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ORIGIN OF JOVE PEAK ORBICULITE IN WENATCHEE RIDGE AREA, NORTHERN CASCADES, WASHINGTON

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ABSTRACT. The sill-like, metagabbroic Jove Peak Orbiculite intruded the Chiwaukum Schist during the Skagit Metamorphism and was later intruded by quartz diorite. Orbicules, unique in that they are composed almost entirely of hornblende, nucleated on pyroxene or hornblende phenocrysts, or xenoliths of gabbro, hornblendite (?), pyroxenite (?), mica schist, or amphibolite. Igneous origin of the orbicules is shown by arithmetic succession of concentric shells, many of which display an outward increase of radial arrangement of hornblende. Other characteristics, such as local inward-radiating bunches of acicular hornblende, partially annealed shell boundaries, and incompletely hornblendized core pyroxene, definitely indicate post-orbicular recrystallization.

The orbiculite matrix contains abundant relict igneous features such as directionless hypautomorphic-granular texture and common euhedral to subhedral plagioclase with igneous zoning, twinning, and synneusis. Subsequent medium grade metamorphism is shown by hornblendization of plagioclase + magnetite or biotite. The dual igneous-metamorphic, as opposed to migmatitic, history is further illustrated by bimodal plagioclase composition, consistent in part with the gabbroic parent and in part with the Skagit Metamorphism, and by remarkable compositional differences in plagioclase across interfingering mica-schist-orbiculite contacts.

INTRODUCTION

This paper is intended as a contribution to the Northern Cascades project of the University of Washington, a project conceived and directed by Professor Peter Misch and involving many of his graduate students since 1949 (see Misch, 1966, with further references).

Metamorphosed orbicular gabbro crops out close to the summit of Jove Peak, in the southeast corner of the Wenatchee Ridge Area, Washington (see VanDiver, 1967, with further references; see fig. 1). The orbiculite intrudes the heterogeneous Chiwaukum Schist (Page, ms; Van Diver, 1964a, ms, 1967) which, in turn, is correlated with the Skagit Metamorphic Suite of Misch (1963, 1966) in the range farther north. In general, the isochemical portions of the Chiwaukum Schist east of Jove Peak to the Chiwawa River consist of garnet-mica schists, commonly with kyanite and/or staurolite, and subordinate interlayed amphibolites, amphibolitic schists, marbles, quartz schists, and paragneisses. There are also numerous lenticular bodies of quartz dioritic, dioritic, gabbroic, and ultramafic orthogneisses derived from pre-metamorphic intrusives.

Allochemical gneisses make up a large part of the Chiwaukum Schist in the vicinity of Jove Peak and as far east as Wenatchee Ridge (VanDiver, 1964a). Labyrinth Mountain, 3 miles northeast of Jove Peak, consists of a large-scale migmatite of coarse-grained, leucocratic, quartz dioritic gneisses with abundant *in situ* remnants of mica schist from which the gneiss appears to have been derived.

Structural trend in the vicinity of Jove Peak is northwesterly. Schists at the orbiculite contact and for some distance from it are tightly folded

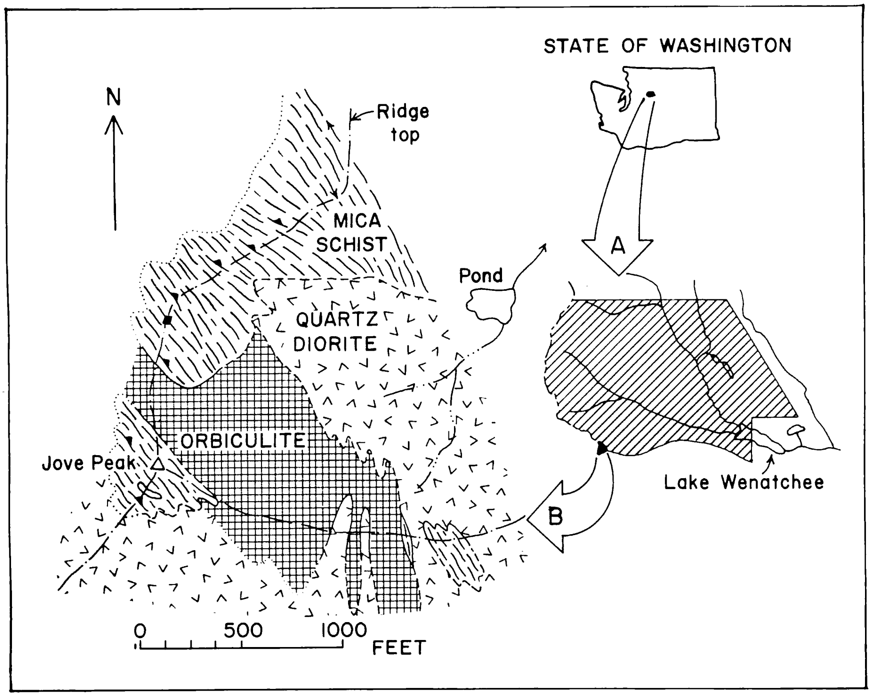


Fig. 1. Geologic sketch map of the Jove Peak orbiculite and associated rocks. Inset A shows the location of the Wenatchee Ridge Area, and inset B shows the location of the geologic map within that area.

and crinkled as a combined result of the deformation associated with regional metamorphism, metasomatism, and intrusive activity.

Only one major episode of metamorphism is discernable in the Chiwaukum Schist (Skagit Metamorphism, Misch, 1966), and this is manifest in the recrystallization, partial and complete, of both the supracrustal and intrusive rocks, including the Jove Peak Orbiculite. The metamorphism in general was regional, synkinematic, and predominantly medium-grade, belonging in the almandine amphibolite facies (Turner and Verhoogen, 1960, p. 544-553; Winkler, 1965, p. 87-97).

The Chiwaukum Schist and associated rocks broadly correlate with the lithologically similar Green Mountain Unit (Bryant, ms) to the northwest which, in turn, is roughly equivalent to the Cascade River Schist (Misch, 1952a, b, 1966). For a comprehensive discussion of metamorphism in these rocks, the reader is referred to Misch (1966, p. 112-113).

Sixty-five thin sections of the Jove Peak Orbiculite and associated rocks were studied. Approximately 864 measurements of An-content in plagioclase were made with the aid of the universal stage, using the *a*-normal and Y:Y methods (Tröger, 1959). The universal stage was also used, in conjunction with X-ray diffraction powder techniques, to identify hornblende and pyroxene in the orbicules.

DESCRIPTION OF JOVE PEAK ORBICULITE

General description.—The main body of the orbiculite underlies the cirque on the eastern side of Jove Peak. Its form is roughly sill-like, more-or-less concordant with the contiguous schists, gneisses, and migmatites (fig. 1).

The orbiculite generally is fine-grained and grayish green, with small, commonly rectangular clots of hornblende which megascopically resemble phenocrysts. Texture is diabasic to gabbroic. Ovoid and spherical orbicules occur throughout the unit but are most abundant near contacts with garnet-mica schist which underlies the uppermost 200 feet of Jove Peak. Small xenoliths of mica schist, schistose amphibolite, and gabbro occur throughout the orbiculite. These also are most numerous near the mica schist contact, and they very commonly form orbicule nuclei.

Petrographic description of matrix.—The matrix (Leveson, 1963, p. 1021) in the bulk of the unit has a fine-grained, hypautomorphic granular texture (Williams, Turner, and Gilbert, 1954, p. 18; Johannsen, 1939, p. 37) inherited from the parent igneous rock. Principal minerals in every sample studied, in order of abundance, are plagioclase, hornblende, biotite, and quartz. There is no pyroxene in the matrix, although it occurs in some orbicules. Ubiquitous, exceedingly fine-grained magnetite is a minor accessory, and there are local traces of apatite, zircon, sphene, and epidote. Garnet is found only where the orbicular rock is contaminated with garnet-mica schist at contacts. Minor secondary minerals include saussurite from plagioclase, chlorite and leucoxene from biotite and occasionally from hornblende. Hornblendization of plagioclase and biotite is unrelated to this low-temperature alteration and will be discussed later.

Plagioclase is almost totally confined to the matrix. It generally is subhedral and markedly lath-shaped, with no preferred orientation except in very fine-grained phases of the rock. Broad, straight, and numerous polysynthetic twin laminae, as well as synneusis and fine, euhedral oscillatory zoning with normal trend, all indicate an igneous origin (Vance, 1961, 1967). A frequency plot of An-content from 341 universal stage measurements of matrix plagioclase (fig. 2A) indicates a bimodal distribution, with maxima at An_{47} and An_{36}, approximately. Patchy zones (Vance, 1965) of more calcic composition than that of the host (up to An_{100}) are fairly common.

Hornblende replaces plagioclase plus magnetite, and biotite (+ plagioclase?). In plagioclase, it occurs as small, rectangular grains adjacent to or including minute magnetite grains, and rimmed by decalcified haloes (pl. 1-A, B). The apparent reaction is: anorthite + magnetite + H_2O = hornblende. In replacing biotite, the hornblende invades biotite parallel to cleavage, deforming it and pushing it aside in the process (pl. 1-C).

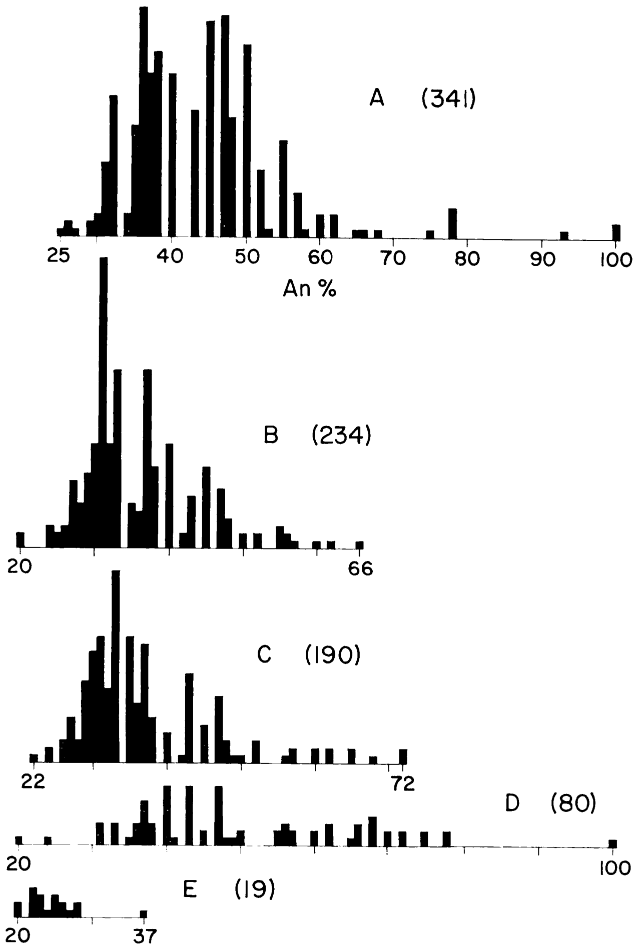
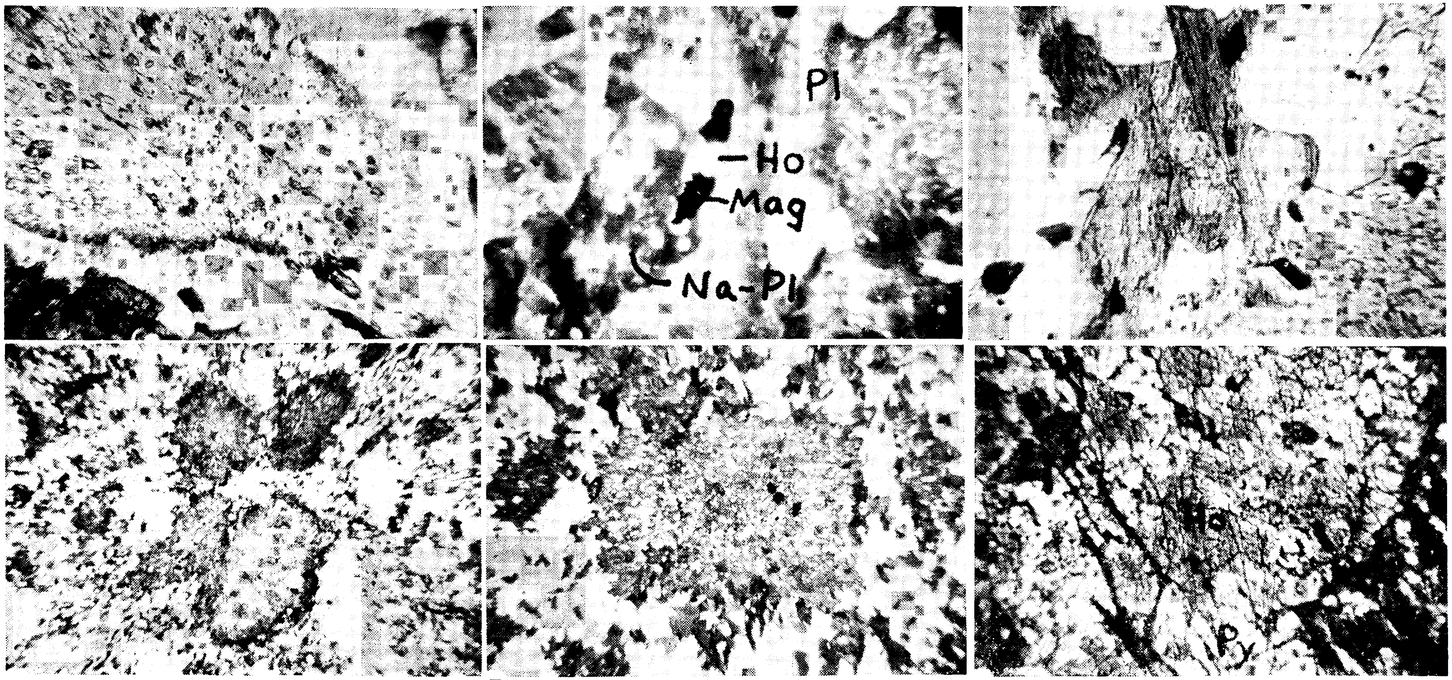


Fig. 2. Frequency plots of An-content in plagioclase. A = orbiculite matrix, B = quartz diorite, C = Chiwaukum garnet-mica schists, D = fine-grained, chill zone orbiculite, and E = quartz dioritic and aplite dikes. Numbers in parentheses represent the total numbers of measurements.

Five thin sections of fine-grained, schistose phases of the orbiculite that locally occur along the boundaries of the unit were studied. These are well recrystallized, protoclastic, chill-zone rocks, mineralogically identical to the main orbiculite, except in that they represent higher temperature origin. Plot of An-content from 80 universal stage determinations, shown in fig. 2D, is bimodal, with maxima at An_{67} and An_{42}, approximately. Their more calcic nature relative to plagioclase of the coarser-grained orbiculite precludes synkinematic, post-intrusive origin because the metamorphic grade required would be higher than otherwise indicated. Tiny, smeared clusters of very fine-grained hornblende, repre-

Plate 1

A. B. C.



D. E. F.

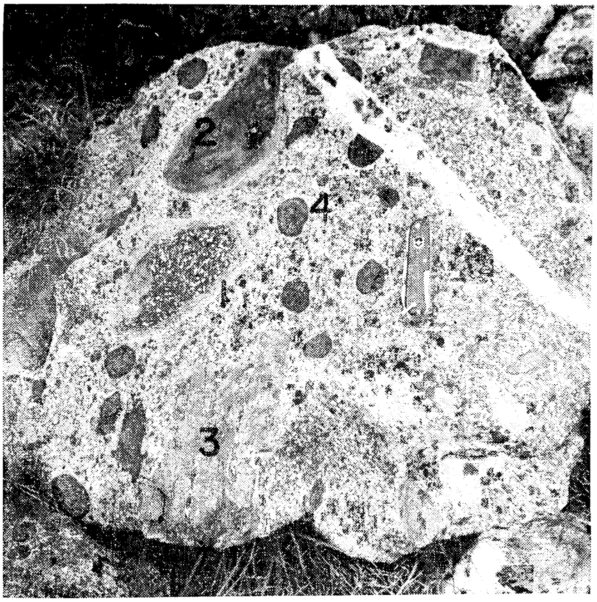
Photomicrographs: A. (80x) hornblende-filled core of metamorphically altered igneous plagioclase; B. (200x) hornblende replacing magnetite and anorthite, with sodic plagioclase halo; C. (200x) hornblende shouldering and replacing biotite; D. (20x) proto-orbicules; E. (20x) sievy, rectangular proto-orbicule; and F. (160x) hornblende replacing pyroxene in orbicule core.

senting proto-orbicules (Leveson, 1963, p. 1018), are abundant in these rocks. Their mode of occurrence indicates that orbicule development began during the early stages of intrusion.

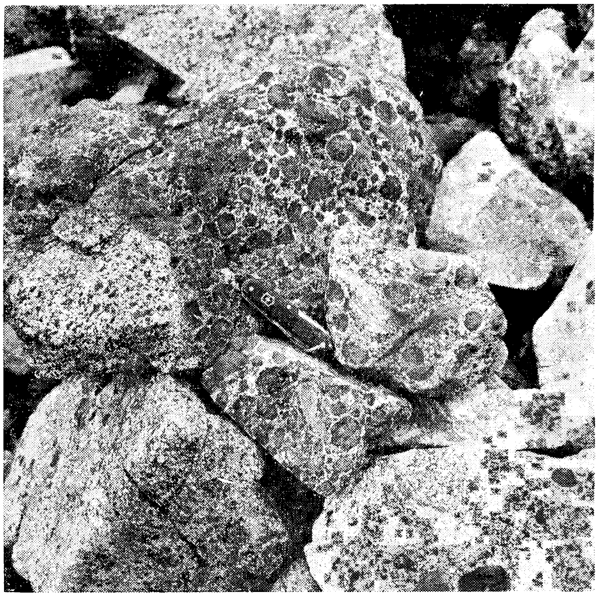
Petrographic description of proto-orbicules—Proto-orbicules, as referred to here, are those which show conspicuous clustering of orbicular minerals around a nucleus but have not yet attained ovoid or spherical form (pl. 1-D). They occur throughout the orbiculite, both separate from and closely associated with fully developed orbicules. Nuclei consist primarily of xenoliths of meta-hornblendite, meta-pyroxenite(?), metagabbro or metadiorite, amphibolite, and mica schist. Small, sieved, directionless clusters of very fine grained hornblende, occasionally with pyroxene, are exceedingly common, especially in the more fine-grained phases of the orbiculite, (pl. 1-E). Many of these have rectangular outlines and brownish core areas. Also present, but less numerous, are coarse-grained, interfeathered xenomorphic aggregates with brownish cores, some containing ragged remnants of pyroxene. Biotite, ubiquitous in the matrix, tends to collect on the peripheries of, but is almost totally excluded from, the interiors of both the proto-orbicules and the fully developed ones.

Petrographic description of large, well-developed orbicules.—Overlay maps of 10 ovoid, well-developed multiple orbicules (Leveson, 1963, p. 1023) are shown in figure 3 at half scale, with insets at full scale drawn from thin sections. Sample A, 11.3 X 9.0 centimeters in diameter, represents the maximum size observed in the field. Most nuclei of the larger orbicules consist of coarse-grained hornblende, locally with up to 10 percent plagioclase and commonly with ragged remnants of pyroxene in various stages of replacement by hornblende (pl. 1-F); others are fragments of amphibolite or mica schist. Cores have irregular outlines and are surrounded by successive, increasingly ovoid, hornblende shells in which spacing is apparently in arithmetic progression (Leveson, 1963, p. 1037). The shells differ widely in texture and preferred orientation of hornblende; however, the innermost two or three shells are the more coarse-grained, and hornblende tends to be elongate and radially arranged (fig. 3A-F). Hornblende within some of the radial shells is almost entirely anhedral and stubby (fig. 3, shells A_4, B_2 in part, F_2), in others stubby euhedral to subhedral (B_2 in part, B_3, C_2, F_3 in part), and in others acicular (D_2, E_2, F_3 in part). A peculiar characteristic of the acicular hornblende is that it commonly forms groups that radiate inward toward the core, indicating post-orbicule, static recrystallization. Radial hornblende, in fact, is not everywhere limited by shell boundaries (B and G, dotted lines), and all shell boundaries are, for the most part, poorly defined. In all samples examined, the outermost hornblende shells are much finer-grained and have little or no ordered arrangement, reflecting more rapid formation. Most of the large orbicules are surrounded by a thin zone which resembles the matrix material but is finer-textured and more leucocratic (fig. 3 A, E, F, G, I; also note large irregular orbicules in pl. 2-A).

PLATE 2



A.



B.

A. Boulder of orbiculite with proto-and well-developed orbicules nucleating on (1)—gabbro, (2)—amphibolite, (3)—mica schist, and (4)—hornblende; B. crowded simple orbicules.

Most of the well-developed orbicules are single-shelled, rather than multiple-shelled, and only 2 to 4 centimeters in diameter (fig. 3I, pl. 2-B). These, however, are similar to the nucleus-plus-first-shell of the multiple-shelled orbicules and need not be described separately; they are merely less fully developed.

DESCRIPTION OF POST-ORBICULITE QUARTZ DIORITE AND ASSOCIATED DIKES

General description.—Most of the area south at least to Union Peak, northwest, and immediately east of the orbiculite exposures, is underlain by homogeneous, leucocratic biotite-quartz diorite (fig. 1). Contact with the orbiculite and Chiwaukum Schist is largely concealed, but apparently irregular. Outcrops as well as numerous float boulders display features that indicate the quartz diorite has intruded the orbiculite and the Chiwaukum Schist. These features include intrusive breccias with quartz diorite matrix (pl. 3), locally with partial assimilation of the orbiculite; abundant quartz dioritic and related aplite dikes; and xenoliths of orbiculite, mica schist, and amphibolite in the quartz diorite (pl. 4-A). Some post-intrusive shearing is suggested by the presence, on the east ridge of Union Peak, of stretched breccias composed of fragments resembling the orbiculite in a quartz diorite matrix (pl. 4-B).

Petrographic description.—The quartz diorite is coarse-grained, hypautomorphic granular, with little or no cataclasis or alteration. Principal minerals in order of abundance are plagioclase, biotite, quartz, and locally, hornblende. There are extremely minor amounts of apatite, sphene, zircon, muscovite, and opaques.

Plagioclase, as in the orbiculite, is characteristically igneous, with rectangular outlines, euhedral oscillatory zoning with normal trend, and synneusis. A plot of plagioclase compositions from 234 measurements indicates maximum at about An_{33} and a range from An_{20} to An_{66} (fig. 2B).

The quartz dioritic and aplitic dikes, which cut the orbiculite and the main quartz diorite as well, contain a more sodic plagioclase with a more limited compositional range (fig. 2E).

CHIWAUKUM SCHIST ALONG THE ORBICULITE CONTACT

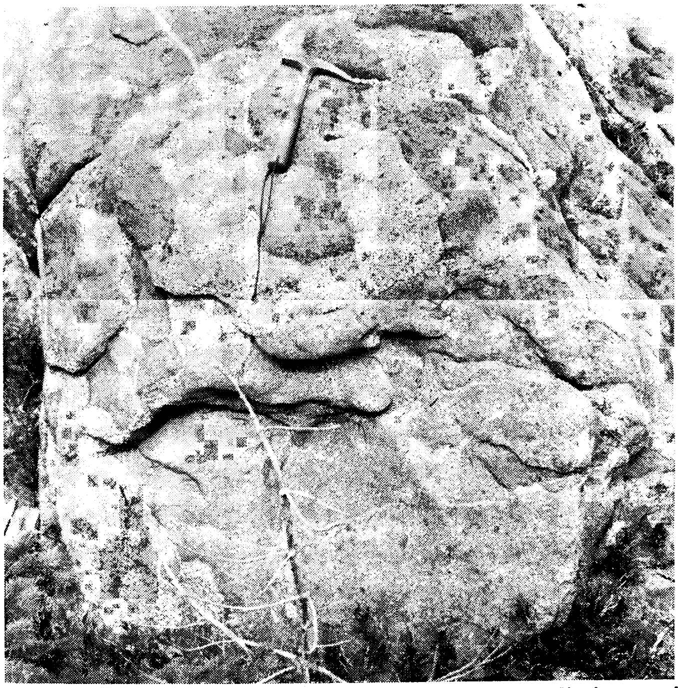
General description.—Contacts between orbiculite and garnet-mica schist are well exposed on the north and east ridges of the Jove Peak. On the north ridge, the two rocks intimately interfinger on the scale of fractions of an inch. Here, and for half a mile to the north along the ridge top, the mica schist is folded, crinkled, and highly migmatitic.

Petrographic description.—Thirteen systematically spaced samples were collected from a traverse across the north ridge contact and studied in thin section (fig. 4). Samples 1 to 7 and 9 are garnet-mica schists, and samples 8 and 10 to 13 are orbiculites. Samples 3 and 4 contain quartz diorite similar to that which has intruded the orbiculite.

Primary minerals in all of the schist samples are, in order of decreasing abundance, quartz, plagioclase, biotite, and garnet. Staurolite occurs in samples 1, 2, and 3, and fibrolite, in sample 2. Minor accessory

PLATE 3

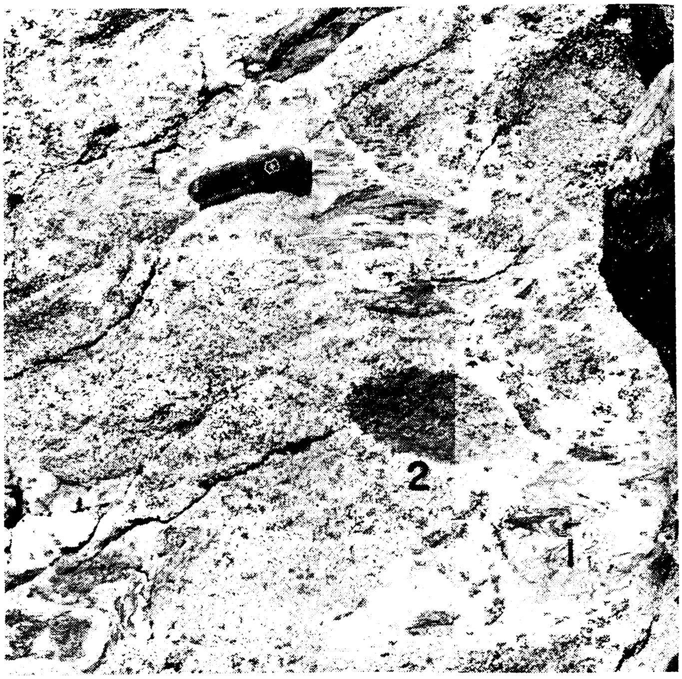
A.



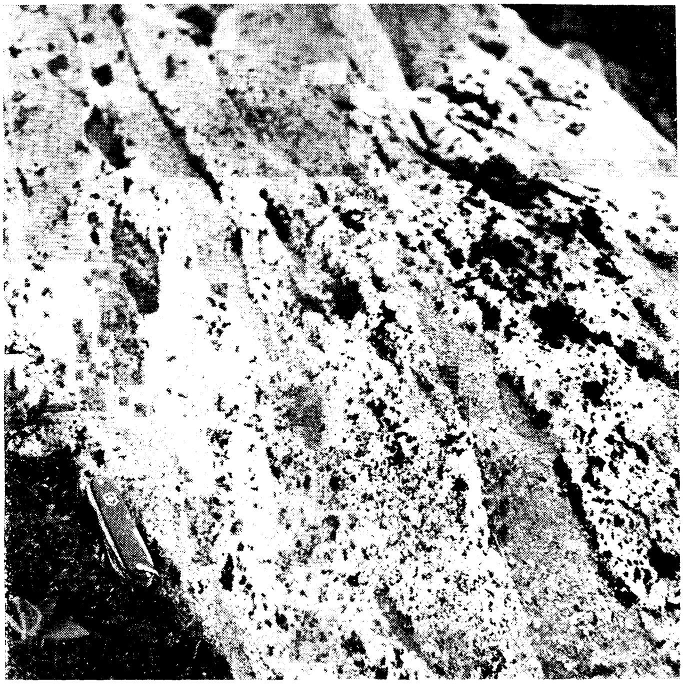
B.

A, B. Intrusive breccias with orbiculite fragments in quartz diorite matrix.

PLATE 4



A.



B.

A. Quartz diorite with xenoliths of (1) —mica schist and (2) —orbiculite.
B. Stretched intrusive breccia of orbiculite in quartz diorite matrix.

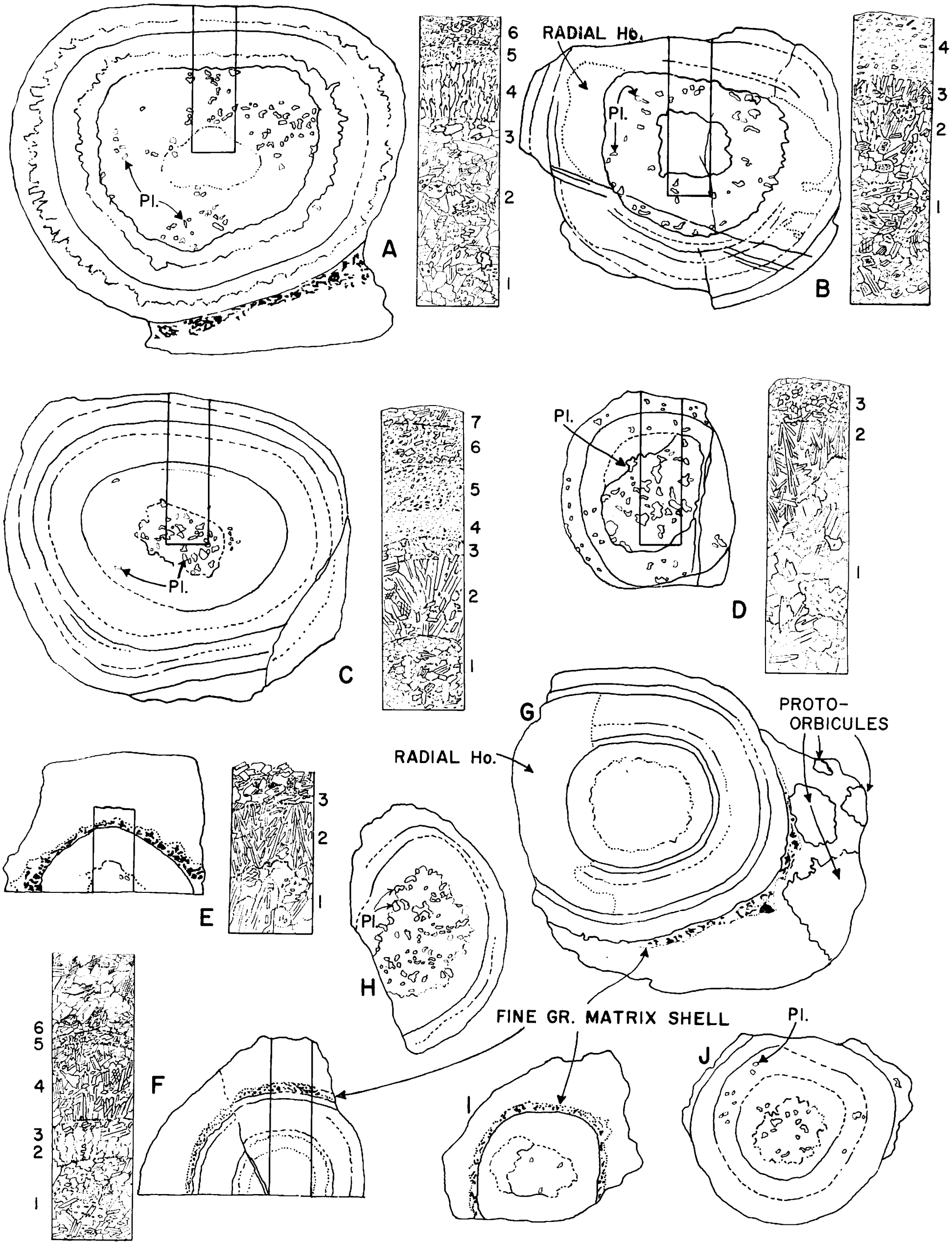


Fig. 3. Overlay maps of ten well-developed orbicules at half-scale and microsketches of six at full scale. Small outlines, shown in and near the nuclei, are plagioclase (Pl.). Ho. = hornblende.

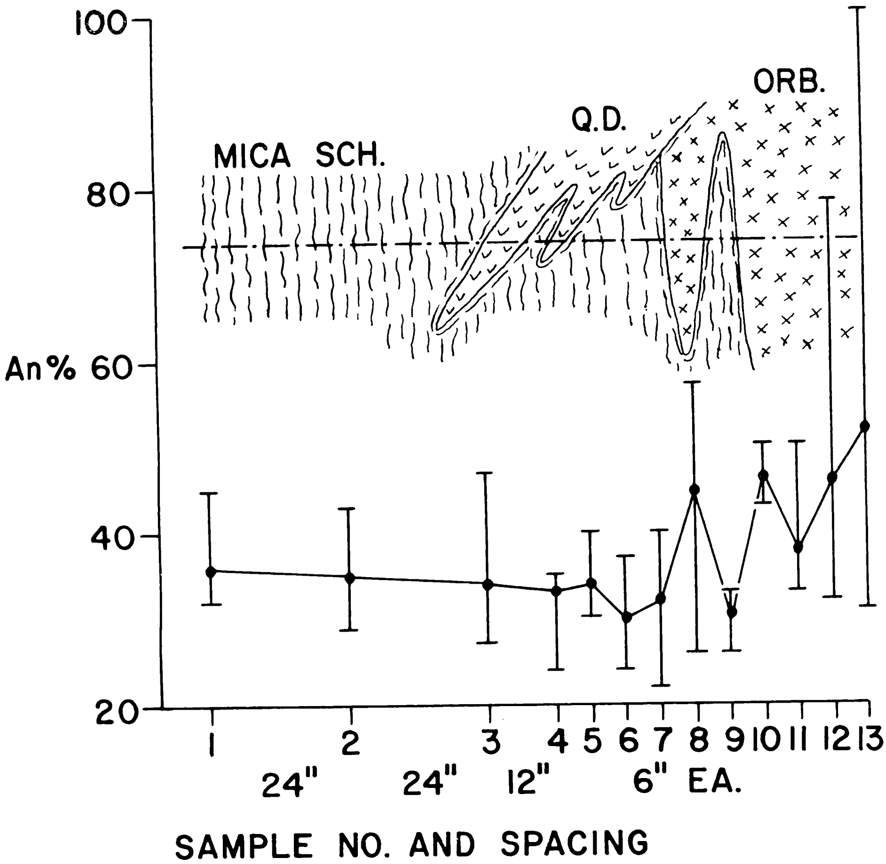


Fig. 4. Range and average An percent of plagioclase from sequence of 13 samples across north ridge contact between orbiculite and Chiwaukum Schist. Sketch map indicates approximate geology along the traverse and the location of the sampling line.

minerals include graphite, apatite, zircon, tourmaline, and secondary chlorite. Samples 7 and 9 from sites adjacent to a finger of orbiculite contain highly altered plagioclase phenocrysts derived from the intrusive material. Sample 9 is moderately sheared and more extensively altered than the other schist samples. With these minor exceptions, there are no significant mineralogical or textural differences between the Chiwaukum rocks here and 62 other samples of mica schist studied in detail in the Wenatchee Ridge Area as a whole. Metamorphic grade, therefore, is not noticeably affected by injection of the orbiculite. Intrusive origin of the orbiculite is, however, substantiated by analysis of 190 plagioclase compositions from all samples in the contact sequence, shown in figure 4. Precipitous and remarkable changes in An-content (and textural character) within inches, and even fractions of an inch, preclude a migmatitic origin. Post-intrusive metamorphism here is inconspicious, except in sample 9, where shearing is attended by messy, low-grade alteration.

A plot of 150 plagioclase compositions from these and other mica schist samples in the vicinity of Jove Peak is shown in figure 2C. The graph is unimodal with a maximum at about An_{35}, consistent with the Chiwaukum Schist as a whole in the Wenatchee Ridge area.

CONCLUSIONS

The main purpose of this study has been to establish the mode of origin of the Jove Peak Orbiculite and closely associated rocks and their time of formation relative to Skagit Metamorphism. Study of the orbicules themselves was incidental to these aims. The actual mechanism of orbicule formation, especially with regard to the periodicity of shell development, has been examined in detail by Leveson (1963) and is largely beyond the scope of this paper.

The Jove Peak Orbiculite intruded the Chiwaukum Schist during a late stage of Skagit Metamorphism, after the schistosity of the Chiwaukum was well developed, but when temperature was still that of medium-grade metamorphism. Orbicules, nucleating on phenocrysts, perhaps of pyroxene, and on xenoliths of all kinds, began developing in the early stages of the intrusion and continued nearly to the point of complete crystallization of the magma.

Orbicule formation was particularly sensitive to conditions existing along the mica schist contacts, probably because xenoliths and ferromagnesian phenocrysts were more abundant there to form nuclei. The reason for the glomerophyric tendency of hornblende (or pyroxene) is not known, but the geometry of the hornblende within the orbicules appears to be a function, in part, of the rate of cooling and, in part, of later recrystallization. Tiny crystals precipitating on the surface of a nucleus or an earlier shell undoubtedly had various orientations. Continuing to grow under conditions of slow cooling the crystals enlarged principally in the *c*-direction. The only ones that grew to very large size were those radially oriented to begin with or rotated into such position and thus met little or no resistance to extension. The resulting texture within a particular orbicule shell is one of increasing grain size and radial arrangement from the inner to the outer shell boundary (fig. 3, B-2, B-3, C-2). Hornblendization of plagioclase, biotite, and the orbicules themselves is attributed to continued medium-grade, regional metamorphism in the absence of penetrative deformation; so is the bimodal composition of the matrix plagioclase (fig. 2A, D) viewed as a result of this recrystallization. Recrystallization of the orbicules is indicated by the inward-radiating acicular hornblende, by the incompletely replaced pyroxene in the cores, and by radial hornblende crystals crossing shell boundaries.

The schist-orbiculite complex was intruded by quartz diorite and associated dikes, either late in the metamorphism (pl. 4-B, of stretched breccias) or subsequent to metamorphism. The latter is suggested by the paucity of low-temperature alteration in these rocks, as compared with that of the quartz dioritic White River Orthogneiss 10 miles northeast of Jove Peak, which was fault-emplaced late in the metamorphism (Van Diver, 1967).

ACKNOWLEDGMENTS

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