UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS OF AN APOLLO 9 PHOTO ANOMALY NEAR POINT OF PINES, ARIZONA

By Calvin S. Bromfield, Gordon P. Eaton,

Donald L. Peterson, and James C. Ratté

Open-file report

1972

72-51

Contents

Illustrations

[All illustrations in pocket]

Tables

Geological and geophysical investigations of an Apollo 9 photo anomaly near Point of Pines, Arizona

By Calvin S. Bromfield, Gordon P. Eaton, Donald L. Peterson, and James C. Ratté

ABSTRACT

An infrared photograph of southeastern Arizona, taken during the Apollo 9 multispectral terrain photography experiment in 1969, reveals a ringlike feature, some 3-4 miles (5-6 km) in diameter, on the Natanes Plateau, 35 miles (56 km) north of the town of Safford. Because the feature occurs in an area of nearly flat lying Tertiary volcanic rocks, the possibilities of its being a small collapse caldera or an exposed circular intrusive body were considered. Geological and geophysical studies of the area were made to test these hypotheses.

The local stratigraphic section consists of approximately 1,500 feet (457 m) of Oligocene and perhaps older volcanic rocks, resting on a moderately irregular basement surface carved from nearly flat lying Paleozoic sedimentary rocks and Precambrian granite. Two northwest-trending Basin-and-Range faults define a broad horst within which two arcuate cross faults, with 300-600 feet (91-183 m) of displacement, bound a downdropped area. Deep erosion along these faults has created a polygonal network of canyons which constitutes the "ring" seen on the photograph. A mild arching of the volcanic rocks within the ring is suggested by structure contours on the base of the youngest flows.

A sharp 350-gamma positive aeromagnetic anomaly is centered within the ring. In its southwest quadrant the anomaly has an elongate extension that trends northwest along an adjoining Basin-and-Range fault. Associated with both is a subtle gravity low. The geophysical data thus suggest the presence of a small blind silicic pluton, possibly of middle Tertiary or younger age. Although it can be argued that the arcuate faults and mild arching of the volcanic pile are related to this postulated pluton, no evidence of hydrothermal alteration or thermal metamorphism of the country rocks was seen. Thus if a pluton is present and of postvolcanic age, it must have been emplaced as a relatively cool dry body; or alternatively, it is older than the surface volcanic rocks. In either instance, its magnetic expression contrasts with that of the known mineralized Laramide porphyry intrusive bodies of the region.

GEOLOGIC INVESTIGATION

By Calvin S. Bromfield and James C. Ratté

Introduction

A "circular" feature 3-4 miles (5-6 km) in diameter was observed by W. D. Carter of the U.S. Geological Survey during a systematic study of infrared photographs from the Apollo 9 multispectral terrain photography experiment conducted in 1969. The feature is located on the Nantac Rim, near Point of Pines, in southeastern Arizona. Follow-up field examinations and geophysical studies to determine the origin of this feature were undertaken in October 1970 and April 1971 and one is the subject of this report. Three man-weeks were spent in field-geologic studies and three more in geophysical investigations. Project responsibilities were as follows: Bromfield and Ratté prepared the geologic maps and sections, collected samples for petrographic, geochemical, and geochronologic studies, and wrote the geologic section of this report. Eaton and Peterson collected, reduced, and interpreted the geophysical data, gathered samples for physical-property measurements, and prepared the section on geophysics.

The circular feature near Point of Pines was known from the outset to occur in an area of volcanic rocks, thus a small collapse caldera, circular plug, or other intrusive were considered as possible explanations for the pattern. Geologic studies have given little support to these speculations. Rather, the surface geology shows a faulted block bounded on two sides by northwest-trending faults, one mappable and the other inferred, both conformable to the regional Basin-and-Range fault system. These bounding faults appear to define a horst within which the two other sides of the circular feature are outlined by cross faults that dip toward the center of the structure, defining a downdropped block within the horst. From the standpoint of the surface geology, the circular feature on the Apollo 9 photos thus would seem to have resulted primarily from a favorable sun angle and photo shadows of an intersecting fault pattern.

Physical features

The circular feature lies just north of the south-facing Nantac Rim on the southern margin of the Natanes Plateau (fig. 1). The south edge of the plateau is a rugged 2,000-foot-high (610 m) northwest-trending escarpment overlooking the alluvium-filled valley of Ash Flat on the south, and the Gila Mountains beyond (figs. 1, 2, 3). From the Nantac Rim the forested surface of the Natanes Plateau slopes gently northward for 4 miles (6.5 km) where the north edge of the plateau is marked by a much less sharply defined and much less conspicuous topographic break of subparallel northwest trend. The north margin of the plateau slopes gently downward and merges with Big Prairie, a nearly flat surface that extends about 10 miles (16 km) northward to the Black River gorge. Altitudes in the area range from about 5,000 feet (1,524 m) on Ash Flat near Arsenic Tubs Ranch to about 7,400 feet (2,256 m) along the Nantac Rim and 6,000 feet (1,829 m) on Big Prairie.

The surface of the Natanes Plateau in the area of the circular feature is deeply incised by two slightly arcuate drainages, Point of Pines Creek and an unnamed drainage just north of and parallel to the Nantac Rim (fig. 2). The western and southern outlines of the circular feature seen on the Apollo 9 photograph are defined largely by the shadows cast by these two canyons. Both these drainages are controlled by faults along them. The northern and eastern parts of the "circle" have no equivalent counterparts in drainage and any bedrock structures are covered by alluvium on the margin of Big Prairie. However, the poorly defined topographic break marking the northeast edge of the Natanes Plateau in this area may be an expression of a buried fault.

Rocks in the Point of Pines area

Precambrian granite and Paleozoic sedimentary rocks crop out locally at the foot of the Nantac escarpment, and are overlain unconformably on a surface of considerable relief by a rather simple layered section of middle Tertiary volcanic rocks that underlie most of the area mapped. The volcanics are well exposed along the Nantac Rim and in the canyons incised into the Natanes Plateau.

The Precambrian granite crops out in two areas, both in the southeast part of the mapped area: one is at the base of the escarpment from the southeast corner of the Point of Pines West quadrangle southeast to Park Creek (fig. 1) a distance of about 10 miles (16 km), and the other is along the east side of Park Creek in the southeast corner of the Point of Pines East quadrangle (fig. 3). The granite is red, coarse grained, and composed chiefly of perthitic potassic feldspar, quartz, albite, and minor amounts of biotite and muscovite.

A maximum of 1,000 feet (305 m) of Paleozoic sedimentary rocks ranging in age from Cambrian to Mississippian overlies the Precambrian granite. These include 500-600 feet (152-183 m) of Coronado Sandstone of probable Middle and Late Cambrian age, 100-300 feet (30-91 m) of El Paso Limestone (Longfellow Limestone of Lindgren, 1905) of Late Cambrian and Early Ordovician age, 100-250 feet (30-76 m) of Morenci Shale of Devonian age, and about 300 feet (91 m) of Escabrosa Limestone (Modoc Limestone of Lindgren, 1905) of Mississippian age. Thin remnants of Pennsylvanian limestones of the Naco Group may be present locally but were not separated in mapping. The Paleozoic rocks crop out under the Nantac Rim north and east of Arsenic Tubs in the Point of Pines West quadrangle (fig. 2), and at the southeast end of the Nantac Rim between Black Mesa and Park Creek in the northwest corner of the Bryce Mountain quadrangle (fig. 1).

The Tertiary volcanic rocks were erupted onto a deeply eroded surface cut into the Paleozoic and Precambrian basement (fig. 4). The total relief on this surface probably exceeds 900 feet (274 m), as volcanic rocks rest on all the underlying rocks from Precambrian to Mississippian. The volcanic section can be separated readily into three major units--lower and upper units of dark andesites, basalts, and accompanying breccias between which is a middle unit of 300-1,000 feet (91-305 m) of light-colored rhyolitic pyroclastics.

The lower basalts crop out in three areas: at the base of the Nantac Rim from near Arsenic Cave southwest 10 miles (16 km) to Black Mesa, in the drainage of Point of Pines Creek, and in Park Creek in the southwest part of the mapped area (figs. 1, 2, 3). The lower unit rests on rocks ranging from Precambrian granite to the Mississippian Escabrosa Limestone and probably has an average thickness of 600 feet (183 m), but may be as much as 1,000 feet (305 m) thick in some places. The unit is made up chiefly of a sequence of thin 10- to 50-foot (3- to 15-m) flows interbedded with thin flow breccias. Locally, as in Park Creek, minor amounts of red conglomerate and volcanic sandstone are interbedded. It is a fine-grained dark-gray to black rock on fresh fracture, but weathers commonly in shades of dark brown or pale purple. Vesicular varieties are common. The most conspicuous visible mineral is reddish-brown iddingsite after olivine, generally as small grains about half a millimeter in diameter or less. Less conspicuous but common are plagioclase laths as much as a millimeter in length. Clinopyroxene also is generally present.

The lower basalts along the Nantac Rim are overlain by about 1,000 feet (305 m) of light-colored rhyolitic tuffs and breccias. The lower half of this rhyolitic unit consists of bedded air-fall tuffs and tuff breccias and reworked bedded materials, whereas the upper half consists mainly of ash-flow tuffs in at least three distinct cooling units, each with a thin zone of rather densely welded tuff. The thinness and poor overall welding of the ash-flow sheets are more characteristic of outflow aprons than of near-source accumulations. Along the Nantac Rim the lower unit is about 400 to 500 feet (122 to 152 m) thick, the upper 300 to 500 feet (91 to 152 m) thick. Northward, toward Big Prairie, the rhyolitic tuffs thin, largely by wedging out of the lower air-fall tuff (figs. 1, 4), and part of the overlying ash-flow tuff, against the lower basalts.

The same stratigraphic sequence, including marker units within the ash-flow tuffs in the upper half of the rhyolitic rocks, can be recognized everywhere within the mapped area.

Above the cliffs and ledges of light-colored rhyolite tuffs are the dark upper andesites, characterized by a striking coarsely porphyritic andesite, the so-called "turkey-track" porphyry; as mapped, these contain also flows of fine-grained dark-gray to black basaltic andesite or basalts. Some fine-grained mafic flows that lie above the turkey-track porphyry may represent a younger unit, but for the purposes of this investigation no attempt was made to separate the two rock types. Turkey-track porphyry forms the rimrock of the Nantac escarpment west of Barlow Pass, underlies most of Natanes Plateau in the Point of Pines area (fig. 2), and extends northward under Big Prairie to the Black River where it forms the rimrock of the Black River gorge (fig. 1). Southeast of the Point of Pines area the turkey-track porphyry has been stripped from part of the area by erosion; near Point of Pines 200-300 feet (61-91 m) remains, but the porphyry thickens westward along the Nantac Rim and, in the Tule Tubs quadrangle, attains at least 1,000 feet (305 m) in thickness.

The turkey-track porphyry consists of coarsely porphyritic gray- to red-weathering flows with abundant large tabular plagioclase phenocrysts as much as an inch or so in diameter. Small scattered phenocrysts of olivine and, less commonly, clinopyroxene are also present in a dark-gray to black fine-grained fresh groundmass. Vesicular varieties are common. All the dikes mapped in the Point of Pines area are of turkey-track porphyry, and all trend north-northwest (fig. 2). Along the Nantac Rim near Barlow Gap they are found cutting both the rhyolite tuffs and lower basaltic andesites and most probably are feeder dikes to turkey-track porphyry flows.

Age of volcanic rocks

Potassium-argon dates were obtained from three rocks collected during this study.

1. Plagioclase from the turkey-track porphyry (upper andesite), AMZ-284, collected near Cienega Creek in the Point of Pines East quadrangle has an age of 28.3±1.5 m.y. (million years).

2. Biotite from a rhyolite tuff in the upper part of the ash-flow tuff unit, AMZ-283, collected on Cienega Creek in the Point of Pines has an age of 32.7±1.3 m.y. Sanidine from the same rock gave an anomalously young age of 21.4±0.9 m.y.

3. A whole-rock age of the lower andesite (AMZ-287) collected on the Barlow Gap road under the Nantac Rim in the Point of Pines West quadrangle gave a minimum age of 27.5±1.3 m.y. This age also is considered anomalously young.

Because sanidines commonly lose argon and whole-rock ages are strictly reliable only as minimum ages, we tend to give credence only to the 28.3-m.y. (plagioclase) age of the turkey-track porphyry and the 32.7-m.y. (biotite) age of the rhyolite tuff. Furthermore, the turkey-track age is in line with other ages of supposed turkey-track porphyry in the region, and the welded-tuff biotite age is concordant with a 33-m.y. age on similar ash-flow tuff at Clifton. The general period of eruption indicated is middle Tertiary, probably Oligocene.

Geochemical reconnaissance

Seventeen stream-sediment samples and nine rock specimens were analyzed by semiquantitative spectrochemical analysis. The stream sediments were taken from beds of streams draining the circular structure and are of -80-mesh fines. The rock samples were selected to represent the principal volcanic units. Sample localities are shown on figures 2 and 3, and tables 1 and 2 give the original laboratory results.

The rock samples show no unusual values. Sample AMZ-284 contains 100 ppm Cu, but this is not unusual for turkey-track porphyry (Cooper, 1961, p. 24) of Arizona, nor for mafic volcanic rocks.

The stream samples also show no particularly anomalous values. AMZ-262, 263, and 265 show 150 ppm Cu, but are from the upper part of Pine Creek and represent chiefly turkey-track porphyry debris. Samples AMZ-258, 259, and 277 seem somewhat high in Ce, possibly reflecting allanite derived from the rhyolitic pyroclastics.

Structure

Regional setting

The area studied lies near the boundary of two major structural provinces--the Colorado Plateaus and Basin and Range provinces. The boundary between these two provinces is arbitrarily assumed to be the south edge of the Natanes Plateau (Bromfield and Shride, 1956, p. 628); the area to the south--Ash Flat and the Gila Mountains (fig. 1)--lies in the Basin and Range province. Geophysical data tend to confirm these assignments. The boundary between the two provinces is probably not a sharp line, but rather a northwest-trending zone in which the plateau edge is successively downfaulted into the structural basin of Ash Flat on the south along en echelon northwest-trending normal faults. Major exposed faults of this type in the study area are the Park Creek fault zone, Dry Lake fault, and Little Rocky Creek fault. The linear trend of the Nantac escarpment suggests a fault or fault-line scarp (Bromfield and Shride, 1956), and the gravity data suggest a major Basin-and-Range fault or fault zone, here called the Nantac fault, concealed beneath the alluvium in Ash Flats, parallel to the Nantac Rim and about a mile or so south of it (figs. 1, 2)--possibly a continuation of the Littly Rocky Creek fault (fig. 1). The location of the Nantac fault as shown on the map is based on simple inspection of the gravity map. Gravity modeling will eventually provide a better fix on its location.

The Tertiary volcanic rocks and exposed Paleozoic sedimentary rocks are flat lying to gently dipping. In the area of the circular feature and southeast, the prevailing dip of the rocks is 2°-8° NE, in part probably reflecting tilt on Basin-and-Range faults. West from the feature the attitudes of the volcanics are less well known, but range from nearly horizontal to west dipping. Along the Nantac Rim, as viewed from Ash Flat, the volcanics descend to the west, the base of the turkey-track porphyry falling nearly 1,000 feet (305 m) in 8 miles (13 km) between the area of the circular feature and the Tule Tubs quadrangle.

In an attempt to determine the regional attitude of the Tertiary volcanics we drew a structure contour map on the base of the turkey-track porphyry on a 1:62,500-scale base map (fig. 5). This surface has the double advantage of being the most widespread in the area and having an apparently conformable relation to the underlying rhyolitic pyroclastics. Two shortcomings of the contour map should be emphasized: (1) Although the surface of rhyolitic pyroclastics on which the turkey-track porphyry was erupted appears to have been relatively flat, it is probable that a small amount of relief was present locally. (2) The mapping on which it is based is a composite of moderately detailed mapping in some areas, particularly near the circular feature, and rapid reconnaissance mapping in other areas, particularly westward from the feature.

The structure map (fig. 5) suggests a gentle arching in the area of the circular feature, or, more speculatively, a northwest-trending anticline part of whose southwest flank has been obliterated along Basin-and-Range faults in Ash Flats. We emphasize that the impression of an anticlinal structure conveyed by figure 5 is dependent in large part on inferred contours west of the structure.

Circular feature

The circular feature detected by Carter on Apollo 9 infrared photographs is defined primarily by the intersection of the Dry Lake, Point of Pines, and Canyon faults (figs. 1, 2, 3). The configuration of these three intersecting faults is a crude semipolygonal-shaped feature, open on the northeast where bedrock is concealed by alluvium of Big Prairie (fig. 2). An inferred fault under the alluvium of Big Prairie (fig. 1) may provide "closure" of the polygonal feature.

The Point of Pines and Canyon faults, particularly the former, have an anomalous trend relative to the general Basin-and-Range structural grain. The Point of Pines fault strikes northerly and is downdropped 300-600 feet (91-183 m) on the east; the Canyon fault strikes easterly, curving southeast at its eastern end and is downdropped 100-500 feet (30-152 m) to the north. Between them is a downdropped block (fig. 4, section *A-A'*), crudely wedge shaped in plan, open to the northeast. The point of this wedge is truncated by the Dry Lake fault, a northwest-trending Basin-and-Range fault, downdropped 300 feet (91 m) to the southwest, away from the circular feature.

An inferred fault parallel to the Dry Lake fault may intersect the Point of Pines and Canyon faults under the alluvium of Big Prairie (fig. 1). This fault would lie along the northwest projection of the Park Creek fault zone. The Park Creek fault has a stratigraphic displacement of nearly 1,500 feet (457 m), down on the southwest, about 5 miles (8 km) southeast of the circular feature but weakens and splays to the northwest, and at Cienega Creek, near the southeast margin of the feature, probably has less than 100 feet (30 m) of displacement. The Canyon fault in its eastward course curves southwest (figs. 1, 3) and may intersect the Park Creek fault. Inasmuch as the sense of displacement of the two faults is opposite they would tend to cancel one another. Northwest from Cienega Creek, along the projection of the Park Creek fault zone, the Natanes Plateau rises from Big Prairie along a low but marked northeast-facing topographic break which may mark a fault-line scarp. Inasmuch as all faults of moderate displacement that cut the volcanic rocks tend to have a positive topographic expression, we infer that the concealed fault is down on the northeast, or opposite to the sense of displacement on this fault zone to the southeast.

In summary, two regional northwest-trending faults, the Dry Lake and an inferred fault about 4 miles (6 km) northeast, define an uplifted block or horst within which two other sides of the polygonal feature are outlined by two cross faults, the Canyon and Point of Pines faults, which enclose between them a downdropped block.

Several other normal faults are within the polygonal-shaped block; the most conspicuous is a north-trending graben on the east side of the block. Two faults bounding the graben are about 2,000 feet (610 m) apart. Between them the turkey-track porphyry is displaced a maximum of 500 feet (152 m). The graben dies out abruptly to the south, and although the graben may extend north under the alluvium toward Point of Pines, the displacement decreases to about 150 feet (46 m) on the east boundary fault at the point where it is last seen.

Geologic conclusions

The following conclusions are based on the surface geology. Geologic implications of the geophysical data are considered in the geophysical section, which follows.

The circular feature detected on the Apollo 9 photograph is largely a sun-angle effect on local topography, chiefly of shadows cast by two slightly arcuate canyons. Mapping shows that these canyons were determined by a semipolygonal fault pattern.

Two interpretations of the circular feature are suggested: (1) that the feature is a chance result of an intersecting fault pattern, or (2) that the feature is defined by tensional faults that are a result of subsidence at the apex of a low dome, and by Basin-and-Range faults which intersect these faults.

The more conservative interpretation (1) suggests that the circular feature is a fortuitous polygonal fault pattern within a horst formed by the Dry Lake fault on the southwest and an inferred buried fault on the northeast, both faults being part of the regional Basin-and-Range fault pattern. The Point of Pines and Canyon faults complete the outline of a downdropped block within the horst. The Point of Pines and Canyon faults, though somewhat anomalous in direction and sense of displacement relative to other mapped faults, may merely reflect deflection and modification of the regional stress field during the time of Basin-and-Range faulting by local inhomogeneities in the subvolcanic basement rocks. That such inhomogeneities are present is suggested by some of the gravity and magnetic data.

A more speculative interpretation (2) suggested by the structural contours on the base of the turkey-track porphyry flows (fig. 5) is that the Point of Pines and Nantac faults are tensional faults developed on the apex of a low dome or anticline in the Point of Pines area. Between them the faults enclose a wedge-shaped keystone block which is dropped 300-600 feet (91-183 m). The origin of the arching is not evident from surface geology.

There is no evidence within the downfaulted block either of a volcano-tectonic subsidence or of an intrusive in the area (other than turkey-track porphyry dikes immediately south of the feature), nor did we note evidence of hydrothermal alteration, of thermal metamorphism of the Paleozoic sedimentary rocks, or of possible mineralization within the fault block. Neither stream-sediment nor rock analyses were anomalous in their trace-metal contents.

GEOPHYSICAL INVESTIGATION

By Gordon P. Eaton and Donald L. Peterson

Introduction

Geophysical investigation of the Point of Pines area included both a gravity and an aeromagnetic survey. The results of these surveys are shown as two maps (fig. 6, a complete Bouguer gravity map; fig. 7, an aeromagnetic map) and a pair of profile sets (fig. 8, A and B) showing the relationship of the gravity and magnetic fields to the local geologic structure and topography. One set of profiles (fig. 8A) was constructed approximately midway between the Dry Lake and Park Creek fault zones (fig. 1). As such, it parallels the regional Basin-and-Range fault system and should be comparatively free of effects resulting from the existence of that system. The other set (fig. 8B) crosses, at approximately right angles, at least three Basin-and-Range faults (Park Creek, Dry Lake, and Nantac).

Physical properties

Tables 3 and 4 list the physical properties of the local stratigraphic units, insofar as we know them at present. Clearly, additional samples are needed, especially for magnetic property measurements. A few comments concerning the tabulated properties will aid in developing the interpretations made below. The high ranges in density for the turkey-track porphyry (upper andesite unit) and lower basalt unit reflect variations in vesicularity. Hypabyssal intrusive bodies of rocks of both these compositions would have density values at the high ends of the ranges. The very large range in density of the ash-flow tuffs is a function of their varied degree of compaction and welding. The upper value (2.40 g/cc) is undoubtedly below that of a hypabyssal intrusive of similar composition. As a basis for comparison, fine-grained silicic intrusives of Tertiary age in the Dos Cabezas Mountains, to the south, have density values ranging from 2.55 to 2.59 g/cc. We did not attempt to construct a weighted average density for the entire section. Instead, the average density used in making the Bouguer and terrain corrections was determined by constructing Nettleton profiles (Nettleton, 1939) from Ash Flat, across the highest part of the Natanes Plateau, to the middle of Big Prairie. That density which gave rise to a minimized correlation between complete Bouguer gravity and topography, and which was therefore used in reducing the data, is 2.45 g/cc. Clearly, the 300-1,100 feet (91-335 m) of relatively light rhyolite tuffs in the section influences this value. Rocks with significant magnetic properties are: (1) the lower basalt (Tb), which has a low to moderate susceptibility and a low normal remanence; (2) the turkey-track porphyry (Tta), which has a low to moderate susceptibility, but a high <u>reversed</u> remanent magnetization; (3) the Precambrian granite (p€g), which has an exceedingly low susceptibility[1] and remanence; and (4) a fine-grained basalt (Upper basalt), which lies above (or within the upper part of) the turkey-track porphyry, and which has a high susceptibility and a very high <u>normal</u> remanence. This last unit was not distinguished from the turkey-track porphyry by Bromfield and Ratté, but was observed at several localities, all of them above 7,100 feet (2,164 m) elevation, on geophysical traverses along, or back of, the top of the Dry Lake fault scarp. It is probably present only as isolated irregular patches and it clearly is relatively thin. Because of this, it probably contributes little to the total magnetic field.

---

[1]This is in contrast to the observation of Brant (1966, p. 87) that the Precambrian granites of Arizona have moderate susceptibilities.

TABLE 3.--*Dry bulk densities of rocks from the Point of Pines study area*

Map unit	Number of specimens	Range of densities observed (g/cc)	Mean density (g/cc)	Standard deviation (g/cc)
Upper basalt[1]-------	6	2.88-2.96	2.92	0.03
Tta----------------	16	2.40-2.74	2.61	.10
Ttu----------------	31	1.30-2.40	2.08	.32
Ttl----------------	9	1.16-1.61	1.49	.15
Tb-----------------	11	2.36-2.70	2.56	.14
O€e-Me-------------	37	2.61-2.77	2.71	.04
€b-----------------	13	2.35-2.66	2.57	.09
p€g (Nantac Rim)----	11	2.53-2.63	2.56	.03
p€g (Fresher samples from Pinaleno and Dos Cabezas Mts., nearby).	28	2.55-2.75	2.63	.05
p€P (Pinal Schist from Dos Cabezas Mts. None exposed in Point of Pines study area).	18	2.57-3.02	2.76	.12

[1]Occurs in unmapped local patches above Tta.

TABLE 4.--*Magnetic properties of rocks from the Point of Pines study area*

[---, property not measured. *, property not measured but assumed, on the basis of composition, to have a relatively low value]

Map unit	Number of specimens	Magnetic susceptibility range (emu/cc) X 10^4	Q^2	Sign of total magnetization[3]	Total magnetization[3] (emu X 10^4)
Upper basalt[1]--	3	23-33	23-84	N	275-1400
Tta (as collected).	8	10-16	3-466	R	215-3140
Tta (after demagnetization).	6	13-16	2-337	R	13-2210
Ttu------------	6	0.5-6.5	3-116	N	2-390
Ttl------------	---	*	---	---	*
Tb-------------	2	2.3-7.0	1-25	N	4-31
Paleozoic sedimentary rocks undivided.	---	*	*	---	*
p€g------------	4	Measured, but below the limits of detectability.			

[1]Occurs in unmapped local patches above Tta.

[2]Q is the Koenigsberger ratio of remanent magnetization to induced magnetization.

[3]Vector sum of the calculated induced and measured remanent magnetization.

From the foregoing, and from experience gained elsewhere in the region, one can make the following generalizations concerning the geophysical interpretations: (1) broad positive gravity anomalies, but little magnetic expression, may be expected from relatively elevated blocks of the observed pre-Tertiary basement rocks (including the Paleozoic carbonate rocks), at least where a substantial fraction of the overlying section is composed of rhyolite tuffs; (2) although no compositional variations within the Precambrian basement were observed along the base of the Nantac Rim during the geologic mapping, they should be kept in mind as possible anomaly sources; for example, the Pinal Schist, which has a density (table 3) ranging from 2.57 to 3.02 g/cc, with a mean value of 2.76 g/cc (sufficiently greater than that of Precambrian granite to create local gravity highs), is seen elsewhere throughout the region, the nearest locality being just across Ash Flat to the southwest (circled station on the flank of anomaly 6, fig. 6); (3) blind plutons of igneous rocks of any geologic age (Precambrian and younger) will have a geophysical expression which is a function of their physical properties and, therefore, their composition; for example, plutons with the composition of the lower basalt (Tb), cutting through almost any part of the section, might be expected to produce relatively low amplitude gravity and magnetic highs, and fine-grained hypabyssal plutons of turkey-track porphyry, if cooled during the same magnetic epoch or event as the rim-forming flows, should produce low to moderate gravity highs and pronounced magnetic lows; (4) abrupt local thickening of the rhyolites (Ttu), particularly in areas of downdropped basement, should produce gravity lows and weak to moderate magnetic highs.

It should be noted, before proceeding to a study of the maps, that nearly flat lying slabs of constant or only very gradually varying thickness will not contribute to noticeable gravity variations and will produce magnetic effects only near their edges. Thus the Tertiary volcanic section at Point of Pines should have little or no geophysical expression everywhere except where faulted or etched into landforms with prominent topographic relief.

Gravity survey

Figure 6 shows the complete Bouguer gravity field for the region surrounding the Apollo 9 photo anomaly. It should be noted that the gravity-station density is high in the immediate vicinity of the feature but low toward the edges of the map. Included, for positioning reference, are: (1) the outlines of the Point of Pines West and East quadrangles, (2) the traces of the Park Creek, Dry Lake, Point of Pines, and Canyon faults (erosion along the last three is believed to have created the photo anomaly), and (3) a series of circled numbers identifying specific anomalies to which reference is made below. With one exception, only those anomalies in the immediate vicinity of the subject feature are discussed here.

One of the more striking features of figure 6 is the gravity trough (1A-1B), which occurs along the southwest edge of the map. It is flanked by a steep gradient on its northeast side and reflects the presence of a deep asymmetrical graben under Ash Flat, probably filled with Gila Conglomerate of late Cenozoic age. The steep gradient marks the presence of a normal fault (herein named the Nantac fault) with at least several thousands of feet (1,000 m or more) of displacement. The approximate location of this fault is indicated by the dotted line. It is seen to be 1.5-2.0 miles (2.4-3.2 km) southwest of the present-day Nantac Rim, which is, therefore, a fault-line scarp. Note that the prominent topographic embayment in the rim near Barlow Pass is not a reflection of a similar bend in the buried fault scarp. The latter strikes smoothly northwestward throughout its mapped length. The topographic reentrant in the rim owes its existence to other factors and as will be noted below coincides with a sharp gravity high (anomaly 4).

From the top of this steep gravity gradient the gravity field rises northward, somewhat irregularly, to a broad high labelled anomaly 2. The gentle gradient on the northeast flank of this high continues downward for at least 20 miles (32 km) to the northeast corner of the map and probably is produced by northeastward crustal thickening associated with the Colorado Plateaus physiographic and structural province. The smoothness of this gradient northeast of Big Prairie indicates that the graben under Ash Flat is the last prominent structural basin encountered in passing northeastward from the Basin and Range province into the Colorado Plateaus province. The Nantac Rim thus marks the southwestern edge of the Plateaus province.

Anomaly 2 occurs between the Dry Lake and extended Park Creek fault zones, which, in the northwestern part of the Point of Pines West quadrangle, defines a broad horst. The gravity high could be explained as resulting, in part, from uplifted relatively dense basement under the horst, but as will be noted below, the horst itself appears to coincide with a chain of plutons and it is possible that collectively these also contribute to the anomaly. On the basis of its areal extent, we think that this anomaly may be largely an expression of a deep-seated crustal feature, although we have not yet modeled it as such. The sharp-nosed northern extension of anomaly 2 probably arises from a relatively shallower source.

Symbols 3A, 3B, and 3C mark the crest of a local gravity ridge which coincides in the aggregate with outcrops of dense Paleozoic and Precambrian basement rocks at the foot of the Nantac Rim. Inasmuch as the gravity field drops gently to the northeast, the basement surface may be tilted in this direction also, in conformance with the slightly northeastward dipping Tertiary volcanic pile which overlies it. As noted earlier, however, the northeast-dipping gradient (in the bulk) is probably due to crustal thickening.

Anomaly 4, which peaks at -149.6 mgals, displays the second highest gravity value on the map. It has steep northwestern, southwestern, and southeastern flanks, but merges gently to the north with anomaly 2 (and to the south with anomaly 3B). Its northwestern flank approximately follows the Canyon fault, which is downthrown to the northwest some 300-350 feet (91-107 m), but the southeastern flank has no counterpart fault, and the displacement on the Canyon fault is insufficient to account for the anomaly. Other features unique to this anomaly are the fact that it coincides: (1) with a sharp reentrant in the Nantac Rim; (2) with a swarm of dikes of turkey-track porphyry; and (3) near its southern end, with an area where the lower basalt appears to cut sharply upward across the Paleozoic section. Interpretation of this anomaly is reserved until its magnetic characteristics are described below.

Anomaly 5 is a very subtle feature with a closure in the area of 5A and extensions, approximately parallel to the Dry Lake fault, at 5B and 5C. Essentially, it is an irregular and barely perceptible low nestled between the subtle gravity high, 3C, and the broad high, 2. Its character is perhaps best seen in gravity profiles A-A' and B-B' (Figure 8). One interpretation of this gravity low is that it reflects a broad basement high projecting upward through the denser lower basalts, just as it does immediately west of Barlow Pass. As noted in the discussion of the geology, the exposed basement displays an erosional relief in excess of 900 feet (274 m). This relief, combined with a density contrast of 0.25 g/cc, could produce a local anomaly of several milligals. Of significance here is the fact that extension 5B falls within the Apollo 9 photo anomaly and also coincides with a pronounced magnetic high having a peak amplitude of 2,000 gammas. The east end of closure 5A and the area of 5C are also approximately coincident with magnetic highs, both exceeding 1,800 gammas in amplitude. An interpretation of these relationships is discussed in the magnetic section below.

Anomaly 6, which has a peak value of -146.7 mgals, occurs over a newly discovered outcrop of what appears to be Precambrian Pinal Schist in the Gila Mountains. A profile drawn from this anomaly to the saddle near anomaly 3B, and thence to the northeast corner of the map, probably defines, to a first approximation, the local regional gradient.

Magnetic survey

The aeromagnetic survey, the results of which are shown in figure 7, was flown at a barometric elevation of 7,500 feet (2,286 m). The Nantac Rim west of Barlow Pass is everywhere greater than 7,000 feet (2,134 m) in elevation, and locally it exceeds 7,300 feet (2,225 m). Northeast of the Dry Lake fault, in the center of the northern part of the Point of Pines West quadrangle, the mountains also exceed 7,300 feet (2,225 m) over a broad area, and just east of the intersection of the Point of Pines fault with the Dry Lake fault, there is a local eminence exceeding 7,300 feet (2,225 m). Thus, in all of these areas, the magnetic sensor was close to the ground. As a result, the most impressive magnetic anomalies with respect to amplitude (both positive and negative) and steep gradients occur in these areas.

Conspicuous on the magnetic map are two belts of intense linear magnetic lows, anomalies 1A and 1B. Anomaly 1A coincides with the Nantac Rim, and anomaly 1B with the Dry Lake fault scarp. Both are edge effects associated with the eroded (1A) or faulted (1B) edges of slabs of negatively polarized turkey-track porphyry. Anomaly 1C, which trends at right angles to these, marks the edge of the turkey-track porphyry where it caps the northeast-trending high bluff on the west side of Point of Pines Canyon. The arm of anomaly 1B that trends northeast, parallel to anomaly 1C, similarly marks the northwest erosional edge of a topographically high area that juts out toward Big Prairie and is underlain by turkey-track porphyry. In the southern part of the Point of Pines East quadrangle, a magnetic trough is associated with turkey-track porphyry along the Park Creek fault. Thus, none of these lows reflects subsurface geology.

Anomaly 2, a large magnetic high in the southeast corner of the Point of Pines West quadrangle, coincides with the southeast side of gravity anomaly 4, also conspicuously positive. With the earth's main magnetic field inclined at approximately 60°, one would expect the magnetic anomaly associated with a given body, to be displaced south of its gravity anomaly. The axis of magnetic anomaly 2 cuts across the rhyolites, the exposed Paleozoic section, and the Quaternary alluvium of Ash Flat. Its trend is at a high angle to the strike of both the rhyolites and the Paleozoic sedimentary rocks, but it is approximately concentric with, and lies immediately west of, a nearly vertical contact bounding an exposed body of lower basalt. A magnetic depth estimate places the top of the source of this anomaly at 5,450 feet (1,661 m), immediately beneath the Quaternary alluvium. These observations, in conjunction with the physical properties noted above, suggest that the anomaly could be caused by a northeast-trending stocklike body of lower basalt in the upper part of the Precambrian basement granite, although the amplitude of the anomaly seems a little high for the total magnetization calculated for the unit (table 2). The geologic map is permissive of the interpretation that the lower basalt shown cutting across the strike of the Bliss Quartzite is an apophysis of this stock.

An alternative interpretation is that magnetic anomaly 2, along with gravity anomalies 4 and 6, reflects variations in composition within the Precambrian basement. Anomaly 6 occurs over a window exposing what is probably Pinal Schist, and the southeast flank of this anomaly is alined with the southeast flank of gravity anomaly 4. The tabular density data presented earlier indicates that the Pinal Schist is denser than the granite and could produce positive gravity anomalies. Unfortunately, we do not know its magnetic properties and cannot say whether magnetic anomaly 2 could be caused by the Pinal Schist. It could, however, be caused by a body of Precambrian gabbro or amphibolite, as both are seen elsewhere in the region. The data at hand are inadequate for selecting, as unique, a single interpretation from among the alternatives presented.

Anomaly 3 is a magnetic low with a closure of approximately 60 gammas. It is completely surrounded by higher field values, but coincides with the middle part of the northeastern wide of gravity anomaly 4. Its source has an elevation of about 5,700 feet (1,737 m), although this estimate of depth is probably less reliable than that for magnetic anomaly 2. At 5,700 feet (1,737 m) the top of the body lies some 300 feet (91 m) below the highest Quaternary alluvium which laps up onto the Nantac Rim in the topographic reentrant near Barlow Pass. It would thus be within the Paleozoic carbonate rocks which immediately underlie the alluvium. A dike swarm of turkey-track porphyry is seen to cut the rhyolite in the cliffs above this area. These facts, coupled with the physical properties of the andesite, lead us to suggest that the bulk of magnetic anomaly 3 may be an expression of a stocklike body of turkey-track porphyry. It is equally possible that it reflects a zone of local alteration. Alternatively, the northeastern arm of the anomaly may be related to the erosional edge of turkey-track flows north of the Canyon fault. If our first interpretation is correct, the body of turkey-track porphyry must have been emplaced immediately against that of the Tertiary lower basalt or Precambrian mafic rock which created magnetic anomaly 2. Together, these two bodies give rise to gravity anomaly 4.

At first glance, magnetic anomaly 4A, which occurs within the Apollo 9 photo anomaly, gives the impression of being related to anomaly 2. Their amplitudes are nearly identical and one can, by imagining anomaly 3 to be absent, convince himself that 4A and 2 are simply parts of a single large magnetic high which trends north-northwest. We do not believe this to be the case, however. Although magnetic anomaly 2 is coincident with a pronounced gravity high (anomaly 4), magnetic anomaly 4A is associated with a subtle gravity low (anomaly 5B). Thus the bodies creating the two large magnetic highs (2 and 4A) are of unlike physical properties and, therefore, of unlike composition. The contrast in geophysical expression of the two can be seen readily in profile A-A' (fig. 8A) which crosses them both. Profile B-B' (fig. 8B) gives a somewhat clearer idea of the nature of the gravity low.

Trailing off from the west side of magnetic anomaly 4A is an elongate high, 4B, which is coincident with the Dry Lake fault. Farther to the northwest along this fault is still another magnetic high with considerable intensity, anomaly 4D. The geographic relationship of 4D, 4B, and the southwest edge of 4A to the fault is remarkable. Two explanations can be offered: (1) the location and trend of the fault were determined by a basement inhomogeneity, the composition of which gives rise to the magnetic highs, or (2) the highs are the geophysical expression of apophyses or dikelike intrusive bodies which were emplaced in the fault zones. The latter explanation is preferred.

Depth estimates of the source for anomaly 4A (admittedly less reliable than those for anomaly 2) place its top at an elevation of 6,150 feet (1,875 m). Construction of geologic cross sections through this area (figs. 4, 8A, and 8B), based entirely on extrapolation of the mapped surface geology, puts the top of the lower basalt at almost precisely this elevation.

Geophysical conclusions

In summary, we can state the following concerning the area inside the Apollo 9 photo anomaly: it coincides with a subtle gravity low and a pronounced magnetic high that has gradients suggesting a steep-sided source and a top coincident with the top of the lower basalt. The causative body appears to be stocklike within the area of the photo anomaly and to extend as a discontinuous or irregularly crested dikelike mass to the northwest, along the Dry Lake fault. The Point of Pines and Canyon faults neatly bracket the main stocklike part of the body (see magnetic profile A-A'). Brant (1966) has commented on the fact that most of the Laramide copper porphyry bodies of Arizona produce magnetic lows. To the extent that the silicic body proposed here as the cause of the circular feature gives rise to a magnetic high, it is not likely to be a mineralized Laramide porphyry.

One can argue that the location and trend of the last-mentioned faults were determined by a prevolcanic basement inhomogeneity, the composition of which gives rise to anomaly 4A. If this is the case, the basement topography, which is highly irregular, crests at 6,150 feet (1,875 m) immediately beneath an area that appears from the surface geology to have subsided between the faults in question. This interpretation (of a prevolcanic basement inhomogeneity) is seemingly in harmony with the fact that no alteration or hydrothermal veining of the rhyolite was observed in the course of geologic mapping, nor were any geochemical anomalies noted in the area. Nevertheless, we prefer an alternative interpretation, because: (1) magnetic anomalies 4B and 4D are coincident with the Dry Lake fault, suggesting a younger-than-Precambrian age and (2) other evidence cited above (magnetic anomalies 2 and 3) is suggestive of the existence of a zone of probable Tertiary intrusions trending north-northeast toward the photo anomaly.

The preferred interpretation is that magnetic anomalies 4A, 4B, 4C, and 4D and gravity anomaly 5A, along with its extensions, 5B and 5C, arise from a post-lower basalt, silicic stock, and associated dike. This silicic rock is slightly less dense than the Precambrian granite, but considerably more magnetic. The stock was emplaced sometime after the accumulation of the lower basalt flows, but how much later we do not know. The structure on the base of the turkey-track porphyry (see profiles A-A' and B-B', figs. 8A and 8B) makes it tempting to suggest that the emplacement of the stock was later than the turkey-track unit, and therefore arched it. The stock's satellite dike utilized as a channelway one member of the developing Basin-and-Range fault system, the Dry Lake fault. Either the inhomogeneity created within the basement by the emplacement of the stock helped shape the later Point of Pines and Canyon faults or an upward surge and slight withdrawal of the magma gave rise to the arching and subsidence of the area between these two faults.

This silicic stock, if real, in our view is but one of several intrusions that trend in a chain from the southeast corner of the Point of Pines West quadrangle out through the center of its northern edge. In addition to the bodies creating magnetic anomalies 2, 3, and 4A, this chain also includes magnetic peak 1638 and coincides approximately with a northwestward-trending axis drawn through gravity anomalies 4 and 2. Because the chain is reflected in a moderate gravity high, as well as in several magnetic highs, we assume that the intrusions are for the most part mafic or intermediate in composition. The lone exception is the body producing magnetic anomaly 4A. It creates a constriction in what might otherwise be a broad gravity high consisting in the aggregate of gravity anomalies 4 and 2 and including the entire northeastern half of the Point of Pines West quadrangle. It should be noted that, with the exception of what may be a crosscutting body of lower basalt in the southeastern corner of this quadrangle, the surface geology gives no hint of the presence of this postulated chain of stocks.

Nevertheless, a line drawn from the north peak of magnetic anomaly 2, through 4A, and on to magnetic high 1638, along profile A-A', traces a coherent magnetic anomaly exceeding 1,500 gammas in amplitude that follows for a way, the axis of the horst between the Dry Lake and Park Creek faults. This anomaly, if due to the presence of a belt of plutons, may help explain the origin of the horst, or alternatively, the stress field that created the horst may have controlled the emplacement of the plutons. Note, however, that the northern continuation of gravity anomaly 2, which approximately coincides with magnetic anomalies 5 and 6, cuts across the northeast margin of the horst.

Magnetic anomaly 7, in the northeast corner of figure 2, occurs on the south slope of Willow Mountain, a huge edifice of basalt. It lies outside the area mapped geologically by Bromfield and Ratté and is in an area where we have absolutely no gravity control. A magnetic depth estimate places the top of the anomaly source close to the ground surface, but there is insufficient evidence of other kinds for speculating about its geologic origin.

REFERENCES CITED

Brant, A. A., 1966, Geophysics in the exploration for Arizona porphyry coppers, *in* Geology of the porphyry copper deposits, southwestern North America: Tucson, Ariz., Univ. Arizona Press, p. 87-110.

Bromfield, C. S., and Shride, A. F., 1956, Mineral resources of the San Carlos Indian Reservation, Arizona: U.S. Geol. Survey Bull. 1027-N, p. 613-691.

Cooper, J. R., 1961, Turkey-track porphyry--a possible guide for correlation of Miocene rocks in southeastern Arizona: Arizona Geol. Soc. Digest, v. 4, p. 17-33.

Lindgren, Waldemar, 1905, Description of the Clifton quadrangle [Arizona]: U.S. Geol. Survey Geol. Atlas, Folio 129.

Nettleton, L. L., 1939, Determination of density for reduction of gravimeter observations: Geophysics, v. 4, p. 176-183.