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IDDINGSITIZATION AND RECURRENT CRYSTALLIZATION OF OLIVINE IN BASALTS FROM THE SIMCOE MOUNTAINS, WASHINGTON

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ABSTRACT. Olivine phenocrysts from Pliocene to Recent basalts of the Simcoe Mountains, Washington, commonly are altered, either in part or completely, to iddingsite. Overgrowths of fresh olivine (Fo_{67} to Fo_{21}) surround or partially surround many of these iddingsitized phenocrysts. Textural evidence suggests that the alteration of olivine phenocrysts occurred just prior to and during extrusion and was not dependent upon the phenocrysts' composition. Similarity in composition of overgrowths and ferriferous groundmass olivine suggests that the overgrowths formed during the groundmass crystallization.

INTRODUCTION

Iddingsite (Lawson, 1893) is the name given to a reddish brown alteration product of olivine occurring in basalts and basalt porphyries. Since the comprehensive study by Ross and Shannon (1925), iddingsite has been generally accepted as a deuteric alteration product of olivine. Ross and Shannon (p. 18) concluded that "iddingsite formed near or just after the close of crystallization, and after the magma came to rest." Textural evidence given by Edwards (1938) indicated that iddingsite formed during or after extrusion. From a study of iddingsite in the Kakoolawe rocks, Macdonald (1940, p. 156) concluded that the alteration occurred "during the time in which the enclosing magma occupied the apex of a cupola, or even the feeding channel of the volcano."

The present investigation was undertaken to determine more clearly the time of olivine alteration and to determine whether or not olivines of certain compositions are preferentially altered as suggested by Ross and Shannon (1925, p. 6) and Tomkeieff (1934, p. 509). Material for study was obtained from Pliocene to Recent olivine basalts of the Simcoe Mountains in south-central Washington. Mineral identifications and textural determinations were made with the standard petrographic microscope. All measurements of 2V (or 2H) were made with the universal stage. Olivine compositions were determined from 2H by utilizing the curve of Poldervaart (1950, p. 1073). Their compositions are expressed as molecular percentages of forsterite.

PETROGRAPHY

Although the olivine basalts are variable in texture even within a single flow, most can be considered holocrystalline, porphyritic, and either intergranular or ophitic to subophitic. Generally, ophitic to subophitic specimens also show the open network texture that Fuller (1931, p. 116) named diktytaxitic. Phenocrysts of plagioclase (An_{56-43}) and olivine are set in a groundmass of plagioclase laths (An_{49-40}), augite ($+ 2V = 45$-$56°$), olivine, magnetite, and apatite.

OLIVINE

Olivine phenocrysts are colorless, untwinned, and fractured. They range in size up to 12 mm but average 1 to 3 mm. Euhedral phenocrysts are rare;

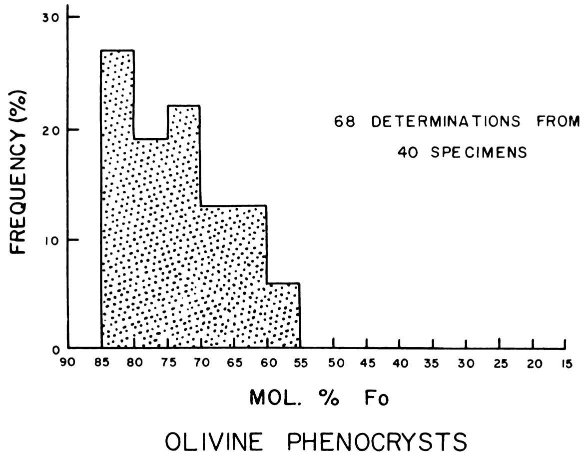


Fig. 1. Histogram showing the distribution of the compositions of olivine phenocrysts occurring in the olivine basalt. Determinations were made from unzoned phenocrysts or cores of zoned phenocrysts.

most are rounded due to resorption, some to such a degree that they have an amoeba-form outline. Inclusions consist of magnetite, picotite, and plagioclase. Glomeroporphyritic clots of olivine phenocrysts with or without plagioclase are common.

Groundmass olivine is subhedral to anhedral, untwinned, and generally less than 0.5 mm in size. In intergranular olivine basalts the groundmass olivine always is larger than the associated augite.

All of the olivine phenocrysts are optically negative and have optic angles ranging from 87° to 76°, corresponding to a compositional range of $Fo_{81\text{-}58}$. Figure 1, which illustrates the distribution of olivine compositions, shows that most phenocrysts are between Fo_{81} and Fo_{70}. Phenocrysts from the same specimen may vary in composition as much as 11 mol. percent Fo. Other workers also have noted the compositional variability of unzoned olivine phenocrysts within a single specimen (Tomkeieff, 1939, p. 241; Kuno, 1950, p. 970).

Groundmass olivines (fig. 2) range from Fo_{70} to Fo_{24}, but most lie between Fo_{65} and Fo_{40}. Olivines of the groundmass are thus more iron-rich than the phenocrysts. This relationship between composition and grain size of olivines occurring in the same specimen has been mentioned by Barth (1931, p. 380), Boque and Hodge (1940, p. 632), and Macdonald (1940, p. 154).

Some unaltered olivine phenocrysts show a narrow continuously zoned rim which is always more ferriferous than the core, as indicated by a smaller 2V and a higher birefringence. In general the outermost part of the zoned phenocryst corresponds in composition to the groundmass olivine. The compositional range from core to rim may be as much as 40 mol. percent Fo. Reverse zoning, i.e., the tendency to produce magnesium-rich rims, was not observed.

Both the zoned phenocrysts and the ferriferous groundmass olivines indicate that the residual liquid became increasingly enriched in iron at the expense of magnesium as crystallization progressed. Probably the ferriferous rims of the phenocrysts were precipitated when the groundmass crystallized

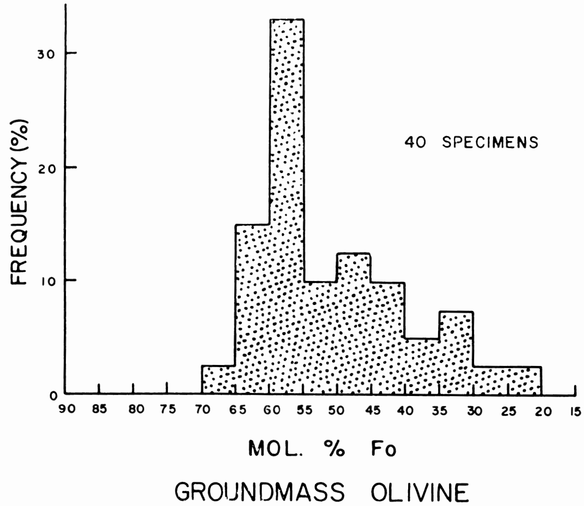


Fig. 2. Histogram showing the distribution of the compositions of groundmass olivine. The histogram was prepared from the averages of 40 specimens.

after extrusion. Relatively rapid cooling after extrusion would inhibit the attainment of equilibrium between phenocrysts and liquid, producing continuous zoning.

OCCURRENCE OF IDDINGSITE

Olivine phenocrysts commonly are altered, either in part or completely, to iddingsite. Most iddingsite appears optically homogeneous, and it generally extinguishes parallel to the unaltered olivine remnant. It is reddish brown to orange, weakly pleochroic, and optically negative with an optic angle ranging from 20° to 74°. One iddingsite pseudomorph was found to be continuously zoned, having a $2V = 74°$ at the core and 37° at the rim.

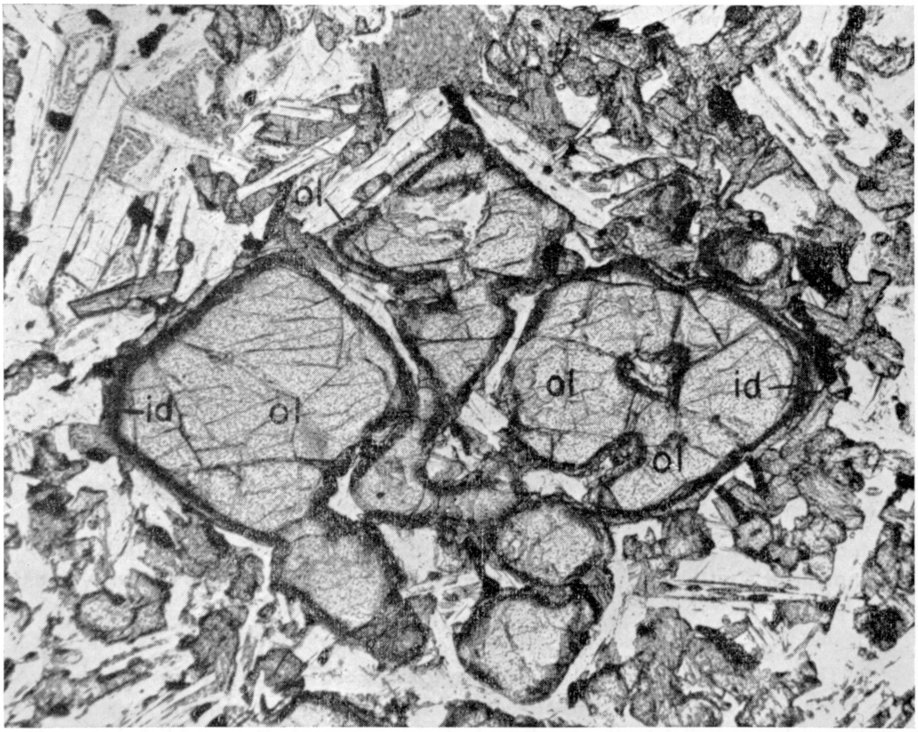
Most olivine phenocrysts are only partly altered; the iddingsite forms a narrow external rind and also penetrates the interior of phenocrysts along cleavages and cracks. The contact between iddingsite and the interior olivine always is fuzzy or feathery. The rinds of iddingsite follow the external form of the phenocrysts closely, no matter whether it is euhedral or is highly embayed due to resorption (pl. 1). Some phenocrysts are completely pseudomorphed; in others small remnant patches of fresh olivine remain in the central portion of the phenocryst (pl. 2). In glomeroporphyritic clots many olivines are altered only along those portions of the phenocrysts which protrude from the clot (pl. 3). No alteration occurs along the inner olivine contacts, and olivines that are completely enclosed within the clot show no alteration.

Groundmass olivines are generally not altered to iddingsite; the few small altered olivine grains that actually do occur in the groundmass may be microphenocrysts.

OLIVINE OVERGROWTHS

An overgrowth of fresh olivine surrounds or partially surrounds some of the iddingsitized phenocrysts (pl. 1). These overgrowths are in optical con-

PLATE 1



Resorbed olivine phenocryst (ol) with marginal alteration to iddingsite (id). Note that the iddingsite follows the resorbed outline of the phenocryst. An overgrowth of fresh olivine (ol) partially surrounds the phenocryst. Ordinary light, X 90.

tinuity with the core olivine and tend to restore euhedral outlines to the phenocrysts. That this fresh olivine is an overgrowth and not the outer rim of a zoned phenocryst that was selectively altered is indicated by the following textural evidence:

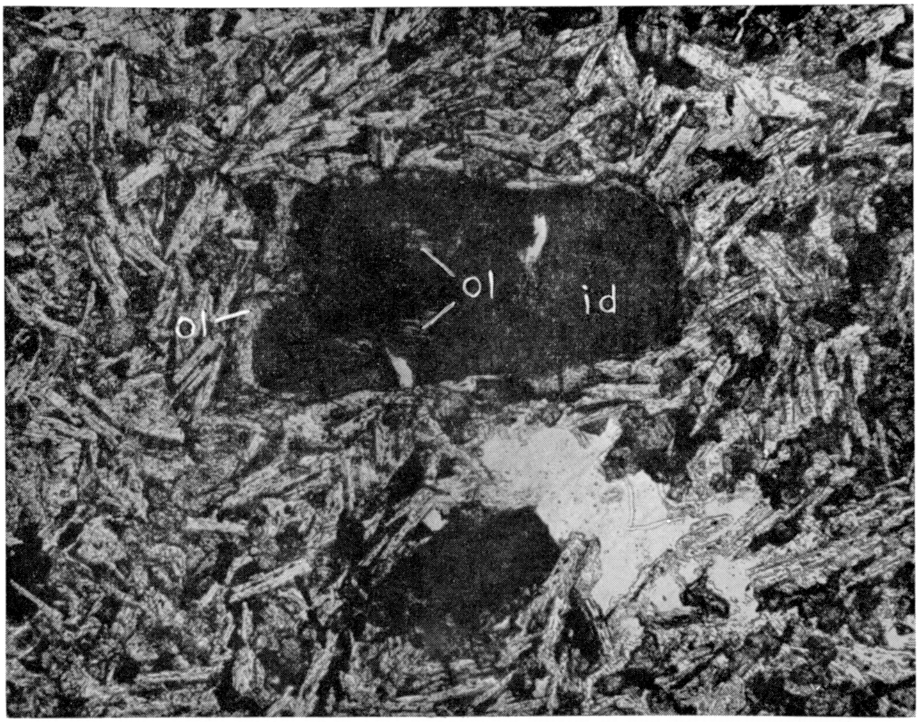
(1) The contact between the rim olivine and the iddingsite is sharp in contrast to the "fuzzy" core olivine-iddingsite contact.

(2) Fractures along which iddingsite has developed in the core olivine do not extend through the rim olivine.

The composition of the overgrowths generally is similar to that of the groundmass olivine, ranging from Fo_{67} to Fo_{21}. Rarely an overgrowth is zoned, being more ferriferous toward the rim. The similarity in composition of overgrowths and groundmass olivine (table 1) suggests that the overgrowths formed during groundmass crystallization. Further evidence for this is supplied by the following:

(1) Overgrowths are absent on iddingsite phenocrysts that are included in ophitic augite.

PLATE 2



Resorbed olivine phenocryst (ol) nearly pseudomorphed by iddingsite (id). Several small remnant patches of olivine still remain. An overgrowth of fresh olivine partially surrounds the altered phenocryst. Ordinary light, X 75.

(2) In places only a partial overgrowth is developed where augite grains and rarely plagioclase laths are attached to the altered phenocryst. Apparently these groundmass constituents prevented access of the liquid to the phenocryst.

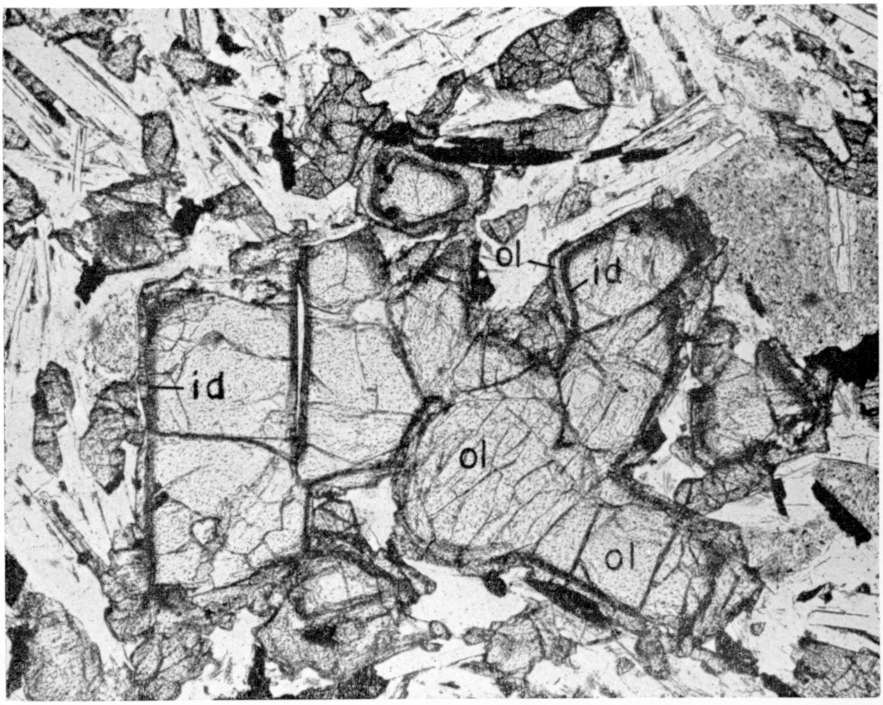
(3) Overgrowths occur on the exterior portions of altered phenocrysts in a glomeroporphyritic clot but are lacking on those portions of phenocrysts enclosed within the interior of the clot.

TABLE 1

Compositions of olivine phenocrysts, overgrowths, and groundmass olivine

Specimen Number	Composition of Core	Composition of Overgrowth	Composition of Groundmass
RS-102	Pseudomorph	Fo_{41}	Fo_{36}
RS-110	Fo_{81}	Fo_{50}	Fo_{32}
RS-111	Fo_{78}	Fo_{32}	Fo_{28}
RS-114	Fo_{78}	Fo_{62}	Fo_{60}
RS-154	Fo_{81}	Fo_{60}	Fo_{62}
RS-158	Fo_{78}	Fo_{52}	Fo_{41}
RS-163	Fo_{81}	Fo_{67}	Fo_{65}

PLATE 3



Glomeroporphyritic clot of olivine phenocrysts (ol) in an olivine basalt. Note that the iddingsite (id) follows the outline of the clot but is not present along the contacts of the individual phenocrysts inside the clot. Ordinary light, X 75.

FORMATION OF IDDINGSITE

The formation of iddingsite has been attributed to weathering by Iddings (1892, p. 389) and Abbot (1958, p. 1671), but most workers now agree that iddingsite is of deuteric origin. Although Ross and Shannon (1925) championed the deuteric origin, they failed to recognize the olivine overgrowths as such and stated (p. 6): "the alteration was partly dependent upon zonal variations in the original olivine from which the iddingsite was derived." Tomkeieff (1934, p. 509) concluded that the outer ferriferous zones were altered to iddingsite. That the alteration of olivine phenocrysts from the Simcoe Mountains is not dependent upon the olivine composition is demonstrated by:

(1) Iddingsite follows the borders of deeply embayed phenocrysts, cutting across zones of contrasting composition in zoned olivines.

(2) Iddingsite occurs along cracks that extend completely through phenocrysts.

(3) Iddingsite occurs along the borders of some phenocrysts but pseudomorphs others.

(4) The overgrowths of ferriferous olivine are closer in composition to iddingsite than the zones of olivine that have been altered. If they were present

when alteration occurred, they should have been completely altered if composition is the main factor.

Comparisons of the chemical compositions of iddingsite and associated olivine have led some workers (Ming-Shan Sun, 1957, p. 531; Wilshire, 1958, p. 140) to conclude that during alteration iron is oxidized and its proportion increased, water is added, and magnesium and silicon are subtracted. Brown and Stephen (1959, p. 258) came to essentially the same conclusions on the basis of structural considerations of olivine and iddingsite. These conclusions differ but slightly from those of Ross and Shannon (1925, p. 7-8), who believed that silica remains constant during alteration.

Ross and Shannon (1925) detected the variable chemical composition and optical properties of iddingsite but accepted it as a distinct mineral. From X-ray powder determinations, Ming-Shan Sun (1957) concluded that iddingsite consists of goethite and other amorphous substances. From similar study Wilshire (1958) thought goethite and smectite-chlorite are the major constituents. Brown and Stephen (1959), using single crystal X-ray techniques, state that iddingsite consists of goethite and a "layer lattice silicate," but are doubtful of the layer lattice silicate's identification with smectite-chlorite. Although recent workers do not agree on the number and specific identification of minerals, they all conclude that iddingsite is a mineralogical mixture.

The homogeneous optical properties displayed by iddingsite have been explained by Brown and Stephen (1959, p. 259) as follows:

> . . . homogeneity in optical properties occurs because small crystals of both components (goethite and a layer lattice silicate) are strictly oriented throughout a single grain. The parallel alignment arises from the nature of the alteration, the products of which inherit, goethite completely and the layer lattice silicate partly, the oxygen framework of the original olivine.

The overgrowths sourrounding olivine phenocrysts that contain an unaltered core offer support for this hypothesis. Although the overgrowths are separated from the core by a band of iddingsite, they always are in optical continuity with the core. This phenomenon necessarily demands that some portion of the original olivine structure remains in the iddingsite so as to permit the precipitation of fresh olivine in optical continuity with the core.

In some phenocrysts the iddingsite band only partially encloses the core. It is conceivable that fresh olivine could first precipitate at the unaltered patch or patches and then continue to grow, covering the iddingsite while maintaining optical continuity with the core. The rarity of such phenocrysts suggests that this supposed mechanism was of minor importance, if it occurred at all.

CONCLUSIONS

A consideration of the foregoing olivine-iddingsite relations suggests the following sequence of events which is similar to that proposed by Macdonald (1940, p. 156):

(1) Early olivine phenocrysts are partially resorbed while still in the magma chamber.

(2) Iron- and water-rich volatiles accumulate at the top of the vent and alter the phenocrysts just prior to and during extrusion. That some phenocrysts are pseudomorphed and others within the same specimen are only marginally

altered probably is a function of the grain size and duration a phenocryst remains in contact with the altering volatiles. Both small grain size and prolonged contact with the volatiles would promote extensive alteration. This alteration is not dependent upon the composition of the olivine phenocrysts.

(3) After extrusion the groundmass crystallized and overgrowths of ferriferous olivine were added to the altered phenocrysts.

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