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ORBICULAR GRANITE SILLS IN THE MAZATÁN CORE COMPLEX, SONORA, MEXICO

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ABSTRACT

Orbicular granites are unusual rocks, and the presence of a large outcrop within the Mazatán metamorphic core complex, Sonora, Mexico, was unexpected. This is the second orbicular rock outcrop recognized in Mexico, after the San Pedro Mártir gabbro in Baja California. Sierra Mazatán is the southernmost metamorphic core complex in the northern Cordillera, which resulted of Mesozoic crustal thickening, followed by Tertiary extensional tectonics.

The Sierra Mazatán is composed of porphyritic granite grading into augengneiss on its periphery, product of cataclastic and ductile Tertiary deformation, with remnants of a Mississippian carbonate intruded cover. The orbicular granite is located in the western rim of the core of the complex, at 800 m a.s.l. on the Los Pedernales creek, in five 2 to 8 m thick superposed sills. The sills are disposed structurally about 800 m under the décollement zone, in the lower plate. Orbicular granite is a two-mica peraluminous granite with a matrix richer in quartz and muscovite than in the orbicules. Orbicules are multishelled, with tangential biotite and radial plagioclase. General composition of plagioclase decreases from the core of orbicules (An_{37}) to the external shells (An_{32-28}), coinciding with an increase of Fe_x in biotite from 0.54 to 0.59. Host rock of the orbicular facies is a porphyritic two-mica granite with oligoclase (An_{19}), Fe enriched biotite, large muscovite flakes and abundant quartz (30 %).

The interpretation of the origin of this spectacular orbicular granite involves magmatic supercooling conditions. Rapid crystal growth with low diffusion rates in the magma produced alternating plagioclase and biotite supersaturation around the orbicules; hence, successive clear and dark shells formed, until the liquid temperature decreased sufficiently for crystallization of a normal granitic matrix.

Key words: Orbicular granite, orbicular texture, metamorphic core complex, Sonora, Mexico.

RESUMEN

Los granitos orbiculares son rocas poco usuales y la presencia de un gran afloramiento en el complejo de núcleo metamórfico de Mazatán, Sonora, fue un hallazgo inesperado. Éste es el segundo afloramiento de rocas orbiculares reconocido en México, después del gabro de San Pedro Mártir en Baja California. La sierra Mazatán es el complejo de núcleo metamórfico localizado más al sur en la cordillera norteamericana, producto de engrosamiento de la corteza durante el Mesozoico, seguido de tectónica de extensión terciaria.

La sierra Mazatán está compuesta por un granito porfídico que varía gradualmente a un augengneis en su periferia, producto de deformación dúctil y cataclástica terciaria, con remanentes de una cubierta carbonatada misisípica que sufrió intrusión. El granito orbicular se localiza en la parte occidental del núcleo del complejo, a 800 m s.n.m.m., en el arroyo Los Pedernales, en forma de cinco diquestratos sobrepuestos de 2 a 8 m de espesor. Los diquestratos están estructuralmente dispuestos alrededor de 800 m bajo la zona de *décollement*, en la placa inferior. El granito orbicular es un granito peraluminoso de dos micas, con una matriz más rica en cuarzo y muscovita que en las orbículas; éstas están como anillos concéntricos múltiples, con biotita tangencial y plagioclasa radial. La composición general de la plagioclasa decrece del núcleo de las orbículas (An_{37}) a los anillos externos (An_{32-28}), coincidiendo con un incremento de Fe_x en biotita de 0.54 a 0.59. La roca encajonante de la facies orbicular es un granito porfídico de dos micas con oligoclasa (An_{19}), biotita enriquecida en Fe, grandes láminas de muscovita y abundante cuarzo (30%).

La interpretación del origen de este espectacular granito orbicular involucra condiciones de superenfriamiento magmático. El crecimiento rápido de los cristales y el bajo radio de difusión en el magma produjeron sobresaturación alternada de plagioclasa y biotita alrededor de las orbículas, desarrollando las bandas concéntricas claras y obscuras sucesivas, hasta que la temperatura del líquido decreció suficientemente para la cristalización de una matriz granítica normal.

Palabras clave: Granito orbicular, textura orbicular, complejo de núcleo metamórfico, Sonora, México.

INTRODUCTION

Cordilleran metamorphic core complexes are found in a large area that extends from southern Canada to northwestern Mexico. Their continuous distribution along the North American Cordillera, among other reasons, allowed Coney and

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Harms (1984) to propose that these structures result of Mesozoic crustal thickening followed by Tertiary extensional tectonics. Sosson (1990) presented a similar point of view for the Santa Catalina and Rincón Mountains core complexes—mapped in detail by Dickinson (1988, 1991)—and proposed an inherited structure from the Jurassic extension and the Cretaceous-early Tertiary compression until the Oligocene and Miocene extension. The presence of a crustal root beneath the Santa Catalina metamorphic core complex is used by Myers and Beck (1994) to propose a crustal thickening associated with shortening of the crust, followed by an episode of extension. The crustal stretching which may exceed locally 100% (Davis, 1983) occurred during the late Cenozoic extension and allowed the tectonic denudation of deeper crustal rocks (Crittenden *et al.*, 1980).

Orbicular granites, albeit the most frequent among orbicular rocks, remain a rare curiosity. Little more than a hundred occurrences of orbicular granites and diorites have been recorded throughout the world, since they were first mentioned at the beginning of the last century by Von Buch (*in* Leveson, 1966). Their distribution is independent of their age, but it seems rather to coincide with the density of geological investigations: 75% of the known occurrences are situated in western Europe, North America and Japan (Leveson, 1966). This can be understood since most exposures constitute small outcrop areas. In Mexico, up to now, only a single outcrop of gabbro in Baja California has been described (Woodford and Harriss, 1938).

The discovery of a magnificent orbicular granitic facies within a metamorphic core complex in Sonora is noteworthy, because the outcrop is large enough and so clearly exposed to become a reference site for further petrological investigations on the origin of magmatic orbicular textures. Moreover, through the shape of the orbicules, this type of rock affords good opportunities to evaluate the magmatic deformations and the superimposed ductile-brittle deformations of the core complex. Here, a general description of the site with preliminary petrological data is reported, and some of the hypotheses that are currently discussed concerning the mode of formation of orbicular rocks are reviewed.

GEOLOGICAL SETTING

The State of Sonora belongs to the southern Basin and Range Province, characterized by the typical morphology of large horizontal plains separated by elongated, 500 to 1,500 m high steep hills and mountains. The Sierra Mazatán—1,550 m a.s.l.—represents the southernmost metamorphic core complex of the American Western Cordillera (Armstrong, 1982). It is located about 70 km to the east of Hermosillo (Figure 1) and exhibits a remarkably smooth domed structure with remnants of its sedimentary intruded host rocks poorly preserved around its base.

Previous works on the Sierra Mazatán are scarce. Menicucci (1975) first noted the curiously isolated occurrence of the highly deformed granite, but did not recognize it as a metamorphic core complex. Some U-Pb analyses on zircon were performed by Anderson and coworkers (1980) and yielded an age of 58 ± 3 Ma for the granitic gneiss. Davis and coworkers (1981) proposed the first description of the southwestern flank of the Sierra Mazatán as part of a typical metamorphic core complex.

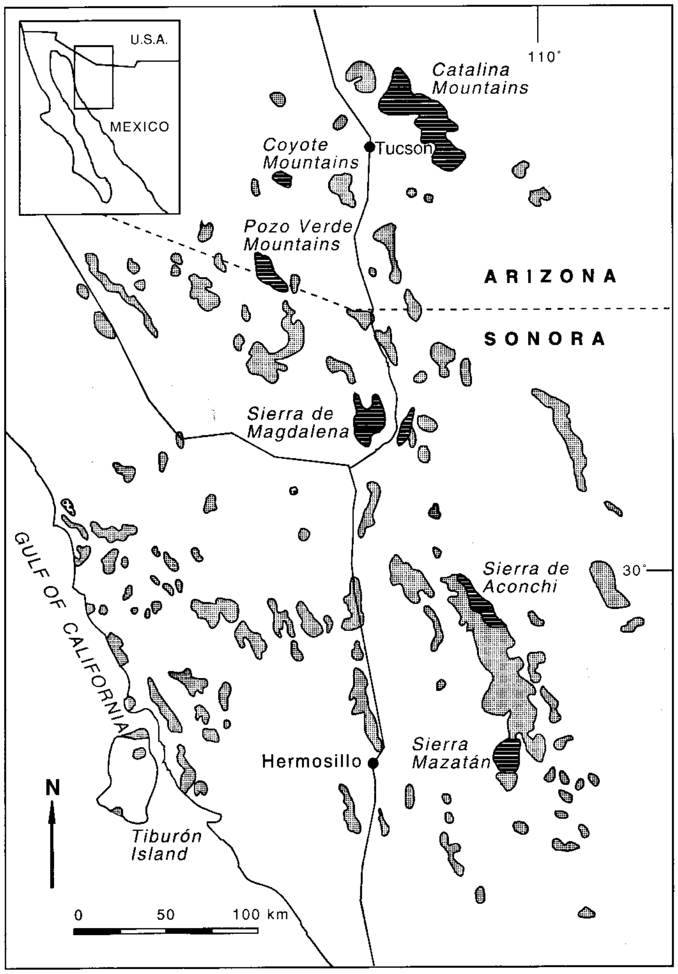


Figure 1.- Location of the Sierra Mazatán and the nearby metamorphic core complexes of northern Sonora (Mexico) and southern Arizona (U.S.A.). Pointed outcrops indicate Laramidic and Tertiary granitoids.

A general NW-SE cross-section of the Sierra Mazatán (Figure 2) shows that it constitutes the western half of a large domal structure, whose eastern half is down faulted. The carbonate host rocks are now detached as part of the upper plate, and they are considered as a roof-pendant on top of the intrusive granite, as indicated by rare traces of thermal metamorphism and associated W-bearing skarns (Menicucci, 1975). Intense brecciation takes place in a conspicuous décollement fault zone separating the carbonate intruded cover from the underlying granites with gneissic to cataclastic texture. The décollement fault is best exposed at the base of the Cerro La Poza and Cerro Feliciana (Figure 2), or near the Rancho Quizuani (Davis *et al.*, 1981). The bulk of the Sierra Mazatán consists of porphyritic granite with K-feldspar me-

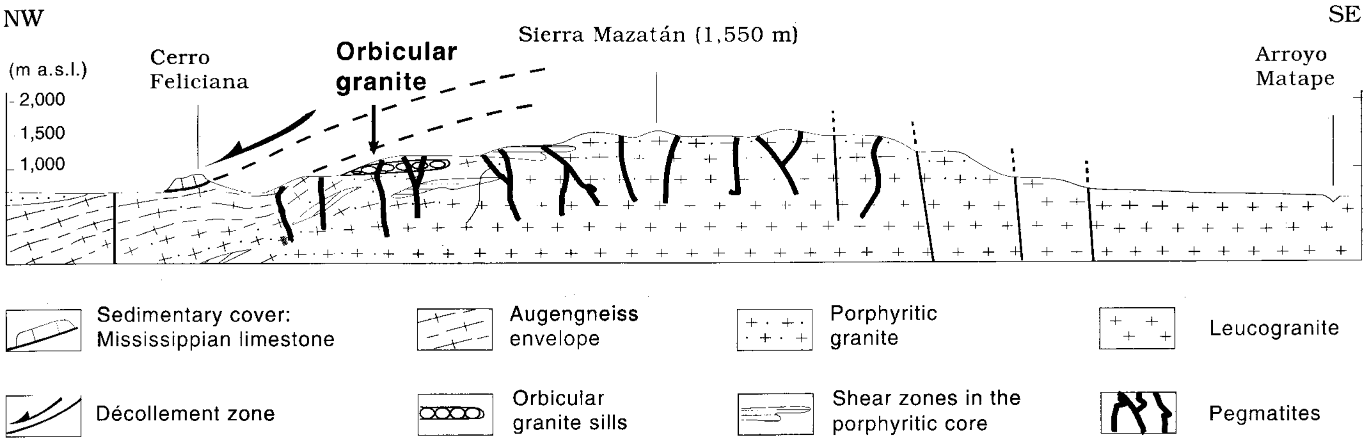


Figure 2.- Structural section of the Sierra Mazatán showing the emplacement of the orbicular granite sills in the porphyritic core.

gacrysts. On the western periphery, the porphyritic granite grades into a 500 to 1,000 m thick section of augengneiss and folded mylonite beneath the décollement fault (Figures 2 and 3).

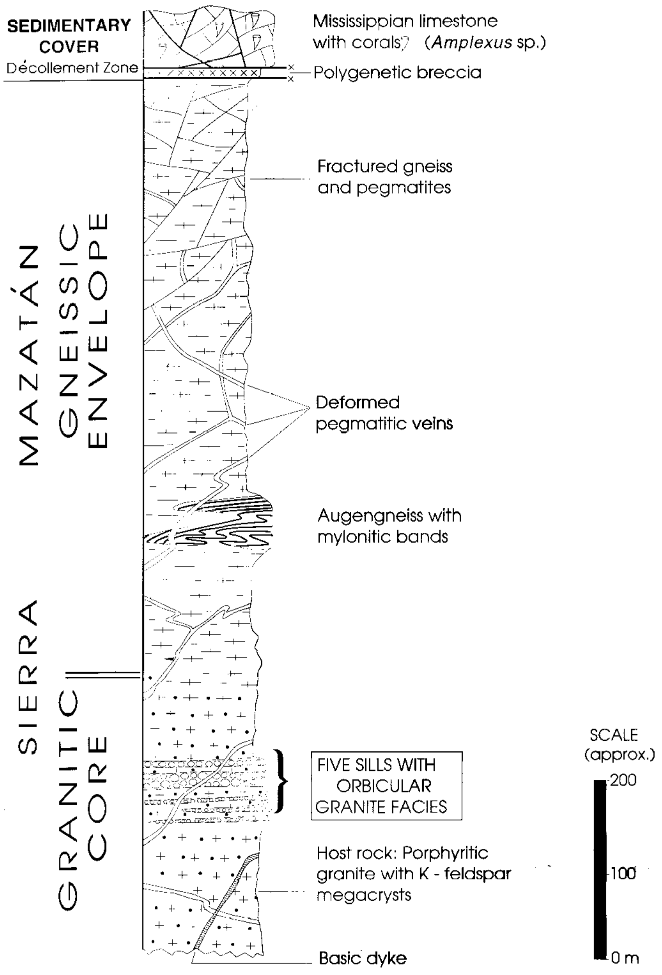


Figure 3.- Lithologic succession of the Sierra Mazatán from the porphyritic granitic core of the sedimentary intruded cover (upper plate), and place of the granitic sills containing the orbicules.

In this part of the sierra, intense ductile deformation is responsible for a N40°W foliation, dipping 13°NE. The outer envelope of the granite is deformed into augengneiss with a variable extension ranging from several hundred meters in the north, to more than one kilometer in the south of the sierra. Simple shear in the gneiss leads to mylonitization along 0.1 to 1 m thick black bands close to the nearly horizontal foliation planes. Shear sense criteria—for example, asymmetric augen-structures, pressure shadows or folding of the mylonitic bands—indicate a top to the west displacement.

Several types of deformation are displayed. The most widespread is a penetrative mineral lineation oriented N60-80°E, which is readily apparent in the augengneiss as well as in the granitic core of the Sierra Mazatán. This lineation also affects the numerous pegmatitic veins that are crosscutting the granite.

ORBICULAR GRANITE SETTING

LOCATION

The orbicular granite is located on the western side of the Sierra Mazatán, at the altitude of 800 m (Figure 2), and is deeply cut by the Los Pedernales creek, which provides the best exposures, several hundred meters long. It is located in the lower plate of the detachment fault, under the augengneiss envelope, *i. e.*, in a much less deformed zone. However, limited displacement of orbicules by plastic and/or brittle deformation is readily apparent at places (Figure 4, a), as already noted by Richard (1985, 1991).

The outstanding feature of this orbicular granite is its arrangement in five distinct layers, 2 to 8 meters thick and over 100 m long, which are intercalated within the normal porphyritic granite. The orbicular layers are nearly horizontal or gently dipping westwards and are limited by clear-cut boundaries at the base, as well as at the top of each layer, when visible. Narrow pegmatitic veins crosscut the host rock and the orbicular facies (Figure 4, b).

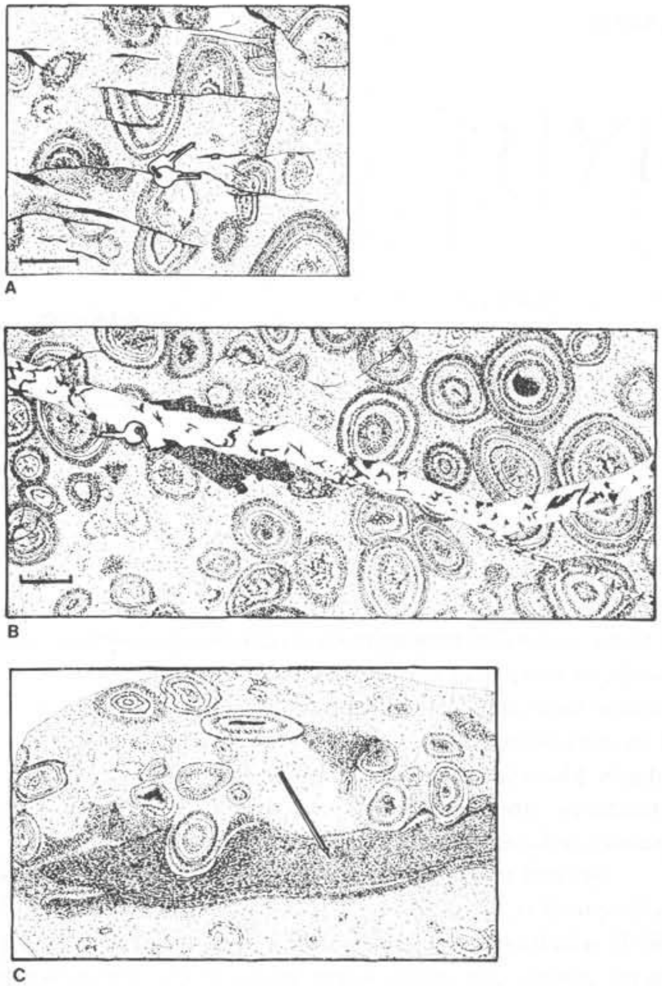


Figure 4.- *A*, Small scale faulting affecting the orbicular granite (dextral and sinistral). Scale bar is 5 cm long. *B*, Pegmatitic vein cutting through orbicules. Note a biotite enclave without envelope (center left), among multishelled orbicules of various sizes and aspects, including one with a biotitic core (upper right). This is interpreted as evidence of mixing of orbicules. Scale bar is 5 cm long. *C*, Large layered biotitic enclave in the matrix and deformed orbicules. Pencil is 15 cm long.

THE ORBICULES

Most of the orbicules (Figure 5) are nearly spherical, and range from 5 to 20 cm in maximum width. They are mainly composed of plagioclase and biotite alternating in conspicuous, clear and dark rings—up to 15 biotite rings—with variable spacing. As a rule, the inner shells are thicker than the outer ones, but the decrease in thickness is not regular from core to outer shells. Contacts between orbicules and matrix are sharp. The volumetric ratio of the orbicules to the matrix is variable, ranging from 5:1 to 1:10. The shape of the core, up to a few centimeters across, may influence the shape of the entire orbicule. Two types of core are present: the most frequent one exhibits the same texture as the granitic matrix, but the composition of plagioclase is Ca-enriched (Figure 6). A faint biotitic boundary separates the core from the outer shells. Another type of core is a biotitic lump, frequently lens shaped, 2 to 8 cm long. Feldspar megacryst is rare as a core (Richard, 1991). Adjacent orbicules of similar size exhibit the same pattern in the last four or five shells. This indicates that limited "mixing" occurred in the last stages of orbicule formation, but the smaller ones usually display different patterns.

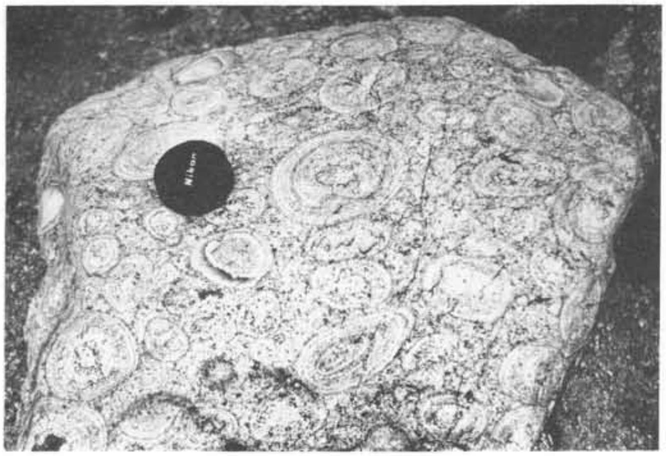


Figure 5.- Photograph of a fragment of the orbicular granite sills that shows the characteristics of the orbicules.

THE MATRIX

Despite a general similarity in the mineral composition of the orbicules and the matrix, the latter is often richer in quartz and contains more muscovite. The grain is coarser and no definite orientation can be detected. Elongated, highly concentrated biotitic patches, up to 1 meter long, are also found in the matrix and may represent fragments of a layered structure (Figure 4c).

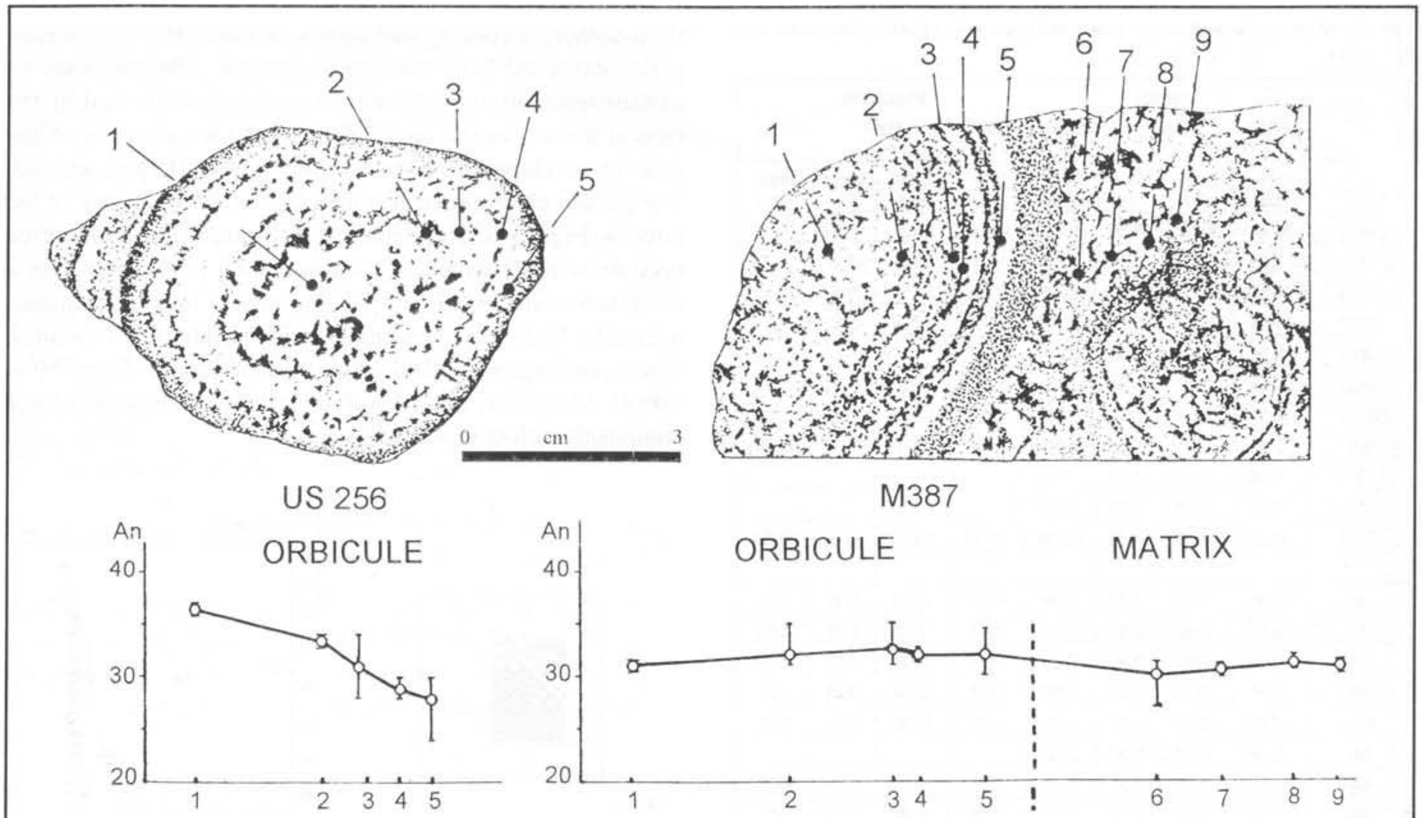
PETROLOGIC DATA

ORBICULES

Although most dramatic on the outcrop, the multiple banding of the orbicules is scarcely apparent through the variable abundance of biotite under microscopic examination. As a rule, biotite is more frequent with a tangential orientation in the black rings, whereas plagioclase is often radially disposed in the clear bands, but this is by no way systematic.

Plagioclase

It constitutes large mosaic with hipidiomorphic texture. Euhedral to subhedral crystals—0.5 to 1 mm long—are not limited by banding, as large crystals may extend across the boundary between two adjacent shells. Two types of plagioclase can be observed, the large one being surrounded by the smaller euhedral one. Albite-pericline twinning is most frequent, and zoning is rare. Distorted twin lamellae are frequently found in the core of plagioclases. Microprobe analyses have been performed on plagioclase crystals of two orbicules:



	1	2	3	4	5
SiO_2	56.08	58.26	58.61	59.62	59.84
Al_2O_3	26.07	25.49	25.16	24.68	24.41
CaO	7.59	6.97	6.67	6.12	5.82
Na_2O	7.26	7.56	7.74	8.14	8.19
K_2O	0.16	0.19	0.18	0.22	0.19
Total	97.16	98.47	98.36	98.78	98.45
Si	10.43	10.55	10.63	10.75	10.80
Al	5.56	5.44	5.38	5.24	5.20
Ca	1.47	1.35	1.28	1.18	1.12
Na	2.55	2.65	2.72	2.84	2.87
K	0.03	0.04	0.04	0.05	0.04
Anor	0.37	0.34	0.32	0.29	0.28

	1	2	3	4	5	6	7	8	9
SiO_2	59.59	59.22	58.94	59.21	58.61	60.47	59.79	59.46	59.78
Al_2O_3	25.05	25.08	25.13	24.86	24.92	24.68	24.86	25.03	24.82
CaO	6.52	6.70	6.86	6.58	6.72	6.22	6.45	6.59	6.44
Na_2O	7.85	7.68	7.66	7.69	7.65	7.84	7.92	7.85	7.92
K_2O	0.22	0.22	0.19	0.22	0.21	0.25	0.25	0.22	0.26
Total	99.23	98.90	98.78	98.56	98.11	99.46	99.27	99.25	99.22
Si	10.70	10.67	10.64	10.70	10.65	10.81	10.73	10.70	10.74
Al	5.30	5.32	5.35	5.29	5.34	5.20	5.26	5.29	5.25
Ca	1.25	1.30	1.32	1.28	1.31	1.20	1.24	1.26	1.24
Na	2.73	2.68	2.68	2.69	2.70	2.72	2.75	2.73	2.74
K	0.05	0.05	0.04	0.05	0.05	0.05	0.06	0.05	0.06
Anor	0.31	0.32	0.33	0.32	0.33	0.30	0.31	0.31	0.31

Figure 6.- Microprobe analyses of plagioclase from the core—1 to 5—to the matrix —6 to 9—of the orbicules.

Anorthite content decreases from the core—An_{37}—to the outer shells of the orbicule—$An_{32\text{-}28}$—where it seems fairly constant—An_{30}—(Figure 6).

K-Feldspar

K-feldspar is present as discrete orthoclase crystals in some orbicules (Richard, 1985), and as perthitic inclusions in plagioclase crystals. Microprobe analytical data substantiate a K-rich composition—Or_{95} - Ab_5.

Biotite

Biotite is responsible for the spectacular aspect of the orbicules. The inner shells contain fewer but larger biotites—1 mm—than the outer ones, where they are smaller—0.2 mm—but more abundant. The last shell of the orbicule is also the darkest. Biotite crystals frequently have their basal plane (001) parallel to the banding. Biotite may also be included in poikilitic plagioclase. Apatite, zircon and rutile are common inclusions. A weak increase in Fe_x, *i.e.* in Fe / (Fe + Mg), from 0.54 to 0.59, has been detected towards the outer shells of the orbicules (Table 1).

Muscovite

Muscovite is present only in the outer part of the orbicules. It may be associated with biotite, or as discrete interstitial crystals. No significant variation in the chemical composition of muscovite has been detected in the external zones.

Table 1.- Microprobe analysis of biotite and muscovite of orbicular granite and host rocks.

	Biotite				**Muscovite**			
	US256	M387		US241A	US256	M387		US24A1
	Orbi-cule	Orbi-cule	Matrix	Host Rock	Orbi-cule	Orbi-cule	Matrix	Host Rock
SiO_2	35.24	35.06	35.30	35.00	44.90	45.21	45.39	45.34
TiO_2	3.08	3.08	3.10	2.11	1.32	0.87	1.27	0.73
Al_2O_3	16.51	16.54	16.72	15.98	30.13	30.37	29.52	30.35
FeO*	19.48	20.69	20.27	23.45	4.85	4.94	5.02	4.37
MnO	0.39	0.43	0.46	0.66				
MgO	9.61	8.16	8.66	7.10	1.43	1.20	1.31	1.26
Na_2O	0.12	0.09	0.10	0.00	0.23	0.22	0.24	0.23
K_2O	9.44	9.57	9.63	9.65	10.58	10.76	10.77	11.02
F	0.34	0.13	0.14	1.11				
Cl	0.07	0.11	0.14	0.05				
Total	94.28	93.86	94.52	95.18	93.44	93.57	93.52	93.50
Si	5.48	5.51	5.50	5.56	6.26	6.28	6.33	6.30
Al	2.52	2.49	2.50	2.44	1.74	1.73	1.61	1.70
Ti	0.36	0.36	0.36	0.25	0.14	0.09	0.13	0.08
Al	0.51	0.57	0.56	0.56	3.18	3.24	3.23	3.27
Fe_{2+}	2.53	2.73	2.64	3.12	0.57	0.58	0.58	0.51
Mn	0.05	0.06	0.06	0.09				
Mg	2.23	1.91	2.01	1.68	0.30	0.25	0.27	0.26
Na	0.03	0.03	0.02	0.02	0.06	0.06	0.07	0.07
K	1.87	1.92	1.91	1.96	1.87	1.91	1.91	1.96
OH	3.82	3.97	3.89	3.42				
F	0.16	0.00	0.07	0.56				
Cl	0.02	0.03	0.04	0.02				
Total	19.58	19.58	19.56	19.68	14.12	14.14	14.13	14.14
Fe/Fe+Mg	0.54	0.59	0.57	0.66	0.66	0.70	0.68	0.66
	A	B	C	D	E	F	G	H

A and C: 5 analyses
B: 4 analyses
D: 3 analyses
E, F and G: 2 analyses
H: 1 analysis

Base: 22 O **Muscovite**
20 O, 4(OH, F, Cl) **Biotite**

FeO*: Total Fe

Quartz

As a minor component, quartz is restricted only to small interstices, or may be totally absent. When present, undulatory extinction denotes deformation.

Chlorite

Biotite is frequently altered into an assemblage of chlorite, sphene, oxides and Fe-epidote. Chlorite is the most abundant. It is dark green and strongly pleochroic with anomalous blue colours when polarized. Its composition is that of ripidolite.

Zircon

Zircon crystals typology was used in order to check the provenance of the orbicular granite. This was performed by the third author, according to Pupin's method (1980) on zircon grains extracted from one single orbicule. The magmatic or metamorphic origin of the zircon cristals is evidenced by the typical pattern in the IA-IT diagram, which depends of the relative development of the crystalline faces (Pupin, *op. cit.*). The pattern clearly indicates the magmatic provenance of the zircons (Figure 7). The statistical distribution of 52 identified crystals is representative of an unimodal population with a calcalkaline affinity (Figure 7). The source magma is characterized by high water content, as evidenced by low IT values. Corresponding crystallization temperature ranges from 750 to 700°C. Moreover, low IA values reflect a magmatic source composition close to Al-rich magmas.

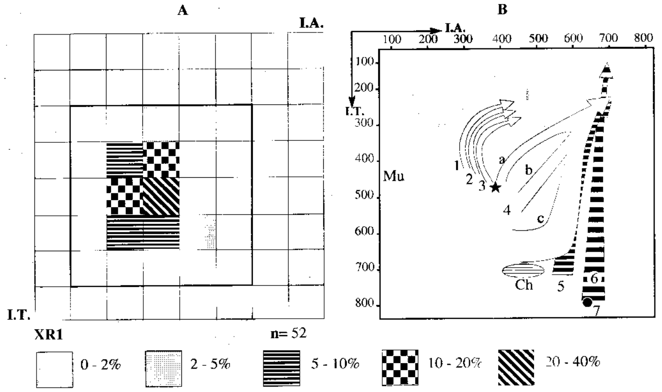


Figure 7.- *A*, Distribution of the morphological types of 52 zircon grains extracted from one orbicule in a diagram (IA-type of pyramids / IT-type of prisms) according to Pupin (1980). *B*, Place of the orbicular granite (star) in the IA/IT diagram. 1, 2, 3: aluminous series; 4 (a, b, c): calc-alkaline series; 5: sub-alcaline series; 6: alcaline series; 7: tholeiitic series; Mu: lower limit of muscovite granites; Ch: charnockites.

MATRIX

The granitic matrix has a similar mineral composition as that of the orbicules, though different in mineral abundance, and coarser in texture. Both quartz and muscovite are much more abundant; in addition, biotite flakes and plagioclase are larger. Plagioclase—An_{31}—is frequently euhedral with constant, but often distorted twinnings. Occasional myrmekitic to micrographic textures, up to 5 mm long, denote eutectic composition. Plagioclase is surrounded by interstitial quartz which is also distorted. Thick biotite flakes—0.6-2 mm—display a strong pleochroism. Composition of biotites in the matrix is very similar to that of the orbicules (Table 1). Chlorite and epidote are found as alteration products. Muscovite is a common mineral in the matrix, in contrast with its almost absence in the orbicules. Muscovite lamellae have crystallized after biotite, but there is no significant difference in composition compared with the muscovite in the outer shells.

HOST ROCK

The host rock of the orbicular facies is a porphyritic granite. Large euhedral K-feldspars—1 to 4 cm across—with no obvious orientations are surrounded by smaller plagioclases —0.5-2 mm—showing frequent undulatory extinctions of the albite twinnings. Mean composition is $An_{19.5}$, denoting a more evolved source than the orbicular facies. Dark brown biotite represents less than 5% by volume and is interstitial and concentrated along deformation planes. Its chemical composition is richer in Fe than that in the orbicules, as indicated in Table 1. Muscovite is in large flakes. Quartz is abundant (30%) as interstitial grains or elongated ribbons in the gneissic fabric.

DISCUSSION AND ORIGIN OF THE ORBICULAR GRANITE

The mode of formation of orbicular granites and diorites is still poorly understood. It has raised long-lived controversies, owing to the scarcity of the occurrences, the small size of the outcrops, and the diversity of the lithologies described so far. Several types of processes have been proposed for the genesis of this peculiar mode of crystallization.

In the earliest interpretations, Liesegang (1913) focused on chemical reactions involving double diffusion with different rates. This is best demonstrated by the Liesegang bands occurring between two supersaturated solutions, which produce alternating rings that are strikingly similar to the orbicular pattern. This process certainly is an attractive model for orbicule genesis, and it has also been invoked for alternating layered rocks in basic intrusions such as the Skaergaard (*cf.* McBirney and Noyes, 1979). Liesegang-type alternating crystallization has also been considered by Leveson (1966) who favoured a metamorphic origin of the orbicules through rhythmic crystallizations.

On the opposite, in the Sierra Nevada batholith, Moore and Lockwood (1973) first demonstrated the close relationship between "comb layering" and orbicular structure. They proposed a process of crystallization taking place not in a granitic magma, but within aqueous fluids circulating along the contact between the intrusive magma and the solidified wallrock. Alternate mineral layering was attributed to changes in the physical conditions within the fluid phase. Orbicules could form around isolated rock fragments falling into the moving fluids, and be carried away. Accumulation of orbicules could have occurred in various traps, such as pipes or dykes coming out of the parent pluton.

In another approach, orbicular textures have been interpreted as resulting from magmatic, undercooling processes, as suggested by laboratory experiments on synthetic and natural compositions (Lofgren, 1980; Petersen and Lofgren, 1986). Vernon (1985) showed that superheating could be an efficient mean to destroy most of the nucleation sites in part of a magma chamber. This permits undercooling conditions to prevail for some time, and forces crystallization on solid objects only, such as remaining micaceous enclaves. In the case of the orbicular granite of the Sierra Mazatán, the texture and the mineralogical content of the core of most of the orbicules are close to those of the surrounding granitic matrix. This speaks against possible reactions between nuclei and matrix, unless some unprobable homogenization process has occurred in the core of the orbicules. On the other hand, a magmatic origin is consistent with the geological setting and the petrological features described above. The distribution of the orbicular facies into five distinctly superposed layers (Figure 3) and the abrupt contacts with the porphyritic host rock, show that the orbicular granite was emplaced in separated thin sills. This restricted type of emplacement is typical of many orbicular occurrences, as illustrated in Moore and Lockwood's (1973, fig. 17) Devil's Bathtub locality, which shows closely-packed orbicules in a granodioritic pipe cutting through alaskite.

In the sills, the general close stacking of the orbicules within the normal granitic matrix indicates that orbicular growth had ceased before the orbicules came in contact with one another. This may be reliably settled, as no example of an orbicule containing two or more nuclei could be observed.

Moreover, on most outcrops, the variable number of shells of different thicknesses reflects the probable mixing of orbicules of various sizes. Multishelled orbicules and micaceous enclaves without any plagioclase envelope were observed together. These features are consistent with the displacement of orbicules away from the place where they originated. Transportation has occurred until a trap such as a narrow sill would stop and accumulate the orbicules, although the granitic matrix could still move through. This is also consistent with the lack of comb layering along both walls of the site itself, but only as reworked fragments in the matrix (Figure 4, c).

A direct link between the porphyritic host rock and the orbicular sills is not supported by microprobe data. Plagioclase and biotite in the orbicules show a weak, but continuous, evolutionary trend from the core through the outer shells, to the matrix of the orbicules (Figure 6). In contrast, the porphyritic host rock of the orbicular sills yielded notably Na-enriched plagioclase (An_{19}) and Fe-enriched biotite (Table 1).

CONCLUSION

The western flank of the Sierra Mazatán provides several sills of orbicular granite intruding a porphyritic Laramide host rock. The intrusion of sills was previous to the pegmatite dykes and to the extensional Tertiary tectonics. This new occurrence of orbicular granite in Mexico poses the problem of orbicular formation in a clear geological context. Petrological investigations have shown that no mineral or geochemical peculiarities could be detected in the orbicules, compared to the normal, randomly crystallized matrix. A brief review of the processes that are currently considered in the formation of orbicular textures favours a magmatic origin in most cases. In the Sierra Mazatán, the magmatic origin of the orbicules is directly indicated by the statistical analysis of zircon morphology.

However, the place where these orbicules were originated, the particular physical conditions as well as the duration of the genetic process, remain uncertain. These conditions must have been transient, as orbicular granites remain truly exceptional rocks.

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