Cenozoic Rocks of the Santa Rita Mountains, Southeast of Tucson, Arizona

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By HARALD DREWES

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A systematic description, augmented by 19 radiometric age determinations, of one of the most complete sequences of Cenozoic rocks in southeastern Arizona

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By Harald Drewes

ABSTRACT

The Santa Rita Mountains of southeastern Arizona are underlain, in part, by volcanic and sedimentary rocks and by many small intrusives, of Cenozoic age. These rocks provide a more complete geologic record than that of other ranges in the region, and consequently the Santa Rita Mountains are a useful reference area from which to develop the Cenozoic geologic history of the region. Many isotopic ages provide the basis for dating key units and add to the confidence in the interpretations of the geologic record of the rocks themselves. The rocks of the greatest potential economic interest are the Greaterville intrusives of the Helvetia and Greaterville mining districts and the quartz vein swarm of the Tyndall and Wrightson mining districts.

The Gringo Gulch Volcanics, deposited in the southeastern part of the mountains, consist largely of rhyolitic to dacitic pyroclastic rocks and some intercalated lava flows, sandstone, and conglomerate. These are of Paleocene(?) age, lying unconformably upon plutonic rock as young as 65 m.y. (million years) old and probably intruded by a plug dated as 55–60 m.y. old. The Gringo Gulch Volcanics probably are correlative with the much altered and mineralized rocks here termed volcanics of Red Mountain, which are abundant in the adjacent part of the Patagonia Mountains to the southeast.

Several kinds of late Paleocene small intrusives are dated as about 55 m.y. old. The plugs of the Gringo Gulch area, to the southeast, are dacite porphyry to microgranodiorite in composition. The Cottonwood Canyon dike swarm, intruding mainly the west flank of the mountains, is a coarsely porphyritic quartz latite. The Helvetia stocks, granodiorite and quartz diorite in composition, and the Greaterville intrusives, of quartz latite porphyry, occur in the northern part of the mountains. The Greaterville intrusives, locally called the ore porphyry, are associated spatially with base-metal and noble-metal mineralization and may be related to it genetically, at least to the extent that magmas and mineralizing fluids used the same ducts.

Small intrusive bodies and veins also were emplaced during the Paleocene to Oligocene interval, possibly mainly during the Eocene. Andesitic dikes and plugs intruded rocks as young as the Helvetia stocks, and small plugs of olivine andesite intruded late(?) Paleocene faults, in the northern part of the mountains. A large swarm of quartz veins contains base metals and silver in the southern part of the range.

Two groups of rocks were deposited and intruded into the area during the Oligocene. One group, on the southwestern flank of the mountains, is made up of an igneous complex of abundant rhyolite and rhyodacite volcanics and subordinate epiclastic rocks (all of the Grosvenor Hills Volcanics), rhyodacite vitrophyre laccoliths and dikes emplaced near the surface, a swarm of rhyodacite dikes emplaced at depths of a few thousand feet, and the top of a granodiorite stock. A genetic association among the rocks of this complex is demonstrated by the similarity of their chemical, petrographic, structural, and isotopic analyses. The other group, in the central and northern parts of the mountains, consists of rhyolite porphyry of one plug and of two northeast-trending dike swarms.

Gravels of late Tertiary and Quaternary age fill the basins around the mountains and lap across narrow pediments on many of their flanks. The oldest of these is Miocene(?) and Pliocene gravel of Nogales, which is commonly tilted and faulted. The gravel of Nogales is overlain by a widespread basin-fill Pliocene and Pleistocene gravel which is only locally tilted and faulted. The basin-fill gravel is overlain by a sequence of three soil-capped terrace and pediment units of Pleistocene age, none of which are tilted and only the older two of which are locally faulted, and by Holocene gravel.

INTRODUCTION

Sedimentary and volcanic rocks and related intrusive rocks, of Cenozoic age, underlie much of the flanks of the Santa Rita Mountains. These rocks constitute most of the geologic record of the time between the main events of the Laramide orogeny, a time of major mountain-making activity that peaked 70–75 m.y. (million years) ago, and the present. During this time the rocks of the region were frequently deformed but less severely than during the Laramide, parts of the region were mineralized, basins containing the chief water supplies were formed, and the present topography was developed. The Santa Rita Mountains provide one of the most extensive geologic records of Cenozoic events in southeastern Arizona and thus serve as a reference area from which to develop a regional geologic history.

The Santa Rita Mountains are the first range southeast of Tucson. They extend more than 25 miles southward from Pantano Wash, along which the main railroad and highway east of Tucson lie, to Sonoita Creek, about 12 miles from the Mexican border (fig. 1). The mountains commonly reach heights of 6,000 to 7,000 feet, and the highest mountain, Mount Wrightson, is 9,453 feet high. The

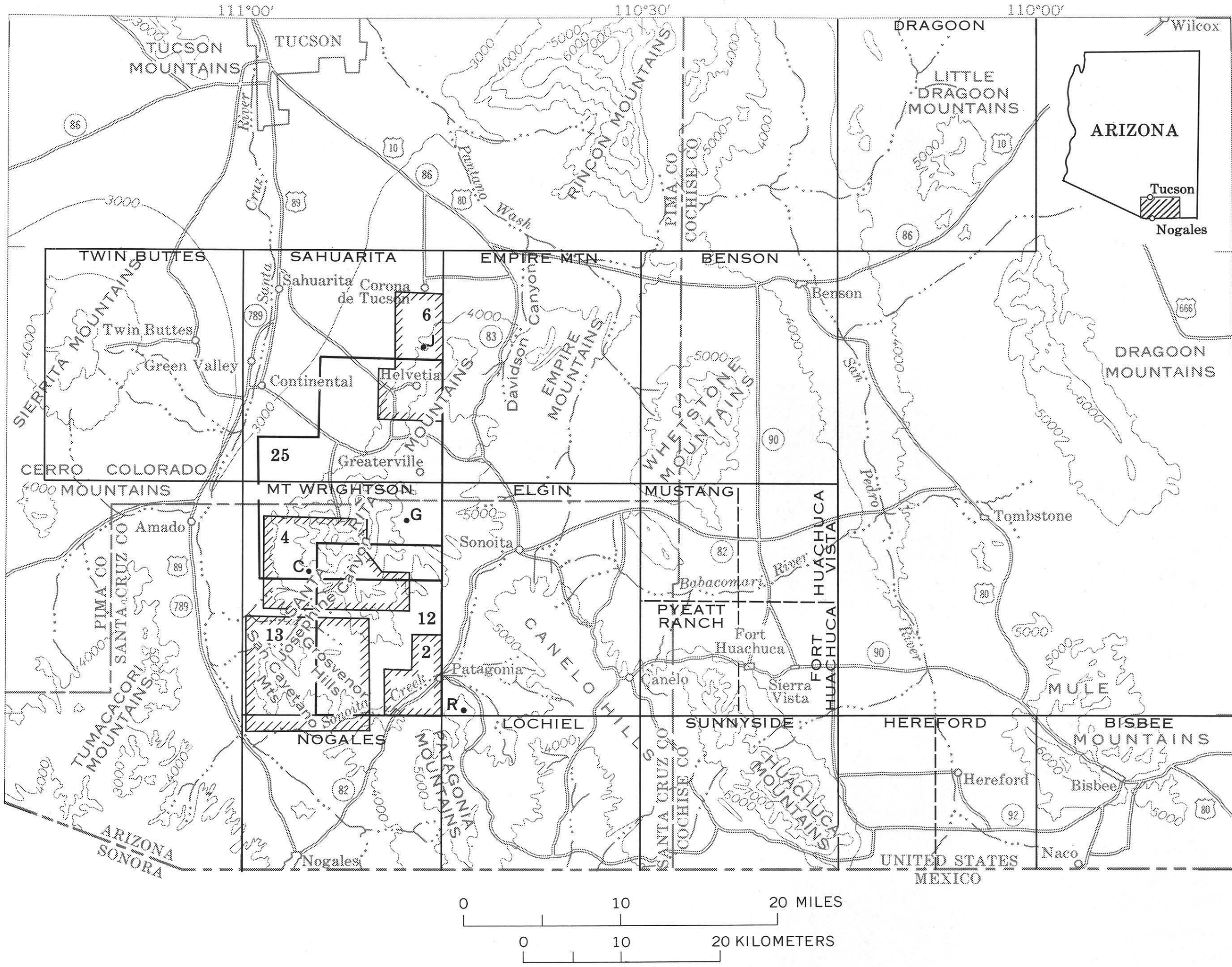

FIGURE 1.—Index map showing location of the Sahuarita and Mount Wrightson quadrangles and the Santa Rita Mountains. Positions of detailed maps used in text are shown by text figure numbers. J, Johnson Ranch and Sycamore Canyon; C, Cottonwood Canyon; G, Gardner Canyon; R, Red Mountain.

broad valley to the east lies at an elevation of about 4,500 feet, whereas that to the west is only at 3,000 feet. The mountains thus are sufficiently high to receive enough moisture to support extensive, largely scrubby forests, which contrast markedly with the grasslands to the east and the Sonoran Desert vegetation to the west.

The Santa Rita Mountains are nearly surrounded by an apron of coalescing alluvial fans; in many places the fans end abruptly against the foot of steep mountains, but in other places they end gradually in a transitional belt of rolling foothills. Along the northwest flank, for instance, the mountains terminate abruptly and the fans lap directly against steep slopes that rise many hundreds of feet. The knob called Elephant Head, 8 miles southeast of Continental, rises 2,000 feet above the flanking alluvial fan in about half a mile. Along much of the east flank and the south end of the mountains, the fans have been dissected to form gentle hills with a local relief of a few hundred feet. Some bedrock hills project above the highest alluvial apron, whereas some have been exhumed from beneath it. Broad pediments are common adjacent to the gentle mountain flanks, and narrow or discontinuous pediments lie off parts of the steeper mountain flanks.

OBJECTIVES

Description of the stratigraphy and petrography of the Cenozoic rocks of the Santa Rita Mountains and interpretation of their environments of deposition or emplacement are the main objectives of this report. The area of concern is the Mount Wrightson and Sahuarita 15-minute quadrangles, which includes in addition to the Santa Rita Mountains the relatively small areas of the San Cayetano Mountains, the Grosvenor Hills, and low unnamed hills which lie between the Santa Rita Mountains and the Patagonia Mountains to the southeast (fig. 1). A small part of the northeast end of the Santa Rita Mountains extends outside the Sahuarita quadrangle, however, and is not described here.

The geologic units described here are all younger than the Piman phase (Drewes, 1969), or main phase, of the Laramide orogeny. They consist of (table 1) (1) some volcanic and clastic rocks deposited between the two local phases of the Laramide, during Paleocene(?) time, (2) several dike swarms and associated plugs, of Paleocene age, (3) stocks of granitoid rocks and intrusives of quartz latite porphyry, also of Paleocene age, (4) quartz veins, volcanics, plugs, and dikes, of Oligocene to Paleocene age, (5) volcanics, laccoliths, and dikes, of late(?) Oligocene age, and (6) assorted gravel deposits and soils flanking the mountains. At least some of the intrusives of group 3 are probably associated with the magmatic events of the Helvetian phase, or late phase, of the Laramide orogeny. They are briefly described in this report, to preserve the continuity of the discussion of geologic events, but inasmuch as they are ancillary to the major plutonic masses of the Laramide, they will be described more fully in another report I am preparing on the plutonic rocks.

The geologic investigation of the Santa Rita Mountains is part of a larger program of the U.S. Geological Survey to map and interpret the geologic history of all the ranges roughly between Tucson and Bisbee (fig. 1). Many geologists are involved in this program, and most of their field studies are completed. Cooper (1970) has mapped the Sierrita Mountains; Finnell (1971), the Empire Mountains; Creasey (1967), the Whetstone Mountains; R. B.

TABLE 1. — *Summary of Cenozoic rocks of the Santa Rita Mountains*

[Broken lines indicate that the adjacent formations are contemporaneous or that their relations are uncertain]

Age		Rock unit			Description	Thickness (feet)
Holocene		Youngest gravel			Gravel and intercalated sand on floors of modern watercourses.	0–100±
Holocene		Low-level terrace deposits		Gravel facies	Cobble to pebble gravel and intercalated sand; capped by infantile gray soil.	0–200±
Holocene		Low-level terrace deposits		Silt facies	Silt and loam of the Santa Cruz River terrace; capped by infantile gray soil.	0–200±
Pleistocene	Late	Intermediate-level pediment and terrace deposits			Boulder to pebble gravel, grit, and intercalated sand; capped by weakly developed thin reddish-brown soil.	0–400±
Pleistocene	Middle	High-level pediment deposits			Boulder to pebble gravel and intercalated sand; locally cemented; capped and overlapped by well-developed thick red soil.	0–50±
Pleistocene and Pliocene		Basin-fill gravel		Piedmont facies	Cobble to pebble gravel, grit, and intercalated sand and silt; commonly pinkish gray, slightly indurated, and locally well cemented.	0–2,000±
Pleistocene and Pliocene		Basin-fill gravel		River facies	Well-sorted cobble to pebble gravel and sand, locally cemented.	0–300±
Pleistocene and Pliocene		Basin-fill gravel		Tuff beds	Very light gray rhyolitic tuff and tuffaceous sandstone.	0–20
Pliocene and Miocene		Gravel of Nogales			Cobble to pebble gravel, which is rich in volcanic clasts, and tuffaceous sand and silt, which is pale red to brownish gray, poorly sorted, and slightly indurated.	0–1,000±
Late(?) Oglicene		Rhyolite intrusives of the northern Santa Rita Mountains			Rhyolite porphyry of a plug and of two dike swarms; locally a brown vitrophyre.	
Late(?) Oglicene		Igneous complex of the southern Santa Rita Mountains	Dikes and stock of the San Cayetano Mountains		Rhyodacite porphyry dike swarm and moderately coarse grained light-gray granodiorite.	
Late(?) Oglicene		Igneous complex of the southern Santa Rita Mountains	Dikes and laccoliths in the Grosvenor Hills area		Rhyodacite vitrophyre intrusives, medium-gray to light-gray.	
Late(?) Oglicene		Igneous complex of the southern Santa Rita Mountains	Grosvenor Hills Volcanics	Rhyodacite member	Rhyodacite lava flows, agglomerate, tuff, and welded tuff.	150–2,200
Late(?) Oglicene		Igneous complex of the southern Santa Rita Mountains	Grosvenor Hills Volcanics	Rhyolite member	Rhyolite tuff and a little welded tuff and lava.	500+
Late(?) Oglicene		Igneous complex of the southern Santa Rita Mountains	Grosvenor Hills Volcanics	Gravel and silt member	Pale-red silt and gravel with well-rounded pebbles; includes some shale and fresh-water limestone.	0–200
Oligocene to Paleocene		Quartz vein swarm			Mineralized quartz veins of the southern Santa Rita Mountains.	
Oligocene to Paleocene		Rhyolitic volcanics			Rhyolitic tuff and lava(?) of Wasp Canyon.	0–100
Oligocene to Paleocene		Olivine andesite plugs			Vesicular and amygdaloidal olivine andesite of Deering Spring.	
Oligocene to Paleocene		Andesitic dikes			Andesite, dacite, and diorite dikes, sills, and some small pipes.	
Paleocene		Greaterville intrusives			Quartz latite porphyry dikes and plugs, light-gray to grayish-orange-pink; contains stubby bipyramidal quartz phenocrysts; associated with base- and noble-metals enrichment; plugs are ameboid shaped.	
Paleocene		Helvetia stocks		Quartz diorite	Medium-dark-gray medium-coarse-grained quartz diorite.	
Paleocene		Helvetia stocks		Granodiorite	Light-gray medium-coarse-grained stocks of granodiorite to quartz monzonite composition; elliptical shaped.	
Paleocene		Cottonwood Canyon dike swarm			Quartz latite porphyry, finely porphyritic to coarsely porphyritic.	
Paleocene		Plugs of Gringo Gulch area		Microgranodiorite	Light-brownish-gray very fine grained granodiorite in core of a plug.	
Paleocene		Plugs of Gringo Gulch area		Dacite porphyry	Hornblende dacite, medium-dark-gray, locally coarsely porphyritic.	
Paleocene(?)		Volcanics of Red Mountain			Intensely altered rhyolitic and andesitic pyroclastic rocks.	
Paleocene(?)		Gringo Gulch Volcanics		Upper member	Rhyolitic to dacitic tuff, welded tuff, tuffaceous sandstone, and a capping andesite lava flow.	900+
Paleocene(?)		Gringo Gulch Volcanics		Lower member	Rhyolitic and dacitic pyroclastic rocks and some flows; contains intercalated epiclastic rocks.	700+

Raup (unpub. data, 1971), the Canelo Hills; Simons (1971a, b), the Patagonia Mountains; Hayes, the Huachuca Mountains, and Raup, the Mustang Mountains (Hayes and Raup, 1968); and Hayes and Landis (1964), the Mule Mountains.

ACKNOWLEDGMENTS

The collateral work produced through a larger program of the U.S. Geological Survey has provided both supporting and restraining data for the interpretations of the Cenozoic geology of the Santa Rita Mountains. However, the Cenozoic record is less complete outside the Santa Rita Mountains than within them, so the validity of the interpretations on correlation and environments of deposition has generally not been widely tested. Nevertheless, some of these interpretations were developed jointly with my colleagues, whose assistance is gratefully acknowledged, and will also be applied to geologic situations in adjacent areas. The interpretations here are thus not necessarily the results solely of my efforts; yet the validity of their local application remains my responsibility.

The success of the field investigation was facilitated by many people. Invaluable assistance in mapping and sampling was provided by G. C. Cone, Bruce Hansen, C. W. Norton, F. W. Plut, J. R. Riele, R. A. Rohrbacker, Albert Sutheimer, and W. M. Swartz between 1963 and 1968. Discussions in the field with R. E. Wallace, M. D. Crittenden, Jr., J. H. Courtright, and P. H. Pickard helped to clarify some problems and to raise others for which I am particularly grateful. The courtesies of George Bradt, Roy Green, Dewey Keith, and George Yakobian, residents near the Santa Rita Mountains, and of Profs. John Anthony, D. L. Bryant, Evans Mayo, and S. R. Titley, at the University of Arizona, and of E. S. Davidson, M. E. Cooley, Fred Pashley, and S. C. Martin, of various government offices, are also acknowledged.

Invaluable support was obtained from many laboratories. Some radiometric dates were obtained from Prof. P. E. Damon before their publication, and many other dates were provided by R. F. Marvin, T. S. Stern, S. C. Creasey, and their colleagues. The numerous chemists and spectrographers who have contributed are acknowledged in the tables included in this report. G. C. Cone also ably assisted in many phases of the general preparatory work.

GEOLOGIC SETTING

The geologic record of the development of the Santa Rita Mountains during the Cenozoic Era follows a fragmentary record of the Precambrian history and a more extensive record of the Paleozoic and Mesozoic history. The basic data appear on the geologic maps, first open-filed in 1966 and 1968 and now published (Drewes, 1971a, c), which will be referred to frequently. Some collateral reports on geochemistry of the area and on stratigraphy are now or will soon be available (Drewes, 1967, 1968, 1971b; 1972a, b; Hayes and Drewes, 1968; Simons and others, 1966).

The oldest known rocks of southeastern Arizona are the Pinal Schist, which generally includes some gneiss and migmatite. The schist is most extensively exposed and best studied in the Little Dragoon Mountains, where Cooper and Silver (1964, p. 11–23) described it in considerable detail as a sequence at least 20,000 feet thick of metamorphosed conglomerate, sandstone, siltstone, shale, and rhyolite and basalt lava flows. They further described the major aspect of this sequence as a "cyclic graywacke-slate lithology," which contains "graded bedding, the intercalated lava flows, and the abundant volcanic debris." L. T. Silver (oral commun., 1968) dated a rhyolite flow as 1,715±10 m.y. old using the U-Pb isotopic method on a suite of zircon samples. The thickness and lithology of the Pinal Schist were interpreted by Cooper and Silver (1964) as indicative of geosynclinal deposits. Some aspects of this geosyncline were reviewed by Anderson (1951, p. 1345).

In the Santa Rita Mountains, schist and gneiss that have been correlated with the Pinal Schist form inclusions, roof pendants, and remnants of wallrock of large granitoid plutons of Precambrian and younger ages. The schist and gneiss are inconsequential as detrital components of the Cenozoic clastic deposits of the mountains.

Extensive masses of coarse-grained and porphyritic alkali granite, quartz monzonite, or granodiorite occur in many of the ranges of southeastern Arizona in which the Pinal is exposed. The batholiths and stocks intruded the Pinal and commonly metamorphosed the schist along their contacts. Several of these granitoid masses have been dated by the U-Pb, Pb-alpha, and Rb-Sr methods. Based on these dates and on geologic relations currently being studied, intrusives in southeastern Arizona are probably representative of two older (1,650–1,760 m.y.) magmatic episodes and a younger (1,430–1,460 m.y.) magmatic episode (Silver, 1969).

In the Santa Rita Mountains much of the basement rock is the Continental Granodiorite, a coarse-grained porphyritic granodiorite and quartz monzonite with a radiogenic date of 1,450 m.y. but possibly older. One sample of this rock was dated by Rb-Sr and by Pb-alpha methods as Precambrian, but another sample, dated by the K-Ar method, records only a Laramide thermal event (Drewes, 1968, p. C5). This rock characteristically disaggregates upon weathering to form grus and gritty detritus that is a widespread component of the younger deposits in the northern part of the mountains.

Rocks of the Apache Group of Precambrian age, although absent in the Santa Rita Mountains, are present in areas a few miles to the northeast, and they shed light on the geology of the Santa Rita Mountains at that time. The Apache Group unconformably overlies the Pinal Schist and the granodiorite masses, and it is intruded by diabase of Precambrian age. The stratigraphic sequence of this group is probably most complete in the Little Dragoon area, where it was described in detail by Cooper and Silver (1964, p. 36–41). But even there the upper of the three formations comprising the group, as present farther to the north, is absent. The total absence of the Apache Group in the central and southern parts of southeastern Arizona, including the Santa Rita Mountains, and the absence of the upper third of that group in the northern part indicate either that during the Precambrian these areas remained sufficiently high so as not to receive sediments during all of Apache time or, more likely, that they were uplifted and the top of the Apache deposits was eroded.

The Precambrian geologic history of the area thus includes an early time of sedimentation, orogeny and attendant metamorphism and batholithic intrusion of at least one episode, further sedimentation, and diabase intrusion and minor crustal disturbance.

The Precambrian rocks of the Santa Rita Mountains are unconformably overlain by a sequence of Paleozoic shallow marine deposits 5,000–6,000 feet thick. The sequence extends from the Bolsa Quartzite of Middle Cambrian age to the Rainvalley Formation of late Early Permian age. Limestone and dolomite are the most common rocks of the sequence, but clastic rocks are fairly abundant near its bottom and top. The continuity of the sequence is broken by several disconformities, of which the largest represents at least most of Ordovician time and all of Silurian time.

The Paleozoic geologic history of the area is one of alternating marine transgressions and regressions, reflecting successive epeirogenic movements. Toward the middle of the Permian Period the area was uplifted more strongly, and continental conditions became prevalent.

Three thick sequences of continental clastic and volcanic rocks, of Mesozoic age, lie unconformably upon the Paleozoic and Precambrian rocks of the Santa Rita Mountains (Drewes, 1971b). The lowest sequence, of Triassic rocks, consists of rhyodacite volcanics and some eolian sandstone and conglomerate of the Mount Wrightson Formation and of red beds and some volcanics and conglomerate of the Gardner Canyon Formation. The middle sequence, of Early Cretaceous age, consists of rhyolitic to andesitic volcanics and of coarse conglomerate of the Temporal and Bathtub Formations, overlain by arkose and conglomerate of the Bisbee Group; the Apache Canyon Formation of the Bisbee Group contains also a little intercalated marine limestone. The highest sequence consists of the Fort Crittenden Formation of Late Cretaceous age, which also contains arkose and conglomerate, and the overlying Salero Formation, which is made up of coarse conglomerate and abundant dacitic and rhyodacitic volcanic rocks. The Santa Rita Mountains were intruded by monzonitic stocks of Triassic age, by a large granite stock, the Squaw Gulch Granite, of Jurassic age, and by several stocks of quartz diorite to quartz monzonite of late Late Cretaceous age.

The Mesozoic geologic history of the area is more complex than the pre-Mesozoic geologic history. Soon after the beginning of continental conditions, the area was strongly faulted, and volcanics and red beds filled some large basins. Late during the Triassic, the rocks were faulted again and were intruded by Piper Gulch Monzonite. These events are possibly distant and slightly delayed effects of the Sonoran Orogeny, proposed by Fries (1962). Further volcanism was followed, near the middle of the Jurassic, by the intrusion of a large granite stock and by strong uplift. During the Early Cretaceous, volcanism was resumed locally, along with the deposition of conglomerate at the foot of block-faulted mountains. The finer clastic rocks deposited later during this time indicate a waning local relief and possibly some subsidence. An arm of a continental sea briefly encroached upon the area and deposited the limestone beds.

A final major geologic event preceded the deposition of Cenozoic rocks and began during the Late Cretaceous, perhaps as long as 90 m.y. ago (Drewes and Finnell, 1968, p. 315; Drewes, 1969). Initial tectonic activity was recorded by a coarsening of the epiclastic deposits, a resurgence of volcanism, and the appearance of unconformities in the stratigraphic column. Before the close of the Cretaceous these rocks and older rocks were strongly thrust faulted and folded, and then they were invaded by a group of granitoid stocks. These stocks are (1)

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a large stock of Josephine Canyon Diorite, mainly a medium-coarse-grained rock of diorite to quartz diorite composition but also containing a late quartz monzonitic phase; (2) smaller stocks of coarse-grained Elephant Head Quartz Monzonite; and (3) a composite stock of coarse-grained Madera Canyon Granodiorite. I have briefly described these rocks previously (Drewes, 1968). Collectively, these events are referred to as the Piman phase of the Laramide orogeny, which is the earlier and stronger of the two phases recorded southeast of Tucson.

The sedimentary and volcanic rocks deposited after the Piman phase, and described in this report, are summarized in table 1. The oldest of these rocks was intruded by both plutonic and hypabyssal masses and was deformed during the Helvetian phase, the younger and weaker subdivision of the Laramide.

PALEOCENE AND PALEOCENE(?) ROCKS

Two groups of rocks of the Santa Rita Mountains are largely or wholly of Paleocene age. The older group consists of a sequence of volcanics and some intercalated epiclastic rocks assigned to the Gringo Gulch Volcanics, of Paleocene (?) age, and a small mass of highly altered volcanic rock assigned to an unnamed unit, here referred to as the volcanics of Red Mountain, also of Paleocene (?) age. The younger group of rocks consists of small stocks, plugs, and dikes, which commonly are of porphyritic texture and of latitic to dacitic composition. Some of the intrusives have associated mineralized rocks. Radiometric dating of some of these intrusives indicates that they are Paleocene.

GRINGO GULCH VOLCANICS

The Gringo Gulch Volcanics (Drewes, 1968, p. C14) are a sequence largely of rhyolitic to dacitic tuffs 1,500–2,000 feet thick that unconformably overlies rocks as young as the Salero Formation and the Josephine Canyon Diorite, both of late Late Cretaceous age. The scanty available geologic data, described later, suggest that these volcanics were deposited before about 55 m.y. ago, at which time they were intruded, altered, and in places mineralized.

The volcanics underlie an area of at least 6 square miles in the southeast corner of the Mount Wrightson quadrangle near Patagonia (fig. 2), and they probably underlie an additional 4 square miles beneath a cover of gravel within the quadrangle. The volcanics also extend southward into the Nogales quadrangle (fig. 1), and their probable correlatives, the volcanics of Red Mountain, which are described under the section "Volcanics of Red Mountain," are extensively exposed in the Elgin and Lochiel quadrangles to the east and southeast.

In outcrops the Gringo Gulch Volcanics are typically composed of light-colored and flat-lying or gently inclined massive units. Although most of the tuffaceous rocks are only moderately well indurated and rather friable, a few bedded units are strongly indurated and form small cliffs, ledges, and buttes that contrast markedly with the gently rolling hills characteristic of the weakly indurated tuffs. In addition to the indurated bedded units, many pods of silicified rock near the Narrows along Sonoita Creek, 3–4 miles southwest of Patagonia (fig. 2, loc. *D*), form knobs and east-west alined rock ribs. Most of the tuffs are very light gray to very pale orange, some are darker gray or bluish gray, and a few are variegated in pale pink and green. The few andesitic lava flows of the formation are brownish gray, and the dacitic and andesitic epiclastic rocks are greenish gray or bluish medium gray.

STRATIGRAPHY AND PETROGRAPHY

The Gringo Gulch Volcanics consist of many lenticular units which are divided on a stratigraphic basis into the lower and upper members. Both members are composed largely of rhyolitic tuffs and tuff breccias; the upper member is distinguished by a basal bluish-gray partly welded tuff and some andesitic flows, whereas the lower member contains some dacitic flows and epiclastic rocks derived from dacitic volcanics.

The formation overlies an unconformity of moderate relief. To the north, along Gringo Gulch (fig. 2), the two members lap unconformably over rocks of the Lower Cretaceous Bathtub Formation (Drewes, 1971b), which is one of the formations mapped as older rocks (Mesozoic) in figure 2. To the south, between Sanford Butte and locality *A* in figure 2, rocks of the lower member lap against the Josephine Canyon Diorite and some older rocks, such as the Salero Formation (Drewes, 1968, and unpub. data). Although the actual contact of the volcanics with the diorite is everywhere covered because of the friability of the volcanic rocks, that contact is believed to be depositional rather than intrusive because the volcanics are neither contact metamorphosed nor included in the diorite, as is the slightly older Salero Formation. Furthermore, in a few places conglomerate lenses in the lower member of the Gringo Gulch Volcanics contain dioritic clasts that could have been derived from the Josephine Canyon Diorite, although sparse alternative sources are also available.

LOWER MEMBER

The lower member of the Gringo Gulch Volcanics is about 700 feet thick and is made up of a lower unit containing dacitic and rhyolitic rocks and an upper unit containing only rhyolitic tuff. The lower unit is exposed in low topographic positions south and west of the lower reaches of Temporal Gulch; the upper unit caps all but the highest of the hills in the same area and extends farther to the northeast.

The lower unit of the lower member consists of a few dacitic flows, many lenses of dacitic sandstone and conglomerate, a rhyolite flow, and some rhyolitic tuff and tuff breccia.

Dacitic lava of the lower unit is medium gray on unweathered surfaces and olive gray to pale yellowish brown on weathered ones. It commonly is finely porphyritic, and along Squaw Gulch it is slightly vesicular and amygdaloidal. In thin section, the phenocrysts are seen to make up 10–20 percent of the rock and to be set in a felty to pilotaxitic groundmass. In a typical sample, plagioclase phenocrysts make up 2–5 percent of the rock and have a sodic labradorite (An_{53}) composition. Quartz is sparse and probably secondary. Pyroxene makes up 4–8 percent of the rock; either orthopyroxene or clinopyroxene is present, but they have not been found together. One specimen contains relicts of amphibole and biotite. Magnetite and apatite accessory minerals are commonly present, and interstitial altered glass is a rare constituent. The rocks are commonly argillized and propylitized, but generally to a much lesser degree than are the Cretaceous and older rocks. The plagioclase is usually albitized as well, and the glass is devitrified.

The rhyolite flow of the lower unit is the only rock of its kind in the Gringo Gulch Volcanics, and inasmuch as it lies in the lowest stratigraphic position, southwest of Sanford Butte, its assignment to the Gringo Gulch is provisional. This flow differs from the next older known stratigraphic unit, the Salero Formation, whose lava flows commonly contain less quartz and more biotite. For convenience, then, the rhyolite is accepted as part of the younger formation.

The rhyolite flow contains about 35 percent phenocrysts, as much as 4 mm (millimeters) long, and it also contains traces of xenoliths. As seen under the microscope, the phenocrysts comprise 15 percent quartz, 10 percent each of intensely argillized potassium feldspar and of albitized(?) plagioclase, and traces of chloritized biotite, magnetite, and zircon.

Rhyolitic tuff and tuff breccia also occur in the lower unit of the lower member of the Gringo Gulch Volcanics, mainly west of Squaw Gulch (fig. 2), where they interfinger with the dacitic rocks. These tuffaceous rocks so closely resemble the more abundant tuff of the upper unit that they are not described separately here.

Dacitic rocks overlie the rhyolite flow and are fairly widespread along canyon bottoms. Dacitic epiclastic rocks are commonly greenish gray to bluish gray and are poorly bedded and poorly sorted. Dacitic sandstone and grit are more abundant than conglomerate, and few of the clasts in the conglomerate are larger than pebbles. Most clasts in the conglomerate were derived from nearby dacitic lavas, but some may have been supplied by the more distant volcanics of the Salero Formation. Along Squaw Gulch north of the Salero Road, the conglomerate beds in this unit contain some clasts of strongly indurated layered volcanics derived from the Triassic Mount Wrightson Formation (Drewes, 1968, 1971b) exposed to the north, some of the Jurassic Squaw Gulch Granite (Drewes, 1968, and unpub. data) probably derived from the north, and some of a diorite whose source may have been the nearby Upper Cretaceous Josephine Canyon Diorite but which may alternatively have been derived from inclusions of lamprophyre dikes found in the Squaw Gulch Granite 2 miles to the north.

The upper unit of the lower member consists of a sheet of rhyolitic tuff breccia about 300 feet thick which lies over the dacitic rocks of the lower unit. This sheet extends continuously from Sanford Butte northeastward to the mouth of Temporal Gulch and extends discontinuously northward to Gringo Gulch. The lower part of this tuff, as much as 80 feet thick, is poorly indurated and resembles the rhyolitic tuff of the lower unit to such an extent that the two tuffs are commonly indistinguishable in the field where the intervening dacitic rocks pinch out. Some of the tuff breccia above the dacitic rocks contains fragments of dacite, suggesting that part of the lenticularity of the dacite is the result of erosion. The poorly indurated tuff thins out east of locality *A* in figure 2 and is not distinguished from the overlying rocks southeast of Sonoita Creek.

The upper part of the upper unit is a well-indurated and strongly jointed very pale orange to pinkish-gray rhyolitic tuff — rarely a welded tuff — about 200 feet thick. In some places the rock forms a strongly pinnacled or castellated topography, of which a modest sample appears in the foreground of figure 3; in other places large surfaces are stripped of cover; and elsewhere joint blocks of indurated tuff have slumped from their source cliffs over the gentle slopes on the underlying weaker tuff. The

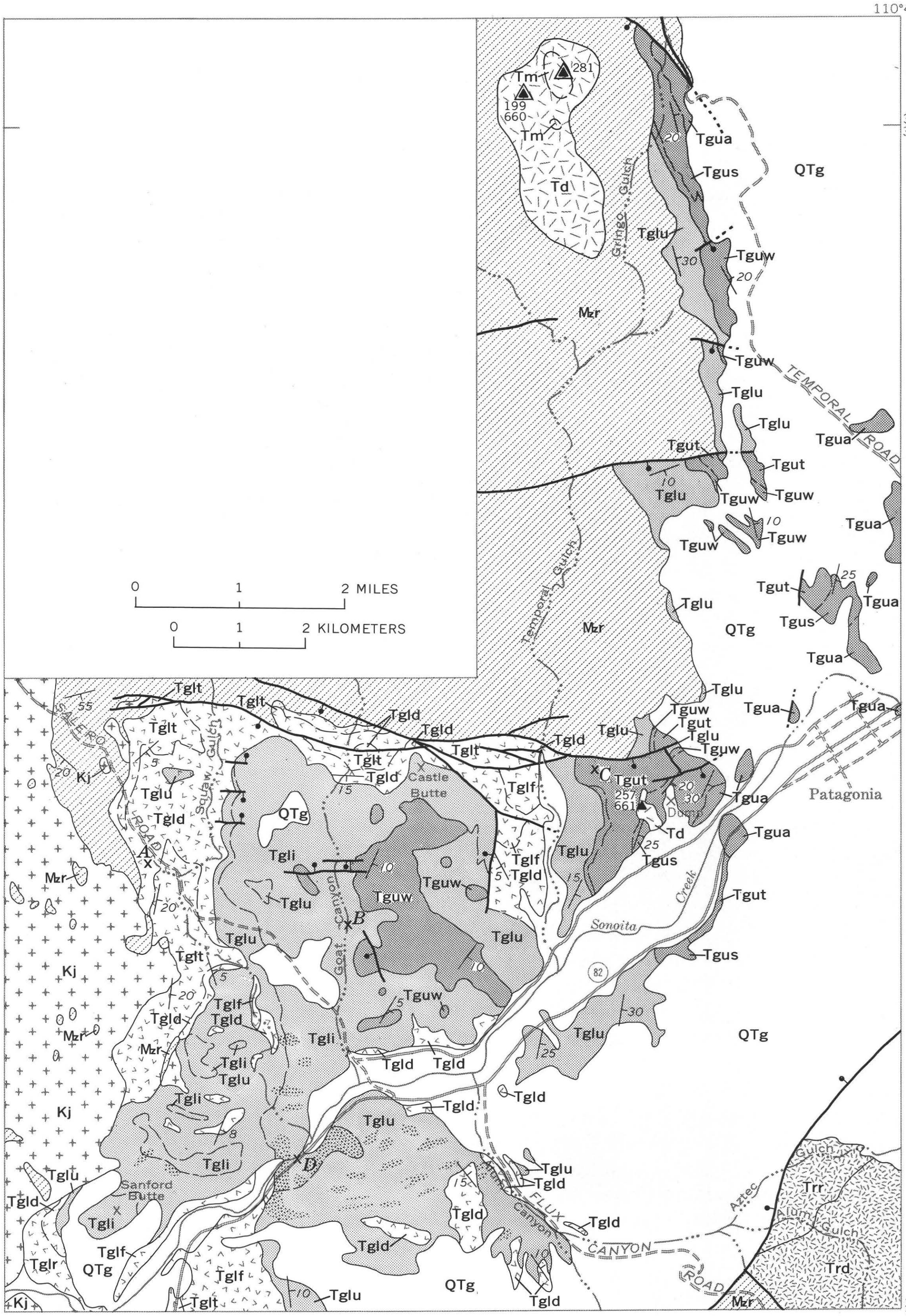

FIGURE 2. — Distribution of the Gringo Gulch Volcanics near Patagonia. Base from U.S. Geological Survey: Mount Wrightson quadrangle, 1:62,500, 1958.

EXPLANATION

Pliocene and Pleistocene — TERTIARY AND QUATERNARY

QTg

Gravel

Paleocene — TERTIARY

Td | Tm

Intrusive rocks

Td, *dacite porphyry*

Tm, *microgranodiorite*

Paleocene (?)

Trr
Trd

Volcanics of Red Mountain

Trr, *rhyolitic rocks*

Trd, *dacitic rocks*

Gringo Gulch Volcanics

Tgua
Tgus
Tgut
Tguw

Upper member

Tgua, *andesitic lava*

Tgus, *andesitic sandstone*

Tgut, *rhyolitic tuff and tuffaceous sandstone*

Tguw, *bluish-gray tuff*

Lower member

Tgli
Tglu

Upper unit

Tgli, *indurated rhyolitic tuff*

Tglu, *rhyolitic tuff breccia*

Stipple, silicified tuff

Tgld | Tglf
Tglt | Tglr

Lower unit

Tgld, *dacitic clastic rocks*

Tglf, *dacitic lava flows*

Tglt, *rhyolitic tuff and tuff breccia*

Tglr, *rhyolite flow*

Upper Cretaceous — CRETACEOUS

Kj

Josephine Canyon Diorite

Mzr

Older rocks (Mesozoic)

Contact

Dashed where approximately located

Fault

Dotted where concealed. Bar and ball on downthrown side

5

Strike and dip of beds

x*A*

Locality referred to in text

257

Collection site of chemically analyzed specimen

281

Collection site of radiometrically dated specimen tuff in the upper part of the upper unit decreases rapidly eastward in degree of induration and merges with the tuff in the lower part of the upper unit. In a few places, as near the unnamed spring along lower Goat Canyon, near locality *B* in figure 2, and also in the cliffs southeast of State Highway 82 at the Narrows, locality *D* in figure 2, pumiceous fragments in the tuff are flattened, presumably a result of incipient welding.

Under the microscope, specimens of the tuff and indurated tuff are seen to contain crystal and lithic fragments in equal abundance, neither of which exceeds 10 percent of the rock. The tuff groundmass is cryptocrystalline, is faintly fragmental, and contains abundant clay minerals and some sericite and secondary(?) quartz. Quartz xenocrysts make up at least 5 percent of the crystals, many of which are partly resorbed. Plagioclase makes up 2½ percent of the rock; it is albite, and presumably it is albitized from a more calcic mineral. Potassium feldspar, in one specimen a sanidine, also makes up 2½ percent. Most rocks contain no pseudomorphs of ferromagnesian minerals, but remnants of altered biotite are preserved in a thin indurated tuff breccia 1½ miles northwest of Patagonia. The ubiquitous accessories — magnetite, apatite, and zircon — occur in minor amounts, and a trace of leucoxene enclosed in sanidine was seen in one specimen. The welded tuff in Goat Canyon contains an inclusion of glass in quartz, and it also contains several unidentified secondary minerals. Alteration of the rock was widespread, and though relatively mild, it affected most of the original minerals sufficiently to leave them unsuitable for isotopic dating.

Between Sanford Butte and the Flux Canyon road, the tuff breccia contains many east-trending silicified pods, which form bold outcrops stained with oxides of iron and manganese. The pods are commonly 100–200 feet wide and 500–1,000 feet long; those exposed along the deeper canyons have a greater height than width. Near Sanford Butte the pods blend into the intensely indurated sheet of tuff, but a few pods seem to be superposed on the indurated rock and to cross its basal contact. Under the microscope, specimens from the pods are seen to contain abundant secondary quartz in small disseminated crystals and in patches of small crystals. Clay minerals are abundant, and X-ray diffraction tests indicate that alunite is commonly present.

UPPER MEMBER

The upper member of the Gringo Gulch Volcanics is probably more than 900 feet thick and is made up of a lithologic assortment much like that of the lower member except for a distinctive basal bluish-gray tuff and for the presence of andesitic rather than dacitic rocks. The basal tuff is welded west of Temporal Gulch but is unwelded to the east and north. Rocks of the upper member cap the higher hills between locality *A* (fig. 2) and lower Temporal Gulch, and they underlie numerous areas between the Temporal Gulch–Gringo Gulch area and Patagonia. In sequence above the bluish-gray welded to unwelded tuff are a light-colored rhyolitic tuff and tuffaceous sandstone unit, a brownish-gray volcanic sandstone unit, and a medium-gray andesitic lava unit. Even within the limited area of exposure of these four units, the lithologies change laterally, but at least the andesitic lava extends east of Patagonia.

The basal bluish-gray tuff commonly is about 50 feet thick, but near locality *B* (fig. 2) it is as much as 150 feet thick, and farther south and east it is as little as 15 feet thick. The thicker tuff forms small ledges and cliffs (fig. 3); the thinner tuff underlies gentler slopes strewn with blocky detritus. Where it is welded, the tuff has lenticular, flattened inclusions of light-gray altered glass, some small xenoliths, and phenocrysts of altered biotite and plagioclase. In the unwelded facies, the flattened inclusions are absent, and the xenocrysts and phenocrysts are scarcer than in the welded facies. In thin section, the welded tuff is seen to have a coarsely microcrystalline groundmass in which the flattened pods, elongated to 15 times their thickness, are of altered glass having a still finer grain size (less than 0.005 mm). Oxybiotite phenocrysts make up 7 percent of the rock and appear only as relict cores in pseudomorphs of iron oxide and sericite. Albitized plagioclase phenocrysts form 3 percent of the rock and are strongly argillized. Magnetite and apatite are present in trace amounts. Quartz forms many small patches of anhedral crystals in the groundmass, as well as replacements of some phenocrysts, and so it is at least in part secondary.

The second unit, of light-colored rhyolitic tuff and tuffaceous sandstone, is about 300 feet thick. In most places this rock is only moderately well indurated, but 1½ miles west of Patagonia it contains a medial, thin, well-indurated tuff marker bed. Locally, at hill 4,335 (loc. *C* in fig. 2) and also south of Sonoita Creek, the rock is so intensely altered that the distinction between the two lower units of the upper member is unclear; at locality *C* at least, the abundance of coarse breccia in the tuffs suggests a proximity to a vent area. Along Gringo Gulch the unit consists of a friable pale-pink and pale-green tuff overlain by, and locally interfingering

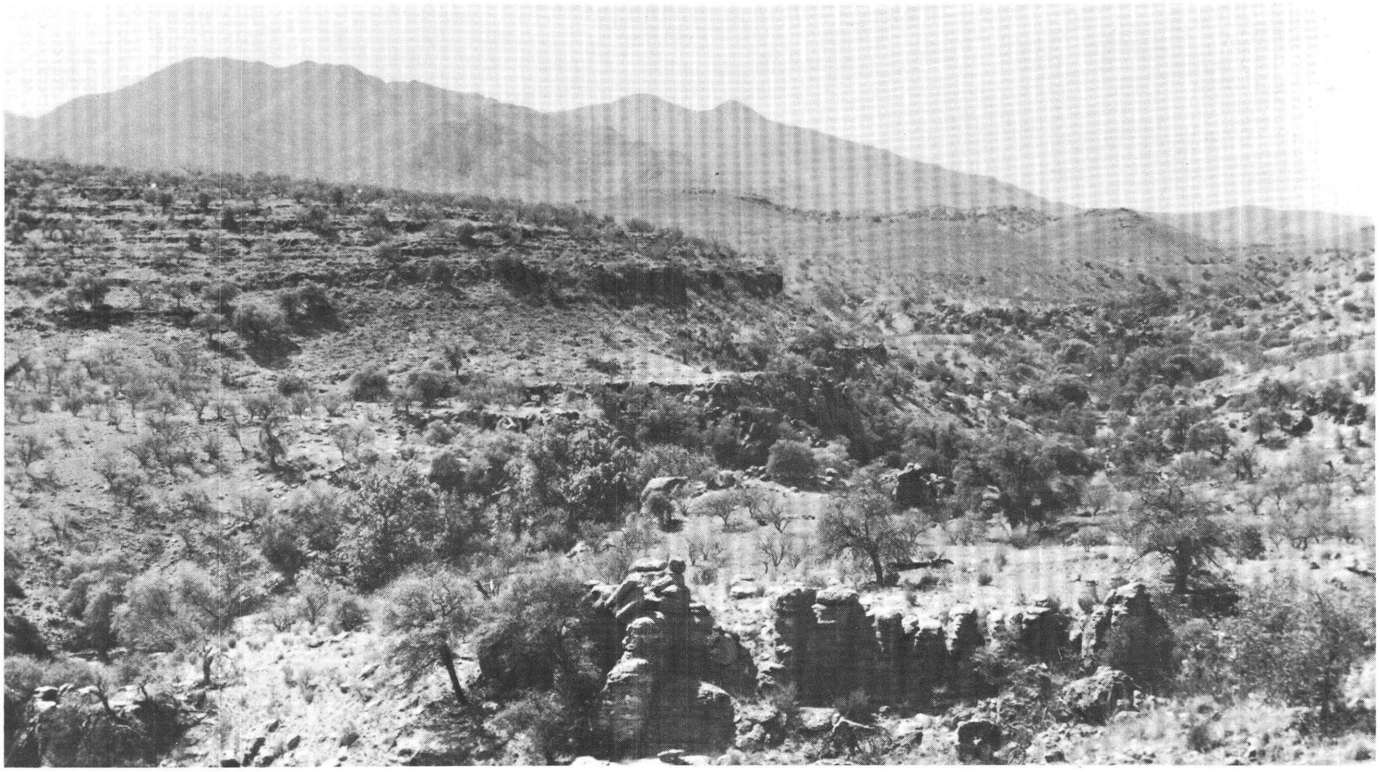

FIGURE 3. — Gringo Gulch Volcanics; view toward Patagonia Mountains to the southeast. Pinnacled outcrops in foreground are the top of the lower member of the volcanics; ledgy outcrops on low ridge to left are the basal welded tuff of the upper member.

with, a white tuff. About 4 percent of the tuff is made up of crystal fragments, of which half are oxybiotite and a quarter each are albite and potassium feldspar. Traces of magnetite, apatite, and zircon are present, and in one specimen a small vug contains quartz crystals. Iron oxide and clay minerals are dispersed in the largely cryptocrystalline groundmass.

The third unit, of brownish-gray volcanic sandstone, is 200–400 feet thick and lies concordantly and probably disconformably on the rhyolitic tuff. West of Patagonia the unit is thickest and consists of reworked white tuff with admixtures of andesitic or dacitic fragments. Half a mile north of Patagonia the unit consists of poorly sorted and poorly indurated, thin- to thick-bedded, coarse-grained sandstone. Along Gringo Gulch, where the unit is thinnest, it consists of andesitic or dacitic conglomerate and sandstone.

The top unit of the upper member, composed of medium-gray andesitic lava, is probably more than 200 feet thick. It is sporadically exposed on small somber-colored knolls within about a mile of Patagonia. The lava of the knolls is finely porphyritic, but phenocrysts differ slightly in kind from place to place; hence, the rocks probably represent more than one flow. The phenocrysts are about 1 mm long and make up 5–10 percent of the rock. The groundmass is felty to hyalopilitic, its crystal laths are about 0.1 mm long, and its granular crystals are 0.01–0.05 mm across. A clinopyroxene, possibly augite, is the most abundant phenocryst type. The augite(?) of one specimen contains cores of hypersthene, and the same specimen also contains plagioclase crystals whose cores are partly resorbed. Magnetite and apatite are the accessory minerals. Ferromagnesian minerals make up about 10 percent of the groundmass, and plagioclase (An_{55-50}) most of the remainder. Quartz and potassium feldspar(?) probably form some of the interstitial granular grains in the specimens that are free of hypersthene. Calcite, epidote, chlorite, iron oxide, clay minerals, and perhaps some quartz are the secondary minerals.

AGE

The Gringo Gulch Volcanics, as suggested by their geologic relations, probably are of Paleocene age. The volcanics unconformably overlie the upper Upper Cretaceous Salero Formation and are inferred to lie unconformably upon the Upper Cretaceous Josephine Canyon Diorite, whose youngest phase is dated as about 65 m.y. old (Drewes 1968, p. C12).

The time lapse between the emplacement of the diorite pluton and the deposition of the volcanics, recorded by the erosion of the roof of the pluton, is not believed to have been large, for the abundance of inclusions or pendants of the Salero in the diorite indicates that the top of the pluton is exposed, and the relatively fine grain size of the diorite suggests a rapid rate of cooling, also compatible with a shallow intrusion level.

The volcanics are further believed to be older than a small hornblende dacite plug near the Patagonia town dump. On the basis of petrologic similarity, this small plug is probably correlative with a larger plug a few miles to the north, which is isotopically dated as about 55–60 m.y. old (table 2). The Gringo Gulch Volcanics thus are dated as about 60 m.y. old, or as Paleocene(?). This age seems especially reasonable in that it explains why these volcanics, and more particularly the correlative volcanics of Red Mountain, are altered and mineralized in the manner of rocks near many ore porphyries of late Laramide (Paleocene) age but are not hornfelsed or deformed to the extent that many of the upper Upper Cretaceous rocks are.

ENVIRONMENT OF DEPOSITION

The Gringo Gulch Volcanics were deposited largely by airfall and fluvial processes. The few lava flows and welded tuff sheets occur mostly in the southern and western parts of the area, suggesting that their source lay in those directions. Other volcanics may have come from the Red Mountain area. The irregularities along the basal contact show that the surface on which the lowest rocks were deposited was hilly, yet the relative sparseness of clasts of older rocks in the intercalated epiclastic beds does not require strong local relief. The low relief and the absence of coarse-textured igneous rocks suggest a relatively inactive Gringo Gulch time between times of greater tectonic and plutonic activity more typical of the Laramide.

VOLCANICS OF RED MOUNTAIN

Intensely altered rocks, mainly of rhyolitic to dacitic or andesitic composition, underlie the flank of Red Mountain in the southeast corner of the Mount Wrightson quadrangle and are here referred to as the volcanics of Red Mountain. They are only briefly described in this report, inasmuch as they extend widely into the adjacent quadrangles, where they have been more thoroughly studied by R. B. Raup and F. S. Simons (unpub. data). The volcanics are poorly exposed on steep slopes of the mountain, but they are well exposed along gully bottoms near the mouth of Alum Gulch (fig. 2).

In the limited area in the Mount Wrightson quadrangle that is underlain by the volcanics of Red Mountain, only a few outcrops provide any definitive information bearing on the composition, structure, or origin of the rocks because the rocks are flooded with iron oxide and are strongly argillized and partly silicified. However, in some places relict porphyritic and pyroclastic textures indicate that the rocks probably are volcanic. Medium-gray rocks probably were altered from volcanics of dacitic or andesitic composition, and light-gray ones may have had a rhyolitic affinity. In many places along the canyon bottoms the volcanics contain disseminated sulfides, whose oxidation produces the pronounced reddish-brown color characteristic of much of Red Mountain. The rocks that are grayish brown rather than reddish brown are silicified.

A specimen of relatively unaltered dacitic or andesitic rock is made up of about 20 percent phenocrysts as much as 3 mm long scattered in a felty altered groundmass in which grain size is about 0.05 mm. Partly albitized sodic andesine is the most abundant of these phenocrysts. Amphibole and pyroxene(?) are less abundant, and accessory magnetite and sphene least abundant. Iron oxide, epidote, quartz, montmorillonite(?), kaolinite(?), chlorite, and leucoxene are the chief alteration minerals.

The lighter colored rocks crop out northwest of the dacitic and andesitic ones. In some places they contain relict textures of sandstone, and in a few places they are conglomerate or breccia. Fragments of the coarser clastic rocks include granite, probably derived from a nearby stock of Jurassic age, and quartzite and laminated siliceous volcanics of the Mount Wrightson Formation of Triassic age, present in the Flux Canyon area to the southwest. The conglomerate or breccia forms a steeply northwestward-inclined lenticular body bounded by faults along, and subparallel to, the range front.

Typical rhyolitic rock of this area contains 10 percent phenocrysts 0.5–1.5 mm long set in a nondescript granular groundmass of possible tuffaceous origin having a grain size of 0.01–0.03 mm. Most phenocrysts are of albitized and strongly kaolinized plagioclase. Traces of titaniferous magnetite and zircon are present. Secondary minerals are clay minerals, quartz, sericite, iron oxide, and chlorite.

The volcanics of Red Mountain are provisionally correlated with some or all of the Gringo Gulch Volcanics of Paleocene(?) age. However, inasmuch as the volcanics of Red Mountain are part of a complexly altered sequence and are separated by a major fault from the less altered Gringo Gulch sequence, the actual age assignment, correlation, and

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TABLE 2. — *Summary of radiometric dates of Cenozoic rocks of the Santa Rita Mountains and vicinity*

Specimen No.	Field No.	General location[1]	Rock: Structure	Rock: Composition	Material dated	Method used	Calculated age, in m.y.[2]	Author(s) and year of original report (all are written commun.)	Reference
				Pliocene and Miocene rocks					
1	70D1133	6 mi. southwest of San Cayetano Mountains.	Lava flow	Olivine basalt	Groundmass	K-Ar	12.6±0.8	R. F. Marvin, H. H. Mehnert, and Violet Merritt, 1970.	
					Pyroxene	K-Ar	13.8±13.5	R. F. Marvin, H. H. Mehnert, and W. T. Henderson, 1970.	
				Upper(?) Oligocene rocks					
2	65D687	San Cayetano Mountains	Stock	Granodiorite	Biotite	K-Ar	27.6±3%	R. F. Marvin, H. H. Mehnert, and Wayne Mountjoy, 1965.	Drewes (1971c).
3	63D315	Grosvenor Hills (SE.)	Laccolith	Rhyodacite vitrophyre	Hornblende	K-Ar	27.3± ~5%	S. C. Creasey, 1964	Do.
					Zircon	Pb-alpha	40±10 (40)	T. W. Stern, 1964	Do.
4	64D581	Grosvenor Hills (NW.)	do	do	Hornblende	K-Ar	27.8±2.8	H. H. Mehnert, R. F. Marvin, and Wayne Mountjoy, 1965.	Do.
5	66D710	Grosvenor Hills (NE.)	Lava flow	do	Plagioclase[3]	K-Ar	27.6±1.6	R. F. Marvin, H. H. Mehnert, and Violet Merritt, 1968.	Do.
6	63D338	Gardner Canyon	Dike	Rhyolite porphyry	Zircon	Pb-alpha	43±10 (40)	T. W. Stern, 1965	Do.
7	65D899	Greaterville	do	Rhyolite vitrophyre	Sanidine	K-Ar	25.9±0.8	R. F. Marvin, H. H. Mehnert, and Violet Merritt, 1967.	Drewes (1971a).
				Upper(?) Paleocene rocks					
8	65D893	Greaterville	Plug	Quartz latite porphyry	Zircon	Pb-alpha	(180± ~20%)	T. W. Stern, 1968	
9	68D1472	do	do	do	Biotite	K-Ar	55.7±1.9	R. F. Marvin, H. H. Mehnert, and Violet Merritt, 1968.	
10	66D1185	Helvetia-Rosemont	do	do	do	K-Ar	55.8±1.7	R. F. Marvin, H. H. Mehnert, and Violet Merritt, 1967.	Drewes (1971a).
11	67D1245	Helvetia	do	do	do	K-Ar	56.3±1.7	do	Do.
12	66D1051	do	Stock	Quartz monzonite	do	K-Ar	53.5±2.0	do	Do.
13	70D1612	do	do	do	do	K-Ar	53.9±2.0	H. H. Mehnert, R. F. Marvin, and Violet Merritt, 1970.	Drewes (1972a).
				Lower(?) Paleocene rocks					
14	63D281	Gringo Gulch	Plug, core[4]	Microgranodiorite	Biotite	K-Ar	60.3± ~5%	S. C. Creasey, 1964	Drewes (1971c).
					Zircon	Pb-alpha	47.7± (50)	T. W. Stern, 1964	Do.
15	64D660	do	Plug, rim[4]	Dacite porphyry	Hornblende	K-Ar	60.4±6.0	H. H. Mehnert, R. F. Marvin, and Wayne Mountjoy, 1965.	Do.
16	63D379	Temporal Gulch	Dike	Quartz latite porphyry.	do	K-Ar	67.5± ~5%	S. C. Creasey, 1964	Do.
					Zircon	Pb-alpha	61.2±20 (60)	T. W. Stern, 1965	Do.

[1]Specific location of specimens 1, 8, and 9 given in this report; that of other specimens given on maps listed in reference column of this table.
[2]Reported Pb-alpha ages shown parenthetically.
[3]K_2O content used in calculation based on average of 10 replicate analyses.
[4]Plug referred to as Gringo Gulch pluton on map (Drewes, 1971c).

interpretation of their origin is deferred to the reports of adjacent areas by other authors.

INTRUSIVE ROCKS

Dikes and plugs of porphyry and small stocks of granitoid rocks, of Paleocene age, are scattered through the Santa Rita Mountains. Their composition is in the quartz latite (or quartz monzonite) to dacite (or granodiorite) range. Plugs are defined here as intrusives less than half a square mile in extent; stocks, as more than half a square mile. Most of the intrusive rocks of this age fall into one of four groups, of which the plugs of the Gringo Gulch area, referred to on the Mount Wrightson quadrangle map (Drewes, 1971c) as Gringo Gulch pluton, and the Cottonwood Canyon dike swarm are the two oldest, and the Helvetia stocks and the Greaterville intrusives are the two youngest. The remaining intrusives are small, widely scattered, poorly dated, and scantily studied.

PLUGS OF GRINGO GULCH AREA

Two plugs, largely of dacite porphyry, intrude Paleocene(?) and older volcanic and sedimentary rocks near Patagonia (fig. 2). The larger plug is exposed in an elliptical area of about half a square mile lying 3 miles north-northwest of the town and slightly west of Gringo Gulch. The plug has a subdued topographic expression both in the hills to the north and in the gullies to the south. Toward the north the plug walls appear to dip gently outward; to the south, however, they are about vertical, perhaps reflecting the general attitude of the plug as exposed at a deeper level. In the north half of this plug are two bodies of microgranodiorite believed to be late-phase intrusives. Several large blocks of altered volcanics form inclusions in the southern part of the plug.

The smaller plug underlies a low hill a mile southwest of Patagonia. Its contacts, fairly accurately located though nowhere actually exposed, seem to be very irregular. The plug probably intrudes rhyolitic tuff, tuffaceous sandstone, and andesitic sandstone exposed on the flanks of the hill; all are of the upper member of the Gringo Gulch Volcanics, and they contain no clasts of the dacite porphyry.

DACITE PORPHYRY

Rocks of the dacite porphyry phase of the plugs are medium light gray to medium dark gray and weather to small brownish-gray rounded blocks that resemble the weathered Josephine Canyon Diorite. Phenocrysts commonly make up 5–10 percent of the rock and consist of relatively inconspicuous plagioclase laths and conspicuous hornblende laths. Phenocrysts are absent in the southern end of the larger plug, but they make up as much as 40 percent of the rock in the northwestern part of that plug, where they are as much as 1 centimeter long. No other intrusives of the Santa Rita Mountains have such abundant and large hornblende phenocrysts.

The phenocrysts are seen under the microscope to be scattered in a blocky or felty to intergranular groundmass, whose crystals are 0.01–0.15 mm long. Modes of three rocks are presented in table 3; the groundmass of only one specimen of these rocks is sufficiently coarse for modal analysis. Specimens 1 and 2 are from the southern plug and were collected in the center of SW¼ sec. 12, T. 22 S., R. 15 E.; specimens 3 and 4 are from the northern plug, respectively from the center of the NW¼NE¼ sec. 26, T. 21 S., R. 15 E., and from the NE¼NE¼ sec. 26, T. 21 S., R. 15 E. Plagioclase from the northern plug has an anorthite content which commonly ranges from 35 to 60 percent but which ranges from 0 to 85 percent in some of the crystals that are strongly zoned. Plagioclase from the southern plug is partly albitized sodic andesine. Hornblende is mostly euhedral, but some is rounded and sheathed by granular iron oxide. Some hornblende surrounds quartz xenocrysts. Biotite is present in about half the specimens. Quartz is likewise present in only half the specimens, in which it forms interstitial anhedra, crystal clusters, and, rarely, xenocrysts. Orthoclase is finely disseminated in the groundmass and is strongly kaolinized. Accessory titaniferous magnetite is abundant, and apatite and sphene(?) are scarce. Alteration minerals are chlorite (rarely penninite), kaolinite, sericite, calcite, uralite(?), leucoxene, and iron oxide.

Chemical and spectrographic analyses and the CIPW (Cross, Iddings, Pirsson, and Washington) norm of a specimen of dacite porphyry from the northern plug are presented in table 4.

MICROGRANODIORITE

Two small elliptical bodies of microgranodiorite lie within the north half of the northern plug of dacite porphyry. The contacts of these bodies are unexposed; but inasmuch as the grain size of the microgranodiorite in the larger body decreases toward the contact and that of the adjacent dacite porphyry does not, the microgranodiorite is believed to have intruded the dacite porphyry. Microgranodiorite outcrops are small because the rock is closely fractured and disaggregates readily. The rock is best exposed along a small gully a few hundred feet east of an earthen stock tank in the NE¼NE¼ sec. 26, T. 21 S., R. 15 E. Unweathered microgranodiorite is light olive gray to light brownish gray, and weathered surfaces are a darker brownish gray. In hand specimen the rock is seen to contain fine-grained plagioclase and quartz and some slightly coarser biotite and amphibole, as well as scattered small light-gray fine-grained segregations or inclusions.

In thin section the microgranodiorite is seen to be slightly porphyritic and to be made up of equal amounts of anhedral crystals 0.03–0.1 mm across and subhedral crystals 1–4 mm long. The mode of a specimen obtained from the gully a few hundred feet east of the stock tank is given in table 3.

TABLE 3. — *Modes (in percent) of dacite porphyry and of microgranodiorite from the plugs of the Gringo Gulch area*

[Specimen 1 from southern plug; specimens 2–4 from northern plug]

Rock type	Dacite porphyry				Microgranodiorite
Component	Phenocrysts			Whole rock	
Specimen No.	1	2	[1]3	[1]3	4
Field No.	63D257	64D661	63D199	63D199	63D281
Plagioclase	10.8	21.8	[2]5.0	73.5	52.1
Hornblende	5.8	5.3	3.9	3.3	5.4
Pyroxene	.5	.3	.5	5.0	.0
Biotite	.0	1.0	.0	.9	4.7
Quartz	.0	.8	.0	1.3	19.8
Orthoclase	.0	.0	.0	9.9	14.9
Magnetite	1.4	2.6	1.2	5.5	2.5
Apatite	.0	.0	.0	.6	.4
Zircon	.0	.0	.0	.0	.2
Sphene(?)	.0	.0	.0	.0	Trace
Allanite	.0	.0	.0	.0	Trace
Groundmass	81.5	68.2	89.4	.0	.0
Total	100.0	100.0	100.0	100.0	100.0

[1]Phenocryst mode and whole-rock mode were both obtained from specimen 3, permitting a better evaluation of the phenocryst modes of specimens 1 and 2.

[2]Sizes of plagioclase in groundmass and phenocrysts are gradational, so this figure is of marginal significance.

Quartz and strongly kaolinized orthoclase form anhedral grains in the groundmass. Plagioclase appears as subhedral phenocrysts and as anhedral groundmass grains, and it is moderately altered to kaolinite. Generally the plagioclase has an anorthite content of about 35 percent (sodic andesine); but a few crystals are calcic andesine, and other crystals and rims of normally zoned andesine grains are calcic oligoclase. Biotite forms subhedral phenocrysts and groundmass grains that are pleochroic in pale yellowish brown to moderate yellowish brown and that are slightly altered to chlorite and penninitic chlorite. The hornblende forms long subhedral grains which are sheathed in granular iron oxide and which are strongly altered to chlorite. The accessory minerals are titaniferous magnetite, apatite, sphene(?), zircon, and allanite. Kaolinite is the most abundant secondary mineral; chlorite and sericite are less abundant.

Chemical and spectrographic analyses and the CIPW norm of a specimen of microgranodiorite are given in table 4.

The chemical differences between the microgranodiorite and the dacite porphyry suggest that the porphyry is not just a border-chilled phase of the microgranodiorite, even though their close physical association and similar ages seem to indicate that they are genetically related. The silica content of the porphyry, for example, is only 59 percent, whereas that of the microgranodiorite is nearly 67 percent. The chemical variation between these two rocks

TABLE 4. — *Chemical and spectrographic analyses and CIPW norms, in percent, of two specimens from the plugs of the Gringo Gulch area*

Rock type	Dacite porphyry	Microgranodiorite
Specimen No.	3	4
Field No.	63D199	63D281
Chemical analyses[1] [P. L. D. Elmore, S. D. Botts, Lowell Artis, Gillison Chloe, and H. Smith, analysts]		
SiO_2	59.0	66.9
Al_2O_3	16.3	15.5
Fe_2O_3	3.4	2.7
FeO	2.8	1.4
MgO	2.6	1.4
CaO	4.7	2.8
Na_2O	4.4	4.0
K_2O	2.4	3.2
H_2O-	1.1	.36
H_2O+	1.4	.90
TiO_2	.98	.56
P_2O_5	.21	.18
MnO	.14	.06
CO_2	.12	.10
Total	100	100
Semiquantitative spectrographic analyses[2] [J. C. Hamilton, analyst]		
Ba	0.05	0.15
Be	.0002	0
Co	0	.0007
Cr	0	.001
Cu	.001	.01
Ga	.002	.003
La	0	.005
Nb	.003	0
Ni	0	.0007
Pb	.002	.007
Sc	0	.0007
Sr	.005	.07
V	.001	.01
Y	.002	.002
Yb	([3])	.0002
Zr	.01	.007
CIPW norms		
Q	11.541	24.104
C	0	1.032
or	14.179	18.906
ab	37.212	33.829
an	17.646	12.080
di en	1.144	0
di fs	.172	0
di wo	1.476	0
hy en	5.328	3.485
hy fs	.802	0
mt	4.930	3.085
hm	0	.572
il	1.861	1.064
ap	.497	.426
cc	.273	.227
Total	97.06	98.81

[1]Rapid rock analyses.

[2]Results are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so on, which represent approximate midpoints of group data on a geometric scale. The assigned group for the semiquantitative results will include the quantitative value about 30 percent of the time.

[3]Not looked for.

resembles that of another rock pair in the Santa Rita Mountains, the Cretaceous Josephine Canyon Diorite and Madera Canyon Granodiorite (Drewes, 1968, and unpub. data), which were emplaced next to each other virtually synchronously but which differ in composition. The intrusives of the Gringo Gulch area, however, seem to be 5–10 m.y. younger than the other rock pair.

The age of the larger plug has been determined by three radiometric determinations on specimens 3 and 4 of table 4 (specimens 14 and 15 of table 2). The petrographic similarity of the larger and smaller plugs, both of which are unique among the intrusives of the Santa Ritas, indicates that the two plugs are similar in age. In the Tertiary age range, Pb-alpha determinations are frequently less accurate than are K-Ar counterparts (R. F. Marvin, oral commun., 1970). Thus, the ages of the dacite porphyry and the microgranodiorite are probably in the 55- to 60-m.y. age range.

COTTONWOOD CANYON DIKE SWARM

A swarm of more than 60 dikes of quartz latite porphyry, which generally look alike but which range from finely to coarsely porphyritic, extends discontinuously across the Santa Rita Mountains from near the junction of Mansfield Canyon and Temporal Gulch, in the southeast, to near Yoas Mountain, in the northwest (fig. 4). The swarm strikes roughly N. 60° W.; and although many individual dikes parallel the trend of the swarm, some strike slightly more westerly, and a few strike northerly and northeasterly. Large dikes, as much as 2 miles long and 40 feet thick, are concentrated in the Cottonwood Canyon area; smaller dikes also are present there, but only small dikes appear in the Temporal Gulch and Agua Caliente Canyon

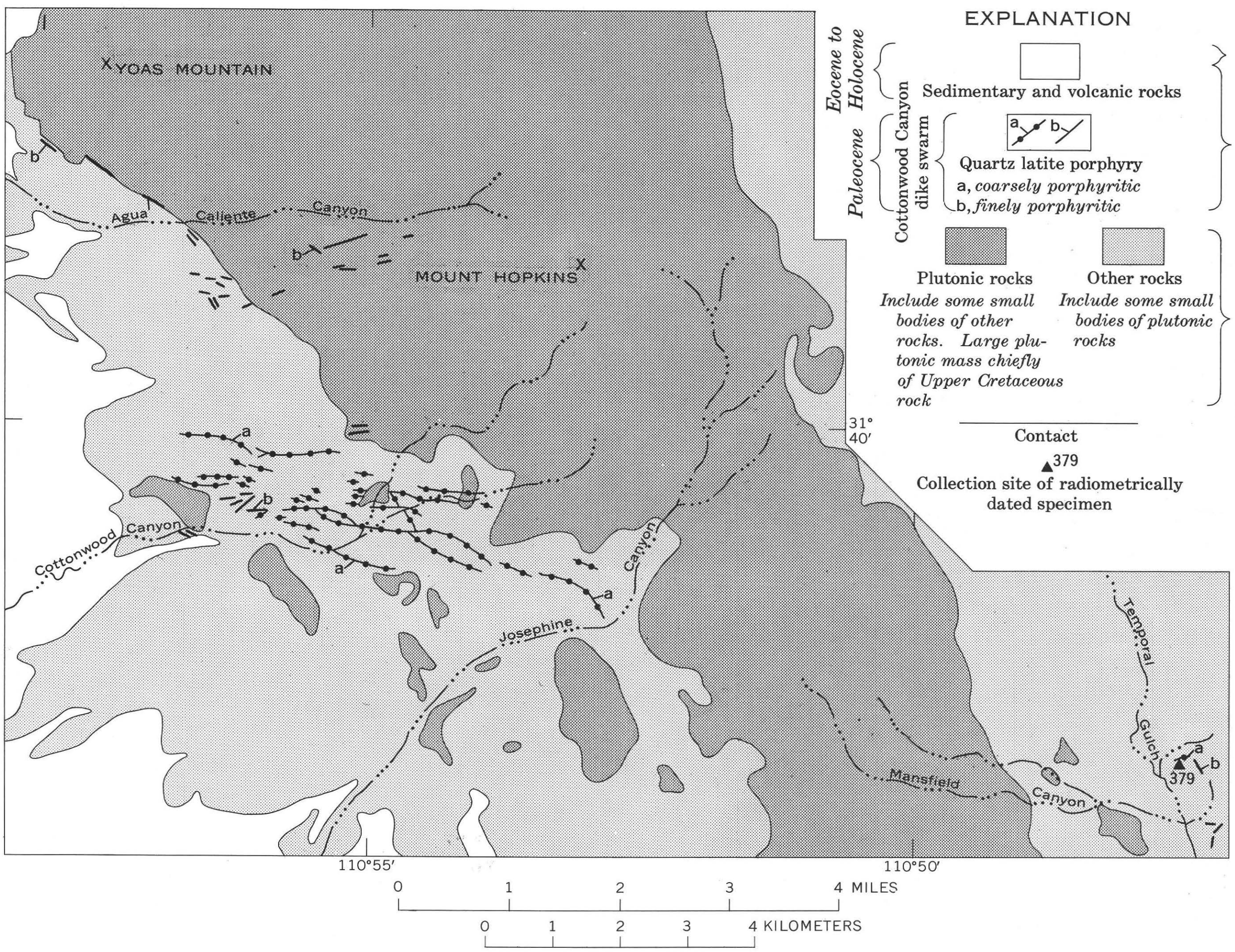

FIGURE 4. — Location of Cottonwood Canyon dike swarm and distribution of coarsely porphyritic and finely porphyritic dikes, southern Santa Rita Mountains. Base from U.S. Geological Survey: Mount Wrightson quadrange, 1:62,500, 1958.

areas. A few of the large dikes bifurcate, and the branches completely or partly surround large lenses of host rock. Most dikes intrude volcanic and sedimentary rocks of Cretaceous or Paleozoic ages, but a few of them intrude plutonic rocks as young as the Elephant Head Quartz Monzonite of late Late Cretaceous age, 68–69 m.y. old (Drewes, 1968, 1971c).

In outcrop, the dikes usually are pale yellowish brown to light brown, much like their host rocks, and only the larger ones weather out in places as low ribs of outcrops. Some of the smaller dikes are so poorly exposed that they are marked chiefly by a train of weathered blocky debris of distinctively porphyritic lithology. Fresh rock surfaces are medium grayish brown to pale greenish gray. The phenocrysts of all the larger dikes and of only a few of the smaller ones are coarse, those of othoclase being ½–1 inch long (fig. 5). Phenocrysts of most of the smaller dikes are only about a quarter of an inch long, but those of a few smaller dikes are of intermediate size.

The rock contains 20–50 percent phenocrysts scattered in a groundmass whose texture is granular to microcrystalline or, less commonly, hyalopilitic, with laths about 0.05 mm long. Modes of three specimens are given in table 5.

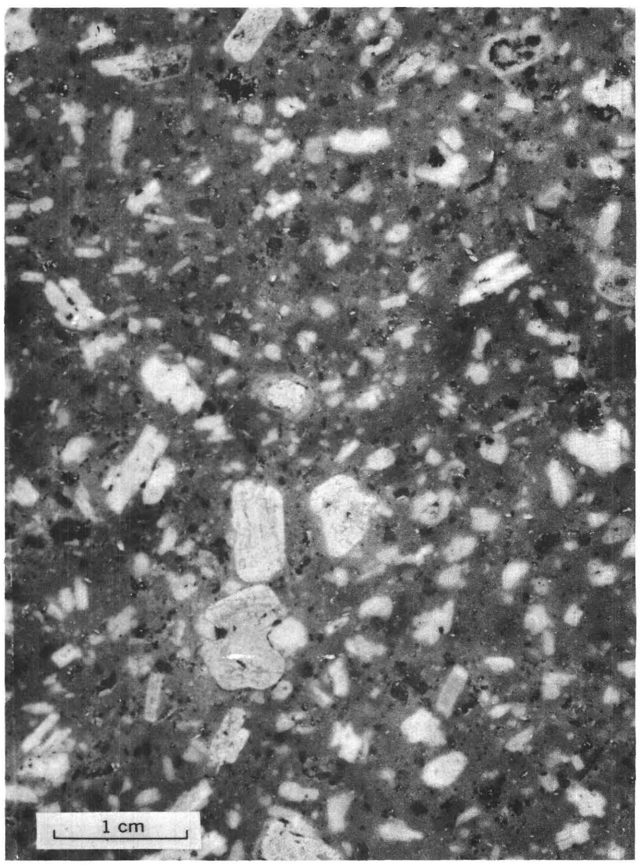

FIGURE 5. — Quartz latite porphyry of the Cottonwood Canyon dike swarm. The specimen, 63D456, is from a large dike in the upper basin of Cottonwood Canyon in the southern Santa Rita Mountains.

TABLE 5. — *Modes (in percent) of quartz latite porphyry of the Cottonwood Canyon dike swarm*

Rock type	Finely porphyritic		Coarsely porphyritic
Specimen No.	1	2	3
Field No.	63D379	63D646	63D456
Plagioclase	14.7	27.6	20.4
Orthoclase(?)	3.8	2.8	10.9
Quartz	3.8	2.3	0
Biotite	11.2	4.5	5.9
Hornblende	2.4	3.7	Trace
Magnetite	.3	.6	.2
Apatite	.3	Trace	.5
Sphene	Trace	Trace	.5
Zircon	Trace	Trace	Trace
Groundmass	63.5	[1]58.5	61.6
Total	100.0	100.0	100.0

[1]Includes 1.3 percent quartz.

Phenocrysts provide most of the petrographic data on the quartz latite porphyry dike swarm. Most of the feldspar phenocrysts are strongly kaolinized and sericitized. The plagioclase of some specimens is albitized from a calcic andesine. Quartz is strongly resorbed and presumably was once present even in those rocks of the Cottonwood Canyon dike swarm that are now without quartz. Biotite of the few hyalopilitic rocks is oxybiotite; that of the other rocks is altered to chlorite, epidote, calcite, iron oxide, and leucoxene. Hornblende is also largely altered like the biotite, but some crystals contain relicts of fresh hornblende, which have an olive-brown to yellowish-brown pleochroism or, in the hyalopilitic rocks, the reddish-brown pleochroism of oxyhornblende. Accessory magnetite, apatite, sphene, and zircon are also commonly present.

A single specimen from the Temporal Gulch area (fig. 4 and table 2, specimen 16) has been dated using the K-Ar method on hornblende and the Pb-alpha method on zircon. The two ages, respectively 67.5 and 61.2 m.y., are compatible in view of their overlapping age ranges (the assigned plus-or-minus values of the dates shown in table 2), so this specimen can be accepted as about 65 m.y. old. However, the younger age is favored because these dikes cut plutons whose main phases are dated as about 68 m.y. and whose latest phase is 65 m.y. old. Also, the northwest trend of this swarm is more characteristic of Laramide structures than of early post-Laramide structures (Drewes, 1972a).

HELVETIA STOCKS

Granitic-textured rocks of Paleocene age form six stocks and other smaller intrusive bodies between the Helvetia mining district and the north end of the Santa Rita Mountains. These rocks will be described in detail elsewhere as part of the plutonic rocks of the region and are mentioned only briefly in the present report to preserve the continuity of the discussion of the geologic events of the Cenozoic, most of which involves hypabyssal rocks. The coarse-grained intrusive rocks range in composition from granodiorite to quartz monzonite, hereafter in this section of the report simply called granodiorite; however, one stock of quartz diorite is shown separately in figure 6.

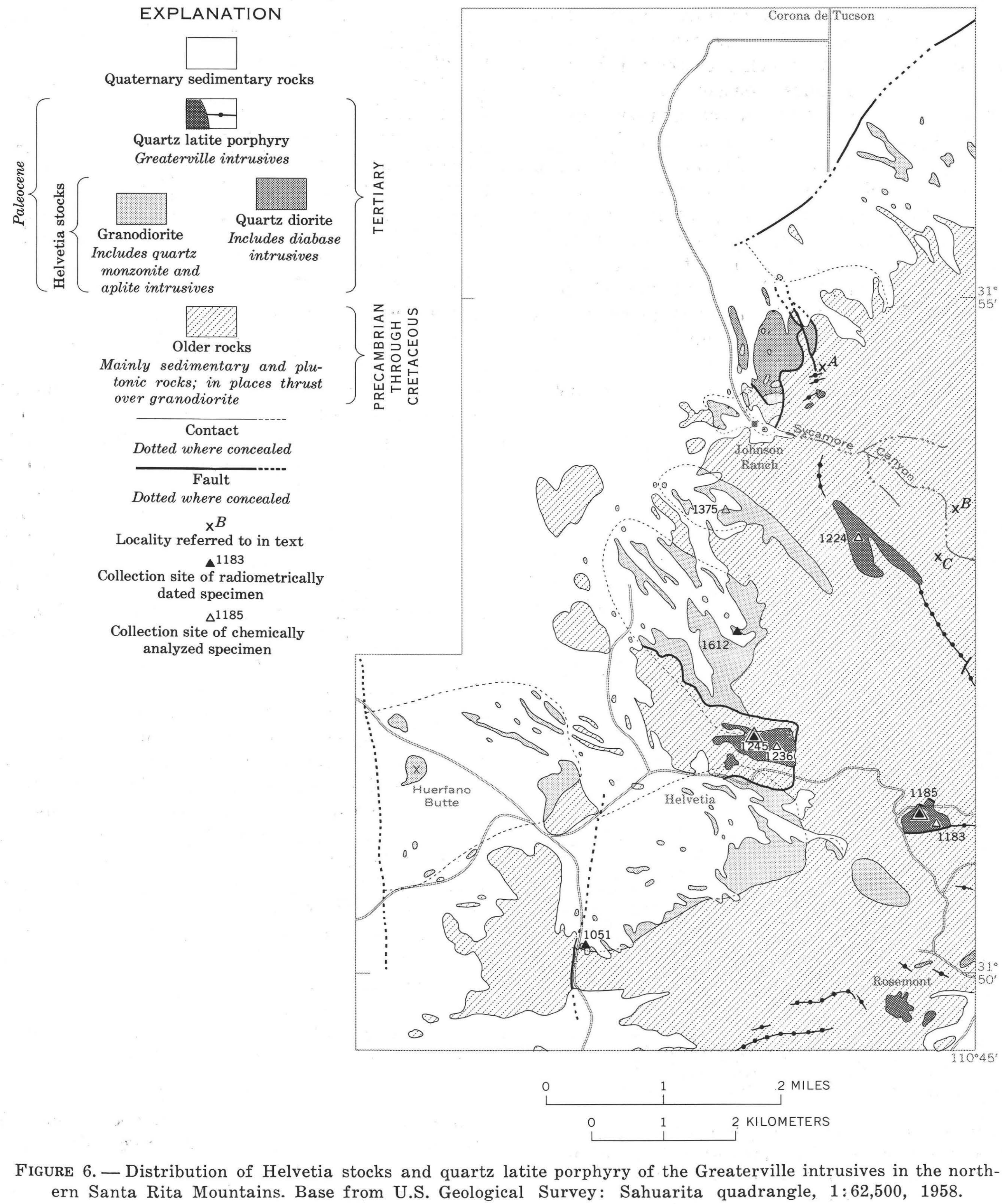

FIGURE 6. — Distribution of Helvetia stocks and quartz latite porphyry of the Greaterville intrusives in the northern Santa Rita Mountains. Base from U.S. Geological Survey: Sahuarita quadrangle, 1:62,500, 1958.

At the present level of exposure the stocks are subelliptical steep-walled bodies which contain only a few small dikes of aplite and lamprophyre and only a few inclusions. The host rocks also contain only a few small apophyses and are not obviously more metamorphosed near individual stocks than away from them. The quartz diorite stock north of Johnson Ranch contains some inclusions of granodiorite, the smaller ones of which are hybridized by the quartz diorite; however, in rarer instances, diorite masses are included in the adjacent granodiorite. Thus the two rocks apparently were emplaced almost simultaneously, the quartz diorite perhaps being slightly younger than most of the granodiorite.

GRANODIORITE

Typical granodiorite of the Helvetia stocks is a light-gray rock that weathers light brownish gray; the quartz monzonite variety is grayish orange pink on both fresh and weathered surfaces. The rock disaggregates readily to form grus, friable massive outcrops, and scattered residual boulders. A blockier rubble weathers from the aplitic bodies. Tongues of the pediment flanking this part of the Santa Rita Mountains extend more widely across the weathered stocks than they do across their host rocks, and unweathered granodiorite usually crops out only along the bottoms of sharply incised gullies. The rock only superficially resembles the Precambrian Continental Granodiorite (Drewes, 1968), which it intrudes near Helvetia. The younger granodiorite contains no large porphyroblasts, and its biotite (or chlorite) forms discrete books rather than a meshwork of fine crystal aggregates (fig. 7).

The granodiorite of the Helvetia stocks has a hypidiomorphic-granular texture and a grain size of about 5 mm (fig. 8). Although porphyritic textures are absent from the normal rock types, the crystal sizes of some rocks are bimodally distributed in the 2- to 3-mm and the 5- to 7-mm sizes.

The major modal constituents of these plutons vary widely. Plagioclase makes up 31–54 percent of the rock, potassium feldspar 13–32 percent, and

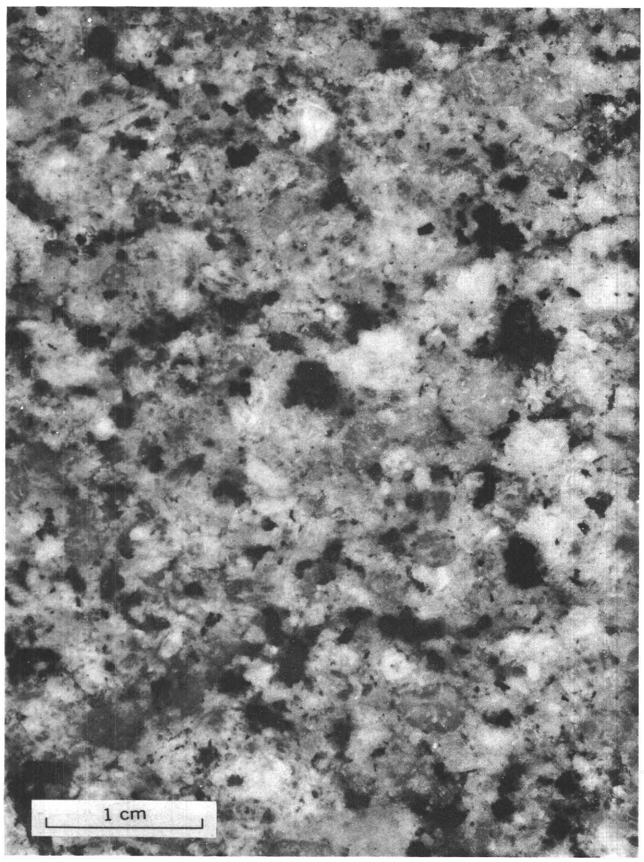

FIGURE 7.—Granodiorite from the Helvetia stocks. The specimen, 67D1392b, is from the stock south of Johnson Ranch, northern Santa Rita Mountains.

FIGURE 8.—Granodiorite of the Helvetia stocks. The specimen, 66D1163, from the stock south of Helvetia, shows: A, apatite; B, biotite; M, magnetite; P, plagioclase; pm, perthitic microcline; Q, quartz; S, sphene; Z, zircon. Crossed nicols.

quartz 19–38 percent. These ranges, of course, are smaller within the more typical granodiorite stocks, but even within individual stocks the compositions is far from uniform. A mode of a representative specimen from the first stock south of the ranch is shown as specimen 1 in table 6. Most plagioclase is

TABLE 6.—*Modes (in percent) of representative specimens of granodiorite and quartz diorite from the Helvetia stocks*

Rock type	Granodiorite	Quartz diorite
Specimen No.	1	2
Field No.	67D1375	67D1402
Quartz	29.8	9.1
Plagioclase	45.7	52.1
Microcline	13.0	.8
Biotite	10.1	0
Amphibole	0	34.4
Magnetite	1.1	1.8
Apatite	.2	.5
Sphene	0	1.4
Zircon	.1	.05
Total	100.0	100.15

calcic oligoclase, whose outer rim is zoned to albite. Specimens with microcline are as abundant as those with orthoclase; both minerals commonly are finely but not abundantly perthitic, as seen in figure 8. Biotite ranges in abundance from 1 to 10 percent, and the range even within a single stock is large. One specimen from near the quartz diorite stock contains a little hornblende in addition to ubiquitous biotite. Accessory magnetite and apatite are everywhere present, zircon and sphene are common, and allanite is very sparse. Secondary minerals are generally sparse away from weathered rock and include some clay minerals, sericite, epidote, chlorite, and leucoxene.

Chemical and spectrographic analyses and the CIPW norm of a granodiorite specimen from one of the Helvetia stocks are given in table 7. These analyses, like the mode, are of a representative rock from a suite which will be described in greater detail in a collateral paper on plutonic rocks (Drewes, unpub. data).

QUARTZ DIORITE

The quartz diorite is a medium-dark-gray to slightly greenish-gray rock that weathers slightly brownish gray. The slopes it underlies are more somber colored than the adjacent slopes of granodiorite or of Mesozoic and Paleozoic wallrock and inclusions. The rock also forms fewer outcrops than the host rock, and these outcrops are commonly most extensive in small gullies.

The quartz diorite has a hypidiomorphic-granular to faintly felty texture with a trace of poikiloblastic and granophyric intergrowths (fig. 9). A mode of a representative specimen, obtained from the wash east of the road and half a mile north of Johnson

TABLE 7.—*Chemical and spectrographic analyses and CIPW norm, in percent, of a representative specimen, 67D1375, of granodiorite from one of the Helvetia stocks*

Chemical analysis (rapid rock method)

[P. L. D. Elmore, Lowell Artis, G. W. Chloe, H. Smith, J. Kelsey, and John Glenn, analysts]

SiO_2	71.2	H_2O-	0.20
Al_2O_3	14.3	H_2O+	.78
Fe_2O_3	1.0	TiO_2	.35
FeO	1.5	P_2O_5	.18
MgO	1.0	MnO	.12
CaO	3.1	CO_2	$<.05$
Na_2O	3.0		
K_2O	3.2	Total	100

Semiquantitative spectrographic analysis[1]

[J. L. Harris, analyst]

Ag	<0.0001	Pb	0.001
Ba	.07	Sc	.0003
Be	.0002	Sr	.02
Cu	.001	V	.002
Ga	.001	Y	.003
La	.007	Yb	.0003
Nb	.001	Zr	.01

CIPW norm

Q	33.305	mt	1.450
C	.812	il	.665
or	18.913	ap	.426
ab	25.390	cc	.114
au	13.890		
hy {en	2.491	Total	99.030
hy {fs	1.574		

[1]Results are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1, which represent approximate midpoints of interval data on a geometric scale. The assigned interval for semiquantitative results will include the quantitative value about 30 percent of the time. Elements looked for but not found: As, Au, B, Bi, Cd, Co, Cr, Eu, Ge, Hf, In, Li, Mo, Nd, Ni, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, and Zn.

Ranch, is listed as specimen 2 in table 6. The plagioclase is a strongly sericitized sodic labradorite. Hornblende composition varies slightly, as indicated by the small differences from specimen to specimen in the range of its pleochroic colors of bright green to pale yellow brown, and of blue green to olive green. Biotite is present in some rocks, although absent in specimen 2. The accessories resemble those of the granodiorite, except that allanite was not seen. Alteration minerals are also like those in the granodiorite but are more abundant and include a greater proportion of chlorite and epidote to clay minerals.

Two small intrusive bodies in the Rosemont area (fig. 6) are here provisionally associated with the quartz diorite because of their general similarity of composition and age. These rocks are dark greenish gray, intensely altered, and poorly exposed. The core of the larger intrusive is diabase; the margin of that intrusive and the entire smaller intrusive are andesite, some of which is amygdaloidal or vesicular. These intrusives are emplaced in strongly altered clastic rocks; the rocks around the larger intrusive are mainly arkose and arkosic conglomerate whose clastic texture is not entirely obliterated, and therefore the contact position is readily determined.

FIGURE 9.—Quartz diorite of the Helvetia stocks. The specimen, 67D406b, from the stock half a mile north of the Johnson Ranch, northern Santa Rita Mountains, shows: B, biotite; H, hornblende; M, magnetite; P, plagioclase; Q, quartz; S, sphene. Crossed nicols.

However, the clastic rock around the smaller intrusive is mainly hornfels, some of which is porphyroblastic and so closely resembles the andesite that the contact position is relatively uncertain.

Under the microscope, a specimen of the diabase shows a strongly developed network of feldspar laths which contain intersertal and some intergranular amphibole which probably replaced pyroxene. The pseudomorphous amphibole has the pale-olive-green to yellowish-brown pleochroism of actinolite. Aside from some remnants of primary magnetite, the rest of the rock consists of abundant clay minerals, chlorite, epidote, iron oxide, and a little secondary (?) quartz.

The Helvetia stocks are younger than structures of the Piman phase of the Laramide orogeny of Late Cretaceous age and are older than the quartz latite porphyry of the Greaterville plugs, of late (?) Paleocene age (Drewes, 1971a). Within this interval, the stocks are penecontemporaneous with faults of the Helvetian phase of the orogeny of Paleocene age. The stock south of Helvetia is dated as 53.5±2.0 m.y. (table 2, specimen 12). This age, which supersedes that of 52.2 m.y. reported earlier by Drewes and Finnell (1968, p. 323), was determined by the K-Ar method on a biotite concentrate obtained from the specimen (collected at site 1051 in fig. 6). The dated rock is quartz monzonite, although most specimens of the stock are granodiorite; the rock shows no signs of recrystallization, and it is virtually free of secondary minerals. A second specimen (table 2, specimen 13), from a new roadcut in the first stock north of Helvetia townsite (NW¼NW¼NW¼ sec. 14, T. 18 S., R. 15 E.), gives a K-Ar age of 53.9±2.0 m.y. The calculated ages probably are very slightly too young with respect to those obtained for the nearby quartz latite porphyry plugs (table 2 and fig. 6), as explained in the section on the plugs, but they fall within the age range of the estimated analytical error.

GREATERVILLE INTRUSIVES

At least six plugs and many associated dikes of quartz latite porphyry, of Paleocene age, intrude the rocks of the northern Santa Rita Mountains. The porphyry is typically a closely fractured light-gray to grayish-orange-pink rock. It weathers to yellowish-brown or grayish-brown chips and forms outcrops less prominent than those of Paleozoic limestone host rock but more prominent than those of Cretaceous arkose host rocks. The porphyry is characterized by its sparse small biotite crystals and conspicuous stubby bipyramidal quartz crystals; much of the rock contains disseminated sulfides. Because the host rocks of these intrusives are mostly contact metamorphosed and are enriched in base and noble metals, the porphyry is locally referred to as the ore porphyry, and it is so termed in this report.

The ore porphyry forms a small group of plugs, dikes, and sills in the Greaterville district (fig. 1; Drewes, 1970, fig. 2), two plugs in the Rosemont district, one on the crest of the range between Rosemont and Helvetia (fig. 6; Creasey and Quick, 1955, pl. 28; Drewes, 1971a), another plug at Helvetia, and two in the Sycamore Canyon area. Porphyry dikes extend east from the plug on the range crest and southeast from the plug south of Sycamore Canyon. Another dike extends northwest from the south Sycamore Canyon plug but is not contiguous with it. A group of dikes strikes west and southwest of the plugs at Rosemont. Another group of porphyry dikes assigned to these rocks crops out near Box Canyon; of these dikes, the largest strikes east (Drewes, 1971a). A third group of porphyry dikes lies near Fish Canyon (Drewes, 1971a, c).

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Many of the Greaterville plugs are irregularly shaped in plan, which distinguishes them from the elliptically shaped Helvetia stocks. Tongues of porphyry extend outward from the plugs along many faults, and I assume the plugs have this habit at depth (Drewes, 1970, p. A10 and pl. 1); some of the tongues of porphyry are long enough to be dikes. Most of these dikes are less than half a mile long, in contrast to the much longer ones of the younger dike swarms, but a few dikes are several miles long. A typical shorter dike is about 10–15 feet thick and 500 feet long, and it pinches and swells and changes its trend from place to place. In general, though, the dikes trend east.

Phenocrysts of the dikes are relatively small and sparse, but those of the plugs are more abundant and consist of conspicuously stubby bypyramidal quartz (fig. 10), fairly abundant feldspar, and some biotite or chloritized biotite. The groundmass is commonly sugary textured and fine, but in a few rocks it is granitoid. The subtle variations in kind and abundance of phenocrysts in the dikes of the Greaterville area suggest that the dikes may have a more complex magmatic history than the one outlined here.

Under the microscope, quartz latite porphyry typically is seen to have a porphyritic idiomorphic-granular texture (fig. 11). Phenocrysts make up 20–40 percent of the rock of the plugs; in most rocks they are less than 4 mm long, but in a few rocks they are as much as 8 mm long. Groundmass grains range in size from less than 0.01 mm (virtually cryptocrystalline) to about 0.2 mm. Granophyric intergrowths of quartz and feldspar appear in the groundmass of some samples of the main plug at Greaterville and of the plug south of Sycamore Canyon. Grain size of the dike rocks is commonly finer than that of the plugs. Two of the more southerly dikes contain interstitial altered glass. The ore porphyry thus has the typical texture of hypabyssal intrusives, and the plugs have shapes suggesting an emplacement from a fairly fluid magma. The rock

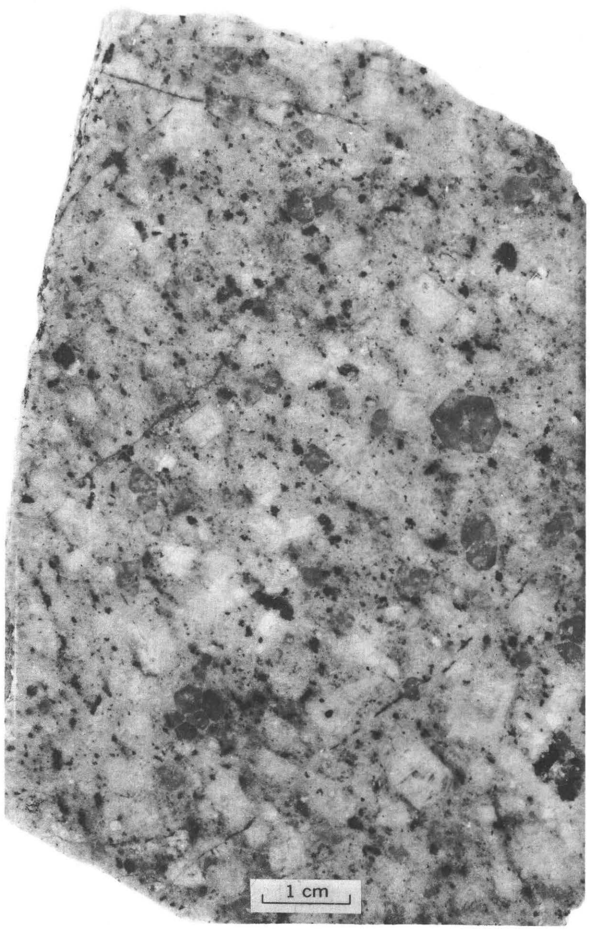

FIGURE 10. — Quartz latite porphyry, or ore porphyry, from the Greaterville intrusives. The specimen, 66D1185, is from the plug on the ridge between Helvetia and Rosemont.

FIGURE 11. — Quartz latite porphyry, or ore porphyry, of the Greaterville intrusives. The specimen, 66D1185, from the plug between Helvetia and Rosemont, contains: B, biotite; M, magnetite; O, orthoclase; P, plagioclase; Q, quartz.

texture appears, however, to grade northward, presumably with increasing depth, into granitic texture and southward with decreasing depth into vitrophyric texture.

Modes of the quartz latite porphyry are given in table 8. These modes are more uniform than modes of the Helvetia stocks summarized in table 6.

A few mineralogic features of the quartz latite porphyry are also distinctive, but many of them resemble those of other hypabyssal rocks of the Santa Rita Mountains. Generally, the stubby and commonly bipyramidal quartz phenocrysts, unlike the idiomorphic quartz crystals of the groundmass, are partly resorbed. In some porphyry, quartz forms loosely clustered crystals rimmed by other small interlocking quartz crystals. Undulatory extinction of the quartz is slight or absent. Feldspars occur as tabular euhedral phenocrysts or crystal clusters, as well as hypidiomorphic to idiomorphic groundmass crystals, all of which generally are strongly kaolinitized and sericitized. The composition of plagioclase, usually determined only on phenocrysts, ranges from sodic andesine to sodic oligoclase. Plagioclase of the groundmass, especially in dikes, may range in composition from andesine to albite, but the fine grain size and intense alteration hinder reliable measurements. The potassium feldspar of most samples is sanidine or is suspected to be sanidine, but in the coarse-grained rocks it is orthoclase and microcline. A small amount of fine perthitic intergrowths appears in both the orthoclase and the sanidine. Most of the biotite is chloritized; the unaltered remnants are commonly pleochroic in yellowish-brown to dark-brown, and rarely in reddish-brown, colors. Accessory minerals are titaniferous magnetite, apatite, sphene, zircon, and sparse allanite. Pale-brown devitrified glass constitutes about 25 percent of a specimen from a flow-laminated part of the long dike south of the Greaterville plugs, and a trace of opaline material appears in a veinlet of that specimen. Secondary minerals usually consist of abundant clay minerals, sericite, chlorite, and iron oxide, of less abundant epidote and tremolite(?), and of a trace of tourmaline.

The quartz latite porphyry is a chemically uniform rock. Analyses of four samples, a pair from each of two plugs, are nearly identical. Both pairs of analyses are also closely similar to analyses of single samples from other plugs, shown in table 9. In the last two columns of the table the average of the six analyzed specimens is compared with Nockolds' (1954) averages. As a whole, the quartz latite porphyry resembles his average adamellite (quartz monzonite) most closely, but the total iron and the magnesium contents resemble more closely those of his average calc-alkali granite.

The spectrographic analyses show that the ore porphyry contains anomalous amounts of several base metals and especially of copper. As this topic is discussed in a collateral paper (Drewes, 1971b), only a summary of the pertinent observations is given here. The copper content of the six specimens in table 9 and that of three other specimens from other Greaterville plugs average about 0.2 percent. That of 10 specimens of granodiorite of the Helvetia stocks, on the other hand, averages only about 0.0007 percent, or 2½ orders of magnitude less than the ore porphyry. At least some of the copper in the ore porphyry is contained in the biotite, whose concentrates have been shown by Lovering, Cooper, Drewes, and Cone (1970) to contain anomalous amounts of copper. Their preliminary findings suggest that the copper content of biotite may be a practical guide to recognizing ore-associated igneous rocks where other direct indications are absent or are inconclusive.

Biotite concentrates from samples of three plugs (table 2, specimens 9, 10, and 11) give radiometric

TABLE 8. — *Modes (in percent) of quartz latite porphyry, or ore porphyry, of the Greaterville intrusives*

[Phenocryst modes given in parentheses]

Location of plug	South Sycamore Canyon	Helvetia		Range crest between Helvetia and Rosemont			Greaterville, largest plug		Rosemont, larger plug		Average 1–7
Specimen No.	1	2	3	4	4	5	6	7	8	9	
Field No.	66D1224	67D1244	66D1245	66D1183	66D1183	66D1185	65D893	66D921	66D1129	66D1098	
Quartz	25.2	30.6	24.1	26.1	(4.4)	27.9	22.9	24.4	(22.3)	(5.4)	25.9
Plagioclase	45.3	43.4	44.9	37.0	(2.6)	41.9	45.2	56.1	(14.3)	(31.2)	44.8
Potassium feldspar											24.9
Sanidine	......	22.4	27.4	......	......	......	......	......	......	......	......
Sanidine(?)	......	......	......	31.8	(19.2)	26.3	......	......	(2.1)	(.5)	......
Orthoclase and microcline	26.2						26.3	13.6			
Biotite	2.9	2.2	2.7	3.3	(3.3)	3.0	3.9	4.2	(2.3)	(1.9)	3.2
Magnetite	.1	1.0	.3	1.3	(.4)	.7	1.1	1.4	(.1)	(Trace)	.8
Apatite	.2	.1	.4	.2	(.2)	.2	.3	.2	(Trace)	(Trace)	.2
Sphene	.1	.3	.1	.2	(.2)	Trace	.2	.1	(.1)	(Trace)	.2
Zircon	0	Trace	.05	.1	(.1)	Trace	.05	Trace	(Trace)	(0)	Trace
Allanite	0	0	.05	0	(0)	0	.05	0	(0)	(0)	Trace
Groundmass	0	0	0	0	[1]69.6	0	0	0	58.8	61.0	0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1]Not included in average.

TABLE 9. — *Chemical and spectrographic analyses and CIPW norms, in percent, of six specimens of quartz latite porphyry, or ore porphyry, compared with Nockolds' average analyses*

Location of plug	Greaterville, largest plug	Range crest between Helvetia and Rosemont		Helvetia		South Sycamore Canyon	Average of 6 specimens, Santa Rita Mountains	Average of Nockolds (1954, p. 1012, 1014)	
Sample No.	6[2]	4	5	10	3	1		Adamellite	Calc-alkali granite
Field No.	65D893	66D1183	66D1185	66D1236	67D1245	66D1224			
Chemical analyses[1] [P. L. D. Elmore, Lowell Artis, G. W. Chloe, H. Smith, J. Kelsey, and John Glenn, analysts]									
SiO_2	69.4	72.2	72.5	72.6	72.9	70.9	71.8	69.15	72.08
Al_2O_3	16.0	14.7	14.4	14.4	14.2	15.0	14.8	14.63	13.87
Fe_2O_3	1.8	1.2	1.2	.94	.86	.78	1.13	1.22	.86
FeO	.82	.52	.36	.60	.76	.84	.65	2.27	1.67
MgO	.51	.46	.46	.47	.49	.58	.50	.99	.52
CaO	2.3	1.2	1.7	1.6	1.4	2.3	1.8	2.45	1.33
Na_2O	4.2	3.5	3.8	4.2	4.2	3.7	3.9	3.35	3.08
K_2O	3.5	4.6	4.4	3.9	4.0	3.8	4.0	4.58	5.46
H_2O-	.21	.08	.17	.05	.04	.22	.13	....	....
H_2O+	.89	.74	.67	.51	.51	.98	.72	.54	.53
TiO_2	.39	.17	.14	.15	.15	.16	.19	.56	.37
P_2O_5	.14	.08	.07	.06	.08	.11	.09	.20	.18
MnO	.06	.07	.02	.04	.03	.16	.06	.06	.06
CO_2	$<.05$	$<.05$	$<.05$	$<.05$	$<.05$	.28	....	....	....
Total	100	100	100	100	100	100	....	....	....
Semiquantitative spectrographic analyses[3] [J. L. Harris, analyst]									
Ag	0	<0.0001	0	<0.0001	0	<0.0001			
Ba	0.1	.1	0.07	.07	0.07	.07			
Be	.0001	.0003	.0003	.0002	.0003	.0002			
Ce	.01	0	.03	.03	.02	.015			
Cr	0	0	.0003	0	.002	0			
Cu	.0003	.15	.05	.07	.015	.0003			
Ga	.0015	.0015	.0015	.0015	.0015	.001			
La	.005	0	.01	.01	.007	.007			
Mo	.0003	0	.0003	0	0	.0003			
Nb	.001	.001	.001	.001	.001	0			
Pb	.0003	.0007	.0007	.0003	.0005	.001			
Sc	.0005	.0003	.001	.0003	.0007	.0003			
Sr	.05	.03	.03	.03	.03	.015			
V	.003	.0015	.0015	.0015	.0015	.0015			
Y	.002	.0015	.002	.002	.0015	.002			
Yb	.0002	.00015	.0002	.0002	.00015	.0002			
Zr	.015	.01	.007	.007	.01	.01			
CIPW norms									
Q	26.348	31.479	29.582	29.480	29.668	29.751			
C	1.567	2.098	.579	.622	.725	1.534			
or	20.626	27.300	26.016	23.145	23.715	22.498			
ab	35.443	29.744	32.173	35.692	35.657	31.368			
an	10.153	5.137	7.665	7.261	6.128	8.938			
hy en	1.267	1.150	1.146	1.176	1.224	1.447			
hy fs	0	0	0	.152	.495	.933			
mt	1.703	1.418	.820	1.369	1.251	1.133			
hm	.620	.227	.635	0	0	0			
il	.739	.324	.266	.286	.286	.304			
ap	.331	.190	.166	.143	.190	.261			
cc	.113	.114	.114	.114	.114	.638			
Total	98.91	99.18	99.16	99.44	99.45	98.81			

[1]Rapid rock analyses.
[2]Average of 2 replicate analyses.
[3]Results are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1, which represent approximate midpoints of interval data on a geometric scale. The assigned interval for semiquantitative results will include the quantitative value about 30 percent of the time. Elements looked for but not found: As, Au, B, Bi, Cd, Co, Eu, Ge, Hf, In, Li, Nd, Ni, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, and Zn.

ages, based on the K-Ar method, of 55.7–56.3 m.y. Specimen 9, which is not shown on the Sahuarita quadrangle map (Drewes, 1971a), was collected from the south end of the dike in a saddle area on the ridge between Ophir Gulch and Enzenberg Canyon (NW¼NW¼SE¼ sec. 23, T. 19 S., R. 15 E.). The consistency of these ages and the absence of signs of recrystallization of the porphyry suggest that an age of 56 m.y. is essentially a true age of the crystallization of the rock. This age provides an important reference point in interpreting the geologic development of the area, specifically in dating faults such as the late-phase faults of the Laramide orogeny, with which the porphyry has a close temporal and spatial relation (Drewes, 1971a, 1972a).

A zircon concentrate from one plug (table 2, specimen 8), collected on a nose at elevation 5,880 feet (SW¼NE¼NW¼ sec. 25, T. 19 S., R. 15 E.) is dated as 180 m.y., an age that is older than that of the rocks it intrudes. Apparently some of this zircon is unrecognized xenocrystic material derived from the underlying Precambrian rocks. Provisionally this isotopic age is considered to be enigmatic and is not used in dating the plugs.

A comparison of the isotopic ages of the Greaterville plugs and the Helvetia stocks with their geologic relations indicates a dating problem which makes me suspect that the ages that date two of the stocks are slightly too young. In the field, the plugs are seen to be younger than the stocks, because they intrude faults that cut the stocks. But the isotopic ages from two stocks are slightly younger than the three ages from the plugs. This amount, however, is less than the combined range of analytical error given for the ages of the two rock types, so it may not be significant. With the data presently available, it is most likely that, for unknown reasons, the ages on the stocks are a few million years too young, although it is also possible either that the span of time between emplacement and cooling of the stocks is significantly greater than that of the plugs, or that the emplacement of the stocks or development of the poststock and preplug faults are not fully synchronous.

PALEOCENE TO OLIGOCENE ROCKS

A few igneous rocks, whose geologic ages are inferred to postdate some volcanics and intrusives of Paleocene age and to predate other volcanics and intrusives of late(?) Oligocene age, underlie small areas of the Santa Rita Mountains. They include a group of andesitic dikes, olivine andesite plugs, rhyolitic volcanics, and a swarm of quartz veins. The relations among these rocks and generally also the relations to older and younger rocks are incompletely known. As a result, the Paleocene to Oligocene rocks remain a fairly enigmatic part of the local geologic record.

ANDESITIC DIKES

Small intrusive bodies of andesite, dacite, and diorite occur in widely scattered parts of the Santa Rita Mountains. These bodies are typically dikes, sills, and intrusive pipes which will here all be referred to as dikes. Only those dikes are described here which appear to be sufficiently younger than the nearest plutonic body to cast doubt on their genetic association with the plutons.

The andesitic dikes of Sycamore Canyon are greenish- to brownish-gray fine- to medium-grained rocks. Two northwest-trending dikes at locality *A* (fig. 6) are about 10 feet wide and a mile long, and they weather to form rounded blocks. A dike at locality *B* forms a string of pods that follows the folds in the steeply dipping beds of the Lower Cretaceous Apache Canyon Formation, shown with the older rocks in figure 6 and described by Drewes (1971b). The dike at locality *C* is only 2 feet wide and is very inconspicuous because it weathers like its host rock, which is also steeply dipping Apache Canyon Formation. The few other andesitic dikes shown in the Sycamore Canyon area (Drewes, 1972a, pl. 5) resemble those at localities *A–C* and are not described separately.

Under the microscope, the andesitic rocks are seen to be nonporphyritic to sparsely porphyritic ophitic rocks with grains 0.5–3 mm long. Amphibole forms acicular crystals between which the other minerals form subhedral to anhedral grains. Unaltered remnants of amphibole have pale pleochroic colors like those of actinolite, but most of the amphibole is chloritized. The rocks contain much chlorite, epidote, kaolinite, and sericite. Plagioclase is typically albitized, but one specimen contains remnants of calcic andesine. Magnetite and apatite are ubiquitous, and one specimen also contains traces of sphene, quartz, and possible biotite.

OLIVINE ANDESITE PLUGS

Two plugs of vesicular olivine andesite intrude metamorphosed Lower Cretaceous Glance Conglomerate (Drewes, 1971b) less than a mile north of the east end of Box Canyon (Drewes, 1971a; 1972a, pl. 5). The Glance here dips moderately to the west and overlies a thrust fault. The plugs are roughly elliptical, and they are separated from each other by a septum of conglomerate. One plug cuts the thrust fault, and the other is faulted against gravel of Pliocene and Pleistocene age.

The olivine andesite makes only a few inconspicuous outcrops because in most places it is strongly weathered; however, relatively unweathered rock crops out at the dry falls along the canyon northwest of Deering Spring. The rock is medium gray and fine grained, and much of it contains abundant large vesicles or calcite amygdules.

In thin section, the andesite is seen to have a strongly felty texture of plagioclase laths with interstitial granular ferromagnesian minerals. Plagioclase makes up 65–80 percent of the rock; it is albitized and is strongly altered to clay minerals and sericite. Iddingsite(?), apparently formed from olivine, makes up about 10 percent of the rock. Some of the interstitial material may have been an amphibole. Magnetite makes up 2–4 percent of the rock, and apatite a trace. The rock also contains calcite and an isotropic iron-poor pearly lustered chlorite (R. E. Wilcox, oral commun., 1968) in amygdules and interstitial pockets. Iron oxide occurs as rims and disseminated grains. Epidote is widely scattered in the rock, as are a few veinlets of chalcedony, quartz, and calcite.

The olivine andesite is provisionally dated as early Tertiary because it postdates a thrust fault whose latest movement may be as young as Paleocene (Drewes, 1972a) and because it lacks the glassy groundmass and fresh appearance typical of volcanics of late(?) Oligocene or younger age. The abundance of vesicular structure suggests that the rock was emplaced near the surface, a situation most compatible with conditions well after the Laramide orogeny. The andesite may have been emplaced about the time of extrusion of dacitic flows 6 miles to the northeast (Finnell, 1971).

RHYOLITIC VOLCANICS

Rhyolitic lava(?) and tuff underlie a small area along the east edge of the Sahuarita quadrangle about 2 miles north of the east end of Box Canyon (Drewes, 1971a; 1972a, pl. 5). These rocks are much less altered than the underlying rocks of the Cretaceous Bisbee Group, and they are unconformably overlain by terrace gravel. They are a light-gray to pale-reddish-purple coarsely fractured rock that contains lithic fragments, chiefly felsite, less than an inch across. Approximately 50 percent of the rock consists of fragmental and partly resorbed phenocrysts about 2 mm across, some of which are sericitized and kaolinitized plagioclase laths. A little biotite, replaced by a hydromica, and a trace of magnetite and zircon(?) are also present. The groundmass consists of brown partly devitrified flow-laminated glass, and of clay minerals.

The absence from the rhyolitic rock of the strong mineralization of Paleocene age (Drewes, 1971b) that is so widespread in the adjacent and underlying Cretaceous rock indicates that the rock probably is no older than Paleocene. T. L. Finnell (oral commun., 1968) indicated that about 3 miles northeast of the outcrop area of the rhyolite, where the rocks are more extensively exposed, the volcanics unconformably underlie the older part of the Pantano Formation, probably of Oligocene age, which does not appear in the Sahuarita quadrangle. The rhyolitic rocks are therefore likely of Paleocene to Oligocene age.

Dating by Damon and Bikerman (1964) of tuff low in the Pantano Formation near the junction of Pantano Wash and Davidson Canyon (Finnell, 1970), 15 miles northeast of the Wasp Canyon area, gives K-Ar ages of 32.8 ± 2.7 m.y. (biotite) and 36.7 ± 1.1 m.y. (sanidine). Another tuff higher in the sequence near Pantano Wash is dated as 29.0 ± 0.9 m.y. (biotite) and 29.4 ± 0.9 m.y. (biotite). A tuff from the lower part of the Pantano Formation near the Babocomari Ranch, near the intersection of Babocomari River and the Pima-Cochise County line, 23 miles southeast of the Wasp Canyon area, gives a K-Ar age on biotite of 38.9 ± 1.3 m.y. (R. F. Marvin, H. H. Mehnert, and Violet Merritt, written commun., 1969).

QUARTZ VEIN SWARM

Veins largely or wholly of quartz are scattered throughout the Santa Rita Mountains. In the central and northern parts of the mountains the veins are generally sparse and fairly small and irregular in trend and thickness, whereas in the southern part of the mountains the veins are abundant, are at least a few feet thick and a few hundred feet long, and are regular in trend and thickness. Veins commonly occur singly or in small clusters; however, in the Alto Gulch and Mansfield Canyon areas (fig. 12) there is a swarm of more than 300 quartz veins, which is alined roughly east-west and which fans out eastward.

Typical quartz veins of this swarm, here referred to as the Alto veins, are about 5 feet wide and 2,000 feet long, are regularly tabular, and are inclined between 70° N. and 70° S. The veins cut rocks as young as the Gringo Gulch Volcanics and are unconformably covered by gravel of Pliocene or Pleistocene age. They are more abundant in the volcanic and sedimentary rocks of the flanks of the mountains than in the plutons along the crest of the mountains, and they are more abundant in the Josephine Canyon Diorite than in the other plutonic rocks. The veins intrude both altered and unaltered rock, and with one exception described in a collateral report (Drewes, 1972b), alteration does not increase near the veins. Thus the veins seem to be genetically unrelated to the alteration, and they are probably younger than that alteration. The veins commonly weather out as low ribs of nearly white rock, many of whose fractures are coated with brown iron oxides. A few veins follow normal faults. Only the large northwest-trending vein near the Salero Ranch is brecciated by younger faulting and is recrystallized; younger movement of silica has changed part of the vein into a broad silicified zone.

The Alto veins are of particular interest because of their mineralization, which was described by Schrader (1915) and by Drewes (1972b). Briefly, the veins carry sulfides of copper, lead, zinc, silver, and iron. As early as the 18th century the Spaniards mined silver from some of the larger veins in the Alto and Salero areas. The last widespread mining activity ceased with the Indian uprisings toward the end of the 19th century, but sporadic interest in exploration and development work in the area continues.

The structural significance of the Alto veins is of additional interest (Drewes, 1972a). The veins make an intriguing pattern mainly in the structural blocks between two large northwest-trending faults (to the southwest and to the east) and the zone of weakness followed by the dike swarm at Gardner Canyon (to the north). In essence, I believe the vein swarm lies in a tension fracture system that developed after the relaxation of the compressive stresses of the Laramide orogeny. The further development of the tension fracture system gave rise to the injection of the dikes of Gardner Canyon and Box Canyon (fig. 25), the injection of the feeder dikes of the

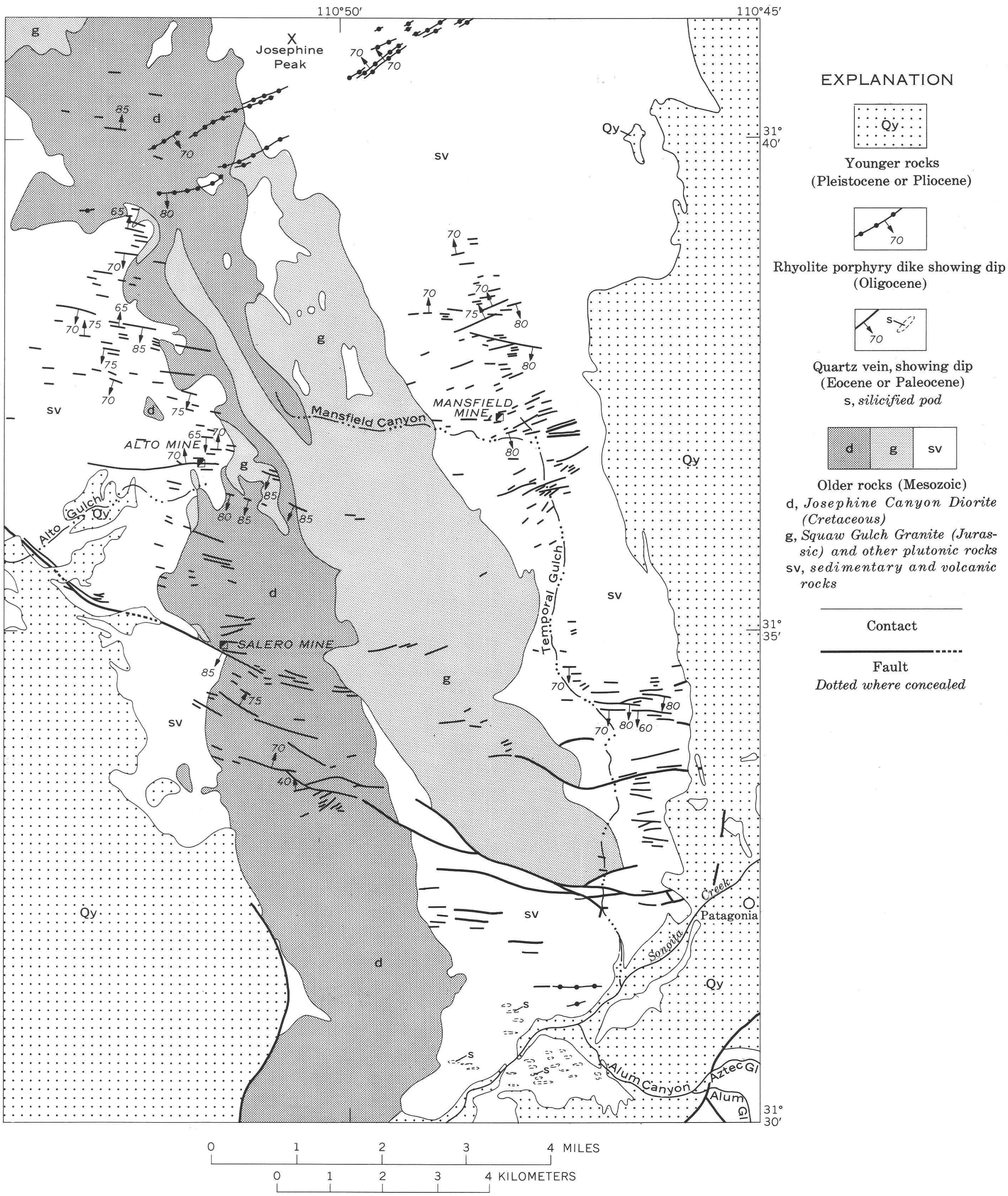

FIGURE 12. — Distribution of the quartz vein swarm in the southern Santa Rita Mountains. Base from U.S. Geological Survey: Mount Wrightson quadrangle, 1:62,500, 1958.

Grosvenor Hills Volcanics, and the beginning of the northeast-trending range-front faults.

The age of the Alto veins falls in the range of Paleocene to Oligocene. The veins postdate some rocks of Paleocene age and appear to postdate the metamorphism and alteration, which probably are also as young as Paleocene. The veins are older than the Grosvenor Hills Volcanics, whose basal gravel contains pebbles of vein quartz, and they are also probably older than the dike swarms in Gardner Canyon and in Box Canyon — which are isotopically dated as about 26 m.y. (table 2) — because sulfide mineralization is strongly associated with Paleocene intrusives and because sulfides are virtually absent from the Oligocene intrusives and extrusives. Yet the veins were emplaced sufficiently later than the Paleocene intrusives to permit the compressional stresses of the Laramide to give way to the later tensional stresses. Thus the veins may be Eocene.

The area of east-trending silicified pods in the Gringo Gulch Volcanics does not overlap the area of east-trending quartz veins. Nevertheless their common orientation suggests that at least a uniform structural control existed in both areas. The mineralized rock of the veins, as seen in the field, is similar to that of the silicified pods, as determined spectrographically. Many veins contain sulfides of lead, zinc, and copper. A little molybdenite was seen, and silver ore has been mined from several veins. Semiquantitative spectrographic analyses (made by E. L. Mosier, written commun., 1964) of samples from six silicified pods follow (N.D., not detected; threshold of detectability, 200 ppm):

Metal	*Concentration (ppm)*	*Frequency (of six samples)*
Ag	1–2	2
Cu	150	2
Mo	1–2	2
Pb	50–100	4
Zn	N.D.	0

The concentrations of at least silver, copper, molybdenum, and lead are three or more times their background values. In addition, alunite, indicative of hydrothermal alteration, is present in several of the pods.

The similarity in the orientation and mineralization of pods and veins and the restriction of pods and veins to adjacent though separate areas suggest that the pods are genetically as well as structurally related to veins. Possibly the pods are relatively near surface expressions of veins. They thus may represent the deposits formed as surface leakage of veins, presumably in a hot-spring environment, and perhaps mineralized veins lie at depth beneath them. Since the emplacement of the veins and pods, the southern Santa Rita Mountains have been tilted gently southward to expose progressively deeper levels of the vein and pod system toward the north. Southward tilting during the late Tertiary is supported by other structural evidence (Drewes, 1972a).

OLIGOCENE ROCKS

Volcanic, intrusive, and minor sedimentary rocks, of late(?) Oligocene age, occur in scattered parts of the Santa Rita Mountains. The southern part of the mountains contains an igneous complex of volcanic, hypabyssal, and plutonic rocks, which probably are genetically related. The northern part of the mountains contains only rhyolite intrusives.

IGNEOUS COMPLEX OF THE SOUTHERN SANTA RITA MOUNTAINS

Abundant rhyolite and rhyodacite of the Grosvenor Hills Volcanics, many rhyodacite dikes, some rhyodacite laccoliths, and a small granodiorite stock occur in the Grosvenor Hills and the adjacent San Cayetano Mountains, two small hilly areas on the southern and southwestern flanks of the Santa Rita Mountains. The relatively deep seated rocks in the San Cayetano Mountains and the volcanics and shallow intrusives in the Grosvenor Hills are brought together by large vertical movement on a normal fault of mid-Tertiary to late Tertiary age. The petrography and stratigraphy of the rocks of this igneous complex are described separately; their chemistry, age, and structure, however, are described together in order to facilitate the comparisons that indicate the rocks are genetically related. In brief, these rocks probably represent parts of (1) a deep parent-magma reservoir, (2) shallow magma chambers, (3) connecting conduits between the deep and shallow bodies, and (4) lava spilled out at the surface above, and in part adjacent to, the internal "plumbing system."

STRATIGRAPHY AND PETROGRAPHY

GROSVENOR HILLS VOLCANICS

Rhyolite and rhyodacite lava and pyroclastic rocks and subordinate amounts of sedimentary rocks, together about 2,000 feet thick, have been named the Grosvenor Hills Volcanics (Drewes, 1968, p. C14–C15). This formation underlies an area of about 20 square miles, chiefly in the Grosvenor Hills but extending southward beyond the Mount Wrightson quadrangle and across Sonoita Creek (fig. 13) as well as northwestward to the pediment along Montosa Canyon in the northwestern part of the Mount Wrightson quadrangle (Drewes, 1971c). It lies unconformably upon Jurassic and Cretaceous plutonic and volcanic rocks and is unconformably overlain by Miocene and Pliocene gravel of Nogales. The volcanics are commonly gently inclined to the south or west; steeper dips occur only next to some faults and intrusives and locally within some tuff sheets that were deformed penecontemporaneously with their deposition.

The basal unconformity is best exposed along the northeastern edge of the volcanics and around the two small inliers within the volcanic pile (fig. 13). It forms a nearly flat and gently southwestward-inclined surface into which several small channels have been cut. The channels are filled with fairly thick lenses of the basal gravel and silt of the overlying formation. The gentle topography and the typically thin veneer of basal clastic deposits suggest that the prevolcanic surface was a pediment.

The Grosvenor Hills Volcanics are divided into a thin basal gravel and silt member, a moderately thick medial rhyolite member, and a thick capping rhyodacite member. The two volcanic members are made up of lava flows, tuff (some of it welded), and agglomerate. Still further subdivisions, such as individual welded tuff sheets, were mapped; they cannot be shown at the scale of figure 13, but they are shown on the quadrangle map (Drewes, 1971c).

Gravel and Silt Member

The gravel and silt member typically occurs as a discontinuous thin sheet along the base of the formation, but some lenses are as much as 200 feet thick. The member is well exposed along the banks of the larger gullies half a mile southwest of the Salero Ranch and along the canyon about 1,000 feet north of the northernmost laccolith (fig. 13). Small slices of the member are also brought up along the margins of the laccoliths, and one slice is dragged up along the San Cayetano fault.

The member consists chiefly of a distinctive pale-red to pale-reddish-brown very weakly consolidated silt and intercalated thin beds of gravel. However, a mile south of Cinigita Tank the member is made up of bedded siltstone, shale, and sublithographic limestone, and at locality *D* in figure 13 it includes some olive-gray shale. The pebbles of the gravel are distinctly more rounded than those of the younger gravels of the area. They consist of detritus of the Squaw Gulch Granite (Jurassic), vein quartz, Mount Wrightson Formation (Triassic), and volcanics of the Salero Formation (Cretaceous). The limestone and the olive-gray shale contain fossil plant material.

The small size and round shape of the pebbles are noteworthy, inasmuch as a likely source of the pebbles occurs close by in the adjacent Santa Rita Mountains but apparently in few other adjacent areas (Drewes, 1971b). A small pebble size suggests a source area of low relief. The proximity of the apparent source of the pebbles seems to contradict the amount of transport implied by the degree of rounding, especially of such hard rocks as the volcanics of the Mount Wrightson Formation. Either the pebbles were recycled or they were deposited by streams in a climate different from the present one. For instance, a more moist climate in which rainfall was more equitably distributed than it is today might have favored more extensive scouring of the hard coarser pebbles by the bypassing finer particles, whereas during infrequent but heavy downpours, typical of the present climate, bypassing is not favored.

Rhyolite Member

The rhyolite member forms a sheet at least 500 feet thick that overlies the basal gravel and silt member and laps over the Mesozoic rocks (fig. 13). It is best exposed along the south, east, and north margins of the volcanic pile. The member is chiefly tuff and tuff breccia, but it also contains about 5 percent each of tuffaceous sandstone, agglomerate, lava, and welded tuff, and a trace of coarse breccia. A small body of rhyolite breccia, possibly an intrusive, lies near the base of the member south of Cinigita Tank. The pyroclastic rocks commonly underlie lowlands, in which small outcrops of white to very pale yellowish brown massive rock are abundant and in which ledges of similarly colored bedded tuffaceous rock are widely scattered. The rhyolite flows of this member, which occur between Josephine Canyon and Tejano Spring to the north and in the lower reaches of Coal Mine Canyon and the upper part of Fresno Canyon to the south, are moderate-orange-pink to pale-yellowish-brown or light-red, conspicuously color-laminated, finely porphyritic bodies.

In thin section, the tuffaceous rocks are seen to contain fragments of vitrophyre and pumice. In a few rocks, such as those along the lower part of Hangmans Canyon, some of the pumice fragments are flattened, so they may be incipiently welded. Most lithic fragments, however, resemble the lava flows of the member. Some opaline material is also present.

The tuff commonly is altered only by pervasive argillic material. However, some tuff 1–2 miles southwest of the Salero Ranch is altered to a greenish-gray rock, whose color probably is due to the presence of a mineral with X-ray characteristics that resemble those of clinoptilolite.

Rhyolite lava consists of a cryptocrystalline to devitrified groundmass, abundant microlites, and phenocrysts. Phenocrysts, 10–20 percent of the rock, are, in decreasing order of abundance, plagioclase,

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FIGURE 13. — Slightly generalized geologic map of the Grosvenor Hills and San Cayetano Mountains on the southwest flank

EXPLANATION

QTg — Gravel (Quaternary and Tertiary)

TERTIARY

Tn — Gravel of Nogales (Pliocene and Miocene)

UNCONFORMITY

Grosvenor Hills Volcanics

Tgdf, Tgda, Tgdw, Tgdt — Rhyodacite member
- Tgdf, *flows*
- Tgda, *agglomerate; includes some tuffaceous rocks*
- Tgdw, *welded tuff*
- Tgdt, *unwelded tuff*

Tgrf, Tgrt, Tgrw — Rhyolite member
- Tgrf, *flows*
- Tgrt, *tuff; includes tuff breccia and tuffaceous sandstone*
- Tgrw, *welded tuff*

Tgg — Gravel and silt member

Oligocene

Age relations unknown

Trl — Rhyodacite vitrophyre
In laccoliths and associated dikes

Tr — Rhyolite plug and dike

Ts, Trp — Intrusive rocks of the San Cayetano Mountains
- Ts, *granodiorite stock*
- Trp, *rhyodacite porphyry dike swarm*

UNCONFORMITY

Mzu — Sedimentary, volcanic, and plutonic rocks (Mesozoic)

65 — Contact, showing dip
Dotted where concealed

80 — Fault, showing dip
Dotted where covered or intruded. Bar and ball on downthrown side

25 — Strike and dip of beds

▲▲▲▲ — Breccia

x*A* — Locality referred to in text

○385 — Collection site of chemically dated specimen

●315 — Collection site of radiometrically analyzed specimen

SCALE 1:62 500

0 1 2 3 MILES

0 1 2 3 KILOMETERS

of the Santa Rita Mountains. Base from U.S. Geological Survey: Mount Wrightson and Nogales quadrangles 1:62,500, 1958.

quartz, oxybiotite, oxyhornblende, and accessory magnetite, apatite, and zircon. Most plagioclase is sodic oligoclase to sodic andesine, but in some specimens the plagioclase is albite.

Modal analyses of two specimens of lava, one of the intrusive breccia, and one of a lithic fragment in tuff breccia are presented in table 10. The analyses probably are fairly representative of the tuff, too, because the tuff contains abundant lithic fragments that are like the lava (compare modes of specimens 1 and 2 with that of specimen 13). Specimens 1 and 2 were also chemically analyzed (table 14). Specimen 1 is a porphyritic rhyolite from a fragmental flow, collected in the SW¼NW¼ sec. 28, T. 21 S., R. 14 E. Specimen 2 is also a porphyritic rhyolite, from a flow in the SW¼NE¼ sec. 12, T. 18 S., R. 13 E.

TABLE 10. — *Modes (in percent) of some rocks of the rhyolite member of the Grosvenor Hills Volcanics*

Rock represented	Lava flow		Instrusive breccia	Fragment in tuff breccia
Specimen No.[1]	1	2	12	13
Field No.	63D443	64D624	63D290	63D286a
Quartz	3.7	6.6	7.8	1.9
Potassium feldspar	0	0	7.6	0
Plagioclase	4.7	12.4	6.6	7.6
Biotite	2.0	1.4	.8	3.2
Hornblende	0	0	0	.6
Magnetite	.2	.2	.2	.2
Apatite	0	Trace	.1	Trace
Zircon	0	0	0	Trace
Groundmass	89.4	79.4	76.9	86.5
Total	100	100	100	100
Anorthite content of plagioclase	19–23	30–35	0	18–28

[1]Specimens 1 and 2 are keyed to table 14.

The source of the volcanics of the rhyolite member remains conjectural, in part because of the extensive cover of younger volcanics. Evidence of a single major volcanic center is absent. Indeed, some circumstantial evidence points to sources at several small local vents. The breccia body 1½ miles south of Cinigita Tank (fig. 13) may indicate the site of one such vent. The widely scattered small bodies of lava and welded tuff may have issued from separate vents. The group of rhyolite dikes and the plug at the south end of the San Cayetano Mountains (mapped by F. S. Simons, written commun., 1966) may have been feeders of still other vents of the rhyolite member.

RHYODACITE MEMBER

The rhyodacite member, which caps the Grosvenor Hills Volcanics, is commonly at least 800 feet thick and consists of abundant agglomerate and lava flows, some welded tuff, and a little unwelded tuff. With the exception of the nearly white unwelded tuff, these rocks are dark gray to dark brown, and they form prominent scarps or steep slopes above the pale-colored rocks of the rhyolite member. Most of the individual units of the rhyodacite member are lenticular or wedge shaped, and therefore the stratigraphic sequence varies from place to place. In general, the thicker parts of the units lie to the west. Some stratigraphic units also change facies laterally; lava is generally most abundant in the western part of the pile, and tuff is most abundant in the east and northeast parts.

The thickness of the member increases westward, but to the west the full thickness is unknown because either the top of the member is eroded or the bottom is concealed. The rhyodacite along lower Ash Canyon to the southeast, where both top and bottom of the member are present, is 150–250 feet thick. Near the center of the pile, in the highest part of the Grosvenor Hills (fig. 13), the member is at least 800 feet thick, and near Sheuy Well it is at least 1,000 feet thick. A composite of the major subdivisions, probably nowhere actually present, is more than 2,200 feet thick.

The basal contact of the rhyodacite member is generally gradational, and locally the member interfingers on a small scale with the underlying rhyolite; but in places the contact is unconformable.

The lowest rocks of the member are commonly gray rhyodacite agglomerate, at whose base lies a transitional sheet a few tens of feet thick of tuffaceous agglomerate consisting of scattered rather than of abundant rhyodacite blocks in a tuffaceous matrix. Such a transitional basal sheet of tuffaceous agglomerate is 100 feet thick along parts of Fresno Canyon. West of lower Fresno Canyon the lowest mapped unit of the rhyodacite member is a welded tuff, but it, too, rests on a sheet of tuffaceous agglomerate commonly too thin to be mapped. This agglomerate contains many blocks of petrified wood, which suggests, according to Damon and Miller (1963), that a forest growing on the tuff was overwhelmed by a rhyodacite block flow. Their interpretation implies that locally the base of the rhyodacite member is placed beneath the tuffaceous agglomerates. Only rarely do the rhyodacite fragments so decrease in size as well as in abundance as to create a gradation between the agglomerate and the underlying rhyolite tuff. Less commonly gray rhyodacite lava flows or welded tuff form the lowest unit of the member. Their basal contacts are relatively sharp, but most of them also have a thin basal sheet of fragmental rocks of mixed types. Less commonly, too, tuffaceous agglomerate or tuff breccia of the rhyodacite member rests on, or interfingers with, tuff breccia, apparently of the rhyolite member. Thus, in a few places, as at the head of Cinigita Canyon and nearby to the north and west of that canyon head, the contact between the members is gradational, and locally its mapped position is tenuous.

Agglomerate is the most abundant rock type of the rhyodacite member, and it commonly is the basal unit. On the flanks of the high hills a mile east of Sheuy Well, a lower wedge of agglomerate underlying a welded tuff is as much as 1,000 feet thick, and an upper wedge of agglomerate near the crest of the hills is about 440 feet thick. The lower agglomerate wedge thins from the Sheuy Well area toward the north, east, and south, and in places it seems to pinch out entirely. Similarly, the upper agglomerate wedge thins eastward, but it is restricted to the graben between the Sheuy and George Wise faults.

The agglomerate consists of abundant rhyodacite blocks, commonly 1–3 feet across (fig. 14) but as much as 20 feet across, set in a relatively sparse tuffaceous matrix. The rock typically underlies moderately steep slopes that are irregularly broken by cliffs and numerous small outcrops. The weathered blocks are brownish black, and the matrix is pale yellowish brown to reddish brown. The blocks are more resistant to weathering than is the friable tuff and tend to project above the rest of the surface and to form a colluvial veneer. Where the proportion of matrix to blocks increases, usually toward the base or thin margins of a wedge of agglomerate, the rock grades into tuff breccia. North of Cinigita Canyon a little of the relatively thin part of the lower wedge of agglomerate is welded, as a result of which vitrophyre blocks as much as 2 feet across are flattened to 3–4 inches, and the pumiceous tuff matrix is indurated and strongly jointed. West of peak 5,469 (fig. 13) the clasts of the upper wedge of agglomerate include a few blocks of granodioritic rock that resembles the granodiorite of the San Cayetano Mountains. In hand specimen the vitrophyre is seen to contain moderately large phenocrysts of plagioclase and at least two kinds of ferromagnesian minerals (fig. 15).

Lava flows are next in abundance to agglomerate in the rhyodacite member. They form prominent cliffs, and the rocks typically contain strongly de-

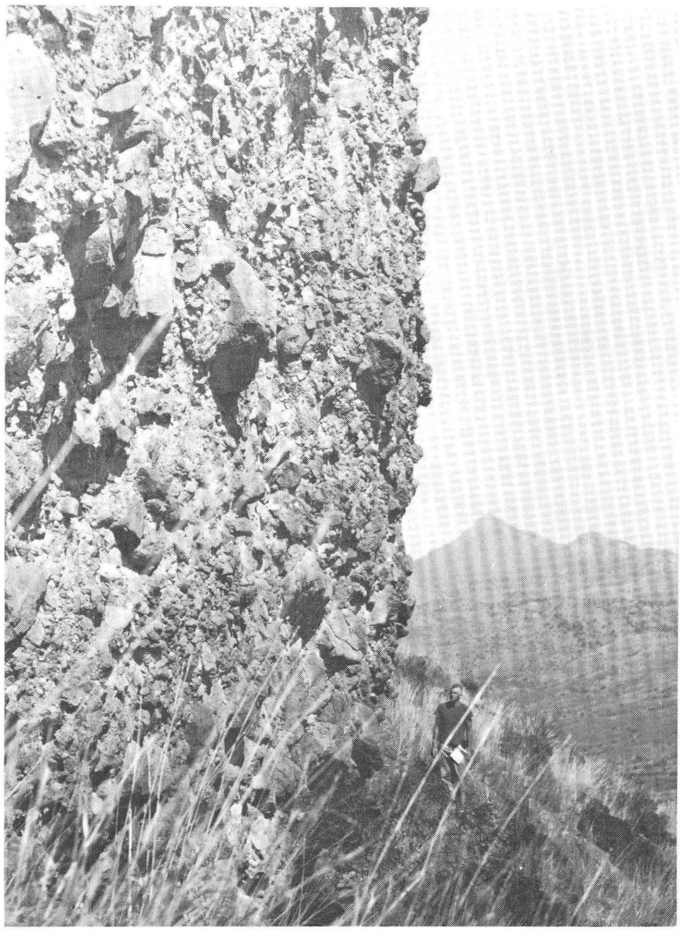


FIGURE 14.—Typical agglomerate of the rhyodacite member of the Grosvenor Hills Volcanics.

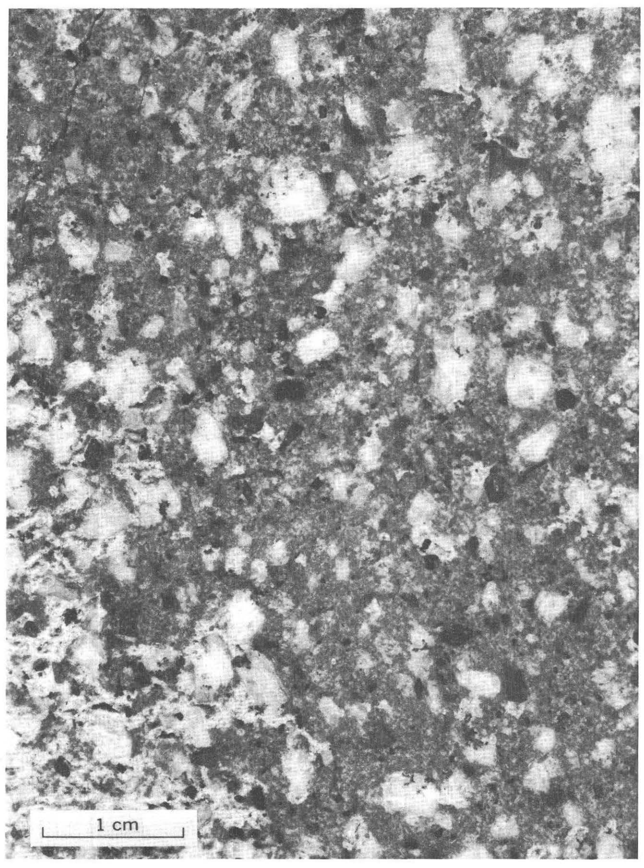


FIGURE 15.—Vitrophyre block from the rhyodacite member of the Grosvenor Hills Volcanics. The specimen, 63D411, is from the agglomerate sheet that caps the ridge near hill 5,228.

veloped fracture sets and a subhorizontal sheeting. A thick sheet of lava, with a few intercalated lenses of agglomerate, lies between Sheuy Well and the west edge of the volcanic pile. Thinner sheets of lava spread northward, eastward, and southward from the Sheuy Well area, and they typically overlie agglomerate but in places overlap it to lie upon the tuff breccia of the rhyolite member. A single rhyodacite flow occurs to the north along Josephine Canyon, and another one crops out to the southwest between the lower reaches of Coal Mine and Hangmans Canyons. Two rhyodacite flows, however, lie northeast of the Sheuy fault; the upper of these flows forms the highest stratigraphic unit of the member.

The rock is medium gray and contains moderately abundant coarse phenocrysts of plagioclase and of two ferromagnesian minerals, like those in the agglomerate blocks. Only the flow near lower Coal Mine Canyon is different in that it is light gray and contains fewer phenocrysts; thus it is somewhat transitional in appearance between the flow rocks typical of the rhyolite member and those typical of the rhyodacite member.

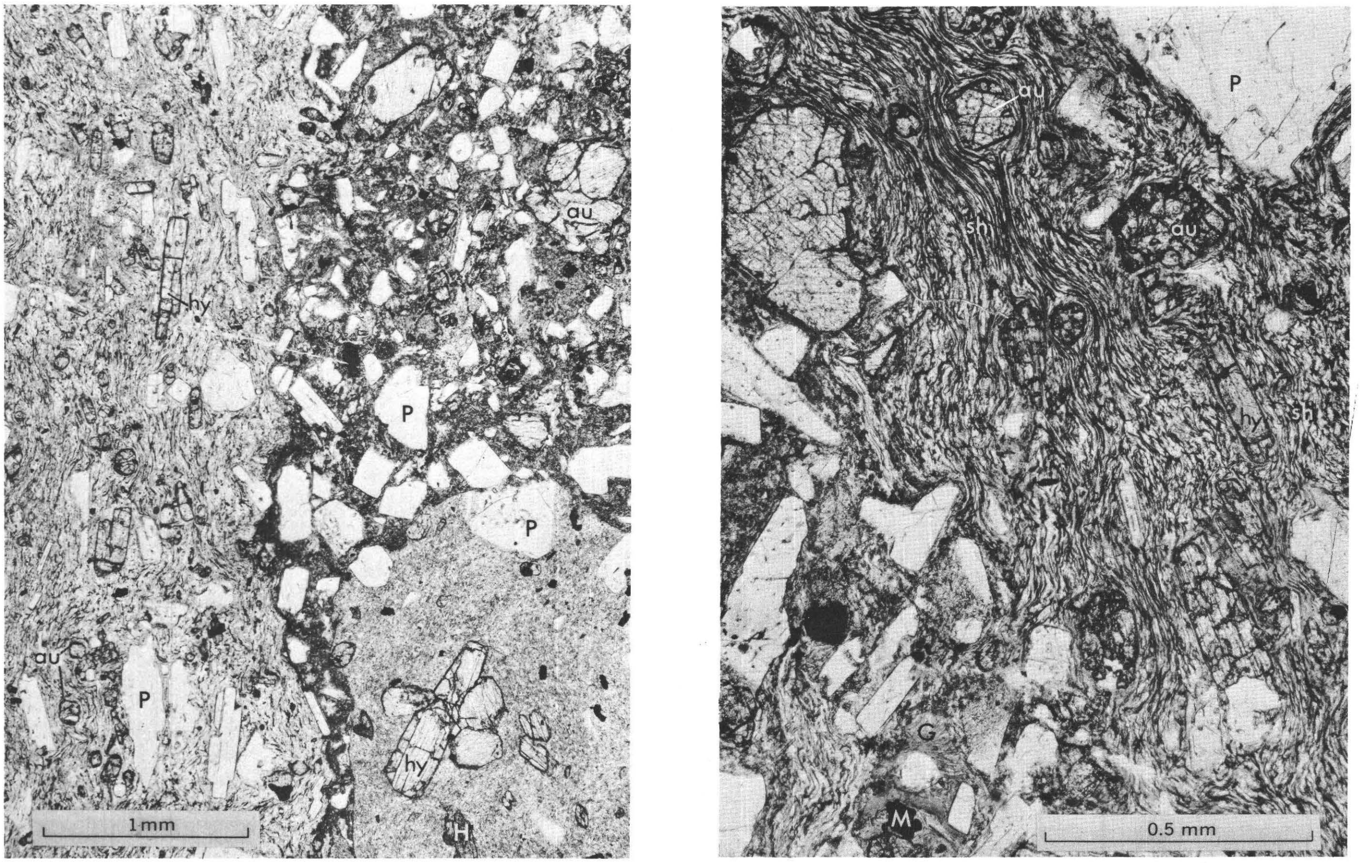
Welded tuff makes up less than 10 percent of the rhyodacite member. At least five sheets of welded tuff, separated by sheets of lapilli tuff breccia, form a single sequence between the two wedges of agglomerate in a graben between the Sheuy and George Wise faults. These sheets of welded tuff, each 60–120 feet thick, and intercalated tuff breccia, each commonly 10–20 feet thick, have a combined maximum thickness of at least 500 feet along the western part of the north margin of the graben. These sheets thin rapidly southward across the graben to pinch out in places north of the George Wise fault, and they thin gradually eastward along the graben. This thinning is distributed throughout most of the individual beds and is not a progressive onlapping of the base of the unit or a truncation of the top. In another downfaulted area, along Fresno Canyon, there is commonly only one sheet of welded tuff and it is about 100 feet thick. It lies between agglomerate beds toward the northwest but laps across the underlying agglomerate sheet and rests on the rhyolite member to the south. The welded tuff of Fresno Canyon is roughly contemporaneous with the welded tuffs in the graben although none are continuous across the intervening area. Apparently, separate hot-ash flows were confined to the depressions and avoided the intervening high block.

Welded tuff weathers to form dark-brown cliffs having an irregular polygonal jointing that resembles the jointing of the cliffs held up by the lava flows. The welded tuff consists of small very dark gray lenticular flattened clots of vitrophyre set in a pale-brown relatively friable matrix (fig. 16). Both the flattening of the clasts and the development of the polygonal joints diminish gradually toward the intercalated tuff breccia sheets. The phenocryst content of the vitric clots resembles that of the flows and agglomerate blocks.

Unwelded tuff is the least abundant rock type of the rhyodacite member. In outcrop and hand specimen it resembles the tuff of the rhyolite member, but unlike the underlying tuff, at least some of the unit contains no rhyolite fragments, and part of the unit contains small vitric fragments that resemble the rhyodacite.

The flows, the blocks of the agglomerate, and the clots in the welded tuff all have a glassy to cryptocrystalline groundmass enclosing phenocrysts and xenocrysts, which make up 30–40 percent of the rock. The glass has an index of refraction of n=1.505–1.506. Phenocrysts and xenocrysts, as much as 7 mm long, are chiefly plagioclase, in part quartz, hornblende, biotite, augite, and hypersthene, and rarely magnetite, apatite, and zircon (fig. 17). Plagioclase commonly has the composition of sodic andesine, but it ranges from calcic oligoclase to sodic labradorite. Most plagioclase is clouded, and some crystals are partly resorbed. Some plagioclase from the agglomerate of lower Ash and Hangmans Canyons has reverse compositional zoning. Most quartz of the rhyodacite is also partly resorbed. Hornblende and biotite are somewhat erratically distributed in that they occur in some samples of the flows north of upper Cinigita Canyon but not in others. Hornblende and biotite in about half the specimens are oxidized, and many crystals are partly resorbed. Where unoxidized, the hornblende is pleochroic in shades of olive brown. Augite occurs as euhedra and also as reaction rims around hornblende or biotite, or less commonly, around hypersthene. A nonpleochroic orthopyroxene, possibly enstatite, appears in place of hypersthene in the agglomerate of Ash and Hangmans Canyons and in the flow that caps the central part of the pile.

Modal analyses of seven rocks of the rhyodacite member are listed in table 11. Specimens 3 and 4 are hypersthene augite rhyodacite vitrophyres. Specimen 4 contains xenocrystic hornblende, biotite, and plagioclase. This plagioclase has reverse zoning, the outermost zone of the plagioclase phenocrysts having the more calcic composition. Rarely, plagioclase and quartz xenocrysts are rimmed by augite (fig. 18). Specimen 3 is from a flow in the SW¼SW¼ sec. 22, T. 21 S., R. 14 E., and specimen 4 is from a block of the agglomerate sheet in the NE¼SE¼



A *B*

FIGURE 16. — Welded tuff from the rhyodacite member of the Grosvenor Hills Volcanics. The specimen, 63D414, shows: au, augite; G, glass; H, hornblende; hy, hypersthene; P, plagioclase; sh, shards of flattened vesicles. *A*, At low magnification: dark-gray tuffaceous groundmass, light-gray rhyodacite vitrophyre xenocryst, and, across the left side, banded xenocryst of flattened rhyodacite pumice or tuff. *B*, At high magnification: textural details of rhyodacite pumice or tuff xenocryst, showing remnants of flattened shards or vesicles.

TABLE 11. — *Modes (in percent) of rocks of the rhyodacite member of the Grosvenor Hills Volcanics*

Rock represented	Lava flow				Agglomerate			Average
Specimen No.[1]	3	14	15	16	4	17	18	
Field No.	63D382	63D426	65D710	65D718	63D425	63D386	64D601a	
Quartz	0	0	0	Trace	0	0	0	0
Plagioclase	26.2	19.7	26.5	19.2	22.1	36.2	21.5	24.5
Biotite	0	1.4	.2	0	1.1	.3	0	.4
Hornblende	0	0	.8	3.7	3.3	0	2.4	1.5
Augite	4.7	0	4.5	3.1	5.5	3.8	1.8	3.3
Hypersthene	4.9	0	3.1	1.2	1.9	3.9	.1	2.2
Magnetite	1.4	1.0	1.6	.7	1.7	1.2	.7	1.2
Apatite	Trace	.1	.2	.2	.2	Trace	.2	.1
Zircon	0	Trace	0	0	0	0	0	0
Groundmass	62.8	77.8	63.1	71.8	64.2	54.6	73.3	66.8
Total	100.0	100.0	100.0	99.9	100.0	100.0	100.0	....
Anorthite content of plagioclase:								
Phenocrysts	44–50	27–30	40–45	49–55	45–49	36–43	45–47	....
Xenocrysts	....	....	33	....	32–44	....	....	....

[1]Specimens 3 and 4 are keyed to table 14.

sec. 15, T. 22 S., R. 14 E. (unsurveyed). Of the rocks with modal analyses, only these two were chemically analyzed (table 14).

Most rocks of the rhyodacite member — especially the vitric rocks, the flows, the blocks of the agglomerate, and the clots in the welded tuff — are only mildly altered to clay minerals. However, along the west edge of the volcanic pile, where the flows and agglomerates thicken, the rocks are strongly montmorillonitized.

The site of the vent of the rhyodacite volcanics is unknown, as is true for that of the volcanics of the

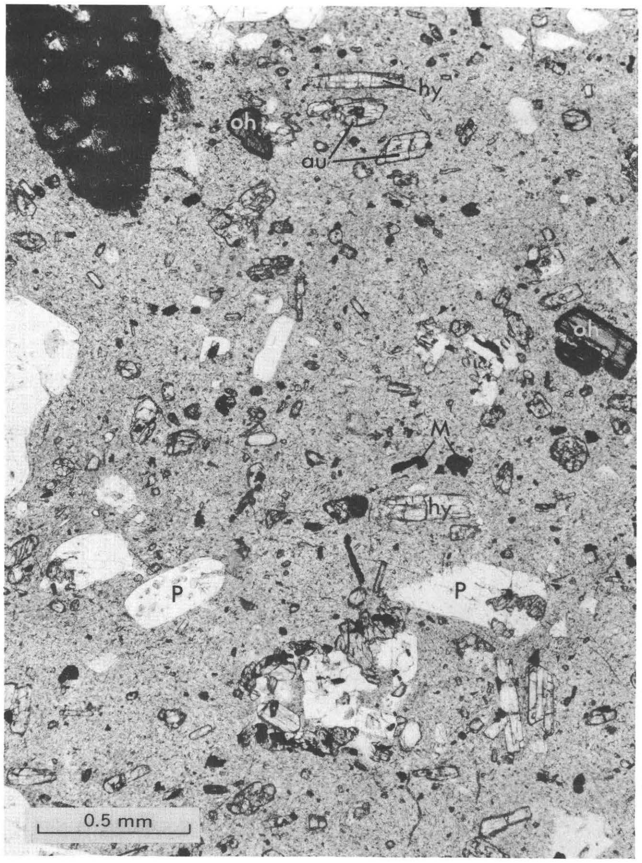


FIGURE 17.—Vitrophyre from a flow in the rhyodacite member of the Grosvenor Hills Volcanics. The specimen, 65D710, from the top of the lower flow on the ridge almost 2 miles south of the Salero Ranch, shows: au, augite; hy, hypersthene; oh, oxyhornblende; M, magnetite; P, plagioclase.

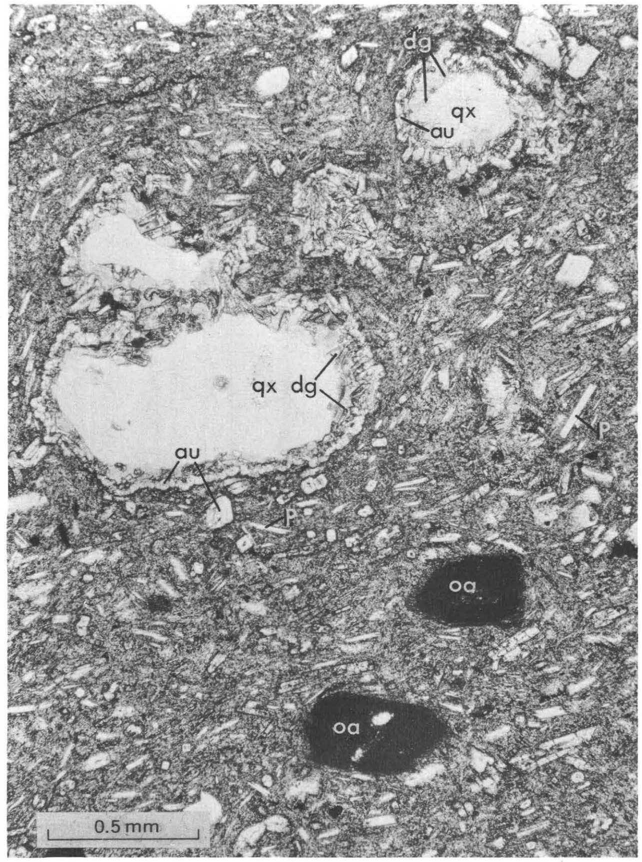


FIGURE 18.—Quartz xenocrysts rimmed by augite, from the rhyodacite member of the Grosvenor Hills Volcanics. The specimen, 63D421, from a lava flow about a mile south of George Wise Spring, contains: au, augite; dg, devitrified glass (?) ; oa, oxidized amphibole, probably hornblende; P, plagioclase; qx, quartz xenocryst.

rhyolite member. Unlike the rhyolite volcanics, however, the rhyodacite volcanics may have come from a single vent, whose location probably lay west of Sheuy Well and either just east of the San Cayetano fault or perhaps well within the San Cayetano fault block. Such a location is suggested by the thickening of many units toward that area and by the gradation of some flows into agglomerates or block flows away from that area. The montmorillonitic alteration of the rocks at the west edge of the pile and the inclusion of granodiorite resembling that of the stock in the San Cayetano Mountains are compatible with a vent area in or near those mountains.

DIKES AND LACCOLITHS IN THE GROSVENOR HILLS AREA

A swarm of dikes and five bulbous laccoliths, of medium-gray to light-gray rhyodacite vitrophyre, intrude the Grosvenor Hills Volcanics (fig. 13). With the exception of the southernmost laccolith, these intrusive bodies lie in an arcuate zone centered roughly in the middle of the San Cayetano Mountains. This zone is peripheral to the postulated site of the rhyodacite vent.

The dikes occur either singly or in small clusters, spaced at intervals of about a mile. Dikes are commonly more than 50 feet thick, and several of them flare out into bodies many hundreds of feet thick. Most dikes trend N. 70° W., but the northernmost dike strikes N. 60° E. One small cluster of dikes is continuous with a laccolith, and another dike merges with or abuts a tabular intrusive resembling the margin of a sill or laccolith. The wider dikes typically form rock ribs, whereas the narrower ones are less resistant to weathering and underlie relatively low belts.

Individual laccoliths are as much as 1½ miles long, almost 1 mile wide, and about 900 feet thick. They are shaped like conventional doorknobs (fig. 20*C*) that have slightly flattened elliptical cross sections, rather than the lenticular cross sections of the classical laccoliths (fig. 20*A*) of the Henry Mountains (Hunt and others, 1953). In plan, the laccoliths are also roughly elliptical and are elongated parallel to most of the dikes. Only a few minor bulges mar the symmetry of their outlines. The laccoliths commonly intrude the tuffaceous rhyolite member of the Grosvenor Hills Volcanics, but locally the beds adjacent to this tuff are also intruded. Laccoliths, because they resist weathering better than their tuffaceous host, typically underlie buttes or hilly areas rimmed by cliffs. Coarse reddish-gray residual blocks of rhyodacite vitrophyre are strewn over the gentler slopes. The cores of the laccoliths contain one or two sets of relatively widely spaced fractures more or less transverse to the elongation of the laccoliths, and the marginal zones display more closely spaced radial fractures (fig. 19) and a peripheral sheeting. In many places the marginal zones are stripped of most of their cover because of the ease of erosion of the host rock; however, a thin veneer of talus or rock-fall debris commonly covers the contact itself. In such places the peripheral sheeting still reliably conveys the local attitude of the contact. And nowhere does the tuff that surrounds the massive rhyodacite bodies contain detritus derived from them.

The floors of the laccoliths are virtually flat and are roughly parallel to, and at or slightly above, the base of the Grosvenor Hills Volcanics. The marginal contacts themselves generally steepen toward the floors, and in places they dip inward, as shown in the foreground of figure 19. Consequently, small segments of the contacts are actually beneath the overhanging cliffs of the outward-bulging, higher parts of the laccolith. Flat basal contacts are seen where canyons cut deeply into some laccolith margins, such as occurs half a mile northeast of Tejano Spring. A gently inward-dipping base of the east end of the laccolith at George Wise Spring is also suggested at the strong reentrants at both ends of the narrows of Hangmans Canyon.

Some indirect evidence also supports the interpretation that the intrusives are virtually flat floored. Many small slices of the gravel and silt member of the Grosvenor Hills Volcanics lie along the margins of the laccoliths, but rocks of pre-Grosvenor Hills age are not found along the margins. If the dominant movement direction along the intrusive margins was upward, then slices of the older rocks would be expected, along with those of the silt and gravel member. However, if the dominant movement of intrusion was horizontal, such movement not only

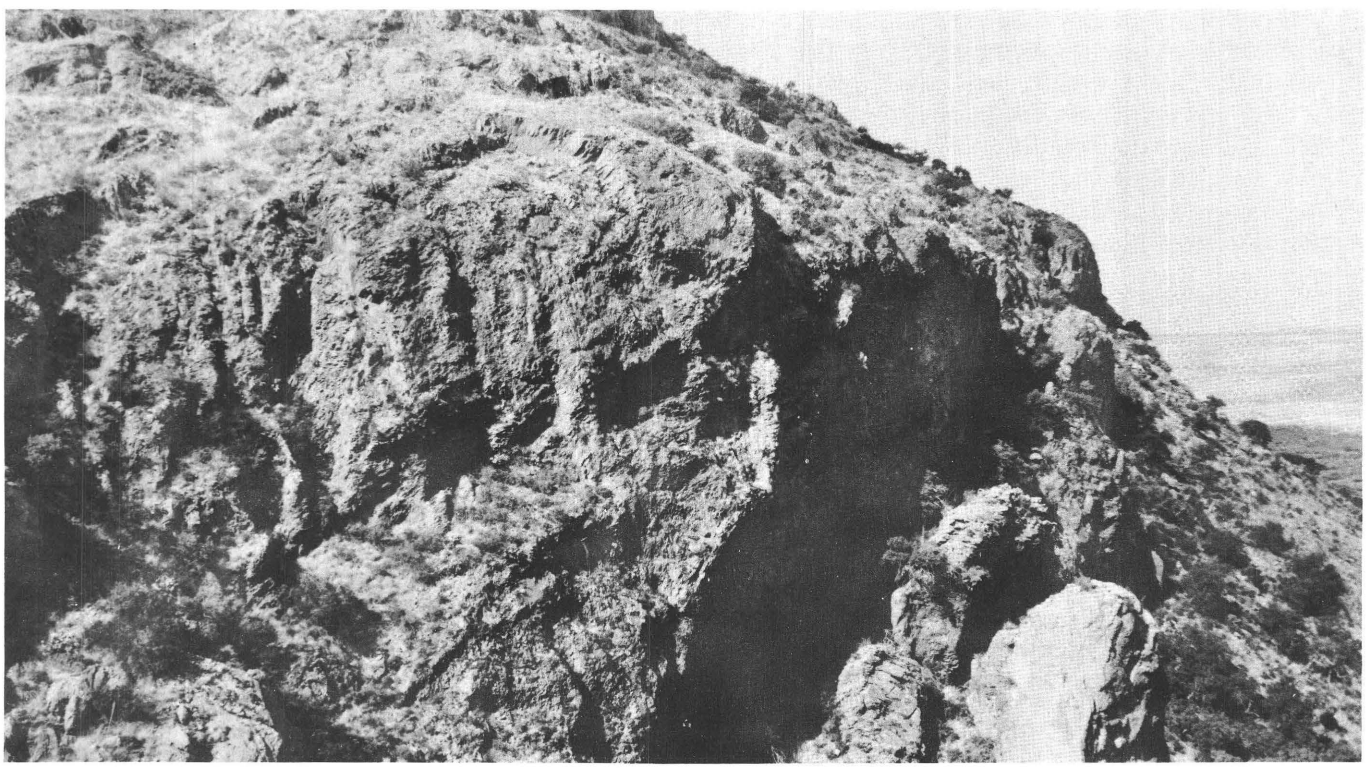


FIGURE 19. — Northeast margin of the laccolith northeast of Tejano Spring. The radially jointed margin makes a cliff about 100 feet high, as shown in the center of the photograph, and overhangs the contact with the tuff of the rhyolite member of the Grosvenor Hills Volcanics, largely covered by the talus to the lower right.

would have been favored by the thick sheets of unconsolidated silt and rhyolite tuff but also might be expected to have pushed aside the weak rocks without dragging any of the underlying indurated rocks. Such horizontal movement implies flat floors.

Evidence indicating that the laccoliths had flat tops is also available. The peripheral sheeting of many laccoliths flattens upward and inward from vertical margins toward the roofs of the laccoliths, which suggests that the margins also flatten upward. A flat-lying cap of dark-gray rhyodacite vitrophyre directly overlies part of the laccolith northeast of Tejano Spring, around locality *A* in figure 13. This vitrophyre resembles the narrow zones of chilled border rocks of lava flows and of the rhyodacite dikes. Presumably it is the chilled border at the top of the laccolith, which thus shows that the upper margin of this laccolith was flat lying and which further gives a basis for estimating a 900-foot thickness of the doorknob-shaped laccolith.

The inference that these rhyodacite bodies were intruded into the volcanics rather than extruded, as domes, onto them is based in part on the interpretation of the caprock on the body northeast of Tejano Spring as a chilled border phase. Their intrusive origin is also based in part on the absence of a breccia border, on the absence of detritus from the rhyodacite bodies in the adjacent tuff, and on their shape. Extrusive domes, such as the rhyolitic domes at Mono Craters, Calif., described by Putnam (1938), are sheathed in rubble (fig. 20*B*), a feature which is lacking around the laccoliths. Under normal circumstances of surface weathering and deposition, some detritus derived from a topographically high extrusive dome would be expected to be incorporated into surrounding onlapping tuff, which is not the case in the laccoliths. Putnam described the shape of the extrusive domes as subrounded on their tops but abruptly angular toward their bases, whereas the laccolithic bodies are rounded toward both their tops and bases. Furthermore, the sheeting and radial fractures of the rhyodacite bodies seem more likely to have formed in a somewhat slower cooling intrusive body than in a very rapidly cooling extrusive one. Finally, the overall regularity of the ellipsoidal bodies suggests, but more tenuously than the preceding evidence, that they were confined during emplacement, and their moderately flat shape also suggests that they were emplaced beneath a cover.

Some structures at the junctures of several of the laccoliths also give the impression that the laccoliths swelled outward rather than that they were vertically emplaced cylindrical intrusives. Three of the four

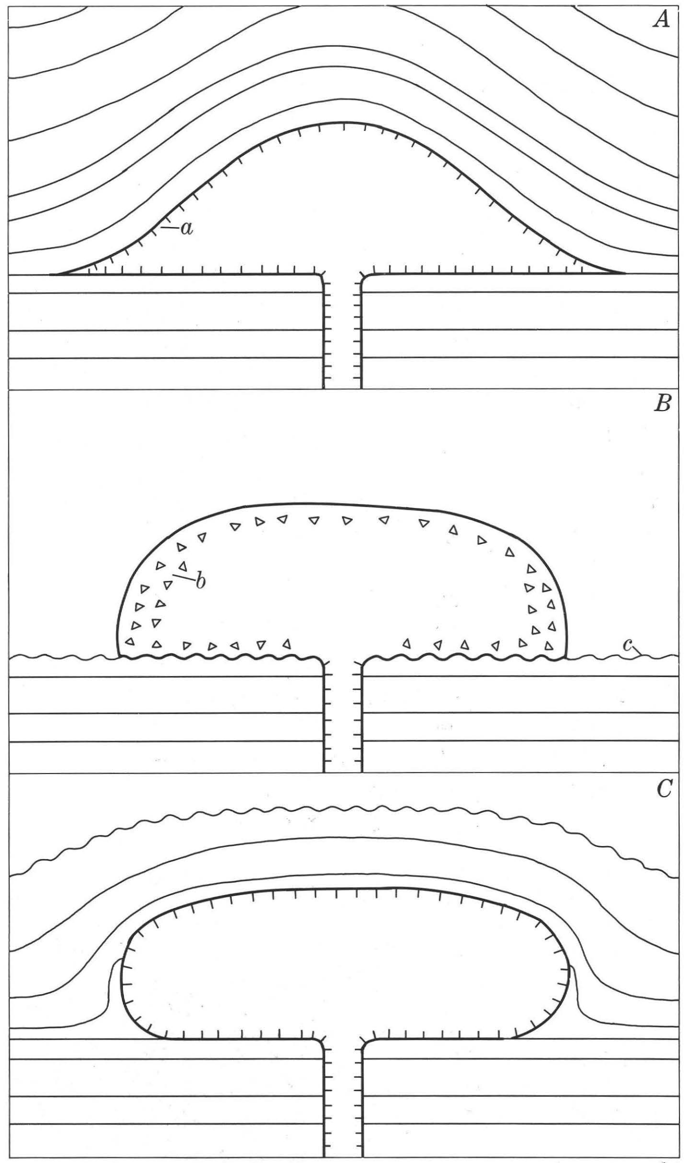


FIGURE 20. — Two kinds of laccoliths and an extrusive dome. *A*, Classical laccolith of Henry Mountains, Utah, modified from Hunt, Averitt, and Miller (1953); *a*, radially oriented joints along chilled margins. *B*, Extrusive dome of Mono Craters, Calif., modified from Putnam (1938); *b*, rubble-sheathed margin; *c*, surface at time of emplacement. *C*, Bulbous laccolith of report area.

northern laccoliths near Tejano Spring are separated from each other by narrow septa of volcanics, mainly tuff of the rhyolite member of the Grosvenor Hills Volcanics. A mile south of the spring, two of the laccoliths actually abut, the intervening tuff septum having wedged out completely over a distance of about 700 feet. The peripheral sheeting in the laccoliths parallels the margins of the laccoliths against the septa and continues adjacent to the contact between the two juxtaposed laccoliths. Clearly the magma did not flow laterally between the laccoliths. Furthermore, no evidence suggests that one of these laccoliths cuts the other; the intrusive masses seem merely to flatten slightly against each other. The preservation between the intrusives of these septa and especially of the thin wedges of weak tuff seems incompatible with a field of vertically moving magma cylinders emplaced near the surface. Their preservation appears to be more reasonable, on the other hand, in a field of horizontally swelling magma blisters.

The intrusive rocks are petrographically much like the rocks of the rhyodacite member of the Grosvenor Hills Volcanics, particularly the rhyodacite flows north of the upper reaches of Cinigita Canyon. The groundmass of the intrusive rocks is vitric or cryptocrystalline, and it surrounds abundant phenocrysts of andesine and sparse phenocrysts or xenocrysts of quartz, hornblende, biotite, augite, and hypersthene. The hornblende of most intrusive rocks is bright green rather than olive brown as in the volcanics. Nonpleochroic orthopyroxene, possibly enstatite, is sparse, and oxybiotite and oxyhornblende are also fairly sparse. Most specimens from the interiors of laccoliths contain phenocrysts of andesine, hornblende, and biotite (fig. 21), but two specimens from the vitric cap of the laccolith at Tejano Spring contain andesine, augite, and hypersthene. One of the Tejano Spring specimens is from the chilled margin of the narrow dike three-fourths of a mile east-southeast of the juxtaposed laccoliths, and the other is from the 15-inch-wide chilled margin of the feeder dike to the southeastern laccolith.

The change from hornblende and biotite in the cores to augite and hypersthene in chilled margins is apparently due to subtle differences in the composition of the magma during emplacement. Such changes in magma composition are also indicated by the reaction rims around some ferromagnesian minerals of the rhyodacite member of the Grosvenor Hills Volcanics, by the reverse zoning of some plagioclase, and perhaps even by the sporadic association of quartz and hypersthene and the frequent occurrence of xenocrysts in general. A compound xenocryst of biotite and hornblende, rimmed by augite and plagioclase, is illustrated in figure 22.

Modal analyses of eight specimens of rhyodacite from the laccoliths and related dikes are shown in table 12. Five of the eight specimens have been chemically analyzed (table 14), and their collection localities on the Mount Wrightson quadrangle map (Drewes, 1971c) are as follows: Specimen 5 is a hornblende biotite rhyodacite from near the base of the laccolith in the NW¼SE¼ sec. 18, T. 22 S.,

FIGURE 21. — Rhyodacite vitrophyre from the southeastern laccolith intruding the Grosvenor Hills Volcanics. The specimen, 63D315, from locality shown in figure 13, contains: B, biotite; H, hornblende; M, magnetite; P, plagioclase.

R. 15 E. (unsurveyed). Specimen 6 is also a hornblende biotite rhyodacite, collected about 75 feet from the edge of a laccolith in the NE¼NE¼ sec. 20, T. 21 S., R. 14 E. Specimen 7 is a hornblende biotite rhyodacite from near the core of a laccolith in the SE¼NE¼ sec. 28, T. 21 S., R. 14 E. Specimen 8 is a hypersthene augite rhyodacite vitrophyre from the probable chilled cap of the same laccolith as specimen 7 at the NW¼NW¼ sec. 27, T. 21 S., R. 14 E. Specimen 9 is a quartz-bearing hypersthene augite rhyodacite vitrophyre from the chilled margin of the thick dike(?) in the SE¼SW¼ sec. 32, T. 21 S., R. 14 E.

DIKES AND STOCK OF THE SAN CAYETANO MOUNTAINS

A swarm of rhyodacite porphyry dikes and a granodiorite stock cut the rocks of the San Cayetano Mountains (fig. 13). The host rocks are chiefly Josephine Canyon Diorite and gently southward-dipping volcanic and sedimentary rocks of the Salero Formation, both of Late Cretaceous age. Other dikes and a plug, of porphyritic rhyolite, at the south end of the mountains were mapped by F. S. Simons (written commun., 1966). The rocks are unconformably overlain by gravel of Pliocene and Pleistocene age. The swarm is made up of more than 60 nearly vertical dikes; most of these dikes strike N. 60°–70° W., but a few to the north strike N. 60°–70° E. The dikes of the swarm are clustered at intervals of about a mile. Each cluster commonly has one or two larger dikes, at least 50 feet wide and a mile long, and many narrower, shorter dikes.

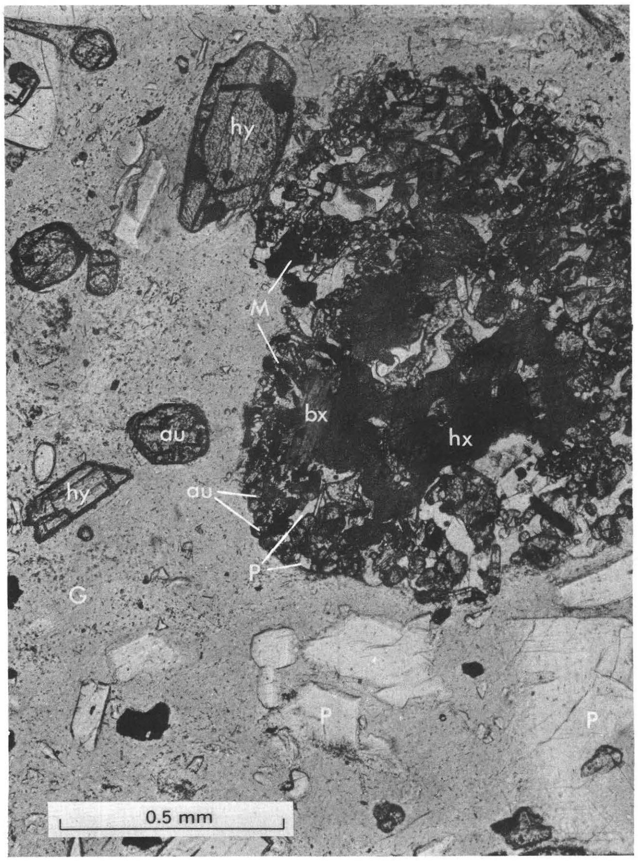


FIGURE 22. — Compound xenocryst of biotite and hornblende from a rhyodacite vitrophyre dike cutting the Grosvenor Hills Volcanics. The specimen, 63D518, from the intrusive three-fourths of a mile north of Sheuy Well, contains: au, augite; bx, biotite xenocryst; G, glass: hx, hornblende xenocryst; hy, hypersthene; M, magnetite; P, plagioclase.

Seen at a distance, the dikes form very light gray bands along which outcrops are scarce. However, low on the west flank of the range, near the granodiorite stock, the dikes form low ribs and alined low knobs. Locally on ridge crests and along gullies the dikes form bold outcrops.

The dike rock generally contains abundant phenocrysts, as much as 5 mm long, of feldspar, quartz, biotite, and amphibole, but near the stock, phenocrysts are scarcer. The phenocrysts are scattered in a groundmass whose grain size is commonly 0.02–0.1 mm and is rarely as much as 0.5 mm. Much of the groundmass consists of finely interlocking quartz and feldspar, and in some specimens the groundmass has a crudely granophyric texture that is considerably obscured by intensive kaolinization.

Modal analyses of two rhyodacite porphyry dikes are shown in table 13. Specimen 10 is from a dike in the SW¼SW¼ sec. 13, T. 22 S., R. 13 E. (unsurveyed). Its chemical analysis is given in table 14. The groundmass of both dikes contains a large proportion of orthoclase, and that of specimen 10 contains about 7.5 percent quartz.

Granodiorite underlies a semicircular area low on the west flank of the San Cayetano Mountains, where its west edge is buried beneath gravel. The covered part of the stock is presumed to be no larger than the exposed part, so the stock is a nearly circular body about a mile in diameter. The contact

TABLE 12. — *Modes (in percent) of rhyodacite intrusives into the Grosvenor Hills Volcanics*

Intrusive body	Laccoliths				Dikes				Average
Specimen No.[1] / Field No. (63D–)	5 / 315	6 / 498	7 / 385	8 / 386	9 / 518	19 / 420	20 / 422	21 / 410a	
Quartz	0	0	0	0	Trace	4.4	0.6	1.0	0.8
Plagioclase	38.8	26.0	23.0	28.4	35.5	18.8	25.2	23.8	27.4
Biotite	2.2	.8	Trace	0	.1	2.9	.5	1.5	1.1
Hornblende	3.4	10.1	9.1	0	.3	10.2	4.3	1.4	4.9
Augite	0	0	0	2.4	4.2	0	0	1.5	1.0
Hypersthene	0	0	0	3.1	0	0	0	3.9	.6 (Hypersthene and Enstatite)
Enstatite	0	0	0	0	1.9	0	0	0	
Magnetite	1.5	1.3	.7	.5	1.6	1.6	.8	.5	1.1
Apatite	.2	.2	Trace	Trace	.1	.3	.1	.1	.2
Zircon	.1	.2	0	0	0	.2	.2	.1	.1
Groundmass	53.9	61.4	67.3	65.7	56.3	61.6	68.3	66.3	62.6
Total	100.1	100.0	100.1	100.1	100.0	100.0	100.0	100.1	....
Anorthite content of plagioclase:									
Phenocrysts	40–44	35–40	36–43	33–44	31–42	32–35	35–46	45–53	....
Xenocrysts	32–33	....	....	....	....	....	....	....	....

[1]Specimens 5–9 are keyed to table 14.

TABLE 13. — *Modes (in percent) of some dikes and a stock from the San Cayetano Mountains*

Rock type and intrusive body	Rhyodacite porphyry, dikes		Granodiorite, stock	
Specimen No.[1]	10	22	11	23
Field No. (64D–)	564	558	570	571
Quartz	8.9	6.1	23.2	22.4
Plagioclase	35.7	36.4	50.6	47.7
Orthoclase	0	0	15.4	20.7
Biotite	2.2	3.4	5.2	5.3
Hornblende	2.2	5.2	4.5	3.2
Magnetite	.7	.8	.8	.4
Apatite	.2	.1	.2	.2
Zircon	.1	Trace	Trace	Trace
Sphene	.2	Trace	.1	.1
Groundmass	49.8	48.0	......	......
Total	100.0	100.0	100.0	100.0

[1]Specimen 10 is keyed to table 14.

of the granodiorite with its host, the Josephine Canyon Diorite, is mostly covered, and in the few gullies where the contact is exposed, it is steep and without apophyses, chilled margins, or contact metamorphic features. The granodiorite, however, is a massive moderately coarse grained light-gray rock that, because it is distinctly less chloritized and epidotized than the diorite, is presumed to be younger.

The stock cuts some of the rhyodacite porphyry dikes of the large swarm and is cut by others. These relations suggest that dikes and stock were emplaced penecontemporaneously.

The microscopic features of the granodiorite are typical of granitoid stocks. The rock has a hypidiomorphic-granular texture and a 4-mm grain size. Of the two specimens whose modes are shown in table 13, No. 11 was collected about 1,000 feet from the margin of the stock, and No. 23 about 50 feet from the margin; both are from the SE¼SW¼ sec. 2, T. 22 S., R. 15 E. (unsurveyed). A chemical analysis of a typical specimen is given in table 14. Anhedral quartz and orthoclase grains are interstitial to subhedral plagioclase. The orthoclase contains a little lace perthite. The anorthite content of the plagioclase is 32–35 percent. Biotite forms subhedral grains that are only very slightly altered to chlorite and leucoxene. Amphibole grains, pleochroic in shades of pale olive green, are subhedral to euhedral. The magnetite is titaniferous. Traces of sericite, epidote, kaolinite, and iron oxides are also present.

CHEMISTRY OF THE IGNEOUS ROCKS

Chemically, the several groups of igneous rocks of Oligocene age of the Grosvenor Hills area have much in common with each other, and some of them are much like those of the San Cayetano Mountains; but in detail there are some differences among them (table 14). The chemical similarity is greatest between the volcanic rocks of the rhyodacite member of the Grosvenor Hills Volcanics and the intrusive rhyodacites in the Grosvenor Hills area, as illustrated by comparison of the analyses of specimens 3 and 4 with those of 5–9. The combined average of these seven analyzed rocks is nearly identical with Nockolds' (1954, p. 1014) average rhyodacite. Likewise, the analyses of a representative dike and a stock of the San Cayetano Mountains, specimens 10 and 11, are much alike, and these rocks closely resemble Nockolds' (1954, p. 1014) average hornblende-biotite granodiorite.

The average of the analyses of the vitrophyric rocks in the Grosvenor Hills area (specimens 3–9) differs slightly from the analysis of the nonvitric dikes of the San Cayetano Mountains (specimen 10). The vitrophyres contain less SiO_2 and Na_2O, for example, and a little more Fe_2O_3, MgO, and CaO. Chemically, the San Cayetano dikes are intermediate between the rhyolites and the rhyodacite volcanics, with a greater similarity to the rhyodacite volcanics. An assumed mixture of one part of rhyolite to four parts of rhyodacite volcanics would be chemically closest to the composition of the granodiorite of the stock. These chemical variations may be related to the origin of the rocks, described in a following section.

The abundance of 17 trace elements (table 14) also shows a strong similarity between the rhyodacite vitrophyres and the intrusives of the San Cayetano Mountains. In general, the sulfophile and siderophile elements are less abundant in the rhyolites than in the other rocks. The high copper content in the dike from the San Cayetano Mountains with respect to the otherwise very similar analysis of the granodiorite (compare specimens 10 and 11) is the main apparent anomaly.

Specimen 2 of table 14 was collected from a site north of the area of figure 13, in the SW¼NE¼ sec. 12, T. 21 S., R. 13 E. All other collection localities are shown in figure 13.

FAUNA AND AGE

A few of the sedimentary rocks intercalated in the Grosvenor Hills Volcanics are fossiliferous. Damon and Miller (1963) described remnants of wood, possibly of *Pinus* and apparently in place, in the tuff of the rhyolite member. The wood was buried by, and was partly incorporated into, a thin sheet of agglomerate at the base of a welded tuff of the rhyodacite member east of the lower end of Fresno Canyon (locality *B*, fig. 13). They indicated that the plant material is insufficiently diagnostic to date the rock, but they judged its age to be Miocene.

A small lens of olive-gray poorly indurated shale that is part of the gravel and silt member exposed in a fault block at localty *C* (fig. 13), east of the

TABLE 14. — *Chemical and spectrographic analyses and CIPW norms, in percent, of the Grosvenor Hills Volcanics and related intrusive rocks in the Grosvenor Hills area compared with Nockolds' average analyses*

[Modes of the specimens and the locations of collection sites are given in the text sections on the respective units]

	Grosvenor Hills Volcanics					Dikes and laccoliths in the Grosvenor Hills area					Average rhyodacite member and dikes and laccoliths (specimens 3–9)	Average rhyodacite of Nockolds (1954, p. 1014)	Dikes and stock of the San Cayetano Mountains		Average hornblende-biotite granodiorite of Nockolds (1954, p. 1014)
	Rhyolite member			Rhyodacite member											
	Flow breccia	Flow	Average rhyolite (specimens 1, 2)	Flow	Block in agglomerate	Base of laccolith	Margin of laccolith	Core of laccolith	Cap of laccolith	Dike			Dike	Stock	
Specimen No.	1	2		3	4	5	6	7	8	9			10	11	
Field No.	63D443	64D624		63D382	63D425	63D315	63D498	63D385	63D386	63D518			64D564	64D570	
Chemical analyses[1] [P. L. D. Elmore, S. D. Botts, Gillison Chloe, Lowell Artis, J. L. Harris, and H. Smith, analysts]															
SiO_2	76.5	74.2	75.4	63.6	64.1	66.8	66.7	65.5	68.1	65.4	65.7	66.27	68.4	69.5	65.50
Al_2O_3	11.9	13.2	12.6	16.3	15.0	15.9	15.7	16.2	16.0	15.8	15.8	15.39	15.5	15.2	15.65
Fe_2O_3	.76	.75	.76	2.0	3.6	2.5	2.4	2.6	1.3	1.7	2.3	2.14	1.4	1.0	1.63
FeO	.08	.18	.13	2.2	.72	1.0	.68	.60	1.5	2.0	1.2	2.23	1.2	1.1	2.79
MgO	.1	.3	.2	2.5	2.6	1.5	1.8	2.1	1.2	1.8	1.9	1.57	1.2	1.4	1.86
CaO	.47	.95	.71	4.0	3.8	3.4	3.2	3.4	2.9	3.4	3.4	3.68	2.9	3.2	4.10
Na_2O	3.0	3.3	3.2	3.9	4.1	4.0	4.2	4.4	3.9	4.0	4.1	4.13	4.5	4.4	3.84
K_2O	4.4	3.0	3.7	2.7	2.8	2.9	2.9	2.3	3.0	2.4	2.7	3.01	2.8	2.8	3.01
H_2O-	.34	.68	.5	.25	1.2	.66	.88	.29	.31	.47	.6	....	.20	.27	....
H_2O+	.60	1.2	.9	1.5	1.0	.74	.72	1.8	1.6	1.7	1.3	.68	1.2	.58	.69
TiO_2	1.8	1.8	1.8	.68	.61	.54	.52	.50	.47	.55	.6	.66	.58	.31	.61
P_2O_5	.02	.18	.1	.22	.16	.16	.19	.22	.26	.13	.2	.17	.14	.14	.23
MnO	.02	.04	.03	.10	.05	.03	.07	.02	.05	.05	.05	.07	.05	.04	.09
CO_2	.05	.05	.05	.09	.05	.05	.08	.05	$<.05$	.05	.06	....	$<.05$	$<.05$	....
Total	100	100	100	100	100	100	100	100	100	99	....	....	100	100	....
Spectrographic analyses[2] [A. L. Sutton, Jr., J. C. Hamilton, Barbara Tobin, and W. B. Crandell, analysts]															
B	0.003	0.003	0.003	0.002	0	0	0	0.0015	0.003	0.003	0.0015	....	0	0	....
Ba	.05	.05	.05	.1	.1	.07	.1	.1	.1	.1	.1	....	.1	.1	....
Be	.0001	.0001	.0001	.0003	.0002	0	.0002	.0002	.0002	0	.0002	....	0	.0002	....
Co	0	0	0	.002	.005	.0007	.001	.001	.001	.001	.002	....	.0005	.001	....
Cr	0	.0003	.00015	.01	.015	.005	.01	.01	.005	.007	.01	....	.002	.007	....
Cu	.0003	.0003	.0003	.002	.005	.005	.002	.002	.0015	.003	.003	....	.01	.0005	....
Ga	.0015	.0015	.0015	.003	.005	.002	.002	.002	.002	.005	.003	....	.0015	.002	....
La	0	0	0	.005	.003	0	.002	.003	.002	.003	.003	....	.003	.003	....
Mo	0	0	0	.0015	0	0	0	0	0	0	.0002	....	0	0	....
Ni	0	0	0	.007	.01	.003	.007	.007	.003	.003	.005	....	.003	.005	....
Pb	.0015	.002	.002	.0015	.002	.0015	.002	.0015	.002	.0015	.0015	....	.002	.0015	....
Sc	0	0	0	.0015	.0015	.001	.0015	.001	.001	.001	.001	....	.0007	.001	....
Sr	.007	.015	.01	.07	.15	.07	.07	.07	.07	.1	.1	....	.05	.07	....
V	0	0	0	.01	.01	.01	.01	.01	.01	.007	.01	....	.005	.007	....
Y	.001	.001	.001	.002	.0015	.0015	.0015	.0015	.0015	.0015	.0015	....	.001	.002	....
Yb	.0001	.0001	.0001	.0003	.00015	.0002	.00015	.0002	.0002	.00015	.0002	....	.0001	.00015	....
Zr	.007	.007	.007	.015	.007	.007	.001	.01	.01	.01	.01	....	.015	.01	....
CIPW norms															
Q	41.129	41.566	....	18.514	18.758	23.388	22.410	21.471	26.233	22.708	....	20.8	23.927	24.645	20.0
C	1.399	3.231	....	.429	0	.387	.478	.938	1.691	.756	....	0	.245	0	0
or	25.995	17.724	....	15.952	16.543	17.133	17.133	13.589	17.724	14.179	....	17.8	16.526	16.543	17.8
ab	25.372	27.909	....	32.983	34.674	33.829	35.520	37.212	32.983	33.829	....	35.1	38.032	37.212	32.5
an	2.200	3.536	....	17.833	14.264	15.818	14.125	15.110	12.685	16.014	....	14.5	13.141	13.464	16.4
di wo	0	0	....	0	1.477	0	0	0	0	0	....	1.3	0	.623	.9
di en	0	0	....	0	1.277	0	0	0	0	0	....	(3)	0	.462	(4)
di fs	0	0	....	0	0	0	0	0	0	0	....	....	0	.100	....
hy en	.249	.747	....	6.224	5.196	3.734	4.481	5.228	2.987	4.481	....	....	2.985	3.023	....
hy fs	0	0	....	1.450	0	0	0	0	.997	1.453	....	....	.182	.656	....
mt	0	0	....	2.900	.716	1.756	.913	.550	1.885	2.465	....	3.0	2.027	1.450	2.3
hm	.760	.750	....	0	3.106	1.289	1.770	2.221	0	0	....	0	0	0	0
il	.212	.466	....	1.291	1.159	1.026	.988	.950	.893	1.045	....	1.4	1.100	.589	1.2
ru	1.689	1.555	....	0	0	0	0	0	0	0	....	0	0	0	0
ap	.047	.426	....	.521	.379	.379	.450	.521	.616	.308	....	.3	.331	.332	.6
cc	0	0	....	.205	0	0	.182	.114	0	0	....	0	.113	0	0
Total	99.05	97.91	....	98.30	97.55	98.74	98.45	97.90	98.69	97.24	....	....	98.61	99.10	....

[1]Rapid rock analyses.

[2]Semiquantitative spectrographic analyses. Elements looked for but not detected: Ag, As, Au, Bi, Cd, Ce, Ge, Hf, Hg, In, Li, Nb, Pd, Pt, Re, Sb, Sn, Ta, Te, Th, Tl, U, W, and Zn. Results are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, and so on, which represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time.

[3]Reported total en = 3.9 and total fs = 1.3.

[4]Reported total en = 4.6 and total fs = 2.9.

north end of the San Cayetano Mountains, contains plant fragments. E. B. Leopold (written commun., 1964) has identified pollen of *Pinus* from this shale and suggests a Late Cretaceous or Cenozoic age for these long-ranging fossils.

Undiagnostic plant(?) remains also occur in the limestone beds intercalated in a lens of the gravel and silt member a mile south of Cinigita Tank.

Radiometric ages provide much more definite data on the age of the igneous rocks of and intruding the formation than do the fossils from sediments intercalated in the formation. Altogether, five ages were determined from four samples of the igneous rocks. Potassium-argon methods on hornblende, biotite, or plagioclase were used on each sample, and the Pb-alpha method was also used on one of them. Sample localities are shown in figure 13. The four radiometric ages obtained using the K-Ar method are virtually identical at 27 m.y., or late(?) Oligocene. The date obtained by the Pb-alpha method is 40 m.y., a typical Pb-alpha age for rocks having a 25- to 30-m.y. K-Ar age (R. F. Marvin, oral commun., 1970).

STRUCTURE

The genesis of the igneous complex of the southern Santa Rita Mountains is closely associated with the structural development of the area. The structural development therefore is summarized in the following paragraphs, although it is described in more detail in a companion report (Drewes, 1972a). Figure 23 illustrates some pertinent structural features of the Grosvenor Hills and the San Cayetano Mountains in vertical section, although that section does not intersect the fault at the east margin of the volcanic field.

The Grosvenor Hills–San Cayetano Mountains area consists of two main structural blocks separated from each other by the large north-trending San Cayetano normal fault. The Grosvenor Hills block forms a broad grabenlike area between this large fault along the San Cayetano Mountains to the west and a smaller north-trending fault, the Hangmans fault, to the east. Movement on the large fault has been recurrent and diverse, but the volcanics appear simply to have dropped as much as 500 feet on the fault during or after the late Oligocene volcanism. In general the volcanics of the Grosvenor Hills block dip regularly and very gently southwestward, but in the western part of the block slightly steeper westward dips are more common, and near the San Cayetano fault along the west margin of the block the rocks dip steeply eastward. The Grosvenor Hills block has dropped an estimated 1,000–2,500 feet along the southern part of the San Cayetano fault, adjacent to the main part of the San Cayetano block. This movement is the cumulative result of faulting during or shortly after late Oligocene volcanism and of faulting after the deposition of the gravel of Nogales upon the upper(?) Oligocene volcanics. Additional, prevolcanism displacements are also inferred along the San Cayetano fault (Drewes, 1972a). The amount and direction of displacement along the northern part of the San Cayetano fault, beyond the area of figure 13, differ from those along the segment in the San Cayetano Mountains and are of little consequence in the genesis of the igneous complex.

Many lesser faults cut the volcanics in the Grosvenor Hills block. The largest set of faults trends N. 70° W., parallel to the orientation of the intrusives, and another strongly developed set trends northward. In those places shown in figure 13 where small faults are especially abundant, local marker beds are also abundant, which permitted recognition of the faults. Similar faults probably remain undetected near the intrusives where such beds are lacking. The small faults among the cluster of laccoliths trend randomly, separating numerous small triangular structural blocks; many of the faults merge with the margins of the laccoliths. A few of the faults, such as those in the southwest corner of the northern laccolith, however, may be truncated by the laccolith. This group of faults appears to have formed by collapse as the volcanics settled between the growing laccoliths; a few of them may have formed adjacent to laccoliths during an early stage of laccolith emplacement, only to be truncated by the laccoliths during their subsequent expansion.

A graben between the Sheuy and George Wise faults trends almost entirely across the Grosvenor Hills block. The graben is tilted gently northwestward along its axis and is tilted more strongly northeastward across its axis, as recorded by the attitudes of alternating welded and unwelded rhyodacite tuff layers which are restricted to the graben and which diminish in number and thickness southeastward. The wedging out of individual sheets of welded tuff across the graben suggests that some fault movement and tilting may have been contemporaneous with the outpouring of the hot tuff. A breccia body at the northeast margin of the graben, along the central part of the Sheuy fault (fig. 13), consists of unsheared and loosely packed rubble that resembles talus rather than a fault breccia. Welded tuff was deposited against, or upon, this talus, which suggests that some movement on the Sheuy fault also preceded the outpouring of the hot tuff. Indeed, the restriction of five sheets of welded tuff to the graben and the southeastward decrease in the number of welded tuff sheets suggest that the sheets flowed southeastward along a valley formed along the graben during the time of, and perhaps as a result of, active volcanism.

The faults bounding the graben are also penecontemporaneous with the emplacement of the laccoliths, for the Sheuy fault cuts some intrusives, whereas the George Wise fault is intruded by a feeder dike of the laccolith at George Wise Spring. Conceivably an eastward shift of magma, out of line with the arcuate zone in which the other in-

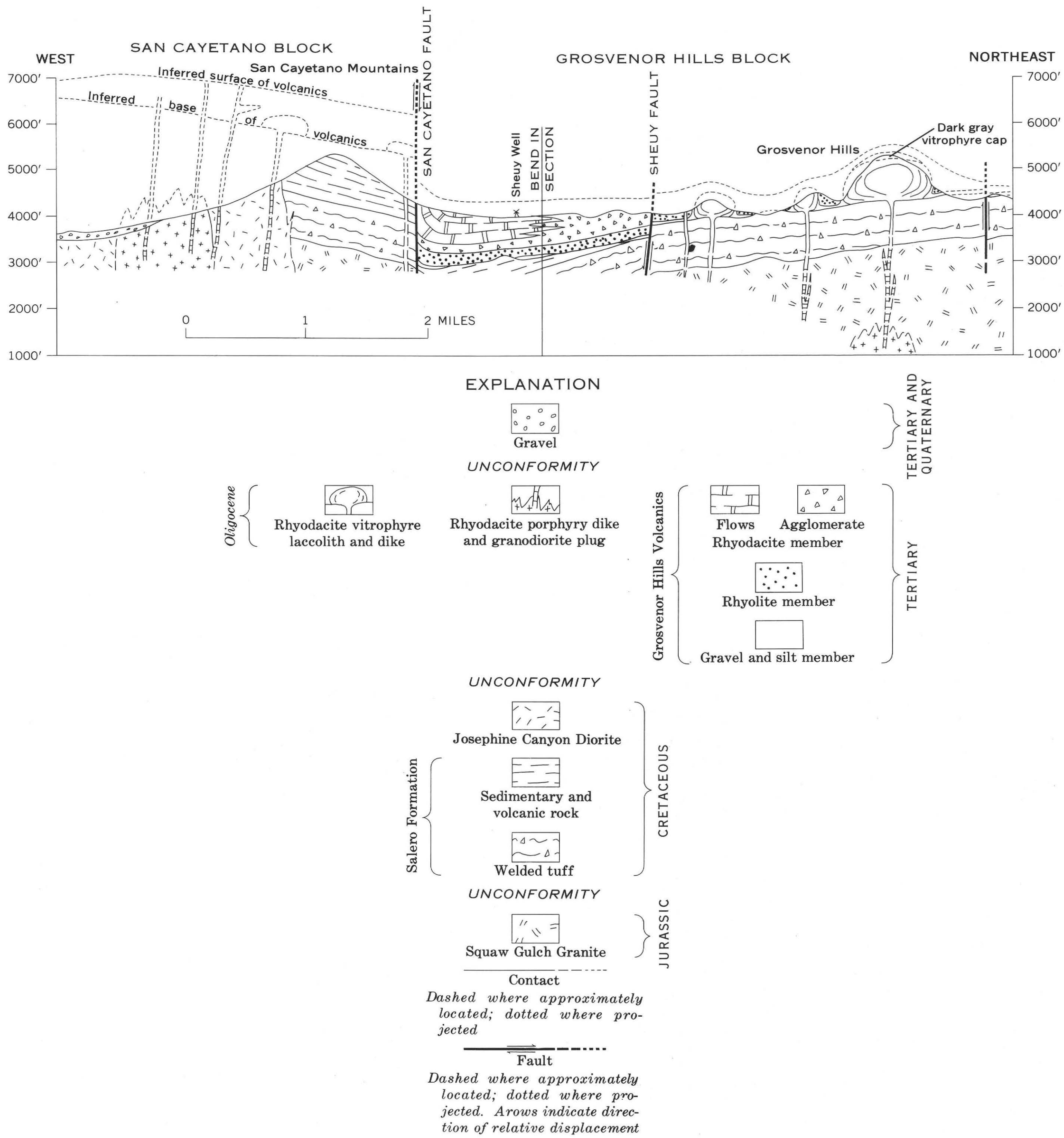


FIGURE 23. — Schematic structure section west and northeast of Sheuy Well, Grosvenor Hills and San Cayetano Mountains.

trusives lie and into the laccolith at George Wise Spring, occurred together with the formation of the tilted graben and its welded tuffs.

The geology of the Grosvenor Hills block thus suggests that the magmatic center of the Oligocene volcanics lay along or just beyond the present west edge of the volcanic pile, that volcanism was genetically associated with intrusion of the laccoliths, and that volcanism and intrusion were closely related to faulting.

The internal structure of the San Cayetano block, in or near which the volcanic center of the rhyodacites is believed to lie, contrasts markedly with the internal structure of the Grosvenor Hills block to the east. Faults are virtually absent within the San Cayetano Mountains, and the few faults at the north end of the mountains seem to be younger than the volcanics, inasmuch as rocks as young as the gravels of Tertiary and Quaternary age are involved (Drewes, 1971c). If the volcanics once covered the San Cayetano block, as seems likely, any small faults were probably restricted to the volcanics (Drewes, 1972a) in the manner typical of the small faults in the Grosvenor Hills block.

The orientation and spacing of the rhyodacite porphyry dikes in the San Cayetano Mountains resemble those of the rhyodacite vitrophyre dikes in the Grosvenor Hills, even to the presence of the northeast-trending dikes in the north end of both blocks. The dikes of the San Cayetano Mountains differ from those in the Grosvenor Hills chiefly in that they are narrower and more regular and are grouped in larger clusters. The structural similarity of the dikes of the two blocks suggests that the dikes were emplaced under similar stress conditions; their differences may be explained as the result of different depths of emplacement — the narrower but more continuous dikes of the San Cayetano block were emplaced under greater confining pressure.

ORIGIN

The Grosvenor Hills Volcanics, the dikes and laccoliths intruding the volcanics, the dikes of the San Cayetano Mountains, and the stock of the San Cayetano Mountains probably were emplaced at different levels of one magmatic complex. The granodiorite stock is seen as representing a cupola of a magma chamber from whose lower levels the hypabyssal intrusives and volcanics were derived. The stock was emplaced probably no less than 3,000 feet beneath the surface, as estimated from the minimum vertical displacement on the San Cayetano fault plus the vertical movement of the San Cayetano block due to eastward tilting.

The rhyodacite porphyry dikes are low-level feeder dikes of part of the volcanic pile and were emplaced at an estimated depth of 2,000–3,000 feet. Their close spatial and chemical relation to the stock supports the idea of their association with deeper parts of the igneous complex. Their more general chemical similarity to the rhyodacite vitrophyre dikes and the structural similarity between the dikes of both blocks permit their genetic association with higher parts of the igneous complex. However, they lack direct physical continuity with the rhyodacite vitrophyre dikes, not only through the intervening San Cayetano fault, but also through a relatively dike-free zone adjacent to that fault. In order to propose a direct genetic connection between the low-level dikes of the San Cayetano Mountains and the high-level dikes in the Grosvenor Hills, it may be necessary to assume a large component of lateral movement of the magma in the dike system, for which there is only tenuous support through the relations between the dikes and laccoliths along the George Wise fault. Perhaps the igneous complex had additional magmatic centers not yet uncovered by erosion; if so, the need to assume lateral movement of the magma is eliminated.

Dikes and laccoliths in the Grosvenor Hills are physically connected, and these intrusives and the rhyodacite volcanics are genetically related, as indicated by their chemical and mineralogical similarity. In addition, the structural observations summarized in the preceding section suggest that volcanism, faulting, and the emplacement of the laccolith at George Wise Spring east of the main zone of intrusives are genetically intertwined.

The hypothesis that the plutonic, hypabyssal, and volcanic rocks are all part of one igneous complex gains additional support from the fact that they are of nearly identical age. That such similar rocks would form so close together at one time without being genetically related would be fortuitous at best.

Chemical similarity among the plutonic, hypabyssal, and volcanic rocks supports their genetic relation. This similarity is summarized in figure 24, in which the chemical composition of the rock is plotted against the estimated average depth of emplacement of the four depth-controlled groups of rocks of the igneous complex. The forms of these curves remain virtually unchanged with any reasonable modification of the estimated depths.

In the discussion of the chemical similarities of the four groups of rocks in figure 24, however, it was pointed out, first, that the resemblance between the granodiorite and the rhyodacite volcanics was not as impressive as that between the hypabyssal rocks

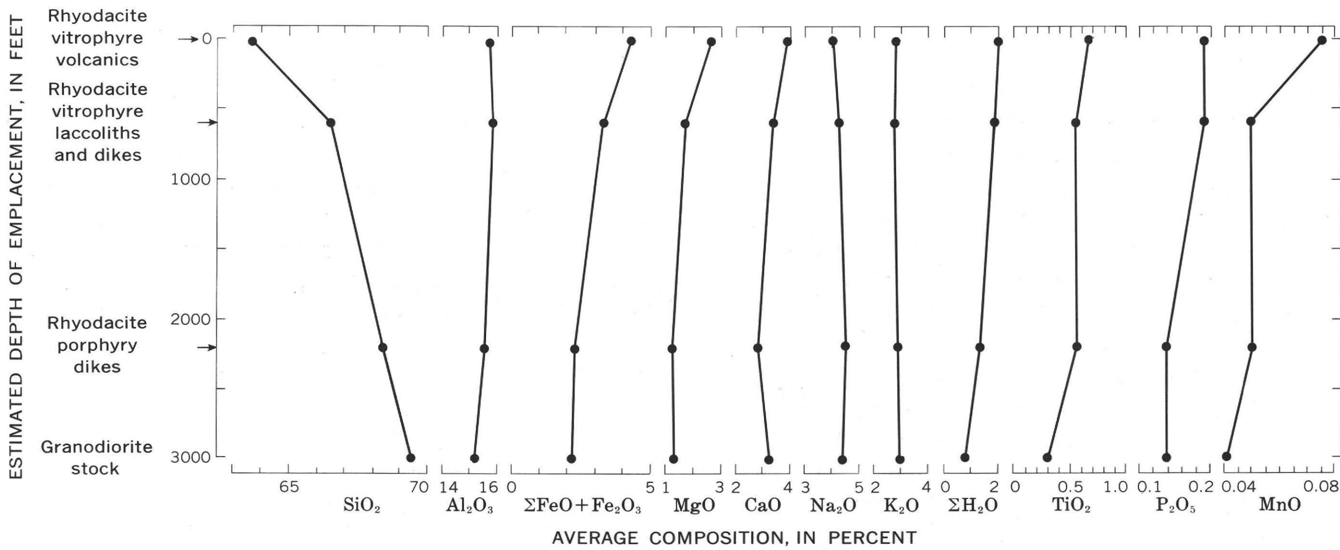


FIGURE 24. — Minor changes in chemical composition with depth of emplacement of rocks of the magmatic complex of the southern Santa Rita Mountains.

and the volcanics and, second, that the composition of the granodiorite lies between that of the rhyodacite and that of the rhyolite volcanics. Apparently, a single-magma igneous system is too simple a hypothesis to cover the available facts. The mineralogical differences between the granodiorite — with its biotite, hornblende, and fairly sodic plagioclase — and the rhyodacite vitrophyre — with its pyroxenes and fairly calcic plagioclase — also present problems to a single-magma hypothesis. In order to reconcile these problems, it seems necessary to tinker with the parent magma before it reached the surface. For example, a granodiorite parent magma may be postulated to have formed two fractions, which reached the surface at slightly different times. Such a postulation not only would explain the chemical and mineralogical variations, but also would explain the presence of some slightly older granodiorite xenoliths in a slightly younger rhyodacite agglomerate, as well as the various reaction rims and the reverse zoning seen in the xenocrysts of the rhyodacite vitrophyre.

In summary, the igneous rocks of Oligocene age of this area probably were emplaced during one magmatic episode. The recorded geologic events began with upward movement of granodiorite magma late during the Oligocene Epoch. For unknown reasons, part of the parent magma separated into a slightly more acidic fraction and a slightly more basic fraction. The granodiorite stock of the San Cayetano Mountains either is the top of the parent magma chamber or is a cupola on a larger mass. The lighter weight, more acidic, and perhaps less abundant fraction reached the surface first, to form the rhyolite volcanics. Being the lighter fraction, it contained most of the volatiles, and most of the earlier volcanics to reach the surface thus are tuffaceous. The rhyolite tuff spread over a pediment which supported a vegetation that contained pines.

During a brief pause after these initial eruptions, another pine forest developed on at least some of the ash-inundated area, only to be overwhelmed by the flood of volcanics of the second magma fraction. The second fraction, of rhyodacite composition, contained xenocrysts of the earlier, more acid fraction. Reaction rims and reversely zoned composition rims were formed around some of the xenocrysts.

The transfer of a large volume of magma to the surface was accompanied and followed by the gradual collapse and tilting of parts of the roof area of the parent magma chamber, which is perhaps roughly coextensive with the Grosvenor Hills volcanic pile. Secondary faulting formed parallel to the trend of the feeder dikes, and subsidiary areas collapsed between some of the secondary faults. The dikes, which were abundant but narrow at depths of a few thousand feet, form fewer but thicker bodies nearer to the surface, suggesting that the host rocks near the magma chamber were more fractured than those well above it. Some of the upwelling magma, upon passing upward from the relative confinement of the indurated Mesozoic rocks to the relative freedom of the unconsolidated silt and rhyolite ash, spread laterally into thickened dikes or incipient laccoliths. Other dikes continued to spread laterally into bulbous laccoliths, alongside and between which the volcanics settled to form a terrane cut by many shallow faults. One of the laccoliths may have been emplaced somewhat laterally southeast of its feeder dikes and away from the more deeply dropped end of a subsidiary graben. Tuffs deposited from successive nueés ardente that flowed down the graben during its subsidence were welded. Following the magmatic episode, the San Cayetano block was strongly uplifted, and a deeper part of the igneous complex was exposed by erosion.

RHYOLITE INTRUSIVES OF THE NORTHERN SANTA RITA MOUNTAINS

Two dike swarms and a plug, largely of rhyolite but locally of rhyolite vitrophyre, intrude the rocks of the northern Santa Rita Mountains (fig. 25). The intrusives are typically light-gray to very pale orange flow-laminated rocks that contain sparse phenocrysts of quartz and feldspar. The dikes range in width from 3 to 50 feet, but most are 10 to 20 feet wide. Most of the wider dikes form ribs which are especially conspicuous along the lower part of the Box Canyon road. Dikes of both swarms trend N. 50°–60° E., dip steeply, and are of regular width. On the geologic quadrangle maps (Drewes, 1971a, c) the dikes to the northwest are referred to as the Box Canyon swarm, and those to the southeast, as the Gardner Canyon swarm (fig. 25).

The Box Canyon dike swarm consists of about 50 dikes which are spread over a fairly wide zone that extends between the Yoas Mountain area in the southwest and the Helvetia mining district in the northeast. Over much of its 15-mile length, the swarm lies close to the northeast-trending segment of the range front. Southwest of Madera Canyon, where the host consists of Cretaceous granitic rocks, the dikes are few and short. Northeast of the canyon and especially northeast of Sawmill Canyon, where the host is either Precambrian granitic rock or Mesozoic sedimentary and volcanic rock, the dikes are more numerous and longer. Small segments of the entire width of two of these dikes, one from which specimen 65D899 was collected and the other a dike northeast of the first one, are a dark-yellowish-brown vitrophyre with a waxy luster, unlike the rocks typical of these dike swarms.

In the Sawmill Canyon–Box Canyon area the dikes intersect northwest-trending faults, whose last recorded movement was Paleocene, or late Laramide (Drewes, 1972a). Some dikes abut individual faults of this system, other dikes cross the faults without a break, and the continuity of still others is broken along the faults. The relation shown by the unbroken dikes that cross faults probably is the most critical one, inasmuch as it shows the dikes to be the younger feature. The other relations probably are the result of the development of fractures at different sites across the fault, rather than the result of postdike offset.

The Gardner Canyon dike swarm contains more than 30 dikes, most of which are closely bunched between the upper reaches of Josephine Canyon to the southwest and Cave Creek to the northeast (fig. 25). The dikes are longer in the Mesozoic volcanic and sedimentary rocks east of Mount Wrightson than in the Cretaceous granitic rocks south of that mountain. A few short dikes near the east end of this swarm trend in an atypical direction, northwest; they are mostly dikes (or sills) lying subparallel to steeply inclined bedded rocks. The continuity of this swarm is briefly interrupted south-southeast of Mount Wrightson. Inasmuch as this gap falls along the high crest of the mountains, the dikes in this area may not extend above an elevation of about 7,000 feet.

Two dikes of rhyolite porphyry, resembling those of the dike swarms of the northern part of the mountains, crop out in the N½ sec. 1, T. 21 S., R. 13 E., along lower Cottonwood Canyon (south of Montosa Canyon). They are considered part of the southeastern swarm with which they are alined even though they lie 5 miles west of the other dikes of that swarm. The two dikes cut rocks as young as Cretaceous(?) diorite and are overlapped by the gravel of Nogales of Miocene(?) and Pliocene age. They lie within half a mile of the nearest outcrops of the Grosvenor Hills Volcanics, but the geologic relation of the dikes to the Grosvenor Hills Volcanics is not known.

The rhyolite plug forms an elliptical body near the east end of the southeastern dike swarm, between Cave Creek and Gardner Canyon. It crops out abundantly in low knobs of closely fractured and iron oxide stained rock. This staining of the rock along fractures is strongest toward the southwest margin of the plug, where fresh rhyolite probably contains disseminated pyrite. Two dikes flare out toward the margins of the plug, and they probably join it rather than abut it. The host rocks of the plug are folded arkose and siltstone of the Upper Cretaceous Fort Crittenden Formation (Drewes, 1971b), which are mildly metamorphosed near the contact only at the north end of the plug. The crest of an anticline, which is open to the southeast but which tightens to the northwest, runs roughly down the axis of the plug. Contacts of the plug dip outward, gently to the south but more steeply to the north, and thus are largely concordant to the adjacent beds. The sheeting along the margins of the plug also parallels the contact. These contact rela-

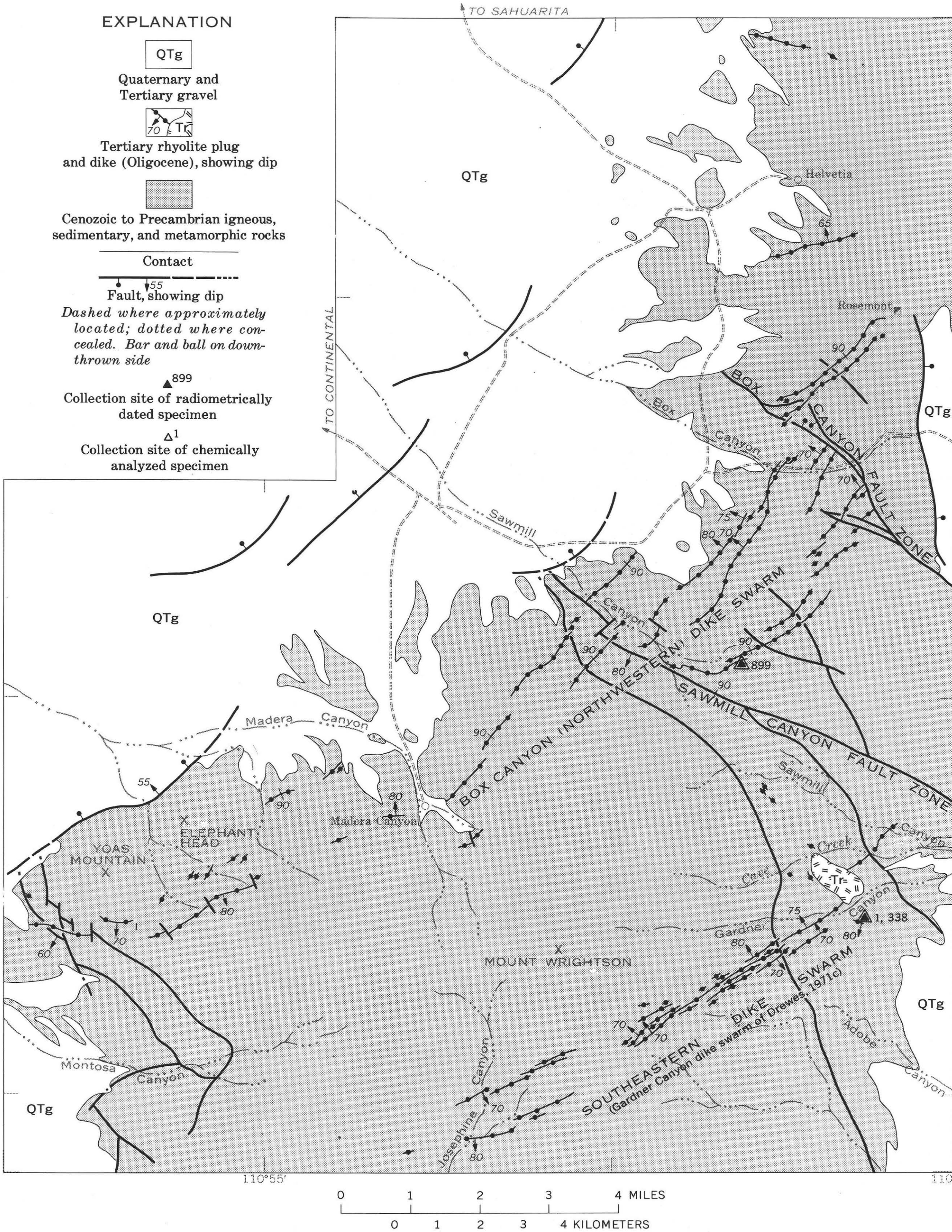


FIGURE 25.—Distribution of Oligocene rhyolite intrusives of the northern Santa Rita Mountains and the relations of the intrusives to some faults. Base from U.S. Geological Survey: Sahuarita and Mount Wrightson quadrangles, 1:62,500, 1958.

tions suggest that the top of the plug lay not far above the present level of exposure of the rhyolite mass. Inasmuch as the base of the mass is unexposed, the term "plug" is applied tenuously; the mass could equally well be the top of a laccolith or phacolith.

PETROGRAPHY

The rhyolite of the Oligocene intrusives of the northern Santa Rita Mountains commonly contains about 10 percent phenocrysts, of 1–4 mm maximum size, set in an altered cryptocrystalline groundmass. A mosaic of indistinctly crystalline material in grains 0.01–0.1 mm across, probably of devitrified glass, makes up the groundmass. Some specimens from the northwestern dikes of that segment of the Box Canyon swarm between Sawmill and Box Canyons have a micrograrophyric groundmass. Two specimens from the southeastern dikes of the same segment of the Box Canyon swarm have a brown glass groundmass in which microlites are flow alined.

The modes of eight specimens, giving essentially the phenocryst abundance, are shown in table 15. Quartz is everywhere present as euhedral grains, and commonly a few grains of each specimen are partly resorbed. Normally both plagioclase and potassium feldspar are present, but in some rocks only one or the other is present. The plagioclase is mostly albitized, from an oligoclase or andesine, as indicated by the relicts in one specimen. Potassium feldspar is sanidine more commonly than orthoclase, but in some specimens it is indeterminate. The finely granophyric rocks contain some perthite. About half the rocks contain pseudomorphs of chlorite or of a hydromica after biotite, of which a very few unaltered relicts form inclusions in quartz or feldspar. In a few rocks amphibole, possibly hornblende, occurs along with, or in place of, the biotite. Accessory magnetite is commonly present, and apatite, zircon, and sphene occur less frequently. Among the alteration products, clay minerals are abundant, and sericite, chlorite, calcite, iron oxides, and epidote are sparse.

TABLE 15. — *Modes (in percent) of rhyolite dikes of Oligocene age from the northern Santa Rita Mountains*

Dike swarm	Southeastern, near Gardner Canyon			Northwestern, or Box Canyon				
Location in swarm	East		Middle	West	Middle		East	
Specimen No.[1]	1	3	4	5	2	6	7	8
Field No.	62D1	63D340	62D19	65D745	65D899	66D1002	66D1029	66D1036
Quartz	9.8	2.6	3.1	2.0	1.7	0.5	9.3	14.8
Plagioclase	0	3.2	12.4	1.2	0	0	13.0	.7
Potassium feldspar	1.7	Trace	[2]7.3	[3]3.7	[2]3.2	[2]5.6	[2]3.9	[3]6.1
Biotite	Trace	0	.8	Trace	0	0	.1	.1
Hornblende(?)	0	0	1.7	0	.1	.1	0	0
Magnetite	Trace	Trace	1.7	Trace	Trace	.1	Trace	Trace
Apatite	Trace	Trace	.3	0	Trace	0	0	0
Sphene	0	0	.1	0	Trace	Trace	0	0
Zircon	Trace	0	0	Trace	Trace	0	0	0
Groundmass	88.5	94.2	72.6	93.1	95.0	93.7	73.7	78.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1]Specimens 1 and 2 are keyed to table 16.
[2]Identified as sanidine.
[3]Identified as orthoclase.

CHEMISTRY

Chemical analyses of two rhyolite specimens are listed in table 16. Specimen 1 is from a short northwest-trending rhyolite porphyry dike south of the plug and was collected in the SW¼SW¼ sec. 12, T. 20 S., R. 15 E. (unsurveyed). Specimen 2 is from the rhyolite vitrophyre at collection site 899 (fig. 25), in the SW¼SE¼ sec. 22, T. 19 S., R. 15 E. The analyses differ considerably from each other, although the difference between some components decreases upon removing the excess water from the vitrophyre analysis and recalculating the oxides to 100 percent. Thus reapportioned, the silica content increases to about 74 percent, a more appropriate amount for a rhyolite. However, the reapportionment does not significantly increase the K_2O content of the vitrophyre, nor, of course, does it change the ratio between CaO and the alkalis, whose abundances are not typical of rhyolites nor even of rhyodacites (Nockolds, 1954, p. 1013–1014).

The difference in chemistry between a vitrophyre and an altered devitrified rock that may be genetically related is difficult to interpret. The devitrified rock contains less CaO and Na_2O and more SiO_2 and K_2O than the vitrophyre. If these rocks were crystallized from the same parent magma — as may be inferred from the similarity of their modes, phenocryst mineralogy, and place of occurrence — then during or after devitrification and hydration the rock must have become so enriched in SiO_2 and K_2O as to resemble a normal rhyolite.

A further problem affecting the interpretation of the genetic relation of the rocks is that the few dike rocks having granophyric texture occur in the same

TABLE 16. — *Chemical and spectrographic analyses and CIPW norms, in percent, of rhyolite from the dike swarms in the northern Santa Rita Mountains*

Rock type	Porphyry	Vitrophyre
Area	Gardner Canyon	Box Canyon
Specimen No.	1	2
Field No.	62D1	65D899
Chemical analyses[1] [P. L. D. Elmore, S. D. Botts, Lowell Artis, H. Smith, John Glenn, and Gillison Chloe, analysts]		
SiO_2	77.6	69.0
Al_2O_3	11.9	12.3
Fe_2O_3	.38	.53
FeO	.12	.32
MgO	.12	.11
CaO	.32	2.8
Na_2O	.96	2.8
K_2O	5.5	1.9
H_2O+	.71	2.9
H_2O-	1.7	6.7
TiO_2	.05	.09
P_2O_5	0	0
MnO	.02	.21
CO_2	<.05	<.05
Total	99.3	100.
Spectrographic analyses[2] [W. B. Crandell and J. C. Hamilton, analysts]		
Ba	0.1	0.015
Be	0	.001
Co	.002	0
Cr	.0015	0
Cu	.005	.00007
Ga	.003	.002
La	.003	.005
Mo	.0007	.0003
Nb	0	.005
Ni	.0015	0
Pb	.0015	.002
Sc	.001	0
Sr	.1	.2
V	.015	0
Y	.0015	.003
Yb	(3)	.0003
Zr	.01	.015
CIPW Norms		
Q	50.114	39.351
C	3.787	.664
or	32.494	11.260
ab	8.119	23.761
an	1.587	13.614
hy en	.299	.275
hy fs	0	.393
mt	.307	.771
hm	.168	0
il	.095	.171
cc	0	.114
Total	96.97	90.37

[1]Rapid rock analyses.
[2]Semiquantitative analyses. Results are reported to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1, which represent the approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time.
[3]Not looked for.

structural block as those having a glassy texture. These textures suggest differences in crystallization habit commonly presumed to be depth associated. Perhaps the chemical and textural problems are related.

AGE AND ORIGIN

The dikes were intruded during late(?) Oligocene time, as determined by isotopic dates on two dikes, one from each swarm (table 2). Sanidine concentrated from the vitrophyre of specimen 65D899 (fig. 25 and table 16) gives a K-Ar age of about 25.9±0.8 m.y. (R. F. Marvin, written commun., 1967). Zircon concentrated from the rhyolite porphyry of specimen 63D338 gives a Pb-alpha age of about 40 m.y. (T. W. Stern, written commun., 1965). As stated before, a 40-m.y. Pb-alpha age is typically compatible with a 25- to 30-m.y. K-Ar age (R. F. Marvin, oral commun., 1970). The collection site of specimen 65D899 is given in the preceding section on chemistry, and that of 63D340 is in the SE¼ SW¼ sec. 1, T. 20 S., R. 15 E.; both localities are shown in figure 25.

The dike swarms and plug were intruded in the northern part of the Santa Rita Mountains at about the same time as the rhyolitic rocks of the igneous complex in the southern part of the mountains were emplaced. Not only are their ages similar, but their chemistry and phenocryst mineralogy are roughly similar, and they were emplaced in similar structural environments associated with normal faults.

The dike swarms probably intruded post-Laramide tension fractures. Rocks deformed and intruded during the Helvetian phase of the Laramide orogeny (late Paleocene) were exposed by an amount of erosion that implies much uplift during post-Paleocene time. At least some of this uplift occurred on the northeast-striking faults along the west front of the mountains, parallel to the dike swarms. These faults are normal faults, formed as a result of tensional stresses which postdate the last compressive stresses of the Laramide. Apparently, some of these tensional fractures tapped a magma body that lay beneath the northern part of the uplifted mass.

MIOCENE(?) TO HOLOCENE ROCKS

Several sequences of conglomerate, gravel, and silt overlie rocks as young as the Grosvenor Hills Volcanics and their associated intrusives. Some of these sequences form thick prisms of alluvium deposited in fans along the flanks of the present mountains, and they presumably fill the intermontane basins. Other sequences form thin sheets of alluvium and include relatively continuous pediment deposits, as well as discontinuous terrace deposits. A few sequences form alluvial deposits restricted to the valleys draining the intermontane basins.

The Miocene(?) to Holocene rocks are divided into nine map units (Drewes, 1971a, c) which constitute six stratigraphic units that are separated from each other and from the underlying rocks by unconformities. As shown in figure 26, the six stratigraphic units consist, successively, of the gravel of Nogales, basin-fill gravel, high-level pediment

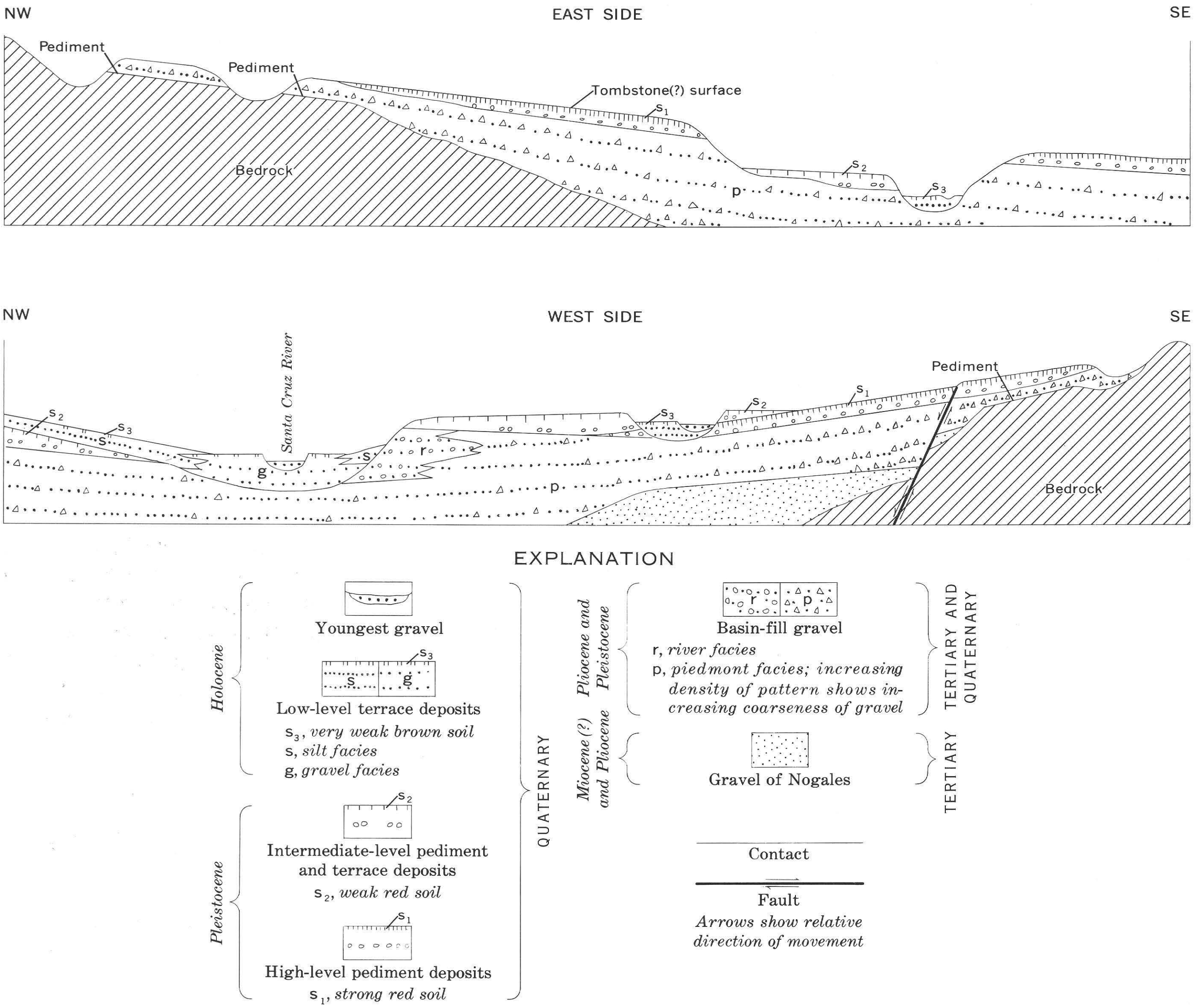


FIGURE 26. — Schematic sections showing the relations among the surficial deposits on the flanks of the Santa Rita Mountains.

deposits, intermediate-level pediment and terrace deposits, low-level terrace deposits, and the youngest gravel. The three units referred to as "deposits" include soils that are generally distinguishable from each other by their different degrees of development. Commonly the soils are formed on the pediment or terrace gravels, which in many places are distinguished from each other mainly by their soil, for the gravels closely resemble each other. In the few places where soils appear to have formed directly on the basin-fill gravel, they are mapped with the appropriate younger deposit but are distinguished from that deposit by a queried symbol on the quadrangle maps. Of the six stratigraphic units, the basin-fill gravel and the low-level terrace deposits each have distinctive facies along the Santa Cruz River which are of sufficient extent and economic significance to be mapped separately. Analogous facies of some other units along the Santa Cruz River are of too limited extent to be distinguished on the map or may occur only in the subsurface. The basin-fill gravel also contains a few small lenses of tuff, which are mapped separately; and in the subsurface along the Santa Cruz River 3–6 miles north of Sahuarita, according to E. S. Davidson (written commun., 1969), the gravel contains abundant gypsum and anhydrite.

Some of the lithologic distinctions of the six sequential units are fairly widespread; others are local. The older units, for instance, are generally redder, better indurated, less well sorted, and more deformed than the younger deposits in the same area. Considered throughout the area, the range of the lithologic characteristics of several units is large, and some of the characteristics overlap those of the adjacent units, but in each locality at least some of the differences persist. Therefore, in places the lithologic criteria used to distinguish some units are augmented by the geomorphic position of the units and by soil development.

GRAVEL OF NOGALES

An extensive body of tilted moderately well indurated tuffaceous gravel and sand containing abundant detritus derived from the upper(?) Oligocene volcanics crops out around Nogales (fig. 1). Rocks having these features extend into the Mount Wrightson quadrangle as far north as Montosa Canyon. They overlap several members of the Grosvenor Hills Volcanics near Sonoita Creek to the south (fig. 13) and overlap rocks as young as the dike swarm of late(?) Oligocene age near Cottonwood Canyon to the north. Elsewhere they are faulted against older rocks. The gravel of Nogales is unconformably overlain by basin-fill gravel, as is illustrated along the 120-foot-high steep south bank of the lower part of Cottonwood Canyon in the N½ secs. 1 and 2, T. 21 S., R. 13 E.

The gravel of Nogales southwest of the Santa Rita Mountains consists of moderately well indurated tuffaceous sand, silt, grit and pebble gravel, and a little cobble and boulder gravel. A typical outcrop of this map unit (fig. 27), at an unknown distance above its base near Cottonwood Canyon, contains 50 percent sandy grit to sandy gravel whose pebbles are less than an inch across, 35 percent silty to sandy grit, and 15 percent coarser gravel. Sorting is poor, and bedding is moderately well developed. The gravel is commonly pale red but ranges from moderate orange red to grayish orange pink, and it is much less commonly brown or light gray.

The pebbles are overwhelmingly of rhyolite and rhyodacite derived from the Grosvenor Hills Volcanics and the related vitric intrusives. Only in the northernmost outcrops do the clasts include some Paleozoic limestone, some granitic rock, and some altered volcanics, possibly of the Salero Formation. The sandy and tuffaceous component presumably is also derived from the pyroclastic rocks of the Oligocene volcanics. The clasts are subangular to angular; only those of moderately friable material are subrounded, apparently due to disaggregation as much

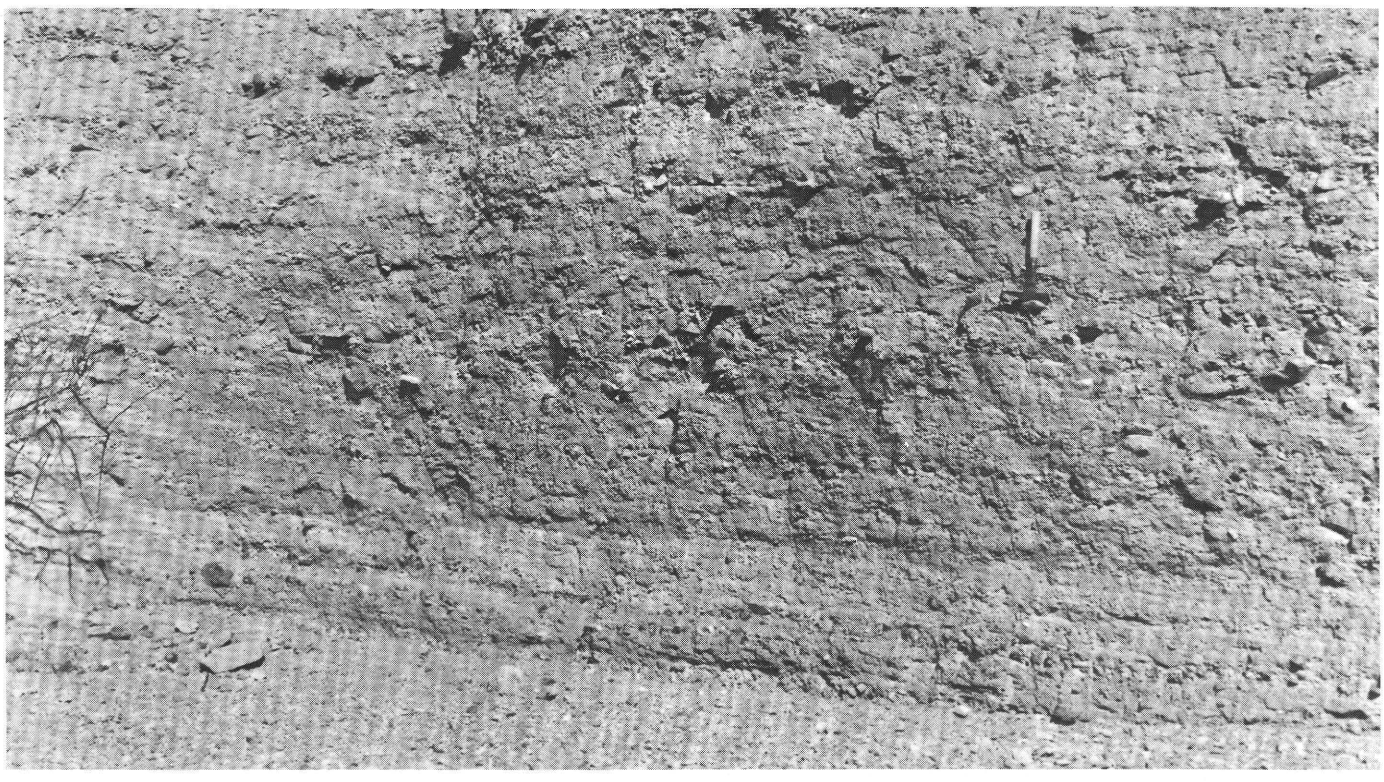


FIGURE 27. — Typical gravel of Nogales cropping out north of Cottonwood Canyon on the southwest flank of the Santa Rita Mountains.

as to abrasion. Although sorting and bedding are generally poor, those of some sand and silt beds north of Josephine Canyon are good. A westward direction of transport is indicated by the imbrication direction of the pebbles in some gravel lentils in the unit near Cottonwood Canyon. The clastic components are commonly indurated by compacted silt and clay, but locally they are also cemented by silica and lime. A thick basal sheet of coarse conglomerate near Sonoita Creek is limier than most other beds, apparently because ground-water movement and consequent deposition of carbonates were concentrated above the relatively impervious underlying volcanics.

The gravel is generally tilted 10°–25° toward the Santa Rita or the San Cayetano Mountains, from which it is separated by faults. Where the tilted beds strike into the faults, southerly dips are more common than northerly ones. Many of the faults are truncated by the basin-fill gravel.

The gravel of Nogales probably was deposited by streams on and next to volcanic hills whose relief was much less than that of the present Santa Rita Mountains and probably was even less than that of the Grosvenor Hills. The preponderance of angular and volcanic detritus indicates that the gravel was locally derived, and the small pebble size and the well-developed bedding, compared with that of the youngest deposits in the same area, suggest that the old relief was less than the present relief. The preponderance of volcanic detritus also suggests that the upper (?) Oligocene volcanics, or at least their tuffs, mantled much of the core of the mountains. The few pre-Oligocene pebbles that do occur in the formation appear only in the northern outcrops, which are farthest from the inferred source of the Oligocene volcanics, and presumably the source area of the pebbles was only thinly veneered by ash deposits. That this ash veneer was sufficiently breached by erosion to expose the underlying limestone and granite by Pliocene time is entirely reasonable, for since then the veneer has been largely removed.

The gravel of Nogales is estimated to be mostly of Pliocene age, but it also includes some rocks of Miocene age. Fossils have not been found, and the only radiometrically datable rocks (table 2, specimen 1) were obtained from an olivine basalt flow intercalated low in the gravel about 4 miles southwest of the southwest corner of the Mount Wrightson quadrangle (500 ft east of the SW. cor. sec. 6, T. 23 S., R. 13 E.). A K-Ar determination on the groundmass of the basalt gives an age of 12.6$\pm$0.8 m.y. (R. F. Marvin, H. H. Mehnert, and Violet Merritt, written commun., 1970) and another determination on pyroxene phenocrysts gives an age of 13.8$\pm$13.5 m.y. (Marvin, Mehnert, and W. T. Henderson, written commun., 1970). Marvin stated that the large analytical error for the pyroxene is due to the presence of 15 percent radiogenic Ar^{40}; the young age and very low potassium content of the pyroxene resulted in only a little argon to analyze. Nevertheless, the agreement between the two ages is good, and the ages indicate that the gravel that contains the basalt flow lies near the Miocene-Pliocene boundary.

Gravel resembling that of Nogales occurs in several other basins near the Santa Rita Mountains. In the southern part of the Sierrita Mountains (fig. 1) J. R. Cooper (oral commun., 1968) mapped a unit of Tinaja Peak, whose lower part consists of vitric volcanics and whose upper part is a gravel derived from those volcanics. The volcanic gravel, judged from its lithologic similarity to the gravel of Nogales, may be correlative with part of the gravel of Nogales, whose nearest exposures are only 15 miles away. South of the Mustang Mountains, 22 miles east of the Grosvenor Hills, the basal part of a poorly indurated tuffaceous sandstone and fine-grained angular-pebbled conglomerate sequence contains intercalated biotite-bearing tuff, mentioned previously in this report and dated as about 39 m.y. The upper part of the sequence overlying the tuff may be correlative with the gravel of Nogales.

BASIN-FILL GRAVEL

A pinkish-gray gravel of Pliocene and Pleistocene age, which commonly is at least several hundred feet thick and which may be several thousand feet thick in the centers of the intermontane basins, unconformably overlies the gravel of Nogales and is overlain by terrace and pediment deposits. The gravel consists of subangular clasts that are moderately well sorted and bedded. Commonly the rock is weakly indurated. In the Tucson basin, where intensive studies have been made, gravel of this lithology and stratigraphic position is called the basin-fill gravel by E. S. Davidson, M. E. Cooley, and E. F. Pashley, Jr., (oral communs., 1963–68). This informal name is here retained for the extensive gravel around the Santa Rita Mountains, even though locally it caps a pediment and contains other rock types, such as the tuffaceous rocks described under "Tuff Beds."

The basin-fill gravel around the Santa Rita Mountains consists of three mapped units — a widespread unit referred to as the piedmont facies, a relatively local unit called the river facies, and tuff beds (Drewes, 1971a, c). Despite its limited extent in the

Santa Cruz River valley, the river facies is mapped separately because of its potential commercial importance. The tuff beds have attracted attention as a possible means of dating the adjacent gravel by radiometric methods. Toward the mountains the gravel grades into coarser detrital facies including colluvium, talus, and landslide blocks, all generally unmapped.

PIEDMONT FACIES

The piedmont facies of the basin-fill gravel is at least 500 feet thick along Davidson Canyon east of the northern part of the Santa Rita Mountains, and it is probably much thicker in the basin centers, especially along the Santa Cruz River. In many places the unit laps directly against Cretaceous or older rocks on a steeply dipping unconformity, but along parts of the west side of the range — such as between Josephine and Montosa Canyons, at the head of Madera Canyon fan, and north of Helvetia — it laps across a narrow and gently westward-dipping pediment. In a few places — such as along the east side of the Santa Rita Mountains at Box Canyon, at the foot of the Patagonia Mountains south of Patagonia, and at the north end of the San Cayetano Mountains — it is faulted against older rocks.

The piedmont facies consists mainly of light-gray to grayish-orange-pink beds of cobble, pebble, or boulder gravel, with intercalated beds of sand and silt (fig. 28). These beds are typically a few inches to a few feet thick and are poorly sorted to moderately well sorted. Channel-fill lenses and intraformational unconformities are abundant. The gravel is commonly sufficiently indurated to stand in nearly vertical cliffs where undercut by streams, but the cliffs weather readily in other circumstances. Outcroppings of gravel offer considerable resistance to the penetration of a geologic pick but can easily be disaggregated by hand. A little lime cement is normally present, but thoroughly cemented or caliche-rich beds are mostly restricted to deposits derived from carbonate source rocks. The clasts of the gravel were derived from rocks in the mountains near which they were deposited, although in some places, described in the following paragraphs, they were not derived from the nearest part of the mountains. The clasts are typically subangular; in places near the mountain fronts, however, the clasts are conspicuously angular, and in beds near the river facies they are somewhat more rounded.

The general description of the piedmont facies, given in the preceding paragraphs, is typical of

FIGURE 28. — Basin-fill gravel overlain by terrace deposits of intermediate height, in a cut along Josephine Canyon at the north end of the San Cayetano Mountains.

deposits that fill the basins near the Santa Rita Mountains, but a few of the lithologic variations and exceptions provide some insight into local conditions. Some of the lithologic variations probably reflect changes in stratigraphic position within the facies; others are simply facies changes that reflect changes in source material or rate of deposition from fan to fan and from the head of a fan to the toe. These facies changes are unmapped because of the difficulty in maintaining stratigraphic control within the facies, especially where the gravel is only sparingly exposed. A few of the other local lithologic variations are described in the following paragraphs.

Gravel in the upper reaches of Box Canyon drainage, 2–3 miles north of Greaterville, was deposited by streams that flowed northeastward, rather than westward as they do at present. The gravel contains abundant granodiorite and some gneiss clasts derived from Precambrian formations, such as underlie the hills to the southwest, and it contains very few clasts of sedimentary rocks of Mesozoic and Paleozoic formations, such as lie immediately west of the gravel. When the basin-fill gravel was deposited, the local streams apparently flowed northeastward. Since that time, and probably during the Pleistocene, the Box Canyon drainage must have captured the northeastward-flowing streams.

East of the Santa Rita Mountains the piedmont facies contains abundant intercalated silt beds 3–4 miles north of Patagonia and along Gardner Canyon north of Sonoita (a few miles east of the Mount Wrightson quadrangle), and west of the mountains silt is abundant northwest of Helvetia and along the lower reaches of Cottonwood Canyon. Melton (1965, fig. 2) considered the fine-grained deposits east of the mountains to be the southwestern limit of his "lake beds," correlative with the thick silt sequence along the San Pedro River, some 25 miles to the east. No evidence has been found to suggest that the silt beds east of the mountains are lacustrine, nor is there any support for the idea that they are different in lithology or origin from the silt beds west of the mountains. Most likely these are local subaerial deposits on flood plains or at the toes of fans, such as those in the lowest stream terraces near Sonoita and along the Santa Cruz River.

The piedmont facies deposits near the Patagonia Mountains are atypical in a few respects. In general the piedmont facies forms a prism of gravel that thickens toward the rugged Patagonia Mountains to the southeast. North of Alum Gulch (fig. 2) the gravel near the foot of the mountains is a typical coarse fanglomerate, and the dips are mostly away from the mountains. However, south of the gulch the deposits are mainly of sand and grit, with some scattered small lenses of pebbles and cobbles and only a few boulders, and they dip gently toward the mountains. These finer grained deposits are believed to be abnormal alongside the rugged mountains, and they suggest that here a range-front fault separates the piedmont facies from the mountains (Drewes, 1972a).

Deposits of the piedmont facies on the Madera Canyon fan, an alluvial fan with a radius of 10 miles, are typical of this facies in most ways, but the particular assortment of rock types of which it is composed has one noteworthy feature. The fan is almost wholly made up of detritus of very hard siliceous volcanics derived from the Mount Wrightson Formation and of friable granitoid rocks derived from the Madera Canyon Granodiorite, Josephine Canyon Diorite, and Elephant Head Quartz Monzonite. The proportion of relatively large clasts of durable volcanic rock to weaker granitoid rock increases downfan. In fact, many granitoid cobbles simply disaggregate where they were initially deposited on the fan, whereas the volcanics are recycled with only a gradual decrease in size and increase in roundness. As a result, abundant detritus of the Mount Wrightson Formation reaches the Santa Cruz River from this fan. This concentration of distinctive volcanic clasts should provide a useful marker for subsurface studies of the deposits in the Tucson basin.

In contrast to the piedmont facies deposits on the Madera Canyon fan, the deposits north of the fan, along the Box Canyon drainage, are much finer across the entire stretch of alluvial apron (rather than alluvial fan). The change in grain size and depositional morphology probably reflects, to a large extent, the change from a less friable source rock in the south to a more friable source rock in the north and is typical of lateral facies variations in the piedmont facies.

RIVER FACIES

Deposits of the river facies of the basin-fill gravel are of unknown but probably considerable thickness; they are mapped along the low bluffs east of the Santa Cruz River roughly between Continental and Sahuarita but are probably more extensive in the subsurface. The river-facies gravel consists of well-sorted and well-bedded deposits of subrounded to rounded cobbles and pebbles alternating with a nearly silt-free and clay-free sand. The bedding is distinctly channeled, as shown in figure 29. The clasts include much volcanic rock, some quartzite and limestone, and a little granitoid rock. In a few places,

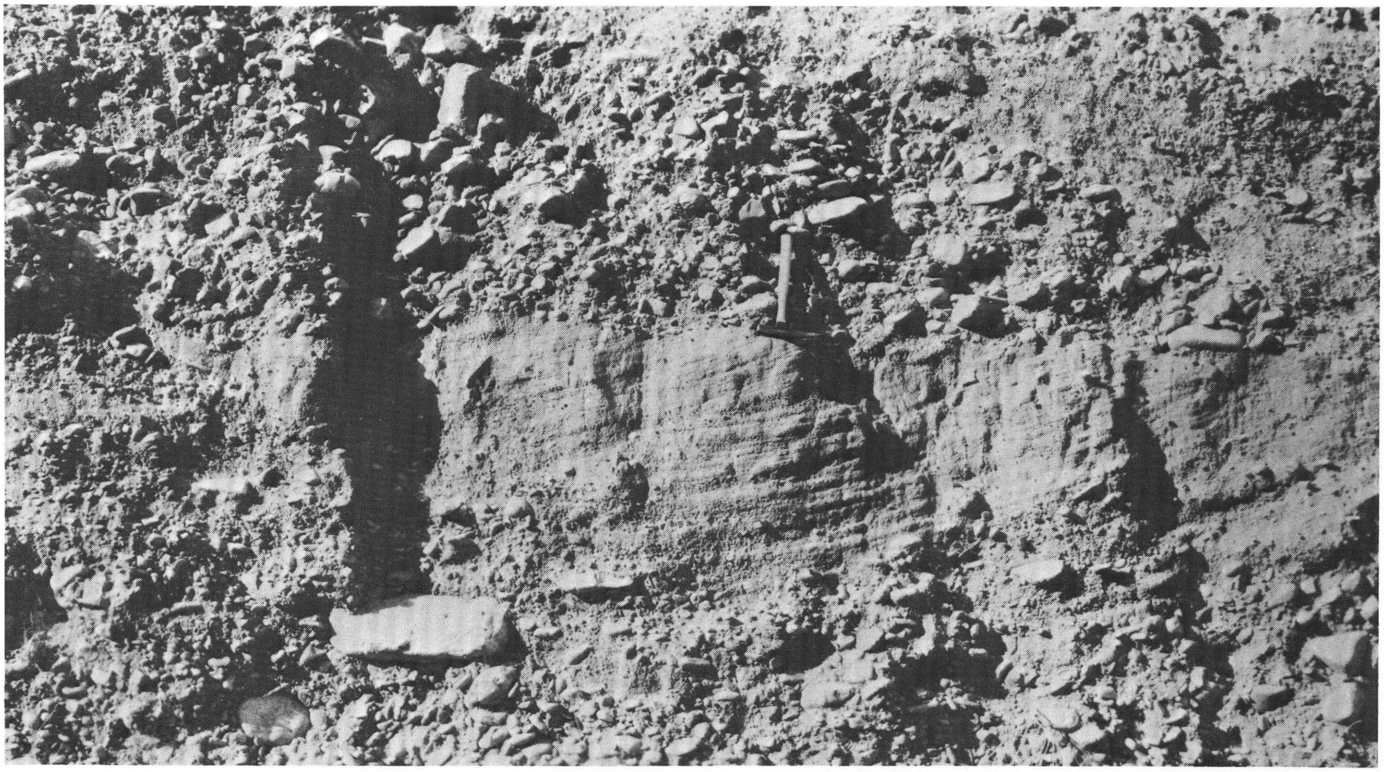


FIGURE 29. — Channeled, well-sorted, and subrounded river facies deposits of the basin-fill gravel, a mile north of Continental.

as on part of the low ridge in the fields 1½ miles southeast of Sahuarita, the gravel is well cemented by caliche, but generally it is uncemented and poorly indurated.

Toward the east and south the river-facies gravel interfingers with the piedmont-facies gravel. In the transition zone between the two facies, gravel beds that contain subrounded pebbles alternate with beds that contain subangular pebbles. Away from typical river-facies gravel the beds with the subrounded pebbles gradually lose their identity through an increasing admixture of more angular locally derived detritus. Similar transition beds also occur in the bluffs east of the Santa Cruz River in the southwest corner of the Mount Wrightson quadrangle; although here these beds are mapped with the piedmont-facies gravel, they suggest that the river-facies deposits may be present nearby.

The river-facies gravel is of potential economic importance for two reasons. Its well-sorted condition should make it better suited for construction material than the gravel of the piedmont facies, and especially better than material rich in weathered detritus derived from a granitic terrane. The location of the river-facies gravel near the Santa Cruz River makes it accessible from the main roads and also reduces the problem of obtaining ground water for washing the gravel.

The river-facies gravel may also be of potential economic importance as an aquifer. In the subsurface it probably forms a thick midvalley zone of limited width and irregular lateral extent but of considerable length and down-valley regularity. Its exceptional sorting should give it excellent permeability, provided that caliche is not more abundant elsewhere than it is in the available outcrops. Locating the subsurface extension of this facies should be a consideration in developing the ground water of the valley.

TUFF BEDS

A few tuff and tuffaceous sandstone beds are intercalated in the basin fill near Patagonia (Drewes, 1971c). A bed of tuffaceous sandstone, too small to be shown on the map, lies along the base of the basin-fill gravel of Adobe Canyon, north of Patagonia. Another bed, east of the mouth of Alum Canyon (fig. 2), is half a mile long and as much as 4 feet thick. One of two beds of tuff south of Alum Canyon is as much as 20 feet thick and is more than a mile long. Tuffaceous sandstone commonly overlies the tuff beds, and it also underlies the thickest of them. All of these beds are low in the basin-fill gravel, although not necessarily at the same horizon.

The tuff is very light gray, and where thickest, it forms bold outcrops, in part bedded and in part massive (fig. 30). The bedded tuff contains frag-

FIGURE 30. — Tuffaceous sandstone and overlying massive nearly white rhyolite tuff beds intercalated in the lower part of the basin-fill gravel south of Alum Canyon, low on the flank of the Patagonia Mountains.

ments of well-sorted pumiceous rhyolite and gritty tuffaceous sandstone. The massive tuff contains scattered small chips of pumiceous rhyolite and biotite-plagioclase rhyolite, as well as small biotite flakes. The tuff beds probably are entirely of epiclastic origin, so an isotopic age of the biotite it contains will not date the enclosing gravel. The interpretation that the tuff is epiclastic is based on its limited distribution, its restriction to the margins of the Grosvenor Hills volcanic pile where Oligocene tuff is extensively exposed, and the occurrence of tuffaceous sandstone immediately beneath some massive tuff, as shown in figure 30.

AGE AND CORRELATION

The basin-fill gravel in the Mount Wrightson and Sahuarita quadrangles probably correlates with gravel in nearby areas that has been dated as mid-Pliocene to mid-Pleistocene. A well 2½ miles north of Sonoita penetrated 35 feet of gravel, which is probably basin-fill gravel. Stirton (1940) reported that two teeth of *Neohipparion* were recovered from the well, and Lance (1960) dated these fossils as probably of mid-Pliocene age. The basin-fill gravel flanking the Santa Rita Mountains probably is largely correlative with a fossiliferous sequence near Benson, along the San Pedro Valley (fig. 1). This sequence includes beds ranging from about middle Pliocene to middle Pleistocene (Lance, 1960; Wood, 1960).

HIGH-LEVEL PEDIMENT DEPOSITS

At many places around the flanks of the Santa Rita Mountains the basin-fill gravel is overlain by a thin sheet of gravel that typically is browner, coarser, less well sorted and bedded, and less well indurated. In most places this gravel sheet caps flat interfluves on the highest, or all but the highest, parts of the high alluvial fans and fan aprons, but in some places it descends to the levels of younger gravel deposits, which lap across them. The gravel caps a pediment that is cut chiefly on basin-fill gravel. Commonly the pediment gravel carries a mature thick red soil, which in places laps beyond the sheet of gravel directly onto the pediment surface. Together, the gravel and the soil are mapped as the high-level pediment deposits.

Along the Santa Cruz River valley, high-level pediment deposits form extensive caps on the basin-fill gravel of the Madera Canyon and Sycamore Canyon fans in the Sahuarita quadrangle (Drewes, 1971a), and they underlie parts of the fans at Montosa, Cottonwood, and Josephine Canyons in the Mount Wrightson quadrangle (Drewes, 1971c). They also occur locally on the flanks of the San Cayetano Mountains and east of the Santa Rita Mountains, where they are outliers of a broad sheet that extends around Sonoita Creek valley to the foot of the Whetstone, Mustang, and Huachuca Mountains to the east.

The sheet of gravel of the high-level pediment deposit is commonly 10–20 feet thick, but locally, as at the north side of Madera Canyon fan, it is as much as 40 feet thick. In places the sheet appears to lap out or is eroded out so that it is much thinner. Indeed, some of the flat interfluves of the Sycamore Canyon fan seem to be exhumed pediments from which the high-level pediment deposits have barely been stripped, leaving only remnants of the base of a mature soil.

The contact at the base of the pediment gravel is poorly exposed along the edges of flat interfluves of the dissected fans. In most places the contact is too far back from the adjacent watercourses to be undercut, and the gravel sheet is so poorly consolidated that it slumps across all but a few small and fairly uninformative segments of the contact. Most likely, the deposits rest disconformably upon slightly eroded basin-fill gravel. That erosion occurred along the surface below the contact is suggested by the close lithologic and morphologic similarity between the high-level pediment gravel and the terrace gravels and by the fact that erosion cut the terraces upon which the terrace gravels were deposited. Locally the gravels may be gradational, because of reworking of the older deposits.

High-level pediment deposits are offset by faults that cut across Madera Canyon and Sycamore Canyon fans. These faults have low scarps, across which the red soil is displaced as much as 15 feet.

The high-level pediment gravel consists of boulders, cobbles, and pebbles in a brownish-gray sandy to gritty matrix. With very few exceptions, the pediment gravel is coarser than the underlying gravel, upfan as well as downfan (that is, the high-level pediment gravel is coarser than the underlying gravel in the same part of the fan, although it may be finer downfan than the underlying gravel is upfan). At midfan positions, the underlying gravel is commonly sandy pebble gravel with some cobbles, whereas the pediment deposit tends to be gravel with cobbles and boulders, much like the two deposits shown in figure 28. In general the grain-size distinction is greater downfan because the range in grain size of the detritus in both deposits is smaller there and size ranges overlap less. The high-level pediment gravel is more poorly sorted and has better rounded clasts than most of the basin-fill gravel, and locally the entire sheet appears to form a single massive bed. Features of the capping gravel suggest that it is not a lag concentrate; rather it appears to be a fluvial deposit largely carried down from the mountains at the heads of the fans. No lag concentrate, for example, would include the considerable amount of coarse granitic detritus such as that of capping gravel high on the Madera Canyon fan, because similar granitic detritus of the underlying gravel is seen to decompose so rapidly in place that it could not be reworked into a lag deposit. High-level pediment gravel is sparsely cemented by caliche on only those fans, such as the Sycamore Canyon fan, that contain limestone detritus. Normally the gravel is unconsolidated except for the clay-enriched part of the soil that is developed on it.

The top surface of the high-level pediment deposits is the smoothest of the area. The surface dips gently toward the intermontane valleys, and along the Santa Cruz River valley it also has a component of dip toward the interfan drainages. On several fans, such as those of Madera and Sycamore Canyons, an old surface slopes more steeply toward the valley than do the younger terrace surfaces, although the head of the Cottonwood Canyon fan shows the reverse relation. The top surface of the high-level deposits generally is found only on the upper parts of the fans; downfan the top generally is buried, but in the northern part of the Sycamore Canyon fan it is eroded. In many places, the top surface is crudely paved with a thin layer of grit, chips, and sand. Probably the only reason that a well-developed desert pavement is absent is the fact that the rainfall is high enough to support a considerable vegetation density and rodent population, thereby leading to periodic overturning of the lag concentrate of chips and pebbles.

The soil that has formed on the high-level pediment gravel and on some of the adjacent parts of the pediment that are uncapped by gravel is commonly 2–4 feet thick and is brownish pale red to moderate reddish brown. In some places this soil, or more properly, paleosol, is buried beneath younger gravel deposits, and in others it is partly truncated by erosion. Even where nearly complete, it shows the uneven development of zones characteristic of soils in a semiarid environment. An A horizon with abundant humic material is virtually absent. However, the B horizon with its clay enrichment is so pronounced that it constitutes most of the soil. The B horizon consists of clayey sand in which there are scattered pebbles and cobbles of unweathered parent gravel; their size and abundance depend chiefly on their lithology and position on the fan. Lime concentrates occur locally in the C horizon near the base of the soil, but they are nowhere well developed, except where all the gravels contain limestone clasts and caliche zones. Thus the degree of redness and the thickness of the red zone are the most distinctive characteristics of the oldest paleosol of the area; younger paleosols are browner and thinner.

The vegetation on the high-level pediment deposits tends to be distinct from that on adjacent gravel. High on the fans along the Santa Cruz River valley the high-level pediment deposit generally is densely grass covered, a situation that is enhanced artificially through a mesquite control program. At lower elevations scrubby mesquite is more abundant on the pediment gravel than on the basin-fill gravel, apparently because the pediment gravel holds more water. In many places ocotillo grows most densely along the edges of the pediment gravel, probably because there a perched water table beneath the pediment gravel reaches the surface. At still lower levels, at about an elevation of 3,000 feet, greasewood favors the better cemented and probably limier basin-fill gravel to the pediment gravel sheet, except where that sheet also contains caliche zones.

The age of the high-level pediment deposits has not been determined, and I can only tenuously propose that the mature red soil capping the pediment gravel is mid-Pleistocene. The gravel itself, of course, is older, and it probably is sufficiently older to have allowed a long period of intensive chemical weathering in order to develop the red soil. I favor a mid-Pleistocene age of the older red soil of the area because I do not believe that the Wisconsin time was climatically suitable or the Holocene sufficiently long for any red soil to have formed, and because I am tentatively assigning a Sangamon age to the younger red soil. The high-level pediment and its overlying deposits probably are correlative with similar features around the Huachuca Mountains which Haynes (1968, p. 79) correlated with the Tombstone surface and its red soil, of Bryant (Gilluly, 1956, p. 121). Haynes further correlated the red soil overlying the high-level Tombstone surface with a red soil in the Safford area, 80 miles northeast of the Santa Rita Mountains.

The proposed mid-Pleistocene age of the older red soil of the Santa Rita Mountains is not supported by work by Melton (1965, p. 15), who correlated a red soil on the Madera Canyon fan (the only red soil recognized by him on that fan) with the red soil at Safford. He assigned this soil a Sangamon age through a further correlation between the lowest beds of the fan at Safford, on which the red soil at Safford lies, and the apparently equivalent highest beds of "lake" deposits in Safford Valley, which, according to Lance (1960), contain fossils of late Blancan to Irvingtonian (Kansan) age. The above correlations seem to need the support of detailed field mapping, without which it may be difficult to recognize significant facies changes in the gravels or to correctly identify the several red soils.

Haynes (1968, p. 79) extended the Tombstone, or higher surface of Bryant (Gilluly, 1956, p. 121), with its mature red soil, to the flanks of the Huachuca Mountains. He also correlated this soil with Melton's soil in the Safford area. Very likely the high-level pediment deposits of the Santa Rita Mountains underlie a further extension of the Tombstone surface, and the red soil of the high-level pediment deposits of the Santa Ritas is the equivalent of the red soil on the flanks of the Huachuca Mountains.

INTERMEDIATE-LEVEL PEDIMENT AND TERRACE DEPOSITS

A sheet of coarse subrounded poorly sorted alluvium caps terraces of intermediate height along both sides of the Santa Rita Mountains. East and south of the mountains remnants of this terrace are relatively small, widely separated, and 30–100 feet above the level of the lowest flood-plain terraces. West of the mountains the terrace remnants are larger, closer together, and commonly only 20–50 feet above the flood-plain terraces. Most valleys contain only one intermediate-level terrace (and alluvial sheet), but along lower Josephine Canyon there are three terraces of intermediate level, one of which is clearly more strongly developed than the others. Possibly some of the widely scattered terrace gravels in other valleys are also remnants of several terrace levels, which are here combined because they seem to be more closely related physiographically to each other than to the high-level or the low-level deposits.

Along the Santa Cruz River and its tributaries an intermediate terrace forms a narrow, fairly continuous bench capped by gravel on which is a weakly developed red soil. Only small remnants of the intermediate-level Santa Cruz terrace occur in the Mount Wrightson quadrangle, for the river is outside the quadrangle to the west. However, the river flows through the western part of the Sahuarita quadrangle, and there, large terrace remnants are preserved. The terrace remnants merge and become broader near Continental and in turn merge with an extensive pediment. Along and near the north edge of the Sahuarita quadrangle, the sheet of gravel, sand, and silt on the pediment laps against hills of older gravel.

The intermediate-level pediment and terrace deposits contain gravel, sand, clay, and the soil formed on them. These generally are coextensive, but in places the soil laps beyond the edge of the gravel, and elsewhere the gravel is without a soil cover. Locally a soil also occurs within the gravel, to indicate again that this gravel probably consists of a closely related complex of deposits rather than a single sheet. The deposits typically form a sheet a few tens of feet thick lying disconformably on a cut surface, as shown in figure 28. Where the deposits spread out and overlie what appears to be a pediment, east of Continental, they may thicken to at least 100 feet; or, upon changing lithology there, they blend with the underlying deposits, making the position of their base uncertain.

Gravel of intermediate terraces, like that of high-level deposits, is browner, coarser, and better rounded but less well sorted than adjacent basin-fill gravel. At midslope it is typically poorly bedded cobble gravel which has a brownish-gray sandy gritty matrix and which is only locally and sparsely cemented by caliche. The clasts were probably derived largely from the mountains at the heads of the fans. They were deposited by streams on the floor of the Santa Cruz River valley and its tributaries after their incision, in most places well below the level of high-level pediment deposits. In many places this gravel is distinguished from other terrace gravels mainly by its soil and its position.

Intermediate terrace deposits east of the mountains occur as small remnants on the north walls of the tributary valleys. Near these valleys the deposits consist of the usual kind of alluvial sheet capped by a thin red soil. Away from the valleys they grade into a locally derived colluvial sheet, also capped by or incorporating a red soil, which may be partly reworked from the older red soil of the nearby high-level deposits.

Gold occurs in the gravel of the intermediate terraces near Greaterville, but few remnants there are large enough to be shown at a map scale of 1:48,000. Placer mining was very active at Greaterville in about 1878 (Schrader, 1915).

The terrace gravel along State Highway 82 near the mouth of Alum Canyon is relatively well indurated and is irregularly impregnated with a black material that presumably is rich in iron and manganese oxides. The black material contains anomalous amounts of base metals (Drewes, 1972b). This mineral matter was probably introduced by surface and ground waters that were charged with metals derived from mineralized terrane of the nearby Patagonia Mountains, as is the present water in Alum Canyon.

East of Continental and roughly a mile north of the road to Box Canyon and Madera Canyon, gravel of the intermediate terrace becomes gradually sandier, containing increasing amounts of grus derived from the Precambrian Continental Granodiorite north of Sawmill Canyon, and decreasing amounts of volcanic rocks from Madera and Florida Canyons. Upslope on the pediment(?) the gravel is chiefly grit but has about 10 percent chips and blocks — largely of aplite, quartz monzonite, and granodiorite — occurring in crudely sorted lentils and as scattered fragments (fig. 31). At midslope the deposit is a silty grit with about 5 percent chips and blocks, almost devoid of granodiorite. Low on the slope and west of marker line *b* on the Sahuarita quadrangle map (Drewes, 1971a), the grain size has further decreased so that silt is dominant over grit, chips are scarce, and clay is relatively abundant. In this area, too, massive beds of silt alternate with better bedded lentils of grit and sand.

The gravel sheet on intermediate terraces is relatively smoothly surfaced and crudely paved, much like that of high-level deposits. Scrubby mesquite prefers these deposits to the basin-fill gravel. However, where the coarser terrace gravel gives way to the finer silt, grit, and chip deposits (sandy deposits that contain scattered small angular pebbles), the surface is less smooth, and the control of vegetation is more obscure. The surface is typically very gently

FIGURE 31. — Typical poorly sorted angular gravel of the intermediate-level terrace deposit, high on the fan (pediment?) east of Continental.

rolling, and its local relief is commonly no more than a few feet. Few gullies are long, and at midslope they are rarely incised more than 6 feet. Low on the slope, where the silt and clay content increases, there are a few vertical-walled gullies that are as much as 6 feet deep. Along the lower reaches of the broad part of the terrace in the northern part of the Sahuarita quadrangle (Drewes, 1971a, west of marker line *b*), the surface contains numerous silt pans, which are barren flats resembling playa floors that are laced by widely spaced shallow gullies.

A weakly developed reddish-brown soil, typically 6–9 inches thick, caps the intermediate-level terrace gravel. The soil is somewhat thicker where it seems to contain fine material washed in from nearby areas that are underlain by the older red soil. On the bluffs east of the Santa Cruz River valley (Drewes, 1971a, west of marker line *a*), the soil is as much as 4 feet thick, possibly reflecting in part the inwashing of red soil from upslope and in part an abundance of pinkish-gray silt in the parent basin-fill gravel. On the other hand, soil is virtually absent on the silt, grit, and chip sheet on the pediment(?) (fig. 31); in part the soil grades out northward along with the lithologic transition, and in part a thin red soil is buried beneath a few feet of grit low on the slope. Thin reddish-brown soil exposed in deep cuts west and northwest of Sahuarita is probably correlative with that on the terraces of intermediate height.

The weakly developed reddish-brown soil ranges from pale reddish brown to grayish orange pink and to moderate orange pink. Redder hues are most conspicuous on dry soil (those normally recorded), and browner hues, on moist soil. In the transition zone between terrace gravel and pediment grit, the soil color gradually becomes paler northward until it resembles the color of the parent material.

The soil on the terrace gravel is zoned, like the older red soil, with a weak to nonexistent A horizon and a rather strong B horizon. Locally, the thicker body of soil west of line *a* contains an A horizon as much as 15 inches thick, and in many places the lower half contains abundant small caliche nodules of a weak C horizon. In many places this soil is modified by cultivation. In several places it appears to consist of several soils, one of them somewhat browner than the others. To the east, near line *a*, the soil is buried beneath a few feet of sand and silt that are probably part of the deposits of the intermediate-level complex. To the north a broad, low mound of silt of suspected eolian origin lies between(?) two soils of this complex, and it contains some debris from occupation sites of Indians.

The grit, chip, and silt deposits of the pediment(?) areas were probably transported largely by sheet wash, rather than chiefly by streams, as was the terrace gravel. This difference in mode of transport undoubtedly reflects the difference in mechanical weathering properties of the dominant granodiorite parent rock; the piedmont slope was flooded with porous grus. The grus was readily transported by streams issuing from the canyons, and because of its fineness it was transported on a fairly gentle gradient. Rapid water loss, due to the highly porous character of the grus and augmented by the gentle gradient on the slope, resulted in a system of watercourses in which water gathered locally and spilled over the banks in local distributaries. With the gradual loss of an integrated drainage system on the slope, surface wash transport became increasingly effective relative to stream transport. The virtual absence of a soil in the grit area suggests that the grains were turned over too frequently for products of chemical weathering to form and accumulate as a soil. Some of the small amounts of soil that may have formed locally appears to have been washed down slope and to have accumulated in the silt area northeast of Continental.

The age of the intermediate-level terrace deposits can only be estimated, for no fossils have been obtained from them. Because of the extensive development of reddish-brown soil on the gravel, I tentatively assume the soil to be of Sangamon age. The gravel on which it is formed, then, is Sangamon or older, but it postdates the valley cutting in the high-level pediment deposits, whose soil is of presumed mid-Pleistocene age. The surface on the deposits may be correlative with the Whetstone surface, of intermediate level, along the San Pedro River, which was described by Gilluly (1956, p. 121).

LOW-LEVEL TERRACE DEPOSITS

A thin sheet of gravel underlies the lowest terraces and fills many valley bottoms on the flanks of the Santa Rita Mountains; similarly, sand and silt form a broad, low bench along the Santa Cruz River (fig. 26). These low terraces are commonly 2–10 feet above the level at which the youngest alluvium is being deposited, and locally they are still part of the flood plain of the watercourses. Where the watercourses are small, only the dominant deposit was mapped, either the low-level terrace deposit or the youngest gravel, although both generally are present. West of the Santa Cruz River and north of Green Valley (fig. 1), the low-level terrace deposits spread out as a sheet of slope-wash deposits derived from grus.

Two facies of low terrace deposits are shown on the Sahuarita quadrangle map (Drewes, 1971a): a gravel facies of the piedmont and a silt facies of the Santa Cruz River valley. Although not shown separately on the Mount Wrightson quadrangle map (Drewes, 1971c), the silt facies underlies the southwest corner of the area as well as much of the flats along Sonoita Creek southwest of Patagonia.

GRAVEL FACIES

Deposits of the gravel facies consist largely of unconsolidated cobble, boulder, and pebble gravel with sand in the matrix and in intercalated lenses. The gravel in some of the higher of these terraces consists of a coarse, thin, capping deposit and a finer underlying unit, as is common in some of the higher terrace and pediment gravels, but in other low-level terraces this dual character is not apparent. Sorting, bedding, and rounding of the gravel are highly variable from place to place but commonly are poor. Small channels are exposed in cutbanks. The terrace surface retains vestiges of such channels, as well as of cobble trains and subsidiary terrace ledges, which leave this surface rougher than that on the older, higher surfaces. Vegetation is markedly denser on the low-level terrace deposits than on the higher ones, and the mesquite is rarely scrubby. The deposits which form a sheet west of the Santa Cruz River consist of grayish-yellow-brown grit, sand, and silt, with scattered pebbles and lentils of pebbles, much like the deposits on the intermediate terraces east of the river.

A very immature gray or brown soil is developed on much of the low-level terrace gravel. It consists of a slight concentration of humic material at grass roots level and a slight accumulation of clay in the underlying few inches of alluvium.

SILT FACIES

Terrace deposits along the Santa Cruz River are predominantly of silt and loam. Gravel of the low-level terrace deposits of tributaries grades laterally into the river silt deposits, and in places some of the youngest gravel is washed across the silt terrace to form small tributary fans. In places, as west of Sahuarita, the youngest grit, sand, and silt of the low-level terrace deposits extends at least half a mile across the river silt and loam. Some foundation problems around the Sahuarita High School may be due to subsurface flowage, under heavy loads and excessive irrigation, of material at the stratigraphic level of the river silt and loam.

The silt facies consists of a mixture of light-brownish-gray silt and loam that contains lentils of sand and gravel and, less commonly, humic material and black sand. Locally the deposits contain considerable clay and are darker gray, perhaps owing to accumulations of cienega (humic swale) soil. In many places the silt facies stands in vertical banks that are maintained, or worn back rather than down, during floods.

A dusky-brown (moist) to pale-yellowish-brown (dry) soil caps the silt terraces. It is weakly developed and reflects the high humus-producing environment and fine grain size of its parent material rather than an extended period of weathering. It has an A horizon several inches thick, a very thin B horizon, and no C horizon.

The low terrace surface was farmed by Indians and Spaniards, who used simple irrigation methods and the surface waters of the Santa Cruz River, a procedure no longer practical because of the depth to which the river has cut its bed below the surface of the silt deposits. Today, the low river terrace is intensively cultivated and irrigated from wells. During preparation of fields, the terrace surface is considerably regraded, and tributary channels are commonly enlarged, straightened, and bordered by dikes. Ground water is obtained at fairly shallow depths of 100–200 feet.

The low terrace deposits are estimated to be largely or entirely of Holocene age, and the age of the youngest of the deposits probably ranges into historic time. If the association of the older terrace and pediment deposits with interglacial times is valid and if the youngest red soil is accepted as Sangamon, then the low-level terrace deposits postdate the Wisconsin. Carbonaceous deposits from similarly low terraces along Cienega Creek, about 12 miles east of the northern Santa Rita Mountains, were reported by Melton (1965, p. 31) to be dated by the radiocarbon method as about 1,800–2,500 years old.

YOUNGEST GRAVEL

Unconsolidated gravel and some sand, virtually barren of perennial plants, cover the floors of most modern watercourses, where they are transported by each passing flood. The material is locally largely derived from the other surficial deposits. Inasmuch as the youngest gravel is restricted to present-day channels, which are incised as much as 10 feet, it postdates the channeling of the bottom lands. This channeling is generally attributed to changes in climate or land use that occurred between 1880 and 1890 (Bryan, 1925).

REFERENCES

Anderson, C. A., 1951, Older Precambrian structure in Arizona: Geol. Soc. America Bull., v. 62, no. 11, p. 1331–1346.

Bryan, Kirk, 1925, Date of channel trenching (arroyo cutting) in the arid Southwest: Science, new ser., v. 62, p. 338–344.

Cooper, J. R., 1970, Preliminary geologic map of the Twin Buttes quadrangle, Pima County, Arizona: U.S. Geol. Survey open-file map.

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

Creasey, S. C., 1967, Geologic map of the Benson quadrangle, Cochise and Pima Counties, Arizona: U.S. Geol. Survey Misc. Geol. Inv. Map I-470 with 11 p. of text.

Creasey, S. C., and Quick, G. L., 1955, Copper deposits of part of Helvetia mining district, Pima County, Arizona: U.S. Geol. Survey Bull. 1027-F, p. 301-323 [1956].

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

Damon, P. E., and Miller, H. W., Jr., 1963, A lava covered Tertiary forest in southern Arizona: Arizona Acad. Sci. Jour., v. 2, no. 3, p. 117-119.

Drewes, Harald, 1967, A geochemical anomaly of base metals and silver in the southern Santa Rita Mountains, Santa Cruz County, Arizona, *in* Geological Survey research 1967: U.S. Geol. Survey Prof. Paper 575-D, p. D176-D182.

———1968, New and revised stratigraphic names in the Santa Rita Mountains of southeastern Arizona: U.S. Geol. Survey Bull. 1274-C, 15 p.

———1969, The Laramide orogeny of Arizona southeast of Tucson, *in* Abstracts for 1968: Geol. Soc. America Spec. Paper 121, p. 501-502.

———1970, Structure control of geochemical anomalies in the Greaterville mining district, southeast of Tucson, Arizona: U.S. Geol. Survey Bull. 1312-A, 49 p.

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

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

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

———1972a, Structural geology of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Survey Prof. Paper 748 (in press).

———1972b, Geochemical reconnaissance of the Santa Rita Mountains, southeast of Tucson, Arizona: U.S. Geol. Survey Bull. 1365 (in press).

Drewes, Harald, and Finnell, T. L., 1968, Mesozoic stratigraphy and Laramide tectonics of part of the Santa Rita and Empire Mountains, southeast of Tucson, Arizona, *in* Titley, S. R., ed., Arizona Geol. Soc. Southern Arizona Guidebook III: p. 315-324.

Finnell, T. L., 1970, Pantano Formation, *in* Cohee, G. V., Bates, R. G., and Wright, W. B., Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1968: U.S. Geol. Survey Bull. 1294-A, p. A35-A36.

———1971, Preliminary geologic map of the Empire Mountains quadrangle, Pima County, Arizona: U.S. Geol. Survey open-file map.

Fries, Carl, Jr., 1962, Reseña de la Geologia del Estado de Sonora con Enfasis en el Paleozoico: Bol. Assoc. Mexicana Geólogos Petroleros, v. 14, no. 11-12, p. 257-273.

Gilluly, James, 1956, General geology of central Cochise County, Arizona, with sections on age and correlation, by A. R. Palmer, J. S. Williams, and J. B. Reeside, Jr.: U. S. Geol. Survey Prof. Paper 281, 169 p.

Hayes, P. T., and Drewes, Harald, 1968, Mesozoic sedimentary and volcanic rocks of southeastern Arizona, *in* Titley, S. R., ed., Arizona Geol. Soc. Southern Arizona Guidebook III: p. 49-58.

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

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

Haynes, C. V., 1968, Preliminary report on the late Quaternary geology of the San Pedro Valley, Arizona, *in* Titley, S. R., ed., Arizona Geol. Soc. Southern Arizona Guidebook III: p. 79-96.

Hunt, C. B., Averitt, Paul, and Miller, R. L., 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geol. Survey Prof. Paper 228, 234 p. [1954].

Lance, J. F., 1960, Stratigraphic and structural position of Cenozoic fossil localities in Arizona: Arizona Geol. Soc. Digest, v. 3, p. 155-159.

Lovering, T. G., Cooper, J. R., Drewes, Harald, and Cone, G. C., 1970, Copper in biotite from igneous rocks in southern Arizona as an ore indicator, *in* Geological Survey research 1970: U.S. Geol. Survey Prof. Paper 700-B, p. B1-B8.

Melton, M. A., 1965, The geomorphic and paleoclimatic significance of alluvial deposits in southern Arizona: Jour. Geology, v. 73, no. 1, p. 1-38.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. America Bull., v. 65, no. 10, p. 1007-1032.

Putnam, W. C., 1938, The Mono Craters, California: Geog. Rev., v. 28, no. 1, p. 68-82; abs., *in* Geol. Soc. America Proc. 1936, p. 333, 1937.

Schrader, F. C., 1915, Mineral deposits of the Santa Rita and Patagonia Mountains, Arizona, *with contributions by* J. M. Hill: U.S. Geol. Survey Bull. 582, 373 p.

Silver, L. T., 1969, Precambrian batholiths of Arizona, *in* Abstracts for 1968: Geol. Soc. America Spec. Paper 121, p. 558-559.

Simons, F. S., 1971a, Geologic map of the Nogales quadrangle, Santa Cruz County, Arizona: U.S. Geol. Survey open-file map.

———1971b, Geologic map of the Lochiel quadrangle, Santa Cruz County, Arizona: U.S. Geol. Survey open-file map.

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

Stirton, R. A., 1940, Phylogeny of North American Equidae: California Univ., Dept. Geol. Sci. Bull., v. 25, no. 4, p. 163-197.

Wood, P. A., 1960, Paleontological investigations in the 111 Ranch area: Arizona Geol. Soc. Digest, v. 3, p. 141-143.

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