blown in during March, 1904. By 1906, its new 250-ft. smokestack was the tallest in the world. The C & A rebuilt and enlarged their smelter in 1913. It is the one now operating. The two companies merged in 1931. The red and white tower to the right and others scattered around Douglas are air quality monitoring stations.

In 1915, Agua Prieta, just across the Mexican border from Douglas was the scene of a major battle of the Mexican Revolution. 12,000 troops under the command of Pancho Villa attacked a 6,000 strong force of Federales. Villa was repulsed after two days of heavy fighting and aerial bombardment (Barnes, 1960).

0.4

364.6 U.S. 666 to Willcox on right. Continue straight ahead on U.S. 80. Sierra de los Ajos at 11:00; Mule Mountains at 12:00; Dragoon Mountains at 1:30; Swisshelm Mountains at 3:00; and Pedregosa Mountains at 4:00.

0.3

364.3 Bridge over Whitewater Draw, which drains south to Rio San Bernardino and the Gulf of California via the Rio Yaqui. Because of its ample supply of water in 1900, it was selected as the site for the Douglas smelter.

About 8 mi. up Whitewater Draw are important Cochise culture sites dated at about 5,000 years B.P. (before present). The Cochise culture (nothing to do with the Apache chief) has been dated by $Carbon^{14}$ methods from 2,000 to 6,000 years B.P. The people were pre-ceramic and subsisted by hunting and gathering. They are intermediate between the Early Man big-game hunters of the Pleistocene and the much more recent pueblo pottery makers of the southwest. Sites are characterized by dart points and stone grinding implements (Maylor, pers. comm.).

2.3

362 Prominent inclined hogback cliffs (9:00) in Sierra de los Ajos are of Mural Limestone which thickens southward in Mexico.

3.0

359 San Jose Peak at 10:30, Mule Mountains at 1:00, southern Dragoons at 2:00, Dos Cabezas in distance at 3:00, and Swisshelms at 3:30. The southern boundary of the Swisshelm Mountains is at Leslie Canyon,which separates the Swisshelms from a prominent east-west trending ridge in the Pedregosa Mountains. The Castle Dome thrust of Epis (1956) was extended by Cooper (1959) northwestward along the western base of the Swisshelms. Much of the Swisshelm Mountains is mapped as a large recumbent syncline overturned towards the west-southwest. This syncline has been truncated by a number of east-to northeast-dipping, high-angle, reverse-separation faults, which place Precambrian granite and Bolsa Quartzite over the Bisbee Group in the northern part of the range. In the southwest limb of the overturned fold, east-dipping Upper Paleozoic rocks and Bisbee Group are intruded by the Oligocene (20.9 to 34 m.y.)

Elfrida stock. (Marvin et al, 1978; Shafiqullah et al., 1978). The overall geometry of Laramide structures in the Swisshelm Mountains suggest southwest-directed tectonic transport. Drewes (1976a) placed most of the Swisshelms in the upper plate of the Cochise plate above the north-east-dipping thrust faults just described. The Swisshelms are then a klippe of the main Cochise plate farther west.

0.9

358.1 Cochise College on right.

1.7

Paul Spur road on left. Paul Spur cement plant and quarry at 10:00. The quarry for metallurgical grade ~~limestone is~~ in Mural Limestone of the Bisbee Group.

A cement plant and small community are located at this place on the railroad where there is also a section house. It was so named for Alfred Paul, Sr. (b. Germany, 1878), who came to Arizona in 1885. Paul helped lay out the site of Douglas. The fact that the Calumet and Arizona Mining Company was using the flotation process to extract copper led to Paul's putting in a lime kiln at this place after 1914 because lime was needed to neutralize acid in the ore. Currently this place is producing cement.

P.O. est. July 24, 1930. Bert Whitehead, p.m. Discont. May 2, 1958 (Barnes, 1960).

About 13 mi due north of here an oil test (Allen #1 Davis well) was drilled in Sulphur Springs Valley. The hole penetrated 2,710 ft. of fine-grained, gypsiferous, lacustrine sediments and interbedded coarser alluvium of Plio-Pleistocene age. The hole continued through Miocene(?) volcanics consisting mostly of rhyolite and bottomed in andesite porphyry at 5,400 ft (Peirce and Scurlock, 1972).

1.4

355 Slow down for left turn onto Gold Hill road at the truck crossing sign ahead.

0.2

354.8 Turn left on Gold Hill road and cross cattleguard. This road becomes a Gold line road for the Phelps Dodge power line. Mural Limestone caps spurs to the right and left.

Begin cumulative mileage.

0.6

0.6 Curve to right under power line.

Pull over and park along road for STOP 1.

STOP 1: CORAL-ALGAL-RUDIST BIOHERM IN THE MURAL LIMESTONE

Exposed in the bluff north of Gold Hill road is a spectacular patch reef composed mainly of corals and stromatolites. These phenomena are commonly well developed in the Lower Cretaceous Mural Limestone of southeastern Arizona. The Mural carbonate section has been extensively studied by Scott (1979) who has subdivided the Mural into several mappable facies and microfacies. According to Scott, the mappable facies are sequences of beds, each characterized by a predominant lithology and set of carbonate microfacies. The sequences are named on the basis of the textural classes of Dunham (1962) modified by the two or three most abundant allochems. Regional stratigraphic relations of the facies are shown in Figure 4. Five depositional environments have been interpreted by analysis of facies and stratigraphic relations. The material below is taken from Scott (1979).

The patch reef we are looking at is an outstanding example of the coral-rudist fragment facies. The coral-rudist fragment facies represents the reef-flank environment (Fig. 9). This facies, which is present around the margins of the reef-core facies, consists of abundant rounded, micritized grains of corals and rudists. Texturally, these rocks are grainstones and packstones. The outcrop expression is thin-bedded to massive, light to medium-gray limestone 7 to 10 m thick with a few intercalated thin shaly breaks. Generally, fossil grains are sand to granule size, subangular to subrounded, subparallel with bedding but not distributed into laminae. Some beds, however, are graded in a fine to coarse to fine sequence or in a coarsening-upward succession.

The matrix of most thin sections is micrite with patches of secondary spar. Major allochems are rudistid fragments and other mollusks, *Orbitolina*, and coral fragments. Most grain margins are either micritized or encrusted by a structureless micrite layer about 0.04 mm thick. Some sand-size grains are totally micritized. Sand to gravel-sized grains of recrystallized spar are common in most samples; these probably are altered coral and caprinid fragments. Other fossils are the skeletal red alga, *Permocalculus*, calcispheres, benthic forams, bryozoans, brachiopods, ostracods, echinoids, serpulids, and tintinnids.

This facies indicates energy conditions capable of moving and abrading shell fragments. Breakage probably was accomplished mainly by biologic activity. The micrite matrix suggests a high rate of production of fine material by algae, borers, grazers, and predators. No megafossils are preserved in place, and many of the forams have been current oriented. Perhaps orbitolinids lived on or near the substrate where encrusting blue-green algae coated grains and some branching green algae lived. Generally, the substrate was mobile.

The area where this facies grades directly into the inner reef core (Fig. 9) is probably the side of highest energy. However, the area where the outer core rudist community is well developed is probably a lee side of the reef. Because no complete reefs are known, the value of these relations as current indicators cannot be assessed.

The coral-rudist fragment facies also grades into the mollusk-miliolid-orbitolinid facies by a decrease in the abundance of large bioclasts and an increase in abundance of peloids and benthic forams (Fig.9). These gradational relations indicate that these three facies were deposited in proximity to each other. Locally in this facies the *Petalodontia* shells may not be far from where they lived and may represent a petalodontid bioherm.

Return to cars and continue westward along Gold Hill road.

2.8

3.4 Road on right to sand and gravel operation in wash.

0.2

3.6 Ridge on right is capped by an allochthonous block of Horquilla Limestone and Glance Conglomerate resting on Mural Limestone. The fault surface separating upper and lower plate rocks dips gently east and is marked by a vegetation line which runs diagonally down the hill from the left to the right. Observe the highly fractured nature of Horquilla Limestone and V-shaped graben structures in the upper plate.

0.3

3.9 Clastic section below Mural Limestone in hills to right and left is Morita Formation of Bisbee Group. Road bears left around the hill ahead and services a flux quarry in a quartzite unit of the Morita Formation.

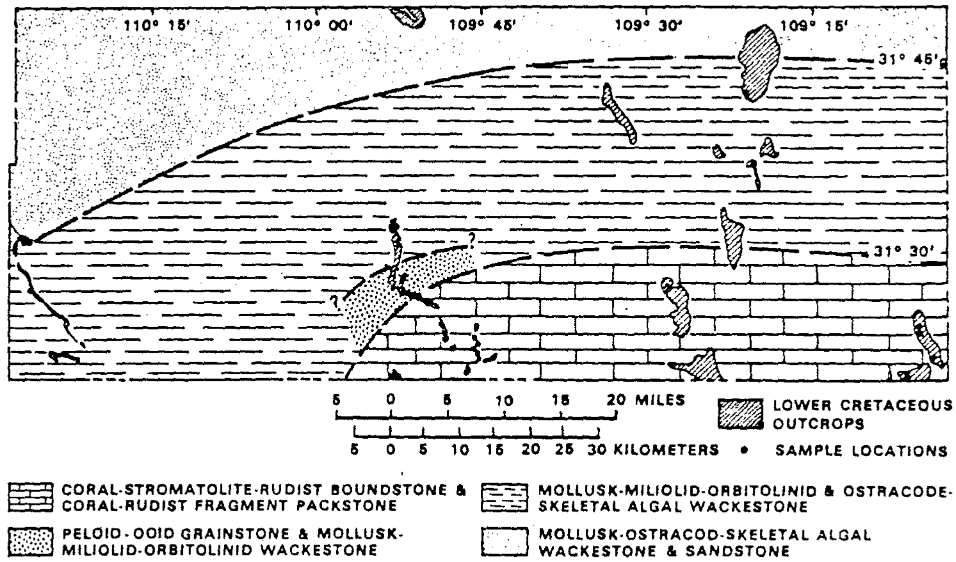


FIG. 3—General facies distribution map of upper Mural member.

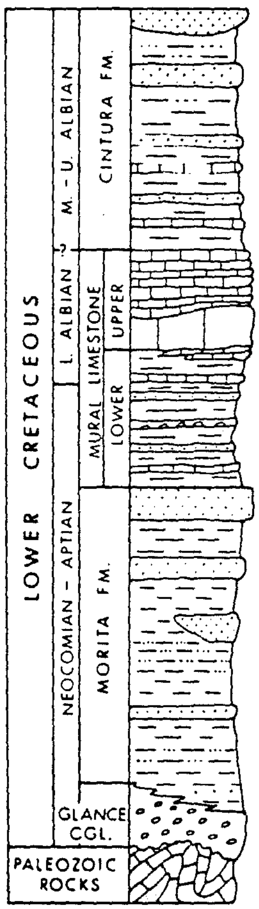


FIG 2—General stratigraphic section of Cretaceous rocks in southeastern Arizona.

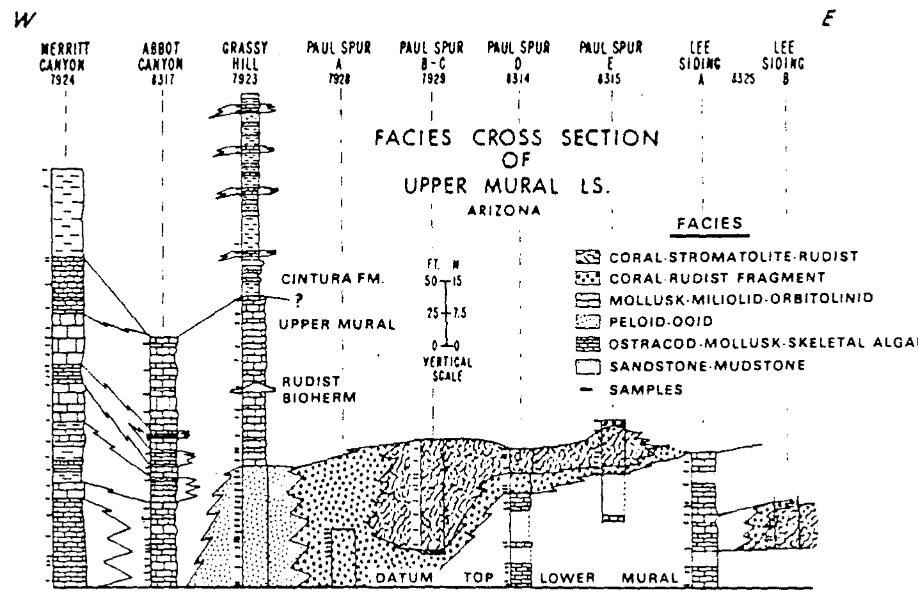


FIG. 4—West-east facies cross section of upper Mural member. See Figure 1 for location.

From Scott (1979)

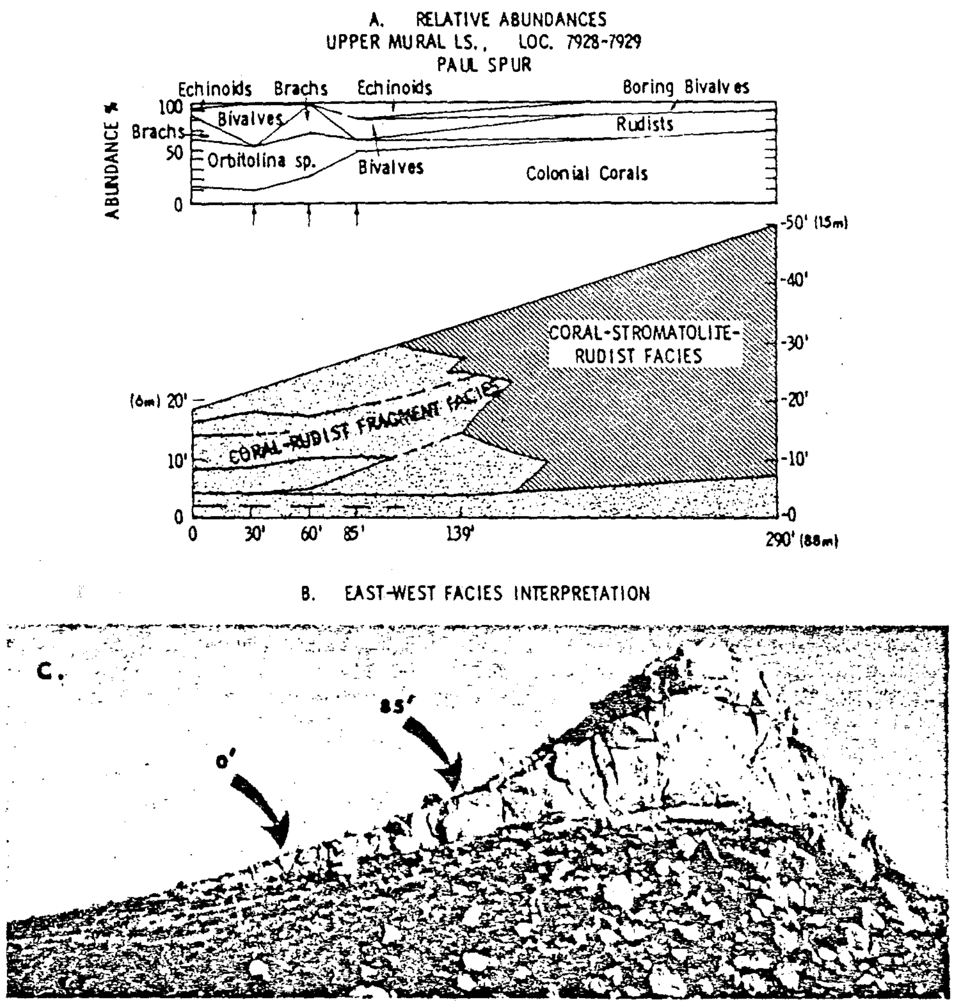


FIG. 9—Cross section of south end of Paul Spur reef (loc.7928). A, gives relative abundance of fossils. Position of measured section B indicated at 0' in C; beds were traced to right and sampled at indicated footages. Footages in B correspond to same points on outcrop in C

From Scott (1979)

0.3

4.2 A rather obscure turnoff on the right leads through a gully and is the continuation of the Gold Hill service road for the Phelps Dodge power line. This road (for field vehicles) continues west for about 5 mi to a junction with the paved Warren road, which connects northward to U.S. 80.

0.3

4.5 STOP 2. After parking climb low hill to southeast.

GEOLOGY OF SOUTHEASTERN MULE MOUNTAINS

William L. Bilodeau and Stanley B. Keith

Introduction. Objectives of this stop include: (1) observation of rocks in the Lower Cretaceous (Aptian) Morita Formation of the Bisbee Group, (2) discussion of tectonic significance of Glance Conglomerate in its type locality, and (3) development of structural evolution of Gold Hill reverse fault and the allochthon to the northeast.

Orientation. From top of the ridge south of the parking area the Mule Mountains extend 15 to 20 mi northwest. To the south, the Mexican border is 3.5 mi away just beyond the Southern Pacific Railroad tracks. San Jose Peak is 15 mi southwest in northern Sonora, Mexico. Ten miles west-northwest are the Naco Hills, and 5 mi west are the leveed tailing ponds from the Phelps Dodge Lavender Pit copper mine. The pit is located 3 mi north of the tailings pond. Bisbee is one mile northwest of the pit or 7 mi northwest of Stop 3.

Geology. This hill is composed chiefly of quartzite, sandstone, shale and siltstone in the Morita Formation. The quartzite here was of sufficient metallurgical grade to be used as flux at the Douglas smelter. Surface talus was screened and the plus 8-inch size contained mostly pure quartzite with most of the alumina removed by weathering. This surface silica "enrichment" dissipated quickly with depth, as did the flux operation.

To the south and west the 10 mi^2, broad, pedimented expanse is the type locality of the Lower Cretaceous Glance Conglomerate (Ransome 1904). The name was derived from Glance, a station on the now long-abandoned El Paso and Southwest Railroad. The railroad paralleled the present Gold Hill road. Glance Station was on Glance Creek at the northern foot of this hill. The Glance Conglomerate is a poorly sorted, limestone, schist and quartzite conglomerate deposited on alluvial fans bordering an Early Cretceous, fault-block mountain range.

In the type area Bilodeau (Bilodeau, 1978) has mapped two facies of Glance Conglomerate, a Precambrian Pinal Schist-clast facies and a Paleozoic limestone-clast facies. The Pinal Schist-clast facies forms the reddish-brown ledge that caps the low hills which include the Glance mine to the southwest. It also crops out in low ridges farther to the southwest in the middle distance. Light-gray, lime stone-clast conglomerate facies generally underlies Pinal Schist-clast facies in the lower slopes of the hills, south of Gold Hill and between the Pinal Schist-facies hills in the middle distance.

Mapping of these facies in the Glance Conglomerate by Bilodeau led to the discovery of a large, previously unmapped, northwest-striking, southwest-dipping, reverse fault with at least 1,500 ft. of stratigraphic throw. The higher, Pinal Schist-clast facies of Glance Conglomerate crops out on the downthrown block. In the upthrown block closer to our view the limestone conglomerate facies probably veneers Horquilla Limestone.

South of Gold Hill, Glance Conglomerate and Morita Formation are in fault contact with a steeply dipping, west-northwest-striking fault which may connect with the Abrigo and Escabrosa faults farther west in the northern Naco Hills. The Naco Hills are the locality for Ransome's Naco formation which was later elevated to group status by Gilluly and co-workers (1954). The intervening area is concealed by Plio-Pleistocene alluvium. According to Bilodeau vertical movement on the west-northwest trending Abrigo and Dividend faults brought the north blocks up in Early Cretaceous time and induced basinward transport of clastic debris on southward-sloping alluvial fans. The Pinal Schist-clast facies overlying the limestone-clast facies represents erosional unroofing of the Paleozoic section and the exposure of underlying Precambrian Pinal Schist in the block north of the Dividend fault. An Early Cretaceous sea then transgressed and marine conditions prevailed during deposition of the Mural Limestone.

Laramide structural development. Following retreat of the "Bisbee sea," the fold-thrust tectonics of the Laramide orogeny began in Late Cretaceous to Tertiary time. The Laramide orogeny is actually several tectonic episodes, some of which are not classic Laramide but which in southeast Arizona are of late Sevier age. Drewes (1978) has recently grouped all of these orogenies as phases under the term Cordilleran orogeny.

Laramide deformation at Stop 3 is manifested by the Gold Hill reverse fault first recognized by Ransome (1904). Upper plate rocks consist of Paleozoic strata in the unnamed hill one mile to the northwest. The southern base of this hill as mapped by Hayes and Landis (1964) contains light-brown, slope-forming, aphanitic dolomites of the Martin Formation. These are overlain by ledges of light-to medium-bluish-gray, predominantly massive, crinodal lime stones in the Escabrosa Limestone. The top of the hill is capped by alternating ribs of fusulinid-bearing carbonates and slope-forming, pinkish beds of shale and siltstone of the Horquilla Limestone. This sequence of Paleozoic rocks is truncated by the moderately to gently inclined, Gold Hill reverse fault, which appears as a conspicous vegetated line at the base of the gray-toned, allochthonous Paleozoics. Below the fault line are steeply upturned, northeast-dipping beds of Morita Formation on trend with those on which we stand. The reverse fault crosses Glance Creek, steepens in dip and continues southeast between us and the Glance Conglomerate to the south. To the northwest the Gold Hill reverse fault follows the topography behind the unnamed hill, suggesting a lower angle. To the right of Black Knob, northeast-dipping beds of Mural Limestone overlie Morita Formation.

Resting on the Mural is a curious and controversial allochthonous block of Horquilla Limestone overlain depositionally by Glance, which was originally mapped by Ransome (1904) and later by Hayes and Landis (1964). The low-angle fault which separates the allochthonous Paleozoic and Glance block from the underlying Mural Limestone is marked by a conspicuous vegetation line. Note the 'V' shaped graben structures initially emphasized by Jones (1966), although they are clearly shown in a photograph in Ransome (1904).

These geometric relations have intrigued geologists for years and every published opinion differs. Ransome (1904) originally suggested the Gold Hill reverse fault was an overthrust to the east and that the allochthonous block was part of an overthrust to the west, with the Gold Hill fault flattening with depth. Ransome viewed the allochthonous block as an overthrust klippe. Hayes and Landis (1964) agreed with Ransome that overthrusting was important but disagreed on transport direction. Hayes and Landis suggested that the allochthonous outlier is a thrust klippe emplaced from the west and inferred that it was once continuous with the Gold Hill reverse fault. As such, the Gold Hill reverse fault has been broadly arched. Whether the arching was during or after the overthrust is not clear. Hayes and Landis flattened the Gold Hill reverse fault to the west.

Jones (1963, 1966) presented a different interpretation. For Jones the Gold Hill fault was formed by differential vertical uplift, not horizontal compression. Consequently the Gold Hill reverse fault is postulated to be fanlike and to steepen with depth; the Paleozoic rocks in the upper plate thus represent a vertically uplifted anticlinal arch. During uplift of the arch a piece of the Paleozoic rocks and overlying Glance Conglomerate broke loose and slid down an eastward-inclined paleoslope. Jones believed the enigmatic allochthon was a slide block emplaced from the west off a vertically uplifted Paleozoic arch. He concluded that neither Gold Hill nor the Glance overthrusts reported by previous workers demonstrate significant Laramide compression in the Mule Mountains.

A fourth interpretation is possible, in light of the following observations:

(1) The 'V'-shaped graben structures within the allochthonous block suggest the block was in extension during its emplacement (assuming the grabens were formed during emplacement of the block), as predicted by the slide block interpretation of Jones. Assuming that "slides" do not move upslope, it is reasonable to "slide" the block eastward down a paleoslope.

(2) The presence of Glance Conglomerate in the overlying plate of the outlier suggests the Glance tract to the west was a likely source for the klippe and restricts horizontal movement to no more than 2 mi.

(3) Dips on the Gold Hill reverse fault suggest shortening, which is consistent with compression. Shortening (as evidenced by the distribution of Glance Conglomerate) was no more than 2 mi and perhaps only 1 mi.

(4) Low dips along the Gold Hill overthrust occur at the northeast corner of the Glance Conglomerate block to the southwest. Extending west-northwest from Gold Hill is the probable continuation of the Abrigo-Escabrosa fault system. Extending southeast from Stop 3 is the probable higher angle segment of the Gold Hill reverse fault. So geometric and kinematic connection between these faults is strongly immplied.

(5) The Abrigo-Escabrosa fault system has demonstrable Early Cretaceous movement (Bilodeau, 1978) and thus was a pre-existing basement flaw available for reactivation by subsequent structural development.

This interpretation suggests that "Laramide" east-northeast compression formed the Gold Hill reverse fault at the northeast corner of the Glance block to the west. This compression initiated recurrent left-slip on the pre-existing Abrigo-Escabrosa fault system. The straight, northwest-striking, high-angle part of the Gold Hill reverse fault broke normal to the direction of compression, as would be expected in an isotropic rock undergoing triaxial stress. Progressive deformation forced the northeast corner of the Glance block to overthrust adjacent Lower Cretaceous strata producing a topographic welt. Subsequently parts of the leading edge became unstable and the enigmatic allochthon broke loose and slid eastward down an east-facing paleoslope of the topographic welt. Continued deformation caused the deep-seated Abrigo fault to break eastward, resulting in the fault-slice aspect of the Gold Hill area. Movement on the high-angle part of the Gold Hill reverse fault was by reverse slip throughout this deformation.

Thus the Gold Hill reverse fault maintains its high angle to depth and does not steepen or flatten. The low-angle part of the Gold Hill reverse fault near Gold Hill was rooted in the high-angle Abrigo fault prior to its truncation by continued left-slip movement on the Abrigo fault during the waning stages of deformation.

Return to cars and proceed to obscure turnoff (see mileage entry 4.2)

0.3

4.8 Make sharp left onto dirt road. Outcrops along road after it ascends onto terrace north of the gully are of Morita Formation.

0.5

5.2 Somewhere near here the road crosses the trace of the Gold Hill thrust fault. Prospect pit on hillslope north of the road is in Devonian Martin Formation. Outcrops ahead will be of Martin Formation.

0.1

5.3 Gate. Glance Hill and Mine are at 9:00. Gold Hill is at 1:00. Road ahead traveses pediment capped be veneer gravels that rest on the limestone clast facies of Glance Conglomerate. In Glance Hill the mixed facies (ledge-formers on top of hill) overlies slope-forming lighter-colored limestone clast facies Glance Conglomerate at the bottom of the hill.

0.8

6.1 Firt Road on right. Turn right.

0.2

6.3 Park vehicles for STOP 3.

STOP 3: LIMESTONE CLAST FACIES OF GLANCE CONGLOMERATE

Hike about 60 m to the west where the lower limestone-clast member of the Glance Conglomerate is well exposed. Here the Glance is a poorly-sorted cobble to boulder conglomerate composed predominantly of late Paleozoic limestone clasts, 65%, lesser amounts of purplish-red volcanic clasts, 25%, with the remaining 10% made up of chert, quartz and sandstone clasts. The presence of volcanic clasts of cobble to boulder size in the Galnce suggests that earlier Mesozoic volcanic rocks were present in the Mule Mountains area but have subsequently been removed by erosion. The Glance Conglonmerate in the Mule Mountains rests unconformably on either Precambrian Pinal Schist, late Paleozoic limestones or Jurassic granite. No known Mesozoic volcanic rocks are exposed in the Mule Mountains.

Also well exposed at this locality are the two primary types of internal conglomerate fabric -- matrix-supported and clast-supported fabric. The matrix-supported conglomerate was deposited by debris flow processes and the clast-supported conglomerate by fluvial processes. Cobble imbrications at this locality show south-directed paleoflow.

Return to vehicles and proceed back to the main dirt road and turn right (west).

0.2

6.5 Turn right (west) onto Gold Hill road.

0.5

7.0 Road on left provides access to well exposed Pinal Schist clast facies of Glance conglomerate. At 8:00 one can observe a northwest-trending color break between light bluish white outcrops of limestone clast facies Glance Conglomerate and reddish-brown Pinal Schist facies of Glance Conglomerate. This color break marks the trace of a northwest-striking, southwest dipping high angle reverse fault named the Glance fault by Bilodeau (1979). The Glance fault juxtaposes the upper mixed-clast Glance Conglomerate member containing schist, quartzite and limestone clasts and a drak red matrix with the lower limestone-dark clast member containing over 90% light gray limestone clasts and light pink matrix.

To the northwest Gold Hill is now in good view at 1:00. According to the mapping of Hayes and Landis (1964) the cliff-former that caps Gold Hill is comprised of Permian-age Colina Limestone Underlain by stope-forming Pennsylvanian Permian age Earp Formation. The lower ledge-Paleozoic section is separated from the Glance Conglomerate at the base of Gold Hill by a high-angle fault. This fault marks the eastern extension of the WNW-striking Abrigo fault system that may be traced for several miles west along the southern edge of the Mule Mountains. The Gold Hill thrust fault is exposed on the north side of Gold Hill out of view and places the Paleozoic section in view on Gold Hill over Glance Conglomerate. Refer to STOP 2 discussion for tectonic interpretation.

0.3

7.3 Road crosses the northwest-striking reverse fault mentioned above.

1.1

8.4 Road enters small wash. Park vehicles for STOP 4.

<u>STOP 4</u>: PINAL SCHIST CLAST FACIES OF GLANCE CONGLOMERATE AND INTERTONGUING RELATIONSHIPS OF GLANCE CONGLOMERATE AND MORITA FORMATION

Pinal Schist clast facies of Glance Conglomerate is reasonably well-exposed in small gullies north of the road. Also, the intertonguing contact of Glance Conglomerate lithologies with Morita-like lithologies is well demonstrated.

The Pinal Schist-clast conglomerate is poorly sorted, poorly to fairly well bedded, mostly clast-supported with a matrix of dark brownish red to maroon silt and sand and frequent small lenses of maroon siltstone and sandstone. Occasional matrix-supported zones help delineate bedding attitudes (Fig. 8). The clasts are subrounded to rounded pebbles, cobbles, and occasional boulders, with few clasts over 25 cm in diameter. The clast size decreases upward until the average size is in the range of 3-5 cm near the upper contact with the Morita Formation. Dark maroon sandstones, siltstones, and shales are interbedded with pebble beds as this gradational contact is reached.

Compositionally, the Pinal Schist-clast conglomerate member contains 80-90% schist clasts, with 5-10% quartzite, and the rest being granite, limestone, chert, and vein quartz. Granitic clasts are mostly found in the highest level and thus westernmost outcrops of the schist-clast conglomerate in the western half of the southern structural block (refer to Bilodeau paper). The eastern block, between the Glance fault and the Gold Hill fault, contains only a limited capping of transition zone mixed-clast to schist-clast conglomerate. The schist-clast conglomerate member of the Glance has been removed from this block by uplift and erosion.

Return to cars and continue west on Gold Hill road.

0.1

8.5 Road intersection. <u>Bear left onto well-graded dirt road</u>.

0.3

8.8 Road intersection. Turn right (west) onto excellently graded dirt road. Once on the road, the town of Don Luis and the southwest end of Escabrosa ridge will be in a good view at 11:00. Mill tailings ponds from the Bisbee porphyry copper deposit are at 10:00 to 11:00 with the town of Naco backed by San Jose Peak at 9:00. The Huachuca Mountains are on the far skyline at 11:00.

1.1

9.9 Intersection with paved road. Turn right (north) and proceed through Black Gap into Warren. Black Gap is a topographic notch in a west-northwest-trending ridge of north-northeast dipping Paleozoic rocks in the central block north of the Abrigo fault system (see Bilodeau paper for structural terminology). Cambrian age Abrigo Formation is present in the lower southern slopes of the ridge. Devonian age-Martin Formation occupies ridgecrest east of Black Gap whereas Mississippian age Escabrasa Limestone underlies the northern flank of the ridge east of Black Gap and the ridgecrest of the ridge west of Black Gap.

Once Warren is entered a good view of the entire Bisbee Group section may be seen above the tailings dump north of Warren.

1.6

11.5 Reservoir on right. Pull over to the side of the road and park for STOP 5.

STOP 5: BASAL CONTACT OF THE GLANCE CONGLOMERATE

At Stop 5 we will observe the Glance Conglomerate of the central structural block unconformably resting on the Permian Colina Limestone. Topographic relief on this unconformity is on the order of 100 m and has resulted in the onlapping of Glance Conglomerate up the sides of paleohills of Permian age Colina Linestone so that the thickness of the Glance ranges from over 200 m to just 20 m over the tops of these buried hills. Notice that the Glance here is a dark purplish-red, cobble to boulder conglomerate with angular to subrounded clasts of Precambrian schist, Cambrian quartzite and minor amounts of Paleozoic limestone (mixed clast facies of Bilodeau, 1979).

This stop also presents an excellent view of the rest of the Bisbee Group strata, the Morita, Mural and Cintura Formations, north of the Dividend Fault, a major west-northwest-trending fault one km north of Stop 5. The Glance Conglomerate that underlies these strata on the northern structural block is a schist-clast conglomerate, is nowhere more than 30 m thick and is locally absent. The Glance also unconformably overlies only Precambrian Pinal Schist or Jurassic Juniper Flat Granite with the entire Paleozoic section removed by erosion. The missing Paleozoic rocks make up the clasts in the Glance on the central and southern structural blocks, showing an inverted stratigraphy that record uplift and erosion, during Glance time (probably early Cretaceous).

Return to cars and continue north on Arizona Street.

0.3

11.8 Intersection with U.S. 80.

End of cumulative mileage. Return to milepost format

Turn Right onto U.S. 80 and continue east. The Bisbee Group section, well exposed in roadcuts ahead for 2 mi, is the most accessible complete Bisbee Group section in southeastern Arizona.

The Bisbee Group, named for the city of Bisbee in the Mule Mountains, is divided, in ascending order, into the Glance Conglomerate, Morita Formation (mainly pinkish-gray sandstone, siltstone and mudstone), Mural Limestone and Cintura Formation (similar to Morita) all of which have type sections in the Mule Mountains (Hayes and Drewes, 1978).

The paleontological date of the Bisbee Group is based on fossils collected from the upper part of the Morita Formation and the Mural Limestone. The Aptian-Albian boundary is contained in the lower Mural Limestone based on these fossils. Extrapolating from sedimentation rates using this fossil datum and the latest radiometric calibration with the Cretaceous ammonite time scale for North America of Obradovich and Cobban (1975), the age of the Bisbee Group from Morita through Cintura Formation is at least 94 m.y. old. This provides an important maximum age for the timing of subsequent Late Cretaceous and Laramide tectonic events.

1.1

346.5 Turnout on right. Pull over and park for STOP 6.

STOP 6: MORITA-MURAL SECTION OF BISBEE GROUP AND DIVIDEND MONOCLINE

The Stop 6 roadcut section of the central Bisbee Group rocks provides excellent exposures of the upper Morita Formation through the lower member of the Mural Limestone. The strata here dip nearly vertical and comprise the steep limb of a west-northwest trending monocline on trend with the Dividend Fault to the west. The monocline signifies reactivation of the Dividend Fault in post-Bisbee (probably Laramide) time. Bedding plane surfaces in the middle limb of the monocline display two sets of bedding plane slickensides. One set plunges steeply down dip and may record motion associated directly with formation of the monoline. In this view the monocline is a drape fold over the eastward projection of the Dividend fault. In early Laramide time reverse motion on the Dividen fault (south block up) in response to north-northeast-trending compression produced the folding. The steep-plunging slickensides record the line or azimuth of the compression.

A second set of slickensides plunges shallowly southeast and indicates a strong component of lateral motion. Possibly this motion is associated with a second episode of motion on the Dividend fault in Laramide time that featured a significant amount of left separation. This movement would correspond to similar left slip movements pastulated for the Abrigo fault system that ultimately produced the Gold Hill thrust structure (see Stop 2 discussion). Regional Laramide timing relationships suggest that the lateral motion recorded by the low-plunging set of slickensides post-dates the vertical movement associated with the formation of the monocline. We will examine a similar movement history on the Prompter fault in the Tombstone Hills (Day 2, Stop 1). While walking along the roadcuts, notice also several sets of flat-lying quartz-filled gash fractures, These gash phenomena are kinematically consistent with first period of presumed reverse movement on the Dividend fault. The westernmost end of the roadcut exposures comprise a sequence of reddish, nonmarine alluvial plain sediments with channel (point-bar) sandstones interbedded with interchannel floodplain siltstones and shales. Close to where the last purplish-red siltstone is exposed, one can closely delineate the surface of marine transgression. Not far above this surface marine trace fossils and molluscan bivalves can be found. Thin beds of sandy, argillaceous and bioclastic limestone becomes increasingly more common as the contact with the lower member of the Mural Limestone is approached. This contact is gradational and hard to pick in this roadcut but is generally considered to be at the top of the last resistant sandstone bed.

The upper member of the Mural Limestone, which contains the coral-algal-rudist reefs, is exposed up the hill to the north but not in the roadcut section. Based on fossils collected from the upper part of the Morita Formation and the Mural Limestone, the Aptian-Albian boundary lies in the lower member of the Mural Limestone.

Return to cars and proceed west on U.S. 80 for Bisbee.

0.6

345.9 Old Bisbee town dump on right. Remains of the original road between Douglas and Bisbee are visible at 3:00. This concrete road, poured in 1916, was the first paved highway in Arizona. At the time Douglas and Bisbee had more votes than Phoenix and Tucson.

0.5

345.4 Warren road intersects from the left. Mural Hill at 1:30 is type section for the Mural Limestone, which is prominent ledge former in hills to right. Roadcuts just west of intersection continue in Morita Formation.

1.4

343. As we approach traffic circle ahead, roadcuts on left are in north-dipping fanglomerates in the Pinal Schist-clast facies of the Glance Conglomerate. Imbrications measured from Pinal Schist clasts indicate stream transport directions in Glance time were from northeast to southwest (Bilodeau, 1978, 1979).

High hills at 9:00 are Morita Formation, Mural Limestone and Cintura Formation. Nearby low hill is Cambrian Bolsa Quartzite, which rests unconformably on Precambrian Pinal Schist in the block north of the Dividend fault. The Glance Conglomerate in view constitutes a fanglomerate wedge derived from this upthrown block which was active in Glance time.

0.2

342.8 Bear right and avoid traffic circle. Follow Route 80 signs, bearing right towards underpass.

0.1

342.7 Continue under the underpass around the north edge of Lavender Pit which will come into view on the left. Road above underpass was for trucks traveling between Lavender Pit and waste dumps. Mill at 12:00.

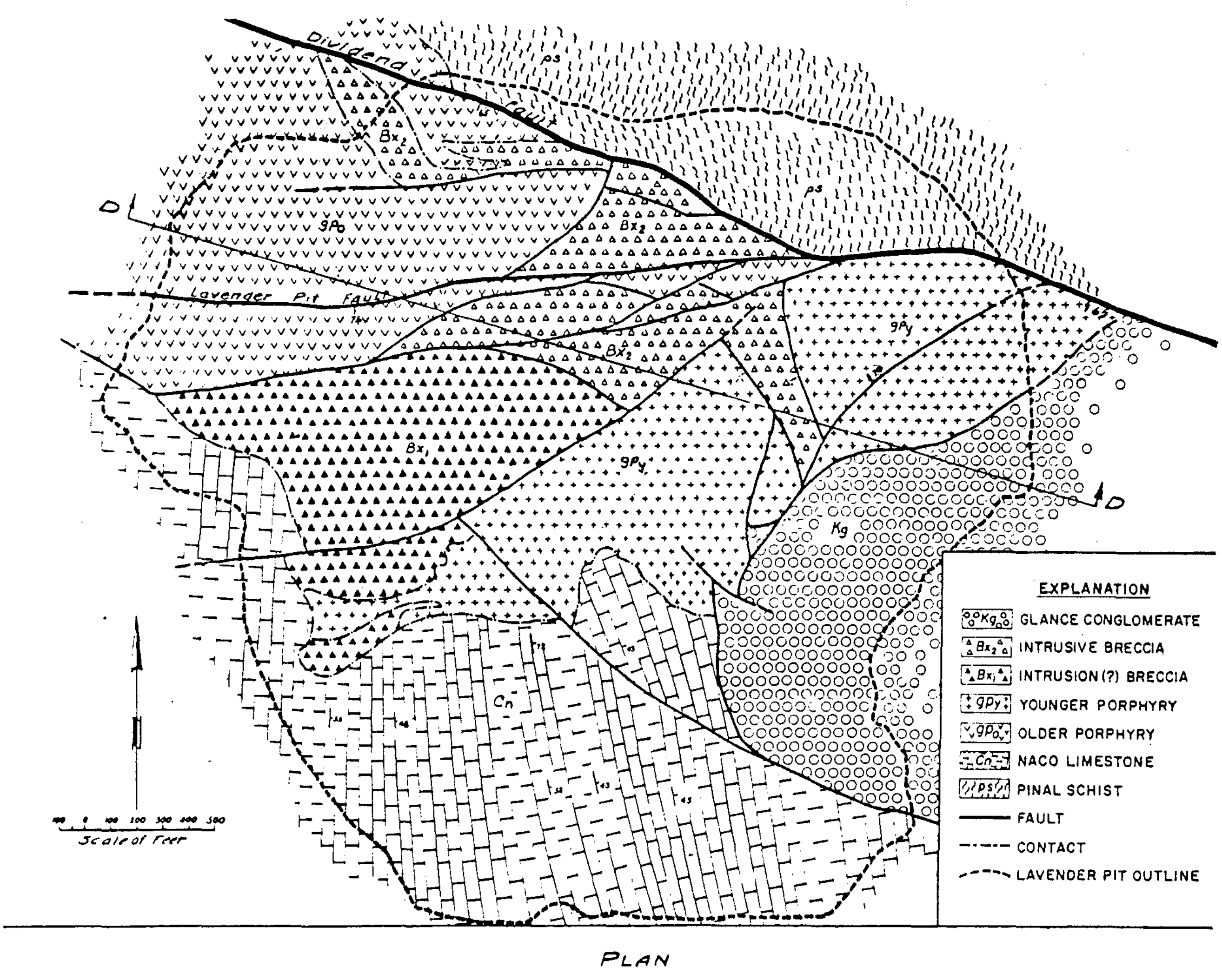
0.1

342.6 Gouge exposed in roadcut on right just beyond underpass indicates the Dividend fault.

0.3
342.3 The conveyor belt ahead carried ore from the primary crusher in the pit to the mill. The oxidized cap over the quartz-sericite-pyrite halo is spectacularly exposed in roadcuts on right.
0.3
342 <u>Stop 7</u>: <u>Turn left</u> into overview parking area. <u>Be careful of oncoming traffic</u>.

The Lavender Pit is one of the smallest open pit porphyry copper mines in the United States. To the right are the remains of Sacramento Hill. Across the pit one can see where the pit intersected old underground workings. The power house at 10:00 is at the head of major slumpage.

The Lavender Pit, which began stripping in 1954, included the Sacramento Pit, initiated in 1913 at what is now the northwest end of the pit. The Lavender Pit was named for Harrison Lavender, who became mine superintendent of the Copper Queen Mine in 1931, having started as a miner, and became general manager in 1937 for Phelps Dodge (Barnes, 1960).



From Bryant and Metz (1968)

The head frames across the pit at 10:00 are the Campbell shafts. This mine was the main underground producer in the Warren district, extending 3,600 ft. deep and supplying three-fourths of the total district production. The ore bodies consisted of rich lead-zinc-copper replacement bodies in Escabrosa, Martin and Abrigo formations.

Production data for the Warren mining district is as follows: 8,051,276,000 pounds of copper; 309,756,000 pounds of lead; 378,450,000 pounds of zinc; 2,726,000 ounces of gold; and 102,861,000 ounces of silver. Although the Warren district is popularly known as a copper camp, not so well known is the fact that the Warren district is by far the leading precious metal district in Arizona. It leads in both silver and gold production by a large margin.

The Warren mining district was named after George Warren a prospector grubstaked by the army scout John Dunn, who had noticed rich ore in 1877 while camping in Mule Pass in pursuit of Apaches. Warren and Dunn owned the Copper Queen mine which merged with Phelps Dodge after 1880.

The upper benches of the southeast pit wall (9:30 to 11:30) are in maroon outcrops of Glance Conglomerate containing over 90% Pinal Schist clasts. The Glance rests depositionally on the Jurassic Sacramento stock in the greenish-brown outcrops of the lower benches (11:00 to 1:00). Glance Conglomerate here contains mineralized clasts of Pinal Schist. The southwest pit wall (12:00 to 2:30) is contact-altered Horquilla Limestone, Earp Formation and Colina Limestone (upper benches), which are overlain at 12:00 by Glance Conglomerate. The entire south wall of Lavender Pit has been downfaulted along the west-northwest-striking Dividend fault which traces through the center of the pit. The north wall of the pit is in upthrown Pinal Schist and is intruded by the Sacramento stock, named for Sacramento Hill at 3:00. Behind the ridge north of the road, Pinal Schist is overlain by Glance Conglomerate (50-200 ft. thick). Thus 5,000 to 6,000 ft. of Paleozoic section has been removed from the north block in Triassic-Jurassic time by activity along the Dividend fault. Bisbee is anomalous in that it is the only known Jurassic porphyry copper deposit in southeastern Arizona.

The Bolsa Quarzite, Abrigo, Martin, Escabrosa, Horquilla and Colina limestones were intruded by the Jurassic Sacramento stock along the Dividend fault. The initial stage of mineralization was intense silicification and pyritization of limestone, schist and porphyry. An estimated 500 million tons of pyrite were deposited during this stage. Additional intrusive activity formed dikes, sills and irregular bodies and at least two stages of intrusive breccia. Copper, followed by lead-zinc mineralization, is associated with this stage. Following renewed activity on the Dividend fault, the resulting pattern is that of a rimless spoked wheel cut in half at the Dividend fault. A hub of pervasive mineralization, centered on the one-mile diameter Sacramento stock, has replacement bodies in brecciated Abrigo and Martin formations along faults radiating out from this hub. The mineralized zones may range up to 2,000 ft. vertically, 500 ft. horizontally and extend to over 12,000 ft. from the Sacramento stock. Final depths are in excess of 3,600 ft. Individual ore bodies ranged up to 1 million tons in size but about two-thirds of them were less than 25,000 tons.

Exhaustion of minable open pit reserves and the extremely high cost of underground mining, exploration and maintaining openings in the highly shattered and altered rocks forced the final closing of the operation in 1975. Leaching of the tailings and workings, as visible to the right, remains in progress.

0.1

341.9 Turn left from Lavender Pit overview on U.S. 80.

0.1

341.8 Sacramento Hill, what is left of it, is on the left. Along this stretch of road are spectacular roadcuts of alteration related to porphyry copper mineralization in alkali granite of the Jurassic Sacramento stock. The surfaces of hills in this vicinity are covered by a bright red oxidized zone which follows the contours of the hills. This constitutes the classic "red thumbprint" oxidized zone present over many porphyry copper sulfide systems. Below the oxidized zone is hypogene (primary quartz-sericite-pyrite) alteration in the Sacramento stock. Note how the upper oxidized zone extends down into primary altered rock along fractures. The classic "red thumbprint" iron oxide cap was the flag that initially drew many of the old prospectors into what are now major porphyry copper districts.

0.3

341.5 Road to right to business section of Bisbee and the picturesque Brewery Gulch section. Bisbee, one of the more colorful mining towns in the American Southwest, was named for Judge DeWitt Bisbee of San Francisco, a shareholder and father-in-law of one of the promotors in the Copper Queen Consolidated Mining Company. Judge Bisbee never visited the town which bore his name. Don't make the same mistake! It's a fascinating town full of old buildings and narrow, twisting streets (see back end sheet).

Bisbee is the largest city in the U.S. without house-to-house mail delivery. All mail is delivered to P.O. boxes as no mailman will walk up and down the hills. Most houses are listed by street and levels above the street. The Copper Queen Hotel in downtown Bisbee serves excellent food in an old time atmosphere. A visit to the mining museum and a stroll up Brewery Gulch are well worth while.

In 1877 while in pursuit of Apache Indians three army scouts camped in Mule Pass. One was John Dunn, who at that time found samples of rich ore. Since his duties would not permit him to work on his claims, Dunn grubstaked a man named George Warren, sending him into Mule Gulch. Warren seems to have been a first-class alcoholic as well as a pick-and-shovel man. To these two men belonged the Copper Queen Mine, so named because of the fame of the Silver King Mine in Pinal County, which it was hoped the Copper Queen would rival.

In 1880 a small eastern mining firm known as Phelps Dodge and Company sent Dr. James Douglas (cf. Douglas) to purchase copper prospects in Arizona. He bought property close to the Copper Queen. The richest ore lay where the Copper Queen and Phelps Dodge properties joined. Rather than pursue litigation over the ores, the two companies merged as the Copper Queen Consolidated Mining Company.

Among the men who promoted the Copper Queen were Ben and Lewis Williams. A shareholder in the company was Judge DeWitt Bisbee, who was also the father-in-law of one of the brothers. The Williams brothers and Judge Bisbee became interested in the property when Edward Reilly, who had an option on the Copper Queen, went to San Francisco where he enlisted the aid of John Ballard and William Martin to supply funds to purchase the mine. Bisbee, Williams and Company undertook to develop the Copper Queen.

In 1929 Bisbee became the county seat for Cochise County, P.O. est. September 7, 1880. Horace C. Stillman, p.m. Incorporated January 9, 1902 (Barnes, 1960).

To the left is the Copper Queen mine; worthwhile mine tours are offered daily. Within the underground working of the Copper Queen mine, some of the world's finest examples of secondary copper minerals have been found. The Warren district is particularly famous for its stalactitic and crystalized specimens of azurite and malachite. It is said that high school proms and Bisbee town council meetings were held in underground caverns adorned with spectacular malachite stalactities locally covered with crystallized rosettes of azurite. To the left just beyond the Copper Queen is a small amount of Martin Formation of Devonian age.

0.2

341.3 Escabrosa Limestone on left. EscabrosaLimestone was named by Ransome (1904) for exposures on Escabrosa Ridge, south of the highway. It consists of about 700 ft. of high cliff-forming, thick-bedded, nearly white to dark-gray, crinoidal, granular limestones (Armstrong).

Castle Rock, the conspicuous turreted crag which overlooks downtown Bisbee is down and to the right of the highway. Castle Rock is mainly composed of Escabrosa Limestone and Martin Limestone which are in fault contact with the Dividend fault to the north.

Excellent views overlooking Tombstone Canyon and Bisbee (to the right) for the next mile.

0.3

341 Milepost 341. Covered area to left conceals Martin Limestone and much of the Abrigo Formation. Martin Limestone was named by Ransome (1904) from exposures on Mount Martin on Escabrosa Ridge south of the highway. The 350-ft thick Martin contains dark-gray, medium-bedded, ledge-forming, fossiliferous limestones, as well as some pinkish shales and olive-gray dolomite (Schumacher, 1978).

0.1

340.9 Abrigo Formation in roadcuts on both sides of highway. Note numerous kink folds in the comparatively incompetent strata of Abrigo Formation. Also note distinctive "graham cracker" texture and ribbed "tire track" aspect of carbonate beds within this part of the Abrigo.

The Cambrian Abrigo Formation was named by Ransome (1904) from exposures in Abrigo Canyon, 3 mi southwest of Bisbee. The Abrigo on Mount Martin is a 770 ft-thick sequence of dark greenish-yellow, thin-bedded, cherty-laminated limestones, which alternate with calcareous shale, and with some sandy limestone and sandstone in the upper part (Hayes, 1978).

340.8 Bolsa Quarzite in roadcuts on both sides of road. Note numerous faults within the relatively competent Bolsa. The contrasting deformation styles in Bolsa Quarzite and Abrigo Formation illustrate the response to stress of rocks of differing ductilities.

The Bolsa Quartzite was named by Ransome (1904) from exposures in Bolsa Canyon on the southwest side of Escabrosa Ridge, although the best exposures are on Mount Martin. The Bolsa unconformably overlies Precambrian Pinal Schist and grades upward from a basal conglomerate to coarse-grained, cross-bedded quarzites. The upper layers of the 430 ft-thick Bolsa are thinner-bedded, more vitreous, fine-grained orthoquartzites (Hayes, 1978). It is conformably overlain by the Late Cambrian Abrigo Formation.

0.1

340.7 Pinal Schist with thermal alteration. Pinal Schist is here separated from Abrigo Formation by a northeast-striking fault strand of the Quarry fault. Roadcuts ahead will be in Pinal Schist for 0.8 mi. Note extremely deformed character of Pinal Schist, which is probably related to motions along Dividend fault. The Dividend fault is difficult to trace northwest of these roadcuts. Its projected trace has been a matter of considerable speculation. Perhaps the deformed southwest border of the Jurassic Juniper Flat Granite represents an intruded segment of the Dividend fault (Hayes and Landis, 1964).

0.9

339.8 Bridge. Roadcuts ahead in Juniper Flat Granite.

0.2

339.6 U.S. 80 Bisbee business loop intersects from the right.

0.2

339.4 Mule Pass tunnel cuts through drainage divide. Tombstone Canyon drains eastward to Sulphur Springs Valley and Banning Creek drains northwest to San Pedro Valley.

The name Mule Pass first appears on an 1879 map as Puerta de las Mulas. It has been suggested that Indians who stole stock in Mexico drove the animals through the pass (Barnes, 1960).

0.4

339 As we top the ridge after exiting from the tunnel, Juniper Flat Granite crops out in immediate vicinity. Visible terrain to the southwest is mostly Pinal Schist intruded by dikes presumably related to the Juniper Flat Granite. Some of the ridge tops are capped by Bolsa Quartzite resting unconformably on Pinal Schist. To the northwest (out of view) Juniper Flat Granite and Pinal Schist are unconformably overlain by northeast-dipping Bisbee Group. For the next 4 mi roadcuts are in locally mineralized and altered Juniper Flat Granite and sheared Pinal Schist. High ridge to left is Escabrosa Ridge.

About 0.5 miles northwest of the Mule Pass Tunnel a conspicuous fault zone appears in the roadcuts on the right side of the highway. Pull over for STOP 8.

STOP 8: POSSIBLE EXTENSION OF THE DIVIDEND FAULT STRUCTURE TO THE NORTHWESTERN MULE MOUNTAINS

The roadcuts here contain a large fault structure that strikes about N 60°W and dips about 65°S and juxtaposes Jurassic age Juniper Flat Granite in the footwall with 1.7 b.y. Pinal Schist in the hanging wall. Slickensides on the fault surface have oblique orientations and plunge 45 to 55 degrees southeast (the rake angle is about 60-70°). If it is assumed that the footwall block moved upwards relative to the hanging wall, a significant amount of left-slip as well as dip-slip motion occurred.

The strike, dip, separation, character and geographic position of this fault closely match those of the Dividend fault structure exposed in the Lavender Pit at STOP 7. However, existing published maps have yet to define the northwest extension of the Dividend fault structure. Indeed, the northwest extension of this structure has been a matter of considerable interest and speculation. For example, according to Bryant and Metz (1966, page 190):

"On the west, the Dividend fault is lost where it passes into the Pinal Schist near Bisbee. There has been speculation that the southwesterly contact of the Juniper Flat Granite is the Dividend fault because it is fairly straight and regular and the alignment is about right for the projected strike. Also, there has been speculation that the Quarry fault, the major limiting fault on the west side of the Bisbee district, is the continuation of the Dividend curving to the southwest. Evidence for verifying either of these concepts is lacking. Eastward the Dividend fault is lost in the alluvium of Mule Gulch."

All published geologic maps show the western end of the Dividend fault disappearing into Pinal Schist. Drewes (1980) projects the fault into the long axis of the Juniper Flat pluton. We believe relationships at this roadcut and another roadcut a short distance to the northwest forcefully demonstrate that the southwestern contact between the Juniper Flat Granite and the Pinal Schist is a fault. Previous mapping (Ransome, 1904; Hayes and Landis, 1964; and Drewes, 1980) show the contact as an intrusive one. For reasons stated above we believe that this fault is likely the extension of the Dividend fault. As such, the Dividend fault would pass through the Pinal Schist to its contact with the Juniper Flat pluton, pass along the contact of Juniper Flat Granite and Pinal Schist for several miles to the northwest, and disappear under alluvial cover in the northwestern Mule Mountains. Similarly, the Dividend fault may be projected eastward underneath the Monocline along U.S. 80 three miles east of Bisbee (STOP 6; Bilodeau, 1979).

Return to cars and proceed northwestward on U.S. 80.

337.5 Numerous roadcuts on the right expose cobble-boulder colluvium which unconformably overlies Juniper Flat Granite and sheared Pinal Schist. The sheared schist may represent gouge related to the Dividend fault or deformation related to intrusion of the Juniper Flat Granite. For about 3 mi the highway nearly parallels the contact between Juniper Flat Granite and Pinal Schist.

3.2

334.2 Bridge crossing Banning Creek.

0.3

334 Roadcuts are in southwest-dipping Bolsa Quartzite overlain conformably by Abrigo Formation. These are intruded at the southeast end of cut by a dike of Juniper Flat Granite.

0.1

333.9 Roadcut on left is southwest-dipping lower Abrigo Formation with numerous faults.

0.3

333.6 Horquilla Limestone in hills to left. Mississippian and Pennsylvanian strata are well exposed in the long ridge from 8:30 to 11:45. The base of the northwest end of the ridge at 11:30 is massive crinodial limestone in upper Escabrosa Limestone. A break in slope separates the more massive, light to dark gray (band at top) carbonates of Escabrosa from overlying medium-to-thick-bedded limestone ledges of Black Prince Formation, which is the lower member of the Naco Group (Ross, 1973). The slope interval below the Black Prine limestone ledges is probably occupied by a maroon to dark-gray shale which unconformably rests on Escabrosa Limestone.

Above the ledges of Black Prince Formation is a slope former about 200 ft. thick which extends southward along the ridge to 9:00. This is the basal siltstone-shale-micrite unit of the Horquilla Limestone. The lower slope-forming unit of Horquilla Limestone rests unconformably on limestones of Black Prince Formation. Above the slope former, prominent fusulinid-bearing limestone ledges occupy the upper slopes of the ridge from 9:30 to 10:45. The top of the ridge is a sill-like intrusion of Juniper Flat Granite.

The stratigraphic sequence just described is remarkably consistent from the Bisbee area to the Superior region about 175 mi to the northwest. Barrie (1975) has analyzed corodonts in the Black Prince from Bisbee to Superior and has found that the Black Prince at Superior is younger (lower Atokan) than that at Bisbee (middle Morrowan), which suggest an onlap relationship of basal Naco Group from southeast to northwest.

In the low ridge on right, west-dipping Bolsa Quarzite, overlain by Abrigo Formation, is intruded by a prominent Juniper Flat Granite dike (Gilluly, 1956). The Jurassic dates (171 to 184 m.y.) come from one of these dikes about 0.5 mi southeast of here (Marvin et al., 1978). These dikes are part of a prominent northwest-trending dike swarm which cuts Paleozoic rocks in Escabrosa Ridge to the southeast and in the unnamed low hill to the north. As mapped by Gilluly and by Hayes and Landis (1964), these dikes constitute a separate intrusive mass that is largely separated from the larger intrusion.

The prominent massive cliffs of granite are also designated as Juniper Flat Granite by Gilluly and Hayes and Landis. This large body, yet to be dated, only intrudes Pinal Schist, although everything above Pinal Schist is missing. The granite is unconformably overlain by Glance Conglomerate and Morita Formation of the Bisbee Group.

0.3

333.3 Bridge crossing Banning Creek.

0.2

333.1 Roadcuts on right are in middle carbonate member of Abrigo Formation.

0.2

332.9 Junction of U.S. 80 and Arizona 92. Continue straight ahead on U.S.80. Hill at 10:00 to 11:00 is capped by crinodial Escabrosa Limestone. Slope-former at base of hill is Martin Limestone, which contains aphanitic dolomite and sandstone and siltstone lenses. At the base of the Escabrosa cliff is a well-vegetated slope-forming unit that is probably olive-green mud-shales of Percha Formation-newly recognized in southeastern Arizona by Schumacher and others (1976) and Schumacher (1978). The yellowish-gray ledge below the presumed Percha Shale is probably a sandy dolomite in the upper Martin Limestone.

Both Martin and Escabrosa are cut by granophyre dike apophyses of Juniper Flat Granite. Note west-striking fault which off-sets these Paleozoic strata.

0.3

332.6 Roadcut in east-and northeast-striking fault slices of aphanitic dolomites of Martin Limestone, Juniper Flat Granite, and Percha Shale (?). Strike-slip. oblique-slip and dip-slip slcikensides indicate a complicated movement history. Note brittle aspect of this deformation.

On skyline at 6:00 sharply uptruned Horquilla Limestone (5:30) is intruded on the west by Juniper Flat Granite and a Tertiary rhyolite (5:30 to 6:30).

0.6

332 Escabrosa and Horquilla limestones are in low hills to left. Western slopes of low ridge to right are Abrigo and Bolsa intruded by north-trending dikes of Juniper Flat Granite.

0.5

331.5 Mid-Pleistocene surface to left and right in this area is capped by a red soil horizon, which has commonly been removed in other areas.

0.1

331.4 Juniper Flat Granite intrudes Martin Limestone in low ridge to left. Low hill ahead on left is Escabrosa Limestone. Low ridge to right is Abrigo and Bolsa cut by granophyre dikes presumably of Juniper Flat Granite.

0.4

331 Hill at 1:00 is Escabrosa Limestone.

0.4

330.6 Bridge. Outcrops in arroyo are Escabrosa Limestone.

0.6

330 Government Butte (12:00 to 2:00) is composed of Pennyslvanian and Permian Naco Group strata.

1.0

329 Stop 2. Park on right side of road.

STOP 9

GEOLOGY OF GOVERNMENT BUTTE
by Stanley B. Keith and Jan Carl Wilt

Introduction:

Government Butte consists of upper Paleozoic strata, the type sections of which were measured in the Tombstone Hills just north of Government Butte. From this stop a controversial east-west structural zone is visible at the southern end of Government Butte. This structure is related to complex "Laramide" structural development here and in the southern Tombstone Hills just ahead.

Orientation:

The northeast quadrant is dominated by Government Butte (11:50-2:45). Government Butte is separated from the northern Mule Mountains (2:45-5:00) by a conspicuous notch at 2:45. The Banning Creek area, through which we just passed, is to the right of the high bench-like feature (Juniper Flats) at 5:30. Escabrosa Ridge, type area for the lower Paleozoic section, is at 6:00. High points visible on Escabrosa Ridge are Mt. Ballard (left) and Mt. Martin (right) to the rear.

To the southwest across San Pedro Valley loom the Huachuca Mountains (8:00-9:15). The Santa Rita Mountains (topped by Mt. Wrightson) are in the far distance at 9:30, partially blocked by the jagged peaks of the Mustang Mountains. Bronco Hills, just east of the San Pedro River, are in front of the Mustang Mountains. Farther northwest the Whetstone Mountains (10:00-10:30) and Rincon Mountains (capped by Rincon Peak) appear behind the Charleston Hills (11:00). Uncle Sam Hill and the Three Brothers Hills of the western Tombstone Hills form the skyline at 11:15-11:30. Colina Ridge (11:30-11:45), an unnamed peak (11:45), and Horquilla Peak (11:30) in the southern Tombstone Hills are partially concealed behind the western tip of Government Butte.

Stratigraphy:

The lower southern slopes of Government Butte from this view contain typical outcrops of Horquilla Limestone. At the west end of Government Butte(12:30) Horquilla LImestone forms alternating thin ledges and slopes; above this is a slope-forming unit with a few orange limestone ledges. This is the typical outcrop expression of the Earp Formation which contains the Pennsylvanian-Permian boundary. Above this slope interval are bluish-gray, thick ledges and slopes typical of the Colina Limestone. Colina Limestone comprises most of Government Butte, particularly on the north side.

The strata just described continue east through several east-striking faults mapped as high-angle reverse faults and thrust faults by Gilluly (1956), each with the north side slightly up. Consequently, the slope-forming Earp section is structurally higher in a topographic reentrant at 1:00. Farther east Earp Formation is again structurally lower and crops out at the southern base of Government Butte from 1:00 to 2:00.

Structural Geology and Tectonics:

The southern slopes of Government Butte are on the complexly folded and faulted southern limb of a large, west-plunging, anticlinal fold which makes up the bulk of Government Butte. Numerous bedding plane "thrusts" may indicate flexural slip. Gilluly (1956) showed the southern edge of the butte to be marked by numerous east-striking, steeply north-dipping reverse faults.

The structures in Government Butte are part of a 25-mi-long (and possibly as much as 50-mi-long) east-west deformational belt. The Government Butte block is separated from the flat-lying Bisbee Group strata of the northern Mule Mountains by a complex, east-west structural zone of folding and reverse faulting, which passes through the notch at 2:45. This zone extends westward from Government Butte to the southern Charleston Hills (10:00), where east-west folds in the Bisbee Group are truncated by andesites of the Bronco Volcanics. From there the zone may continue west, concealed under alluvial cover, to the north end of the Huachuca Mountains at 9:00, where it may be represented by the Kino Spring fault zone and related structures. The age of this deformation is post-Bisbee Group (about 94 m.y.) and pre-Bronco Volcanics (75 (?) m.y.), which is earlier than the classic Laramide.

To the east this zone extends through the Bisbee Group as a south-facing monocline. Interestlingly, the Bisbee Group has flexed, but not faulted, over the trace of the east-west tectonic zone as it also has over the eastward projection of the Dividend fault (Hayes and Landis, 1964). The interbedded siltstones and shales of the Bisbee Group seem to be capable of absorbing strain by flexure rather than by the brittle rupture which is more common in the underlying Paleozoic section. This theme is persistently repeated throughout deformed Phanerozoic strata of southeastern Arizona.

Gilluly (1956) considered the east-west structural belt to be a product of north-south compressive deformation in post-Bisbee, pre-Bronco Volcanics time (about 75-94 m.y. ago). East of this stop the Government Butte block has been shoved southward over Bisbee Group strata during north-south compression of his first Late Cretaceous orogeny (see milepoint 42.1). Jones (1963), on the other hand, interpreted the monoclinal flexure along the eastward continuation of the east-west zone as a Laramide-reactivation of an earlier-formed anticlinal structure of Triassic-Jurassic age. Jones (1966) analyzed Government Butte as an intrusive, vertically driven tectonic feature. Drewes (1976a) suggested that the fault zone is a vertical strike-slip fault rather than a normal fault.

Keith suggests a two-phase movement history for the Government Butte structure. Initially north-northeast to south-southwest compression from 94 to 75 m.y. ago formed the east-west, high-angle reverse fault in much the manner as Gilluly (1956) suggested. East-northeast to west-southwest compression from 65 to 55 m.y. ago induced left-slip movement along the Government Butte structure. The east-west tectonic zone may have an element of ancient basement flaws of Texas lineament vintage which have localized recurrent Phanerozoic movement, such as those during Laramide orogeny.

The structural-tectonic discussion would be incomplete without a look back to the south at the north end of the Mule Mountains, which display an obvious anticline. In the core of the anticline Precambrian Pinal Schist is intruded by Juniper Flat Granite. To the east the Juniper Flat surface is unconformably overlain by gently northeast-dipping Bisbee Group strata. The Paleozoic section is missing under Bisbee Group in the northeastern Mule Mountains. To the southwest (6:00 to 7:00) the Paleozoic section dips moderately west and south-west forming the south-west limb of the anticline. Jones (1963) inferred an initially Triassic-Jurassic broad anticline which was eroded, and overlain by Bisbee Group strata. The entire assemblage was then refolded around a nearly coincident anticlinal axis during the Laramide orogeny.

3.3

325.7 Bridge over Government Draw.

0.7

325 From 9:30 to 12:00 is part of the southern Tombstone Hills in which much of the classic Naco Group stratigraphy was worked out by Gilluly and others (1954) and Gilluly (1956). Colina Ridge (9:00-10:00) contains the type section of Permian Colina Limestone on the western slopes near the north end. Epitaph Gulch (near 10:30) and the eastern slopes of the north end of Colina Ridge contain the type section of the Permian Epitaph Dolomite. Horquilla Peak (high peak at 10:00) contains the type section of the Pennsylvanian Horquilla Limestone. Earp Hill contains the type section of the Earp Formation in the lower part of the eastermost hill seen in profile at 3:00.

Regionally the Horquilla disconformably overlies Black Prince Limestone and is gradational into overlying Earp Formation. On Horquilla Peak the eroded Horquilla is 1,000 ft. thick and consists of a series of thin-bedded, blue-gray limestones (pinkish gray on fresh fracture) with a few thicker beds which form ledges and a few reddish-weathering shaly limestones near the top. Small fusulinids are common in the Horquilla, and brachiopods and bryozoans also occur (Gilluly, 1956). Fusulinids indicate that its age extends from Morrowan through Virgilian, although deposition probably was not continuous and began earlier in southeasternmost Arizona (Ross, 1978).

The Earp Formation is 595 ft. thick here (Gilluly and others, 1954). It generally forms gentle slopes and low areas because of the greater percentage of shales (particularly in the lower part) and clastics than in either the gradationally underlying Horquilla Limestone or the gradationally overlying Colina Limestone. The lower contact of the Earp is assigned where thin shaly limestones and reddish shales become dominant over the more massive limestones of the Horquilla. Much shale, a little sandstone and a few beds of limestone and shale conglomerate (chert pebble or "jelly-bean" conglomerate) occur higher. In the upper part of the Earp are more massive ledges of limestone with a few conspicuous beds of orange-weathering, commonly cross-bedded, cherty dolomite, the uppermost bed of which is taken as the top of the Earp (Gilluly and others, 1954; Gilluly, 1956). The Pennsylvanian-Permian boundary occurs within the lower part of the formation with Virgilian fusulinids occurring in the lower 100 to 200 ft. and Wolfcampian fusulinids occurring in the lower or upper Earp, with the exact interval varying from section to section (Ross, 1978).

The Colina is 633 ft. thick on Colina Ridge, but is 947 ft. thick on the unnamed ridge extending southeast from Horquilla Peak from 10:00 to 12:00 only a mile from Colina Ridge (Wilt, 1969). The variation in thickness is probably attributable to the varying downward extent of diagenetic dolomitization in the Epitaph (Patch, 1969), as the same bed can be traced from undolomitized Colina into dolomitized Epitaph. The Colina Limestone is dominantly a dark-gray, thick-bedded limestone that forms cliffs characterized by massive ledges and steep slopes only slightly less precipitous than the Escabrosa. On fresh fracture the limestones are very dark gray to black and have a fetid odor. The Colina contains more gastropods, particularly the very large, obtuse-angled *Omphalotrochus*, than other nearby limestones. The age of the lower part of the Colina is Wolfcampian as shown by gastropods and fusulinids, while the upper part is Leonardian, as evidenced by brachiopods and fusulinids in southeasternmost Arizona (Dirks, 1966).

The lower contact of the Epitaph Dolomite is taken as the first massive dolomite above the transitional zone of partially dolomitized limestone at the top of the Colina. The lowest member is 200 ft. of medium-to-light-gray to yellow and buff, medium-bedded dolomite containing silica nodules weathering as knots on the surface. It is exposed as the dip slope on the east side of Colina Ridge. The middle part of the Epitaph is exposed in the saddle at 10:30 between Colina Ridge and the low foreground hill. The middle part of the Epitaph consists of about 250 ft. of poorly exposed, reddish, sandy limestone or limy sandstone containing shallow water indicators such as crossbedding, ripple marks and intraformational breccias, and a higher proportion of maroon shale and less dolomite. The upper part of the Epitaph, also exposed in the same hill, consists of over 100 ft. of bluish-gray, thin-bedded limestone.

The Epitaph is unconformably overlain by Glance Conglomerate containing boulders and pebbles of dolomite, limestone, granite, rhyolite and quartzite with an angular discordance of about 15 degrees and with an erosion surface with relief exceeding 20 ft in 300 ft (Gilluly and others, 1954).

1.0

324 Hill to right at 2:00 contains well-exposed, slope-forming Earp Formation in lowerslopes. The Earp is in fault contact with Colina Limestone which is anticlinally folded.

1.0

323 Intricate bedding attitudes in Paleozoic strata west of road underscore complicated structural history of Tombstone Hills. They were mapped and described by Gilluly (1956) who argued for the presence of two orogenies. The first orogeny formed east-trending folds and reverse faults related to a north-south to north-northeast/south-southwest compression after deposition of the Bisbee Group and before deposition of the Bronco Volcanics.

The first orogeny was followed by wide-spread deformation, intrusion (72 m.y.) and mineralization from a second orogeny. This orogeny caused north-trending folds, north-striking reverse faults, and strike-slip movement on east-west faults near and after 72 m.y. His second orogeny has been correlated by many workers with the classic Laramide orogeny.

Davis (Stop 3, this road log) views the Tombstone Hills as a comparatively undeformed block in a large, northwest-trending, basement-cored uplift. Its structural margins are in the Dragoon Mountains to the northeast and the Huachuca Mountains to the southwest. Jones (1966) offered another interpretation: "that in Laramide time rising magmas: (a) broadly domed the area of the Tombstone Hills causing local compressional features of diverse trends but primarily causing normal faulting, (b) pushed up the Precambrian granite, (c) permitted access to the surface of various extrusive rocks, and (d) concluded their active rise by intruding some of the faults and then solidifying in the near surface rocks."

Prominent unnamed hill at 10:30 consists of Colina Limestone intruded by a conspicuous 62 m.y. old rhyolite (Creasey and Kistler, 1962). Note small, sharp kink fold in cliff-forming ledges of Colina Limestone above rhyolite intrusion.

0.6

322.4 Rhyolite exposed in roadcuts and hill slopes on right.

0.2

322.2 Roadcuts on right and left for next 0.2 mi. are in Colina Limestone. Note fault and drag fold in roadcut on left toward the top of the hill. Numerous small faults are exposed in the roadcuts that are not obvious in the outcropping section. At top of hill road ascends onto Pleistocene Tombstone surface (Bryan, 1926).

1.2

321 Hills to left are Horquilla and Earp formations with complicated bedding attitudes.

0.5

320.5 Low roadcuts are in Horquilla Limestone.

0.4

320.1 Broken and gouged zone on left in Horquilla Limestone(?) is trace of east-striking Prompter fault zone. S.O. Hills at 3:00 in middleground are underlain by S.O. Volcanics from which a single K-Ar age date of 48 m.y. on biotite has been obtained (Marvin et al.,1973). At the time of this writing the Anschutz-Buckhorn (formerly Texoma)-Phillips well site was not yet occupied. By the time of our field trip the drill mast should be in place but it will probably be obscured by the hill of S.O. volcanics at 3:00. The IA-TOMBSTONE-STATE well located in the SW 1/4, SW 1/4, Sec. 14, T. 20S, R. 23 E. is permitted for 20,000 and is located on the virtual outcrop projection at the Prompter fault.

0.1

320 Little Joe shaft at 11:00; Rincon Mountains coming into view at 12:00 on far skyline; Tombstone is straight ahead at 12:00; Dragoon Mountains at 1:30; southern Dragoons at 3:00 on skyline; S. O. Hills at 3:00 in middleground are underlain by S.O.Volcanics with a single age date of 47 m.y. (Marvin and others, 1973).

The conspicuous granitic stock in the central Dragoon Mountains is the Stronghold Granite (Gilluly, 1956), named for Cochise Stronghold. Age dates are 25.9 m.y. (Marvin and others, 1973) and 22 m.y. (Damon and Bikerman, 1964).

Stronghold Canyon, on the east side of the Dragoon Mountains, is the site of Cochise Memorial Park. It is reported that when Cochise died on June 8, 1874, he was buried in this area. On the night of his death his followers ran their horses up and down Stronghold Canyon to erase all traces of his grave (Barnes, 1960). (Note: For more information on Cochise, see Supplemental Road Log No. 4.)

0.3

319.7 Mine dumps at 11:00 are from old mines of the Tombstone district. The Tombstone district, discovered in 1877 by Ed Schieffelin, was the second largest silver camp in Arizona from 1879 to 1910; only Bisbee had higher production. From 1879 to 1975 production from the Tombstone district was over 30,000,000 ounces of silver, 242,600 ounces of gold, 3,018,000 pounds of copper, 45,000,000 pounds of lead and 1,179,000 pounds of zinc. Many of the ore bodies occurred as replacements associated with north-east-striking fractures in a basal "novaculite" of the Bisbee Formation (see Devere, this guidebook).

0.1.

319.6 Roadcuts on left are in Bisbee Group within downthrown block north of east-striking Prompter fault. Ridge to south (7:00 to 8:00) is north-dipping Horquilla Limestone in block south of Prompter fault which is intruded by 62 m.y. old rhyolite porphyry.

0.6

319 Roadcuts ahead are in Plio-Pleistocene alluvium overlying bedrock pediment cut on upturned Bisbee Group. To the northeast the Tombstone Hills are separated from the Dragoon Mountains by a broad valley about 8 mi wide which marks the position of a northwest-trending, Basin and Range graben of unknown depth. Note cut and fill aspect of coarse terrace alluvium which overlies finer-grained valley fill in roadcuts. Also note locally thick caliche layers in roadcuts.

0.9

319.9 Turn left on Allen Street just before Gleeson turnoff sign on right. Veer right and travel west on historic Allen Street into Tombstone, past the fabled Oriental Saloon, Crystal Palace and OK Corral. This area was immortalized by dime novelists of the 1880's.

By the end of 1879 Tombstone had about 100 permanent residents, plus at least 1,000 others camped on nearby hills. A year and a half later Tombstone was emerging as one of the largest cities in the West. It is often overlooked that Tombstone was probably the most cultivated city in the West and Southwest. Tombstone was at that time larger than San Francisco and whatever cultural opportunities there were in the West could be found at Tombstone. With a population of 15,000 the community erected an opera house where the best of the world's musicians and actors could be heard.

As the mines flooded, the town began to shrivel. By 1890 Tombstone was nearly dead. Tombstone, however, did not die. Subsequently Tombstone led an anemic existence for many years, but as the past has receded, the town has become a flourishing tourist attraction known as the "Town Too Tough to Die" (Barnes, 1960).

0.5
Stop sign and intersection of Allen and 6th streets. Continue straight ahead.
0.5
Junction; road to U.S. 80 veers to right. Veer right, for one block, and turn left onto U.S. 80 northbound. Continue past Boot Hill Cemetary on right downhill. Lookout Lodge, our headquarters for the night, will be about 0.5 miles down the hill on the left.

GEOLOGY OF DRAGOON MOUNTAINS

After you settle in at Lookout Lodge you will see a splendid vista of the Dragoon Mountain chain about 15 miles to the northeast of Tombstone.

The Stronghold Granite in the central part of the range intrudes a highly deformed terrain of Paleozoic and Cretaceous rocks. The craggy, rough topography characteristic of Stronghold Granite terminates against smoother-textured topography to the south, which contains thermally altered Paleozoic rocks and Bisbee Group. These rocks extend northward into the Stronghold area on the skyline as a roof pendant.

The ridges south of Cochise Stronghold to South Pass consist of a northwest-trending, southwest-dipping set of imbricate thrusts which are transitional to the southwest (south of Middle Pass) into a large, northeast-vergent, overturned fold pair described by Keith and Barrett (1976). Tectonic transport in the central Dragoon Mountains is consistently towards the northeast. Age of this deformation is bracketed between 73 m.y. (tilting of 73 m.y. old Sugarloaf quartz latite at Gleeson in the southern Dragoons) and 52 m.y. (age of Texas Canyon Quartz Monzonite which intrudes the northwest-trending thrust fault in the Little Dragoon Mountains to the northwest). Pre-Cretaceous, post-Paleozoic vertical uplift occurred along the northwest-striking Black Diamond fault (Keith and Barrett, 1976).

The boundary between the central Dragoon block and the southern Dragoon block is at South Pass (2:00), where a major, east-striking fault zone has apparently shifted the southern Dragoon block 3 mi eastward relative to the central Dragoon Mountain block. Much of this transport has occurred along the Courtland overthrust.

Granitic rock in skyline ridges are underlain by Jurassic (178 m.y.-181 m.y.) Gleeson Quartz Monzonite (Marvin and others, 1973; Drewes, 1976a). The rough-textured, craggy and poorly vegetated rock in the ridge at 2:30 in the southern Dragoon Mountain or Gleeson block are outcrops of what Gilluly (1956) mapped as an alaskite facies of Gleeson Quartz Monzonite, although he had observed numerous abrupt contacts with the biotite quartz monzonite main facies of Gleeson Quartz Monzonite. Note the smoother slopes of the main facies adjacent to the craggy outcrops of the alaskite facies.

In the central Dragoon Mountains from Middle Pass to South Pass, Cederstrom (1946) and Gilluly (1956) mapped a major northwest-striking tectonic feature which Cederstrom (1946) named the Dragoon fault. They positioned this fault about half way down the slope on the northeast side of the crestline ridge now in view. Gilluly (1956) suggested several miles of shortening occurred during northeast-directed thrusting along this fault.

Drewes (1976a, 1978) has renamed the Dragoon fault the Cochise thrust. According to Drewes the Cochise thrust in the central Dragoon Mountains is the suture between the overlying Cochise plate and the underlying Hidalgo plate. The Cochise thrust continues through the southern Dragoon Mountains where Gleeson Quartz Monzonite of presumed Jurassic age rests in the upper plate. Drewes (1976b) suggested that Gleeson Quartz Monzonite could be the beheaded portion of the Squaw Gulch Granite in the Santa Rita Mountains 37 mi. west. If so, transport of the Cochise allochthon is 37 mi to the northeast during the Piman phase of the Laramide phase of the Cordilleran orogeny (Drewes, 1978).

Keith and Barrett (1976) presented evidence that the Dragoon fault between Middle Pass and South Pass is instead an unconformity between Glance Conglomerate and the Naco Group. Also Dunn (pers. comm., 1978) suggests that some of the Gleeson Quartz Monzonite may be Precambrian.

To reconcile these diverse views Keith would speculate that the alaskite facies at 2:00 in the Gleeson Quartz Monzonite is indeed a Jurassic pluton (one of the Jurassic dates is on muscovite, presumably from the alaskite phase) and has intruded and reset parts of a larger Precambrian pluton which petrographically resembles other 1,400 m.y. old granites.

The Dragoon Mountains were so named because it was here that the 3rd U.S. Cavalry, known as Dragoons, was stationed. Their name came from the fact that they used heavy carbines rather than the usual sabre and revolver associated with cavalry troops (Barnes, 1960).

DAY 3

ROADLOGS FROM TOMBSTONE TO TUCSON, ARIZONA

STOP 1: LARAMIDE SILVER MINERALIZATION AND POLYPHASE FAULT MOVEMENTS AT THE PROMPTER MINE

Another example of Laramide structural complexity is excellently exposed at the Prompter Mine, one of the former rich manganese silver producers in the Tombstone district. The Prompter shaft is driven down a major east-west-striking south-dipping structure named the Prompter fault by Butler and others (1938) (see Figure 1). The Prompter fault separates a synclinally folded Bisbee Group-Paleozoic section from a north-striking, east-dipping monoclinally folded Paleozoic section south of the fault.

The Prompter fault zone is locally heavily mineralized along strike for about 8500 feet. Butler and others (1938) describe the Prompter-Oregon Mine segment as follows:

> *Oregon-Prompter Mine.*—The Oregon-Prompter workings (Plates VII and XIV) extend to water level, with a maximum vertical depth of 800 feet. The ore bodies exposed in these workings are irregular, pipelike to tabular replacement masses, of which at least twelve have been mined. They occur within certain favorable beds of the Naco limestone where the Prompter fault and bedding slips have localized ore solutions from the northeast fissures.
>
> Associated with the Prompter fault were five separate ore bodies of which three occurred near the Prompter shaft between the surface and the fifth level, and one was 300 to 325 feet east of the Oregon shaft between the surface and the first level (Plates VII and XIV). The limestone beds that contained these bodies in general conformed with the footwall of the fault. This ore in general was of medium to low grade. Some 400 feet south of the Oregon shaft was the Massey-Williams ore body in vertical to steeply northward-dipping beds of Naco limestone beneath the Prompter fault. The stopes here are inaccessible, but according to maps and local information, the ore body extended, with medium to steep eastward plunge, from the fault, at a point approximately 125 feet above the third level, to water level. Throughout most of its vertical extent of 450 feet this ore was of high grade.
>
> The ore bodies related to bedding slips in the Naco limestone are indicated on Plate XIV. In general they were very persistent, and one of them was followed for a length of 850 feet, from the surface near the Oregon shaft to water level. The most western one, the Giacoma ore body, occurs along the intersection of a northeast fissure with steeply northward-dipping limestone beds in the footwall of a bedding slip (Plate XIV). According to John Giacoma, this body yielded $175,000 worth of silver ore.
>
> The Oregon-Prompter structures have not been thoroughly prospected. The favorable limestone beds and associated bedding slips, such as those of the Massey-Williams and Giacoma ore bodies, appear to be intersected by several other northeast ore fissures in unexplored areas. Other favorable beds and favorable structures may exist in the untested area north of the Oregon workings and south of the hornfels contact shown on Plate IV.

As has the Dividend monocline (DAY 2 STOP 6) and the Government Butte structural zone (DAY 2 STOP 9), the Prompter fault exhibits a complex polyphase movement history. At the Prompter shaft the Prompter fault places Abrigo Formation and Bolsa Quartzite over carbonate rocks of the Naco Group. Because Bisbee Group rocks have been deformed by this movement, the Prompter fault has had an episode of post mid-Cretaceous reverse motion. Presumably the east-northeast - striking broad syncline in the Bisbee Group on Reservoir Hill north of the Prompter fault is related to this movement.

Apparently mineralization took place after the reverse movement, but
before an episode of strike-slip motion on the Prompter fault (the man-
ganese-silver mineralization contains numerous slickensides that plunge
shallowly 30 to 45 degrees S50-80 degrees E). Offset of Cambrian for-
mational contacts in the Prompter fault zone are left lateral and com-
bined with the slickenside data suggest that the movement was largely
left slip. The above-mentioned structural relationships are consistent
with the double orogeny concept of Gilluly (1956). That is, early
Laramide tectonism (post-Bisbee and pre-silver mineralization and mag-
76 m.y. matism in the Tombstone district) is formed during a north-south regional
compression and later Laramide orogeny (post-72 m.y. magmatism, but pre
62 m.y. rhyolite dikes) is characterized by northeast-southwest to east-
west compression. These changing stress patterns are consistent with those
implied for structures observed at the Dividend Monocline and Government
Butte.

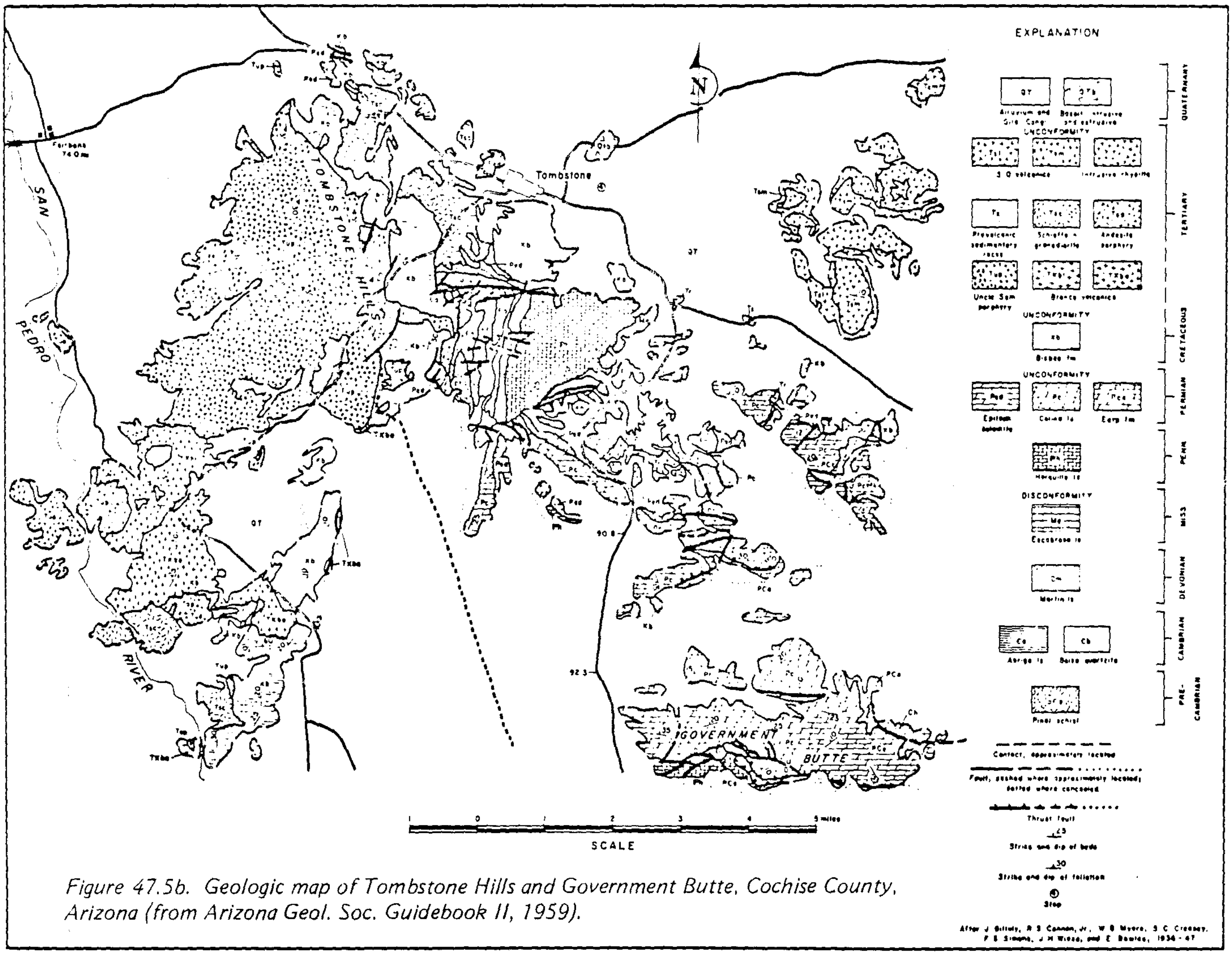


Figure 47.5b. Geologic map of Tombstone Hills and Government Butte, Cochise County, Arizona (from Arizona Geol. Soc. Guidebook II, 1959).

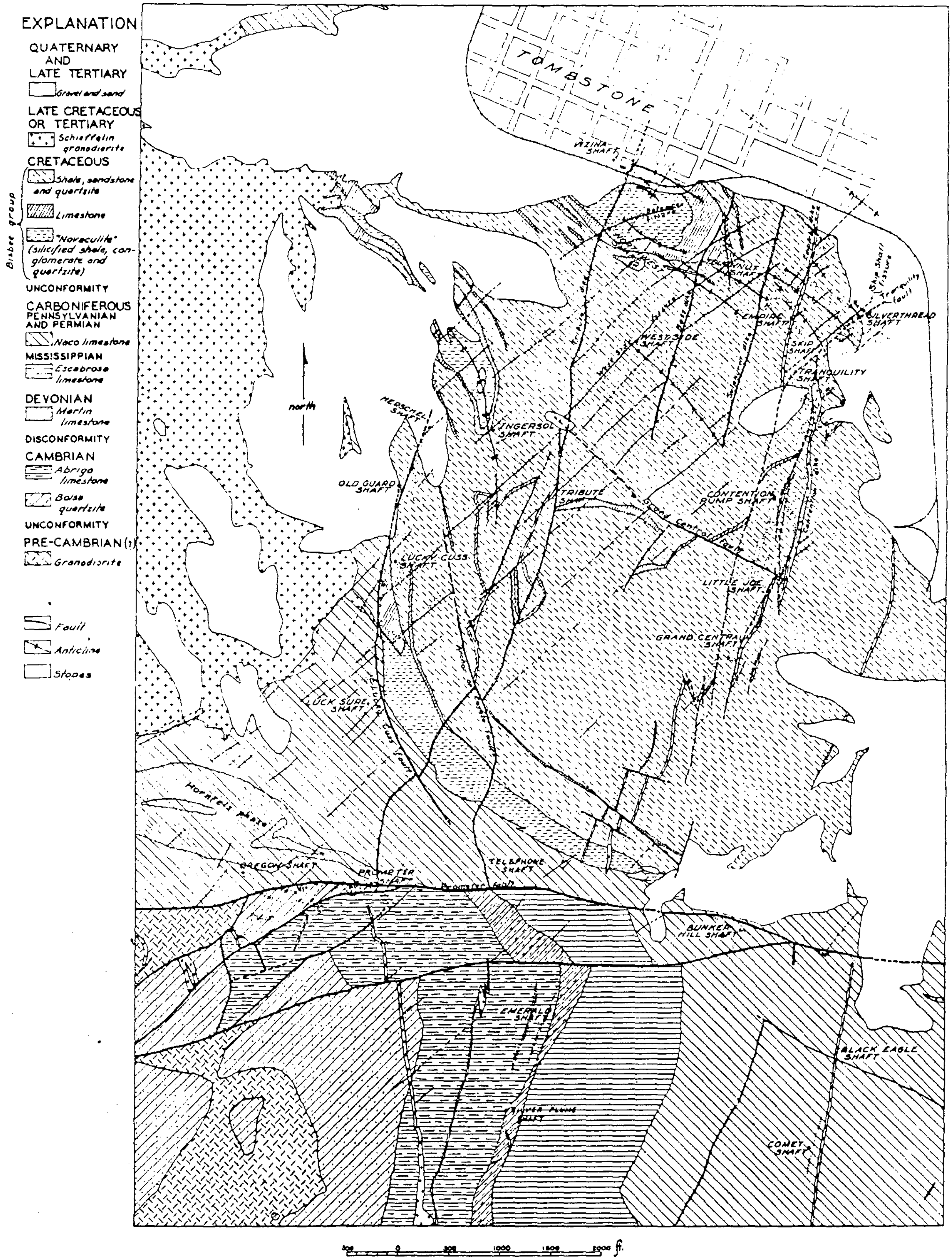


Figure 4. Geologic map of Tombstone district, Arizona (from Butler and others, 1938).

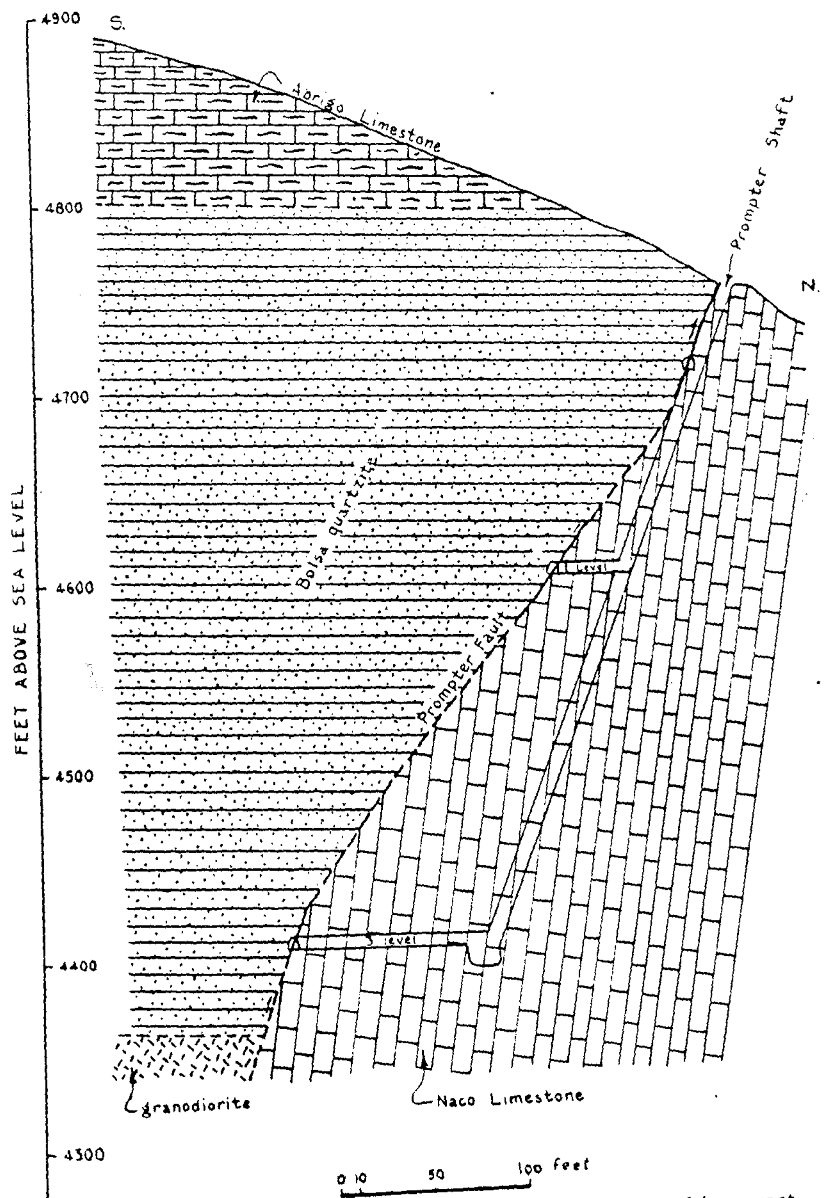


Figure 3.—Cross section through Prompter shaft, looking west.

After Butler and others (1938)

Table 1. Geochronological data for the Tombstone district, Cochise County, Arizona (Roger A. Newell)

Sample #	Sample description and location	Percent K	Radiogenic argon-40 $m \times 10^{-12}$ m/g	Percent atmospheric argon-40	A Age in m.y.
	Hydrothermal sericite from open cut of the Charleston Lead mine, Charleston Hills, Cochise County. E-W vein structure cuts Bronco Volcanics at Charleston mine and Uncle Sam Porphyry along strike.	7.73	1046.0	25.3	74.5 ± 3.0[1] 76.40[3]
GS-2	Hydrothermal sericite from NE-trending vein structure which to the NE carries silver mineralization at the State of Maine mine, Tombstone District, Cochise County. 31°41'38"N., 110°06'46"W.	6.80	890.0	28.5	72.9 ± 2.7[2] 73.95[3]
19A	Hornblende from melanocratic rhyodacite porphyry dike which cuts breccia (mineralized) pipe at Robber Roost along Charleston Rd. 31°40'09"N., 110°07'26"W.	$.71_8$	98.1	77.65	75.2 ± 3.8[2] 77.13[3]
H7-1	K-feldspar from NNW striking dike which cuts hornblende-biotite rhyodacite porphyry dike south of Prompter fault, Tombstone district, Cochise County. 31°41'02"N., 110°04' 22"W. Resembles the rhyolite dated at 62.1 m.y. by Creasey and Kistler (1962).	6.78_1	750.0	28.4	61.9 ± 2.3[2] 62.69[3]

Constants used:

$\lambda_b = 4.72 \times 10^{-10}$/year

$\lambda_e = 0.585 \times 10^{-10}$/year

$K^{40}/K = 1.22 \times 10^{-4}$ g/g

Analyst:

[1] E. H. McKee, Menlo Park, Calif. Sept. 18, 1973.

[2] Analyzed by Geochron Laboratories, Cambridge, MA

[3] Recalculated according to revised decay constants (Steiger and Jager, 1977)

From Keith and Wilt (1978)

TOMBSTONE AREA AND TO THE WEST

31°39'12"N 110°02'42"W	Rhyolite, biotite, No. 95	66±3 (K-Ar)	Marvin and others, 1973, p. 22; Creasey and Kistler, 1962, p. D1, No. 2.
31°39'N 110°03'W	Rhyolite porphyry; sanidine, biotite; 74D143	65.1±1.6(s) 66.6±1.6(B) (K-Ar)	Marvin and Cole, 1978.
31°43'48"N 110°06'09"W	Schieffelin Graniodiorite; biotite, No. 97	76±3 (K-Ar)	Marvin and others, 1973, p. 22; Creasey and Kistler, 1962, p. D1, No. 3.
31°41'N 110°09'W	Granodiorite; biotite, 74D84	149±3 (K-Ar)	Marvin and Cole, 1978
31°37'N 110°10'W	Granodiorite; biotite, 74D91	76.3±1.8 (K-Ar)	Ditto
31°41'15"N 110°14'45"W	Rhyodacite, Uncle Sam Porphyry; biotite, No. 96 (68D582)	73.5±2.8 (K-Ar)	Marvin and others, 1973, p. 22.
31°37'N 110°25'W	Rhyolite tuff, Pantano(?) Fm.; biotite, No. 71	39.8±1.5 (K-Ar)	Marvin and others, 1973, p. 19.

from Marvin and others (1978)

Cumulative
mileage

2.8 Right turn sign. Wash on right just ahead contains outcrops of light-gray Schieffelin Granodiorite. A dark-colored, northeast-striking, rhyodacite dike cuts the Schieffelin and Bisbee Group in the hills to the west. This dike is a part of an extensive northeast-trending dike swarm which cuts Uncle Sam Porphyry, Bisbee Group and Schieffelin Granodiorite. One of these dikes has been dated at 71 m.y. (Newell, 1974, courtesy of Anaconda).

0.1

2.9 Low hill ahead is a contact zone between Schieffelin Granodiorite and Bisbee Group which is exposed in low roadcuts on right. Schieffelin Granodiorite here contains numerous xenoliths of altered metasiltstone from the Bisbee Group. Outcrops of melanocratic rhyodacite dikes are also present. Roadcuts ahead will traverse generally east-dipping Bisbee strata.

0.5

3.4 Speed limit sign (45 m.p.h.) on right. The State of Maine mine and associated workings at 12:30 exploit silver-rich quartz veins in Uncle Sam Porphyry at contact with Bisbee Group. It is the only significant operation that is currently active in the district. The contact between Uncle Sam Porphyry and Bisbee strikes northwest through the area of mine workings visible on the hill slope. According to Newell (oral comm.) the contact dips moderately southwest.

0.2

3.6 Road on right to State of Maine mine and to Ernest B. Escapule mill.

0.3

3.8 Road on left. Roadcuts ahead on right are in contact-altered Bisbee Group.

0.2

4.0 Contact between Bisbee Group and Uncle Sam Porphyry is on right of road just past top of a low rise in road.

Mine workings at 8:30 are the Dry Hill prospect, which explores manganese-silver mineralization in horsetail fault strands of Prompter fault zone which juxtaposes upper and lower Paleozoic stratigraphy. Farther east, out of view, the Prompter and Oregon mines exploited rich silver-manganese mineralization along the Prompter fault, which marks the southern limit of major mineralization in the Tombstone mining district.

Hills ahead at 1:00 are Uncle Sam Porphyry. Road for next several miles crosses an extensive pediment cut on Uncle Sam Porphyry between here and the Charleston Hills at 12:00 in the middle distance. Huachuca Mountains from the far skyline ahead.

1.1

5.1 Tombstone Resources mill on left was one of several recent attempts to awaken interest in the Tombstone district.

Uncle Sam Hill at 3:00 is the type locality for the 72 m.y. old Uncle Sam Porphyry, first named by Butler and others (1938), who described the rock as an intrusive quartz latite porphyry. Ransome (1920) described the rock as an intrusive, but he classified it as a rhyolite flow. Drewes (1971c) called some of the Uncle Sam a welded tuff.

Uncle Sam Porphyry has invaded Colina Limestone, Epitaph Dolomite, Bisbee Group, Bronco Volcanics and Schieffelin Granodiorite east of Bronco Hill. In turn the Uncle Sam is intruded by a rhyodacite west of Ajax Hill and by numerous hornblende andesite (?) dikes between Charleston and the State of Maine mine (Newell, oral comm.). Gilluly (1945, 1956) believed that the Uncle Sam intruded along a major low-angle thrust fault within the Bisbee Group. Newell (1974) considered the Uncle Sam to represent an eruptive pyroclastic rock that cuts the Bisbee.

0.3

5.4 Cattle sign. Uncle Sam Porphyry in low ridges on right. San Jose Peak in Mexico at 10:00.

Bronco Hill at 12:00 in middle distance is type locality for Bronco Volcanics which underlie the pedimented area to the north. Bronco Hill itself, however, is of Schieffelin Granodiorite. Bronco Volcanics are best exposed over 3.5 mi^2 near the Charleston Hills, 9 mi southwest of Tombstone. Lithologically they consist of a lower, dominantly andesitic member and an upper member that is largely quartz latite. These volcanics rest on Bisbee Group, are intruded by Schieffelin Granodiorite and are overlain by Uncle Sam Porphyry. Alteration within the volcanics dates at about 72 m.y. (R. Newell, written comm.).

0.9

6.3 Cattleguard. Brown-and white-colored knob named Robber's Roost at 1:00 is one of numerous breccia columns in Uncle Sam Porphyry. The mineralized breccia column is intruded on its north side by an unmineralized, northeast-striking, melanocratic, rhyodacite porphyry dike (71 m.y.) (Newell, 1974).

0.3

6.6 Low hills in middle distance west of San Pedro River (1:30) are composed of Uncle Sam Porphyry and andesite member of Bronco Volcanics. The Mustang Mountains from the jagged skyline at 1:00, and are separated from the southern Whetstone Mountains by Rain Valley at 1:30 and from the main Whetstone Mountains at 2:00 by the Mescal Spring fault zone. The Whetstone Mountains contain the most complete section of Paleozoic rocks in southeastern Arizona.

The Charleston road is now descending into the drainages of the San Pedro River.

The San Pedro Valley provided the corridor for Spain's entry into what is now the Southwestern United States-the Coronado Expedition of 1540-1542. In search of the fabled "Seven Cities of Gold" at Hawikuh (near Zuni, N.M.), the army that treked along these banks consisted of 340 Europeans and 1,300 Indian allies; along with 1,500 horses, mules, sheep and goats. Although deemed a failure at the time, for no riches were found, they brought back knowledge of lands and people to the north and opened the way for later Spanish exploration, colonization, and the development of a distinctive Southwestern culture (Coronado National Monument, N.P.S., written comm.).

0.5

7.1 Charleston Lead mine at 1:30, at the northern base of the northernmost hill in the Charleston Hills complex. Sericite from the open cut at the mine is dated at 74.5 ± 3 m.y. (Newell, 1974). Deep drilling (3,000+ ft) failed to penetrate Bronco Volcanics and underlying Bisbee Group in this area.

0.3

7.4 Bronco Hills from 9:30 to 10:30; Bronco Hill at 10:30.

0.6

8.0 Good view at 2:30 of northernmost hill in the Charleston Hills complex. Reddish-brown rock comprising upper two-thirds of hill is Uncle Sam Porphyry. Light-colored rocks at base of hill are quartz latite member of Bronco Volcanics. Observe apparent flat contact across Bronco Volcanics.

If Uncle Sam Porphyry is an ash-flow sheet, as suggested by Drewes (1971c) and Newell (1974), then the contact is an angular unconformity. This implies a major rotational tectonic event which post-dates the probable 73 m.y. old quartz latite member of Bronco Volcanics, but predates extrusion of the 72 m.y. old Uncle Sam Porphyry; an extremely tight timing schedule. If the Uncle Sam Porphyry is a shallow laccolithic intrusion (Gilluly, 1956; Butler and others, 1938) the rotational tectonism may post-date intrusion of 72 m.y. old Uncle Sam Porphyry.

The majority of the hills at 12:30 are capped by Uncle Sam Porphyry, in flat-lying contact over the quartz latite member of Bronco Volcanics.

0.4

8.4 Cattleguard.

0.4

8.8 The crumbling adobe cabin at 11:00 low has been called the "bloodiest cabin in Arizona." The cabin was originally built by Frederick Brunckow of the Sonora Exploring and Mining Company of New York in 1857. His murder by Mexican employees in 1861 was the first of 13 known murders in the cabin. The first U.S. Federal marshall for Arizona was also killed there (J. D. Forrester, written comm.).

The cabin and associated claims are on northeast-trending, hydrothermally-altered fissures in Bronco Volcanics. Schieffelin Granodiorite crops out on hill to right.

0.2

9.0 Cattleguard.

0.2

9.2 In wash and roadcut ahead is quartz latite member of Bronco Volcanics. It has been hydrothermally altered along fractures, apparently by fluids related to the Schieffelin Granodiorite visible just to the west.

0.5

9.7 This part of San Pedro Valley northward to a point south of St. David was the site of the San Juan Boquillas land grant. A mile above Fairbank on the west bank of the river is the extensive ruin of Quiburi, a Sobaipuri Indian town and a Spanish colonial presidio in the 1700s (Polzer, pers. comm.).

0.1

9.8 Flood plain of San Pedro River. The edges of this flood plain were frequented by mammoth, horse, bison and other Pleistocene animals about 11,000 years ago. They were hunted by Early Man and 3 important sites have documented Clovis-type spear points and other lithic debris in direct association with faunal remains. The sites date by C^{14} at about 11,200 B.P. (before present) and are the Murray Springs, Lehner and Naco sites (<u>see Lindsay, this guidebook</u>).

0.3

10.1 Railroad crossing and cattleguards. Monument on left (before the first cattleguard) commenorates the Mormom Battalion's "Battle of the Bulls."

The battle actually occurred 20 mi upstream (near Hereford, Arizona), on December 7, 1846 (Young, 1955). The "Battle of the Bulls" was literally a contest between man and animal, as General Cooke and his Mormom Battalion were attacked by a crazed herd of wild bulls. The "battle" lasted for several hours as the rampaging beasts made repeated charges against the mules and wagons. Although, reportedly humorous at times, several soldiers were injured in the chaotic foray. Over 80 bulls were shot and killed before the herd was repulsed; no count on mule casualties. General Cooke unwittingly anticipated history by 15 years, by referring to the fracas as "Bull Run" (H. L. James, written comm.).

The Hereford area was also the setting for the western classic, Red River (1948), with John Wayne. Production crews had to dam the San Pedro in places to create enough water to "ford a cattle drive" that the plot demanded (Bourne, 1970).

The February 1945 issue of *Arizona Highways* featured a picture of the San Pedro by Stan Adler of Bisbee's *Brewery Gulch Gazette*, under which he wrote:

> *Men have drowned in it, men have bathed in it, and men have blistered their cowboy boots trekking across it during a drought. There are stretches of veteran willows and cottonwoods, of sage and sand, of eroded walls dotted with owls' nests, of gravel flats . . . At points the river is a frail ribbon of water, at others it is a wide but shallow expanse. Except for short periods after heavy rains, it can be crossed on horseback at almost any point without wetting the pony's belly . . . In the country of "big water" the San Pedro may not cut much of a swath as an aquatic phenomenon. But the natives of the San Pedro Valley consider it's their river - and they'll stick to it. If you hooraw them about it and ask what the San Pedro has got that other rivers haven't got, they will tell you with justiable pride: "It runs north!"*

The Quaternary stratigraphic sequence exposed in a post-1880 gully at Murray Springs arroyo south of here is the best exposed sequence of flood-plain sediments in lower San Pedro Valley (Haynes, 1968). Following a major entrenchment into the Pliocene St. David Formation about 30,000 years B.P., the area began to backfill. The area continued to backfill from 29,000 to 21,200 years B.P. Following backfilling, the area again was entrenched, after which it again backfilled. The lowermost of these backfill layers yielded a radiocarbon age of 11,230 years B.P. and contained Clovis spear points in a mammoth skeleton. Another undated entrenchment and backfilling sequence, which contained Cochise artifacts, ensued and was followed by yet another downcutting and backfilling cycle. Numerous radiocarbon dates from layers within these sediments range from 5,500 to 1,550 years B.P.; these layers contain San Pedro artifacts. The uppermost unit of flood-plain sediments contains artifacts of a U.S. Army encampment at Murray Springs between 1913 and 1918.

The arroyo cutting of the main San Pedro River began in this area in 1883 (Bryan, 1925), and progressed up the tributary at Murray Springs soon after 1900. If the Quaternary stratigraphy of Murray Springs is representative of flood-plain deposition below the Aravaipa surface within San Pedro Valley, then the present flood plain evolved after a series of downcutting and backfilling events which postdated a major downcutting event that had ended about 30,000 years ago.

0.3

10.4 Narrow bridge crossing San Pedro River. Be Careful!

Site of ghost town of Charleston is in grove of trees (to the right) along the west banks of the river. A satelite town, called Milltown, occupied the east bank (a short distance downstream). These towns were established to process ores from the Tombstone mines, using water from the San Pedro River.

0.2

10.6 Cattleguard. Road ahead ascends onto Whetstone surface of Bryan (1926).

1.2

11.8 Highway curves right. Southern Bronco Hills are east of San Pedro River from 9:00 to 10:00. They contain west-dipping Bisbee Group intruded by Schieffelin Granodiorite. The southernmost hill is just east of an angular unconformity between the andesite member of Bronco Vocanics and deformed Bisbee Group in a railroad cut north of Lewis Spring. Road continues on Whetstone surface.

1.1

12.9 Cattleguard and intersection with Moson road. To the right are the Whetstone and Mustang mountains with the Huachuca Mountains straight ahead. Ahead road ascends onto Tombstone surface, the highest aggradational surface in the San Pedro Valley (Bryan, 1926).

0.9

13.8 Cattle sign. Santa Rita Mountains now on far skyline at 1:00.

1.8

15.6 Dirt road intersection and cattleguard. Huachuca Mountains now dominate skyline. Mount Thompson is at the south end of the range at 10:00; Miller Peak (9,466 ft) at 10:30 is the tallest peak in the Huachucas; Carr Peak at 10:45; Ramsey Peak at 11:00; Garden Canyon at 11:30; Huachuca Peak (8,410 ft) at 12:00.

Low foothills along the entire northeast-facing slope of the Huachuca Mountains are in Precambrian granite, unconformably overlain by Bolsa Quartzite. Note the conspicuous Bolsa cliffs below Carr Peak and the unnamed, Bolsa-capped peak just north of Huachuca Peak at 12:05.

Near the crest of the range Paleozoic strata through Escabrosa Limestone have moved southwesterly over overturned Bisbee Group strata on a northeast-dipping, moderately-inclined, reverse fault. Hayes and Raup (1968) interpret this fault to flatten at depth, which implies the northeastern Huachuca Mountains are a southwest-directed, "thin-skinned" thrust slice.

According to Davis (discussion at Stop 2) these reverse faults steepen with depth. In this version, the northeastern Huachuca Mountains are part of a deep-seated, basement-cored uplift in a style similar to those in the classic Colorado and Wyoming Rockies. Drewes (1978) believes that the folds in the Huachuca Mountains are probably the upper ends of minor imbricate thrust faults which flatten downward to the southwest and perhaps merge with a major thrust fault.

0.7

16.3 Cross railroad tracks. Highway for the next few miles continues on relatively undissected, red soil-capped, Tombstone surface.

1.6

17.9 Junction of Charleston road and Arizona 92 (Sierra Vista bypass). Turn right.

0.5

18.4 Cross abandoned railroad grade.

0.7

19.1 North end of Huachuca Mountains is now clearly in view at 11:45. The east-west striking Kino Spring fault zone skirts the north edge of the Huachuca Mountain block and separates it from the low topography to the north between the Huachuca Mountains and Mustang Mountains. A similar fault north of the Babocomari River separates the southern end of the Mustang Mountains from the low topography to the south of them. At 11:00 numerous fire break roads in foothills are in Fort Huachuca on Precambrian granite. Town of Sierra Vista is to the left. Highway continues on Tombstone surface for next several miles.

3.0

22.1 Junction with Arizona 90 at stop light. Continue straight ahead across intersection towards East Gate.

0.3

22.4 East Gate of Fort Huachuca. Continue straight ahead on three-lane main road past barracks area. The old post is at 12:00. Fort Huachuca is the only military installation still active of those established to control Apaches along the border with Mexico. The fort was commonly garrisoned by black cavalry troopers (Buffalo Soldiers), a point overlooked in most western movies and novels.

The name Huachuca was apparently first used for a Pima Indian village on what came to be the Babocomari Land Grant.

Camp Huachuca succeeded Camp Wallen (q.v.)*as a military post of principal importance in Arizona. Camp Huachuca was established on March 3, 1877, at the mouth of what was known then descriptively as Cental Canyon, in the Huachuca Mountains. Increasing difficulties with Apaches added to the importance of the camp and in 1882 it was made a permanent post. Following the surrender of Geronimo in 1886, the post was relatively inactive until the Madero revolt in Mexico in 1911. Camp Huachuca then became headquarters for troops along the border. It reached its maximum importance during World War 11 when 22,000 soldiers and 8,000 civilans swarmed on the military reservation. In 1949 Fort Huachuca was transferred to the state of Arizona for use by the National Guard. For a brief period it was abandoned as a military establishment. The growing importance of military electronic devices caused the reactivation of the post as a federal project in the early 1950's.*

P.O. est. as Camp Huachuca, November 24, 1879. Fred L. Austin, p.m. Name changed to Fort Huachuca, February 5, 1892. Wells Fargo Station, 1885 (Barnes, 1960).

Huachuca Canyon and Precambrian granite foothills at 12:00. Conspicuous Bolsa-capped ridges are on either side of canyon.

1.2

23.6 Intersection with Irwin Street at stop sign. Turn right.

0.9

24.5 Intersection with Arizona Avenue to Libby Army Airfield. Continue straight ahead.

0.9

25.4 Stop sign. Intersection with Whitside road to North Gate of Fort Huachuca and Arizona 90 to right. Continue straight ahead. Irwin Street curves left and becomes Gatewood Road.

0.6

26.0 Road crosses wash from Huachuca Canyon, which is parallel to the contact between Pleistocene' alluvium and deformed Pantano equivalent(?) rocks west of the wash on Laundry Ridge. After crossing wash, road ascends hill in these older gravels.

0.4

26.4 Road is now on a veneer of Pleistocene gravels which are part of a dissected, low-relief, oblate fan, headed in Split Rock Canyon to the southwest. These gravels rest on a pediment surface which bevels Pantano equivalent(?) gravels and Bisbee(?) Group to the left. Triassic-Jurassic(?) volcanics and sediments to the right, and Precambrian granite ahead. The Mesozoic rocks are fault slices within the Kino Spring fault zone, which here trends west-northwest.

0.5

26.9 Intersection with Canelo road to West Gate of Fort Huachuca. Turn right. Roadcuts ahead are in shattered Precambrian granite just south of the Kino Spring fault. Note cataclastic foliation in some of the granite.

Road ascends onto terrace alluvium. To the north notice the extensive, early Pleistocene surface between the Huachuca Mountains and the Whetstone-Mustang mountains. This surface is the Tombstone pediment of Bryan (1926), which has been dated as younger than 700,000 years in San Pedro Valley on the basis of magnetostratigraphy (Johnson and others, 1975).

0.7

27.6 Road on right leads to riding stables. Just ahead road descends onto pediment which here bevels Triassic-Jurassic(?) volcanics and sediments. These are in a fault slice in the Kino Spring fault zone (Hayes and Raup, 1968). Demonstration Hill is ahead on right.

0.4

28.0 Road on right to Demonstration Hill. Road is again on pediment-veneer gravels.

0.3

28.3 Road descends into wash. Roadcuts ahead are in deeply weathered and deformed shales and arkoses of Bisbee Group in another fault slice of Kino Spring fault. As road ascends west side of wash, observe shattered Precambrian granite just south of the road across the wash. Also observe fault contact between Bisbee Group(?) and Precambrian granite.

0.6

28.9 (45 m.p.h. sign). Road is again on residual gravels veneering Pleistocene pediment; these gravels are part of a fan headed in Blacktail Canyon at 11:30. Outcrops in hills to south continue in Precambrian granite. Kino Spring fault is concealed just north of road.

0.8

29.7 Picnic area on right.

0.5

30.2 Intersection. Bear left following road to West Gate of Fort Huachuca. The Blacktail fan is now in good view on left. The road will traverse the head of this thin, gently sloping, broad alluvial fan which rests on an extensive pediment which bevels Precambrian granite, Triassic-Jurassic volcanics and sediments and older, tilted, red conglomerates that are possibly equivalent to the Pantano north of the Kino Spring fault zone. These fan gravels are probably younger than the terrace gravels of the Tombstone surface, which rest unconformably on 700,000 year old beds of upper St. David Formation at Curtis ranch in San Pedro Valley (Johnson and others, 1975).

The Blacktail Canyon fan is similar to many other fans, such as the Madera Canyon fan in the western Santa Rita Mountains (see Supplemental Road Log No. 1). Many of these thin, gently sloping fans rest on extensive pediments in southwestern Arizona, are no longer depositionally active and have been subjected to degradational processes of entrenchment by modern day streams sometime after the fans and pediments were formed in early Pleistocene time. These fans represent the highest level of aggradational back-filling of valleys such as San Pedro Valley to the east and Sonoita basin to the northwest.

The surface of the Blacktail fan is sloped to the Babocomari River, which skirts the southern Mustang Mountains at 3:00. On the western slopes of the Mustang Mountains a well-defined surface slopes southwesterly toward the Babocomari River. These surfaces are part of a large, generally gently northeast-sloping, aggradational surface in the Sonoita area to the northwest.

The topographic low between the northern Huachuca Mountains and the southern Mustang Mountains is not a Basin and Range basin. Thin fanglomerates rest on an extensive pediment beveled on pre-Basin and Range rocks (tilted Pantano-like gravels) from our viewpoint all the way to the Mustang Mountains.

0.2

30.4 Dirt road on left. Precambrian granite is thrust over southwest-dipping Bolsa Quartzite in the east wall of Blacktail Canyon at about 9:00 (Hayes and Raup, 1968). Bolsa Quartzite caps the prominent skyline ridge on the east side of the canyon from 8:30 to 9:00. Ridge in background is capped by Morita Formation, which in lower, tree-covered slopes is in thrust fault contact with complexly faulted Paleozoic rocks.

The main northeast-dipping thrust fault is at change in slope marked by a vegetation line on the foregound ridge in west wall of Blacktail Canyon. Fault here juxtaposes Precambrian granite over Mississippian Escabrosa Limestone, which forms ledges at the top of ridge. The thrust continues across our view and traverses the lower reaches of an unnamed, V-shaped canyon at 11:00. Extensively faulted Paleozoic slices occur in this canyon. The main thrust is approximately located in the middle part of the hill near 12:00, which is capped by Bolsa Quartzite.

The thrust continues to the northwest and joins the Kino Spring fault zone at the extreme north end of the hill just east of Kino Spring. The thrust is considered by Drewes (1976a, 1978) to be an element of the Cochise thrust and would mark the boundary between the overriding Cochise plate (here in Precambrian granite) and the lower Hidalgo plate (here in Paleozoics and Bisbee Group) to the southwest.

0.2

30.6 Road descends into wash on west side of Blacktail fan. Precambrian granite crops out on both sides of the road, in the wash, and along the road ahead.

0.1

30.7 Road on left.

0.6

31.3 Approximate location of intersection where main thrust is truncated by Kino Spring fault (Hayes and Raup, 1968).

0.2

31.5 Road on left. Small holes and holding tanks mark Kino Spring. Kino Spring is a modern name because the area was known to Padre Eusebio Francisco Kino as "Boconcos." This was an area of intense mission activity in the late 1600's. (Polzer, pers. comm).

Jurassic Huachuca Quartz Monzonite(?) is to left of road and poorly exposed Jurassic-Triassic volcanics and sedimentary rocks are to right of road.

0.2

31.7 Outcrops in this vicinity are in extremely deformed Jurassic-Triassic(?) volcanic and sedimentary rocks, a fault slide in Kino Spring fault zone.

0.2

31.9 West Gate. Begin dirt road. Road continues in sheared Jurassic-Triassic(?) volcanic and sedimentary rocks.

0.2

32.1 Road turns west at telephone pole. Hills south and east of Manila Canyon (about 11:00) are in extensively faulted, Paleozoic through Glance Conglomerate strata. The crest of ridge at 11:30 is Concha Limestone, which is overthrust by Glance Conglomerate on the west side of the ridge (Hayes and Raup, 1968). At the turn, the road will bear west down the southern boundary fault of the Kino Spring fault zone. Low roadcuts ahead are in deformed Glance Conglomerate.

0.3

32.4 Ranch house on right. Slow down for STOP 2.

0.2

32.7 STOP 2. Turn left onto dirt track and park.

The northern Huachuca Mountains are to the southeast and south and the Canelo Hills are to the west, with the Santa Rita Mountains in the northwest over the high, mid-Pleistocene surface at Sonoita. In the far north-northwest, Rincon Peak tops the southern Rincon Mountains. The Mustang Mountains are to the north, backed by the Whetstone Mountains, the least structurally disturbed mountain range in southeastern Arizona. The low valley between the Mustang Mountains and Stop 2 is drained by the Babocomari River, which joins the San Pedro River about 15 mi to the east.

Traverse through Laramide tectonite fabrics:

We will examine the contact of a north-to north-northeast-striking thrust fault mapped by Hayes and Raup (1968), Dockweiler (fig. 79.92), and Drewes (written comm.). The upper plate rocks are Glance Conglomerate, which are in low-angle fault contact with Morita Formation. At the end of the dirt track are outcrops of Glance Conglomerate between the mesquite trees. Walk southwest for 150 to 200 ft and cross the thrust contact between Glance and Morita. Steeply east-dipping, inverted cross-bedding in the siltstones of the Morita confirms the overturned nature of rocks in this area. The thrust is poorly exposed.

Careful search of Glance Conglomerate in the upper plate reveals zones of tectonically flattened and elongated limestone and chert clasts. The chert clasts are erosionally resistant and stick out of the rock like cigars. Long axes are N.30°E. to N.60°E., which is the inferred transport direction and axis of shortening for Laramide orogenesis. Because the Glance is located at a ductility contrast between more brittle underlying Paleozoics and more ductile or flexible higher Bisbee Group strata, the Glance commonly is a zone of intense shear strain. Observe numerous extensional fractures normal to the long axes.

Rocks and tectonic fabrics in Morita rocks of the lower plate are excellently exposed about 600 ft. farther south on the ridge, where overhanging cliffs of upper plate Glance rest in low-angle fault contact on Morita Formation. The thrust is also well exposed under numerous overhangs as you follow the ridge south.

About 1,200 ft. south along the ridge severely splintered Morita siltstones reflect a pronounced lineation parallel to the axes of rootless reclined folds. Axial surfaces of these reclined folds are generally subparallel to the plane of the overlying thrust. Axes of the folds and lineations plunge east-northeast to east. Within the Morita Formation below the thrust are intact kink-fold pairs with varying axial orientations. The overall geometric aspects of the kink-fold pairs and the reclined folds suggests that kind-fold pairs initially formed with fold axes perpendicular (northwest) to the direction of tectonic transport. As strain continued these folds became progressively attenuated and detached. Fold axes rotated towards the direction of tectonic transport and the rock became progressively rotated and acquired a splintered character. The highly lineated outcrops have a fabric aligned subparallel to the tectonic transport direction. Another 15 ft. to the south end of the cliff line is an excellent view of the overthrust.

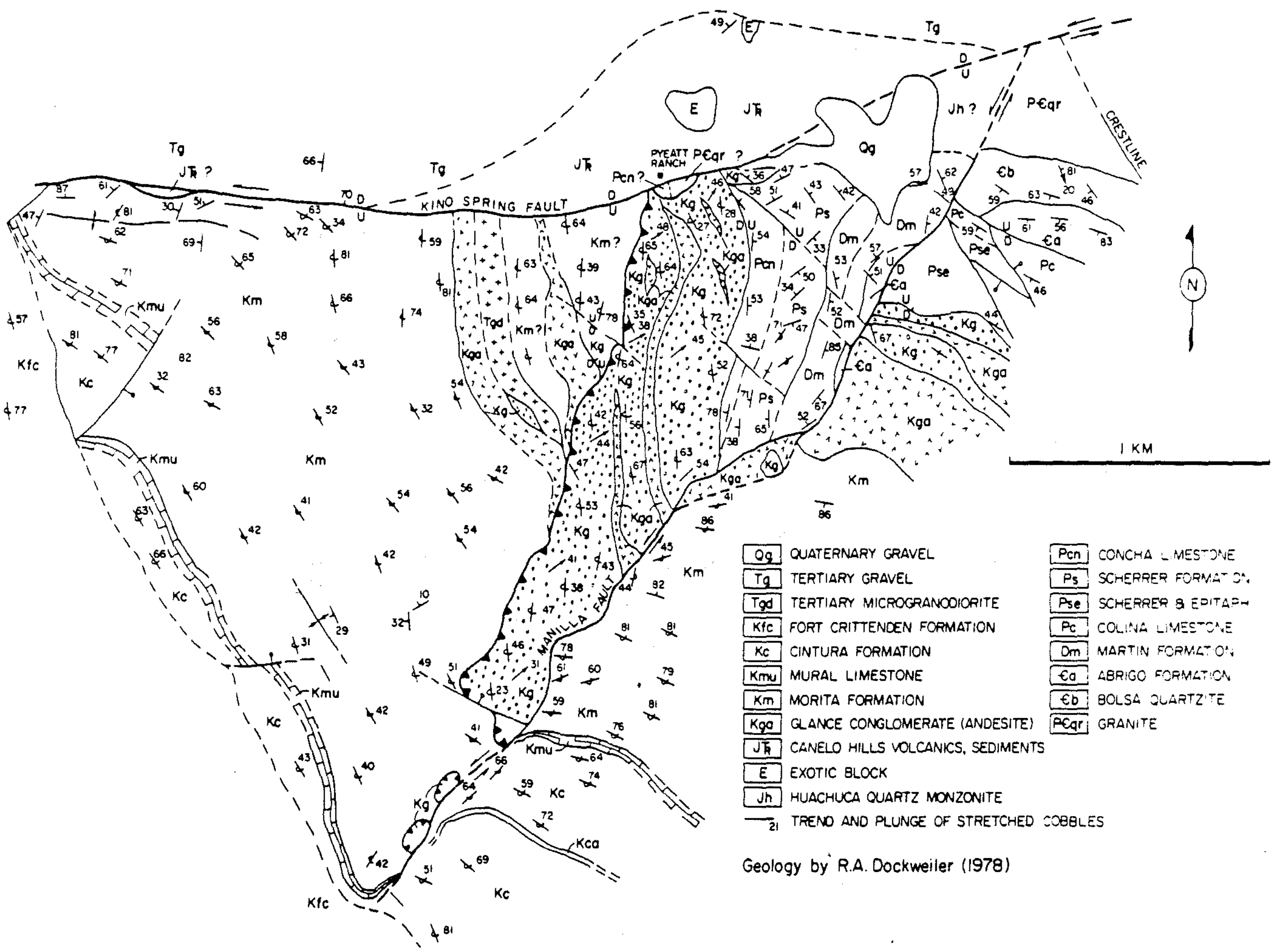


Figure 79.9a. Geologic map of the northern Huachuca Mountains (by R. A. Dockweiler).

TECTONICS OF THE HUACHUCA MOUNTAINS

G. H. Davis

A major feature of the Huachuca Mountains is a northeast-dipping, N. 40°W.-striking, thrust/reverse fault zone (fig. 79.9b). Everywhere along it, relatively old rocks on the northeast are juxtaposed against relatively young rocks on the southwest. Slickensides are dip-slip and, together with the sense of stratigraphic separation and drag folding, disclose thrust-slip and reverse-slip movements directed southwestward. Cretaceous footwall rocks near the crest of the mountain locally are deformed by large overturned folds.

The expression of this zone of folding and faulting in the northern Huachucas is anomalously intense. A block of Precambrian basement and Paleozoic-Mesozoic sedimentary rocks representing the framework of the northernmost Huachuca Mountains (figs. 79.9a,b) has been displaced southwestward approximately 0.6 mi. Translation was accommodated by: (1) left-slip on the northeast-striking Manilla fault, (2) thrust-slip movements on low-angle northeast-dipping faults, and (3) reverse-slip movement on the Kino Spring fault. Thrust-slip faulting has resulted in overturning of the Glance Conglomerate-Permian disconformity and the development of one of the few penetrative tectonic fabrics seen in the region, as discussed previously. These record attenuation and thinning during northeast to southwest transport. The influence of this southwest-directed displacement on the major northwest-trending syncline on the west flank of the Huachuca Mountains is striking, for it becomes progressively overturned to the north (figs. 79.92, b).

Concentration of deformation along the Glance/Morita contact reflects the influence of the mechanical properties of southeastern Arizona strata. Flexural-slip along layering was <u>not</u> a favored mode of strain when Sevier-Laramide stresses were transmitted through the Paleozoic section, with its massive strata broken by faults, variously tilted, and lacking continuity. Likewise, folding was not favored in Triassic (?)-Jurassic strata because of the abundance of wedge-like rhyolitic volcanic and coarse-clastic depositional units, the local "inclusions" of enormous landslide blocks of upper Paleozoic strata within the sequence, and the abundant faults and joints imposed during the late Triassic (?) to mid-Jurassic interval.

In contrast to pre-Cretaceous strata, Cretaceous strata readily deformed by macroscopic folding because of great thicknesses of thin- to medium-bedded strata, especially sandstone, siltstone, mudstone and shale, and because of the pre-Laramide, post-Early Cretaceous continuity of undeformed horizontal strata over large areas. As the northern Huachuca locality shows, the base of the Cretaceous commonly marks the transformation from dominantly faulting to dominantly folding. Seen in this way, the penetrative deformation concentrated in Glance Conglomerate in the northern Huachuca Mountains may be understood in the context of decollement tectonics.

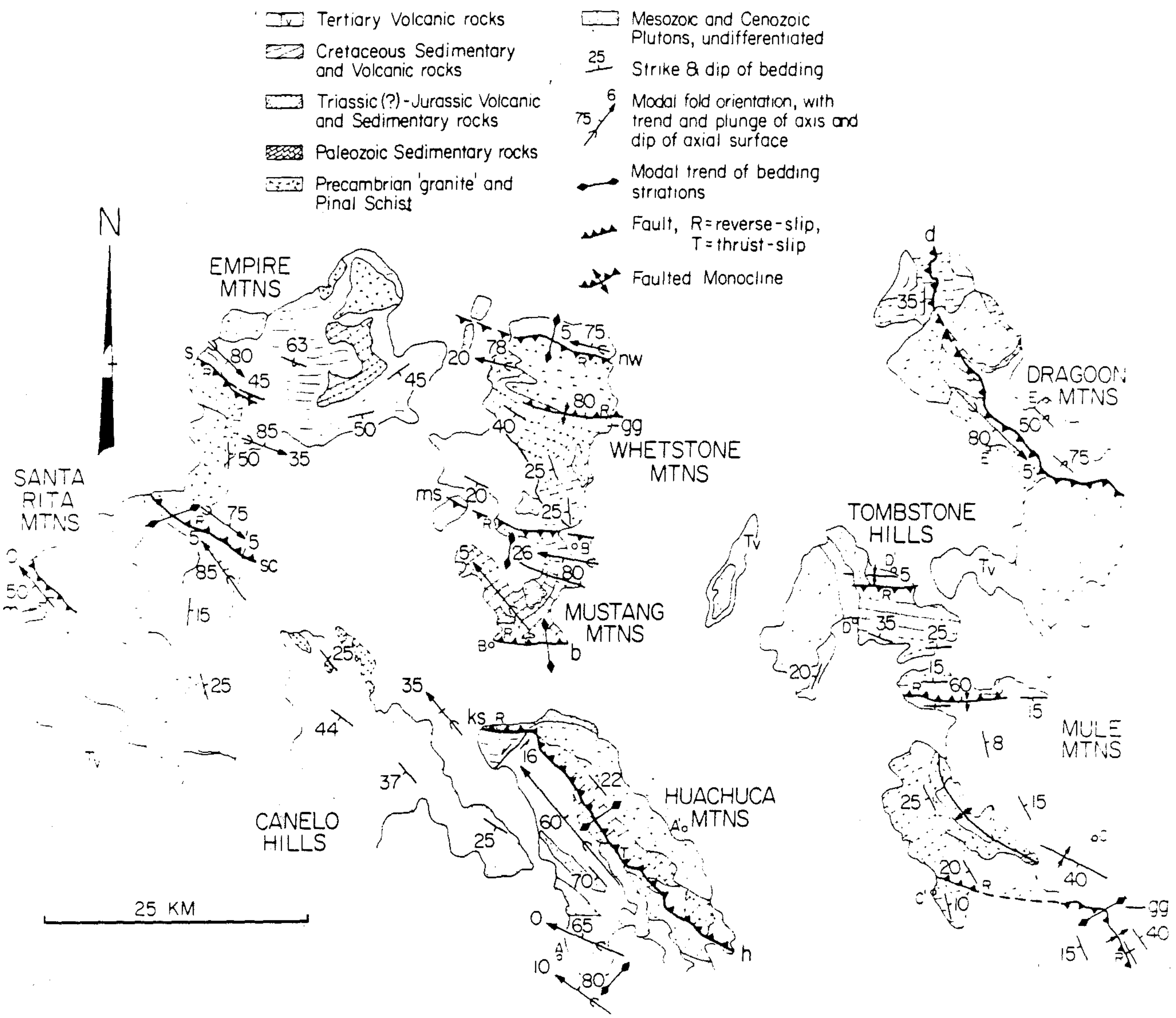


Figure 79.9b. Generalized structural-geologic map of part of southeastern Arizona showing locations of major faults and folded belts (from Davis; in press, *American Journal of Science).*

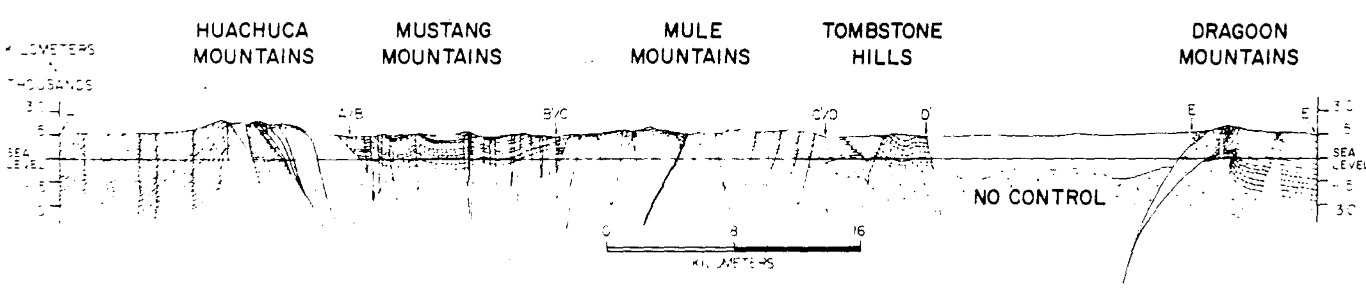


Figure 79.9c. Interpretative southwest-northeast cross-section of basement-core uplift (from Davis, in press, *American Journal of Science).*

Kino Spring Fault

A major reason for the intensity of deformation in the northern Huachuca Mountains is the Kino Spring fault zone (fig. 79.92). Drewes has studied this zone in detail and major aspects of the following descriptive and interpretive narrative grew out of conversations with him.

The Kino Spring fault is part of a northwest-trending system of faults having a complex and long-lived history of movement. North of this fault is a suite of Jurassic Canelo Hills Volcanics and some older redbeds and the mid-Tertiary Pantano Formation; south of the fault is a suite of Precambrian granitic rock, Paleozoic sediments and Cretaceous volcanic and sedimentary rocks. The fault zone lies along the road at the long grade west of Pyeatt ranch and forms a broad belt; nearby the fault dips 45 to 80 degrees north. This fault contains signs of multiple movements, including left-slip, features typical of the major system of faults in southeastern Arizona. Many faults are probably rejuvenated segments of flaws in the basement (fig.79.9b).

Multiple movements along the Kino Spring fault are suggested by the diverse suites of rock adjacent to the fault and by the intercalation along the fault of a few tectonic silvers of Cretaceous(?) granitic rock unlike any known from adjacent terrains. A strike-slip component of movement along the Kino Spring fault is demonstrated by drag of Cretaceous beds immediately south of the fault between Pyeatt ranch and Ferosa Canyon. These beds, variously of the Cintura and Morita formations and of Glance Conglomerate or a pre-Glance, andesite lava-bearing Cretaceous or Jurassic formation, strike north to northwest toward the Kino Spring fault, and dip 45 to 70 degrees northeast to east (fig. 79.9a). Numerous quartzite beds provide detailed control of attitude, and show the strike of beds to bend systematically westward near the fault. Some folds and faults in the Createaceous rocks also seem to be deflected, thereby implying that left-lateral slip occurred after thrusting and folding of these rocks.

The history of deformation that may be inferred from the relations along the Kino Spring fault is similar to segments of the history of other faults of the northwest-trending system. The Kino Spring fault is actually one of a pair of east-trending complex structures in this area. The other such fault is found along the Babocomari River on the south side of the Mustang Mountains (fig. 79.9b), an area shown by Hayes and Raup (1968). Pantano Formation occurs south of that fault, the terrain between the pair of faults thus being a mid-or late-Tertiary graben. To the east the pair of faults probably merge at the complex fault zone north of the Mule Mountains; to the northwest they probably also merge at the Sawmill Canyon fault zone in the Santa Rita Mountains. Several faults splay southeastward off the Sawmill Canyon-Kino Spring fault zone, and they also show evidence of left-lateral-movement and a polyphase history. The distribution of these faults is shown by Drewes (1978), but the significance of segments of some strands of this fault system has long been appreciated (Ransome, 1904).

Regional context of deformation in the northern Huachuca Mountains

The themes of compression-induced folding and faulting, and reactived high-angle faults, emphasized at this stop, relate importantly to the tectonic setting of southern Arizona and the nature of Laramide deformation. Drewes (1978) has underscored this in his tectonic narrative for southern Arizona. Laramide compressional stresses, directed northeast-southwest, induced major reverse-slip and thrust-slip faulting along zones of weakness in the region. Two major zones of faulting are recognized, one passing along the Huachuca Mountains northwestward through the Kino Spring zone to the Sawmill Canyon zone; a second trending northwest-southeast along the Dragoon Mountains (figs. 79.9b, c). Both of these zones were tectonically active in Triassic(?)-Jurassic time and constituted "lines" of weakness in the crust. The major zones are marked by anomalously intense deformation and serve to demarcate the margins of a northwest-trending block, approximately 35 mi. wide. Phanerozoic strata in the central basement core (e.g. in the Whetstone, Mustang and Mule mountains) are marked by gentle structures in the form of monoclines, homoclines and open upright folds. Phanerozoic strata along the margins of the uplift are cut by reverse and thrust-slip faults, tight upright to overturned folds, and axial plane cleavage. Tectonic movements and fold vergence are directed away, i.e., outward from the core of the uplift.

0.2

32.8 Cattleguard and Santa Cruz County line. We are traveling along the Kino Spring fault on this downhill section. Observe west-northwest-striking beds of upturned Morita Formation which suggest a period of left-slip movements on the Kino Spring fault. Road ahead passes poor exposures of Morita Formation, Glance Conglomerate and Tertiary granodiorite.

0.1

32.9 Roadcuts on right are in Morita Formation.

0.3

33.2 Road now in the Kino Spring fault zone, expressed as gouge in roadcuts on right. After curving right 0.4 mi ahead, Pantano Formation continues to crop out south of the fault.

0.9

34.1 Cross Lyle Canyon. Observe Pantano Formation exposed in gullies to either side. Volcanic rocks intercalated within these conglomerates yield dates of 38.9 m.y. (Marvin and others, 1973) from south of the Babocomari River and 27.2, 26.1, and 24.3 m.y. (Vice, 1974) from the Babocomari River area.

The Babocomari River valley to the north received its name from the Babacomari (sic) Land Grant made in 1832 by the Mexican government to Ignacio Elias, who erected a hacienda at the center of an important cattle ranch. Depredations by Apaches forced its abandonment , and although already falling into ruins, it was used as a fort by people in San Pedro Valley in 1855 (Barnes,1960).

0.4

34.5 Cattleguard. Entrance to Research Ranch area of the Coronado National Forest.

0.5

35.0 Cretaceous Fort Crittenden Formation is poorly exposed in roadcuts on left (see Hayes and Drewes, 1978).

0.2

35.2 Road now on block south of the Kino Spring fault, which is here concealed by younger alluvium. Road crosses into Plio-Pleistocene gravels for the next 0.5 mi. To the left is a good view of overturned Bisbee Group strata in a major overturned fold structure on the west side of the northern Huachuca Mountains. The upper continuation of this structure is truncated by the northwest-trending, northeast-dipping thrust fault zone (Hayes and Raup, 1968). An extensive, dissected pediment bevels upturned Bisbee Group and Fort Crittenden Formation in the northwestern foothills of the Huachuca Mountains. Plio-Pleistocene gravels rest on this pediment.

0.2

35.4 Explanatory sign for the Research Ranch of the Coronado National Service.

0.1

35.5 Roadcuts in poorly exposed conglomerate member of the Fort Crittenden Formation.

0.2

35.7 Roadcuts on right are in poorly exposed Cintura Formation. These rocks mark the core of a northwest-trending anticlinal structure at the northwest tip of the Huachuca Mountains.

0.5

36.2 Cattleguard. Leaving Research area. Canelo Hills are on the skyline at 12:00. Outcrops continue in Cintura Formation.

0.1

36.3 Road crosses contact of Cintura Formation and lower conglomerate member of Fort Crittenden Formation. Note lag gravels composed of rounded pebbles and cobbles washed out of the Fort Crittenden Formation. Roadcuts ahead on the left are in Fort Crittenden Formation. We are in the southwest limb of the anticline.

0.3

36.6 Junction; turn right for Sonoita, Arizona 83 leads south to Parker Lake. Canelo Hills are on skyline to the west. The name Canelo in Spanish means "cinnamon" and the name of the hills probably refers to their light brown color. The Canelo Hills are the type locality of the Canelo Hills Volcanics and redbeds. Radiometric dates on the Canelo Hills Volcanics are 173 and 165 m.y. (Marvin and others, 1973). The core of the Canelo Hills comprises a large, anticlinal fold structure in upper Paleozoic strata (Feth, 1947) flanked by Canelo Hills Volcanics. These rocks are cut by northwest-striking reverse faults, which may be southeastward continuations of similar structures in the Sawmill Canyon zone of the Santa Rita Mountains to the northwest.

0.2

36.8 Abandoned schoolhouse on left.

0.2

37.0 "Metropolis" of Canelo ahead.

0.1

37.1 Road on right to Elgin. Road for next few miles crosses low hills in flat-lying, Plio-Pleistocene, alluvial valley-fill.

1.1

38.2 Junction with Forest Service road on left. Turn right, cross cattleguard, and follow Arizona 83 to Sonoita. Mount Bruce in the northern Mustang Mountains is a conspicuous landmark at 12:30 after the road turns north. Road continues on valley-fill alluvium and younger flood plain sediments.

3.0

41.2 Outcrops of Fort Crittenden Formation are on both sides of road in low ridges and gullies for next 2.5 mi.

0.7

46.9 Coronado National Forest boundary sign.

1.6

43.5 Younger gravels unconformably overlie extensive pediment cut on Fort Crittenden Formation.

0.2

43.7 Road for next 25 miles is on alluvium of an aggradational surface entrenched by local low-relief washes and gullies.

0.3

44.0 Mount Wrightson (9,453 ft.) is prominent peak in central Santa Rita Mountains at 9:00. The northern Santa Ritas form low peaks on skyline from 9:30 to 10:30. Empire Mountains are in the middle distance at 11:00. The Santa Catalina Mountains are in the far distance, north of Tucson area, at 10:45 with the Rincon Mountains at 11:30 east of Tucson. Rincon Peak (11:30) is backed by Mica Mountain which is the low rounded mountain to the left of Rincon Peak.

The Mustang Mountains with the Whetstone Mountains beyond are from 12:00 to 1:00. Mustang Peak is the prominent, east-northeast-trending ridge in the Mustang Mountains at 1:00. The cliff-former capping Mustang Peak is Permian Concha Limestone underlain in the middle slopes by Scherrer Formation, which consists mostly of ortho-quartzite and redbeds. Observe the broad, northwest-plunging, anticlinal arch in Mustang Peak.

The Whetstone Mountains were labeled "Mustang 'Mountains'" on the 1879 map but by 1883 only the southern extremity was called the Mustang Mountains. The Mexicans called the range the Mestinez (Sp.=mustang) because in 1870 the hills sheltered a herd of about 60 wild ponies. These ponies may have been descendents of the stock brought into the region by Father Kino. In 1697 Kino and Manje made a trip up San Pedro Valley, on which they noted the Sobaipuri Indians rode horses. Manje said that in 1687 several stock ranches near the Pima County border had been abandoned because of Indian raids. The unclaimed stock went wild and soon became "mestena" or mustangs, and the Sobaipuri Indians captured and used the horses (Barnes, 1960).

0.4

44.0 Road on right to Elgin. Bear left on Arizona 83.

0.1

44.1 Roadcuts are in dark-gray, loamy soils of the entrenched flood plain. Compare these soils with the older Pleistocene soils which contain bright-red argillic (B) horizons and white petrocalcic (Cca) or "caliche" horizons, which cap the early Pleistocene surface throughout the Sonoita area. The flood-plain soils are possibly no older than 10,000 years (Holocene). Some have assigned a Sangamon interglacial age to the red paleosol (Melton, 1965a, b).

2.7

46.8 Pavement begins-yea!

0.3

47.1 Low roadcuts contain a thick petrocalcic (Cca) horizon; here the red argillic horizon has been stripped.

egin milepost
ormat.

0.6

25 Low roadcuts ahead contain excellent examples of the red argillic (B) horizon.

0.7

25.7 Mount Fagin in the northern Santa Rita Mountains is at 12:00. Empire Mountains are at 12:30 in middle distance, backed by Rincon and Santa Catalina massif in far distance.

1.5

27.2 Dirt road to Elgin on right. Whetstone Mountains from 1:00 to 2:00; Mustang Mountains from 2:00 to 3:00, with Mount Bruce at 2:30 and Mustang Peak at 3:00. The Mustang Mountains are separated from the central Whetstone Mountains on the north by the Mescal Spring fault and from the low valley south of the Mustangs by an east-west striking fault along the Babocomari River. Rocks within the Mustang Mountain block are mostly upper Paleozoic rocks (Horquilla through Rain Valley formations) and Triassic-Jurassic volcanics and sediments, which are probable Canelo Hills Volcanics equivalents. These rocks have been broadly flexed around northwest-plunging fold axes. Local bedding-plane faults resulting from this folding were mapped by Hayes and Raup (1968) in the southern Mustang Mountains. The Mustang Mountains are the type locality for the Rain Valley Formation, the youngest Paleozoic formation (late Early Permian) in southeastern Arizona.

0.6

28 Note buried soils on right for next 0.2 mi. Underlying soil layer was probably buried by road construction fill.

0.5

28.5 Cattleguard. Just ahead road to Elgin on right. Abandoned railroad grade ahead on right after left turn.

3.3

31.8 Entering Sonoita (Papago meaning: "place where corn will grow"). The scenic qualities of the Sonoita area have attracted film makers for such movies as *Duel In The Sun*, *Oklahoma*, and more recently, *A Star Is Born*. A popular annual quarter horse race held here at the race track on the left attracts racing fans from all over the Southwest. Sonoita at an elevation of 4,865 ft. has an average annual precipitation of approximately 17 inches, sustaining the area's lush, rolling plains grasslands (see Dunham, this guidebook).

In 1859 a traveler noted that the entire Sonoita Valley was golden with grain and that one field alone contained one hundred and fifty acres of corn. Hinton noted that corn grew as high and as lushly in the Sonoita Valley as it did in Missouri bottomlands and that the Sonoita River rose to the ground and disappeared several times within twelve miles of Camp Crittenden. In 1856 Col. Gray referred to the stream as the "Sonoita or Clover Creek."

Like other areas in southern Arizona, the Sonoita Valley, because of trouble with Apaches in the period 1861-1876, was nearly uninhabited by white men.

The present day community of Sonoita is of relatively recent origin, having come into existence in 1882 when it was established on the newly constructed railroad line. When the newer community of Sonoita was established on the railroad to the east of the old Sobaipuri rancheria, a post office was established. P.O. est. May 8, 1912. Clara L. Hummel, p.m. (Barnes, 1960).

0.3

32.1 Junction of Arizona 83 with Arizona 82. Continue straight ahead (north) on Arizona 83. (Note: Supplemental Road Log No. 1 intersects here. The original name for Sonoita was Sonydag or Sonoydak which means "spring-field" in Sobaipuri-Pima. This was the range land for mission cattle belonging to Kino's rancheria at Los Santos Reyes (Polzer, pers. comm.).

0.9

33 We are now on the high grassland of Sonoita basin. The highway has ascended onto the highest Pleistocene surface in the region. This surface was created before Sonoita Creek (to the southwest), slopes northeast and is gently graded to the Babocomari River at the south end of the Mustang Mountains. Drainage related to this surface has been progressively captured by headward erosion of drainage systems such as Sonoita Creek.

Roadcuts are in Plio-Pleistocene valley-fill gravels. Thickness of basin fill is geophysically estimated at about 5,000 ft (Bittson, 1976). From geophysical profiling, the Sonoita basin in general trends northwest; it is bounded on the south by the Sawmill Canyon zone, which may connect to the southeast with Kino Spring fault zone in the northern Huachuca Mountains. To the west the basin is bounded by a north-trending fault at the west edge of the central Santa Rita Mountains.

Bedrock pediments extend far up into the Santa Rita Mountain block; thus the present mountain edge is not the structural edge of the block. The pedimentation process related to backwearing of mountain blocks adjacent to the Sonoita basin is no longer active due to the downcutting episodes which have captured drainages related to the mid-Pleistocene surface.

Basin-Range faulting (since 15 m.y. ago) initially formed Sonoita basin, which filled up with alluvium while the mountain fronts retreated by pedimentation from the initial, mountain-bounding faults. Sonoita basin then filled at a much slower rate and gravels onlapped onto the extensive pediment surfaces until mid-Pleistocene time. At that time a fall in the regional base level in the Gila-Santa Cruz River system induced downcutting in the upper reaches of the system and progressive capture of drainage systems.

The post-1880 gully cutting episode merely reflects the largest in a series of downcutting cycles which began in mid-Pleistocene time. Changes in climate and man-made perturbations have been superimposed on a more regional, geologically pre-determined tendency for net downcutting since mid-Pleistocene time throughout the upper Gila drainage system. Climatic changes, possibly related to glacial cycles, could have promoted cyclic backfilling and downcutting events, which produced numerous sets of terraces in entrenched drainage basins. Thus, entrenchment in many stream systems in southeastern Arizona is not necessarily indicative of tectonic activity. Perhaps the regional base-level fall could be attributed to integration events in the lower Gila River system, with resulting downcutting in the upper reaches. As demonstrated by Sonoita and Cienega creeks, the amount of downcutting and drainage divide migration in Quaternary time has been very impressive.

1.0

34 The west-northwest-striking Mescal Spring fault zone (3:00) separates the central Whetstone Mountain block, on the north, from the Mustang Mountain block, which includes the lower, southern Whetstones and the Mustangs. Mescal Spring fault zone is regarded by some as an element of the notorious Texas lineament.

The Whetstone Mountains are the least structurally disturbed mountain range in southern Arizona. From the Mescal Spring fault zone northward past Apache Peak (1:30), the entire Phanerozoic section from Bolsa Quartzite through Bisbee Group is homoclinally tilted southwestward. The lower Bisbee Group contains concordant bodies of rhyolite which Creasey (1967) indicated to include both extrusive and intrusive rocks. The rhyolite-Bisbee Group section is intruded by the 74 m.y. Mine Camp stock (Creasey, 1967) near Granite Peak (2:30) north of the Mescal Spring fault zone.

0.8

35.8 Road ahead descends into Gardner Canyon, which has numerous Pleistocene surfaces related to long term downcutting and backfilling cycles in the Gardner Canyon drainage. The red argillic horizon at top of roadcut on left displays A, B and C soil horizons.

1.0

36.8 Pima County line. Terrace alluvium on both sides of road ahead is dissected below the upper surface. Observe several sets of surfaces including that produced by the post-1880 downcutting event.

0.2

37 Roadcuts in fine-grained valley fill capped by coarse, rounded, cobble-boulder alluvium on a surface below the high, early Pleistocene, aggradational surface. Note excellent channel at base of terrace gravels. The surface is also present ahead on the north side of Gardner Canyon. Finer-grained sediments represent bank overflow and flood-plain deposits in the wider flood plain of an earlier Gardner Canyon. This proto-Gardner Canyon surface in turn has been entrenched by the modern Gardner Canyon, which is currently entrenching its own flood plain. Similar valley fill is exposed in roadcuts for next 7 mi.

0.2

37.2 Gardner Canyon bridge.

0.1

37.3 Gardner Canyon road on left. Turn left and proceed into Gardner Canyon area for STOPS 3, 4, and 5.

INTERCALATED VOLCANICS AND EOLIAN "AZTEC-NAVAJO - LIKE" SANDSTONES IN SOUTHEAST ARIZONA: ANOTHER CLUE TO THE JURASSIC - TRIASSIC PALEOTECTONIC PUZZLE OF THE SOUTHWESTERN U.S.

by

William L. Bilodeau

and

Stanley B. Keith

INTRODUCTION

Recent reconnaissance geological mapping on the Papago Indian Reservation by U.S. Geological Survey geologists (Haxel and others, 1980), some new age dates and our own local detailed analysis of some specific Mesozoic sedimentary sections has produced new evidence to more clearly define the Early Jurassic paleogeography of southern Arizona. Specifically, thick sequences of mature quartz sandstones intercalated with rhyolitic to andesitic volcanics of dated Early Jurassic age are located in several southern Arizona mountain ranges, and can be correlated with the Early Jurassic Aztec Sandstone 600 km to the northwest in the Mohave Desert (Miller, and Carr, 1978), and the Navajo Sandstone 400 km to the north on the Colorado Plateau (Peterson and Pipiringos, 1979). This correlation is based on similarities in age, lithology, petrography and paleowind drections deduced from the orientation of large-scale crossbeds.

The Early Jurassic paleogeography of southern Arizona was dominated by a northwest-southeast-trending continental margin magmatic arc of Andean type. This magmatic arc extended northwestward into California, southward into Mexico and was directly related to eastward subduction of an oceanic plate beneath the southwestern edge of North America (Coney, 1978). The Lower Jurassic volcanic, plutonic, and associated sedimentary rocks that comprise this arc terrance are widely scattered in the isolated mountain ranges of the southern Basin-and-Range Province of southeastern California (Armstrong and Suppe, 1973), southern Arizona (Hayes, Simon and Raup, 1965; Drewes, 1971; Haxel and others, 1980), and northern Mexico (Anderson and Silver, 1978; Rangin, 1978). The presence of eolian Navajo-Aztec-equivalent sandstones intercalated with arc volcanics along the rear or continent side of the arc and definitely south of the inferred NW-trending ancestral Mogollon highland in Central Arizona suggests that a modification of prior paleogeogrpahic reconstructions is needed (Bilodeau and Keith, 1979).

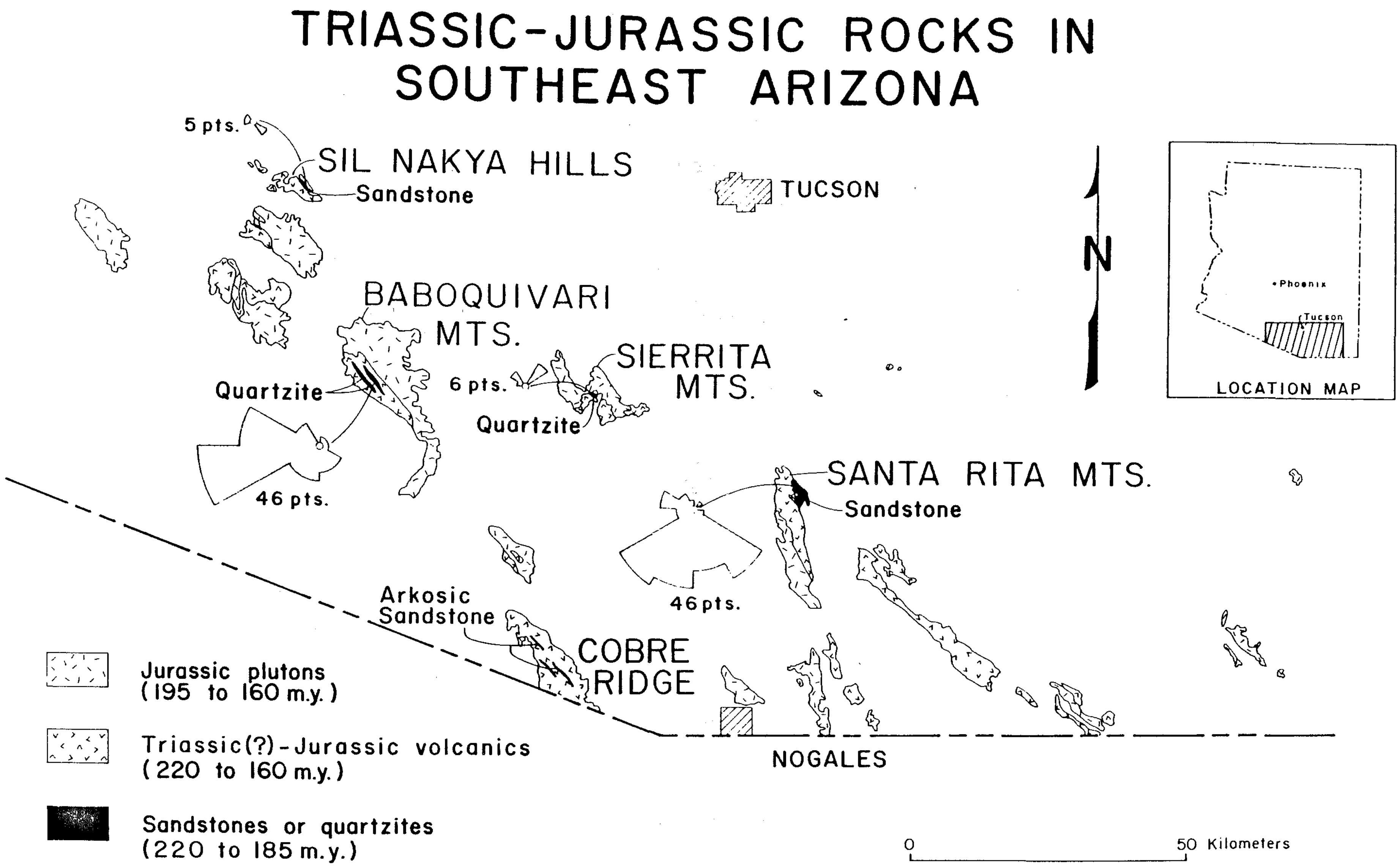

TRIASSIC-JURASSIC ROCKS IN
SOUTHEAST ARIZONA
5 pts.
SIL NAKYA HILLS
Sandstone
TUCSON
N
BABOQUIVARI
MTS.
SIERRITA
MTS.
Quartzite
6 pts.
Quartzite
46 pts.
SANTA RITA MTS.
Sandstone
46 pts.
Arkosic
Sandstone
COBRE
RIDGE
NOGALES
• Phoenix
Tucson
LOCATION MAP
Jurassic plutons
(195 to 160 m.y.)
Triassic(?)-Jurassic volcanics
(220 to 160 m.y.)
Sandstones or quartzites
(220 to 185 m.y.)
0
50 Kilometers

Figure 1.

The southern Arizona Early Jurassic quartz arenites crop out in four widely separated localities: (1) within the Mt. Wrightson Formation in Santa Rita Mountains; (2) within the Ox Frame Volcanics of the Sierrita Mountains; (3) within the Sil Nakya Formation of the Sil Nakya Hills; and (4) within the Ali Molina Formation in the Baboquivari Mountains (Fig. 1). Other Mesozoic(?) age quartzites and quartz arenites are known in southern Arizona and southeastern California, but have not been dated or studied well enough to be included in this discussion at this time.

LOWER JURASSIC SANDSTONES IN SOUTHEAST ARIZONA

Mt. Wrightson Formation

In the north-central Santa Rita Mountains (Fig. 2), located to the south-southeast of Tucson, a minimum of 2800 m of volcanic and sedimentary rocks of Triassic(?)-Jurassic age are widely exposed. These rocks were mapped by Drewes (1971) who named them the Mt. Wrightson Formation and informally divided the sequence into three members. The lower member is 500 m thick, composed mostly of dacitic to andesitic volcanics and lenses of quartzose sandstone and quartzite that are typically 6 - 7 m thick and 50 - 100 m long. At one locality several lenses converge to form a single body of quartzite over 100 m thick (Drewes, 1971). The middle member is approximately 1650 m thick and contains mostly rhyolitic to latitic flows and tuffs with maybe 5% dacitic volcanics and 1% sedimentary rocks. Most of the sedimentary strata are lenses of sandstone and quartzite similar to those in the lower member and characteristically contain large-scale cross stratification. According to Drewes (1971), the sandstone is well-sorted, with subrounded 0.2 - 0.5 mm diameter grains and is 70 - 80% quartz. Clay minerals or sericite makes up most of the remainder. Several of the lenses are also tuffaceous.

The upper member contains the most significant amounts of quartz arenite within the Mt. Wrightson Formation. This member is about 600 m thick, 50% of which is quartzose sandstone, 40% dacitic and andesitic volcanics and 10% rhyodacite (Drewes, 1971). Locally the quartz arenite attains a thickness of 250 m with large-scale trough or wedge-planar cross-stratification present throughout the section. Petrographically, the sandstone is fine grained and well-sorted, contains subrounded to well rounded, frequently frosted grains of which over 90% is monocrystalline quartz. The sandstone is more strongly indurated and silicified the closer it is to the Sawmill Canyon fault zone, becoming a massive quartzite along the fault that forms the northeast boundary of the formation.

Paleocurrent directions from 46 large-scale crossbed orientations recorded in the thickest lens of quartz arenite in the upper member of the Mt. Wrightson Formation are plotted on the rose diagram (a in Fig. 3). The diagram shows major southwest and southeast paleowind directions, normal to the parallel with the trend of the Early Jurassic magmatic arc in southern Arizona.

The age of the Mt. Wrightson Formation is here considered to be Early Jurassic. The basal contact of the Mt. Wrightson is intruded by the Piper

GEOLOGIC SETTING OF MT. WRIGHTSON FORMATION

Geology generalized from Drewes (1971)

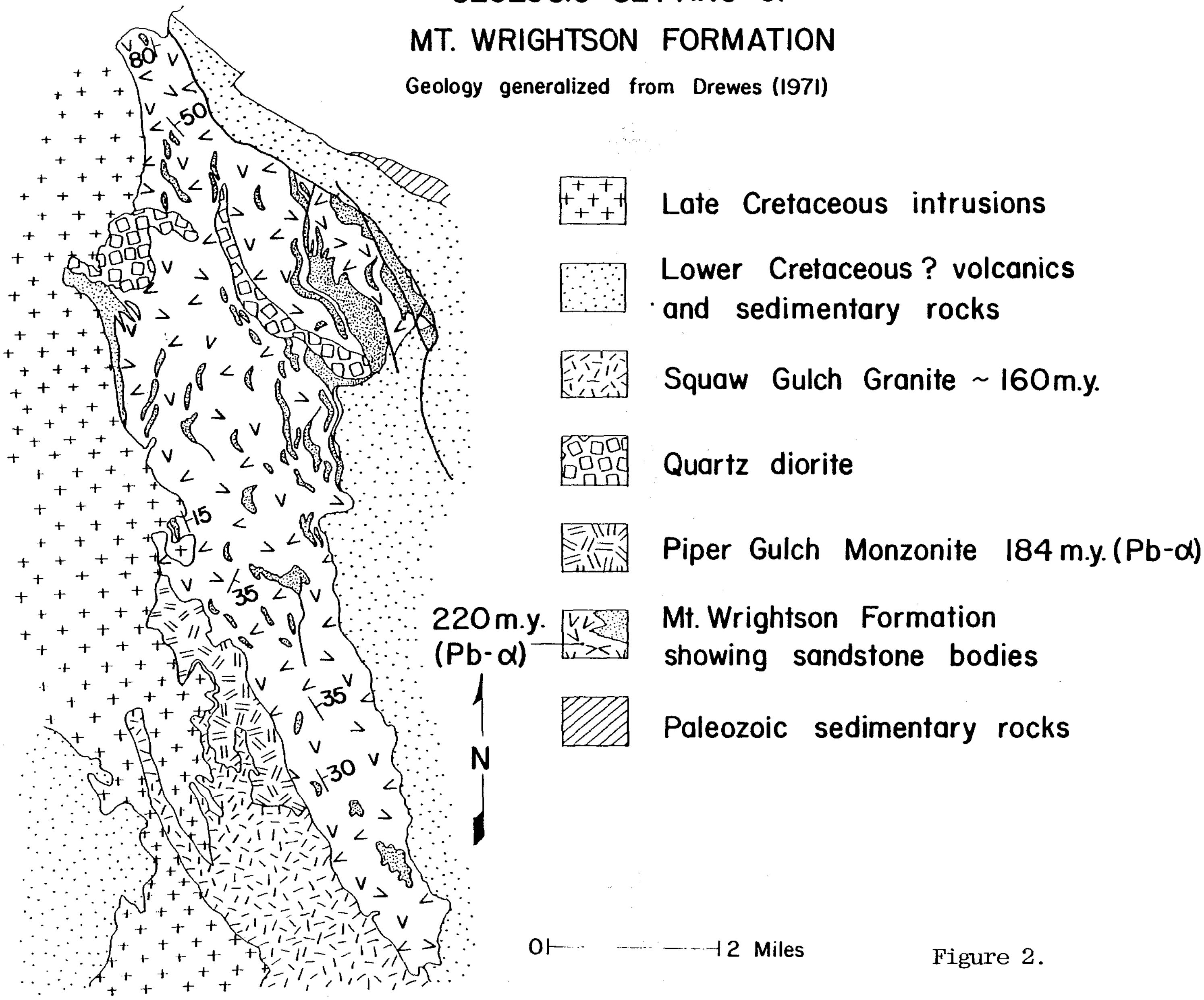


Figure 2.

F. Wrightson Fm.
Santa Rita Mtns

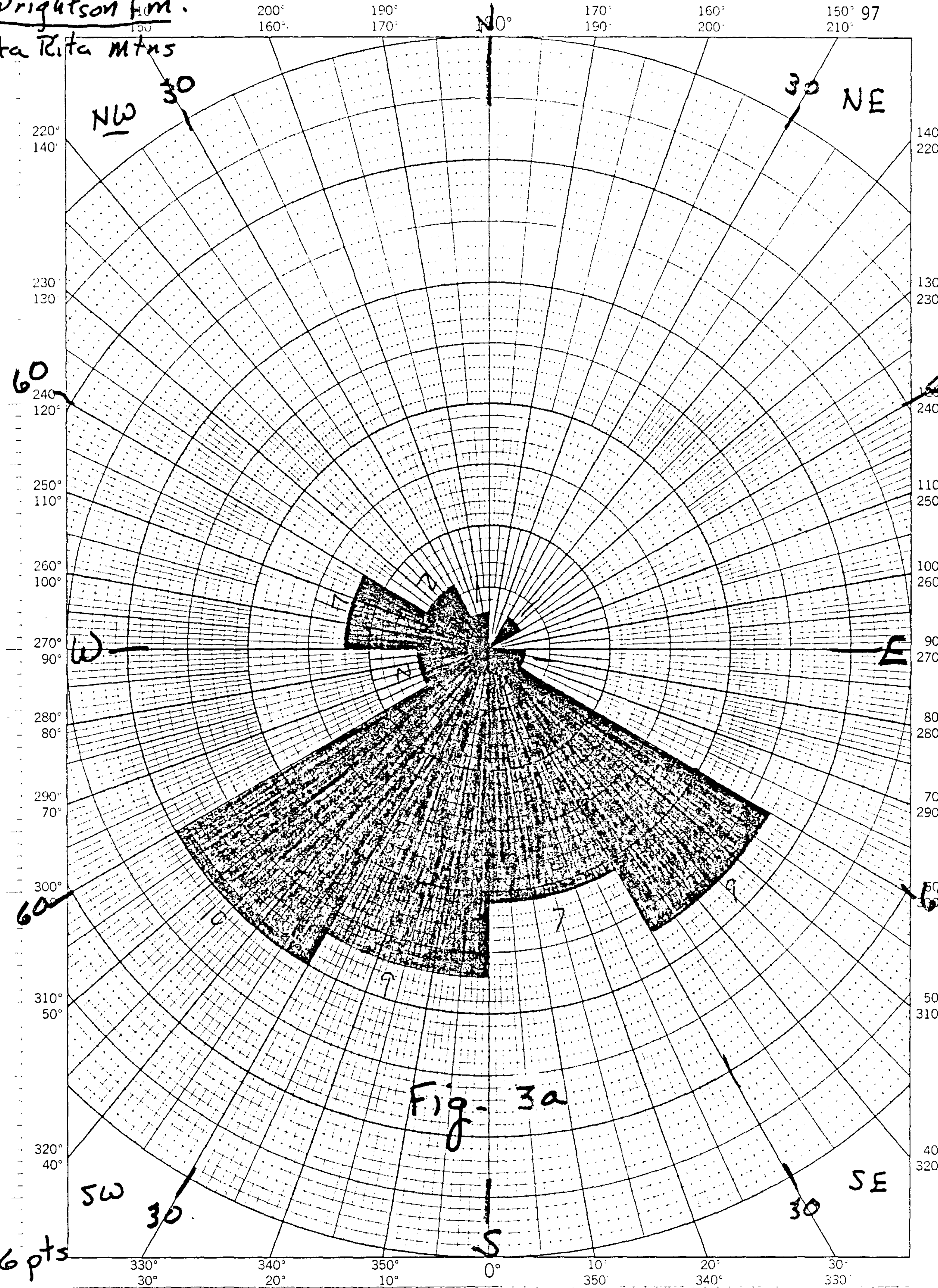


Fig. 3a

Gulch Monzonite, dated at 184 ± 20 my and a date of 220 ± 30 my was obtained on a welded tuff from the middle member (Drewes, 1971). Also, Drewes (1971) has noted that detritus of Mt. Wrightson Formation is contained in the Gardner Canyon Formation. Volcanics interbedded with the mudstone member yielded a zircon concentrate with a 192 ± 20 my lead-alpha apparent age. All dating was done by the lead-alpha method. The lead-alpha method is very imprecise and we consider the 220 my and 192 my lead-alpha ages a bit too old for the age of the Mt. Wrightson Formation (see age discussions for the Ali Molina, and Sil Nakya formations).

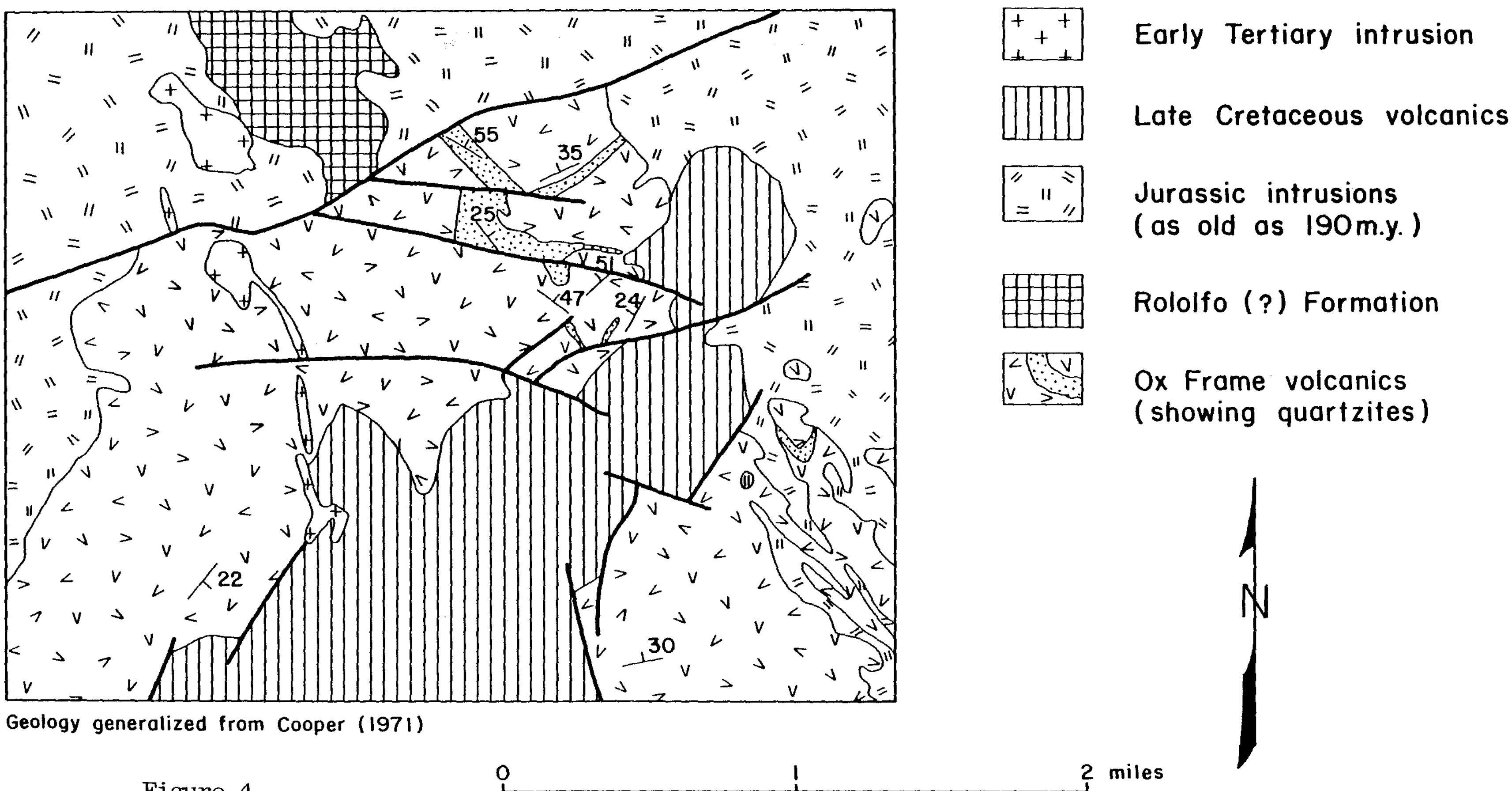
Ox Frame Volcanics

In the central Sierrita Mountains, the next mountain range to the northeast of the Santa Rita Mountains (Fig. 4), at least 1500 m of rhyolitic to andesitic flows and tuffs containing lenticular beds of sandstone, quartzite and conglomerate is exposed (Cooper, 1971). These rocks have been named the Ox Frame Volcanics by Cooper (1971) and have been correlated with the Mt. Wrightson Formation in the Santa Rita Mountains by Cooper (1971) and Hayes and Drewes (1978).

The Ox Frame Volcanics, in their type locality are divided into three members, a lower silicic member composed of massive rhyolite flows, rhyodacite and rhyolite tuffs, a middle andesitic member with flows of dark porphyritic andesite and dacite, and an upper silicic member consisting primarily of rhyolitic welded tuffs and flows with intercalated volcanic sandstone and conglomerate and thick lenses of quartzite (Cooper, 1971). As in the Mt. Wrightson Formation, the quartzite beds are most abundant towards the top of the formation, typically occurring as scattered lenses a couple of meters to a few hundred meters thick and a few tens of meters to over 1000 m long. Petrographically, the quartzite is fine to medium grained (0.2 - 0.3 mm), contains sub- to well-rounded, closely packed grains which are over 90% quartz and is cemented by silica in the form of quartz overgrowths and sericitic material from altered feldspar or volcanic grains. The exposures of the quartzite are typically light or dark gray and occasionally show relict sandstone textures and small- to medium-scale crossbedding. No large-scale eolian cross stratification was observed. Locally, the quartzite are distinctively spotted and mottled. Unfortunately, most of the quartzite lenses are located within 0.5 km of the intrusive contact with the Harris Ranch Quartz Monzonite.

Paleocurrent directions from only 6 crossbed orientations obtained from the quartzite lenses of the Ox Frame Volcanics show two nearly opposite trends (Fig. 3b). Half the readings exhibit a west-northwest direction and the other half an east-northeast direction. Since all of the observed cross-strata were of small- to medium-scale and came from two different lenses, either the paleoslope was highly variable or unrecognized local structural rotations have affected one or both of the localities. We feel that the former possibility is the likeliest as both of these trends were found in the Ali Molina Formation quartzites in the Baboquivari Mountains. The presence of such clean quartz arenite intercalated into a thick pile of volcanic rocks

GEOLOGIC SETTING OF OX FRAME VOLCANICS



Geology generalized from Cooper (1971)

Figure 4.

Sierrita Mtns
Ox Frame Volcs

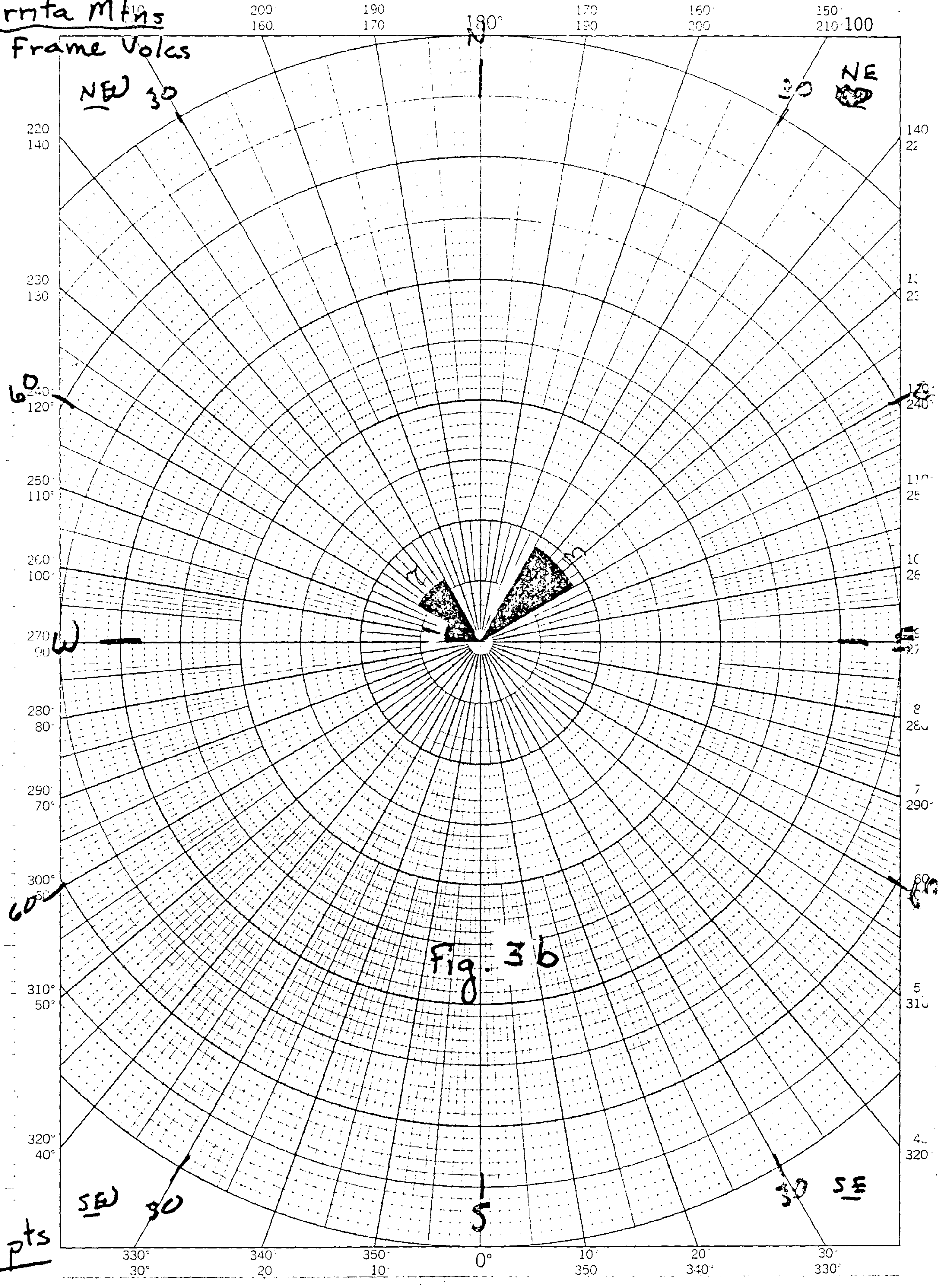


Fig. 3b

6 pts

without other associated sedimentary rocks coupled with the alluvial nature and scale of the crossbedding, suggests that these rocks were fluvially reworked from eolian sand deposits.

The age of the Ox Frame Volcanics is considered here to be Early Jurassic. The Ox Frame Volcanics are intruded by the Harris Ranch Quartz Monzonite (190 ± 20 my, Pb-α, Z), which is, in turn, intruded by the Sierrita Granite (150 ± 20 my, Pb-α, Z; 140 ± 14 my, Rb-Sr, whole-rock). The similarity of lithology and contact relationships support the correlation of the Ox Frame Volcanics with the Mt. Wrightson Formation of the Santa Rita Mountains and the radiometric age dates provide a minimum age of 190 my.

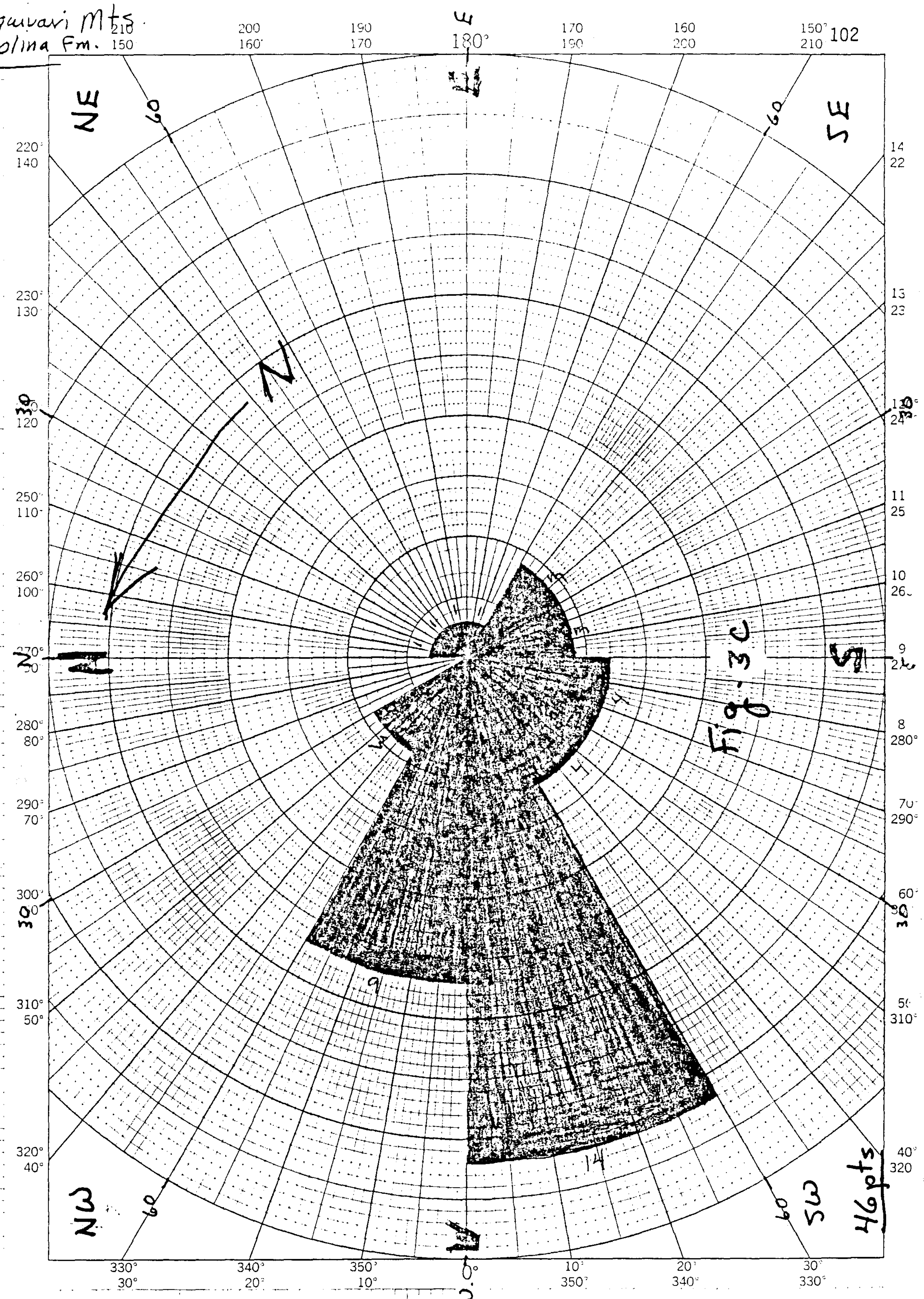
Ali Molina Formation

Several substantial quartzite lenses intercalated with rhyodacitic volcanics of Early Jurassic age are exposed in the west-central Baboquivari Mountains, due west of the Sierrita Mountains (Fig. 5). These rocks are part of a thick section of mildly to moderately metamorphosed sedimentary and silicic volcanic rocks that were originally defined and named the Ali Molina Metamorphic Complex by Heindl and Fair (1965). Recent mapping by Haxel and others (1980) has delineated several thick quartzite lenses within their redefined Ali Molina Formation.

The quartzite lenses range from gray arkosic sandstone with coarse (0.7 - 0.8 mm) K-feldspar grains to white quartz arenite, and from 30 m to over 150 m in thickness. The lowermost lenses are distinctly less arkosic than the uppermost lense. The degree of metamorphism and the pervasive jointing makes identification of primary sedimentary structures difficult but not impossible. Most of the crossbedding recognized in the quartzite lenses were small- to medium-scale. However, several large-scale crossbeds were identified in the lower more quartz-rich lenses. Paleocurrent directions from 44 crossbed determinations are plotted on a rose diagram (Fig. 3c). The diagram shows a dominant west-southwest paleocurrent trend with subsidiary west-northwest and southwest trends. A large proportion of the crossbeds from the clean quartz arenite lenses have paleocurrent trends to the west-southwest while most of the northeast and southeast trends are from the arkosic lenses. The small-scale cross-strata in the arkosic lenses are most likely alluvial in origin and thus show local variability in paleoslope. The arkosic character of the lenses indicates they are reworked from the rhyodacitic volcanics as well as aeolian sandstones. In contrast the large-scale cross-bedding, clean character, and consistent, westward paleocurrent indicators for the lower quartzitic lenses suggests a primarily eolian origin.

The age of the Ali Molina Formation has been determined by Wright and others, (1981) as Early Jurassic. Isotopic ages were resolved for two size fractions of zircons from a quartz prophyry in the Ali Molina resulting in a mean Pb-Pb age of 191 my.

Baboquivari Mts.
Ali Molina Fm.



Sil Nakya Formation

In the Sil Nakya Hills, located 50 miles due west of Tucson (Fig. 6), over 2500 m of Mesozoic age rhyolite to rhyodacitic volcanic flows and tuffs, sedimentary redbeds and quartz arenite are exposed (Haxel and others, 1978). These rocks were originally described by Heindl (1965) and named the Sil Nakya Formation. The silicic volcanics make up over 75% of the section, with the quartzose sandstone comprising most of the remainder.

The quartz arenite is 300 - 400 m thick, white to tan in color, well-sorted and fine-grained with over 95% well rounded quartz grains. Locally, maroon rhyolite porphyry intrudes the sandstone, recrystallizing it to quartzite. The unit is typically thin-bedded (2 - 10 cm) with rare small- to medium-scale cross stratification. No large-scale crossbedding was observed and only 5 crossbed orientation determinations were recorded. The paleocurrent data show no unique trends (see Fig. 3d). The small-scale of the crossbeds lack of any unique paleocurrent trends, clean character, and thin-bedding suggests the sandstone is of fluvial origin and reworked from a former eolian parent.

The Sil Nakya Formation has been isotopically dated by Wright and others, (1981) as Early Jurassic. Zircons from welded tuff in the Sil Nakya give a Pb-Pb age of 188 my. This age is considered by Wright and others (1981) to be indistinguishable, within analytical error, from the isotopic age of the Ali Molina Formation in the Baboquivari Mountains.

CORRELATION OF SOUTHERN ARIZONA SECTIONS

We are in full agreement with Haxel and others (1980) in correlating the Sil Nakya and Ali Molina formations on the Papago Indian Reservation with the Ox Frame Volcanics and Mt. Wrightson Formation to the east, and that these rocks are all Early Jurassic in age. Age data is summarized on Table 1. In addition to the dated sections we also add the Cobre Ridge tuff in the Oro Blanco area (30 km south of the Ox Frame Volcanics) to the correlation. Here, Knight (1970) has described an extensive section of ignimbritic rhyodacitic to rhyolitic tuffs locally interfingered with arkosic quartzites. The sequence is intruded by a monzonitic pluton (Warsaw quartz Monzonite of Knight, 1970). The entire package is, in turn, unconformably overlain by clastic sedimentary rocks of the Oro Blanco Formation, a presumed Bisbee time equivalent. Because of the impressive lithological similarity and analogous stratigraphic position we believe it is highly likely that the Cobre Ridge tuff correlates with the other early Jurassic eolian and volcanic sequences.

GEOLOGIC SETTING OF SIL NAKYA FORMATION

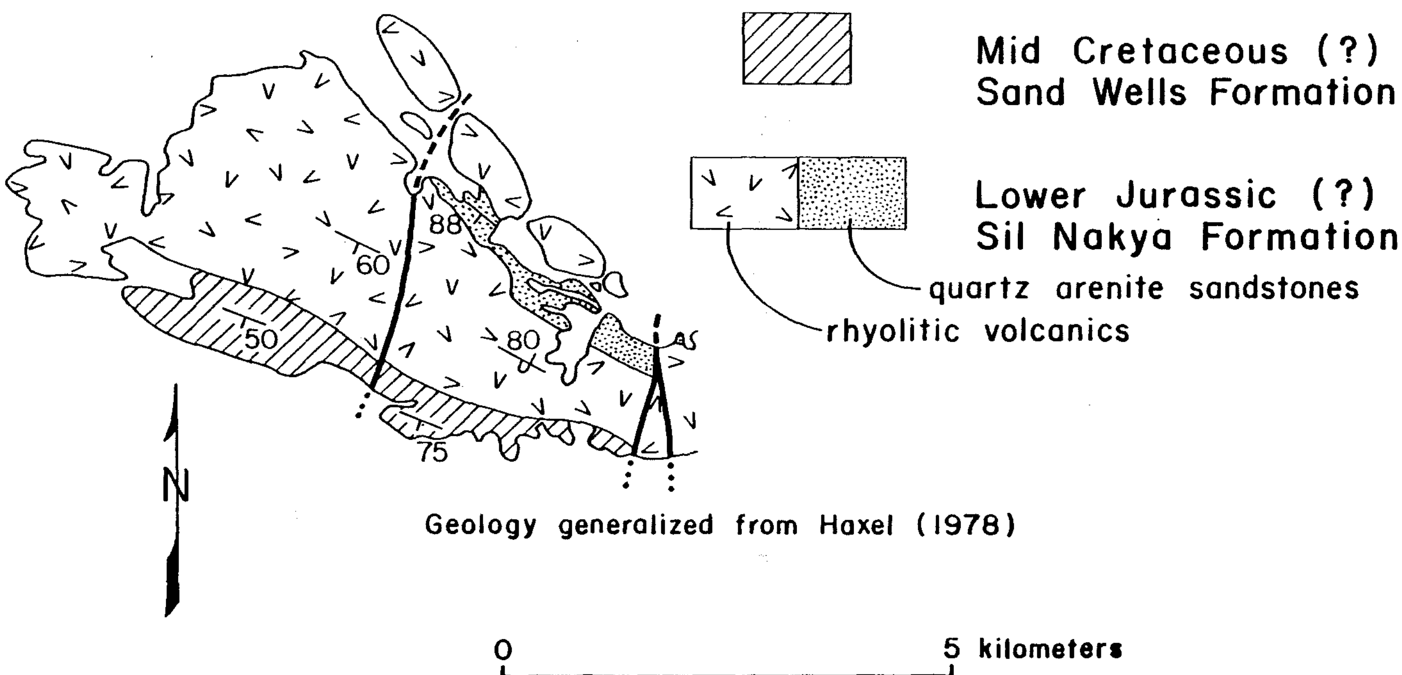


Figure 6.

CORRELATION WITH COLORADO PLATEAU AND MOJAVE DESERT MESOZOIC SANDSTONES

The Early Jurassic mature quartz sandstones in southeast Arizona are here specifically correlated with the Navajo Sandstone 400 km to the north on the Colorado Plateau and to the Aztec Sandstone 600 km to the northwest in the Mojave Desert and southern Nevada. Of the four southern Arizona localities of these sandstones the Mt. Wrightson Formation in the Santa Rita Mountains is the best exposed, least metamorphosed and contains ubiquitous large-scale sweeping crossbeds of eolian origin. The southwest to southeast paleowind directions (Fig. 3a) correlate well with the south-southwest (Aztec) directions and southeast (Navajo) directions reported in Poole (1962). The age of the Navajo Sandstone, previously thought to be Triassic(?)-Jurassic, is now considered to be entirely Early Jurassic based on fossil palynomorphs of Early Jurassic age (212 to 178 my according to the revised time scale of Armstrong, 1978) found in the Moenave Formation, the basal unit of the Glen Canyon Group (Peterson and Pipiringos, 1979).

Another intriguing age and paleogeographic constraint is provided by fission-track ages on single grain zircons for Navajo sandstone from three localities in southeast Utah (Jennison, 1980). In addition to several 630 to 958 my Precambrian apparent ages, Jennison reported younger clusters of ages with mean ages of 306±7 my and 229±5 my. The second cluster of ages was comprised of seven ages ranging from 250 to 184 my. Jennison interpreted the source for these zircons to be the Triassic arc terrance in western Nevada and eastern California northwest of the Navajo dune sea in southeast Utah. As such, the ages may be interpreted as maximum ages for the Navajo sandstone in southeast Utah. These ages are consistent with the southeast Arizona sandstone age data (Table 1).

SEDIMENTOLOGICAL INTERPRETATION

Mature quartz sandstones interbedded with very thick sequences of rhyolitic to andesitic volcanics is an unusual occurrence. Especially when the quartz arenites are hundreds of meters thick and are the dominant sedimentary rock type in the section, with only minor sedimentary redbeds and volcanogenic sediments. The provenance of the sandstones must be unrelated to the volcanic arc and the depositional mechanism must produce a well-sorted, mature quartz arenite. The large-scale crossbedding, so common in the Mt. Wrightson Formation and less common in the other units, provides evidence for eolian transport and deposition of sands from the north and northeast (Fig. 3). Fluvial reworking of the quartz arenites (small-scale crossbedding) and deviation from prevailing wind directions due to local topography in the backarc area are two possible explanations for the various paleocurrent trends shown on the rose diagrams of Figure 3.

Sil Nakya Hills

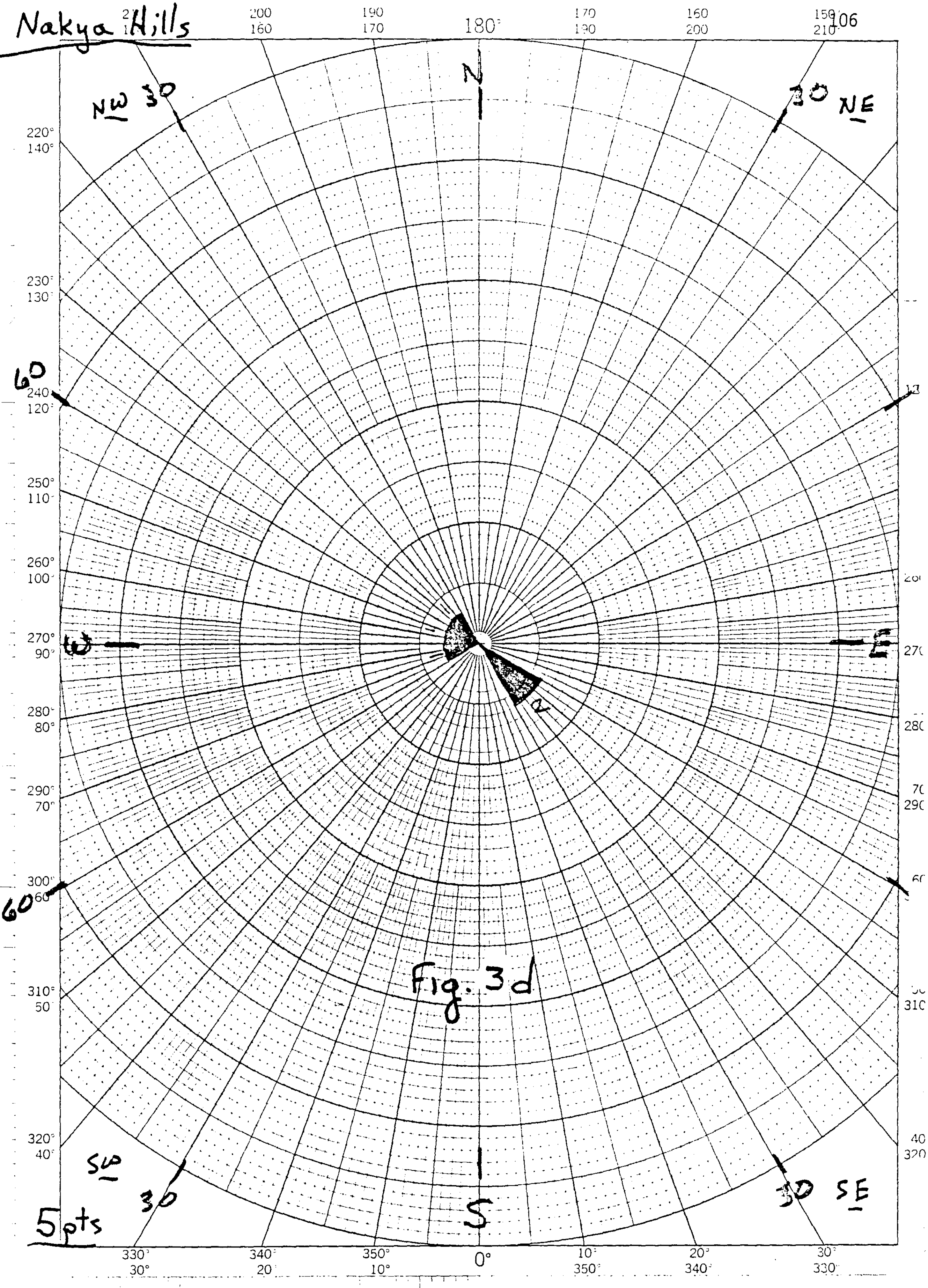


Fig. 3d

Table 1: SUMMARY OF AGE INFORMATION FOR EARLY JURASSIC EOLIAN-LIKE SANDSTONE IN SOUTHEAST ARIZONA.

Formation	Isotopic dates Method	 Apparent age	Reference
Mt. Wrightson Formation	Pb-α Pb-α	pre-184 my syn- to post 220	Drewes (1971) Drewes (1971)
Ox Frame Volcanics	Pb-α	pre-190 my	Cooper (1971)
Cobre Ridge Tuff	no data		Knight (1970)
Ali Molina Formation	U-Pb	syn-191 my	Wright and others (1981)
Sil Nakya Formation	U-Pb	syn-188 my	Wright and others (1981)

PALEOGEOGRAPHIC IMPLICATIONS

The early Jurassic sandstone sequences provide important details for defining the northwest-southeast trend of the Early Jurassic continental margin magmatic arc as well as the northeastern or continentward edge of the arc (see Fig. 8.)

Quartzite and quartz arenite interbedded with volcanogenic sediments on the Mojave Desert region have been correlated with the Aztec Sandstone in southern Nevada (Miller and Carr, 1978). These Aztec- or Navajo-equivalent sandstones suggest that clean quartz sands were blown up against the rear or continental side of the Early Jurassic magmatic arc in southern California. Our studies suggest that this was also the case in southern Arizona. Indeed, the relationships in Arizona present much stronger evidence in support of the interpretation of eolian sands being blown into the region of the magmatic arc than the Mojave strata have supplied so far because of isotopic dating of interbedded volcanics of arc affinity and the recorded paleowind directions from crossbed orientation studies of the Arizona rocks.

The effect of this correlation on reconstructions of Early Jurassic paleogeography in central and southern Arizona are very significant. The presence of north derived eolian sandstones intercalated with arc volcanics in southern Arizona place important restrictions on the location, elevation and duration of the Mogollon Highlands in the Late Triassic (Shinarump-Chinle time) and the Late Jurassic (Morrison time), supplying a sediment source to various Colorado Plateau formations. Our data suggest that the Mogollon Highlands either (1) were not high enough or (2) as a series of distinct uplifts separated by wide lowlands or passes, were not continuous enough to block southward transport of eolian sands across central Arizona and up the rear flank of the Early Jurassic magmatic arc.

Paleocurrent data (Fig.3) support the chained uplift option. The Mogollon Highlands in Arizona are here considered to have been a chain of separate uplifts that continued across central New Mexico as the Florence, Grahma, Burro and Florida Uplifts shown on Figure 8 and in Greenwood, Kottlowski, and Thompson (1977). The eolian sands were blown from a large interior desert at the south end of a shallow backarc sea (Stanley, Jordan and Dott, 1971), through low-lying passes in the Mogollon Highlands and up against the magmatic arc where the quartz sands interfingered with the arc volcanics. One such low-lying pass was probably positioned between the Graham and Florence uplifts. Paleowinds blew southward through this pass and deposited locally thick dunefields on the northeast side of the lower Jurassic valcanic arc in the central Santa Rita Mountains. Paleowinds also turned westward to deposit similar dunefields in the Baboquivari Mountains south of the Florence uplift. Fluvial reworking and local lacustrine conditions commonly destroyed the eolian sedimentary structures and produced a variety of local secondary paleocurrent directions directed parallel to and away from the volcanic arc.

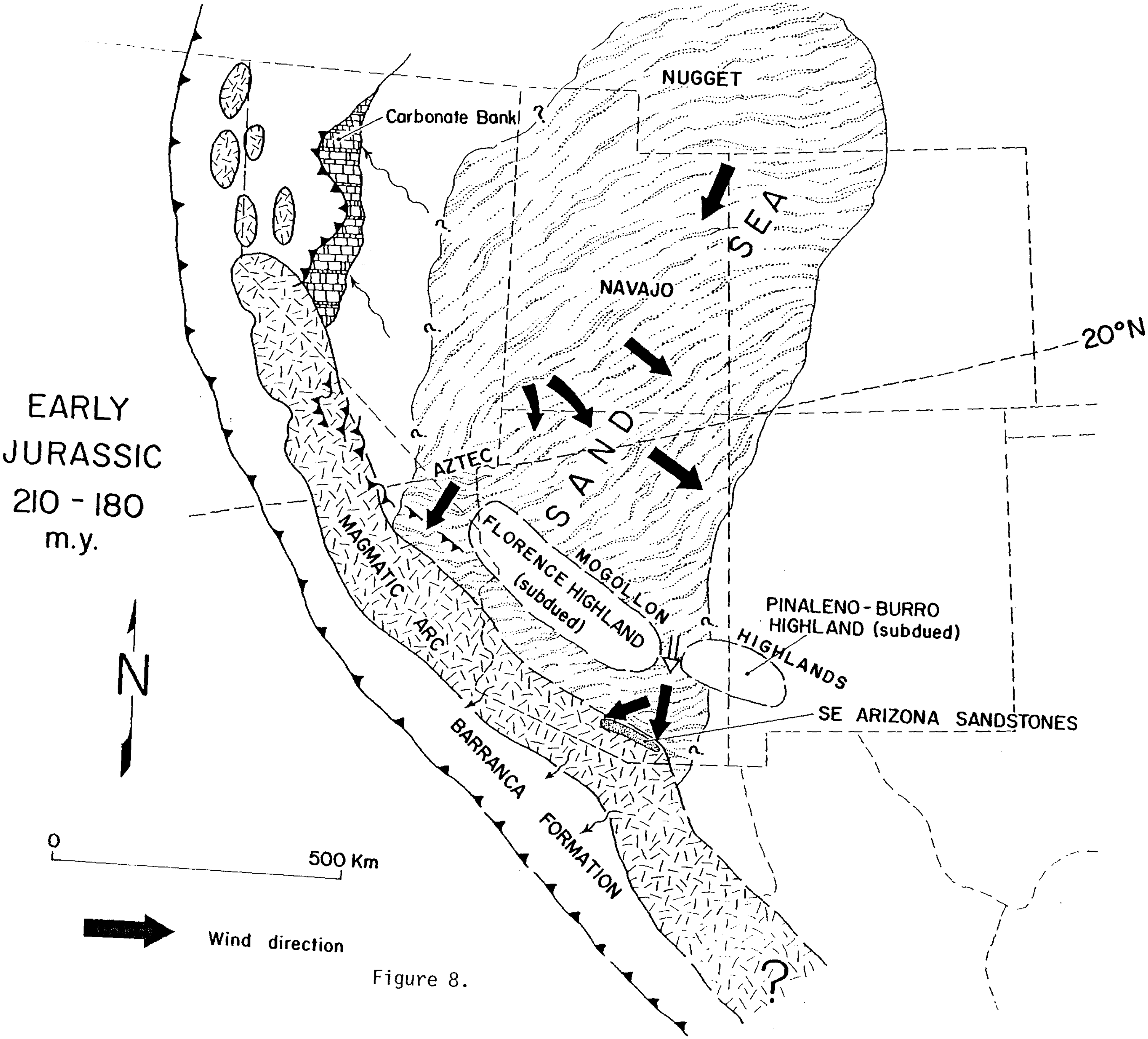

EARLY
JURASSIC
210 - 180
m.y.
NUGGET
Carbonate Bank
NAVAJO
SAND SEA
20°N
AZTEC
MAGMATIC ARC
FLORENCE HIGHLAND
(subdued)
MOGOLLON
HIGHLANDS
PINALENO-BURRO
HIGHLAND (subdued)
SE ARIZONA SANDSTONES
BARRANCA FORMATION
N
0
500 Km
Wind direction

Figure 8.

REFERENCES

Anderson, R.H. and Silver, L.T., 1978, Jurassic magnatism in Sonora, Mexico (abs.): Geol. Soc. Am., Abtracts with Programs, v. 10,no. 7, p. 359.

Armstrong, R.L., 1978, Pre-Cenozoic phanerozoic time scale -- computer file of critical dates and consequences of new and in-progress decay content revision, in Cohee, G.V., Glaessner, M.R., and Hedberg, H.D., eds., Contributions to the geologic time scale: Amer. Ass. Petroleum Geologists, Studies in Geology, no. 6, p. 73-92.

Armstrong, R.L., and Suppe, 1978, Potassium - argon geochromometry of mesozoic rocks in Nevada, Utah and Southern California: Geol. Soc. Am., Abstracts with Programs, v. 10, no. 7, p. 359.

Bilodeau, W.L., and Keith, S.B., 1979, Intercalated volcanics and eolian "Aztec-Navajo-like" sandstones in southeast Arizona -- another clue to the Jurassic-Triassic paleotectonic puzzle of the southwestern U.S. (abs.): Geol. Soc. Am., Abstracts with Programs, v. 11, no. 3, p. 70.

Coney, P.J., 1978, The plate tectonic setting of southeastern Arizona, in Callender, J.R., Witt, J.C., and Clemons, R.E., eds., Land of Cochise: New Mexico Geol. Soc. Guidebook, 29th Field Conf., p. 285-290.

Cooper, J.R., 1971, Mesozoic stratigraphy of the Sierrita Mountains, Pima County, Arizona: U.S. Geo. Survey Prof. Paper 658-D, 42 p.

Drewes, H., 1971, Mesozoic stratigraphy of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Survey Prof. Paper 658-C, 81 p.

Greenwood, E., Kottlowski, F.E., and Thompson, J., III, 1977, Petroleum potential and stratigraphy of Pedregosa Basin: comparison with Permian and Orogrande basins: Am. Assoc. Petroleum Geologist Bull, v. 61, p. 1448-1469.

Haxel, G., Briskey, J.A., Rytuba, J.J., Bergquist, J.R., Blacet, P.M., and Miller, S.T., 1978, Reconnaissance geologic map of the Comobabi Quadrangle, Pima County, Arizona: U.S. Geol. Survey Misc. Field Studies Map M-F 964.

Haxel, G., Wright, J.E., May, D.J., and Tosdal, R.M., 1978, Reconnaissance geology of the Mesozoic and Lower Cenozoic Rocks of the Southern Papago Indian Reservation, Arizona: a preliminary report, in Jenney, J.P., and Stone, C., eds., Studies in Western Arizona: Arizona Geol. Soc. Digest XII, p. 17-29.

Haxel, G., May, D.J., Wright, J.E., and Tosdal, R.M., 1980, Reconnaissance geologic map of the Baboquivari Peak quadrangle, Arizona: U.S. Geological Survey Map MF-1251, scale: 1:62,500.

Hayes, P.T., and Drewes, H., 1978, Mesozoic depositional history of southeastern Arizona, in Callender, J.T., Witt, J.C., and Clemons, R.E., eds., Land of Cochise: New Mexico Geol. Soc. Guidebook, 29th Field Conf., p. 201-207.

Hayes, P.T., Simons, F.S., and Raup, R.B., 1965, Lower Mesozoic extrusive rocks in southeastern Arizona: U.S. Geol. Survey Bull. 1194-M, 9 p.

Heindl, L.A., 1965, Mesozoic formations in the Comobabi and Roskruge Mountains, Papago Indian Reservation, Arizona: U.S. Geol. Survey Bull. 1194-H, 15 p.

Heindl, L.A., and Fair, C.L., 1965, Mesozoic(?) rocks in the Baboquivari Mountains, Papago Indian Reservation, Arizona: U.S. Geol. Survey Bull., 1194-I, 12 p.

Jennison, M., 1980, Zircon ages and feldspar mineralogy of the Navajo sandstone (M.S. thesis): Salt Lake City, University of Utah, 76 p.

Miller, E.L., and Carr, M.D., 1978, Recognition of possible Aztec-equivalent sandstones and associated Mesozoic metasedimentary deposits with the Mesozoic magmatic arc in the southwestern Mojave Desert, California, in Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States, Pacific Coast Paleogeog. Symposium 2: Soc. Econ. Paleon. and Mineralogists, Pac. Sec., p. 283-289.

Peterson, F., and Pipiringos, G.N., 1979, Stratigraphic relations of the Navajo sandstone to Middle Jurassic Formations, southern Utah and northern Arizona: U.S. Geol. Survey Prof. Paper 1035-B, 43 p.

Poole, F.G., 1962, Wind directions in Late Paleozoic to Middle Mesozoic time on the Colorado Plateau: U.S. Geol. Survey Prof. Paper 450-D, p. 147-151.

Rangin, C., 1978, Speculative model of Mesozoic geodynamics, Central Baja California to northeastern Sonora (Mexico), in Howell, D.G., and McDougall, K.A., eds., Mesozoic Paleogeogrpahy of the western United States: Pacific Sec., Soc. Econ. Palentol. Mineral., p. 85-106.

Stanley, K.O., Jordan, W.M., and Dott, R.H., Jr., 1971, Early Jurassic Paleogeography, western United States: Am. Assoc. Petroleum Geol. Bull., v. 55, p. 10-20.

Wright, J.E., Haxel, G., and May, D.J., 1981, Early Jurassic uranium-lead isotopic ages for Mesozoic supracrustal sequences, Papago Indian Reservation, southern Arizona (abs.): Geol. Soc. Am., v. 13, no. 3, p. 115.

After eating lunch walk a short distance down the road to the northeast and descend into Cave Creek north of the road for a look at the conglomerate facies of the upper Temporal Formation.

STOP 4: CONGLOMERATE OF THE TEMPORAL FORMATION AND ITS TECTONIC SIGNIFICANCE
by William L. Bilodeau

The basal Cretaceous unit in the southern half of the Santa Rita Mountains is the Temporal Formation. This unit contains rhyolitic to andesitic volcanics, polymictic conglomerate, and tuffaceous sandstone (Drewes, 1971a). These rocks unconformably overlie Triassic-Jurassic Mt. Wrightson Formation volcanics and eolian sandstones in the northern half of the area, and the Jurassic Squaw Gulch Granite and Piper Gulch Monzonite to the south. This unconformity has a rough topography, often showing considerable local relief. For the purposes of this stop, only the northern section, or more specifically, the upper member, of the Temporal Formation was studied.

The upper member of the Temporal Formation can be divided into a lower conglomerate unit and an upper rhyodacite breccia unit. Intercalated within the lower conglomerate unit are small lenses of rhyolite flows and tuff. The conglomerate unit is about 300 m thick north of Gardner Canyon, where it is truncated by faults subparallel to the Sawmill Canyon fault zone, and thins southwestward until it disappears about 1½ km south of Gardner Canyon. Small lenses of conglomerate are also present within the lower part of the overlying purple rhyodacite breccia, and as much as 120 m of basal conglomerate reappears about 4 km farther south in Temporal Gulch. The rhyodacite breccia is as much as 300 m thick in the northern part of the area and thins southward until it too disappears.

Compositionally, the lower conglomerate is a mixed-clast conglomerate with large amounts of volcanic and granitic clasts and small amounts of quartzite, limestone, and sandstone clasts. Some zones within the member contain volcanic-clast conglomerate with 80-90% red, gray, and purplish red volcanic cobbles and boulders of various sorts. These zones typically contain no granitic clasts. Not more than a few meters away, conglomerate with 50-80% granodiorite poryphyry, pink, equigranular granite and dark gray diorite clasts and containing less than 30% volcanic clasts is present. In general, the clast percentages are around 55% volcanic, 35% granitic, and 10% limestone, quartzite, and sandstone clasts. The unit is typically clast-supported cobble to boulder conglomerate with occasional matrix-supported zones. The matrix is poorly sorted coarse sand, grit, and silt with a range in color from light gray to dark reddish brown. The clasts are subrounded to rounded and may get as large as 1½ m across (porphyritic granodiorite boulder). No systematic variations in clast composition were noted except that the southern half of the outcrop belt, where the upper member conglomerate reappears and thickens to 120 m, the unit is a volcanic-clast conglomerate.

Paleocurrent Determinations.

South of the Sawmill Canyon fault zone, the sediment transport data for the Temporal and Bathtub Formations show three distinct directional modes. Both formations show an explicit south-southwest paleocurrent direction, while the Temporal also displays a secondary northwest direction and the Bathtub a secondary east-southeast direction. This polymodal relationship suggests a mixing of sediments derived from three different source areas. The two data points from the single mapped "Glance" locality suggests a southwesterly source, adding support for an elevated source terrane to the southwest.

Environment and Mechanism of Deposition.

South of the Sawmill Canyon fault zone, the Glance-equivalent Temporal and Bathtub Formations contain poorly sorted, poorly bedded, disorganized matrix-supported conglomerate deposits interbedded with better organized, but still rather poorly sorted, clast-supported conglomerate. Large boulders and fine grained, muddy matrix are commonly associated with the matrix-supported deposits. As discussed in previous chapters, these types of deposits are layed down by subaerial debris-flow processes and are characteristic of alluvial fan depositional environments. Paleocurrent data and the composition of various clast types suggest northern, western, and southwestern source terranes. The porphyritic granodiorite clasts were derived from exposures of Precambrian Continental Granodiorite to the north and northeast. The wide variety of volcanic clasts were derived from the underlying Mt. Wrightson Formation presently exposed to the west and northwest and from intercalated volcanic members in the Temporal and Bathtub Formations. The limestone and quartzite clasts were derived from Paleozoic rocks to the northeast, and some of the pink granitic clasts came from the Jurassic plutons to the south and southwest.

Structural Features and Tectonic Implications

The prominent structural features of the central Santa Rita Mountains are the northwest-trending Sawmill Canyon fault zone and a feature Drewes calls the Santa Rita fault scar (Drewes, 1972), to the south. The Sawmill Canyon fault and the Santa Rita fault scar are structural zones that were active during early to middle Mesozoic time.

The Sawmill Canyon fault zone is the structural feature of greatest interest for this stop. The marked differences in clast composition, thickness, lithofacies relationships, paleocurrent directions, and subjacent rock types suggest that this fault zone was a major structural and topographic feature during Early Cretaceous time. The total stratigraphic relief across the Sawmill Canyon fault zone by the end of Glance time, was at least 3000 m, southwest side down. The present complexity of the Sawmill Canyon fault zone with its system of anastomosing fault traces, predominantly trending N50°-55°W, is suggestive of major late Mesozoic and Cenozoic strike-slip movements and precludes any direct interpretation of possible middle Mesozoic displacements from analysis of the faults themselves. Multiple post-Glance movements along the Sawmill Canyon fault zone are clearly evident, since the fault cuts later Cretaceous formations.

The deposition of a thick, southward-thinning, conglomeratic alluvial fan sequence immediately south of the Sawmill Canyon fault zone, together with the existence of deposits of similar age in the Empire and Mule Mountains where they are related to Early Cretaceous normal fault movements, strongly suggest that the Sawmill Canyon fault zone also has south-side-down normal movement mid-Mesozoic age. The presence of minor amounts of Paleozoic limestone detritus and the abundance of Precambrian debris in the Temporal and Bathtub Formations indicates that most of the Paleozoic strata had already been removed from the block north of the fault zone by Glance or Temporal time. This limestone debris is not found in the exposed Triassic-Jurassic strata of the Santa Rita Mountains and may have been deposited farther to the southeast in possibly older Glance Conglomerate in the Huachuca Mountains.

The second structural feature of interest is the Santa Rita fault scar, a northwest-trending zone indicated by the aligned northeast edges of Jurassic and younger elongate intrusives, by septa in the intrusives, and by striking contrasts in stratigraphic sequences and structural attitudes on either side of the intrusive zone. Drewes (1972) considers that the evidence is sufficent to show that the feature was initially a large, N35°W-trending, early Mesozoic fault zone. The evidence for movement on the fault is sketchy at best, but displacements along faults buried by Cretaceous sedimentation caused uplift of the Jurassic plutons, the Pipe Gulch Monzonite (180 ±20 m.y., Pb-α, zircon) and the Squaw Gulch Granite (160 ±20 m.y., Pb-α, zircon and 145 ±6 m.y., K-Ar, biotite) (Marvin and others, 1973) and exposed them to unroofing and erosion during Glance time.

After examining the Temporal conglomerates return to the vehicles and drive northeast for about one mile. Look for outcrop of conglomerate in Cave Creek. Park vehicles, and descend into the wash for inspection of Fort Crittenden conglomerates.

<u>STOP 5</u>: CONGLOMERATES OF THE FORT CRITTENDEN FORMATION AND THEIR TECTONIC SIGNIFICANCE.

Introduction. Much of the material here is taken from Drewes (1971, p. C55-C65).

The Fort Crittenden Formation consists of five informal members; four are sedimentary rocks, and one is lenticular volcanic rock. The sedimentary members are, in rising succession, the shale member, the lower red conglomerate member, the brown conglomerate member, the subject of this stop, and the upper red conglomerate member. The four sedimentary members show at least a small amount of interfingering with adjacent members, in addition to their dominant sequential order. This interfingering is most pronounced between the lower red conglomerate and the brown conglomerate. Some of the brown clastic rocks are scattered within the red conglomerates, and a few tongues of red rocks also appear within the dominantly brown beds. The fifth member, a rhyolitic tuff, is intercalated chiefly in the upper red conglomerate but also in the adjacent part of the brown conglomerate. To emphasize its geologic significance, Drewes (1971) considers it a separate member because it is the first record of volcanism associated with the magmatic activity of the Laramide orogeny, and it occurs over a distance of at least 10 miles and may occur as far distant as northern Sonora.

Brown Conglomerate Member

About 2,300 feet of dominantly brown conglomerate overlies the lower red conglomerate member in the northeastern part of Adobe Canyon and adjacent canyons. The base of the brown conglomerate member is placed beneath an 80-foot-thick brown unit at about the 5,200-foot contour on the northeast flank of the Adobe Canyon basin about 8 km south of Stop 5. (Drewes, 1971a; unpub. data). As defined by Drewes (1971), the brown conglomerate member underlies an extensive area from Hog Canyon and the upper reaches of Adobe Canyon northwestward to the west side of the Santa Rita Mountains.

This member also consists of heterogeneous rock types, although brown conglomerate is its most typical rock. Unweathered rocks are light greenish gray, but the weathered ones are pale yellowish brown. Between Adobe Canyon and Cave Creek, the member contains intercalated red beds large enough to be mapped at a scale of 1:12,000. Most of the beds of the member are a few feet thick, but they range in thickness from 1 to 50 feet. The rocks consist of pebble-and-cobble conglomerate (10-40 percent), sandstone and arkose (20-50 percent), and siltstone and mudstone (20-30 percent). A few grain-size and color changes are systematic. The red beds intercalated in the brown conglomerate member, for example, decrease in thickness and in grain size northward, which suggests that their provenance lay in the southern quadrants. Clasts in the brown conglomerate are dominantly granitic and probably were derived from a Precambrian source to the north. The finer grained brown beds are arkose, also believed to have come from the north. Some arkose beds exposed a few hundred feet west of the jeep road in Hog Canyon and others in probably the same general horizon that crop out between Cave Creek and Aliso Spring contain fragments of silicified wood, and in one place along Cave Creek scraps of dinosaur (?) bone were found.

Age

The Fort Crittenden has yielded a fairly abundant fauna (see Drewes, 1971, for a detailed fossil discussion) that provides a probable Late Cretaceous age (Santonian, Campanian and Maestrichtian stages). In addition, a rhyodacite welded tuff from a sequence of rocks conformably overlying rocks on the west side of the Santa Rita Mountains and correlated with the red conglomerate member by Drewes (1971) has yielded a 74 m.y. K-Ar age on biotite. Assuming the correlations are valid, this means the Fort Crittenden Formation in the Santa Rita Mountains is probably post-basal Santonian (post-85 m.y. on the Kauffman, 1977 ammonite time sale) and pre 74 m.y. B.P.

Environment of Deposition

The Fort Crittenden Formation was deposited subaerially in a tectonic environment. The abundance of coarse locally derived clastic rocks and of arkose and subgraywacke lithologies in the formation indicates that the detritus of which they were formed came from areas of considerable relief, was transported only a short distance, and was rapidly deposited. The presence of fossil land plants and animals also indicates a subaerial environment-one which was characterized by a mingling of local lacustrine and more widespread fluvial and piedmont conditions.

Reviewed in more detail, the local record indicates that following a little uplift and erosion during post-Bisbee-pre Fort Crittenden time, gravels were deposited at the base of uplifted areas. A lake or freshwater lagoon covered a small area near the site of the present Adobe Canyon and briefly lapped over the gentle rise on its southwestern shore. Organic-rich mud and silt was deposited in the lake, which supported an abundant molluscan fauna and an assortment of fish, turtle, and dinosaur life. Gradually the lake, or at least the part of it that is represented by the present Adobe Canyon area, was filled by gravels brought in by streams. These gravels were contributed by at least two drainage systems, whose domination in the area fluctuated; one system brought in arkosic detritus from the northeast, and the other contributed volcanic detritus from the southwest and perhaps also from the southeast. The increased abundance of fanglomerate that was deposited toward the end of this time resulted from a gradual increase in local relief that is believed to have been associated with an early phase of the Laramide orogeny. Rhyolitic tuff that was deposited in the gravels late during Fort Crittenden time was probably a preliminary sign of the major volcanic episode that followed, and its deposition brought to a close the time of deposition of abundant clastic rocks in the Late Cretaceous.

Correlation (from Drewes (1971)

Sedimentary rocks of unquestioned Late Cretaceous age are scarce in the region around the Santa Rita Mountains, but undoubtedly more will be recognized when areas thus far only mapped in reconnaissance are studied in detail and when other redbed sequences are dated. The deposits which have a lithology and age most similar to the lithology and age of the Fort Crittenden Formation are the Cabullona Group in Sonora, Mexico, 70 miles southeast of Adobe Canyon and 18 miles east-southeast of Bisbee. These rocks, according to Taliaferro (1933), unconformably overlie the Lower Cretaceous Bisbee Group and make a sequence about 8,000 feet thick which contains, in rising succession, (1) the Snake Ridge Formation, of red conglomerate and sandstone, 2,000 feet thick; (2) the Camas Sandstone, of crossbedded sandstone and red and green shale, 1,200 feet thick; (3) the Packard Shale, a dark gray shale containing thin beds of bentonite and capped by white sandstone, 1,800-2,500 feet thick; (4) the upper red beds, of sandstone and shale, 2,000 feet thick; and (5) the light-gray rhyolite tuff, 800 feet thick. Both marine and nonmarine fossils are present, and adrosaurian remains from the upper part of the Snake Ridge Formation are probably of Santonian age, an age apparently preferred for the entire Cabullona Group.

The Fort Crittenden Formation has also been recognized by Hayes in the northwestern corner of the Huachuca Mountains (Hayes and Raup, 1968), about a quarter of the distance from the Santa Rita Mountains to the Cabullona area. The rocks of this area consist of at least 1,500 feet of interbedded shale, sandstone, and conglomerate, which are also dominantly reddish brown but include some greenish-gray to dark-gray beds. They rest unconformably upon folded and faulted rocks high in the Bisbee Group and are themselves folded; thus, the structural relations also resemble those in Adobe Canyon.

East and northeast of Adobe Canyon, there are also some rocks which Drewes believes may be correlated with the Fort Crittenden Formation. In the Winchester Mountains, 10 miles northeast of the Little Dragoon Mountains, Cooper and Silver (1964,p.76-77) described red and green conglomerate, sandstone, and shale about 4,000 feet thick, which contains intercalated rhyolitic tuff and which is overlain by andesitic sedimentary and volcanic rocks. Likewise, in the Chiricahua Mountains, about 30 miles northeast of Bisbee, the Javelina formation of Epis (1956) consists of conglomerate and sandstone, apparently lying unconformably between the Bisbee and andesitic volcanics, a stratigraphic position suggestive of the Fort Crittenden.

To the north and west, similar rocks are reported, although they are assigned various stratigraphic positions. Fort Crittenden rocks were recognized by T. L. Finnell (oral commun., 1968) in the northeast corner of the Santa Rita Mountains, where they also contain some rhyolitic tuff lenses. J. R. Cooper (oral commun., 1968) described rocks in Demetrie Wash in the Sierrita Mountains as consisting of a lower tongue of conglomerate, siltstone, and sandstone overlain by rhyolite tuff and andesite breccia. At least the lower tongue in Demetrie Wash may be correlated with the Fort Crittenden Formation, and the breccia may be correlated with the lowest two members of the Salero Formation.

Each of these areas of southeastern Arizona has a similar succession of Cretaceous rocks. From older to younger, they are: (1) Bisbee; (2) unconformably overlying conglomerate, sandstone, and shale, which are dominantly red and commonly contain lenses of rhyolite tuff at or near their tops; (3) andesitic volcanic breccia, locally including andesitic sandstone; and (4) rhyodacitic tuff, commonly welded. This regional similarity strongly suggests that the units are generally correlative, and although specific units such as the rhyolitic tuff may not be completely synchronous, the volcanic rocks may be of roughly the same age. The volcanic rocks herald the arrival of major magmatism into the southeast Arizona region from southern California (Coney and Reynolds, 1977; Keith, 1978).

Return to Arizona 83, turn left, and proceed north.

39.8 Empire ranch road on right. The Empire ranch was purchased by Anamax Mining Company for the water rights to develop the Helvetia-Rosemont deposits in the northern Santa Rita Mountains near the skyline ridge at 9:30.

1.3

41.1 Madern Canyon-Greaterville road via Box Canyon is just ahead on left.

Greaterville developed after the discovery of placer gold in 1874. The mining district was organized in March, 1875. Scarcity of water made it necessary to work placers by rocker and long tom. Water was brought in canvas or goatskin bags from Gardner Canyon, four miles away. By 1881 the gold had nearly played out and miners began to desert the camp. Others left because of Indian attacks. From 1886 to 1900 Greaterville was dead on its feet. (Barnes, 1960).

The great depression of 1929 supplied incentive to revive its popularity for weekend dry gold panners.

2.4

43.5 Road crosses major drainage divide. Gently tilted Plio-Pleistocene valley fill is exposed in roadcuts ahead.

0.5

44 Empire Mountains (1:00) are separated from the northern Santa Rita Mountains (9:00 to 12:00) by Davidson Canyon. A conspicuous change in geomorphic style at drainage divide 0.5 mi ahead illustrates headward erosion and progressive stream capture by Davidson Canyon of the high Pleistocene surfaces in the Sonoita area that were formerly graded to the Babocomari River. The higher gradients of streams such as Davidson Canyon, Cienega Creek to the east, and Box Canyon and Sonoita Creek are related to the considerably lower base level of the Santa Cruz River system to the west, which is as much as 1,600 ft. lower than the San Pedro-Babocomari system to the east. The difference between geomorphic styles of the headcutting streams and the former, low-relief, low-gradient, mid-Pleistocene drainage is particularly well displayed at this drainage divide.

Roadcuts ahead are in gently tilted, Plio-Pleistocene valley fill, which rests on an extensive, now exhumed topography of pre-Pliocene(?) age in the Empire and northern Santa Rita mountains.

1.0

45 Empire Mountains at 11:00 to 12:00; northern Whetstones at 1:00. Southern Empire Mountains in view are a southeast-dipping homocline of Paleozoic through Mesozoic rocks. They are intruded in the core of the range by the Sycamore Canyon quartz monzonite, known informally as the Sycamore stock, which has yielded dates of 71.9 and 80 m.y. (Marvin and others, 1973). Next to the Whetstone Mountains, the southern Empire Mountains contain the

second most complete Naco section exposed in southeastern Arizona and have a different nomenclature from the Mule Mountains. A good Bisbee group section is also exposed (Hayes and Drewes, 1978).

Mount Fagin (9:00 to 9:30) in the northern Santa Rita Mountains is composed of Late Cretaceous pyroclastic volcanics of the Salero Formation. On the west side of Mount Fagin these volcanics rest with angular discordance upon Bisbee Group, which is tightly folded about east-west, low-plunging fold axes. In Davidson Canyon Salero Formation laps across the Empire thrust fault (Drewes and Finnell, 1968). Roadcuts ahead continue in gently tilted, Plio-Pleistocene valley-fill alluvium.

0.9

45.9 Roadcut on right contains a well-exposed angular unconformity between Plio-Pleistocene valley fill and underlying Pantano Formation, which here is moderately to steeply tilted, red boulder conglomerate. Dacite intercalated in the Pantano Formation has yielded a date of 28.7 m.y. (Finnell, 1970b). Roadcuts ahead are in poorly-sorted, poorly-bedded, red boulder conglomerates of Pantano Formation, named by Brennan (1962) for exposures along Pantano Wash about 12 mi north-northeast of here.

0.1

46 Roadcuts ahead are in extremely jumbled, unbedded Pantano Formation. Note size and diversity of some blocks; neither matrix nor clasts are well indurated. Perhaps this chaotic assemblage represents a landslide or debris-flow deposit.

0.6

46.6 Rosemont junction on left. This road passes the Helvetia-Rosemont porphyry copper deposit which is on the east side of the northern Santa Rita Mountains at 8:00. The road also connects with Helvetia west of the main ridge. Mineral deposits of the Helvetia-Rosemont area are thought to be closely affiliated with 53.3 to 57.6 m.y. (Drewes, 1976b) quartz latite porphyry dikes which are abundant throughtout the northern Santa Rita Mountains.

Reserves as of 1973 for the Rosemont deposit were estimated at 320 million tons of 0.64% sulfide copper and 20 million tons of 0.55% oxide copper. Production data for the Rosemont-Helvetia district (1908 to 1975) is 34,860,000 pounds of copper, 521,000 pounds of lead, 1,360,000 pounds of zinc, 346,900 ounces of silver and 158 ounces of gold. Gold placers in the Greaterville area at 7:00 are popular with weekend gold seekers from the Tucson area.

For more discussion of the geology of the northern Santa Rita Mountains see Drewes (1971a, b, c, 1972, 1976b, and Keith and others 1978).

0.1

46.7 Roadside table on left. Here a thin veneer of terrace alluvium rests unconformably on northwest-striking, moderately southeast-dipping Pantano Formation. Road ahead crosses Davidson Canyon where a major fault separates Pantano Formation from the exotic block member of Salero Formation.

0.8

47.3 Bridge across Davidson Canyon. Roadcuts for next several miles are in exotic block member of Salero Formation, which is the lower member of this Upper Cretaceous formation. Note altered and poorly indurated character and poor outcrop expression of these rocks. These characteristics are typical of volcanics of this age throughout southeastern Arizona (see Hayes and Drewes, 1978).

The name Salero comes from the Salero mine, which is reputed to be one of the oldest in southern Arizona. It is said to have been worked by Jesuits in the 17th century, although no documentary evidence has been found to substantiate this. However, it is known that it was worked from about 1828 to 1830 by Mexicans. Hinton related a legend that the padres at San Jose de Tumacacori were expecting a bishop for dinner who had complained about a lack of salt for his dinner. The priests fashioned a salt cellar from a piece of ore taken from the Salero mine (Barnes, 1960).

Historically, the Salero mine is an example of the extreme hardships imposed by Apaches in the late 1850's and early 1860's. In 1857 John and William Wrightson became owners of the old mine, forming the company in 1858 with H. C. Grosvenor as engineer, Raphael Pumpelly as geologist and Gilbert W. Hopkins as mineralogist with headquarters at Tubac. Only Pumpelly escaped death at the hands of Indians, and he had plenty of hair-raising escapes as told by his journals (Pumpelly, 1918).

0.7

48 Southeast-dipping Horquilla Limestone is on the main crest of the Empire Mountains at 12:00. East of the main ridge the entire Naco Group is exposed with only minor structural complications. This section is accessible by a dirt road on the right 1.1 mi ahead. Roadcuts continue in exotic block member of Salero Formation.

1.0

49 Roadcuts in quartz latite porphyry dike. This dike is part of the wide-spread dike swarms which crop out throughout the northern Santa Rita Mountains, thought to be closely associated with porphyry copper mineralization. Such rocks are popularly known among exploration geologists as "mill rocks" because when you stand on one of these rocks you are usually within view of a mine, smelter or mill. The westerly trending ridges at 8:00 are quartzite beds in the Bisbee Group, which forms a west-northwest trending isoclinal syncline that is overturned to the south.

0.1

49.1 Road on right is main access to Empire Mountains (2:00 to 4:00) and the upper Paleozoic and Bisbee Group sections. Ahead terrace alluvium rests unconformably on exotic block member of Salero Formation.

0.9

50 Near here several dikes of quartz latite porphyry intrude exotic block member of Salero Formation. Well-developed, but now dissected, depositional stream terraces are on the east side of Davidson Canyon ahead on right. Hills southwest of road are capped by Pantano Formation, which unconformably overlies exotic block member of Salero Formation.

0.7

50.7 Quartz latite porphyry dike intrudes Willow Canyon Formation in the ridge from 1:00 to 2:00.

0.3

51 Roadcuts are in contact-altered Bisbee Group at the west edge of the Sycamore stock. A quartz latite porphyry dike cuts this assemblage at north end of roadcut on left; beyond, roadcuts are in the Sycamore stock. Road ahead crosses the west edge of this stock which has an area of about 4 mi^2. The stock is well exposed in the central Empire Mountains where it intrudes a southeast-dipping Palezoic section. Mineralization in contact-altered zones and veins in these Paleozoic rocks may be related to this stock. Recorded production through 1972 for the Empire mining district is 344,000 pounds of copper, 16,671,000 pounds of lead, 515,000 pounds of zinc, 206,400 ounces of silver and 744 ounces of gold.

0.5

51.5 Low hills to west and roadcut ahead on left are in Bisbee Group that is tightly folded about east-trending fold axes.

0.5

52 Limestone ledges at 2:00 are Rain Valley(?) or Concha(?) limestone overlain by exotic block member of the Salero Formation (Finnell, 1970a, 1971). For about 1.5 mi highway parallels north-striking Empire thrust. Glance Conglomerate, Triassic Gardner Canyon equivalent(?) volcanics and red beds, and Rain Valley and Concha limestones are in upper plate; Bisbee Group strata are in lower plate.

0.4

52.4 Old Sonoita highway sign. Drewes and Finnell(1968) described rocks in these roadcuts as Bisbee "Formation" and conglomeratic mudstones of Triassic(?) age with the Empire thrust fault intervening between them. On the Finnell (1971) geologic map the thrust is shown to cut the exotic block member of the Salero Formation; on the Drewes and Finnell (1968) generalized geologic map the thrust is shown to place upper Paleozoic rocks over Bisbee Group with no Salero Formation shown.

Another interpretation is possible. The upper greenish and fragmental-bearing, "punky" rock in the upper part of the left roadcut is probably the exotic block member of Salero Formation. The underlying, steeply upturned, generally east-striking beds in the lower part of the roadcut are probably clastic sedimentary rocks in either the Shellenberger Canyon or Apache Canyon formations. Close inspection of the contact between these two rock units suggests a surface of relief and channelling phenomena which would indicate an unconformable relationship between the two units. A number of flat faults or flat shear surfaces cut the overlying Salero Formation and locally parallel and offset the low-relief, flat-lying erosional contact. Observed displacement on several of these fault strands where they cut the underlying Bisbee Group or offset the unconformable contact is no more than a few feet.

The strong angular discordance between the underlying Bisbee strata and the overlying lower Salero Formation indicates a major Late Cretaceous tectonic event which post-dates Lower to mid-Cretaceous Bisbee Group (as young as 94 m.y.) and predates Salero Formation (possibly as old as 80 m.y.). This angular truncation of Bisbee Group to lower Salero Formation is noted by Drewes and Finnell (1968) at a number of other localities in the northern Santa Rita Mountains, although not noted by them at this particular spot. The relations in this roadcut suggest that much of the tectonism in the northern Empire Mountains occurred after Bisbee deposition and before Salero with minor tectonism after deposition of the lower Salero.

The strongly upturned, east-striking Bisbee Group is part of the major belt of Late Cretaceous east-west folds and reverse faults. This belt extends from the northern Santa Rita Mountains through the Empire Mountains to the northern Whetstone Mountains and would correspond to the first north-south compressive orogeny of Gilluly (1956) in the Tombstone Hills.

0.3

52.7 Ledge at top of hill at 2:00 (on skyline) is Glance Conglomerate, which unconformably rests on maroon redbeds and siltstones mapped by Finnell (1971) as an equivalent of the Triassic Gardner Canyon Formation. Rhyolite tuff intercalated within the red beds in this area yielded a lead-alpha age on zircon of 170 $\pm$ 35 m.y. (Marvin and others, 1973).

East of Total Wreck Ridge at 3:30 (which is capped by Concha Limestone) is a large, southward-thinning, fanglomerate wedge of Glance Conglomerate which contains clasts of Pinal Schist and Precambrian granite derived from an upthrown block north of the east-striking Empire thrust. North of the Empire fault Glance Conglomerate is thin or absent, as are the Willow Canyon and Shellenberger Canyon formations. The Empire thrust is apparently another fault which has experienced repeated reactivations in Mesozoic and Cenozoic time (see Bilodeau, this guidebook).

0.1

52.8 Hill at 12:30 is capped by Rain Valley Formation with Concha Limestone in lower slopes. Low divide between that hill and hill topped by Glance Conglomerate at 2:00 is capped by presumed Triassic Gardner Canyon equivalent.

0.2

53 Roadcuts on right are Permian Concha Limestone; hill on right is capped by Rain Valley Formation. At north end of roadcuts quartz latitie porphyry is in fault contact with contact-altered Concha Limestone.

Observe extensive dissected pediment that was developed in the northern Santa Rita Mountains.

0.4

53.4 Roadcuts in Shellenberger Canyon Formation. These strata are intruded by a quartz latite porphyry dike, which is part of an extensive west-to west-northwest dike swarm in the northwestern Santa Rita Mountains. Copper mineralization in the Cuprite mine area may be associated with these dikes.

1.1

54.5 Roadcut on right in upturned Shellenberger Canyon Formation angularly overlain by terrace alluvium which fills channels in an erosion surface.

0.4

54.9 Roadcuts on left are in upturned Bisbee Group intruded by quartz latite porphyry dikes.

0.1

55 Low ridge to right contains Precambrian granite depositionally overlain by Shellenberger Canyon Formation and various members of Salero Formation. Uplift and erosion of the entire Paleozoic section probably is coincident with deposition of the thick Glance Conglomerate fanglomerate wedge shed onto Permian rocks south of this block. Road traverses veneer of terrace gravels resting on an extensive pediment.

0.4

55.4 Sahuarita road on left.

0.6

56 Roadcuts ahead in alluvium unconformably resting on an intrusive rock mapped as Paleocene quartz latite porphyry by Finnell (1971) at north end of roadcut on left.

0.4

56.4 Roadcut on left and outcrop on right are quartz latitie porphyry. These are the last bedrock outcrops on this log. Ahead road passes onto alluvium and valley fill in Tucson basin. The size of the pediment in the northern Santa Rita Mountains emphasizes the structural size of the horst blocks as compared to the graben blocks in the valley. The fault is now concealed by valley fill. Following Basin and Range faulting, which terminamed in this area approximately 5 m.y. ago, extensive pediments developed as mountain fronts retreated as much as several miles.

1.6

58 Broad domal physiography of the Rincon, Catalina and Tortolita mountains dominates the skyline from 11:30 to 3:00. At 11:15 are Picacho Mountains with Picacho Peak at 11:00, about mi distant (if visibility permits). Rugged peaks of Tucson Mountains on skyline from 10:00 to 11:00. Del Bac Hills south of Tucson Mountains at 9:45. In far distance at 9:15 loom the Coyote and Quinlan Mountains with Kitt Peak Astronomical Observatory at 9:10. The Sierrita Mountains form a broad, very flat cone at 9:00. Tortolita Mountains form a low ridge at 11:30 behind jagged peaks of Pusch Ridge (11:30 to 12:30) in the western Catalinas.

The large rounded peak at 1:00 in the Rincon Mountains is Mica Mountain (8,666 ft). The conspicuous ridge trending west-southwest from Mica Mountain is Tanque Verde Ridge or the Tanque Verde Mountains. Cow Head Saddle separates Tanque Verde Ridge from Mica Mountain. The top of Tanque Verde Ridge gently plunges southwestward and generally marks the culmination of a large, antiformal foliation arch in mylonitic gneisses. Mica Mountain is separated from Rincon Peak (8,482 ft. at 2:00) by Happy Valley Saddle. The small peal north of the cuesta-like peak and south of Rincon Peak is Wrong Mountain which is the type locality of the two mica-garnet-bearing Wrong Mountain Quartz Monzonite which crops out extensively throughout the Rincon Mountains.

Wrong Mountain Quartz Monzonite is mineralogically similar to the Wilderness Granite in the Santa Catalina Mountains and is extensively interlayered with a darker gneiss, which Drewes (1977) considers to be deformed Rincon Valley and Continental Granodiorites. Age dates on undeformed Rincon Valley Granodiorite outside of the metamorphic area yield K-Ar ages of 1380 to 1560 m.y. on various minerals (Marvin and others, 1973; Drewes, 1977). A specimen of Rincon Valley Granodiorite from Saguaro National Monument northwest of Tanque Verde Ridge gave a 1440 m.y. Rb-Sr age. Drewes (1977) also assigns a Precambrian age to Wrong Mountain Quartz Monzonite based on a hybrid Rb-Sr age of 295 m.y. and by analogy with 1650 m.y. zircons extracted from deformed Wilderness Granite at Windy Point (Catanzaro and Kulp, 1964) (<u>see Silver, this guidebook</u>).

Layers of mylonite schist commonly separate layers of Wrong Mountain Quartz Monzonite from the darker layers of deformed Continental Grandiorite. These schistose lenses have been correlated with Pinal Schist by Drewes (1977).

Low foothills from 12:30 to 2:00 in middle distance are underlain by Paleozoic rocks. Colossal Cave, a local tourist attraction, is in the foothill at 1:30. Paleozoic rocks in the Agua Verde-Colossal Cave area are part of a series of deformed Phanerozoic rocks that also occur at Martinez ranch at the base of the Rincon Mountains at 2:30, in the Loma Alta area (12:30) at the southern base of Tanque Verde Ridge, and in the Saguaro National Monument area just northeast of the nose of Tanque Verde ridge at 12:00. A large pediment in Rincon Valley between Loma Alta and Colossal Cave is cut on Precambrian Rincon Valley Granodiorite.

The Precambrian and Paleozoics are in the upper plate of the major, low-angle, Santa Catalina fault, which is located at the break in slope between the main Rincon massif and the foothill block. The Santa Catalina fault separates the unmetamorphosed, but highly deformed, upper plate rocks from lineated mylonites of the metamorphic core in the main Rincon Mountain mass. Inevitably these complicated geometric relationships have several interpretations. Davis (1975) analyzed fold geometries in Paleozoic and Mesozoic rocks of the upper plate and concluded that they represented a period of major gravitational sliding of the cover down the Santa Catalina fault surface in mid-Tertiary time. Drewes (1977) recognized this mid-Tertiary gravity-induced movement, but also suggested that the low-angle fault was older and represented former thrusts which were emplaced about 73 m.y. ago via regional north-east-southwest compression of Laramide age. These faults were reactivated in Oligiocene times (25 m.y.) during arching of the mylonite rocks of the metamorphic core.

0.3

58.3 Old Sonoita highway on right rejoins Arizona 83.

0.3

58.6 Overpass; Junction with Interstate 10.

0.4

59.0 Merge with westbound lane of I-10.

0.3

281.3 I-10 traverses aggradational surface on Plio-Pleistocene valley fill. Red soil horizon formerly on this surface has generally been removed throughout Tucson basin.

1.4

279.9 Exit 279; Colossal Cave and Vail road. Colossal Cave to northeast is a small, dry cave in Escabrosa Limestone, which is in the allochthonous Paleozoic section above the Catalina fault.

1.9

278. Catalina Mountains are from 1:00 to 2:30 with the high summit of Mount Lemmon (9,157 ft) at 2:30. The five major peaks which comprise Pusch Ridge (1:00 to 3:00) from left to right are Pusch Peak, Table Mountain, Mount Kimball, Finger Rock and Cathedral Peak. Pusch Ridge is composed of gently dipping, light and dark layers of banded gneiss which contain mylonite-capped cataclastic rocks. Pusch Ridge is separated from the main mass of the Catalinas by Romero Pass. A low ridge, called the Forerange, extending east from Cathedral Peak, is also composed of layered cataclastic gneisses.

In the background, the crest of main range is capped by metamorphosed younger Precambrian Apache Group and lower Paleozoic rocks. Below the crest these rocks are intruded by a large- sill-like pluton named the Wilderness Granite by Shakel and others (1977), who reported a minimum uranium lead monazite age of 45 m.y. from this rock. Below the summit of Mount Lemmon and above the Wilderness of Rocks (the type area for the Wilderness Granite) are some prominent, white "teeth"-like cliffs. These mark the position of an extensive alasko-pegmatite border phase of Wilderness Granite which extensively intrudes the overlying younger Precambrian and Paleozoic strata at the crest of the range and the Leatherwood Quartz Diorite just north of the crest. According to the mapping of Banks (1976), sill-like appendages from this pluton occur between dark layers of the banded gneiss inthe Forerange. Zircons extracted by Shakel and others (1977) from those dark layers strongly suggest a correlation with once undeformed 1400-1450 m.y. old Precambrian granite. The Wilderness pluton is part of an extensive Oligocene composite batholith which pervades the entire Catalina Mountains according to Creasey and others (1977). They cite numerous mid-Tertiary age dates by K-Ar and fission track methods to support the mid-Tertiary age assignment. Large muscovite books extracted from the alasko-pegmatitic complex near Summerhaven on Mount Lemmon have yielded 47.9 m.y. K-Ar ages, which Damon and others (1968) interpreted as an intermediate age inherited from some unknown older age. Rincon Mountains are at 2:00 to 4:00 with Mica Mountain now at 3:15.

2.4

275.6 Exit 275; Houghton road to Saguaro National Monument and east Tucson on right and to Pima County Fairgrounds on left.

2.3

273.3 Exit 273; Rita road.

2.1

271.2 Wilmot road sign on right. At 9:30 a water tower presides over a collection of shacks known as Galeyville.

Exxon drilled a deep stratigraphic test into the Tucson basin 2 mi south of here. The upper 7,277 ft. is sand, gravel and clay, filling Basin and Range grabens formed after 12 m.y. From 7,277 to 9,000 ft the hole penetrated a volcanic section of tuff, andesite and rhyolite. Selected cuttings from a tuff at 7,940 to 7,960 ft. yielded a K-Ar age of 23.2 m.y. Below the volcanic section from 9,000 to 9,500 ft reddish brown conglomerates were encountered. At 9,500 to 10,000 ft another volcanic unit was found which yielded K-Ar ages of 16.1 and 18.0 m.y. This was interpreted to be an intrusive dike or sill. From 10,000 to 12,000 ft. more reddish brown conglomerates, silts and shales were drilled. At 12,000 ft to the total depth of 12,590 ft was a quartz monzonite dated at 61 m.y. by K-Ar and 120 m.y. by Rb-Sr methods. Eberly and Stanley (1978) regard the section from 7,277 to 12,000 ft. as deposited after the Eocene and before the Basin and Range faulting about 13 m.y. ago. A seismic profile by Exxon shows the deep part of Tucson basin is surprisingly narrow and shows extensive pediments buried by a basin-ward thickening sequence of alluvial basin-fill (see Scarborough and Peirce, this guidebook).

4.2

267.0 Benson highway (Tucson airport) exit.

2.0

265 Tucson Mountains on skyline from 10:00 to 12:30. From left to right are Beehive Peaks (10:30), Cat Mountain (11:00), Golden Gate Mountain (11:15) and Bren Mountain (11:30). The highest point in the Tucon Mountains is Wasson Peak (4,877 ft) at 11:55. Tumamoc Hill, location of the University of Arizona Palynology and Vertebrate Paleontology laboratories is at 12:30; Safford Peak at 12:45 marks the northern end of Tucson Mountains.

West of Interstate 10 at the foot of "A" Mountain (Sentinel Peak), where Mission Road crosses the Santa Cruz River, is the site of San Augustin del Tucson. Tucson means "at the foot of the Black Mountain." The downtown governmental center is built over the site of a Spanish colonial presidio (Polzer, oral comm.).

Barnes (1960), briefly described the early history of Tucson:

The Papago name for Sentinel Mountain (q.v.) is Chuk Shon, referring to the fact that the base of the mountain has a darker color than the summit. The Papagos customarily name their villages after distinctive landmarks, and an old Indian village was once located at the base of this mountain. Spanish pronunciation was an approximation of the Papago name, Tuqui Son or, in its current form, Tucson. Hodge states that Tu-uk-so-on means "black base." The rancheria at this point has long since disappeared.

That there was prehistoric civilization where present-day Tucson exists is beyond question. When the Pima County Court House was constructed in Tucson in 1928, workmen excavating for the footings not only uncovered a part of the old presidio wall, but also found evidence of prehistoric civilization. Again in December 1954, workment excavating for a proposed building found the northern wall for the same presidio and below it a Hohokam pit house dating at least to 900 A.D. The ruins were covered and plans for a new building abandoned.

Records have much to say about Tucson. Its first mention by a Spanish missionary was that made by Fr. Kino in 1697. However, the place to which Kino referred was about three miles north of the present courthouse and hence outside the original town limits by a considerable distance. This was San Augustin de Oiaur. Kino noted that it was on the banks of the Santa Cruz River, which was then running with some force, and that between that point and San Xavier del Bac was the most thickly populated and fertile spot in the whole Santa Cruz Valley. It is to be noted that Kino did not apply the word Tucson to this place. Co-existent with this place was Chuk Son near Sentinenl Peak.

Many years passed and with them vanished the supremacy of the Jesuits, who fell out of favor with the Spanish court. The Franciscan order took the place of the Jesuit in Arizona, and in 1751 the Indian settlement of Chuk Son became a visita of San Xavier del Bac. During the Pima revolt (1751), both the visita and the mission were abandoned. A few years later, Fr. Francisco Garces was sent into southern ARizona. It was he who, to protect the peaceful Indians against the raiding Apaches, caused a small pueblo with a church and a wall to be constructed for defense in 1769. The fact that there was a wall completely around this small community is the origin of the currently used nickname for Tucson, the Old Pueblo. The name San Augustin del Tuquison was transferred to this place to distinguish it from the nearby Chuk Son (or Kuck Son) which was called San Augustin de Pueblito de Tucson. The latter place was reported to have two hundred families in 1771, but by 1774 only eighty families remained. To protect the missions and the peaceful Indians the Spaniards had previously established a detachment of the military at Tubac (q.v., Santa Cruz County). In 1776 these soldiers were moved to San Augustin de Tucson.

In 1822 Tucson was in the newly created Mexico. Tucson was the military outpost of Mexico until the area in which the settlement was located became part of the United States with the Gadsden Purchase in 1853. Apache troubles in the Santa Cruz Valley caused Tucson's population to fluctuate and after 1848 to increase because of refugees from Tubac and Tumacacori seeking safety within its environs. In 1846 the Mormon Battalion passed through under Gen. Philip St. George Cooke. It was at this time that the Mexican presidio moved permanently from the Old Pueblo.

In 1856 the U.S. Government sent four companies of the First Dragoons, who stayed a very brief time at Tucson before being moved to the vicinity of Calabasas in October. It is this fact which has led to some confusion about the date of the establishment of the post office at Tucson (cf. Fort Buchanan, Santa Cruz).

In the summer of 1861, Tucson had a total of sixty-eight American voters. This handful of men assembled in a convention and elected a "territorial delegate" (Granville Oury, cf. Mount Oury) to the Confederate Congress. In February 1862, Confederates from Texas under Capt. Sherod Hunter marched unopposed into the Old Pueblo. Their stay was a brief one, for they retreated on May 20 before the oncoming California Volunteers, who entered the town and raised the flag of the United States. In June, James H. Carleton, Commander of the California Column, reached Tucson, and Arizona, which had since August 1861 been part of the Con=federacy, returned to the Union.

Two years later in May 1864, Gov. John N. Goodwin (who had recently taken up his duties as the first actual governor of ARIZONA Territory) declared Tucson a municipality, which was tantamount to its incorporation. There was much haggling to establish the permanent capital for the territory at various places and Tucson exerted pressure for her own selection. In 1877 the capital was moved back to Prescott.

In 1879 thousands of people flocking to the Tombstone District had their effect on the economy of Tucson, which began to emerge from being a tiny sleepy village into its life as a city. The fact that it was sleepy applied mostly to the daylight hours, for Tucson had a reputation of being wide open, rough and ready. A favorite story was that concerning the tenderfoot from the East who stepped down from a dusty stage trip at four o'clock in the morning. He made tracks for the nearest bar, which wasn't difficult to locate. The tenderfoot made some comment about it being late for the bar to be open, to which the bartender replied that it was late for the night before last, but "just the shank of the evening for tonight."

P.O. est. July 13, 1865. Mark Aldrich, p.m. Wells Faro Station, 1879. Incorporated February 7, 1877.

Principal rock types in the Tucson Mountains are Laramide volcanic and plutonic rocks (75-56 m.y.). These overlie strongly deformed Amole Arkose, correlated by Hayes (1970b) with the Bisbee Group. Tertiary volcanics and agglomerates (28 to 24 m.y.) unconformably overlie Laramide volcanic rocks.

The Tortolita Mountains at 1:00 include an extension of the metamorphic geology in the western Santa Catalina Mountains. Note the contrast between the Tortolita-Catalina-Rincon metamorphic ranges and the Tucson, northern Santa Rita and Empire mountains. Why have these ranges escaped the metamorphism which pervades the Santa Catalina-Rincon-Tortolia complex?

0.3

144.1 Palo Verde road-Irvington road exit.

0.8

144.9 Entering Tucson. <u>Continue on I-10 downtown Tucson</u>. End of road log.

ROAD LOG REFERENCES

Armstrong, A. K., 1962, Stratigraphy and paleontology of the Mississippian System in southwestern New Mexico and adjacent southeastern Arizona: New Mexico Bur. Mines and Min. Resources Mem. 8, 99 p.

Armstrong, A. K., Silverman, M. L., Todd, V. R., Hoggatt, W. C., and Carten, R. B., 1978, Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico: New Mexico Bur. Mines and Min. Resources, Circ. 158, 18 p.

Bailey, L. R., 1963, The A. B. Gray Report: survey of a route on the 32nd parallel for the Texas Western Railroad, 1854: Los Angeles, Calif., Westernlore Press, 240 p.

Bancroft, H. H., 1962, History of Arizona and New Mexico: Albuquerque, Horn and Wallace, 829 p.

Banks, N. L., 1976, Reconnaissance geologic map of the Mount Lemmon quadrangle, Arizona: U.S. Geol. Survey Misc. Field Stud. Map MF-747.

Banks, N. L., and Docktor, R. D., 1976, Reconnaissance geologic map of the Vaca Hills quadrangle, Arizona: U.S. Geol. Survey Misc. Field Stud. Map, MF-793.

Barnes, W. C., 1960, Arizona place names, revised edition: Tucson, Univ. Arizona. Gen. Bull 2, 519 p.

Barrie, K. A., 1975, The conodont biostratigraphy of the Black Prince Limestone (Pennsylvanian) of southeastern Arizona [M.S. thesis]: Tucson, Univ. Ariz., 43 p.

Bikerman, M., 1962, A geologic-geochemical study of the Cat Mountain rhyolite [M.S. thesis]: Tucson, Univ. Ariz., 43 p.

———, 1965, Geological and geochemical studies of the Roskruge Range, Pima County, Arizona [Ph.D. dissertation]: Tucson, Univ. Ariz., 112 p.

Bikerman, M., and Damon, P. E., 1966, K-Ar chronology of the Tucson Mountains, Pima County, Arizona: Geol. Soc. America Bull., v. 77, p. 1225-1234.

Bittson, A. G., 1976, Analysis of gravity data from the Cienega Creek area, Pima and Santa Cruz Counties, Arizona [M.S. thesis]: Tucson, Univ. Ariz., 76 p.

Bolin, D. S., 1976. A geochemical comparison of some barren and mineralized igneous complexes of southern Arizona [M.S. thesis]: Tucson, Univ. Ariz., 186 p.

Bourke, J. G., 1873, Diary, v. 1, p. 130-132.

Bourne, E., 1970, The San Pedro Valley: Arizona Highways, v. 46, n. 1, p. 12.

Brennan, D. J., 1957, Geological reconnaissance of Cienega Valley, Pima County, Arizona [Ph.D. dissertation]: Tucson, Univ. Ariz., 53 p.

———, 1962, Tertiary sedimentary rocks and structures of the Cienega Gap area, Pima County, Arizona: Ariz. Geol. Soc. Digest, v. 5, p. 45-58.

Butler, B. S., Wilson, E. D., and Rasor, C. A., 1938, Geology and ore deposits of the Tombstone district, Arizona: Ariz. Bur. Mines Bull. 143, 114 p.

Butler, B. S., Grout, F. F., and Bromfield, C. S., 1952, Santa Catalina Mountains metamorphic area: Ariz. Geol. Soc., Guidebook for field trip excursions in southern Arizona, p. 43-49.

Brown, W. H., 1939, The Tucson Mountains—an Arizona Basin Range type: Geol. Soc. America Bull., v. 50, p. 697-759.

Bryan, K., 1925, Date of channel trenching (arroyo cutting) in the arid Southwest: Science, v. 62, p. 338-344.

———, 1926, San Pedro Valley, Arizona and the geographic cycle [abs.]: Geol. Soc. America Bull., v. 37, p. 169-170.

Budden, R. T., 1975, The Tortolita and Santa Catalina Mountains—a spatially continuous gneissic complex [M.S. thesis]: Tucson, Univ. Ariz., 133 p.

Catanzaro, E. J., and Kulp, J. L., 1964, Discordant zircons from the Little Belt (Montana), Beartooth (Montana), and Santa Catalina (Arizona) Mountains: Geochem. et Cosmochim. Acta, v. 28, p. 87-124.

Cederstrom, D. J., 1946, Structural geology of the Dragoon Mountains, Arizona: Am. Jour. Sci., v. 244, p. 601-621.

Clark, K. F., 1970, Zoning, paragenesis, and temperatures of formation in the Lordsburg district; New Mexico Geol. Soc., 21st Field Conf., p. 107-113.

Conkling, R. P., and Conkling, M. B., 1947, The Butterfield Overland Mail: Glendale, Calif., Arthur H. Clark Co., v. 1, p. 130-142.

Cooper, J. R., 1959, Reconnaissance geologic map of southeastern Cochise County, Arizona: U.S. Geol. Survey Misc. Field Stud. Map MF-213.

———, 1960a, Some geologic features of the Pima Mining District, Pima County, Arizona: U.S. Geol. Survey Bull. 1112-C, p. 63-103.

———, 1960b, Reconnaissance map of the Willcox, Fisher Hills, Cochise, and Dos Cabezas quadrangles, Cochise and Graham Counties, Arizona: U.S. Geol. Survey Misc. Field Stud. Map, MF-231.

———, 1973, Geologic map of the Twin Buttes quadrangle, southwest of Tucson, Pima County, Arizona: U.S. Geol. Survey Misc. Inv. Map I-745.

———, and Silver, L. T., 1964, Geology and ore deposits of the Dragoon quadrangle, Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 416, 196 p.

Corn, R. M., 1975, Alteration-mineralization zoning, Red Mountain, Arizona: Econ. Geol., v. 70, p. 1437-1447.

Creasey, S. C., 1967, Geologic map of the Benson quadrangle, Cochise and Pima Counties, Arizona: U.S. Geol. Survey Misc. Inv. Map I-470.

Creasey, S. C., and Kistler, R. W., 1962, Age of some copper-bearing porphyries and other igneous rocks in southeastern Arizona: U.S. Geol. Survey Prof. Paper 450-D, p. 1-5.

Creasey, S. C., and Theodore, T. G., 1975, Preliminary reconnaissance geologic map of the Bellota Ranch quadrangle, Pima County, Arizona: U.S. Geol. Survey, Open-File Report 75-295.

Creasey, S. C., Banks, N. G., Ashley, R. P., and Theodore, T. G., 1977, Middle Tertiary plutonism in the Santa Catalina and Tortolita Mountains, Arizona: Jour. Research, U.S. Geol. Survey, v. 5, p. 705-717.

Creasey, S. C., and Krieger, M. H., 1978, Galiuro volcanics, Pinal, Graham, and Cochise counties, Arizona: Jour. Research, U.S. Geol. Survey, v. 6, p. 115-131.

Cunningham, J. E., 1964, Geology of the north Tumacacori foothills, Santa Cruz County, Arizona [Ph.D. dissertation]: Tucson, Univ. Ariz., 139 p.

Damon, P. E., Livingston, D. E., and Erickson, R. C., 1962, New K-Ar dates for the Precambrian of Pinal, Gila, Yavapai, and Coconino Counties, Arizona: New Mexico Geol. Soc. Guidebook, 13th Field Conf., p. 56-58.

Damon, P. E., Erickson, R. C., and Livingston, D. E., 1963, K-Ar dating of Basin and Range uplift, Catalina Mountains, Arizona: *in* Nuclear Geophysics, NAS-NRC Publ. 1075, p. 113-121.

Damon, P. E., and Bikerman, M., 1964, Potassium-argon dating of post-Laramide plutonic and volcanic rocks within the Basin and Range province of southeastern Arizona and adjacent areas: Arizona Geol. Soc. Digest, v. 7, p. 63-78.

Damon, P. E., Mauger, R. L., and Bikerman, M., 1964, K-Ar dating of Laramide plutonic and volcanic rocks within the Basin and Range province of Arizona and Sonora: Proc. of 22nd Intl. Geol. Cong., New Delhi, India, p. 45-55.

Damon, P. E., and associates, 1965, Correlation and chronology of ore deposits and volcanic rocks: A.E.C. Annual Progress Report No. C00-689, p. 47-51.

Damon, P. E., and associates, 1966, Correlation and chronology of ore deposits and volcanic rocks: A.E.C. Annual Progress Report No. C00-689-40, p. 47-51.

Damon, P. E., and Mauger, R. L., 1966, Epierogeny-orogeny viewed from the Basin and Range province: Soc. Metal. Engineers Trans., v. 235, p. 99-112.

Damon, P. E., Bryant, D. L., and Mayo, E. B., 1968, Stratigraphic and volcanic geology, Tucson Mountains: Ariz. Geol. Soc. Guidebook III, p. 339-350.

Damon, P. E., and associates, 1969, Correlation and chronology of ore deposits and volcanic rocks: A.E.C. Annual Progress Report No. C00-120, p. 24-51.

Davidson, E. S., 1973, Geohydrology and water resources of the Tucson basin, Arizona: U.S. Geol. Survey Water-Supply Paper 1939-E, 81 p.

Davis, G. H., 1975, Gravity-induced folding off a gneiss dome complex, Rincon Mountains, Arizona: Geol. Soc. America Bull., v. 86, p. 979-990.

———, 1977, Characteristics of metamorphic core complexes, southern Arizona [abs.]: Geol. Soc. America, Abs. with Programs, v. 9, p. 944.

———, (in press), Laramide folding and faulting in southeastern Arizona: Am. Jour. Sci.

———, (in press), Structural characteristics of metamorphic core complexes: Geol. Soc. America Mem.

*Bilodeau, W.L., 1979, Early Cretaceous tectonics and deposition of the Glance Conglomerate, southeastern Arizona: unpubl. Ph.D. dissertation, Stanford University, 145p.

Davis, G. H., Anderson, P., Budden, R. T., Keith, S. B. and Kiven, C. W., 1973, Origin of lineation in the Catalina-Rincon-Tortolita gneiss complex, Arizona [abs.]: Geol. Soc. America, Abs. with Programs, v. 7, p. 602.

Davis, G. H., Elipulos, G. J., Frost, E. G., Goodmundson, R. C., Knapp, R. B., Liming, R. B., Swan, M. M., and Wynn, J. C., 1974, Recumbent folds—focus of an investigative workshop in tectonics: Jour. Geol. Education, v. 22, p. 204-208.

Davis, G. H., and Frost, E. G., 1976, Internal structure and mechanism of emplacement of a small gravity-glide sheet, Saguaro National Monument (East) Tucson, Arizona: Ariz. Geol. Soc. Digest, v. 10, p. 287-304.

Dirks, T. N., 1966, The upper Paleozoic stratigraphy of the Quimby Ranch area, southern Guadalupe Canyon quadrangle, Cochise County, Arizona [M.S. thesis]: Tucson, Univ. Ariz., 79 p.

Drewes, H., 1971a, Mesozoic stratigraphy of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Survey Prof. Paper 658-C, 81 p.

————, 1971b, Geologic map of the Sahuarita quadrangle, southeast of Tucson, Pima County, Arizona: U.S. Geol. Survey Misc. Inv. Map I-613.

————, 1971c, Geologic map of the Mount Wrightson quadrangle, southeast of Tucson, Santa Cruz and Pima Counties, Arizona: U.S. Geol. Survey Misc. Inv. Map I-614.

————, 1972, Structural geology of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Survey Prof. Paper 748, 35 p.

————, 1974, Geologic map and sections of the Happy Valley quadrangle, Cochise county, Arizona: U.S. Geol. Survey Misc. Inv. Map I-832.

————, 1976a, Laramide tectonics from Paradise to Hells Gate, southeastern Arizona: Ariz. Geol. Soc. Digest, v. 10, p. 151-167.

————, 1976b, Plutonic rocks of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Survey Prof. Paper 915, 75 p.

————, 1977, Geologic map and sections of the Rincon Valley quadrangle, Pima County, Arizona: U.S. Geol. Survey Misc. Inv. Map, I-997.

————, 1978, The Cordilleran orogenic belt between Nevada and Chihuahua: Geol. Soc. America Bull., v. 89, p. 641-657.

————, (in press), Tectonic map of southeastern Arizona: U.S. Geol. Survey Misc. Inv. Map I-1109.

Drewes, H., and Finnell, T. L., 1968, Mesozoic stratigraphy and Laramide tectonics of part of the Santa Rita and Empire Mountains, southeast of Tucson, Arizona: Ariz. Geol. Soc. Guidebook III, p. 315-324.

Drewes, H., and Williams, F. E., 1973, Mineral resources of the Chiricahua wilderness area, Cochise County, Arizona: U.S. Geol. Survey Bull. 1385-A, 53 p.

Eberly, L. D., and Stanley, T. B., Jr., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona: Geol. Soc. America Bull., v. 89, p. 921-940.

Enlows, H. E., 1955, Welded tuffs of Chiricahua National Monument, Arizona: Geol. Soc. America Bull., v. 66, p. 1215-1246.

Epis, R. C., 1956, Geology of the Pedregosa Mountains, Cochise County, Arizona [Ph.D. dissertation]: Berkeley, Univ. Calif., 263 p.

Erickson, R. C., 1968, Geology and geochronology of the Dos Cabezas Mountains, Cochise County, Arizona: Ariz. Geol. Soc. Guidebook III, p. 193-198.

————, 1969, Petrology and geochemistry of the Dos Cabezas Mountains, Cochise County, Arizona [Ph.D. dissertation]: Tucson, Univ. Ariz., 441 p.

Fernandez, L. A., and Enlows, H. E., 1966, Petrography of the Faraway Ranch Formation, Chiricahua National Monument, Arizona: Geol. Soc. America Bull., v. 77, p. 1017-1030.

Feth, J. H., 1947, The geology of the northern Canelo Hills, Santa Cruz County, Arizona [Ph.D. dissertation]: Tucson, Univ. Ariz., 150 p.

————, 1948, Permian stratigraphy and structure, northern Canelo Hills: Am. Assoc. Petroleum Geologists Bull., v. 32, p. 82-108.

Finnell, T. L., 1970a, Formations of the Bisbee Group, Empire Mountains quadrangle, Pima County, Arizona: U.S. Geol. Survey Bull. 1294-A, p. 28-35.

————, 1970b, Pantano Formation: U.S. Geol. Survey Bull. 1294-A, p. 35-36.

————, 1971, Preliminary geologic map of the Empire Mountains quadrangle, Pima County, Arizona: U.S. Geol. Survey Open-File Report.

Flege, R. F., 1959, Geology of the Lordsburg quadrangle, Hidalgo County: New Mexico Bur. Mines and Min. Resources Bull. 62, 36 p.

Gillerman, E., 1958, Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico and Cochise County, Arizona: New Mexico Bur. Mines and Min. Resources Bull. 57, 152 p.

————, 1968, Geology to be seen from a stop at Road Forks: Ariz. Geol. Soc. Guidebook III, p. 305-307.

Gilluly, J., 1945, Emplacement of the Uncle Sam porphyry, Tombstone, Arizona: Am. Jour. Sci., v. 243, p. 643-666.

————, 1956, General geology of central Cochise Co., Arizona: U.S. Geol. Survey Prof. Paper 281, 196 p.

Gilluly, J., Cooper, J. R., and Williams J. S., 1954, Late Paleozoic stratigraphy of central Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 266, 49 p.

Gray, R. S., 1967, Petrology of the upper Cenozoic non-marine sediments in the San Pedro Valley, Arizona: Jour. Sed. Petrology, v. 37, p. 774-789.

Graybeal, F. T., 1962, The geology and gypsum deposits of the southern Whetstone Mountains, Cochise County, Arizona [M.S. thesis]: Tucson, Univ. Ariz., 80 p.

Hawley, J. W., and Kottlowski, F. E., 1965, Road log from Lordsburg to San Simon Valley: New Mexico Geol. Soc. Guidebook, 16th Field Conf., p. 76-81.

Hayes, P. T., 1970a, Mesozoic stratigraphy of the Mule and Huachuca Mountains, Arizona: U.S. Geol. Survey Prof. Paper 658-A, 28 p.

————, 1970b, Cretaceous paleogeography of southeastern Arizona and adjacent areas: U.S. Geol. Survey Prof. Paper 658-B, 42 p.

Hayes, P. T., and Landis, E. R., 1964, Geologic map of the southern part of the Mule Mountains, Cochise County, Arizona: U.S. Geol. Survey Misc. Inv. Map I-418.

————, 1965, Paleozoic stratigraphy of the southern part of the Mule Mountains, Arizona: U.S. Geol. Survey Bull. 1201-F, p. 1-43.

Hayes, P. T., and Raup, R. B., 1968, Geologic map of the Huachuca and Mustang Mountains, southeastern Arizona: U.S. Geol. Survey Misc. Inv. Map I-509.

Haynes, C. V., 1968, Preliminary report on the late Quaternary geology of the San Pedro Valley: Ariz. Geol. Soc. Guidebook III, p. 79-96.

Hennessy, J. A., 1976, A reinterpretation of the nature of the Precambrian-Paleozoic contact in the northern Santa Rita Mountains: Tucson, Univ. Arizona Dept. Geosciences, Fourth annual Geoscience Daze, p. 14.

Hewitt, C. H., 1959, Geology and mineral deposits of the northern Big Burro Mountains-Redrock area, Grant County, New Mexico: New Mexico Bur. Mines and Min. Resources Bull. 60, 151 p.

Hoggatt, W. C., Silberman, M. L., and Todd, V. R., 1977, K-Ar ages of intrusive rocks of the central Peloncillo Mountains, Hidalgo County, New Mexico: Isochron/West, no. 19, p. 3-6.

Hoy, W. E., 1976, The Fort Bowie Story: Washington, D.C., Journal of the Council on Abandoned Military Posts, Winter, National Park Service, p. 38-47.

Jahns, R. H., 1954, Pegmatites of southern California, *in* Jahns, R. H. (ed.), Geology of southern California, Chapter VII, Mineralogy and Petrology: Calif. Div. of Mines Bull. 170, p. 46.

James, H. L., 1969, History of the United States-Mexican Boundary Survey—1848-1855: New Mexico Geol. Soc. Guidebook, 20th Field Conf., p. 40-55.

Johnson, N. M. Opdyke, N. D. and Lindsay, E. H., 1975, Magnetic polarity stratigraphy of Pliocene-Pleistocene terrestrial deposits and vertebrate faunas, San Pedro Valley, Arizona: Geol. Soc. America Bull., v. 86, p. 5-12.

Jones, R. W., 1963, Structural evolution of part of southeastern Arizona: Am. Assoc. Petroleum Geologists Mem. 2, p. 140-151.

————, 1966, Differential vertical uplift—a major factor in the structural evolution of southeast Arizona: Ariz. Geol. Soc. Digest, v. 8, p. 97-124.

Keith, Stanton B., 1973, Index of mining properties in Cochise County, Arizona: Ariz. Bur. Mines Bull. 187, 98 p.

————, 1975, Index of mining properties in Santa Cruz County, Arizona: Ariz. Bur. Mines Bull. 191, 94 p.

Keith, Stanton B., and Barrett, L. F., 1976, Tectonics of the central Dragoon Mountains: A new look: Ariz. Geol. Soc. Digest, v. 10, p. 169-204.

Keith, W. J., and Theodore, T. G., 1975, Reconnaissance geologic map of the Arivaca quadrangle, Arizona: U.S. Geol. Survey Misc. Field Studies Map MF-678.

Kelley, J. L., 1976, Geology of the Twin Buttes copper deposit, Pima County, Arizona: Amer. Inst. Min. Engineers Preprint 76-I-3, 23 p.

Kinnison, J. E., 1959, Chaotic breccias in the Tucson Mountains, Arizona: Ariz. Geol. Soc. Guidebook II, p. 48-57.
Kinnison, J. E., and Courtright, J. H., 1959, Chaotic breccias in the Tucson Mountains: Ariz. Geol. Soc. Guidebook II, p. 224-226.
Knight, L. H., Jr., 1970, Structure and mineralization of the Oro Blanco mining district, Santa Cruz County, Arizona [Ph.D. dissertation]: Tucson, Univ. Ariz., 172 p.
Lacy, W. C., 1959, Structure and ore deposits of the east Sierrita area: Ariz. Geol. Soc. Guidebook II, p. 185-192.
Lasky, S. G., 1947, Geology and ore deposits of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico: U.S. Geol. Survey Prof. Paper 208, 101 p.
Lindsay, E. H., and Tessman, N. T., 1974, Cenozoic vertebrate localities and faunas in Arizona: Jour. Arizona Acad. Science, v. 9, p. 3-24.
Livingston, D. E., 1962, Older Precambrian rocks near Salt River Canyon, central Gila County, Arizona: New Mexico Geol. Soc. Guidebook, 13th Field Conf., p. 55.
Livingston, D. E., Damon, P. E., Mauger, R. L., Bennett, R., and Laughlin, A. W., 1967, Ar^{40} in cogenetic feldspar mica mineral assemblages: Jour. Geophys. Research, v. 72, p. 1361-1375.
Livingston, D. E., Pushkar, P. D., Shakel, D. W., et al., 1970, Geochronology of the Santa Catalina Mountains *in* Correlation and chronology of ore deposits and volcanic rocks: AEC Annual Progress Report, No. C00-689-130, Contract AT (11-1)-689, p. 32-35.
Lockwood, F. C., 1938, The Apache Indians: New York, McMillan Co., 344 p.
Long, A., 1966, Late Pleistocene and Recent chronologies of playa lakes in Arizona and New Mexico [Ph.D. dissertation]: Tucson, Univ. Arizona., 141 p.
Lynch, D. W., 1966, The economic geology of the Esperanza mine and vicinity, *in* Geology of the Porphyry Copper Deposits: Tucson, Univ. Arizona Press, p. 267-279.
————, 1972, Reconnaissance geology of the Bernardino volcanic field, Cochise County, Arizona [M.S. thesis]: Tucson, Univ. Ariz., 78 p.
Marjaniemi, D., 1968, Tertiary volcanism in the northern Chiricahua Mountains, Cochise County, Arizona: Ariz. Geol. Soc. Guidebook III, p. 209-214.
————, 1969, Geologic history of an ash-flow sequence and its source area in the Basin and Range province of southeastern Arizona [Ph.D. dissertation]: Tucson, Univ. Ariz., 176 p.
Martin, P. S., 1963, Early man in Arizona—the pollen evidence: Am. Antiquity, v. 29, p. 67-73.
Marvin, R. F., Stern, T. W., Creasey, S. C., and Mehnert, H. H., 1973, Radiometric ages of igneous rocks from Pima, Santa Cruz and Cochise Counties, southeastern Arizona: U.S. Geol. Survey Bull. 1379, 27 p.
Matter, P., III, 1969, Petrochemical variations across some Arizona pegmatites and their enclosing rocks [Ph.D. dissertation]: Tucson, Univ. Ariz., 173 p.
Mauger, R. L., Damon, P. E., and Giletti, B. J., 1965, Isotopic dating of Arizona ore deposits: Soc. Mining Engineers Trans., v. 232, p. 81-87.
Mayo, E. B., 1968, A history of geologic investigations in the Tucson Mountains, Pima County, Arizona: Ariz. Geol. Soc. Guidebook III, p. 155-170.
McCool, G., 1967, Sunday Trails in old Cochise: Tombstone, Ariz., Tombstone Epitaph, 107 p.
McCullough, E. J., Jr., 1963, A structural study of the Pusch Ridge-Romero Canyon area, Santa Catalina Mountains, Arizona [Ph.D. dissertation]: Tucson, Univ. Ariz., 67 p.
Meinzer, O. E and Kelton, R. C., 1913, Geology of water resources of Sulphur Springs Valley, Arizona: U.S. Geol. Survey Water-Supply Paper 320, 231 p.
Melton, M. A., 1960, Origin of the drainage of southeastern Arizona: Ariz. Geol. Soc. Digest, v. 3, p. 113-122.
————, 1965a, The geomorphic and paleoclimatic significance of alluvial deposits in southern Arizona: Jour. Geol., v. 73, p. 1-38.
————, 1965b, Debris-covered hill slopes of the southern Arizona desert—consideration of their stability and sediment contribution: Jour. Geol., v. 73, p. 715-729.
Miller, H. W., 1964, Cretaceous dinosaurian remains from southern Arizona: Jour. Paleontology, v. 38, p. 378-384.
Moore, B. N., Tolman, C. F., Butler, B. S., and Kernon, R. M., 1941, Geology of the Tucson quadrangle, Arizona: U.S. Geol. Survey Open-File Report, 20 p.
Moore, Y. (ed.), 1958, The Overland Butterfield Mail across Arizona: Tucson, Arizona Pioneer's Historical Society, 32 p.
Morrison, R. B., 1965, Geologic map of the Duncan and Canador Peak quadrangles, Arizona and New Mexico: U.S. Geol. Survey Misc. Inv. Map I-442,
Mulligan, R. A., 1965, Apache Pass and Old Fort Bowie: Tucson, Ariz., The Smoke Signal, n. 11, Spring, The Westerners, 24 p.
Nelson, F. J., 1968, Volcanic stratigraphy and structure of the Pena Blanca and Walker Canyon areas: Ariz. Geol. Soc. Guidebook III, p. 171-182.
Nevin, A. E., 1971, Normal faulting in the Dragoon Pass area, Cochise County, Arizona: Ariz. Geol. Soc. Digest, v. 9, p. 189-195.
Newell, R. A., 1974, Exploration geology and geochemistry of the Tombstone-Charleston area, Cochise County, Arizona [Ph.D. dissertation]: Stanford, Calif., Stanford Univ., 205 p.
Obradovich, J. D., and Cobban, W. A., 1975, A time-scale for the Late Cretaceous of the western interior of North America: Geol. Assoc. Canada, Spec. Paper 13, p. 33-54.
Pashley, E. F., 1966, Structure and stratigraphy of the central, northern and eastern parts of the Tucson basin, Pima County, Arizona [Ph.D. dissertation]: Tucson, Univ. Ariz., 273 p.
Patch, S., 1969, Petrology and stratigraphy of the Epitaph Dolomite (Permian) in the Tombstone Hills Cochise County, Arizona [M.S. thesis]: Tucson, Univ. Ariz., 42 p.
Percious, J. K., 1968, Geology and geochronology of the Del Bac Hills: Ariz. Geol. Soc. Guidebook III, p. 199-207.
Peterson, R. C., 1968, A structural study of the east end of the Catalina forerange, Pima County, Arizona [Ph.D. dissertation]: Tucson, Univ. Ariz., 105 p.
Phillips, M.S., 1976, Geology of Tumamoc Hill, Sentinel Peak and vicinity, Pima County, Arizona [M.S. thesis]: Tucson, Univ. Ariz., 83 p.
Peirce, F. L., 1958, Structure and petrography of part of the Santa Catalina Mountains [Ph.D. dissertation]: Tucson, Univ. Ariz., 86 p.
Peirce, H. W., Keith, S. B., and Wilt, J. C., 1970, Coal, oil, natural gas, helium, and uranium in Arizona: Ariz. Bur. Mines Bull. 182, 289 p.
Peirce, H. W., and Scurlock, J. R., 1972, Arizona well information: Ariz. Bur. Mines Bull. 185, 195 p.
Pumpelly, R., 1870, Across America and Asia: New York, Leypoldt and Holt, 454 p.
————, 1918, My reminiscences: New York, H. Holt, 2 v., 844 p.
Ransome, F. L., 1904, Geology and ore deposits of the Bisbee quadrangle, Arizona: U.S. Geol. Survey Prof. Paper 21, 167 p.
————, 1920, Deposits of manganese ore in Arizona; Bisbee and Tombstone districts: U.S. Geol. Survey Bull. 710, p. 96-119.
Raydon, G. T., 1952, Geology of the northeastern Chiricahua Mountains, Arizona [M.A. thesis]: Berkeley, Univ. Calif., 138 p.
Reeder, H. O., 1957, Groundwater in Animas Valley, Hidalgo County, New Mexico: U.S. Geol. Survey Technical Report 11, 101 p.
Ross, C. A., 1973, Pennsylvanian and Early Permian depositional history, southeastern Arizona: Am. Assoc. Petroleum Geologists Bull., v. 57, p. 887-912.
Sabins, F. F., 1957a, Stratigraphic relations in Chiricahua and Dos Cabezas Mountains, Arizona: Am. Assoc. Petroleum Geologists Bull., v. 41, p. 466-510.
————, 1957b, Geology of the Cochise Head and western part of Vanar quadrangles, Arizona: Geol. Soc. America Bull., v. 68, p. 1315-1342.
————, 1965, Road log from San Simon Valley to Blue Mountain: New Mexico Geol. Soc. Guidebook, 16th Field Conf., p. 81-84.
Sabins, F. F.,and Ross, C. A., 1963, Late Pennsylvanian, Early Permian fusulinids from southeastern Arizona: Jour. Paleontology, v. 37, p. 323-365.
————, 1966, Stratigraphy and fusulinids of Naco Group in Chiricahua and Dos Cabezas Mountains, Arizona: New Mexico Geol. Soc. Guidebook, 16th Field Conf., p. 148-157.
Scarborough, R. B., 1975, Chemistry and age of late Cenozoic air-fall ashes in southeastern Arizona [M.S. thesis]: Tucson, Univ. Ariz., 107 p.
Schreiber, J. F., Jr., Pine, G. L., Pipkin, B. W., Robinson, R. C., and Wilt, J. C., 1972, Sedimentologic studies in the Willcox Playa area, Cochise County, Arizona, *in* Playa Lake Symposium, Reeves, C. C., Jr. (ed.): Internat. Center for Arid and Semi-arid Land Studies Publ. 4, p. 133-184.
Schumacher, D., Witter, D. P., Meader, S. J., and Keith, S. B., 1976, Late Devonian tectonism in southeastern Arizona: Ariz. Geol. Soc. Digest, v. 10, p. 59-70.
Schwennesen, A. T., 1918, Ground water in the Animas, Playas, Ha-

* chita, and San Luis basins, Arizona and New Mexico: U.S. Geol. Survey Water-Supply Paper 422, 152 p.

Shakel, D. W., 1974, The geology of layered gneisses in part of the Santa Catalina forerange, Pima County, Arizona [M.S. thesis]: Tucson, Univ. Ariz., 233 p.

Shakel, D. W., Livingston, D. E., and Pushkar, P. D., 1972, Geochronology of crystalline rocks in the Santa Catalina Mountains, near Tucson, Arizona. A progress report [abs.]: Geol. Soc. America, Abs. with Programs, v. 4, p. 408.

Shakel, D. W., Silver, L. T., and Damon, P. E., 1977, Observations on the history of the gneissic core complex, Santa Catalina Mountains, southern Arizona [abs.]: Geol. Soc. America, Abs. with Programs, v. 9, p. 1169-70.

Silver, L. T., and Deutsch, S., 1963, Uranium-lead isotopic variations in zircons—A case study: Jour. Geology, v. 71, p. 721-758.

Simons, F. S., 1972, Mesozoic stratigraphy of the Patagonia Mountains and adjoining areas, Santa Cruz Co., Arizona: U.S. Geol. Survey Prof. Paper 658-E, 23 p.

————, 1974, Geologic map and sections of the Nogales and Lochiel quadrangles, Santa Cruz County, Arizona: U.S. Geol. Survey Misc. Inv. Map I-762.

Smith, R. L., 1960, Ash flows: Geol. Soc. America Bull., v. 71, p. 795-842.

Steiger, R. H. and Jäger, E., 1977, Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology: Earth and Planet. Sci. Letters, v. 36, p. 359-362.

Strangway, D. W., Simpson, J., and York, D., 1976, Paleomagnetic studies of volcanic rocks from Mogollon Plateau area of Arizona and New Mexico: New Mexico Geol. Soc. Spec. Pub. 5, p. 119-124.

Sueminicht, G. A., 1977, The geology of the Canada del Oro headwaters, Santa Catalina Mountains, Arizona [M.S. thesis]: Tucson, Univ. Ariz., 108 p.

Swan, M. M., 1976, The Stockton Pass fault—An element of the Texas lineament [M.S. thesis]: Tucson, Univ. Ariz., 119 p.

Taliaferro, N. L., 1933, An occurrence of Upper Cretaceous sediments in northern Sonora, Mexico: Jour. Geol., v. 41, p. 12-37.

Thoms, J. A., 1966, The geology and ore deposits of the Tascuela area, Sierrita Mountains, Pima County, Arizona [Ph.D. dissertation]: Ann Arbor, Univ. Michigan, 179 p.

Thorman, C. H., and Drewes, H., 1979, Geologic map of the Gary and Lordsburg quadrangles: U.S. Geol. Survey Map (in press).

Thrapp, D. L., 1967, The Conquest of Apacheria: Norman, Univ. Oklahoma Press, 384 p.

————, 1978, Cochise: Arizona Highways, vol. 54, no. 10, p. 38-46.

Titley, S. R., 1959, Igneous rocks of the Basin and Range province in Arizona: Ariz. Geol. Soc. Guidebook II, p. 85-88.

————, 1976, Evidence for a Mesozoic linear tectonic pattern in southeastern Arizona: Ariz. Geol. Soc. Digest, v. 10, p. 71-101.

Todd, V. R., Silberman, M. L., and Armstrong, A. K., 1975, Geochemistry, petrology, and K-Ar ages of igneous rocks in the central Peloncillo Mountains, Hidalgo County, New Mexico [abs.]: New Mexico Geol. Soc. Guidebook, 26th Field Conf., p. 343-344.

Tyrrell, W. W., 1957, Geology of the Whetstone Mountain area, Cochise and Pima Counties, Arizona [Ph.D. dissertation]: New Haven, Yale Univ., 171 p.

Utley, R. M., 1958, Historical Report on Fort Bowie, Arizona [unpublished manuscript]: Santa Fe, N.M., National Park Service.

————, 1977, A Clash of Cultures: Washington, D.C., National Park Service, 88 p.

Vice, K. H., 1974, The geology and petrography of the Babocomari Ranch area, Santa Cruz-Cochise Counties [M.S. thesis]: Tempe, Ariz. State Univ, 152 p.

Waag, C. J., 1968, Structural geology of the Mt. Bigelow-Bear Wallow-Mt. Lemmon area, Santa Catalina Mountains Arizona [Ph.D. dissertation]: Tucson, Univ. Ariz., 133 p.

Wallace, A. 1971, The Image of Arizona: Albuquerque, Univ. New Mexico Press, 224 p.

Wilson, E. D., 1939, Pre-Cambrian Mazatzal revolution in central Arizona: Geol. Soc. America Bull., v. 50, p. 1113-1164.

Wilt, J. C., 1969, Petrology and stratigraphy of the Colina Limestone (Permian) in Cochise County, Arizona [M.S. thesis]: Tucson, Univ. Ariz., 117 p.

Wright, C. C., 1978, Folds in a mylonite schist east of Loop Drive in the Saguaro National Monument area, Tucson, Arizona [Senior thesis]: Northfield, Minn., Carleton College, 30 p.

Wright, L. H. and Bymum, J. M. (eds.), 1942, The Butterfield Overland mail: San Marino, Calif., The Huntington Library, 172 p.

Wrucke, C. T., and Bromfield, C. S., 1961, Reconnaissance geologic map of part of the southern Peloncillo Mountains, Hidalgo County, New Mexico: U.S. Geol. Survey Min. Inv. Field Stud. Map, MF-160.

Young, O. E., 1955, The west of Philip St. George Cooke: Glendale, Calif., Arthur Clark Co., 393 p.

Zeller, R. A., 1965, Stratigraphy of the Big Hatchet Mountain area, New Mexico: New Mexico Bur. Mines and Min. Resources Mem. 16, 128 p.

*Scott, R.W., 1979, Depositional model of Early Cretaceous coral-algal-rudist reefs, Arizona: Amer. Assoc. Petroleum Geologists Bull., v. 63, p. 1108-1127.