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VISIT TO AJO PIT APRIL 10, 1952

ON GSA TRIP WITH VELASCO, GARMOE,

HUMPHREY. ABOUT TWO HOURS IN PIT.

Since the visit in 1945, the Ajo pit has been widened toward the east, as suggested it might be by Mr. Barker, and the pit is markedly different in appearance from that time. On the west side, additional stripping is going on along Arkansas Mt., and it is rumored that a cut behind the Mt. has been started which would suggest that the whole high area on the south west side of the pit will be removed. Native copper and some enriched and oxidized material from this part of the pit are still reported. No stop was made there, and this part of the pit was only observed from the public lookout point.

The widening of the pit to the east has proceeded into the volcanics, and has exposed considerable of the so-called "chilled border phase" of the monzonite intrusive. It seems more likely that there are numerous dikes of fine to coarse grained dark rocks -"diorite"-present along the general contact zone between the monzonite and the light colored volcanic rocks. The monzonite definitely engulfs fragments of the volcanic rocks along this contact zone, and a "rock breccia" area similar to those at Cananea is indicated. In this part of the pit there are pyrite seams with some development of sericite, and in general in the parts of the pit visited there is much less fresh monzonite that was in evidence in 1945. Even in the lower south part of the pit where "pegmatitic" mineralization was reported prominent, little strong mineralization was seen, and there was little fresh chalcopyrite with fresh feldspars. While the same conditions as observed in the south part of the pit in 1945 still exist - namely, frsh chalcopyrite, etc. against pearly pink orthoclase, it is probable that the extent of such mineralization now exposed is much less than previously. In the areas visited, while there is no extensive development of sericite, the feldspars observed do not have the same degree of freshness expected from the earlier visit. In general, while the earlier visit suggested that very little alteration was exhibited by the Ajo deposit, the impression now gained is that there is considerable alteration on both the east and west sides of the pit, and that sericitic alteration is not such a stranger in this deposit as previously believed.

Approximately 60,000 tons per day are being mined, something more than one half of this being waste. It is likely that about 27,000-28,000 tons of ore are going to the concentrator. About 12,000,000 pounds of copper per month are being made in the new smelter, and most are being cast into anodes. for shipment to El Paso.

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June 15, 1945

Dear Mr. Mulchay:

Finally finished your report and Mr. Cameron was good enough to check same for me yesterday aft.

Miss La Borde delivered the book and I'm thrilled with it. I've been reading it religiously on the train and subway - to the point where I snub me friends unintentionally. Thanks so very much.

The weather is dreadful - weatherman threatens us with 93° today.

E. M. Beetz

P.S. Sent Mr. Stephens' copy to Mr. Perry and asked him to hold it.

# ANACONDA COPPER MINING COMPANY

25 Broadway

New York 4, N.Y.

OFFICE OF VICE PRESIDENT
IN CHARGE OF MINING OPERATIONS

June 12, 1945

Mr. R. H. Sales, Chief Geologist
Anaconda Copper Mining Company
526 Hennessy Building
Butte, Montana

Dear Mr. Sales:

Enclosed is a summary of general notes which Stephens and I made on our trip through the Southwest porphyry copper deposits May 15th to 22nd. Our time at each property was very limited, and some of the observations may not be completely accurate. Relations of outcrops to underlying copper mineralization, which was our chief interest, were in most cases obscure as mining operations have largely removed the oxidized outcrops immediately above the orebodies. However, in a general way darker, maroon colored outcrops were generally seen around or over oreshoots, and lighter, brighter reds in the outcrops were not indicative of better copper mineralization below surface. These colors, of course, have developed under the special conditions of Southwest climate, and might have little value as criteria under differing conditions.

In addition to the outcrops, we were most interested in the general geology of the various areas visited. As all of our guides at the properties were primarily interested in operation, we obtained a good deal of operating type information which may be of general interest.

Throughout our trip we were treated with the greatest courtesy and both Stephens and I were most impressed with the large amount of information which was made available for us in a casual way at Ajo, Inspiration, Castle Dome, Morenci and Santa Rita. In all cases we were permitted to visit any part of the operation in which we showed interest, and we are most appreciative of the opportunity to make the trip as representatives of Anaconda's geological staff. We received outstanding good treatment.

Yours very truly,

Roland B. Mulchay

RBM:B

Roland B. Mulchay

CC: Mr. C. E. Weed
Mr. V. D. Perry
Mr. Albert Mendelsohn
Mr. E. C. Stephens

File

AJO, ARIZONA

Phelps Dodge Corporation, New Cornelia Branch

The Ajo operation was visited on the afternoon of May 15th and the morning of May 16th with Mr. Barr, Chief Engineer and Mr. Bronson, Assistant Mine Foreman. The operation was also discussed with Mr. Barker, Manager, and Mr. Angst, Mine Superintendent.

At Ajo the open pit is approximately 4000' long by 2000' wide and extends in a general northwest-southeast direction. Elevation of the top of the pit is about 1750' above sea level, and the new bottom level will be at 1500'. The new lower cut has reached about 1520' elevation. Most of the present mining is being done on the 1540' and 1580' benches. Higher ground, above the general level of the top of the pit, occurs on the southwest side of the pit at the Arkansas Mt. area, and with lower hills on the southeast and east. Mineralization observed was in a granitic porphyry, called monzonite porphyry, which intrudes finer grained, gray to white rhyolites, reported to be flows. Areas in the monzonite, generally close to contacts, are much finer grained and darker colored than the average of the intrusive, and are locally called diorite. It is probable that this rock is a phase of the main intrusive rather than a separate rock type. On the southeast end of the pit, well consolidated angular, poorly sorted material, locally called "fanglomerate", overlies both rhyolites and monzonite. Contacts of this material with the underlying rocks are in cases irregular and probably normal contacts of a wash deposit laid down on an uneven erosion surface, and are in part fault contacts. Although this material is very angular and poorly sorted, and includes rock fragments, near the pit, which contain oxidized copper mineralization, banding in this formation strikes northeasterly and dips to the southeast at angles up to 60°. It is probably water lain, and later than the ore deposition. The extent of the fanglomerate to the southeast is probably less than the area mapped by Gilluly of the U.S.G.S., although there are widespread prominent outcrops to the south and southwest. Immediately southeast of the pit and the large outcrops of fanglomerate, there are areas covered with recent wash and it appears likely that some of this material covers rhyolite or monzonite rather than fanglomerate.

Most of the orebody now being mined is in monzonite which is characterized by a lack of sericite-kaolin type alteration generally associated with the large copper districts in the Southwest. While local areas of kaolinization and sericitization were observed, the feldspar and ferromagnesian minerals in the monzonite are remarkably fresh and the rock is generally hard and tough. Large orthoclase crystals and splotchy quartz in monzonite, locally called pegmatitic, occur in several parts of the pit, and are often found in areas in which better ore occurs. The orthoclase is commonly pink, and apparently breaks down less readily than plagioclase. The rock in the southeast end of the pit on the 1580 and 1540 benches is comparatively hard. Better ore occurences, both chalcocite and primary sulphides, are reported in this area. On the southwest side of the pit, at Arkansas Mt., alteration is much more intense than in other parts of the pit, considerable kaolin and sericite have been developed in both rhyolite and monzonite. On the southeast side of Arkansas Mt. in the pit a block of fanglomerate has been dropped down against rhyolite along a steep-dipping fault. Immediately northwest of this fault contact, some areas in the rhyolite appear to be brecciated. However no detail could be observed and it is possible that this broken material may not represent actual brecciation. On lower benches in this Arkansas Mt. area, pyrite is reported to occur in considerable quantity, although it is not prominent in other parts of the pit. Below some comparatively deep oxidation in this area, native copper has been mined. During the week previous to our visit a total of 20,000 tons, which contained enough native copper to be classed as ore, was mined and delivered to the mill. This material was separately treated in the concentrator, and according to Mr. Barker excellent recovery was obtained.

Mineralization in the pit is composed of chalcopyrite, pyrite, bornite, chalcocite, some tennantite, some hematite and specularite, quartz, and molybdenite is reported. These minerals occur almost entirely in disseminations and narrow seams but large specimens, 18" x 30", of massive primary sulphide containing tennantite, chalcopyrite and quartz were seen at the mine office. This mineralization is reported to occur in lensy vein-like form in the southeast end of the pit. Stringers of high grade chalcocite, dark shiny gray in color, are also found at the southeast end of the pit below the oxidized area.

Looking at the southeast end of the pit from the northwest, oxidation extends downward to the 1580 bench through fanglomerate, rhyolite, and monzonite rock types. The color of this material through all three rock types is remarkably a uniform dark maroon red with no great variations. The oxidation at the 1580 bench is limited by a rather steep fault, but at higher elevations, both to the east and west, oxidation extends outward on either side of this structure without evident close structural control, except where there are definite small faults. Sections shown us by Mr. Barker indicated the ore mineralization extends to the southeast, and dips rather abruptly southeasterly below the end of the pit. It is generally believed that this dip to the southeast has been caused by oxidation and consequent secondary enrichment below the erosion surface upon which the fanglomerate was deposited. Inasmuch as we were not informed about the kind of mineralization found in the holes, no assumptions about the downward continuation of the mineralization could be made. However, the sections show a considerable downward extension of mineralization which is classed as ore -plus or minus 1.0% copper- and at least some of this material will be too deep for pit mining. As higher grade, primary ore specimens seen have been encountered in the southeast end of the pit, and are reported to have been found on successive benches, it is not unlikely that a better area of original primary mineralization may have been localized near the present southeast end of the pit. No structural evidence of such a channel way in this area could be seen in the bench faces exposed at the time of our visit. More intense alteration along the southwest side of the pit in the Arkansas Mt. area probably indicates relatively strong mineralizing activity.

Oxidized copper mineralization is exposed in the sides of the pit on the northwest end and on the east side, and according to Mr. Angst, 0.8% copper mineralization extends northwesterly toward the present mine offices. Mr. Barker believes that ore extensions to the east and east-southeast are a distinct possibility, and plans some prospecting in this area at a later date. Rocks in the northwest end and on the east side of the pit are well fractured and locally are crackled enough to appear weakly brecciated. The monzonite porphyry intrusive at Ajo is reported to have a flat extension, and in part at least to have rhyolite beneath it. It may be possible that this so-called flat form may be an outward flare of the intrusive near surface such as found in the northerly part of the 8-110 quartz porphyry, at Cananea.

In a general way, all the outcrops which were observed at Ajo contained generally darker reds and maroons than those seen at other Southwest properties. Oxidized copper outcrops have relatively little iron staining associated with them. On the southwest side of the pit at Arkansas Mt. there are some areas of lighter red coloration which might be related to the larger amount of pyrite reported in the vicinity. The remarkably uniform coloration which extends through the southeast end of the pit in fanglomerate, rhyolite and monzonite is entirely a dark red to maroon color, and probably corresponds to the Southwest "purple" color discussed in the past.

Mining is done on 40' benches, and a 1:1 pit slope is maintained. At present, the waste to ore ratio is about 1:1. The pit will be carried to the 1100 elevation, and in some areas to the 1000 elevation under present plans. Ore and waste are loaded by 4-1/2 yd. Marion electric shovels into 30 yd. side dump axle-less railroad cars which hold approximately 63 tons. These are hauled up 2% grades by steam locomotives at approximately 15 miles per hour. Maximum haul at present is about 8 miles to concentrator bins. For blasting, 43' churn drill holes are drilled, large cartridges of gelatin dynamite are loaded from a small tripod with spring winding arrangement, and detonated with primacord. At present 8 shovel shifts are working, two churn drill shifts are needed per shovel shift. Approximate production per man shift is 110 tons. During the week of May 14th mining was at the rate of 15,000 tons per day, which was to be increased to 18,000 tons by the week of May 21st; capacity of concentrator is 25,000 tons.

For sampling, first 40' of blast holes are sampled by running all of material through splitter on drill, with one sample caught in galvanized wash tub. This sample is set aside by the driller, and later run through a spitter by a sampling crew who visit all churn drill rigs. Sample is split until material of approximately ten pounds (dry weight) remains which is put into a two to three gallon wide mouth sample can. Sampling crew transports sample to sample mill where material is crushed further before additional spitting is done. This crushing has been done both before or after drying of sample. Assay averages of blast hole drilling are reported to check within 0.02% copper with mill head results. Mine grade is currently that much high though in past it has run 0.02% Cu. low. All drilling done for special sample information is sampled at five foot intervals.

INSPIRATION-MIAMI

The Inspiration-Miami surface was briefly visited the afternoon of May 17th. Few outcrops over known orebodies can still be seen as the surface is caved and coloration on the caved ground is much more apparent than the original surface colors. Outcrop specimens in the schist areas above older parts of the mine toward Miami ground contain abundant quartz, and there is a distinctly browner coloration than is observed in other localities. Easterly toward the Miami ground the caved areas show varying shades of red, some rather brilliantly colored, but all generally grading toward a maroon to brick red color. A few outcrops east of the Capitan orebody toward the Miami fault area appear to have a brownish rust-red coloration. In general, the colors are more brilliant than the Ajo maroons and there is wide variation in the shading which may have been caused by varying oxidation processes on the numerous fault blocks in the Inspiration-Miami orebody. In the Sulphide tunnel area, oxidized copper mineralization which occurs nearly at surface and in the faces of relatively recent cuts, contains little iron oxide staining.

The amount of quartz present in the schist in the easterly part of the Inspiration outcrop is especially notable in comparison with other disseminated deposits seen, but this may be due at least in part to the rock type. Locally unmineralized sections of schist contain abundant quartz, and part of the quartz seen in and over the orebody may not be closely related to the mineralization.

CASTLE DOME

The Castle Dome property was briefly visited on the morning of May 18th for about two hours. Compared with other open pits visited, the operation is relatively small. Mining is proceeding on benches around Castle Dome Mt. in low grade material. The ore minerals are chiefly chalcocite with pyrite, quartz, little chalcopyrite and very little molybdenite in a coarse grained granitic rock, locally called the Ruin Granite. Outcrops are generally reddish to dark brickish red, with considerable variation and no large extent. Oxidation, as shown in the face of the pit, extends downward in a wedge shape along a prominent, though possibly not strong, fault structure. The coloration on the face of the pit is a reddish brown. There are at least two rather flat dipping, dark colored diabase dikes cutting through the main rock mass, and better chalcocite enrichment is reported close to these structures. Ore and waste are handled in trucks; approximately 12,000 tons per day are being mined. Concentrates are running about 38% copper with a tail below 0.1% copper and heads slightly less than 0.8% copper. Concentrates are hauled to the west end of Miami in trailer trucks and treated at the International Smelter.

MORENCI - Phelps Dodge Corporation, Morenci Branch

The Morenci Pit was visited on May 19th and part of May 20th was spent on the Humbolt area and at Metcalf.

The Morenci Pit is operating on 17 benches of 50' height with the lowest bench at 4600' elevation; the pit will reach to the 4200' elevation under present plans.

Outcrops near the top of the present pit, which may not directly overlay ore, show darker red to maroon colors in generally reddish-brown areas. Darker colors are often associated with small stringer veins. On the 4600 bench where sulphide mineralization came very close to surface, oxidation coloration is not intense and is brownish-red, rather than maroon. However the exposures seen were small and may not indicate coloration over very large areas. Along small veins in this area on the 4600 bench there is strong, dark red iron oxide which probably overlies chalcocite enrichment as chalcocite seams and disseminations are found nearby. Over the Humboldt area, the coloration appears reddish-brown to red with some darker maroon reds generally along small mineralized structures.

Rocks in the main Morenci pit are closely similar to intrusive porphyries at Cananea. On the 5150 bench from north to south the bench shows a siliceous quartz porphyry with sericite and little kaolin which resembles many of the mineralized quartz porphyry intrusives at Cananea. Near the center of the bench there is a 40' band of softened white feldspathic porphyry, and immediately to the south of this an area plus 200' wide contains garnetized limestone and quartzite fragments and feldspathic porphyry. Through this breccia there is some irregular iron oxide mineralization with little copper staining. On the southerly edge of the breccia there is 10' of strong iron oxide mineralization with quartz and some copper oxide staining which cements rock fragments. From a distance this breccia area appears to strike northwest and southeast. Immediately south of the breccia area there is a large section of feldspathic quartz porphyry with some mixed copper oxide and sulphide mineralization. Near the southerly end of the bench where surface wash is encountered, large quartzite blocks are found engulfed in the porphyry with very little weak iron oxide mineralization. The prominent breccia area in the center of the bench is reported to have been partly prospected in workings of the old Esperanza Mine. The extent of this underground exploration was not explained by our guide. Strength of gossan mineralization observed on the south side of the breccia strongly suggests a mineralized structure in this area with possibilities for primary ore.

The Humbolt area contains a definite rock breccia in which locally fragments of limestone and quartzite are caught in a large porphyry intrusive. This porphyry has varying textures or may be made up of varying intrusives of about the same chemical composition. Large tonnages have been mined in the Humbolt area by underground mining methods and it is likely that low grade mineralization extends from this area into the main open pit area to the northwest. The easterly boundary of the Humboldt area is along a series of overlapping intersecting fractures which give a generally curving shape to the northerly end of the caved area on the east side. No evidence of a sharply defined primary mineralization channelway was observed, although the widespread low grade mineralization in this area appears to be definitely associated with a rock breccia structure.

At Metcalf, no close observation of the old mines was attempted. From a distance the outcrops on the crests of the steep slopes are generally very dark maroon color and some areas probably contain prominent manganese. From general observation at Cananea and Morenci, it appears that limestone deposits often give darker colored gossan outcrops than mineralized porphyry deposits. On the Coronado Trail highway, west of the old Shannon and Metcalf ore deposits and north of the present settlement at Metcalf, there is a large mineralized breccia outcrop which may be up to 1000' in length and from 400' to 500' wide. (larger! RBM 1950) This breccia structure was previously noted by Perry. Parts of the breccia contain copper stain, and rock fragments are locally cemented by ragged, vuggy quartz and iron oxide. The northerly part of this breccia, north of a steep dipping fault, contains little mineralization. There is no surface evidence that there has been exploration of this structure by underground work or surface drilling, and its location in a well mineralized area which has a considerable production record makes the structure worthy of exploration in hopes of discovery of a copper orebody of considerable size. (min generally weak at surface RBM 1950)

Generally speaking, the entire Morenci district closely resembles Cananea as regards rock types and alteration features. The feldspathic porphyry seen in the open pit and at the Humboldt is very similar to the porphyry in which the Cananea 6-139 orebody is being developed in the 8-110 porphyry area. The more siliceous porphyry, which makes up a large part of the east and northerly parts of the Morenci pit, closely resembles many of the Cananea quartz porphyries. Limestone alteration with widespread garnet and epidote is like the alteration in upper limestones at Cananea, although locally there is more epidote in the altered limestones at Morenci than at Cananea. Structurally there are many more veins and fault structures reported at Morenci than have been observed at Cananea. However, the presence of rock breccia structures and mineralized breccia pipes at Morenci lead to the belief that there are likely to be primary ore deposits in this district which have not yet been encountered.

As at Ajo, ore and waste are handled by Marion shovels and 26 electric-battery-trolley locomotives and Diesel locomotives provide motive power for the extensive railraod system. On upper benches some truck haulage is used for waste removal. Material is loaded into 85-90 ton side-dump railroad cars and hauled on a maximum 4% down-grade away from the pit. 90 pound rails are used on benches and 130 pound rails on the main line tracks. Production now shows better than 103 tons per man shift over all. Copper grade is reported slightly over 1.0% copper; 33,000 tons of ore are being milled daily. The plant is run continuously for twelve days with a two-day shutdown at the end of each second week. Sampling procedure is similar to Ajo practice where a large part of the open pit operating staff previously worked. Blast holes are drilled five to eight feet below the bench level. The rock is generally softer than at Ajo, probably slightly harder than at Castle Dome, and harder than Chino. It appears to break somewhat like Cananea open pit mineralization.

SANTA RITA - New Mexico Chino Mines Division, Nevada Consolidated Copper Company

The operation at Santa Rita was visited for the full day of May 21st with Mr. Morris, the Chief Engineer.

The Chino pit is the largest of those seen and in the present operating pit there is an exposed length of approximately 5000'. Outcrops over known ore are almost entirely gone, but the sides of the pit toward the south, where the pit will be extended, show varying shades of red, generally lighter shades. However, to the east where the upper part of the pit has been opened for over 20 years, darker red to maroon colors predominate. A brief trip over parts of the old waste dump, which contains surface material from directly over the main part of the pit, showed fairly dark reds to brickish shades on older surfaces. Prospect drilling to the east and northeast of the present pit has shown some ore. Mineralization at surface directly over this section is weak, and the color of the oxides is a rusty reddish-brown; the porphyry and volcanic rocks between seams and stronger disseminated mineralized areas is a lightly stained brownish color. While this coloration may not represent areas with mineralization as strong as in the main mineralized area, a thickness of 400' of ore is reported in one hole. The surface in this new area is not impressive. Exploration is being continued in this direction, apparently with some success and an extension easterly below recent volcanics may be found.

The Chino pit is in igneous rocks called grano-diorite by the operators and the USGS. There are local wide variations in textures, and to some extent in composition. It appears likely that there are differing ages of intrusives of approximately the same composition. In the northerly end of the old pit, now inactive, two definite ages of intrusive rocks were observed, a narrow dike cutting through a larger mass of granodiorite which in turn was intruded into highly altered and mineralized sedimentaries with pyritic mineralization. In the pit there are granodiorite "dikes" which contain little mineralization and may even be post-mineral.

In the northeast part of the lowest bench of the present pit, better mineralization is found over a 200' area. Numerous seams of molybdenite were observed and seams of massive dark gray chalcocite are common. To the west of this area in the side of the pit there is a large block of highly altered sediments (Abo shales). Near the granodiorite-Abo contact there is a rock breccia in which a porphyry engulfs quartzy rock fragments. Whether this quartzy rock is a mineralization feature or an actual rock type was not determined. About 25' to the east, stringers of similar silica or quartz appear to cut through porphyritic rock in small veinlets. A diamond drill hole drilled to 1700' below surface just to the north of this area contained native copper at the bottom and some sections of good chalcocite ore. Another hole drilled close to this area to 550' below the pit bottom to check the 1700' hole showed spotty chalcocite mineralization, and one section of 20' which averaged 20.0% copper. Through this section the drill may have followed a chalcocite stringer and have been thereby salted. The pit contains some sections of definite quartz porphyry and feldspathic quartz porphyry but these are considered as local variations in the mass of the granodiorite by the operators. No definite contacts with the granodiorite were observed, so this conclusion may be justified. The ore has many more seams of pyrite and chalcocite than observed in other pits; some of the chalcocite is massive and has a steely, gray color. Faulting does not appear to be prominent although some small faults were observed. There are numerous rather closely spaced northeast shears which allow the rock to break up well when blasted. These shears extend northeast of the higher grade portion of the mineralization described above, and prospecting along the general trend of the zone away from the better grade section has led to the discovery of the mineralization now being drilled northerly and easterly from the pit. On the 6100 bench on the south side of the pit, good chalcocite ore is being mined which probably will extend southerly toward a deposit of low grade mineralization which was partly developed for underground mining in the late 1920's. Mr. Goodrich, Mine Superintendent, believes that part of this orebody can now be mined by open pit methods and that a further extension to the south and west may be developed. From the character of the ground in the pit, it appears that this ore should cave readily.

Approximately two miles northwest of the pit underground work is now developing a considerable body of zinc ore. Extensive bodies of sphalerite ore in a gangue of garnet and hedenbergite occur near a granodiorite dike which cuts across rather flat bedded limestones and which is paralleled by steep, northeast fault structures. Two oreshoots have been partly developed. The easterly one, which is the largest, occurs as a mass whose east boundary is the granodiorite and extends out into the limestone for a width of plus 50' over a vertical height of approximately 150'. The orebody has been explored by crosscuts and diamond drill holes for approximately 1000'. The second body, lying west of the shaft, is much smaller and on a separate structure, but has not been fully explored. Both structures might have considerable extensions. Zinc oreshoots recently developed by the U. S. Smelting Company and in the older mines of the Santa Rita-Hannover District on several different structures make it appear that there are excellent chances for the development of other mines in the district, both in and along granodiorite sills and dikes, and in limestones. Production from the Kennecott zinc orebody will be delayed until it has been more completely developed.

The Chino pit rim is at an approximate elevation of 6300' and the present bottom is at 5900'. Extensions to east and south will prolong pit life if development is successful. The pit will be extended to the south and deepened in part for 100' more. At present approximately 20,000 tons of ore are being mined and 17,000 tons of waste. The ore is hauled in 50-ton AT&SF railroad cars by electric locomotives up 2% grades and hauled from Santa Rita to Hurley by the AT&SF. Waste is hauled in company cars to the waste dump where an extensive leaching process is in progress and a considerable production of cement copper is made. Sampling is entirely by grab sampling on the blasted ore piles in contrast to sampling methods at the other pits. 200-pound samples are taken from 30' lateral sections; about 3 samples are obtained from each of these sections as three shovel cuts across the ~~order~~ ore are generally needed to muck an entire blast. Mine grade against mill head assays are reported to check within 0.02% copper.

The leaching operation at Chino has assumed increased importance in recent years and it is reported that as much as 20% of the total copper production is from leachings of the old waste dumps. Possibilities for similar leaching on old waste dumps at other properties is worthy of careful consideration to increase ultimate over-all copper production of low grade orebodies.

Mr. R. B. Mulcahy
c/o Chile Exploration Co.
Chuquicamata, Chile, S.A.

# EXOTIC BLOCKS AND COARSE BRECCIAS IN MESOZOIC VOLCANIC ROCKS OF SOUTHEASTERN ARIZONA

By FRANK S. SIMONS, ROBERT B. RAUP, PHILIP T. HAYES, and HARALD DREWES, Denver, Colo.

*Abstract.*—In the Canelo Hills and the Huachuca, Patagonia, and Santa Rita Mountains of southeastern Arizona, thick sequences of Mesozoic volcanic and volcanic-sedimentary rocks contain sizable exotic blocks or coarse sedimentary breccias of older rocks. The large blocks were emplaced by dragging or rafting by lava flows, by gravity sliding, or possibly by transport in ash flows. These exotic blocks and coarse breccias, together with conglomerate at several horizons, indicate widespread tectonic activity in southeastern Arizona during Mesozoic time.

Several mountain ranges in Santa Cruz and Cochise Counties, southeastern Arizona, contain thick volcanic and volcanic-sedimentary sequences of Triassic to Cretaceous age (fig. 1). In many places these volcanic-sedimentary sequences contain sizable blocks or coarse sedimentary breccias of older rocks. Maximum dimensions of some of the larger blocks are locally measurable in thousands of feet. The volcanic rocks are mainly rhyolite, quartz latite, and dacite, but some are trachyte and trachyandesite. The geologic age of some of the volcanic sequences has been determined by their relation to fossiliferous rocks or by isotopic age determinations, but the age of others is known only within broad limits.

The exotic blocks in the Mesozoic rocks commonly are of upper Paleozoic sedimentary strata but also include lower Paleozoic sedimentary rocks and Precambrian metamorphic rocks as well as Mesozoic volcanic material. The large blocks were emplaced in several ways; some were picked up and dragged by flowing lava or appear to have been rafted on or in lava flows, whereas others are interpreted as gravity slide blocks, some of which may have glided along muddy layers in the host rock. The sedimentary breccias are thick and very coarse but otherwise are lenticular stratigraphic units that were deposited near a rugged source area.

Exotic blocks or breccias from four ranges are described briefly, and some ideas on Mesozoic paleogeography of southeastern Arizona are presented. The Canelo Hills have been studied by Raup, Simons, and Hayes, the Huachuca Mountains by Hayes, the Patagonia Mountains by Simons, and the Santa Rita Mountains by Drewes.

## CANELO HILLS

The Canelo Hills comprise a group of low narrow ridges lying between the Huachuca Mountains to the east and the Patagonia and Santa Rita Mountains to the west (fig. 1). They extend from about 6 miles north-northeast of Patagonia southeastward for 22 miles. The northern half of the Canelo Hills is underlain by sedimentary rocks of Paleozoic and Mesozoic age and volcanic rocks of Mesozoic and Tertiary age, whereas the southern half consists largely of silicic and intermediate volcanic rocks of Mesozoic and Tertiary age.

### Northern Canelo Hills

The northern part of the Canelo Hills consists mainly of Paleozoic sedimentary rocks, mostly limestone, overlain by Canelo Hills Volcanics of Triassic and Jurassic age (Hayes and others, 1965). The basal unit of the volcanic rocks is as much as 2,000 feet thick and is made up of red beds, tuff, tuffaceous sandstone, conglomerate, and thin silicic lava flows. At most places it rests on Permian Concha Limestone and was deposited on a surface of moderately high relief marked locally by a zone suggestive of a poorly developed regolith. Exotic blocks, probably emplaced by gravity sliding, are abundant in sedimentary rocks near the base of this unit.

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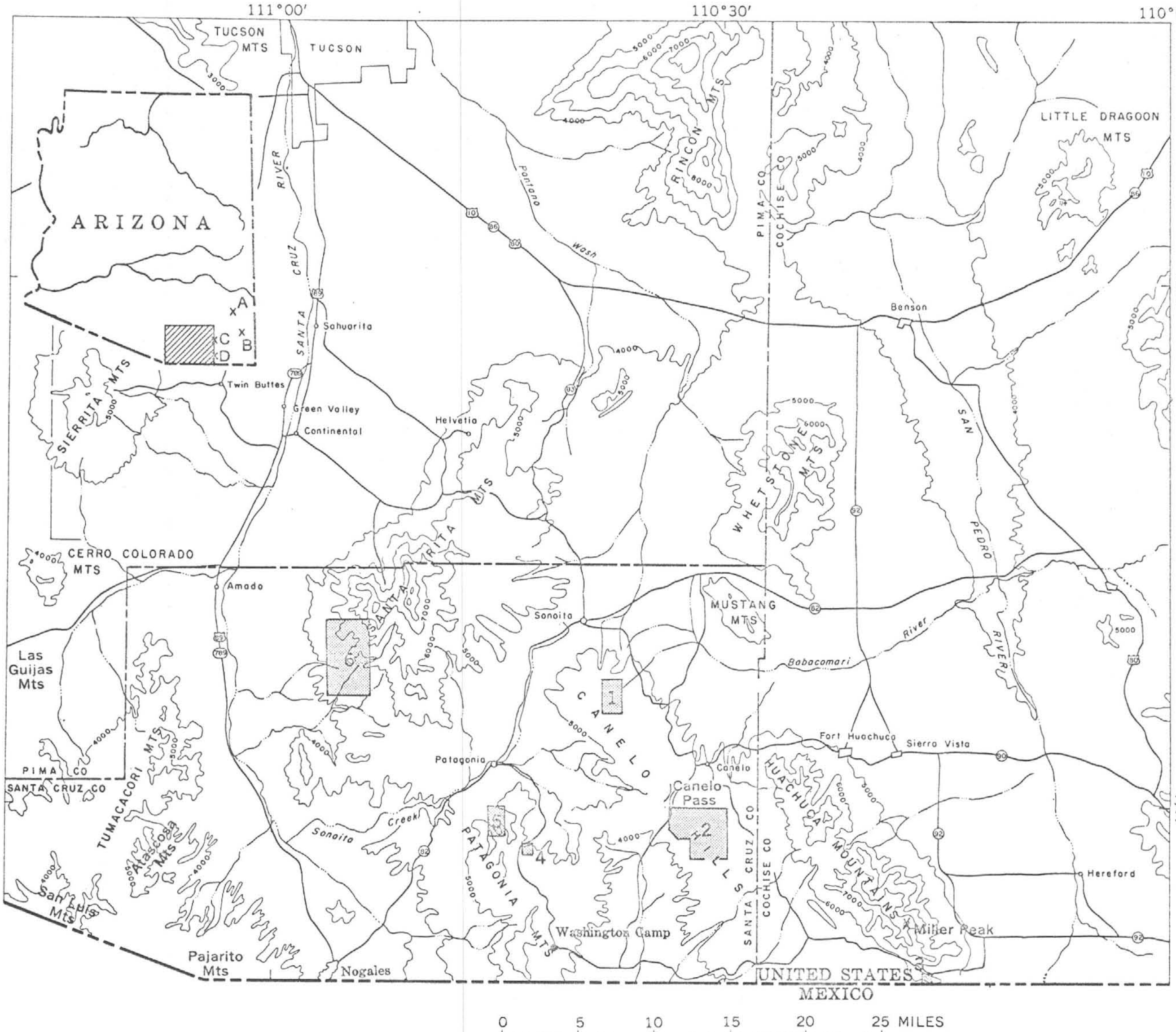


FIGURE 1.—Index map of a part of southeastern Arizona, showing location of areas described in the text. *1*, northern Canelo Hills; *2*, southern Canelo Hills; *3*, Coronado National Memorial, Huachuca Mountains; *4*, American mine area, Patagonia Mountains; *5*, Flux mine area, Patagonia Mountains; and *6*, Josephine Canyon–Montosa Canyon area, Santa Rita Mountains. Index map: *A*, Dos Cabezas Mountains; *B*, Chiricahua Mountains; *C*, Dragoon Mountains; and *D*, Mule Mountains.

Host rocks for the exotic blocks are mainly conglomerate and red beds. The conglomerate is largely massive limestone conglomerate but locally is composed principally of clasts of volcanic rock in a tuffaceous matrix. Interbedded with the conglomerate are thin-bedded tuff and tuffaceous sandstone. The red beds comprise red mudstone with a few thin and discontinuous limy layers and brown medium-grained sandstone. Volcanic flows and tuff occur locally in the red-bed sequence, indicating that the red beds were deposited during a period of volcanic activity in the region.

A typical exotic block is a bedding-plane slab lying generally parallel to the layering in the host rocks. Such blocks range in length from a few tens of feet to at least 4,000 feet and in thickness from a few feet to more than 150 feet. Most blocks are limestone or dolomite of Permian age, from either the Concha Limestone or the Scherrer Formation; some are quartzite or feldspathic sandstone, also of the Scherrer.

All the blocks are brecciated, but the degree of brecciation is not uniform. Distance from possible source rocks, where any estimate can be made, or type of host rock seem to have little influence on the intensity of brecciation; in general, however, brecciation diminishes toward the centers of blocks, so that thick blocks are less brecciated than thin ones.

Breccia fragments of limestone are not everywhere easily recognized owing to subsequent healing of fractures. In some places, original fragments show up because of slight color differences between them and the healing material. The effect of brecciation on chert and fossils is more evident. Chert nodules, so abundant in the Concha Limestone, are thoroughly shattered and their distinctive shapes are destroyed, although the general distribution of chert is little changed. Silicified brachiopods are common in chert nodules of the Concha, and in places the only recognizable fossils remaining in exotic blocks are in fragmented nodules; unsilicified fossils have been obliterated.

Fragments in exotic blocks have been rotated, at least locally. Evidence of rotation can be seen only in fragments of quartzite, which is laminated, and not in fragments of the unlaminated carbonate rocks. Parting planes generally are intact. Near the base of one block, fragments in a thin unit of distinctly laminated quartzite are oriented at random, indicating considerable rotation on a small scale, but the contact between quartzite and the overlying fragmented carbonate rock is practically undisturbed. Apparently the blocks moved as bodies that were sufficiently competent to preserve gross stratigraphic features, even though beds between parting planes were disturbed locally to a greater extent.

All the exotic blocks whose stratigraphic position relative to the underlying Paleozoic bedrock is known are within 300 feet of the Paleozoic rocks, and most are within 100 feet or less. Although blocks occur throughout this interval, within a given area they tend to be concentrated at a particular horizon. Field evidence shows clearly that at least some of the blocks could not have reached their present stratigraphic position as a result of faulting, and it seems likely that all were emplaced by gravity sliding.

Examples of exotic blocks in conglomerate may be seen north of the Canelo Pass road just east of the pass. Here, large blocks, mainly of Concha Limestone, are enclosed in a unit of massive limestone conglomerate and volcanic sedimentary rocks. The conglomerate unit thins abruptly toward the north, suggesting that it was deposited in a local basin. The blocks appear to be ordinary components of the conglomerate, but one exposure suggests that they may have slid on muddy layers within the conglomerate. At this place, the basal few feet of an exotic block of Concha Limestone is typically brecciated, and the healing material is red limy mudstone with only sparse rounded granules and small pebbles of limestone. The mudstone may represent the surface material on which the block slid.

Examples of exotic blocks in red beds are common along both flanks of a faulted syncline on the east side of the northern Canelo Hills. Along the east flank, part of which is shown on figure 2*A*, the relation of exotic blocks to source rocks is particularly well displayed; the exposed source rocks are the lower part of the Concha Limestone, and the blocks too are derived from the lower part of that formation. The surface on which the red beds were deposited is fairly irregular, with local relief of at least 400 feet. Depressions in the older terrane were filled in by red beds with a thin basal conglomerate and abundant exotic blocks. After the depressions were filled, more blocks were emplaced sporadically within a narrow stratigraphic interval.

#### Southern Canelo Hills

The southern part of the Canelo Hills is made up mainly of rhyolite lava flows more than 1,000 feet thick, overlain by rhyolite welded tuff more than 6,000 feet thick (fig. 2*B*). These rocks have a general northwest strike, and dip moderately southwest.

Several lenses of upper Paleozoic sedimentary rocks, largely of Permian age, are enclosed in or underlain by rhyolite lava, and other lenses have similar, but not entirely clear, field relations. Two are overlain directly by welded tuff. The lenses range in length from 200 to 3,500 feet and are as much as 750 feet in outcrop width. Two lenses are at or near the top of the lavas, two others are probably near the same stratigraphic position, and another seems to be several hundred feet below the top of the lavas. The stratigraphic location of other lenses is uncertain. Carbonate rocks, mostly limestone, are dominant in the lenses, but quartzite is present in four of them.

The lenses have several features in common. All are brecciated; indeed some are so thoroughly fractured that over sizable outcrop areas no fragments more than a few inches across remain unbroken. In some lenses brecciation is most intense near contacts. In general the lenses are little recrystallized, silicified, or otherwise altered, although the limestone of some lenses is slightly reddened near contacts. The lenses are cut by numerous veinlets of white calcite; and dolomitic limestone may be divided into various-sized blocks by irregular septa of lighter colored carbonate which is dedolomitized rock. The lenses seem for the most part to be bedding-plane slabs whose bedding is

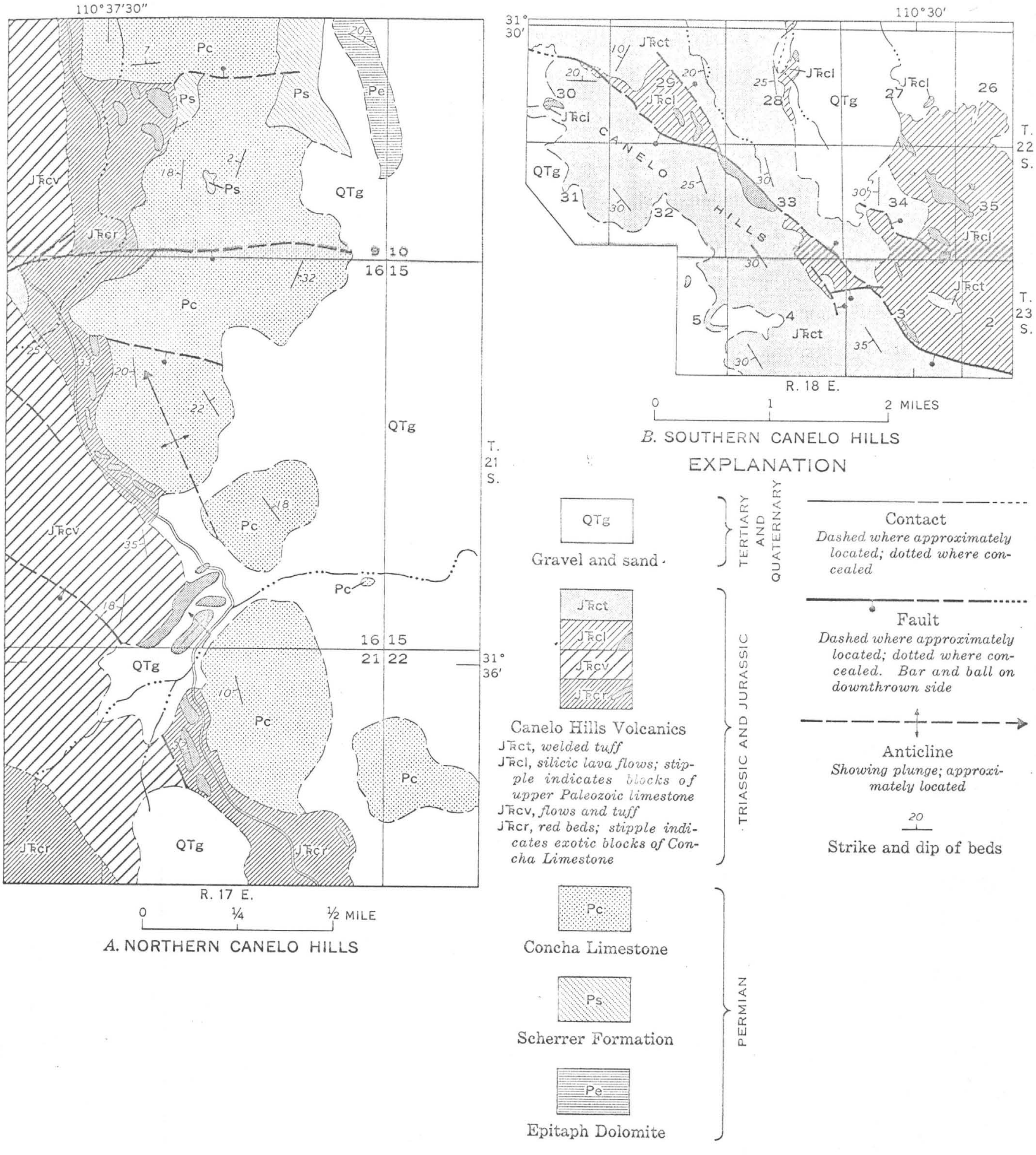


Figure 2.—Generalized geologic maps of parts of the northern (*A*) and southern (*B*) Canelo Hills, Santa Cruz County, Ariz.

roughly parallel to the enclosing lavas or to nearby welded tuff. No exposure of a contact between a lens and volcanic rock was found.

In most places, the only rocks associated with the lenses are volcanic. However, one composite block about 1,300 feet long consists of two lenses that are in contact at their north ends; south of the juncture they are separated by as much as 50 feet of conglomerate composed of partly rounded fragments of limestone and volcanic rock in a matrix of calcarenite.

These exotic lenses in volcanic rocks may be interpreted as hills of bedrock protruding through the volcanic material, as slivers along faults, as landslide blocks, or as slabs transported on or within lava flows. Some may indeed be bedrock hills, but such an explanation seems unlikely for long and narrow lenses that crop out on ridgetops and have steep contacts with the lavas. No evidence was found that any of the lenses is a fault sliver, although at least one is bounded by a fault along one side. All the lenses are a mile or more horizontally from the nearest outcrop of what is undoubted prevolcanic bedrock, and several apparently are separated by hundreds of feet of lavas from any underlying prevolcanic rock. The lenses could have been emplaced by landsliding, but some are long thin slabs that might have been noticeably disrupted during landsliding rather than merely brecciated. Two of these thin slabs are underlain by an appreciable thickness of lava and must have travelled a considerable distance.

It seems most likely that the lenses were transported on or in lava flows. At present the nearest outcrops of Paleozoic source rocks are 10 miles west or southwest in the Patagonia Mountains, 5 miles or more northwest in the Canelo Hills, and 8 miles northeast in the Huachuca Mountains. The direction from which the volcanic rocks came is unknown, so no logical choice can be made among these possible source areas. It is possible, of course, that Paleozoic rocks may have been exposed somewhere nearby at the time of extrusion of the lavas; in that event such extensive transport would not need to be invoked.

Transportation by lava, although producing considerable brecciation, has resulted in little or no alteration of the slabs, presumably either because the lava was already rather cool at the time the blocks were entrained, or because the length of time between picking up of the slabs and cooling of the lava was very short.

## HUACHUCA MOUNTAINS

The Huachuca Mountains are a northwest-trending range about 20 miles long in the southwest part of Cochise County (fig. 1). The mountains are made up of Precambrian granitic rocks, Paleozoic sedimentary rocks, a wide variety of Mesozoic sedimentary, volcanic, and intrusive rocks, and subordinate Cenozoic igneous rocks.

In the southern part of the Huachucas, numerous exotic blocks of Paleozoic sedimentary rocks are enclosed in volcanic rocks of Mesozoic age. Some of the most instructive examples are in the extreme southern part of the range in Coronado National Memorial between Joe's Canyon Trail and the Mexican border (fig. 3). Here there is a well-exposed body of grayish-red trachytic lava, containing large exotic blocks. It is conformably underlain and overlain by thick units of very poorly sorted volcanic cobble- to boulder-conglomerate that is assigned to the Glance Conglom-

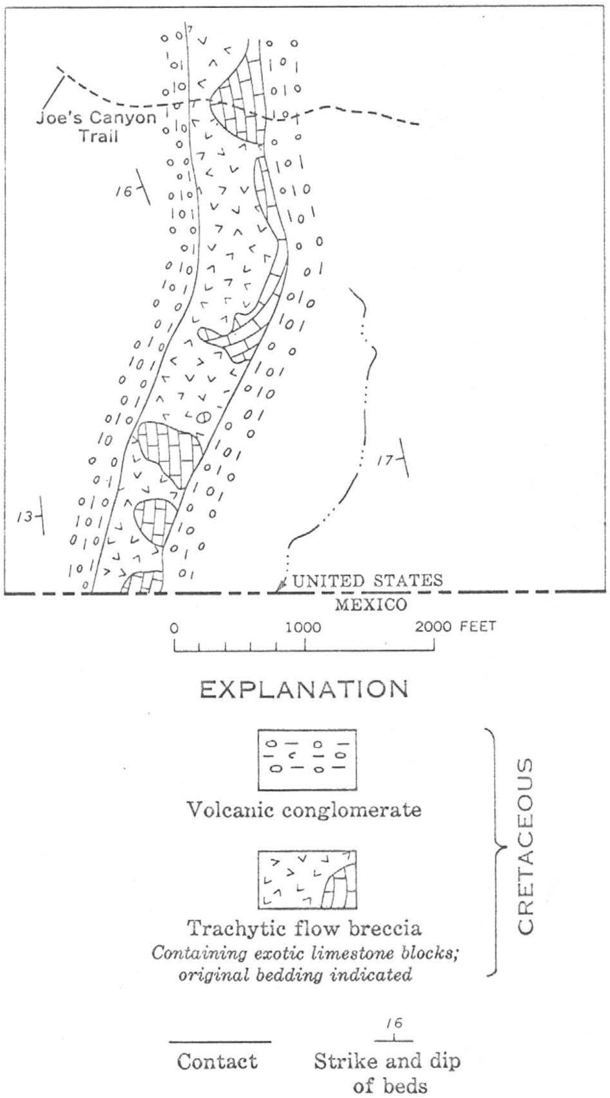


FIGURE 3.—Geologic sketch map of lava flow containing exotic blocks, in Coronado National Memorial, Huachuca Mountains, Cochise County, Ariz. (fig. 1, loc. 3).

erate of the Bisbee Group of Early Cretaceous age. The upper conglomerate unit contains sparse limestone clasts as well as volcanic detritus.

The trachyte seems to be a single lava flow about 200 feet thick. In most places it is a flow breccia, but breccia is much more apparent in the upper part, some of which is vesicular. The rock contains as much as 20 percent phenocrysts of plagioclase up to 5 mm in length.

The exotic blocks are as much as 1,500 feet long and 200 feet high. All the larger blocks are at or very near the base of the trachyte (fig. 3). The blocks readily identifiable as to origin were derived from the Permian Concha Limestone, the youngest Paleozoic formation recognized in the Huachuca Mountains. Bedding in most of the limestone blocks is readily apparent, even though the blocks are highly brecciated, and most bedding is subparallel to the containing lava flow.

Brecciation in the central parts of the larger blocks is not everywhere easily recognized, but close examination generally reveals the limestone to be brecciated and recemented. Brecciation is most intense near the outer edges of the blocks, where in many places lava fills spaces between breccia fragments. Furthermore, the lava near the blocks contains numerous smaller blocks and fragments of limestone, presumably derived from the larger blocks.

These blocks of Concha Limestone undoubtedly were shoved or carried along at or near the base of the trachyte flow and were brecciated during transport. Fragments of limestone that were broken off edges of the blocks were set adrift in the flowing lava. Whether the larger limestone blocks were plucked from bedrock or were landslide blocks picked up by the flow is conjectural.

Elsewhere in the southern Huachuca Mountains, exotic blocks of upper Paleozoic rocks are abundant in a thick and widespread sequence of intermediate volcanic rocks that are considerably older than the trachyte flow described above. The older volcanic rocks are dominantly nonwelded lithic tuffs, but some possible welded tuff and lava have been noted.

Few if any single blocks exceed 1,500 feet in length and 300 feet in thickness, but on the steep slopes east of Miller Peak (fig. 1) the blocks in places are so abundant and so closely spaced as to form masses of brecciated limestone, virtually free of volcanic material, that range from about half a mile to more than 1 mile in length along strike. The enclosing tuffs are generally so poorly exposed and badly weathered that their origin is doubtful. Therefore it is uncertain whether the exotic blocks were transported by ash flows or lahars, or both.

## PATAGONIA MOUNTAINS

The Patagonia Mountains (fig. 1) extend from near the village of Patagonia south-southeastward about 14 miles to the Mexican border and beyond for several miles into Mexico. They consist of Precambrian, Mesozoic, and Cenozoic igneous rocks and subordinate amounts of Paleozoic and Cretaceous sedimentary rocks. Exotic lenses and blocks of Paleozoic limestone in younger volcanic terrane crop out in several areas; the most extensive are near the American mine near Harshaw Creek (fig. 4*A*) and in upper Flux Canyon, 4–5 miles south of Patagonia (fig. 4*B*).

### American mine area

The area around the American mine (fig. 4*A*) is underlain by rhyolite lava and flow breccia that rest on Concha Limestone and the underlying Scherrer Formation, both of Permian age. The rhyolite is correlated tentatively with pre-Lower Cretaceous silicic volcanic rocks of the central Patagonia Mountains northwest of Washington Camp, which in turn may be equivalent in part to the lower Mesozoic Canelo Hills Volcanics (Hayes and others, 1965).

The largest limestone occurrence is along and at the west end of the east-trending ridge north of the American mine. This ridge consists of blocks of brecciated limestone and some quartzite enclosed in rhyolite. East of Harshaw Creek this limestone-rhyolite complex crops out over an area about 1,500 feet long and 700 feet in maximum width; west of the creek it is very poorly exposed but may extend a distance of 1,000 feet or more. Eastward the complex thins abruptly and passes into limestone conglomerate that in turn lenses out near the Bender mine about 3,500 feet east of Harshaw Creek. The limestone blocks are derived from the Concha Limestone and the quartzite from the Scherrer Formation. Most of the blocks are a few feet across but some are much larger; the largest, at the base of the ridge just east of Harshaw Creek, is a highly brecciated mass of dark-gray limestone possibly 100 feet or more across. The limestone-rhyolite breccia and conglomerate lie as much as 1,000 feet stratigraphically above the base of the volcanic section, and the nearest outcrops of possible source rocks for the limestone fragments are about 1,000 feet south.

A large block of coarse-grained white limestone is exposed in a small gully west of Harshaw Creek and along the westward prolongation of the breccia north of the American mine. It is about 300 feet long and

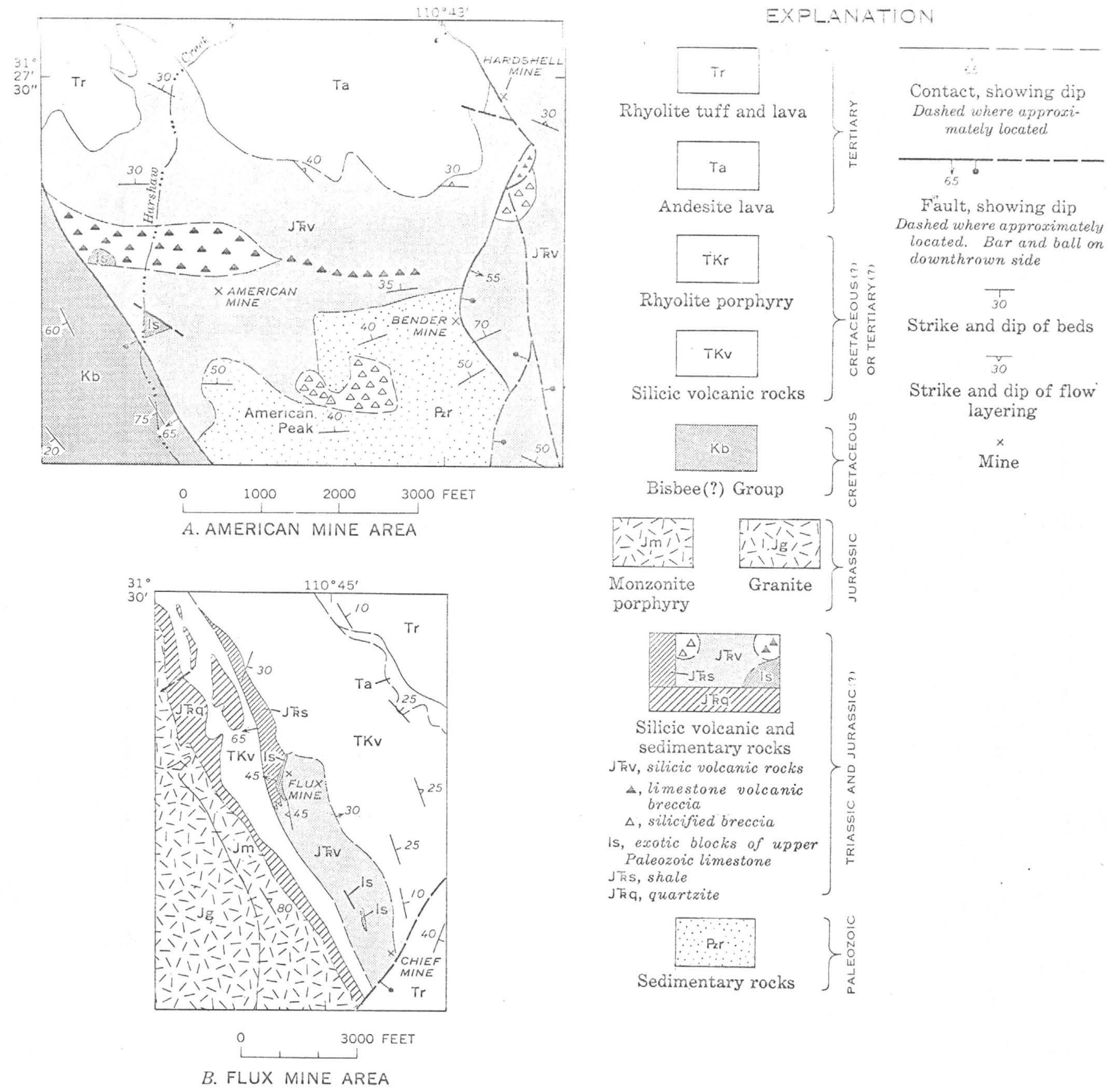


FIGURE 4.—Generalized geologic maps of the American mine area (*A*) and the Flux mine area (*B*), Patagonia Mountains, Santa Cruz County, Ariz. (fig. 1, locs. 4 and 5).

is surrounded by rhyolitic volcanic rock. The ridge to the north offers few exposures, but scattered outcrops of limestone indicate that it probably consists of limestone breccias similar to those north of the American mine.

A limestone block 1,000 feet southwest of the American mine is roughly triangular in outline and is entirely surrounded by rhyolite lava and flow breccia. The northeast contact is a fault dipping southwestward. The limestone block is thoroughly brecciated and bleached, and its identification is uncertain but it is probably Scherrer Formation or Concha Limestone; Permian Concha Limestone crops out 1,500 feet southeast of it.

A small area of limestone breccia crops out 2,000 feet south of the Hardshell mine, 0.8 mile northeast of the American mine (fig. 4*A*). Here a knoll 500 feet long and as much as 200 feet wide is underlain by a coarse limestone breccia resting on rhyolite tuff. The breccia-tuff block is bounded by faults against silicic volcanic rocks. The limestone fragments are as much as several tens of feet across and are mostly if not entirely of Permian Concha Limestone; the enclosing volcanic rocks are the same as those in the American mine area.

### Flux mine area

Rocks at and southwest of the Flux mine, 4 miles south of Patagonia (fig. 4*B*), are mainly silicic volcanic rocks interlayered with a little coarse sandstone, quartzite and shale and intruded by a large sill(?) of rhyolite porphyry. This volcanic-sedimentary sequence trends north-northwest, dips steeply, and is correlated tentatively with silicic volcanic rocks of pre-Early Cretaceous age in the central Patagonia Mountains. It is overlain unconformably by silicic volcanic rocks of Cretaceous(?) or Tertiary(?) age. Limestone slabs, probably all of late Paleozoic age, and associated limestone conglomerate are enclosed in the volcanic-sedimentary sequence at the Flux mine and northwest of the Chief mine.

Many of the workings of the Flux mine are in a lens of highly brecciated limestone with an outcrop length of about 1,000 feet and a maximum width of 75 feet. This lens strikes north and dips steeply west. To the south it tapers out and becomes a thin layer of limestone conglomerate. At the mine road and for some distance uphill to the north, the rocks immediately to the east are much-altered green andesite lava and tuff 40–50 feet thick containing scattered fragments of limestone; farther east are rhyolite lavas. Overlying the limestone to the west is an uncertain thickness, perhaps 40–50 feet, of coarse sandstone and arkose. Apparently these clastic rocks interfinger to the south with silicic volcanic rocks, and to the west they are intruded by rhyolite porphyry. Contacts between limestone and other rocks are rarely exposed but seem to be somewhat sheared and brecciated.

The limestone is a massive gray to dark-gray somewhat cherty rock of uncertain age; it might be from the upper part of the Permian Concha Limestone or, less likely, could be Escabrosa Limestone (Mississippian).

A limestone lens 1,000 feet northwest of the Chief mine is about 600 feet long and as much as 100 feet wide. It consists of jumbled blocks of fossiliferous limestone and silty and sandy limestone, either Horquilla Limestone (Pennsylvanian) or Earp Formation (Pennsylvanian and Permian). The enclosing rocks are mainly rhyolite lavas and tuff, with some shale and sandstone.

Another smaller lens 2,000 feet northwest of the Chief mine is similar in all respects.

The nearest outcrops of Paleozoic source rocks are more than 3 miles to the southeast, around American Peak (fig. 4*A*), but what the relationship may have been at the time the limestone masses of Flux Canyon were emplaced has not yet been determined because of structural complications and uncertain correlations among the volcanic rock units.

## SANTA RITA MOUNTAINS

The Santa Rita Mountains (fig. 1) are underlain by abundant volcanic, sedimentary and plutonic rocks of Mesozoic and Cenozoic age, and by small amounts of sedimentary rocks of Paleozoic age and metamorphic and plutonic rocks of Precambrian age. The Mesozoic rocks include Triassic silicic and intermediate volcanic rocks and intercalated sedimentary rocks, Upper(?) Triassic monzonite, Middle(?) Jurassic granite, and a very thick section of Upper Cretaceous sedimentary and silicic to intermediate volcanic rocks. The Mesozoic complex is intruded by many Paleocene (Laramide) granitoid bodies.

On the west side of the mountains, between Josephine and Montosa Canyons (fig. 5), is a thick sequence of Upper Cretaceous silicic volcanic rocks that dips gently southward. This sequence comprises basal dacitic tuff breccia and lava flows, dacitic breccia enclosing many exotic blocks, and latitic welded tuff. Each unit is commonly several hundred feet thick and in places may be as much as 1,000 feet thick. These rocks rest unconformably on a surface of considerable relief carved across Jurassic granite. Unconformities and the distribution of coarse conglomerate indicate that during Cretaceous time this surface sloped westward from a rugged mountain range that lay about along the present crest of the Santa Rita Mountains.

Dacite breccia forms small bluish-gray or greenish-gray outcrops over about 4 square miles. It consists of fragments commonly 3–6 inches in diameter, set in a friable matrix of similar appearance. Phenocrysts in a finely crystalline to glassy highly altered groundmass make up 20–40 percent of the rock. The feldspar phenocrysts are now clay pseudomorphs after hornblende, biotite, probably a little augite, and perhaps an orthopyroxene. Some of the rocks contain finely disseminated silica and a little calcite. The origin of the breccia is uncertain, but most likely it is a flow breccia.

Scattered widely through much of the flow breccia are hundreds of exotic blocks of pre-Cretaceous rocks as large as 1,000 feet across. Only those most conspicuous for their size, or representing some of the less

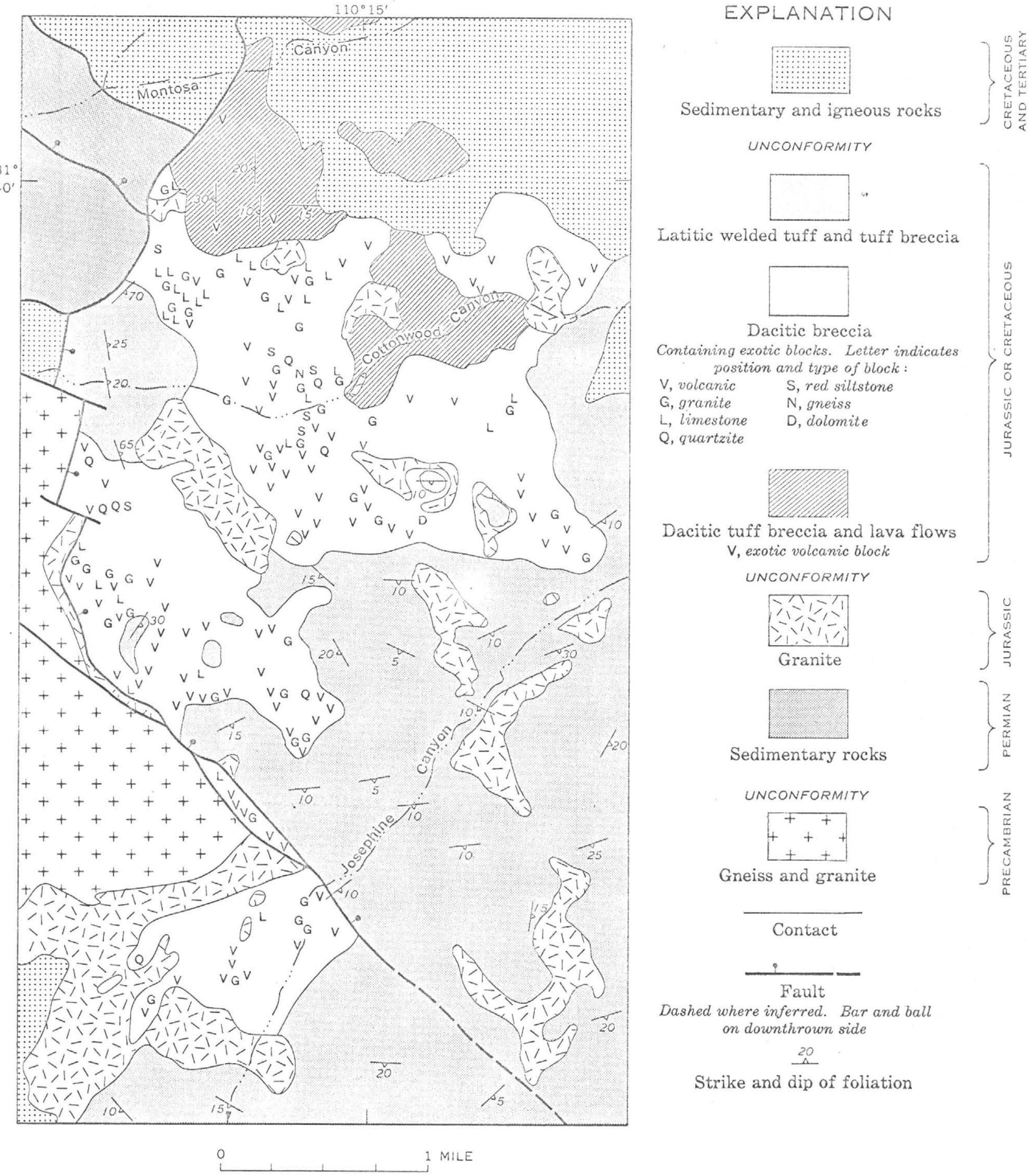


FIGURE 5.—Geologic map showing distribution of volcanic breccia containing exotic blocks, Santa Rita Mountains, Santa Cruz County, Ariz. (fig. 1, loc. 6).

abundant lithologies, are shown by letters on figure 5. The most abundant and generally the largest of the exotic blocks are assorted latite to andesite volcanic rocks derived from Triassic rocks that now crop out only along the crest of the mountains, at least 3 miles to the east. Blocks of Jurassic granite are next in size and abundance, and blocks of Paleozoic rocks, including Permian Concha Limestone, Cambrian Bolsa Quartzite, and possibly also Permian red siltstone and Devonian dolomite, are scarcer and smaller. Permian rocks are exposed immediately north of the breccia area, but the older Paleozoic rocks appear no closer than 5 miles to the northeast. A few large blocks of Triassic monzonite and some very small blocks of Precambrian gneiss were also identified. The blocks are internally unshattered, are unoriented, and show no spatial variation in type or size, except that where the basal unit of the volcanic sequence is absent and the breccia rests directly on Jurassic granite, abundant small granite chips, apparently weathered debris from the Early Cretaceous(?) land surface, are incorporated in the breccia.

In a few places along the bottoms of canyons the contacts between exotic blocks and breccia matrix are well exposed, and where the blocks are limestone the contacts provide considerable information about geologic conditions prevailing during emplacement of the blocks. One of several limestone blocks, located in Josephine Canyon just southwest of the fault (between the 3 "G" symbols in fig. 5) is shown in figure 6. The volcanic matrix contains abundant chips of disintegrated Jurassic granite and some fragments of other exotic material. The contact between block and host shows many irregularities, and many tongues of volcanic material penetrate the limestone for a foot or more. It seems that when the exotic blocks were emplaced some of the limestone was dissolved along cracks and the spaces were filled by the volcanic material suggesting at least a highly fluid and perhaps warm environment.

Emplacement of the blocks by some sort of flowage is indicated by the widespread distribution of the blocks and the nature of their contacts with the host breccia. Movement on or in a volcanic flow is the

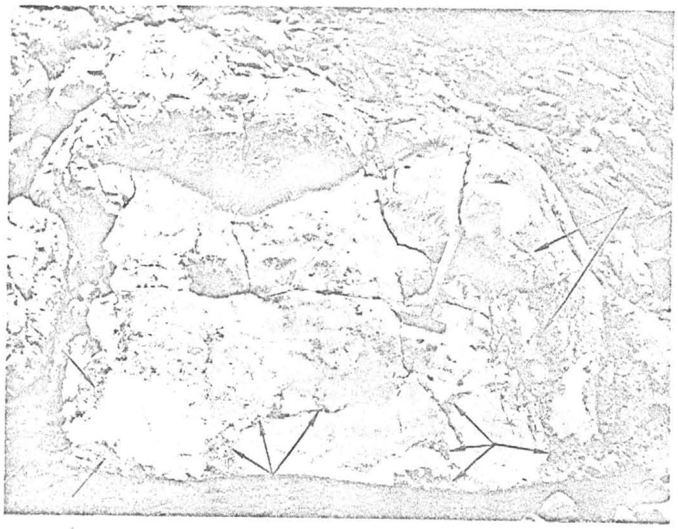

FIGURE 6.—Block of light-gray Paleozoic limestone in dark-gray dacitic breccia, Santa Rita Mountains, Santa Cruz County, Ariz. (fig. 1, loc. 6). Arrows indicate cracks in limestone from which limestone has been dissolved and which are filled with a fine-grained volcanic matrix.

favored explanation, but movement in hot mud flows is also a possibility. Possible source areas of most of the exotic blocks lie to the northeast, suggesting that a volcanic source also lay in that direction, conceivably in the area now occupied by a Paleocene (Laramide) dioritic pluton. As already mentioned, the Cretaceous land surface sloped westward, so that the requisite gradient was available for westward movement of the flow breccia. Some of the little exotic blocks may have been ejected from a vent, some larger exotic blocks may have been incorporated into the base of the breccia during flow, and possibly still others fell into the breccia from adjacent steep slopes.

## PALEOGEOGRAPHY

During the past few years, extensive fieldwork and radiometric age determinations by members of the U.S. Geological Survey have revealed a tectonically eventful early Mesozoic history in much of southeastern Arizona. Little information had been available for the interval between the Early Permian and Late Cretaceous, although previous workers recognized that both plutonic and volcanic rocks had been emplaced in that interval (Ransome, 1904, p. 84; Schrader, 1915, p. 54, 57–60; Gilluly, 1956, p. 53–70; Sabins, 1957, p. 506; Cooper and Silver, 1964, p. 71–73).

The data at hand suggest at least 2 periods of widespread volcanism, one of Late Permian or Early Triassic age and one of Late Triassic or Early Jurassic age, as well as 2 periods of plutonism of Late Triassic and Middle Jurassic age, respectively. The products of the volcanic episodes have been recognized over an area of 3,000 square miles, including in addition to the mountain ranges discussed herein, the Little Dragoon and probably the Dragoon Mountains. These volcanic rocks are separated by regional unconformities from the underlying Paleozoic sedimentary rocks and the overlying Lower Cretaceous rocks. No volcanic rocks of Triassic or Jurassic age have been identified farther east, in the Mule, Chiricahua, or Dos Cabezas Mountains, and in view of the considerable amount of work that has been done in these ranges it is unlikely that any are present. We do not know whether their absence is due to erosion or to nondeposition. Little detailed geologic mapping has been done immediately west of the Santa Rita and Patagonia Mountains, but it will not be surprising if lower Mesozoic volcanic rocks eventually are identified in the Pajarito, Atascosa, Tumacacori, San Luis, Las Guijas, or Cerro Colorado Mountains.

The many exotic blocks, some of which probably are far travelled, as well as conglomerate at several horizons in the volcanic sequences, attest to widespread tectonic activity during the early Mesozoic, and the region may well have been the source of volcanic ash and other volcanic debris in the Triassic and Jurassic rocks of northeastern Arizona.

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File: Santa Rita-Patagonia Mts
Santa Cruz Co.

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# Road log for southern Santa Rita Mountains, Santa Cruz and Pima Counties, Arizona

by

Harald Drewes

Open-file report

1966

(Prepared for Arizona Geological Society field conference, April 1966)

Road log for southern Santa Rita Mountains

Santa Cruz and Pima Counties, Arizona

by Harald Drewes

## Introduction

Geologic mapping of the Mount Wrightson quadrangle has been completed recently by the U.S. Geological Survey. As a result, I am able to present a summary (table 1) of the rocks exposed and to indicate their ages and relations with each other. The Mesozoic rocks are emphasized because the local geologic record of this era is more complete in the southern part of the Santa Rita Mountains than elsewhere in southern Arizona. For example, there is evidence to indicate that about 10,000 feet of volcanics (including pillow lava), eolian sandstone, and possibly even red beds was deposited during Triassic time and that these rocks were intruded by a monzonite stock before the end of that period. It is hoped that release of the data at this time, prior to the final publication by the U.S. Geological Survey, will stimulate in the geological community of southern Arizona a timely interest in some of the complex problems of the Mesozoic tectonic history. Solutions to these problems may suggest new approaches to minerals exploration in this region.

Acknowledgments.--The geologic investigation of the south half of the Santa Rita Mountains is part of a larger geologic field study by the U.S. Geological Survey, and many ideas presented here have been developed jointly with, or have been tempered by, J. R. Cooper (working in the Sierrita Mountains), Frank Simons (Patagonia Mountains), P. T. Hayes (Huachuca and Mule Mountains), R. B. Raup, Jr., (Canelo Hills and Mustang Mountains), S. C. Creasey (Whetstone Mountains), and T. L. Finnell (Empire Mountains). I am also indebted to R. F. Marvin, H. H. Mehnert, Wayne Mountjoy, T. W. Stern, G. C. Cone, and Creasey, all of the U.S. Geological Survey, for assistance in sample preparation and for the radiometric dating, which provide excellent support for the geologic field relations.

Table 1.--Summary of rocks of the Mount Wrightson quadrangle, Arizona

| Age | | Radiometric date[1] | Description[2] | |
|---|---|---|---|---|
| Quaternary | Pleistocene and Pliocene | | 4 gravel units of which the oldest is faulted | |
| | | | Unconformity | |
| | Pliocene and Miocene | | Poorly consolidated conglomerate of Nogales | |
| | | | Unconformity | |
| Tertiary | Oligocene | (6) 27 m.y. | Rhyodacite volcanics of the Grosvenor Hills, about 2,000 ft thick, laccoliths (4 dates) and dike swarm; dacite porphyry dike swarm and granodiorite stock (1 date) of San Gayetano Mountains; rhyolite porphyry dike swarm (1 date) and plug of Gardner Canyon | |
| | | | Intrusive | |
| | Oligocene and Eocene(?) | | Rhyolitic and dacitic volcanics and sediments of Gringo Gulch, about 2,000 ft thick | |
| | | | Unconformity | |
| | Paleocene (Laramide) | (8) 60-68 m.y. | Latite porphyry dikes (1 date) (some dikes may be 50 m.y. old and of Eocene age), granodiorite (1 date) and dacite porphyry (1 date) of Gringo Gulch, quartz monzonite of Elephant Head area (1 date), granodiorite of Madera Canyon (1 date[3]), diorite of Josephine Canyon (3 dates), and other plutonic rocks | |
| | Late Cretaceous | | West<br>Rocks of Salero area: red beds, arkosic conglomerate, and sandstone containing plant fossils; welded tuff (1 date); agglomerate with exotic blocks; andesite; total about 4,000 ft thick | East<br>Rocks of Sonoita Creek area: arkosic sandstone, red beds, conglomerate and black shale containing Maestrichtian fauna |
| Cretaceous | ------?------ | | | ------------?------------ |
| | | | | Brown sandstone, siltstone, and conglomerate; total about 5,000 ft thick |
| | | | | Fault |
| | Early(?) Cretaceous | | | Volcanics and conglomerate of Bathtub area, about 2,000 ft thick |
| | | | | Unconformity |
| | | | | Volcanics and conglomerate of Temporal Gulch, about 2,000 ft thick |
| | | | Unconformity or faulted | |
| Jurassic | Middle(?) Jurassic | (3) 145-161 m.y. | Granite of Squaw Gulch (3 dates) | |
| | | | Intrusive | |

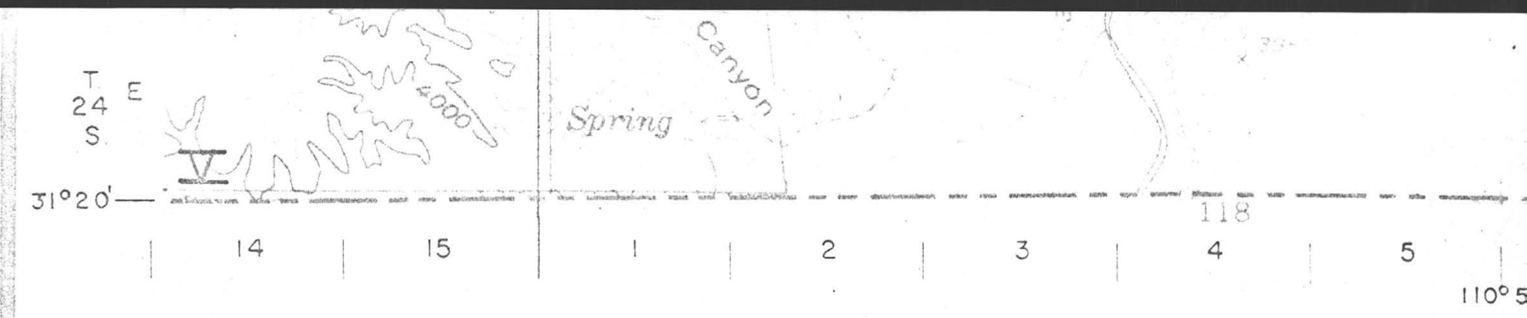
Table 1.--Summary of rocks of the Mount Wrightson quadrangle, Arizona--Continued

| Age | | Radiometric date 1/ | Description 2/ |
|---|---|---|---|
| Triassic | Upper(?) Triassic | (1) 184 m.y. | Monzonite of Piper Gulch (1 date) |
| | | | (Unknown) |
| | | (1) 192 m.y. | Red siltstone and dacite volcanics (1 date) of Apache Spring |
| | | | Fault |
| | ------?------ Lower(?) Triassic | | Volcanics of the Mount Wrightson area: Eolian sandstone, rhyolitic and andesitic volcanics, pillow lava; rhyolitic volcanics and quartzite; dacite volcanics and quartzite; total about 10,000 ft thick |
| | | | Unconformity |
| Permian | | | Rainvalley Formation, fossiliferous<br>Concha Limestone, fossiliferous<br>Scherrer Formation<br>Epitaph Dolomite<br>Colina Limestone, fossiliferous |
| | | | Fault |
| Pennsylvanian | | | Earp Formation |
| | | | Fault |
| | | | Horquilla Limestone, fossiliferous (Escabrosa Limestone [Mississippian] faulted out) |
| | | | Fault |
| Devonian | | | Martin Limestone, fossiliferous |
| | | | Fault |
| Cambrian | | | Abrigo Limestone, fossiliferous |
| | | | Fault |
| | | | Bolsa Quartzite |
| | | | Unconformity or fault |
| Precambrian | | | Granodiorite and quartz monzonite porphyry |
| | | | Intrusive |
| | | | Gneiss |

1/ Number in parentheses indicates total number of radiogenic age determinations, including Pb-$\alpha$ on zircon and K-Ar on biotite or hornblende. All ages rounded to nearest million years and presented without the range of analytical error.

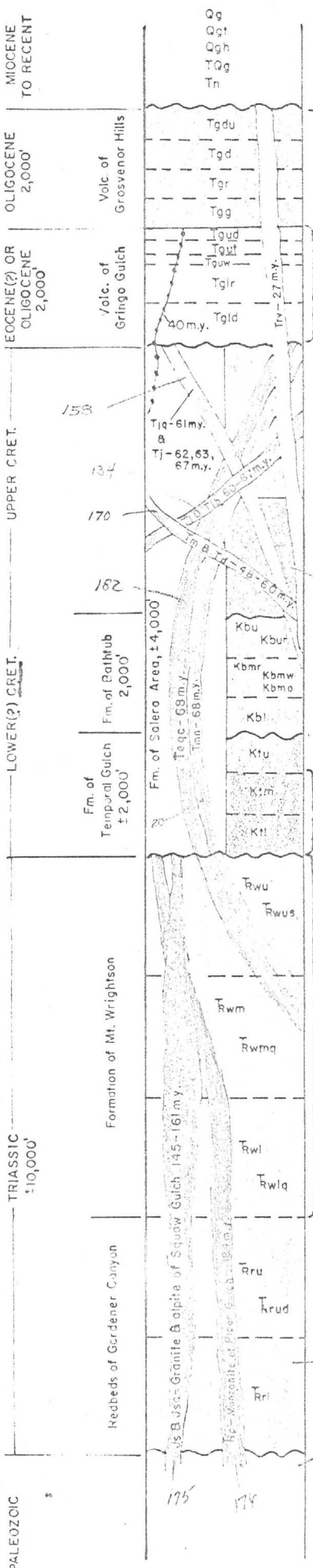
2/ Specific rocks that have been radiogenically dated and number of age determinations marked parenthetically, as for example (4 dates).

3/ Dated by Paul Damon, Univ. of Arizona (written commun., 1965).




# SOUTHEAST SANTA RITA MTNS.

(Member thicknesses arbitrary)




Gravels, block talus & tuffs

Upper rhyodacite vitrophyre flow, agglom., tuff bx. & basal welded tuff

Lower rhyodacite vitrophyre flows, agglom., tuffaceous agglom. welded tuff & some tuff bx. intercolated near base

135

Largely rhyolitic tuff bx., tuffaceous sandstone & agglom., includes few rhyolite porp. flows

Gravel & sandstone member

Dacite flow near Patagonia & dacite congl. along Gringo Gulch

Tuff & tuffaceous sandstone

Bluish grey welded tuff west of Temporal Gulch—unwelded on east side

Rhyolite tuff bx. & tuff bx.—includes abund. pods of silicified rx. along Sonoita Creek

139

Tr & Ta—Rhyolite & andesite of Red Mt.

Dacite flows & congl., includes some rhyolite rx.

FORMATION OF SALERO AREA

Ksu— Tuff bx., tuffaceous sandstone, redbeds, agglom., congl., & qtzite.

Ksw— Latite weld. tuff, 72m.y.

Kswa—Ark., ark. tuff & congl., grades laterally into Ksw & base of Ksu

168

Kse— Dacitic volc. bx., with exotic blocks

Ksl— Dacitic flows & tuff bx.

SONOITA GROUP

Ksub—Brown sandstone

Ksu— Brown polymictic congl., red siltstone, & some volc. congl. near top

Ksr— Red congl. member, includes ark. & siltstone

Kss— Dk. grey mudstone & siltstone, brw. congl. at top—Maestrichtian Fauna (only fossil)

Ksls— Sandstone & siltstone & congl.

Ksl— Ls. congl.

Dacite volc. bx.

Kbur—rhyolitic flow, tuff bx. & tuffaceous sandstone

Rhyolitic tuff, tuff bx. & flows, some tuffaceous sandstone

Kbmw—rhyolite welded tuff

Kbma—andesite flows

145

Polymictic boulder congl. to No., & dacitic sandstone to So.

Rhyodacite volc. bx., small lenses of rhyolite flows & tuff, & some polymictic cobble congl. to the So.

Rhyolite tuff overlying dacitic congl. & sandstone to No., polymictic congl. in ctr., qtz. latite flows in So.

Ktlm— UNDIVIDED: Andesite volc. bx. & Flows 194

Upper rhyolitic tuff & tuff bx., medial congl. polymictic to No.—dacitic to So., basal rhyolitic tuff to No., weld. tuff in ctr. & dacitic bx. to So.; all units interfinger with ark. fanglom. to extreme So.

Andesite agglom., flows, & pillow lava, & rhyolitic flows

Rwus—aeolian sandstone & qtzite

Rhyolite & qtz. latite volc. (to the No. welded tuff dominant over flows, in ctr. flows dominant over welded tuff, & to the So. bx. dominant over flows)

Rwmq—aeolian sandstone & qtzite. & some congl.

Rw—UNDIVIDED: Fm. of Mt. Wrightson 135

Dacitic & latitic flows

Rwlq—qtzite. & congl.

Redbeds—largely mudstone, minor siltstone, sandstone, & congl.

Rrud—dacite porp. tuff, flows & intrusive

Redbeds of Gardener Canyon

185

Red, locally very pale-brw. siltstone, 2 thin ls. units, upper one a dk. grey calcarenite

154

Not exposed

INTRUSIVE ROCKS

Trv—Rhyodacite vitrophyre laccoliths of Grosvenor Hills, 27m.y.

↔ Rhyolite porp. dikes of Gardener Canyon, 40m.y.

Tm—microgranodiorite of Gringo Gulch pluton, 48–60m.y.

Td—dacite porp. phase of Gringo Gulch pluton, 60m.y.

Tl— qtz. latite porp. dikes & stocks, 60–67m.y.

Tlb— latite int. bx., 60–67m.y.

Teqc—qtz. monz. of Quantrell stock (coarse), 68m.y.

Tjq— qtz. monz. phase of Josephine Canyon, 61m.y.

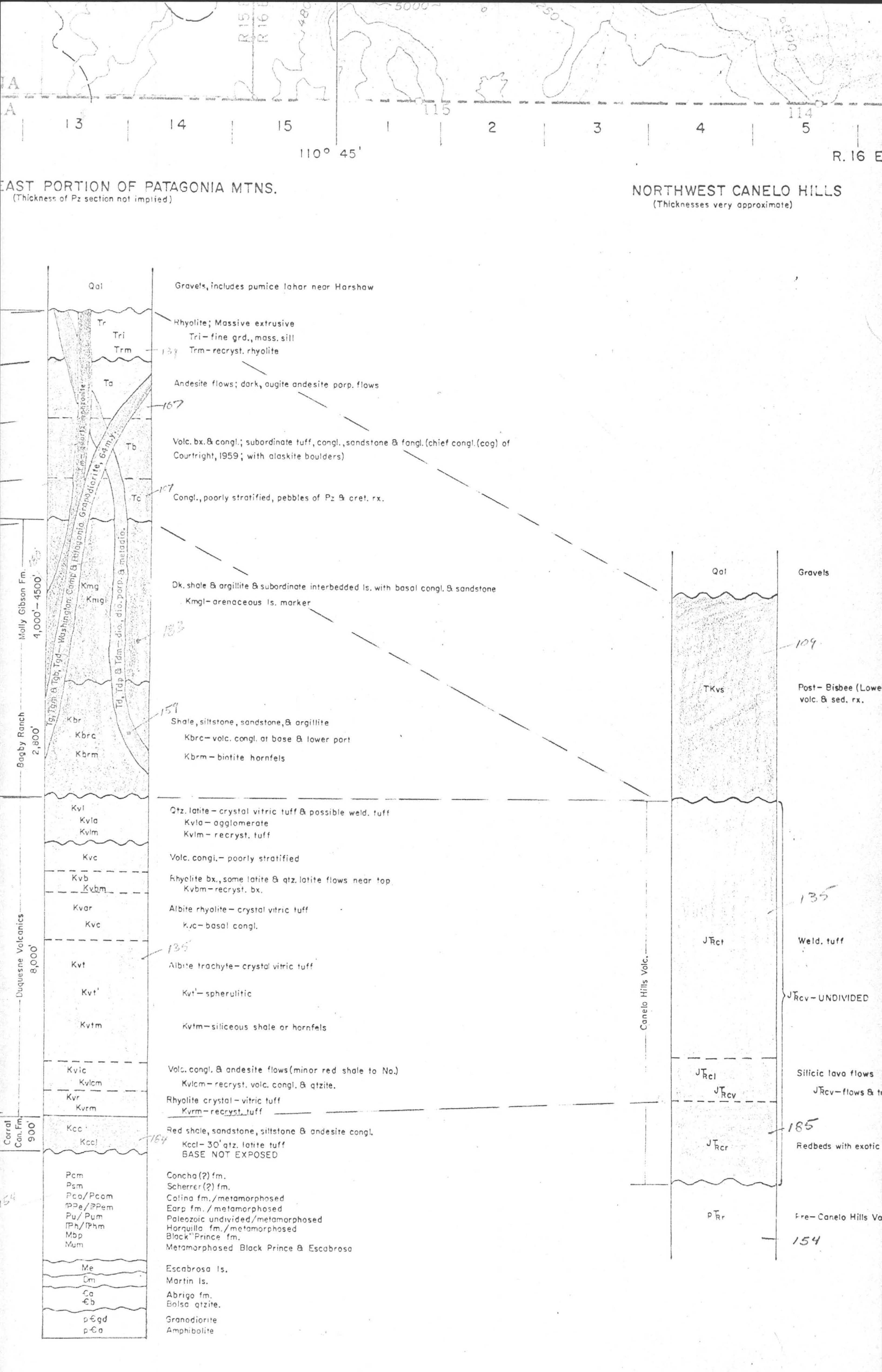
Tj— diorite of Josephine Canyon, 62, 63, & 67m.y.

Tmn—granodiorite of Madera Canyon, 68m.y.

Breccia pipes (?)

* Sample site & date

Gr - Precambrian (?) granite


R 15 E
R 16 E
5000
115
114
13
14
15
1
2
3
4
5
110° 45'
R. 16 E
EAST PORTION OF PATAGONIA MTNS.
(Thickness of Pz section not implied)
NORTHWEST CANELO HILLS
(Thicknesses very approximate)
Qal
Gravels, includes pumice lahar near Harshaw
Tr
Tri
Trm
Rhyolite; Massive extrusive
Tri – fine grd., mass. sill
Trm – recryst. rhyolite
Ta
Andesite flows; dark, augite andesite porp. flows
Tb
Volc. bx. & congl.; subordinate tuff, congl., sandstone & fangl. (chief congl. (cog) of Courtright, 1959; with alaskite boulders)
Tc
Congl., poorly stratified, pebbles of Pz & cret. rx.
Tqm, Tqs quartz monzonite
Tg, Tgm & Tgb, Tgd – Washington Camp & Patagonia Granodiorite, 64 m.y.
Td, Tdp & Tdm – dio., dio. porp. & metadio.
Molly Gibson Fm. 4,000'–4500'
Kmg
Kmgl
Dk. shale & argillite & subordinate interbedded ls. with basal congl. & sandstone
Kmgl – arenaceous ls. marker
Bagby Ranch 2,800'
Kbr
Kbrc
Kbrm
Shale, siltstone, sandstone, & argillite
Kbrc – volc. congl. at base & lower part
Kbrm – biotite hornfels
Duquesne Volcanics 8,000'
Kvl
Kvla
Kvlm
Qtz. latite – crystal vitric tuff & possible weld. tuff
Kvla – agglomerate
Kvlm – recryst. tuff
Kvc
Volc. congl. – poorly stratified
Kvb
Kvbm
Rhyolite bx., some latite & qtz. latite flows near top
Kvbm – recryst. bx.
Kvar
Kvc
Albite rhyolite – crystal vitric tuff
Kvc – basal congl.
Kvt
Kvt'
Kvtm
Albite trachyte – crystal vitric tuff
Kvt' – spherulitic
Kvtm – siliceous shale or hornfels
Kvic
Kvicm
Volc. congl. & andesite flows (minor red shale to No.)
Kvicm – recryst. volc. congl. & qtzite.
Kvr
Kvrm
Rhyolite crystal – vitric tuff
Kvrm – recryst. tuff
Corral Can. Fm. 900'
Kcc
Kccl
Red shale, sandstone, siltstone & andesite congl.
Kccl – 30' qtz. latite tuff
BASE NOT EXPOSED
Pcm
Psm
Pco/Pcom
PPe/PPem
Pu/Pum
Ph/Phm
Mbp
Mum
Concha (?) fm.
Scherrer (?) fm.
Colina fm./metamorphosed
Earp fm. / metamorphosed
Paleozoic undivided/metamorphosed
Horquilla fm./metamorphosed
Black Prince fm.
Metamorphosed Black Prince & Escabrosa
Me
Dm
Ca
Cb
Escabrosa ls.
Martin ls.
Abrigo fm.
Bolsa qtzite.
p€gd
p€a
Granodiorite
Amphibolite
Qal
Gravels
TKvs
Post – Bisbee (Lowe
volc. & sed. rx.
Canelo Hills Volc.
JTRct
Weld. tuff
JTRcv – UNDIVIDED
JTRcl
JTRcv
Silicic lava flows
JTRcv – flows & t
JTRcr
Redbeds with exotic
pTRr
Pre – Canelo Hills Vo
139
167
107
183
159
135
164
154
109
135
185
154

# Lower Mesozoic Extrusive Rocks in Southeastern Arizona—the Canelo Hills Volcanics

*By* PHILIP T. HAYES, FRANK S. SIMONS, *and* ROBERT B. RAUP

CONTRIBUTIONS TO STRATIGRAPHY

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# CONTENTS



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nearest of these to southeastern Arizona is, to our knowledge, a few miles east of Soda Lake in San Bernardino County, Calif., about 400 miles northwest of the Canelo Hills. The Canelo Hills Volcanics and possible equivalent rocks elsewhere in southern Arizona may be the sources postulated by Stewart, Williams, Albee, and Raup (1959, p. 523) and Cadigan (1963) for volcanic detritus in the Upper Triassic Chinle Formation of northeastern Arizona.

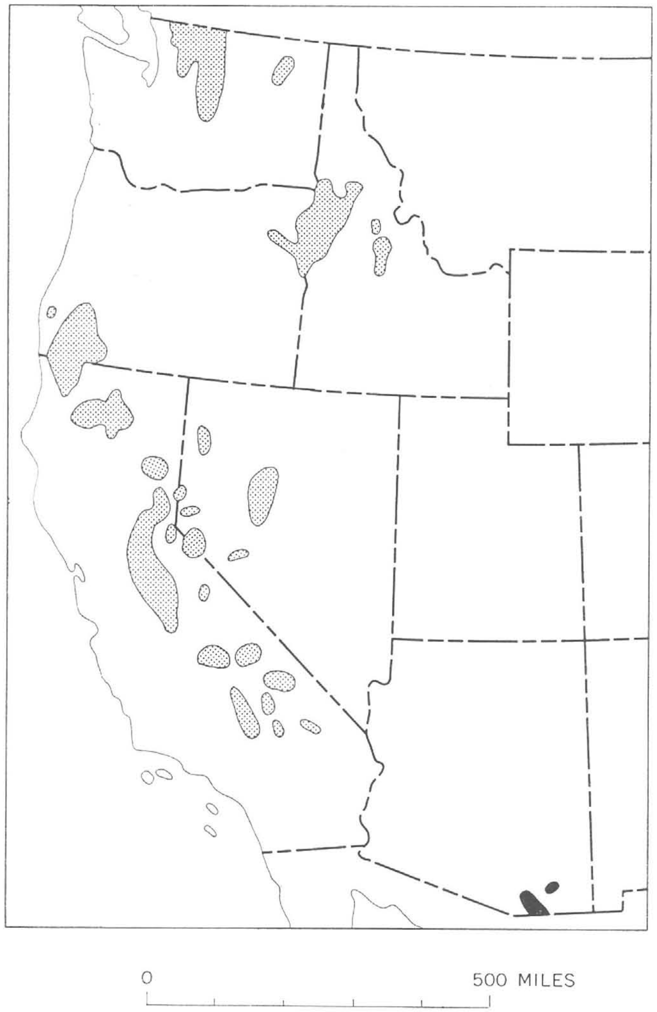



FIGURE 2.—Previously known distribution in Western United States of volcanic rocks of Late Permian, Triassic, and Jurassic age (stippled), and areas underlain by Canelo Hills (larger solid black area) and Walnut Gap (smaller solid black area) Volcanics in southeastern Arizona. Previously known areas from McKee and others (1956, 1959) and Gilluly (1963).

CONTRIBUTIONS TO STRATIGRAPHY

# LOWER MESOZOIC EXTRUSIVE ROCKS IN SOUTHEASTERN ARIZONA—THE CANELO HILLS VOLCANICS

By PHILIP T. HAYES, FRANK S. SIMONS, and ROBERT B. RAUP

ABSTRACT

The name Canelo Hills Volcanics is here given to rocks extensively exposed in southeastern Arizona. The formation includes thick units of rhyolitic lavas and tuffs and subordinate sedimentary rocks and is assigned to the Triassic and Jurassic. Other volcanic units of southern Arizona, previously thought to be younger, may also be of early Mesozoic age.

## INTRODUCTION

A thick sequence of rhyolitic tuffs and lavas and interbedded volcanic sediments of early Mesozoic age has been identified by the writers in the Canelo Hills and nearby areas in eastern Santa Cruz and southwestern Cochise Counties, Ariz. This sequence of rocks is herein named the Canelo Hills Volcanics. The only other volcanic rocks of this age previously reported in southeastern Arizona—the Walnut Gap Volcanics—are poorly exposed in a few small outcrop areas in the Gunnison, Johnny Lyon, and Red Bird Hills, about 55 miles to the northeast (Cooper, 1959, 1960; Cooper and Silver, 1964). Volcanic rocks of possible Triassic or Jurassic age were mapped by Gilluly (1956, p. 68–69) near South Pass in the Dragoon Mountains, about 40 miles to the northeast, but local geologic relations do not permit definite dating of those rocks. Fieldwork of Simons in the Patagonia Mountains, 10 miles to the southwest, and of Harald Drewes (U.S. Geol. Survey, 1963, p. A92) near Mount Wrightson in the Santa Rita Mountains, about 15 miles to the northwest, indicates that thick sequences of post-Paleozoic and pre-Cretaceous volcanic rocks are present in those ranges. Elsewhere in southeastern Arizona, Sabins (1957, p. 506) and Gilluly (1956, p. 67) noted volcanic frag-

745-125—65 

ments in the basal conglomerate (Glance Conglomerate and equivalents) of the Lower Cretaceous Bisbee Group. These occurrences suggest that post-Paleozoic and pre-Cretaceous volcanic rocks once may have been widely distributed in southeastern Arizona. The sequence exposed in the southern Canelo Hills is the first yet discovered that can be dated with certainty on geologic evidence as younger than Early Permian and older than Early Cretaceous.

## CANELO HILLS VOLCANICS

The Canelo Hills Volcanics is named for its exposures in the Canelo Hills (fig. 1), its type area. The formation is subdivided for descriptive purposes into three thick units: basal interbedded volcanic and sedimentary rocks, rhyolitic lavas, and an upper welded tuff. All three units, however, are not everywhere present.

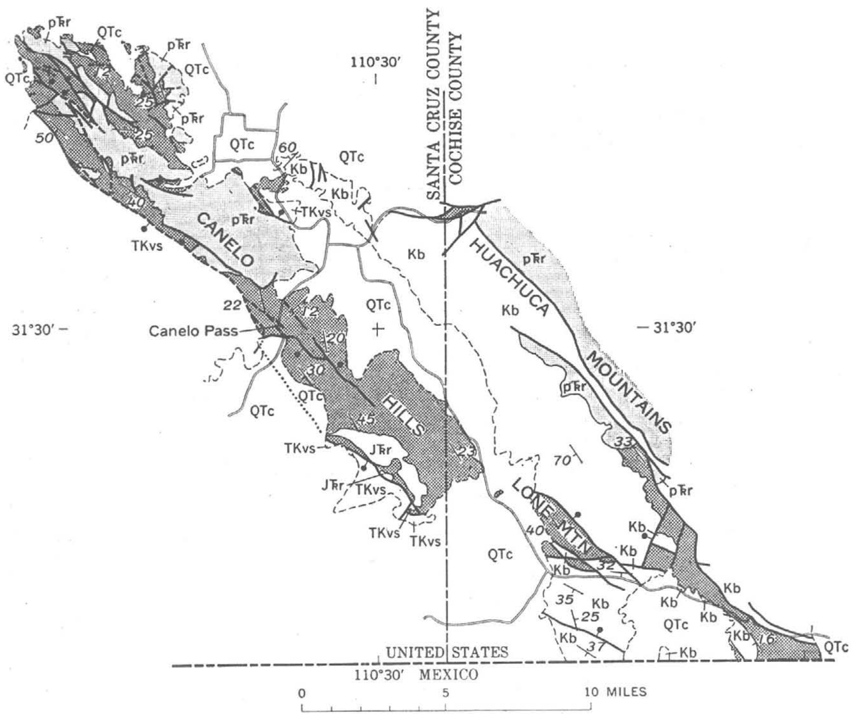



FIGURE 1.—Geology of Canelo Hills and vicinity. *QTc*—conglomerate, gravel, and alluvium (Quaternary and upper Tertiary); *TKvs*—post-Bisbee volcanic and sedimentary rocks (lower to middle Tertiary and Cretaceous); *Kb*—Bisbee Group (Lower Cretaceous); J₸r, rhyolite porphyry (Jurassic and Triassic); stipple pattern—Canelo Hills Volcanics (Jurassic and Triassic); and p₸r, pre-Canelo Hills Volcanics (mostly Paleozoic).



altered biotite(?). Modal analyses of three specimens gave the following results, in percent.

| | Range | Average |
|---|---|---|
| Quartz | 4.0- 8.1 | 6.5 |
| Sanidine | 21.2-26.5 | 23.2 |
| Groundmass | 68.7-70.7 | 69.8 |
| Other | .3- .7 | .5 |
| Total | ----------- | 100.0 |

The only contact metamorphic effect of the rhyolite porphyry on the welded tuff wallrock seems to have been the nearly complete destruction of shard outlines and eutaxitic texture, which elsewhere are generally recognizable even after thorough devitrification.

## AGE OF CANELO HILLS VOLCANICS

The Canelo Hills Volcanics can be dated, on geologic evidence, as younger than Early Permian and older than Early Cretaceous. The formation unconformably overlies Lower Permian formations, and in several localities, large masses of Permian rock are included as exotic blocks in the lower two units of the Canelo Hills Volcanics. The earlier mentioned occurrences of the basal conglomerate of the Bisbee Group unconformably overlying the welded tuff unit indicate that the Canelo Hills Volcanics is probably of pre-Cretaceous age. The formation is here considered as Triassic and Jurassic.

This early Mesozoic age assignment for the Canelo Hills Volcanics is substantiated by a potassium-argon isotope age determination of biotite from the welded tuff unit 2 miles southeast of Canelo Pass in the northwest corner of the SE¼ sec. 29, T. 22 S., R. 18 E. The age, determined by S. C. Creasey of the U.S. Geological Survey (written commun., 1963), is 173±7 million years; thus, the welded tuff unit is probably Late Triassic or Early Jurassic in age.

## REGIONAL CONSIDERATIONS

Although, as stated, certain volcanic units in southeastern Arizona have been assigned a tentative early Mesozoic age, and although volcanic detritus has been identified in the lowest Lower Cretaceous conglomerates, heretofore there has been no conclusive evidence for an early Mesozoic age assignment for volcanic rocks in the region. It seems possible, if not probable, that some of the volcanic rock units assigned a Late Cretaceous or early Tertiary age elsewhere in southern Arizona are early Mesozoic. Some previous ideas on structural relations might warrant reappraisal.

Volcanic rocks of Late Permian, Triassic, and Jurassic age are present at many places in the far Western United States (fig. 2). The

| | 1 | 2 | | 1 | 2 |
|---|---|---|---|---|---|
| $SiO_2$ | 78.1 | 74.57 | $H_2O-$ | .19 | ----- |
| $Al_2O_3$ | 11 | 12.58 | $H_2O+$ | 1 | .66 |
| $Fe_2O_3$ | .75 | 1.3 | $TiO_2$ | .15 | .17 |
| FeO | .08 | 1.02 | $P_2O_5$ | 0 | .07 |
| MgO | .2 | .11 | MnO | .04 | .05 |
| CaO | .07 | .61 | $CO_2$ | $<.05$ | ----- |
| $Na_2O$ | .92 | 4.13 | | | |
| $K_2O$ | 7.4 | 4.73 | Total | 99.9 | |

NOTE.—Powder density, air pycnometer, 2.58.

1. Rhyolite welded tuff, center N½ sec. 34, T. 22 S., R. 18 E., Lochiel quadrangle, Arizona. Lab. No. 159243. Rapid rock analysis by P. L. D. Elmore, S. D. Botts, and G. W. Chloe, U.S. Geol. Survey.
2. Average alkali rhyolite plus rhyolite-obsidian (Nockolds, 1954, p. 1012, table 1, col. 4).

The fine-grained devitrified groundmass of the tuff obviously has approximately the composition of a mixture of slightly sodic potassium feldspar and quartz. The very small amounts of CaO and $Na_2O$ are notable; rocks of such composition (CIPW class 1, order 3, rang 1, subrang 2) are represented in Washington (1917, p. 56–59) by only 10 analyses of rhyolites, 2 of pitchstones, and 1 of felsite.

## RHYOLITE PORPHYRY

An irregular body of rhyolite porphyry intrudes the welded tuff unit on the southwest side of the Canelo Hills but is probably only slightly younger and may have come from the same magma chamber; the two rocks are certainly similar in composition. Fragments of the porphyry are locally present in the basal conglomerate of the Bisbee Group; so, the porphyry is older than the Bisbee, and probably pre-Cretaceous in age.

The contact between the tuff and the porphyry, although exposed in only a few places, seems to be roughly parallel to the strike of the tuff. Wherever exposed, the contact is frozen and the texture of the intrusive rock is porphyritic right to the contact, although the groundmass is slightly finer grained at contacts than elsewhere. In a few places the rhyolite porphyry shows vague flow layering within a few inches of a contact, but in general it has no apparent linear or planar structures. At one locality the porphyry near the contact is sheared and brecciated as if some movement had occurred during or slightly after consolidation.

The porphyry is a uniform rock composed of conspicuous phenocrysts as much as 5 mm across of quartz and pale-red to white feldspar set in a pale-red very fine grained to aplitic groundmass. In thin section, subhedral and embayed grains of quartz and very dusty phenocrysts of perthitic sanidine are enclosed in a fine-grained intergrowth of dusty potassium feldspar, quartz, and a little iron ore and much



## BASAL INTERBEDDED VOLCANIC AND SEDIMENTARY ROCKS

The basal unit is present at many places in the northern Canelo Hills, where it rests with marked unconformity on Paleozoic carbonate rocks and is as much as 2,000 feet thick. The lowest part of the unit shows much lateral variation. In the northernmost Canelo Hills, red beds such as those described by Feth (1948) as Canelo Redbeds, minor conglomerate, and sandstone are dominant at the base; southward, clastic rocks are subordinate and interbedded thin silicic flows and tuffs are dominant; and near Canelo Pass, thick limestone conglomerate overlies the Paleozoic rocks. Interlayered thin beds of volcanic and sedimentary rocks are typical of the upper part of the unit.

South of Canelo Pass the best exposures of rocks tentatively assigned to the basal unit are on the southwest side of Lone Mountain where nearly 2,000 feet of beds is exposed, apparently bounded on all sides by faults. Clastic sedimentary rocks probably make up more remainder. Sandstone is dominant, but conglomerate, siltstone, and than half of the basal unit, silicic tuffs and lavas constituting the shale are also present.

Volcanic rocks in the basal unit are rhyolitic to latitic in composition and consist of both pyroclastic and flow rocks. Tuffs, some weakly welded, are dominant. The lavas are porphyritic and most show poorly defined flow structure. The lavas are pale red to moderate red, and the tuffs are pinkish gray to moderate red. Conglomerate is made up of subangular to rounded fragments as much as several inches across of limestone, quartzite, and silicic volcanic rocks in a poorly sorted reddish-brown matrix. Some of the conglomerates are monolithologic. Sandstones are pale red to reddish brown and are generally tuffaceous. The siltstone and shale range from pale red to moderate red or reddish brown.

A striking feature of the basal unit is the presence of scattered exotic blocks of highly brecciated Paleozoic limestone as much as several thousand feet long. We regard these as ancient landslide blocks.

## RHYOLITIC LAVAS

The rhyolitic lava unit crops out extensively along the northeast side of the southern Canelo Hills. Smaller outcrop areas are along the crest of the Canelo Hills, on Lone Mountain, and in the southeast part of the Huachuca Mountains. The greatest exposed thickness is on the northeast side of the Canelo Hills, about 5 miles east-southeast of Canelo Pass, where more than 1,000 feet is present.

The base of the unit is not exposed except possibly a short distance west of Canelo Pass and at the north end of Lone Mountain (fig. 1). At those places, the lava flows rest on Paleozoic limestone, outcrops of which are too small to be shown at the scale of figure 1. This limestone may have been bedrock of an area in which the basal unit of the Canelo Hills Volcanics was not deposited, but more likely it makes up large exotic blocks enclosed in lava. The lavas are overlain by welded tuff.

The lavas are sparsely porphyritic rocks that range from mainly pale to moderate red to grayish red and light gray. They characteristically display highly contorted flow layering and tend to split easily along the layers. Many flows were strongly brecciated. Gray spherulites a few centimenters in diameter and lithophysae as much as 1 foot across are abundant in some flows. Although probably more than 95 percent of the lava unit is made up of lava flows, it does contain a few tuff beds. Locally, red welded tuff similar to that in the overlying tuff unit seems to be interlayered with the lava flows.

All the lavas contain scattered phenocrysts of cloudy sanidine 1–2 mm across, and some also have sparse phenocrysts of quartz, sodic plagioclase, and(or) altered biotite. Phenocrysts make up less, ordinarily much less, than 10 percent of the rocks. The groundmass in all thin sections examined is patchily devitrified glass, usually spherulitic, and shows contorted flow layering.

### WELDED TUFF

The upper unit of welded tuff makes up most of the southern Canelo Hills and also crops out extensively at the north end of the Canelo Hills, on and near Lone Mountain, and in several large areas in the southern part of the Huachuca Mountains. The greatest apparent thickness is along a southwest-trending section on the southwest side of the Canelo Hills about 4 miles southeast of Canelo Pass, where a thickness of about 6,400 feet is indicated without either base or top being exposed.

The welded tuff rests with apparent conformity on the rhyolitic lavas where they are present. Elsewhere, as in the Huachuca Mountains and northern Canelo Hills, the tuff lies unconformably on volcanic rocks of the lower unit or on Paleozoic formations. The tuff is unconformably overlain by various younger formations. The oldest rock overlying the tuff is conglomerate at the base of the Bisbee Group of Early Cretaceous age. This contact is well exposed at the south end of Lone Mountain near the center of sec. 36, T. 23 S., R. 19 E., and about 2 miles to the east in the Huachuca Mountains.

The welded tuff sequence in the northern Canelo Hills crops out no closer than about 5 miles from the dated tuff south of Canelo Pass. Correlation of these tuff sequences is based on similarities in their textural features, mineralogy, and geologic relations. The northern sequence is dominantly welded tuff, but unlike the southern sequence, it comprises several cooling units commonly separated by less welded ash beds and very thin flows. Lithic fragments in the tuffs tend to be more common in the northern sequence.



The welded tuff is a porphyritic rock ranging from moderate to grayish red to pale red or grayish pink. It invariably contains conspicuous 1- to 3-mm phenocrysts of clear quartz, pink to white feldspar, pumice lapilli, and lithic fragments. In many places the fragmental character of the rock is clear, and the attitude is indicated by pumice lentils; elsewhere, the tuff is so massive that it is almost unrecognizable as a layered rock.

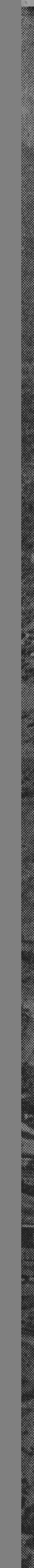
The welded tuff is commonly separated from the underlying silicic lavas by light-gray and greenish-gray nonwelded tuff as much as 30 feet thick. In some places the nonwelded tuff is missing and in its place is a breccia composed of closely packed fragments of silicic lava as much as 6 inches across in a sparse sandy matrix of quartz, feldspar, and glass. Locally, the welded tuff may rest directly on lava. In one small area the tuff is welded to the underlying lava as if the tuff were very hot or the lava were still hot when the tuff was deposited. The dark vitrophyre zone so commonly found near the base of welded tuff cooling units is absent; this zone, if it ever existed, is unrecognizable now owing to devitrification.

Excellent exposures of the lower few hundred feet of welded tuff show a gradual change upward from soft, rather porous, and nonwelded tuff to hard and densely welded tuff, and an accompanying change in color from light greenish gray to grayish red. In thin section the densely welded tuff consists of euhedral crystals, embayed grains, and fragments of quartz and cloudy perthitic potassium feldspar 0.5–3 mm across, together with sparse much-altered biotite and lithic fragments, in a matrix of completely devitrified bent and compacted glass shards and highly flattened axiolitic pumice lentils.

Modal analyses of 14 samples of welded tuff from various places in and near the southern Canelo Hills gave the following results, in percent.

| | Range | Average |
|---|---|---|
| Quartz | 4. 7–15. 3 | 10. 4 |
| Potassium feldspar | 9. 9–33. 5 | 14. 6 |
| Other minerals (biotite, iron ore) | . 0– 8. 1 | 1. 6 |
| Lithic fragments | . 0– 3. 5 | . 7 |
| Groundmass | 52. 5–80. 0 | 72. 7 |
| Total | | 100. 0 |

Chemical analyses of densely welded tuff, together with Nockolds' (1954) average alkali rhyolite, are as follows:



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