TURKEY-TRACK PORPHYRY—A POSSIBLE GUIDE FOR CORRELATION OF MIOCENE ROCKS IN SOUTHEASTERN ARIZONA

By

John R. Cooper

U. S. Geological Survey, Denver, Colorado

INTRODUCTION

The Tertiary igneous rocks of southeastern Arizona include a very distinctive porphyry characterized by abundant tabular phenocrysts of plagioclase as much as 1 inch or locally even 2 inches in diameter, in a gray to reddish-brown, fine-grained to glassy groundmass. Many years ago Eldred D. Wilson referred to the rock as the turkey-track porphyry—an apt descriptive name which has come into fairly wide popular usage and has appeared in at least one published report (Denton, 1947, p. 14). In most geologic reports the rock has been called basalt or andesite. These names imply more about the composition of the rock than it is possible to determine by petrographic means, and therefore the purely descriptive term turkey-track porphyry is preferable unless chemical analyses are available.

Turkey-track porphyry flows, dikes, and sills are found at many places within a radius of 75 miles of Tucson. Individual flows and groups of flows probably nowhere exceed 1,000 feet in thickness. At some places the flows occur as tongues and lentils in other types of volcanic rock and in sedimentary rocks of the intermontane-basin type.

The turkey-track porphyry is so distinctive and so similar in appearance from place to place that the question naturally arises: Is it a valid marker for regional correlations within the large but limited area in which it is found? Macroscopic features like color and texture are certainly not enough to answer this question. This preliminary paper presents certain additional data that bear on the problem in the hope of obtaining criticisms and suggestions for further work and of encouraging others to map and study the rock more thoroughly than has been done in the past. The new information presented comes almost wholly from three areas: The Twin Buttes quadrangle about 20 miles southwest of Tucson, the Dragoon quadrangle about 50 miles east of Tucson, and the Klondyke quadrangle about 50 miles northeast of Tucson. Some information from other areas is included.

TWIN BUTTES AND DRAGOON QUADRANGLES

The turkey-track porphyry in the Twin Buttes and Dragoon quadrangles is petrographically and apparently chemically similar. Therefore it is convenient to consider the two areas together.

TABLE 1
COMPOSITION OF PLAGIOCLASE PHENOCRYSTS IN TURKEY-TRACK PORPHYRY FROM VARIOUS LOCALITIES IN SOUTHEASTERN ARIZONA

Locality	Type of material	Number of samples	N on cleavage flakes parallel 001 or 010	Indicated anorthite content (percent)
Twin Buttes quadrangle	Flows	4	1.5545-1.557	51 - 56
Dragoon quadrangle	Flow in conglomerate	2	1.556 -1.558	53 - 58
Dragoon quadrangle	Winchester Mountains flows	6	1.552 -1.556	46 - 54
Dragoon quadrangle	Winchester Mountains tuff	1	1.554 -1.556	50 - 54
Dragoon quadrangle	Kelsey Canyon flow	1	1.555 ± .0005	51 - 53
South end of Graham Mountains	Flows	5	1.5535-1.5563	49 - 55
South end of Graham Mountains	Dike	1	1.555 -1.556	52 - 54
Dos Cabezas Mountains	Dike	1	1.5515-1.5555	46 - 53
Northern Galiuro Mountains	Flow	1	1.555 -1.5583	52 - 59
Fresnal Canyon, Baboquivari Mountains	-	1	1.553 -1.555	48 - 52

TABLE 2
CHEMICAL ANALYSES, IN PERCENT, AND NORMS OF TURKEY-TRACK PORPHYRY, DIABASE PORPHYRITE, AND AVERAGE DOREITE

	1	2	3	4
Laboratory No.	G2973 (278330)	---	---	F2682
Chemical analyses				
SiO_2	57.55	58.28	56.00	52.45
Al_2O_3........	18.36	19.37	16.81	16.99
Fe_2O_3	3.45	1.35	3.74	6.11
FeO	1.36	2.98	4.36	2.88
MgO.........	1.47	1.30	3.39	3.10
CaO	6.32	4.78	6.87	7.02
Na_2O	4.13	4.40	3.56	3.79
K_2O	3.28	3.75	2.60	2.71
H_2O+	.60	1.78	.92	.86
H_2O-	.92	.44	-	1.08
TiO_2	1.50	.96	1.29	1.79
P_2O_5	.43	.35	.33	.67
MnO.........	.05	.87	.13	.13
CO_2	.44	.33	-	.13
Cl...........	.01	-	-	.01
F............	.06	-	-	.07
BaO	-	.25	-	-
SrO	-	.09	-	-
Total	99.93	101.28	100.00	99.79

TABLE 2
CHEMICAL ANALYSES, IN PERCENT, AND NORMS OF TURKEY-TRACK PORPHYRY, DIABASE PORPHYRITE, AND AVERAGE DOREITE—CONTINUED

	1	2	3	4
Laboratory No.	G2973 (278330)	---	---	F2682
		Norms		
Salic:				
Quartz	8.56	5.58	7.2	4.38
Orthoclase ..	19.40	22.24	15.6	16.12
Albite	34.90	37.20	29.9	31.96
Anorthite ...	21.82	21.96	22.2	21.41
Total	84.68	86.98	74.9	73.87
Femic:				
Wollastonite .	1.60	-	4.1	3.36
Enstatite	3.68	(	8.5	7.70
		(6.07		
Ferrosilite ..	-	(	3.0	-
Magnetite ...	.19	1.86	5.3	4.41
Hematite	3.33	-	-	3.04
Ilmenite	2.86	1.82	2.4	3.50
Apatite	1.01	.67	.8	1.68
Total	12.67	10.42	24.1	23.69

1. Turkey-track porphyry flow, near center NE 1/4 sec. 13, T. 17 S., R. 12 E., Twin Buttes quadrangle, Pima County, Ariz. Analyst: J. W. Goldsmith.

2. Diabase porphyrite, Crazy Mountains, Montana. Analyst: W. F. Hillebrand. (Clarke and Hillebrand, 1897, p. 143.)

3. Average doreite according to Nockolds (1954, p. 1018).

4. Turkey-track porphyry, Little Table Mountain, Klondyke quadrangle, Pinal County, Ariz. Analyst: D. F. Powers (Analysis furnished by F. S. Simons, August 1960).

Distribution and Stratigraphic Relations of the Turkey-Track Porphyry

In the Twin Buttes quadrangle, turkey-track porphyry flows occur in a zone several hundred feet thick in the lower part of the Helmet fanglomerate of early Miocene(?) age. A map and discussion of the field relations are given elsewhere (Cooper, 1960a).

In the Dragoon quadrangle, turkey-track porphyry flows crop out in several areas. On the east side of the Steele Hills, a flow about 60 feet thick occurs in conglomerate that underlies the volcanic rocks of the Steele Hills and Winchester Mountains. At the south tip of the Winchester Mountains and about 10 miles to the west in Kelsey Canyon, flows and tuff breccias with a maximum thickness of about 450 feet occur on top of the conglomerate, at the base of the great volcanic pile that forms the Winchester and Galiuro Mountains. Both the conglomerate unit and the turkey-track porphyry flows wedge out to the east and are missing about 2 miles northeast of the Dragoon quadrangle, where overlying units of the volcanic sequence lie directly on Precambrian granite.

Petrography

The turkey-track porphyry in both quadrangles is characterized macroscopically by abundant large thick tabular phenocrysts of plagioclase and scarce small phenocrysts of pyroxene or its alteration products. Specks of magnetite are commonly discernible with a hand lens. The constituents of the gray to red-brown groundmass are not determinable in hand specimen.

The plagioclase phenocrysts are 5 to 35 mm in diameter. They contain irregular inclusions of groundmass material and scarce inclusions of pyroxene. In spite of their large size, the phenocrysts are only slightly zoned, and the zoning present is mostly of the oscillatory type. The anorthite content indicated optically is $An_{52 \pm 6}$. (See table 1.) A range of $\pm An_1$ to $\pm An_4$ has been detected within individual crystals. The weak zoning suggests crystallization near equilibrium conditions.

Both augite and hypersthene are present as phenocrysts. These minerals have not yet been studied in detail, but the augite seems to have a rather small optic angle—(+) 2V 40°-50° estimated—but not as small as in pigeonite. The hypersthene is commonly altered to material resembling bowlingite.

The groundmass consists of tiny crystals of plagioclase, pyroxene and its alteration products, magnetite and/or hematite, long needles of apatite(?), and interstitial partly devitrified glass. Devitrification products include potassium feldspar(?) and tridymite(?).

A point-count mode of the chemically analyzed specimen (analysis 1, table 2) is as follows:

Phenocrysts

Plagioclase ($An_{52 \pm 2}$)	40.9
Augite	1.7
Hypersthene	1.0

<u>Groundmass</u>

Plagioclase	16.8
Augite and bowlingite(?)	2.9
Magnetite, ilmenite, hematite	1.8
Interstitial partly devitrified glass and apatite(?)	35.0

Chemical Composition

The chemical composition and norm of a representative and little-altered specimen from the Twin Buttes quadrangle are given as analysis 1, table 2. This rock falls in a CIPW group containing only 7 analyses in Washington's (1917) tables, and only one of these analyses—of a diabase porphyrite dike in the Crazy Mountains, Montana (analysis 2, table 2)—really resembles that of the turkey-track porphyry. Clearly the porphyry from Twin Buttes is a queer rock chemically.

According to Nickolds' classification (1954) the turkey-track porphyry from Twin Buttes is a doreite*. It is, however, notably low in iron and magnesia and high in alkalies, compared with the average doreite (analysis 3, table 2). This is expressed in the norm by low total femic minerals and high alkali feldspar.

Partial chemical analyses (table 3) suggest that the very unusual features of the complete chemical analysis are duplicated by other samples from the Twin Buttes quadrangle, and that the unusually low total iron is also duplicated in the Dragoon quadrangle. The indicated alkali content of the rock from the Dragoon quadrangle is variable and averages distinctly lower than that of the rock from Twin Buttes. The total alkali content and particularly the K_2O content are consistently higher than the average doreite, however. Except for analysis 6, which is unusually high in K_2O, the ratio $Na_2O:K_2O$ is nearly the same in the turkey-track porphyry specimens analyzed.

Available spectrographic data (table 4) suggest that the turkey-track porphyry is remarkably uniform in its trace-element content. No unusual features, like those in the major constituents, are apparent, however.

KLONDYKE QUADRANGLE

The Klondyke quadrangle, which is about 40 miles northwest of the Dragoon quadrangle, has been mapped by F. S. Simons who kindly supplied most of the data here presented. I assume full responsibility for the interpretations given.

---

*Nockolds applies the name doreite to a group of rocks not adequately provided for in most schemes of classification. The doreites are fine-grained rocks with the plagioclase:K-feldspar ratio of granodiorite but without essential quartz. The name trachy-andesite would be suitable but has been used in other and less definitive senses.

TABLE 3
PARTIAL ANALYSES OF TURKEY-TRACK PORPHYRY FLOWS FROM THE TWIN BUTTES AND DRAGOON QUADRANGLES

	1	2	3	4	5	6	7
Laboratory No.	278328 G2966	278329 G2967	278330 G2973	278331 G2968	278332 G2969	278333 G2970	G2972
Total Fe as Fe_2O_3 1/	5.7	6.9	5.2	5.3	5.6	6.3-6.4	-
TiO_2 1/	1.4	.94	1.4	1.2	1.2	1.4	-
Na_2O 2/	4.10	4.04	4.18	3.43	3.60	3.83	-
K_2O 2/	3.09	3.37	3.14	2.80	2.94	3.75	-
F 3/	.06	.06	-	.04	.04	.06	.07
Cl 3/	.01	.01	-	.02	.02	.01	.01

1/ Determined colorimetrically. Analysts: W. D. Goss (total Fe in number 6) and G. T. Burrow (all the rest).

2/ Determined by flame photometer using internal standard. Analyst: Wayne Mountjoy.

3/ Determined chemically. Analyst: V. C. Smith.

1. Gray phase, near center sec. 13, T. 17 S., R. 12 E., Twin Buttes quadrangle.

2. Red phase, SW 1/4 sec. 14, T. 17 S., R. 12 E., Twin Buttes quadrangle.

3. Gray phase, NE 1/4 sec. 13, T. 17 S., R. 12 E., Twin Buttes quadrangle (standard rock analysis of this sample in table 2).

4. Gray phase, NE 1/4 sec. 2, T. 14 S., R. 22 E., Dragoon quadrangle.

5. Gray phase, NE 1/4 sec. 2, T. 14 S., R. 22 E., Dragoon quadrangle.

6. Red phase, NE 1/4 sec. 2, T. 14 S., R. 22 E., Dragoon quadrangle.

7. Gray phase in conglomerate, sec. 33, T. 14 S., R. 22 E., Dragoon quadrangle.

TABLE 4
SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSES OF TURKEY-TRACK PORPHYRY FROM VARIOUS LOCALITIES IN SOUTHEASTERN ARIZONA

(Figures are reported to the nearest number in the series 7, 3, 1.5, 0.7, 0.3, 0.15, etc. in percent. These numbers represent midpoints of group data on a geometric scale. Comparisons of this kind of semiquantitative results with data obtained by quantitative methods, either chemical or spectrographic, show that the assigned group includes the quantitative value about 60 percent of the time. M, major constituent - greater than 10 percent. O, looked for but not found. -, not looked for. d, detected. Analyst: J. C. Hamilton. Looked for but not found: P, Ag, As, Au, B, Bi, Cd, Dy, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Ir, Li, Lu, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sn, Sm, Ta, Tb, Te, Th, Tl, Tm, U, W, Zn)

	1	2	3	4	5	6	7
Laboratory No.	278328 G2966	278329 G2967	278330 G2973	278331 G2968	278332 G2969	278333 G2970	F2682
Si	M	M	M	M	M	M	-
Al	M	M	M	M	M	M	-
Fe	3	3	3	3	3	3	-
Mg	3	3	3	3	3	3	-
Ca.	3	3	3	3	1.5	1.5	-
Na.	3	3	3	3	3	3	-
K.	3	3	3	3	3	3	-
Ti	.7	.7	.7	.7	.3	.7	-
Mn	.07	.07	.07	.07	.07	.07	-
Ba	.07	.07	.07	.07	.07	.07	0.07
Be	.00015	.0003	.00015	.0003	.0003	.0003	.00015
Ce	d	d	d	O	d	d	d
Co	.0015	.0015	.0015	.0015	.003	.0015	.003
Cr	.003	.003	.003	.003	.003	.007	.003
Cu	.007	.007	.015	.007	.015	.015	.03
Ga	.0015	.0015	.0015	.0015	.0015	.0015	.0015
La	.007	.007	.007	.007	.007	.007	.007
Nb	.0015	.0015	.0015	.0015	.0015	.0015	.0015
Nd	.015	.015	.015	.015	.015	.015	.015
Ni	.007	.007	.007	.003	.007	.007	.007
Pb	.0015	.0015	.0015	.0015	.003	.0015	d
Sc	.0015	.0015	.0015	.0007	.0007	.0007	.0015
Sr	.15	.15	.15	.15	.07	.15	.15
V	.03	.03	.03	.015	.015	.015	.03
Y	.003	.003	.003	.003	.003	.003	.003
Yb	.0003	.0003	.0003	.0003	.0003	.0003	.0003
Zr	.03	.03	.03	.03	.03	.03	.03

1. Gray phase, near center sec. 13, T. 17 S., R. 12 E., Twin Buttes quadrangle, Pima County.

2. Red phase, SW 1/4 sec. 14, T. 17 S., R. 12 E., Twin Buttes quadrangle, Pima County.

TABLE 4
SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSES OF TURKEY-TRACK PORPHYRY FROM VARIOUS LOCALITIES IN SOUTHEASTERN ARIZONA—CONTINUED

3. Gray phase NE 1/4 sec. 13, T. 17 S., R. 12 E., Twin Buttes quadrangle, Pima County.

4. Gray phase, NE 1/4 sec. 2, T. 14 S., R. 22 E., Dragoon quadrangle, Cochise County.

5. Gray phase, NE 1/4 sec. 2, T. 14 S., R. 22 E., Dragoon quadrangle, Cochise County.

6. Red phase, NE 1/4 sec. 2, T. 14 S., R. 22 E., Dragoon quadrangle, Cochise County.

7. Little Table Mountain, Klondyke quadrangle, Pinal County.

In the Klondyke quadrangle, turkey-track porphyry flows occur at two and possibly more widely separated stratigraphic horizons in the lower and middle parts of the volcanic pile that there makes up the Galiuro Mountains (F. S. Simons, oral communication, 1960). The rock resembles that in the Twin Buttes and Dragoon quadrangles but differs somewhat in mineralogy: It once contained phenocrysts of olivine now completely replaced by red, iron-rich material, and hypersthene has not been identified (F. S. Simons, oral communication, 1960). The abundant tabular phenocrysts of plagioclase have about the same diameter as those in the Twin Buttes and Dragoon quadrangles but are distinctly thinner. Oft-repeated oscillatory zoning is conspicuous but the variation in composition is small. Extinction angles on albite-carlsbad twins suggest that the plagioclase is a fairly calcic labradorite, but the single specimen from this general area that I have examined in oils is not greatly different in composition from the phenocrysts in other areas—An_{53-59} as compared with An_{46-58} at 22 other localities (table 1).

The porphyry from the Klondyke quadrangle is close to the average doreite in chemical composition (analyses 3 and 4, table 2). It is notably higher in iron and magnesia and lower in alkalies than the porphyry from Twin Buttes. The trace-element content is almost the same (table 4).

OTHER LOCALITIES

The following summary of other turkey-track porphyry localities is not intended to be exhaustive but rather to review other data now available that bear on the stratigraphic relations and possible consanguinity of the rock. Additional work at some of the localities is planned.

Cienega Gap Area

In the Cienega Gap area, which is about halfway between the Twin Buttes and Dragoon quadrangles, Brennan (1957) has described two units of turkey-track porphyry flows in alluvial and lacustrine deposits long known locally as the Pantano beds, or the Pantano formation. This formation and the Helmet fanglomerate of Twin Buttes are probably parts of the same continuous wedge of sediments because:

1. Data from drill holes in the Santa Cruz valley (Schwalen and Shaw, 1957, p. 15, 22, 92; Cooper, 1960a, p. 79) suggest that the two formations are physically continuous with one another beneath younger valley fill.

2. The pebbles and boulders in the two formations are of the same rock types (Brennan, op. cit., p. 14-22; Cooper, 1960a, p. 79). Most are from sedimentary and volcanic rocks lithologically identical to Cretaceous and lower Tertiary types of the region; some are from Paleozoic limestone and intrusive igneous rocks; no fragments of identifiable Precambrian rocks have been reported; no fragments of gneiss like that in the nearby Rincon and Santa Catalina Mountains have been reported in the Helmet fanglomerate or in the Pantano formation of Brennan (1957) in the Cienega Gap area, although such fragments predominate in the upper part of the Pantano formation as originally defined (Moore and others, 1941, p. 13-15).

3. Turkey-track porphyry flows are present in both formations, although the detailed petrographic and chemical characteristics of the porphyry in the Cienega Gap area are not known.

4. Minor amounts of rhyolitic tuff occur in the Helmet fanglomerate (Cooper, 1960a, p. 83-84) and in beds originally referred to the Pantano formation (Moore and others, 1941, p. 13-15). Brennan (1957), however, does not mention such tuffaceous beds in the Cienega Gap area.

The presence of turkey-track porphyry flows and acidic tuff beds are the only suggestions that the Helmet and Pantano may correlate with the conglomerate that passes beneath the volcanic rocks of the Galiuro and Winchester Mountains in the Dragoon quadrangle.

Graham Mountains and Fisher Hills

About 75 miles east of Tucson at the south end of the Graham Mountains and in the Fisher Hills, turkey-track porphyry flows lie at and near the base of a sequence of Tertiary volcanic rocks that resemble those in the Winchester Mountains. The porphyry, mapped as andesite (Tva) by Cooper (1960b), interfingers with dark-red rhyolite at the extreme south tip of the Graham Mountains, and elsewhere contains a little intercalated gravel, sand, and silt. In the eastern part of the area, the porphyry rests directly on Precambrian(?) granite, and elsewhere lies on older volcanic rocks (TKv) or tongues of the dark red rhyolite (Tvr). The stratigraphic relations and most of the rocks associated with the porphyry are very similar to, though not identical with, those in the Dragoon quadrangle about 25 miles to the southeast.

The turkey-track porphyry in the Graham Mountains-Fisher Hills area is macroscopically identical to that in the Dragoon and Twin Buttes quadrangles except at a few places where the phenocrysts are scarce or absent, perhaps due to filter-press action at the time of eruption. The plagioclase phenocrysts from 5 flows and 1 dike are in the range An_{49-55} (table 1).

Dos Cabezas Mountains

In the Dos Cabezas Mountains about 10 miles south of the area just described, turkey-track porphyry forms a set of dikes, mapped as Tia by Cooper (1960b), in a belt 7 miles long and less than half a mile wide that trends N. 65° W. through older Precambrian schist and granite. The plagioclase phenocrysts examined are An_{46-53} (table 1). No turkey-track porphyry flows are known in the Dos Cabezas Mountains or any of the ranges farther south.

Sentinel Peak

Just west of Tucson, a turkey-track porphyry flow crops out on the southwest side of Sentinel Peak, or "A" Mountain as it is commonly called. The area has been mapped and described in detail by Tolman (1909). The porphyry lies on the Shorts Ranch andesite of Brown (1939, p. 734-735), which is the youngest of the Tertiary volcanic units that form the central and southern parts of the Tucson Mountains. The porphyry is overlain by nearly horizontal olivine basalt flows containing some intercalated conglomerate and rhyolite tuff. Tolman's map shows that the turkey-track porphyry is several hundred feet thick where it passes beneath overlapping alluvium on the east and wedges out completely toward the west in less than half a mile.

The petrography of the porphyry (Tolman, 1909, p. 80-81) is similar to that in the Klondyke quadrangle. Augite occurs as scarce, small phenocrysts and as a constituent of the groundmass. No hypersthene is reported by Tolman but olivine, commonly altered to "red ferritic material," is found in some but not all specimens. The abundant large plagioclase phenocrysts are only slightly zoned and are "a rather basic type of labradorite as shown by the extinction angle on the albite twinning plane." The actual composition of the plagioclase may not be very different from that herein reported from other turkey-track localities. It is now known that high-temperature plagioclase, which is found in volcanic rocks, differs in optical properties from the low-temperature variety found in plutonic rocks—on which were based all extinction-angle curves available in 1909. Application of these curves to high-temperature plagioclase leads to overestimation of the anorthite content, commonly in the order of 10 percent An. (See Troger, 1956, p. 111.) The method of determination used in this study (N on cleavage flakes parallel to 010 or 001) indicates virtually the same composition for high- as for low-temperature plagioclase within the composition range of the phenocrysts in the turkey-track porphyry.

San Xavier Indian Reservation

Turkey-track porphyry crops out at several places on the San Xavier Indian Reservation, which is about 10 miles southwest of Tucson and just north of the Twin Buttes quadrangle. According to Heindl (1959), the porphyry occurs as dikes and probable flows. An outline of the reported section on the north side of Black Mountain is as follows:

		Feet
1.	Basalt and andesite	400±
2.	Basal conglomerate and sandstone, composed largely of turkey-track porphyry fragments	0-15
	Erosion surface	
3.	Turkey-track porphyry flow	150±
4.	San Xavier conglomerate beds of local usage, exposed	450±
	Concealed interval	
5.	Rhyolite	

The so-called San Xavier conglomerate resembles the lower part of the Helmet fanglomerate in color and in the composition and angularity of fragments. It is generally finer textured and considerably better bedded and better sorted, however. The plagioclase phenocrysts in the turkey-track porphyry are said to be as much as three quarters of an inch long and are referred to as andesine, but the method of identification is not given (Heindl, 1959, p. 156).

Drill holes through the alluvial cover south of Black Mountain disclose a section similar to that reported by Heindl and show that, in addition, a considerable thickness of beds resembling the San Xavier conglomerate but containing turkey-track porphyry fragments occurs stratigraphically above the turkey-track porphyry (K. E. Richard, oral communication, 1958).

Mineta Ridge Area

In the Mineta Ridge area, which is on the east side of the Rincon Mountains about 30 miles east of Tucson, turkey-track porphyry is associated with the Mineta formation of Chew (1952). This formation consists of conglomerate, sandstone, siltstone, and fresh-water limestone, and has yielded a fossil rhinoceros approximately of early Miocene age, certainly not older than late Oligocene or younger than middle Miocene (Lance, 1960, p. 156).

The turkey-track porphyry occurs stratigraphically above the fossil horizon at the edge of the fault block that contains the Mineta formation. Chew says (1952, p. 31), "Immediately north of the Bar L Y ranch house, the porphyry, which is developed as a single mass elsewhere, divides into a number of thinner branches with Mineta sediments in between which then return to the main porphyry mass. These small branches have a composition nearly that of basalt. Occasional agglomerate phases also occur here. Over these small branches lies the main porphyry mass." Because of these "dikes and sills," Chew regards the porphyry as intrusive but says that this relation is not proved and that the porphyry could be a "flow over the Mineta formation."

During a brief field examination of the area, I found that the porphyry as mapped by Chew includes at least two lithologic types. The main mass that overlies the fossiliferous beds is typical turkey-track porphyry. The smaller bodies within the fossiliferous beds generally consist of fine-grained equigranular rock; no phenocrysts of plagioclase could be found, although scarce phenocrysts of pyroxene(?) are present locally. I could find no indication of gradation between the two lithologic types, which seem to be separated everywhere by the sedimentary rock. The structural relations are obscured by crumpling, faulting, and slumping. Some bodies of the even-grained rock certainly have intruded the Mineta formation, and others are probably flows intercalated with it. The turkey-track porphyry is concordant with the underlying beds except where these beds are crumpled, probably by post-porphyry movement along the contact. Whether the porphyry is a flow or a sill could not be determined.

The turkey-track porphyry at the Mineta Ridge locality is certainly younger than the so-called Mineta formation, which is between late Oligocene and middle Miocene in age. The best estimate of the age of the porphyry is probably Miocene, for abundant boulders of the porphyry are reported in much-faulted conglomerate and sandstone exposed about 3 miles northeast of the Mineta Ridge area (Chew, 1952, p. 32), and Pliocene fossils, some as old as early Pliocene, are found in little-deformed alluvial and lacustrine deposits within existing valleys of the Basin and Range province in Arizona (Lance, 1960, p. 156).

SUMMARY OF DATA

The turkey-track porphyry, in all its occurrences in southeastern Arizona, has the same macroscopic characteristics including a somewhat unusual and very distinctive texture. Two chemically analyzed specimens from widely separated localities are both doreites, a fairly uncommon rock type. The analyzed specimen from the Klondyke quadrangle is a plagioclase-olivine-augite porphyry near the average doreite in chemical composition. The analyzed specimen from the Twin Buttes quadrangle is a plagioclase-hypersthene-augite porphyry that is very low in iron and magnesium and very high in alkalies, for a doreite. Specimens from the Dragoon quadrangle are petrographically the same as those from the Twin Buttes quadrangle and have at least some of the same queer chemical characteristics. Seven spectrographic analyses indicate that the trace-element content of the rock from the Klondyke, Twin Buttes, and Dragoon quadrangles is practically the same.

Chemical and spectrographic analyses of the turkey-track porphyry from other areas are not available, and definitive petrographic data are scarce. The rock from Sentinel Peak is a plagioclase-olivine-augite porphyry apparently very similar petrographically to the analyzed specimen from the Klondyke quadrangle. Thus each of the two known petrographic types of turkey-track porphyry occurs at widely separated places. The apparent anorthite content of the plagioclase phenocrysts is between 45 and 60 percent in all the specimens that I have examined in oils (table 1).

The geologic occurrence of turkey-track porphyry flows, particularly their local intercalation with other kinds of rock, shows that eruptions were repeated and must have been spread out over a long span of time, as most people view it. Nevertheless the indicated span of time at any one locality was short geologically. Rough contemporaneity of turkey-track porphyry eruptions is suggested by stratigraphic relations in the Twin Buttes, San Xavier Indian Reservation, and Cienega Gap areas. General contemporaneity is also suggested by stratigraphic relations in the Dragoon quadrangle, Graham Mountains, and Fisher Hills. There is no geologic evidence disproving rough contemporaneity in all the areas reviewed.

In the Mineta Ridge area, the turkey-track porphyry cannot be older than late Oligocene and is probably of Miocene age.

PETROLOGIC INTERPRETATIONS

Data are too few for firm conclusions but permit formulation of the following tentative and deliberately provocative hypothesis: All turkey-track porphyry in southeastern Arizona that is chemically and petrographically within the range indicated by the analyzed specimens from the Twin Buttes and Klondyke quadrangles came from the same deep-lying magma chamber during a geologically short interval of time, and therefore the porphyry is a valid though somewhat rough marker for regional correlations.

The hypothesis supposes that the magma chamber had about the same horizontal dimensions as the area in which the porphyry is now found, and that extrusions and intrusions from this chamber occurred at various places during a geologically short interval of time. The wide geographic distribution of the porphyry and apparent lack of large quantities of it at any one place preclude the possibility that it all came from a single vent or closely spaced group of vents.

The hypothesis further supposes that the parent magma had a composition near that of the average doreite, perhaps the composition of the analyzed specimen from the Klondyke quadrangle. While this magma was still in the deep chamber, it cooled slowly and the phenocrysts gradually formed under equilibrium or near-equilibrium conditions. When eruptions took place the interstitial magma of the erupted part was chilled to form the present groundmass. Porphyry of the type found at Twin Buttes represents a differentiated phase formed by removal through settling out of early-formed mafic crystals prior to eruption. The only other crystals then present in the magma, the plagioclase crystals, did not settle appreciably because of their lesser density. The way this crystal-sorting mechanism would work may be illustrated by the following simple calculation based on normative minerals:

	A Norm Klondyke quad. (table 2)	B Normative minerals assumed to settle out of A	C A minus B computed to 100 percent	D Norm Twin Buttes quad. (table 2)
Quartz	4.38	-	5.11	8.56
Orthoclase	16.12	-	18.82	19.40
Albite	31.96	-	37.31	34.90
Anorthite	21.41	-	24.99	21.82
Wollastonite	3.36	2.0	1.59	1.60
Enstatite	7.70	4.5	3.74	3.68
Magnetite	4.41	4.3	.13	.19
Hematite	3.04	-	3.55	3.33
Ilmenite	3.50	1.1	2.80	2.86
Apatite	1.68	-	1.96	1.01

The general agreement of columns C and D supports the hypothesis proposed. To be sure, the figures in column B were arbitrarily selected with such agreement in mind; nevertheless these figures seem as reasonable petrologically as could be expected in such an approximate computation. Olivine phenocrysts occur in the rock from the Klondyke quadrangle and these would have been one of the phases that settled out**. Settling out of olivine in lieu of pyroxene would increase the amount of free quartz remaining in the magma. The normative hematite probably indicates late oxidation of iron, which in the ferrous state could and unquestionably did enter silicate phases to a certain extent. Such oxidation would also distort the amount of normative magnetite compared with reality.

Any plagioclase that was removed by settling or other mechanism would decrease the amount of remaining plagioclase and make it less calcic, and at the same time would increase the amount of orthoclase and quartz.

**Olivine would be expected to form at an early stage of crystallization of a magma with the composition of the Klondyke rock; under equilibrium conditions, even without fractionation, the olivine would later react with the magma to form pyroxene. (See Bowen, 1928, p. 29-31, 41-44.)

Column D differs from column C in all these respects, and therefore the agreement would be even closer if a little plagioclase had been removed.

Comparison of the norm and mode of the rock from Twin Buttes suggests that little if any fractionation of the constituents of plagioclase, and to that extent supports the origin proposed. The normative plagioclase in this rock has the composition $Ab_{62}An_{38}$ by weight. According to Bowen's (1928, p. 33-35) equilibrium diagram, the first crystals to form when a magma with the composition $Ab_{62}An_{38}$ cools would be An_{74}. As cooling progressed under equilibrium conditions, the crystals would grow and at the same time react with the magma to become less calcic. Eventually they would reach the composition An_{52}, that is, the same composition as the phenocrysts now present in the rock. At this stage, the hypothetical magma would consist of 64 percent crystals of composition An_{52} and 36 percent liquid of composition An_{14}. If eruption and chilling took place at this instant, two plagioclases would be present in the rock in nearly the same proportion they are in mode:

	Norm (table 2)	Mode (p. 21)
Plagioclase phenocrysts (norm An_{52}; mode An_{52})	36.3	40.9
Groundmass plagioclase (norm An_{14}; mode $An_{?}$).....	20.4	16.8
Total plagioclase	56.7	57.7

The close agreement in proportions may be due partly to coincidence. It is an oversimplification to consider only the normative plagioclase and to ignore all the other constituents of the rock in tracing the course of crystallization. Furthermore the ratio of plagioclase phenocrysts to groundmass plagioclase in the turkey-track porphyry varies somewhat from place to place and specimens could doubtless be found in which the same comparison would fail to show agreement.

Whether the turkey-track porphyry actually formed in the way suggested can never be demonstrated, but the probability that it did will be greatly increased if future work shows that the samples so far studied in detail are truly representative. It is almost inconceivable that a rock with the same unusual textural, mineralogical, and chemical characteristics could have formed repeatedly at many places in the same large but apparently limited area. More geologic, petrographic, and chemical data are needed.

REFERENCES

Bowen, N. L., 1928, The evolution of the igneous rocks: Princeton Univ. Press, 332 p.

Brennan, D. J., 1957, Geological reconnaissance of Cienega Gap, Pima County, Arizona: Arizona Univ. PhD thesis, 53 p., 18 illus. including geologic map.

Brown, W. H., 1939, Tucson Mountains, an Arizona basin-range type: Geol. Soc. America Bull., v. 50, p. 697-760.

Chew, R. T., III, 1952, The geology of the Mineta Ridge area, Pima and Cochise Counties, Arizona: Arizona Univ. M.S. thesis (ms. on file at Arizona Univ. library), 53 p., 14 figs., 2 pls.

Clarke, F. W., and Hillebrand, W. F., 1897, Analyses of rocks with a chapter on analytical methods laboratory of the United States Geological Survey 1880 to 1896: U.S. Geol. Survey Bull. 148, 306 p.

Cooper, J. R., 1960a, Some geologic features of the Pima mining district, Pima County, Arizona: U.S. Geol. Survey Bull. 1112-C, p. 63-103.

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

Denton, T. C., 1947, Aravaipa lead-zinc deposits, Graham County, Arizona: U.S. Bur. Mines Rept. Inv. 4007.

Heindl, L. A., 1959, Geology of the San Xavier Indian Reservation, Arizona: *in* Arizona Geol. Soc. Southern Arizona Guidebook II, 1959, p. 153-159.

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

Moore, B. N., Tolman, C. F., Jr., Butler, B. S., and Hernon, R. M., 1941, Geology of the Tucson quadrangle, Arizona: U.S. Geol. Survey open-file report.

Nockolds, S. R., 1954, Average chemical composition of some igneous rocks: Geol. Soc. America Bull., v. 65, p. 1007-1032.

Schwalen, H. C., and Shaw, R. J., 1957, Groundwater supplies of Santa Cruz valley of southern Arizona between Rillito Station and the international boundary: Arizona Univ. Agr. Expt. Sta. Bull. 288, 119 p.

Tolman, C. F., 1909, The geology of the vicinity of the Tumamoc Hills, *in* Spalding, V. M., Distribution and movement of desert plants: Carnegie Inst. Washington, 1909, p. 67-82.

Troger, W. E., 1956, Optische Bestimmung der gesteinsbildenden Minerale, Teil 1 Bestimmungstabellen: Stuttgart, 147 p.

Washington, H. S., 1917, Chemical analyses of igneous rocks published from 1884 to 1913, inclusive, with a critical discussion of the character and use of analyses; a revision of Professional Paper 14: U.S. Geol. Survey Prof. Paper 99, 1201 p.