Newly described occurrences of orbicular rock in Precambrian granite, Sandia and Zuni Mountains, New Mexico

Kathleen A. Affholter and E. E. Lambert

1982, pp. 225-232. https://doi.org/10.56577/FFC-33.225

in:

Albuquerque Country II, Wells, S. G.; Grambling, J. A.; Callender, J. F.; [eds.], New Mexico Geological Society 33 rd Annual Fall Field Conference Guidebook, 370 p. https://doi.org/10.56577/FFC-33

This page is intentionally left blank to maintain order of facing pages.

NEWLY DESCRIBED OCCURRENCES OF ORBICULAR ROCK IN PRECAMBRIAN GRANITE, SANDIA AND ZUNI MOUNTAINS, NEW MEXICO

K. A. AFFHOLTER* and E. E. LAMBERT
Department of Geology
University of New Mexico
Albuquerque, New Mexico 87131

INTRODUCTION

Orbicular rocks are igneous, metamorphic or migmatic features witf orbicules consisting of a core, with one or more concentric shells of contrasted mineralogy or texture, surrounded by matrix (Levenson. 1966). Since their first mention, the unusual structure of orbicular roclks has attracted interest and remains enigmatic. Two occurrences of orbicular rock have been discovered recently in Precambrian exposures in the Sandia and Zuni mountains, New Mexico (fig. 1), and are described in this paper.

The Sandia Mountains, east of Albuquerque, are largely composec of the granitic Sandia pluton which hosts at least three orbicular rock occurrences: two previously known exposures near La Luz trail and newly described occurrence in Tijeras Canyon. The Zuni Mountains southwest of Grants, are part of a granitic batholith (Goddard, 1966 which hosts one recently described orbicular occurrence. Petrography wet chemical whole-rock analyses, and mapping are presented for the Tijeras Canyon occurrence (Affholter, 1979); a preliminary descriptior of the Zuni Mountains occurrence is given (Lambert, work in progress)

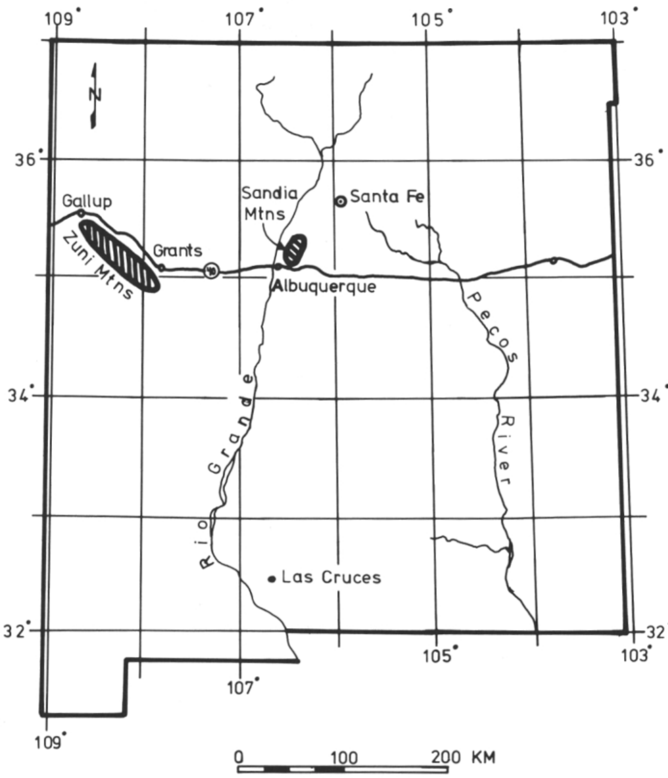


Figure 1. Index map of the Sandia and Zuni mountains, New Mexico.

Table 1. Estimated modes of selected samples[a] from the Sandia pluton.

	(1)[b]	(2)	(3)	(4)	(5)	(6)	(7)
quartz	28.0	25.0	9.4	6.3	10.8	25.0	22.0
K-feldspar	25.0	20.0	17.8	13.4	0.0	72.0	16.0
plagioclase	36.0	39.0	33.2	27.6	87.9	2.0	55.0
biotite	6.0	10.0	30.2	40.6	trace	1.0	3.0
magnetite	2.0	2.5	3.2	5.5	1.3	0.0	0.0
titanite	1.0	1.5	4.0	4.2	0.0	0.0	0.0
others[c]	2.0	2.0	2.2	2.4	0.0	0.0	4.0

[a](1) granite; (2) granodiorite; (3) and (4) biotite-rich quartz monzodiorite, double-shell orbicule; (5) plagioclase shell; (6) microcline perthite-quartz shell; and (7) granodiorite matrix. Rock names according to Streckeisen (1973).
[b]Analyses (1) and (2) are average modes (Condie and Budding, 1979).
[c]Apatite, zircon, epidote, muscovite, hornblende, and hematite.

SANDIA MOUNTAINS ORBICULAR ROCK

Geologic Setting

The Sandia pluton is exposed along the western escarpment of the Sandia Mountains and in a few inliers on the eastern side of the range (Condie and Budding, 1979). The exposed portion of the pluton is approximately 3-5 km wide and 30 km long. Contacts between the pluton and adjacent metamorphic rocks are sharp at the western end of the pluton in Juan Tabo Canyon (Berkley and Callender, 1979) but are gradational toward the southeast in Tijeras Canyon (see Connolly, this guidebook). The western extremity of the pluton is covered by Quaternary alluvium and by Tertiary deposits; the eastern side is in contact with Cibola gneiss in the Tijeras Canyon area (Kelley and Northrop, 1975). The age of the Sandia pluton is reported as 1,504± 15 m.y. (Taggart and Brookins, 1975; Brookins and Majumdar, this guidebook).

The Sandia pluton is predominantly medium- to coarse-grained granite and granodiorite with porphyritic to hypidiomorphic senate texture. The pink to gray granite averages 25-28 modal percent quartz, 20-25 percent potassium feldspar, 36-39 percent plagioclase, and 6-10 percent biotite with accessory magnetite, titanite, zircon, hornblende, apatite, and muscovite (Table 1; see also Condie and Budding, 1979). Subhedral microcline perthite megacrysts occur up to 6 cm in size. Biotite-rich segregations in the Sandia pluton range in composition from biotite monzonite to biotite-rich quartz monzodiorite and contain variable amounts of microcline perthite megacrysts, quartz, oligoclase, biotite, and accessory microperthite, magnetite, apatite, zircon, chlorite, epidote, muscovite, and titanite (Table 1; see also Enz, 1974). Inclusions in the granite and biotite-rich segregations are non-foliated greenstone, gneiss, quartzite, and granitoid (Enz, 1974; Feinberg, 1969). Dikes of aplite, aplite-pegmatite, pegmatite, lamprophyre, and quartz intrude the pluton

*Present address: Department of Geological Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061.

(Kelley and Northrop, 1975). The major dike rocks in the orbicular rock area are aplite and aplite-pegmatite.

Condie and Budding (1979) have suggested that the Sandia pluton actually consists of two plutons, North and South. However, their assertion is based on sparse sampling. Since a detailed study of the Sandia pluton has not yet been made, we believe subdividing the pluton is not warranted (see also Brookins and Majumdar, this guidebook). Brookins (1974), Taggart and Brookins (1975) and Enz and others (1979) give sample localities and a complete discussion of radiometric age determinations of the Sandia granite and related rocks.

La Luz Trail Site

The La Luz trail orbicules derive their name from their close proximity to La Luz Trail on the western face of the Sandia Mountains (fig. 2). Orbicules with cores of granite, plagioclase or microcline single crystals, or greenstone and gneiss fragments are surrounded by up to 14 alternating shells of biotite and plagioclase. Individual orbicules are separated by a fine- to medium-grained granitoid matrix (fig. 3a; Enz and others, 1979). The orbicules and their immediate matrix are partially surrounded by a fine- to medium-grained biotite monzonite which locally contains rounded microcline and plagioclase phenocrysts. The biotite monzonite and orbicular rock appear to be in intrusive contact with the Sandia granite. About 2 km N30°W of this outcrop, plagioclase orbicules without developed shells are surrounded by pink, coarse-grained microcline and quartz (fig. 3b). These orbicules and their matrix are surrounded by pink granodiorite.

The orbicular rock has been studied by numerous workers (Daugherty and Asquith, 1971; Thompson and Giles, 1974; Enz, 1974; Brookins

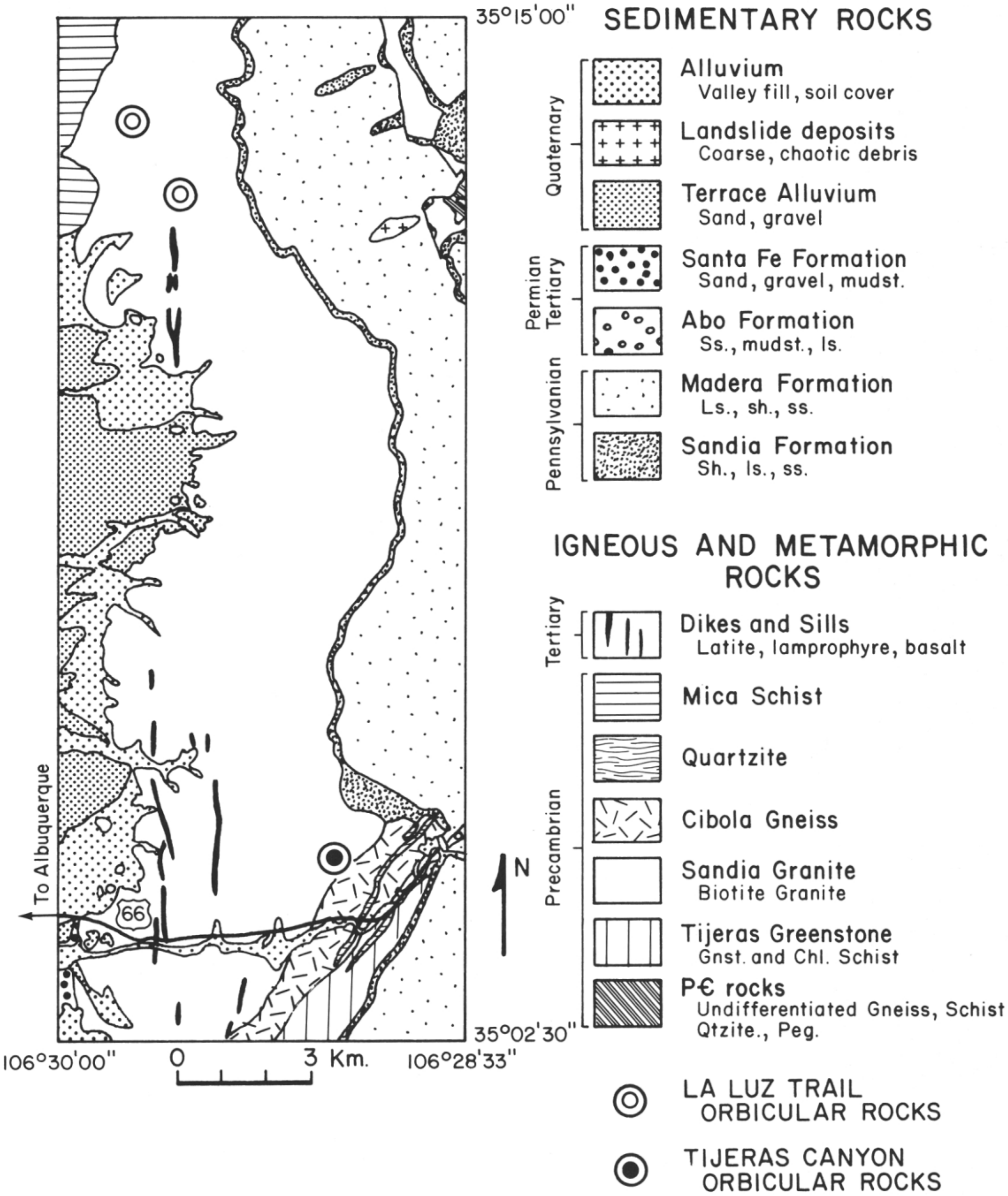


Figure 2. General geologic setting of the Sandia pluton (from Kelley and Northrop, 1975) showing the La Luz Trail orbicular rocks (open circles; from Enz and others, 1979) and the new occurrence of orbicular rock in Tijeras Canyon (solid circle).

and others, 1975; Kelley and Northrop, 1975; Held and Harris, 1978; Enz and others, 1979). All authors suggest an igneous origin except Thompson and Giles (1974) who prefer a metamorphic origin. Using shell geometry (as discussed by Levenson, 1966), chemistry, and petrology, Thompson and Giles (1974) suggest that the La Luz Trail orbicules formed by metasomatic reactions between a biotite monzonite-diorite xenolith and magmatic fluids during crystallization of the granite. In contrast, Enz and others (1979) support an igneous origin of the orbicular rock. Their evidence is as follows: (1) normal zoning of plagioclase occurs from inner to outer shells for some orbicules; (2) plagioclase composition is constant (An,,) in the outermost shells of all orbicules; (3) K-Ar biotite ages of orbicules (1,334 ± 28 m.y. and 1,335 ± 27 m.y.), surrounding biotite monzonite (1,313 ± 28 m.y.), and Sandia granite (1,300-1,350 m.y.) are all similar, and (4) "liquid deformation" has affected some orbicules.

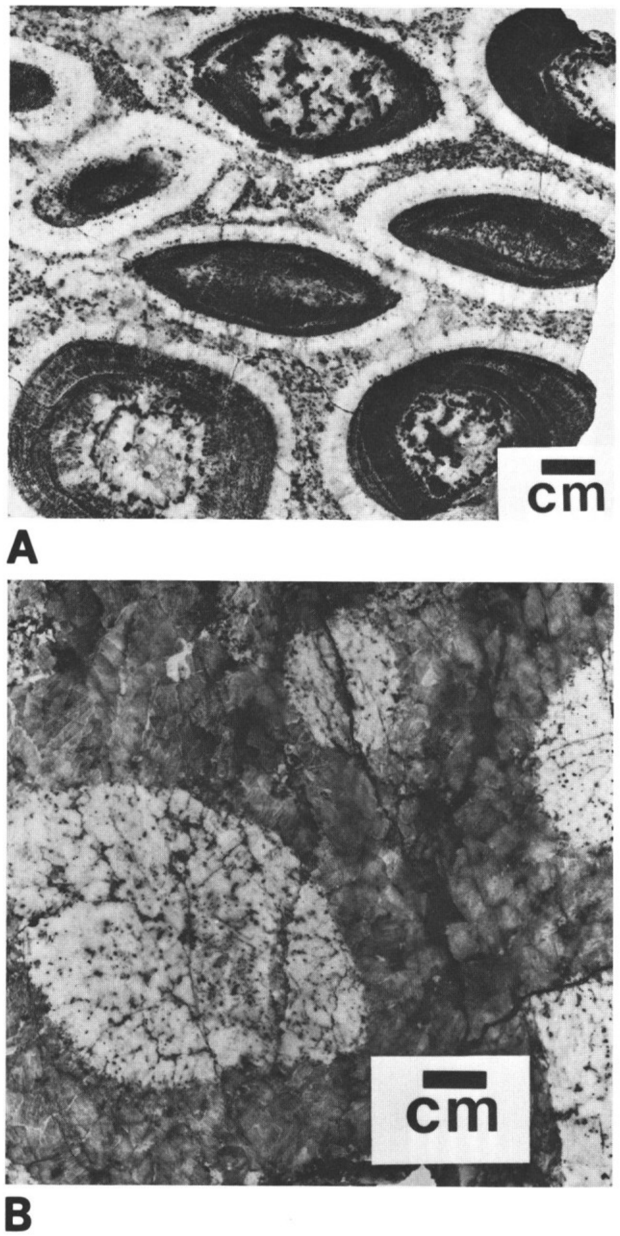


Figure 3. (a) Alternating biotite and plagioclase shells surround igneous and metamorphic rock cores. Enz and others (1979) refer to these as Type I orbicules. (b) Plagioclase "proto-orbicules" are surrounded by coarse-grained microcline and quartz matrix. Enz and others (1979) refer to these as Type V orbicules.

Tijeras Canyon Site

The newly discovered occurrence of orbicular rock is approximately 16 km south-southeast of the La Luz Trail outcrops and 0.5 km west of the Sandia granite—Cibola gneiss contact in Tijeras Canyon (fig. 2). The orbicules have cores similar to those at La Luz Trail, but surrounding the cores are a single white plagioclase shell (An„- An,,,) and 0-2 shells of intergrown salmon-colored microcline perthite (01 $_{96}$Ab$_{4}$; 77 modal percent) and quartz (23 modal percent). The outcrop occurs as two 1-4 m wide dike-like masses, extending for 10 and 16 m, enclosed in biotite-rich (30-40 modal percent) quartz monzodiorite (fig. 4).

The quartz-monzodiorite matrix is medium-grained, allotriomorphic to hypidiomorphic granular, with varying amounts of subhedral microcline perthite megacrysts (Table 1). Some megacrysts have plagioclase mantles resembling rapakivi texture. Inclusions in the quartz monzodiorite are similar to those found elsewhere in the pluton except many are smaller and some of the metamorphic inclusions have thin plagioclase rims. The contact between orbicular rock and quartz monzodiorite is obscured by alluvium and vegetation. The exposed contacts between the Sandia granite and the quartz monzodiorite are sharp but irregular.

Four types of Tijeras Canyon orbicules can be distinguished based on structure and size (fig. 5): (1) single-shell, with a core surrounded by a single white plagioclase shell; (2) double-shell, with a core surrounded by a plagioclase shell and one salmon-colored microcline perthite-quartz shell; (3) triple-shell, with a core surrounded by a plagioclase shell and two microcline perthite-quartz shells; and (4) small orbicules, similar to single- and double-shell orbicules but smaller with more biotite and magnetite in the cores and matrix. The small orbicules appear to have formed at the margins of the orbicular rock dikes, whereas the triple-shell orbicules crystallized toward the center of the dikes.

The cores of all orbicules are composed of igneous- and metamorphic-rock fragments. Microcline perthite megacrysts also form cores for the single-shell and small orbicules. Cores of igneous rocks are most abundant, followed by cores of metamorphic rock, quartz cores, and microcline perthite megacrysts cores.

The first shell of all orbicules consists of subhedral, elongate plagioclase, randomly arranged adjacent to the core but otherwise radial. Orbicules with cores of microcline perthite megacrysts have plagioclase aligned parallel to the crystal faces of microcline perthite in the core, then a second layer arranged radially to the core (fig. 6). The resulting texture imitates rapakivi texture. Plagioclase grain boundaries are dotted with quartz, biotite, magnetite, and apatite. Indentations in the outer margins of the plagioclase shells are filled with quartz. All of the plagioclase shells are the same thickness (about 1 cm) and the same composition (An„), regardless of core type.

The second and third shells of multi-shelled orbicules consist of layers of microcline perthite intergrown with quartz, separated by a 3-4 mm matrix-filled band (fig. 7). The quartz forms anhedral, elongate grains radial to the core. Irregular boundaries between the perthite grains are occupied by quartz and lesser amounts of biotite, muscovite, plagioclase, and magnetite. The composition of the potassium-rich areas in the perthite average Or$_{96}$A13$_{4}$; plagioclase lamellae are nearly pure albite. The thicknesses of the second and third shells average about 1.3 and 1.6 cm. Where crowded together, orbicules may exhibit partially developed outer shells of microcline perthite-quartz that are shared among orbicules of different core types (fig. 5b).

The shape of the shells reflects the shape of the cores. Cores of metamorphic rock and microcline perthite megacrysts have ellipsoidal shells; whereas, cores of igneous rock and quartz have spheroidal shells. Shell thickness is constant within each orbicule type, regardless of the type of core.

Deformed and broken orbicules are not observed at Tijeras Canyon, although they are at La Luz Trail. However, in one case, the Tijeras orbicules are split by an aplite dike.

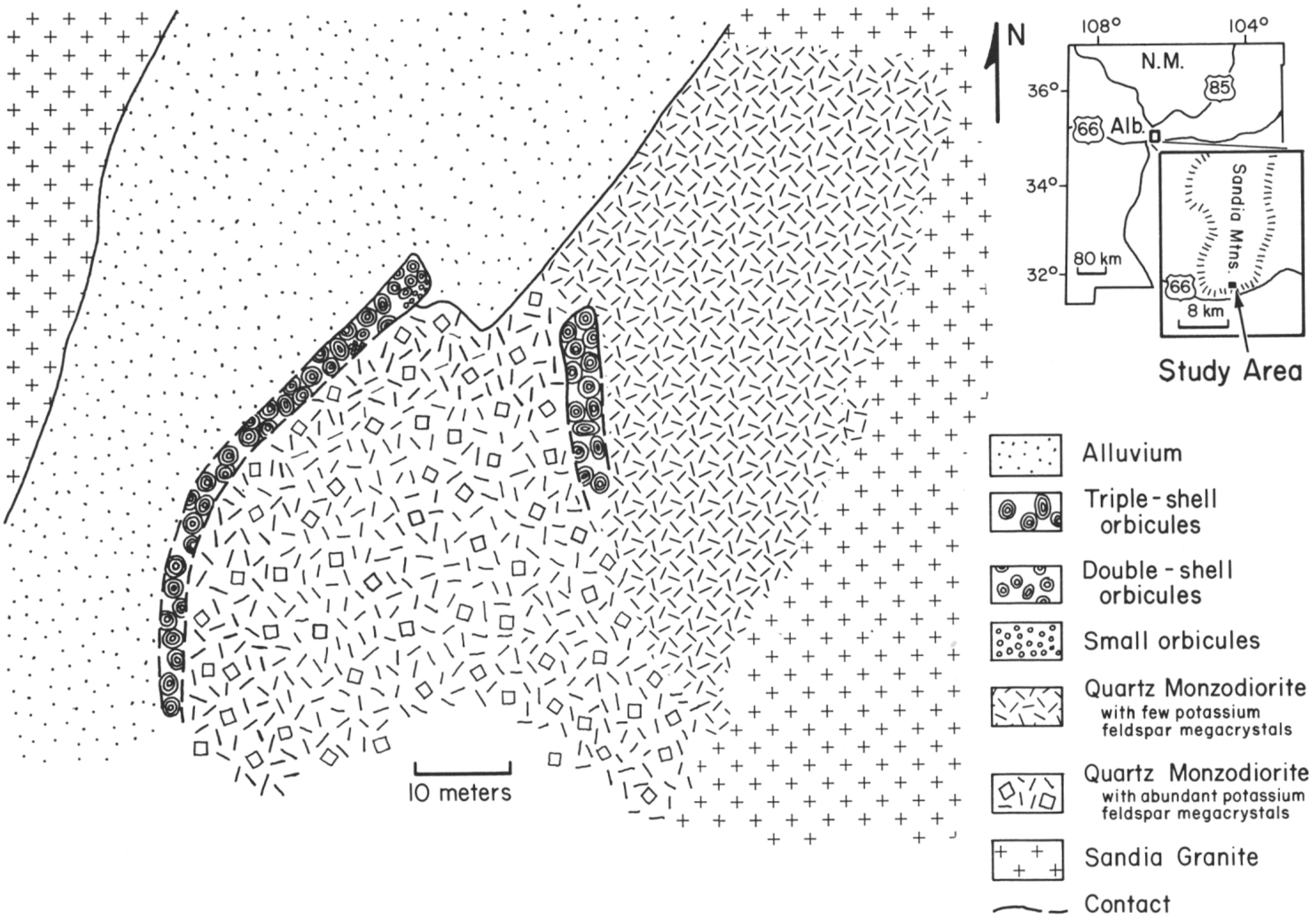


Figure 4. Outcrop map of Tijeras Canyon orbicular rock, associated biotite-rich quartz monzodiorite, and Sandia granite.

The matrix between orbicules is granodiorite (Table 1) with locally aplitic or pegmatitic texture. In addition to granodiorite, matrix between small orbicules consists of metamorphic inclusions and aggregates of biotite and plagioclase.

Whole rock analyses

Chemical data for whole-rock samples of double-shell, triple-shell, and small orbicules; quartz monzodiorite and Sandia granite; and shells and matrix of a double-shell and triple-shell orbicule are presented in Table 2. The core of one double-shell orbicule also was analyzed.

Normative compositions of samples are projected onto a Q-Ab-Or ternary diagram in Figure 8. Most samples plot within the liquidus field of alkali feldspar. The Sandia granite plots near the ternary minimum at 2 kbar PH_20, : whereas, the orbicular rocks plot farther from the ternary minimum.

Analysis of the orbicules indicates the following: (1) chemically, igneous cores are similar to biotite quartz monzodiorite; (2) corresponding orbicule shells are similar regardless of core type; and (3) the matrix surrounding double-shell orbicules is similar to the matrix surrounding triple-shell orbicules.

Discussion

The model proposed for orbicule formation at this site is similar to that proposed by Enz and others (1979) for the La Luz Trail orbicular rock; that is, orbicules crystallized from a water- or vapor-rich fraction of the Sandia granite. The sequence of crystallization in the Sandia granite appears to be potassium feldspar, plagioclase, quartz, and biotite (Enz and others, 1979). However, in the quartz monzodiorite and in Tijeras Canyon orbicules, biotite and plagioclase crystallized before microcline and quartz. This is also the case for orbicular rock and surrounding biotite monzonite at La Luz Trail (Enz and others, 1979). In such a crystallization sequence, early biotite is indicative of high PH_20 (MaalOe and Wyllie, 1975). Other evidence that the orbicules formed from a vapor-rich fraction of Sandia granite includes: (1) cores are surrounded by plagioclase of uniform composition (An_{28-29}) and thickness regardless of core type, which would not be expected in a metasomatic process; (2) radiating cracks filled with matrix occur in the microcline perthite-quartz shells, suggesting that the shells were hard before the matrix had completely solidified; (3) the Q-Ab-Or diagram suggests the orbicules formed under conditions of high $_{PH2O}$; (4) the matrix is locally pegmatitic, and microcline perthite is very coarse in the orbicule shells; and (5) abundant biotite occurs in adjacent rock.

The inferred crystallization sequence of orbicule shells and matrix is as follows. Plagioclase initially nucleated on available seed material (igneous and metamorphic rock, microcline perthite megacrysts), grew first in random arrangement, then radially. The inner microcline perthite-quartz shell crystallized next, followed by the second microcline perthite-quartz shell, trapping matrix material between inner and outer shells. The matrix continued to crystallize after shell formation ceased.

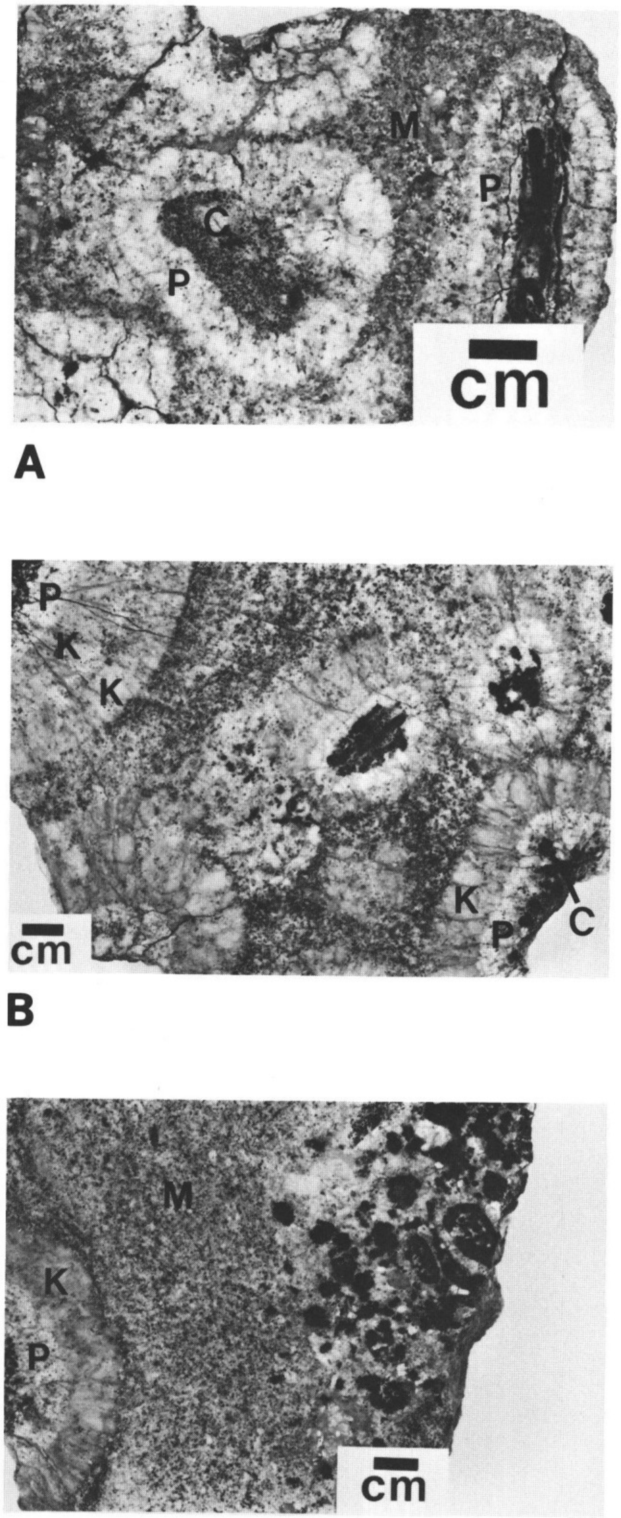


Figure 5. (a) Single-shell orbicules. (b) Double-shell orbicule (lower right) and part of a triple-shell orbicule (upper left) separated by orbicules with partial, outer microcline perthite-quartz shells (center). (c) Small orbicules (right) with cores predominantly of biotite and magnetite, separated from a double-shell orbicule (left) by fine-grained matrix. (C = core, P = plagioclase shell, K = microcline perthite-quartz shell, M = matrix.)

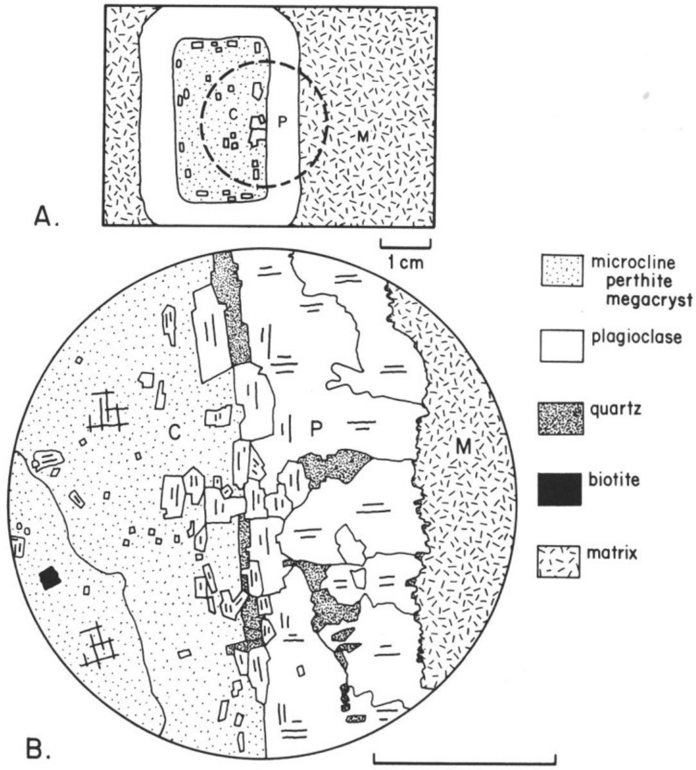


Figure 6. (a) Single-shell orbicule with a microcline perthite core (C = core, P = plagioclase shell, M = matrix). (b) Texture of dashed area in A.

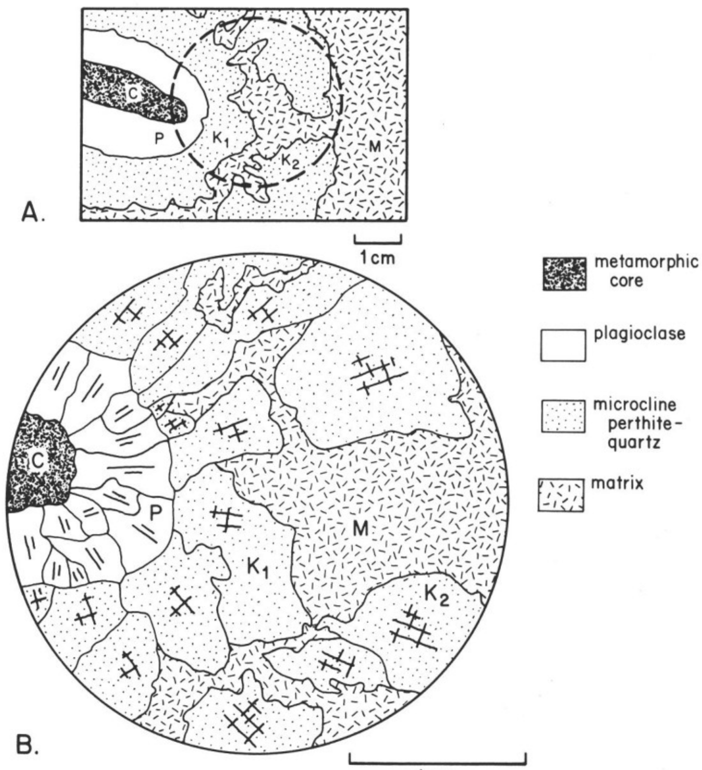


Figure 7. (a) Triple-shell orbicule with a metamorphic core (C = core, P = plagioclase shell, K_1 = inner microcline perthite-quartz shell, K_2 = outer microcline perthite-quartz shell, M = matrix). (b) Texture of dashed area in A.

Table 2. Whole-rock analyses (weight percent) of orbicules and related rocks, Sandia pluton.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
SiO_2	66.77	52.46	58.33	66.07	72.18	68.78	69.51	65.26	72.02	68.73	73.80	69.90	63.83
Al_2O_3	14.40	15.70	14.85	20.00	14.80	16.90	16.28	19.40	14.50	14.80	13.40	16.60	16.50
FeO	2.69	6.68	4.66	0.83	0.16	1.03	0.80	0.20	0.28	0.45	0.77	0.48	2.28
Fe_2O_3	2.50	8.48	5.63	1.28	0.20	1.35	1.16	1.00	0.15	0.93	1.41	0.96	4.21
MgO	1.28	3.09	2.31	0.14	0.03	0.50	0.34	0.07	0.03	0.07	0.48	0.27	0.79
CaO	3.11	3.75	4.01	3.99	1.43	2.79	1.95	3.60	1.72	4.22	1.72	1.69	2.79
Na_2O	3.08	3.55	3.54	6.24	1.81	4.81	3.75	7.03	2.10	2.66	3.44	3.81	4.20
K_2O	3.71	3.62	2.55	0.61	9.08	2.68	4.89	0.73	8.90	8.13	3.44	4.93	3.40
TiO_2	0.56	0.13	1.58	0.09	0.03	0.23	0.18	0.05	0.02	0.06	0.23	0.13	0.56
MnO	0.10	0.27	0.23	0.02	0.01	0.06	0.03	0.01	0.01	0.02	0.04	0.03	0.10
SrO	0.02	0.05	0.02	0.05	0.03	0.03	0.03	0.05	0.03	0.04	0.03	0.03	0.03
H_2O (−)	0.04	0.09	0.01	0.02	0.02	0.01	0.05	0.04	0.02	0.06	0.08	0.02	0.05
H_2O (+)	0.99	1.36	1.68	0.63	0.18	0,81	0.57	0.78	0.24	0.28	0.66	0.76	0.82
P_2O_5	0.29	0.74	0.74	0.02	0.01	0.03	0.05	0.03	0.01	0.01	0.04	0.05	0.22
Total	99.54	99.97	100.14	99.99	99.97	100.01	99.89	98.25	100.03	100.46	99.54	99.66	99.78

(1) Sandia granite; (2) biotite-rich quartz monzodiorite, double-shell orbicule; (3) core; (4) plagioclase shell; (5) microcline perthite-quartz shell; (6) matrix; (7) whole orbicule plus matrix, triple-shell orbicule; (8) plagioclase shell; (9) inner microcline perthite-quartz shell; (10) outer microcline perthite-quartz shell; (11) matrix; (12) whole orbicule plus matrix; and (13) small orbicules.

ZUNI MOUNTAINS ORBICULAR ROCK

Geologic Setting

Kelley and Clinton (1960) describe the structure of the Zuni Mountains as a northwesterly trending, doubly plunging uplift, tentatively of Laramide time. Precambrian igneous and metamorphic rocks are exposed in the core and are flanked by outward-dipping Permian strata. The Precambrian rocks are part of a granitic body of undetermined dimension, and the Permian strata include the Abo and Yeso Formations, the Glorieta Sandstone and the San Andres Limestone (Goddard, 1966).

A gneissic quartz monzodiorite (Tables 3 and 4) surrounds the orbicular outcrops and comprises the bulk of the Precambrian exposures. The age of the quartz monzodiorite is reported as 1,490 ± 9 m.y. by the Rb/Sr whole-rock isochron method (Brookins and others, 1978). Lens-shaped ultramafic and mafic bodies (10-100 by 5-25 m in size) in the vicinity of the orbicular rock trend N70°W, subparallel to the foliation of the surrounding quartz monzodiorite. These outcrops are composed of peridotite, pyroxenite, gabbro, greenstone, and diorite; most are dissected by pink, granitic veinlets, nearly forming a breccia in some cases. Some of the bodies are zoned with serpentinite cores and diorite/gabbro edges.

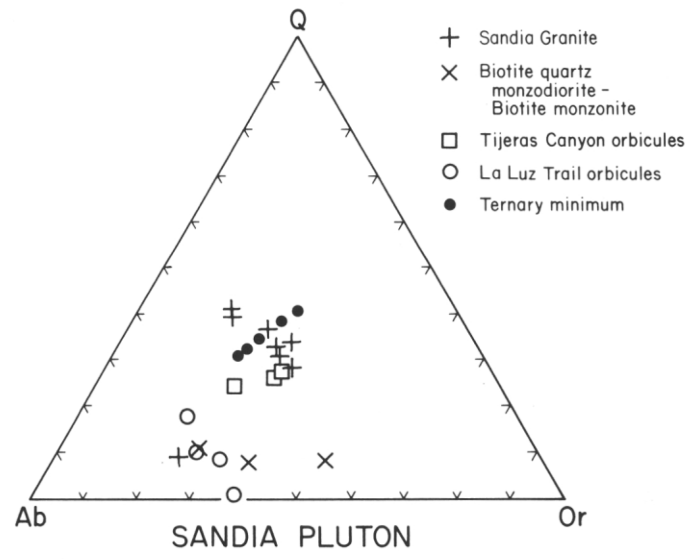


Figure 8. Ternary projection of normative Q-Ab-Or contents of the rocks of the Sandia pluton. Also plotted are minimum melting compositions (solid dots) for the system Q-Ab-Or-H_2O of Tuttle and Bowen (1958) at 0.5, 1.0, 2.0, 3.0, and 4.0 kbar (from right to left). Data from Affholter (1979) and Enz and others (1979).

All mafic rock types appear to have been intruded into the granitic complex and later metamorphosed, as evidenced by their shape, the strong foliation of the granite, and the alteration of the pyroxenes to tremolite-hornblende. The metamorphic conditions in the region are not known.

The Zuni Mountains Site

The newly described occurrence of orbicular rock within the Zuni Mountains is located at longitude 108°05'W and latitude 35°05'N (fig. 9). The outcrops are small, encompassing 120 m^2 and 6 m=, and they occur within 30 m of each other. Graphic granite, aplite, and granitic pegmatite, which intruded into the quartz monzodiorite, immediately surround orbicular rocks. Greenstone and diorite occur nearby. A very small ultramafic body occurs about 20 m from the two orbicular outcrops; however, the major ultramafic bodies are over 100 m away.

The orbicular rock has unusual mineralogy and texture. Dark green orbicules consist of tremolite-hornblende with accessory quartz and opaques (Table 3). These are surrounded by a pink granitic matrix (fig. 10). No core exists per se; composition and texture are uniform through-

Table 3. Estimated modes of selected samples[a] from the Zuni Mountains.

	(1)		(2)
quartz	12.0	tremolite	67.0
K-feldspar[b]	23.0	hornblende	32.0
plagioclase	52.0	quartz	1.0
biotite	trace	opaques	trace
chlorite	9.0		
epidote	4.0		

[a](1) gneissic quartz monzodiorite, Streckeisen (1973) and Goddard (1966) refer to this as a granite; (2) single orbicule.
[b]Orthoclase and microcline.

Table 4. Whole-rock analyses (weight percent) of orbicules and related rocks, Zuni Mountains.

	(1)	(2)
SiO_2	63.94	50.70
Al_2O_3	16.32	5.06
FeO	1.41	4.92
Fe_2O_3	2.05	1.63
MgO	1.33	15.60
CaO	3.92	17.76
Na_2O	3.52	0.51
K_2O	4.16	0.18
TiO_2	0.57	0.48
MnO	0.05	0.18
SrO	0.05	n.d.
H_2O (−)	0.24	0.31
H_2O (+)	1.30	1.30
P_2O_5	0.27	0.03
Total	99.13	98.66

(1) Gneissic quartz monzodiorite; (2) single orbicule.

out the orbicules (Table 4). The tremolite-hornblende shells are discontinuous and wrap around a central point in a helical pattern. In thin section, tremolite appears to have replaced hornblende.

The matrix surrounding the orbicules is composed of quartz, plagioclase, and potassium feldspar which often occur together in a graphic intergrowth. Minor amounts of tremolite-hornblende, similar in appearance to that in the orbicules, is also present in the matrix.

The orbicules vary in size from 1 to 8 cm and are spherical (fig. 10). The density of orbicules within the granitic matrix varies from an open distribution, with 1 cm or more of matrix existing between each orbicule, to a densely packed distribution where 1 mm of matrix occurs between the orbicules. One rare specimen has no matrix at all, consisting instead of tightly packed, small orbicules.

Although the majority of the exposed orbicular rocks have spherical orbicules, some are deformed and broken apart. Deformed and undeformed orbicules frequently occur side-by-side (fig. 11), suggesting they formed at different times. The irregular shape of the deformed orbicules may be the result of plastic deformation of spherical orbicules, or it may be due to conditions of restricted space during growth.

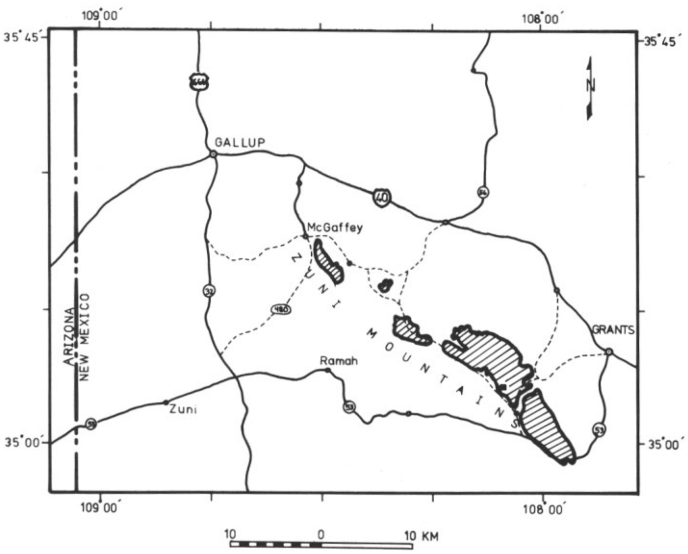


Figure 9. Index map of exposed Precambrian rocks (diagonally ruled) and orbicular rock (solid square) in the Zuni Mountains (after Fitzsimmons, 1967).

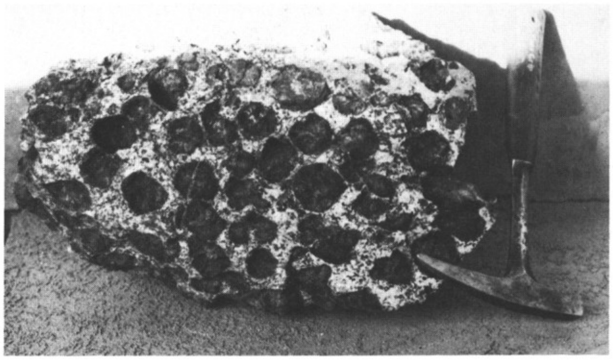


Figure 10. Spherical tremolite-hornblende orbicules are surrounded by pink granitic matrix.

SUMMARY

Orbicular rocks occur in separate granitic Precambrian plutons and batholiths in New Mexico. The orbicules exhibit different mineralogy and shell structure even though three of the four occurrences are in the same pluton. The conditions for orbicule formation are not determined completely, but for the Sandia pluton the orbicules appear to have formed by crystallization on available seed material (igneous and metamorphic rock) from a water- or vapor-rich segregation of the Sandia granite. Preliminary work by Lambert on the Zuni Mountains orbicular rock does not conclusively suggest either a metamorphic or igneous origin. However, the process of orbicule formation in the Zunis appears to be different from that which formed the orbicular rocks in the Sandia pluton.

ACKNOWLEDGMENTS

The authors wish to thank B. C. Chakoumakos for his critical review of the manuscript, and G. V. Gibbs for allowing us access to the computer facilities at VPI&SU. We thank J. Husler for supervising the laboratory work. Special thanks go to our advisors, R. C. Ewing and A. M. Kudo.

REFERENCES

Affholter, K. A., 1979, Petrogenesis of orbicular rock, Tijeras Canyon, Sandia Mountains, New Mexico (M.S. thesis): University of New Mexico, Albuquerque, 124 p.

Berkley, J. L. and Callender, J. F., 1979, Precambrian metamorphism in the Placitas—Juan Tabo Area, northwestern Sandia Mountains, New Mexico: New Mexico Geological Society Guidebook 30, p. 181-187.

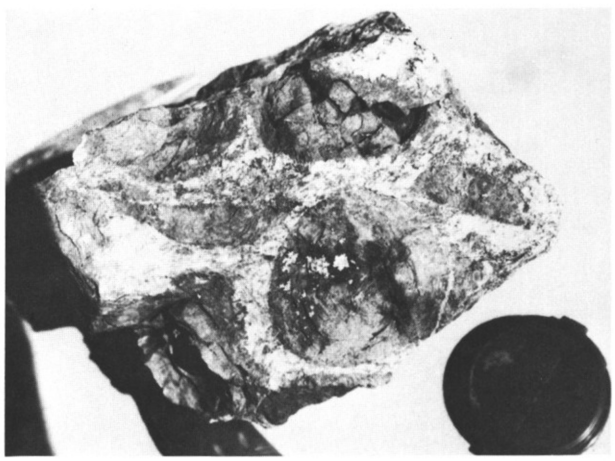


Figure 11. A broken orbicule is separated by matrix. Another undeformed, spherical orbicule appears in the center of sample (lens cap for scale).

Brookins, D. G., 1974, Radiometric age determinations from the Sandia Granite, New Mexico: summary and interpretation: Isochron/West, n. 10, p. 11-14.

Brookins, D. G., Della Valle, R. S., and Lee, M. J., 1978, Rb-Sr geochronologic investigation of Precambrian silicic rocks from the Zuni Mountains, New Mexico: Mountain Geologist, v. 15, p. 67-71.

Brookins, D. G., Enz, R. D., Kudo, A. M., and Shafiqullah, M., 1975, K-Ar and Rb-Sr age determinations of orbicular granite, Sandia Mountains, New Mexico: Isochron/West, n. 12., p. 11-12.

Condie, K. C. and Budding, A. J., 1979, Geology and geochemistry of Precambrian rocks, central and south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 35, 58 p.

Daugherty, F. W. and Asquity, G. B., 1971, Orbicular rocks from the Sandia Mountains, Bernalillo County, New Mexico: Geological Society of America Abstracts with Programs, v. 3, p. 375-376.

Enz, R. D., 1974, Geochemistry and petrology of the orbicular rocks, Sandia Mountains, New Mexico (M.S. thesis): University of New Mexico, Albuquerque, 73 p.

Enz, R. D., Kudo, A. M., and Brookins, D. G., 1979, Igneous origin of the orbicular rocks of the Sandia Mountains, New Mexico: Geological Society of America Bulletin, v. 90, part I, p. 138-140; part II, p. 349-380.

Feinberg, H. B., 1969, Geology of the central portion of the Sandia granite, Sandia Mountains, Bernalillo County, New Mexico (M.S. thesis): University of New Mexico, Albuquerque, 127 p.

Fitzsimmons, J. P., 1967, Precambrian rocks of the Zuni Mountains: New Mexico Geological Society Guidebook 18, p. 119-121.

Goddard, E. N., 1966, Geologic map and sections of the Zuni Mountains fluorspar district, Valencia County, New Mexico: U.S. Geological Survey Miscellaneous Geological Investigations Map 1-454.

Held, H. L. and Harris, R. L., Jr., 1978, Zircon distribution patterns in orbicular rocks: Geological Society of America Abstracts with Programs, v. 10, p. 7.

Kelley, V. C. and Clinton, N. J., 1960, Fracture systems and tectonic elements of the Colorado Plateau: University of New Mexico Publications in Geology, n. 6, p. 44-45.

Kelley, V. C. and Northrop, S. A., 1975, Geology of the Sandia Mountains and vicinity, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 29, 136 p.

Levenson, D. J., 1966, Orbicular rocks: A review: Geological Society of America Bulletin, v. 77, p. 409-426.

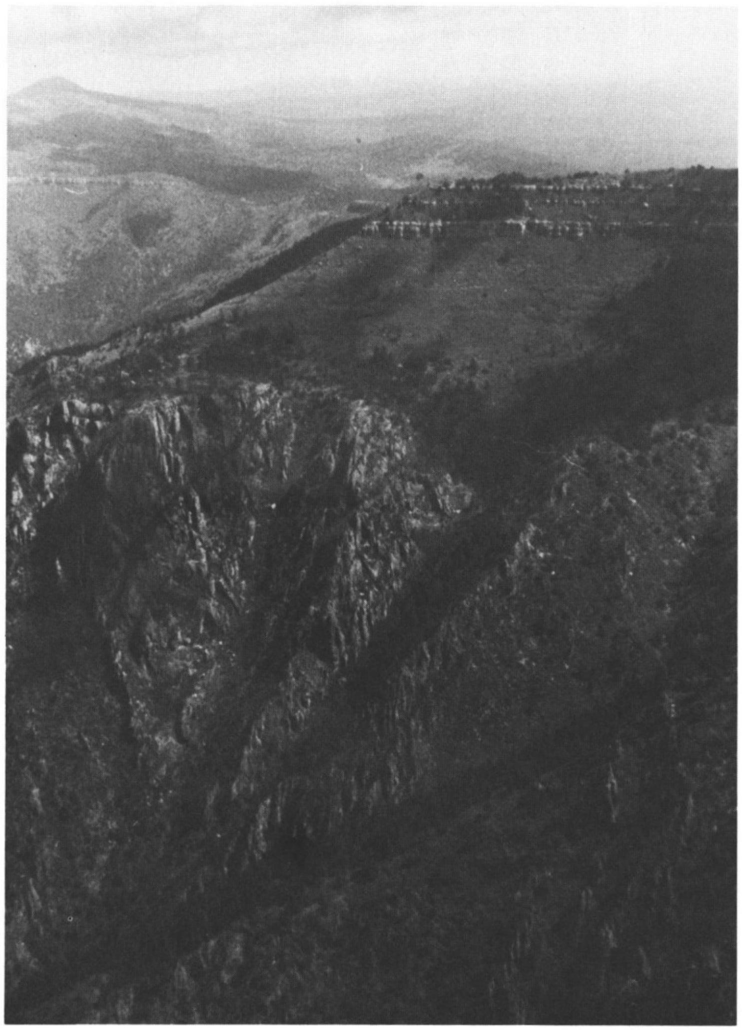
Maal(Oe, S. and Wyllie, P. J., 1975, Water content of a granite magma deduced from the sequence of crystallization determined experimentally with water-undersaturated conditions: Contributions to Mineralogy and Petrology, v. 52, p. 175-191.

Streckeisen, A. L., 1973, Classification and nomenclature of plutonic rocks: Geologische Rundschau, v. 63, p. 773-786.

Taggart, J. E. and Brookins, D. G., 1975, The Rb-Sr whole rock age determinations for Sandia granite and Cibola gneiss, New Mexico: Isochron/West, n. 12, p. 5-8.

Thompson, T. B. and Giles, D. L., 1974, Orbicular rocks of the Sandia Mountains, New Mexico: Geological Society of America Bulletin, v. 85, p. 911-916.

Tuttle, 0. F. and Bowen, N. L., 1958, Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O: Geological Society of America Memoir 74, 153 p.



The Great Unconformity, Manzano Mountains (J. Grambling photo).