

## THE NATURE OF IDDINGSITE IN SOME BASALTIC ROCKS OF NEW MEXICO\*

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### ABSTRACT

No description of iddingsite has demonstrated that it has a definite chemical composition or optical properties. It has been identified largely on the basis of its association with remnants of olivine or as pseudomorphous replacement aggregates. A study of many rocks from New Mexico and some from Colorado containing iddingsite show varying degrees of alteration of olivine which is believed to be largely accomplished in the deuteric stage, and may or may not be continued in the weathering process. The alteration of olivine to iddingsite occurs largely in basaltic rocks whose modal proportion of olivine exceed their normative proportion of olivine because of fractional crystallization.

Study of iddingsite samples from New Mexico and Colorado by the x-ray powder diffraction method shows that goethite is the only crystalline phase and that the other substances shown by chemical analysis to occur in iddingsite are largely amorphous. Iddingsite in this case may therefore be regarded as a complex alteration product of olivine rather than a true mineral.

### INTRODUCTION

Iddingsite is common in rocks of andesitic and basaltic composition in New Mexico (Fig. 1) as an alteration product of olivine. Usually it is associated with various amounts of remnant olivine. One sample from Carrizozo, New Mexico, shows that many olivine grains have completely altered to iddingsite. Usually iddingsite is identified by its brown color and by its association with remnant or as pseudomorphous replacement aggregates of olivine. In other words, if there is some brown material altered from olivine in andesitic or basaltic rocks, it is usually called iddingsite.

Iddingsite was named by Lawson (see Ross and Shannon, 1925) as a hydrous non-aluminous silicate of iron, magnesia, and soda. Lawson also pointed out that limonite was probably present as a pigment in iddingsite. It was first described in detail by Ross and Shannon (1925), and subsequently the composition and origin of iddingsite were discussed by Edwards (1938), Bogue and Hodge (1940), and others. A thorough study of the available data on iddingsite leads to the conclusion that iddingsite does not have a definite chemical composition or optical properties. Iddingsite is found so commonly in volcanic rocks in New Mexico that more exact data than were available previously were desired.

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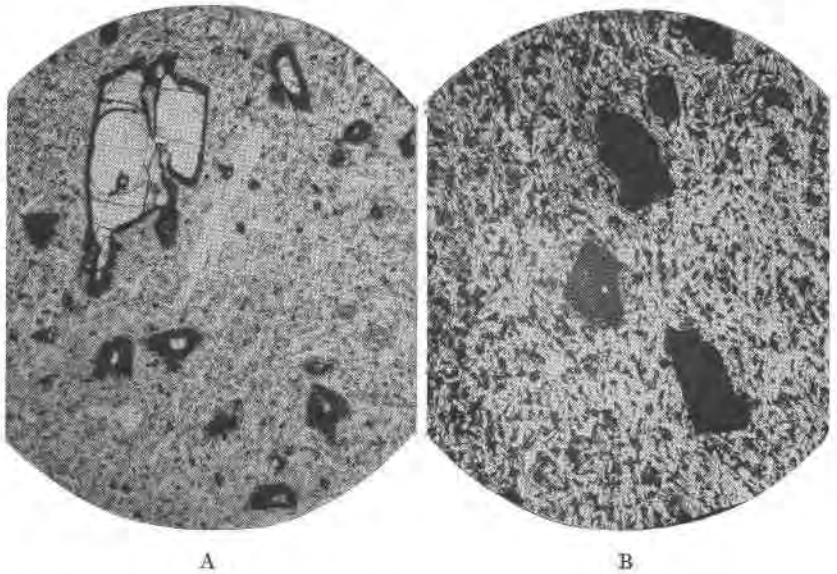


FIG. 1. Photomicrographs showing the occurrence of iddingsite in basaltic rocks. A. Olivine basalt, 132-D-142, from Cienega, New Mexico, showing the iddingsite rims, and the complete alteration of many small olivine grains to iddingsite. B. Basalt, 313-RE3, from Reserve, New Mexico, showing pseudomorphs of iddingsite after olivine. 15X.

### X-RAY ANALYSIS

X-ray powder diffraction photographs were made of all the iddingsite samples, including two original samples of Ross and Shannon (1925). A sample (No. 325-C-61) from Carrizozo, New Mexico provides the best powder diffraction pattern of cryptocrystalline goethite (Fig. 2), and the  $d$  values of this goethite are listed in Table 1. Ross and Shannon (1925), thinking that the  $\text{Fe}_2\text{O}_3$  content of a sample from Brazos River, New Mexico (Sample No. 9, Fig. 3.) was too high, did not include it in the

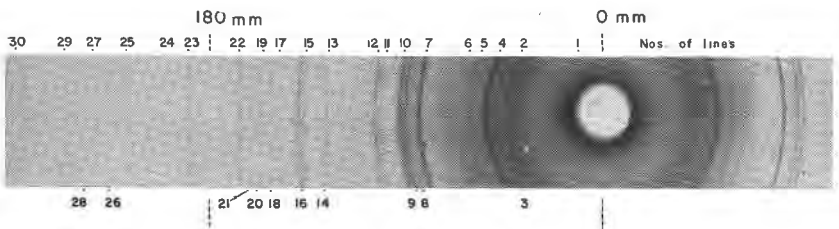


FIG. 2. X-ray powder diffraction pattern of cryptocrystalline goethite in iddingsite from Carrizozo, New Mexico. Camera diameter 114.59 mm., iron radiation,  $\text{Fe K}\alpha = 1.9373 \text{ \AA}$ , Mn filter.

calculation of the chemical formula of iddingsite. However, this sample also shows a good powder diffraction pattern of cryptocrystalline goethite. The pattern of goethite is shown by other samples, but not so well as by the two samples mentioned above. One original sample of Ross and Shannon (1925) from Paton Peak, Colorado shows a few powder diffraction lines of labradorite, and examination of this sample under the petrographic microscope shows the presence of some labradorite. Goethite is

TABLE 1. X-RAY POWDER DIFFRACTION DATA OF CRYPTOCRYSTALLINE GOETHITE IN IDDINGSITE FROM CARRIZOZO, NEW MEXICO

(Sample No. 325-C-61; Fe radiation, Fe  $K\alpha=1.9373$  Å, Mn filter)

Nos.	$d$ (meas.), Å	I	Nos.	$d$ (meas.), Å	I
1 <sup>1</sup>	14.8	10	16	1.693	5
2	5.01	<1	17	1.603	1
3	4.55	1	18	1.566	2
4	4.18	9	19	1.534	1
5	3.68	3	20	1.510	1
6	3.38	<1	21	1.487	2
7	2.70	8	22	1.453	5
8	2.58	<1	23	1.316	2
9	2.52	6	24	1.260	1
10	2.45	7	25	1.192	<1
11	2.27	<1	26	1.164	<1
12	2.20	3	27	1.140	<1
13	1.84	4	28	1.125	<1
14	1.807	1	29	1.103	1
15	1.720	2	30	1.055	2

<sup>1</sup> Intense blackening due to low angle scattering by the amorphous substances of the iddingsite.

found to be the chief crystalline phase and the other substances shown by chemical analysis to occur in iddingsite are largely amorphous. Whereas the powder diffraction lines of a massive goethite from Magdalena, New Mexico are narrow and distinct, those of the goethite in the iddingsite are broad and blurred (Fig. 2) and it is believed therefore, that the goethite in iddingsite is cryptocrystalline. The intense blackening at about  $d=14.8$  Å (No. 1 arc, Fig. 2) is due to low angle scattering by the amorphous material of iddingsite. Those samples which do not show good powder diffraction lines contain relatively smaller amount of goethite and larger amount of amorphous silica, magnesia, and water. If minute grains of olivine are included in iddingsite concentrated from

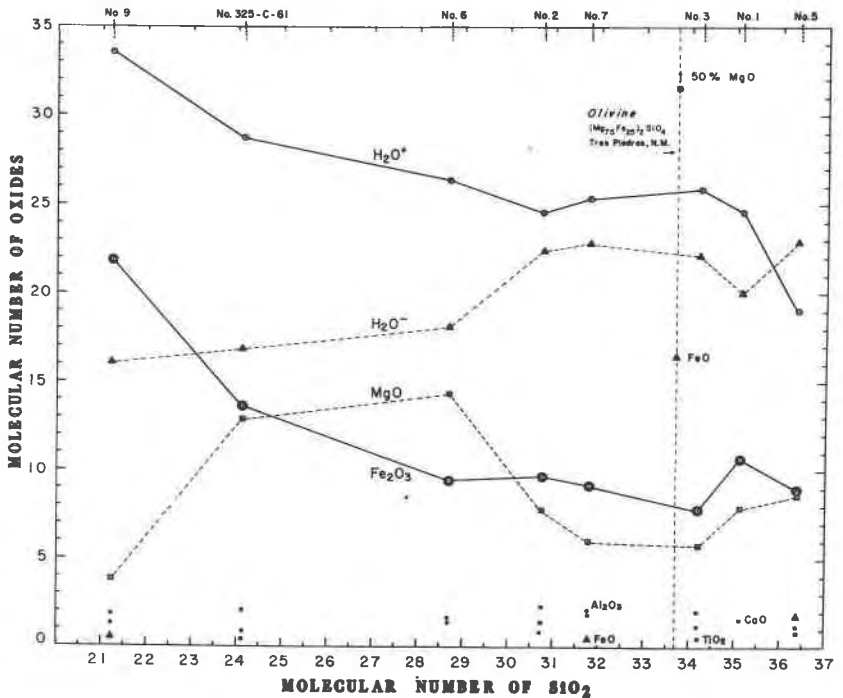


FIG. 3. Variation diagram of iddingsite samples. The composition of a fresh olivine from Tres Piedras, New Mexico is included for reference. Data on samples Nos. 1, 2, 3, 5, 6, 7, 9 are those of Ross and Shannon (1925).

the rock sample, a powder diffraction pattern will show the presence of both goethite and olivine.

#### CHEMICAL COMPOSITION

A complete chemical analysis of iddingsite from Carrizozo, New Mexico is listed in Table 2. The variation in the chemical composition of different samples of iddingsite is illustrated graphically by the variation diagram (Fig. 3). This diagram is prepared by converting the weight percentage of each constituent in the chemical analysis to the molecular number, and the molecular numbers of all the constituents are calculated to a total 100. The molecular numbers of various oxides, including water, are plotted against silica. There are five major constituents, namely, H<sub>2</sub>O<sup>+</sup>, H<sub>2</sub>O<sup>-</sup>, Fe<sub>2</sub>O<sub>3</sub>, MgO, and SiO<sub>2</sub>, and four minor constituents, namely, CaO, Al<sub>2</sub>O<sub>3</sub>, FeO, and TiO<sub>2</sub>. Trace amounts of K<sub>2</sub>O and Na<sub>2</sub>O are not shown in this diagram. It is shown that as the molecular number of silica increases from about 21 to 37, the molecular number of Fe<sub>2</sub>O<sub>3</sub> decreases

from 22 to 9, and that of  $\text{H}_2\text{O}^+$  decreases from 33 to 19.  $\text{H}_2\text{O}^-$  increases slightly with the increase of silica. The variation of MgO is rather irregular.

It seems significant that the ratio between the molecular number of  $\text{Fe}_2\text{O}_3$  and  $\text{H}_2\text{O}^+$  ranges from  $1:1\frac{1}{2}$  to  $1:3$ . The change of this ratio has no relation with the molecular number of silica, MgO, or  $\text{H}_2\text{O}^-$ . Also the change of this ratio does not reflect the degree of the alteration of olivine. Nevertheless, the total molecular number of  $\text{Fe}_2\text{O}_3$  and  $\text{H}_2\text{O}^+$  is high in iddingsite from thoroughly altered olivine, whereas the molecular number of silica is high in iddingsite from partly altered olivine. It is believed that the  $\text{Fe}_2\text{O}_3$  and  $\text{H}_2\text{O}^+$  ratio represents the composition of goethite in iddingsite.

TABLE 2. CHEMICAL COMPOSITION OF IDDINGSITE FROM CARRIZOZO, NEW MEXICO\*  
(Sample No. 325-C-61)

$\text{SiO}_2$	28.	$\text{Na}_2\text{O}$	n.d.
$\text{TiO}_2$	0.64	$\text{K}_2\text{O}$	n.d.
$\text{Al}_2\text{O}_3$	4.	$\text{P}_2\text{O}_5$	0.32
$\text{Fe}_2\text{O}_3$	42.	$\text{H}_2\text{O}^+$	10.
FeO	0.0	$\text{H}_2\text{O}^-$	5.84
MnO	0.35	$\text{CO}_2$	0.1
MgO	10.	$\text{ZrO}_2$	n.d.
CaO	1.		
		Total	102.25

\* Chemical analysis by Dr. H. B. Wiik, Helsinki, Finland, with 0.45 gm of sample.

#### OPTICAL PROPERTIES

Individual grains of the iddingsite from Carrizozo, New Mexico were selected under the binocular microscope. They were crushed and their optical properties studied by the immersion method. Most of the grains show aggregate or fibrous polarization, and only a few small grains of about .02 mm in diameter are optically homogeneous. These small grains are biaxial with large optical angle. They have weak dispersion. The color varies from light yellow to dark brown. The minimum refractive index is  $1.680 \pm .002$ , and the maximum refractive index is  $1.74 \pm .01$ . The birefringence is about 0.06. A few large dark brown and rather opaque grains appear to have much higher refractive indices. It is believed that the maximum and minimum refractive indices are not the same for all the grains, although it has been difficult to make accurate determination. A few small fresh olivine grains are found among the iddingsite grains. The composition of the olivine is  $\text{Fo}_{78}\text{Fa}_{22}$ , estimated according to its refractive indices.

Published data (Ross and Shannon, 1925) show that there is great variation in the optical properties of iddingsite. For instance,  $\alpha$  may vary from 1.608 to 1.792,  $\beta$  may vary from 1.650 to 1.827, and  $\gamma$  may vary from 1.655 to 1.864. No definite relation between the refractive indices and the chemical composition of iddingsite has been found, although there may be a slight indication showing that the higher the refractive indices the lower the  $\text{H}_2\text{O}^+$  content of the goethite in iddingsite. For instance, the  $\text{Fe}_2\text{O}_3$  and  $\text{H}_2\text{O}^+$  ratio of the iddingsite from Brazos River, New Mexico (Fig. 3, sample No. 9) is 1:1½, and its refractive indices are:  $\alpha=1.792$ ,  $\beta=1.827$ , and  $\gamma=1.864$ . Such ratio of the iddingsite from Carrizozo, New Mexico (Fig. 3, sample No. 325-C-61) is 1:2, and its refractive indices are 1.68 to 1.74. Sample No. 1 (Fig. 3) of Race Creek, Colorado, and samples Nos. 2 and 3 of La Jara Creek, Colorado (Fig. 3) have lower refractive indices, and their  $\text{Fe}_2\text{O}_3$  and  $\text{H}_2\text{O}^+$  ratio ranges from 1:2½ to 1:3. However, the  $\text{Fe}_2\text{O}_3$  and  $\text{H}_2\text{O}^+$  ratio of the iddingsite from Gato Creek, Colorado (Fig. 3, sample No. 7) is 1:3, and its refractive indices are:  $\alpha=1.70$ ,  $\beta=1.73$ , and  $\gamma=1.74$ , which are higher than those of samples Nos. 1, 2, and 3.

#### ORIGIN

Previous authors have maintained that (1) iddingsite is a true mineral and was formed in the deuteritic stage in the presence of heat, water, and gases after the magma reached oxidizing conditions at or near the surface, (2) that a hard crust on the magma prevented the escape of gases and water, and that (3) the magma must have come to rest before iddingsite was formed.

The present study has pointed out that iddingsite is not a true mineral but a complex alteration of olivine, that goethite is the only crystalline phase, and that the other substances shown by chemical analysis to occur in iddingsite are largely amorphous. It is believed that the alteration of olivine to iddingsite occurs under the following conditions:

(1) This alteration occurs largely in intermediate or basaltic rocks, whose modal proportions of olivine exceed their normative proportions of olivine because of fractional crystallization of the magma (Bowen, 1928). The normative proportion is a very close approximation to the stoichiometric proportion of olivine which is expected to occur in a rock crystallized from a magma without fractionation. On the other hand, olivine of limburgite, kimberlite, dunite or other ultrabasic rocks alters mainly to serpentine by hydrothermal solution (Wells, 1929). The following examples may illustrate the composition of certain rocks in which the alteration of olivine to iddingsite is likely to occur. The phenocrysts of olivine of a basalt from Cienega, New Mexico (Sample No. 132-D-85) are altered in various degrees to iddingsite. This basalt contains 7.4 per

cent of olivine and some iddingsite in the mode, but none in the norm (Table 3). An olivine basalt from the same area (Sample No. 132-D-142) contains 5.5 per cent of unaltered olivine and 7.1 per cent of iddingsite in the mode and 6.03 per cent of olivine in the norm (Table 4). Absorption embayments and reaction rims of various width which are common in the olivine-iddingsite phenocrysts may have been the weak points where the alteration of olivine to iddingsite began.

TABLE 3. MODE AND NORM OF A BASALT FROM CIENEGA, NEW MEXICO  
(Sample No. 132-D-85)

Mode		Molecular norm	
Olivine, including iddingsite rim	7.4%	Quartz	0.38%
Augite	0.2	Orthoclase	12.45
		Albite	30.05
Groundmass:	92.4	Anorthite	19.67
fine granular and glassy; augite,		Wollastonite	8.10
magnetite, plagioclase and glassy		Enstatite	18.14
material		Ferrosilite	2.10
		Magnetite	4.68
		Ilmenite	2.16
		Apatite	2.27

(2) Because of the fractionation of the magma, volatile constituents in the magma may be continuously concentrated to form a copious residual aqueous solution in the deuteric stage in which the alteration of olivine to iddingsite is largely accomplished. Olivine or other silicate minerals may be decomposed by the action of the residual aqueous solution (Bowen, 1928). Some  $\text{SiO}_2$  and  $\text{MgO}$  of the olivine will be dissolved in the solution and carried away, whereas the  $\text{FeO}$  of the olivine will be oxidized to  $\text{Fe}_2\text{O}_3$  and combined with  $\text{H}_2\text{O}^+$  to form limonite.  $\text{H}_2\text{O}^-$  of the iddingsite may be added partly if not largely in the weathering process. The process in which a noteworthy amount of  $\text{MgO}$  and  $\text{SiO}_2$  of the decomposed olivine is dissolved and lost in the residual aqueous solution is analogous to weathering process. Goldich (1938) pointed out that during weathering a large amount of the  $\text{MgO}$ - and  $\text{SiO}_2$ -content of a rock is lost, whereas  $\text{Fe}_2\text{O}_3$  and water gain relatively. A large proportion of the  $\text{FeO}$ -content of a rock is oxidized to  $\text{Fe}_2\text{O}_3$  during weathering. Therefore, it is inferred that the alteration of olivine to iddingsite may be continued during weathering.

As far as the alteration products are concerned, the alteration of

TABLE 4. MODE AND NORM OF OLIVINE BASALT FROM CIENEGA, NEW MEXICO  
(Sample No. 132-D-142)

Mode		Molecular norm	
Olivine	12.6%	Quartz	none
5.5% fresh olivine		Orthoclase	5.25%
7.1% iddingsite		Albite	23.10
Augite	1.9	Anorthite	25.53
Plagioclase	0.6	Wollastonite	6.10
Magnetite	0.4	Enstatite	18.60
		Ferrosilite	4.52
Groundmass:	84.5	Forsterite	4.86
fine granular and glassy; augite, magnetite, plagioclase, and glassy material		Fayalite	1.17
		Magnetite	5.62
		Ilmenite	2.34
		Apatite	0.61
		Calcite	2.30

olivine to iddingsite is somewhat analogous to the alteration of ilmenite to leucoxene. Leucoxene is composed largely of cryptocrystalline rutile and amorphous titania and iron oxides, whereas iddingsite is composed largely of cryptocrystalline goethite and amorphous magnesia and silica.

(3) The original olivine must contain appreciable amounts of iron. Under oxidizing condition in the deuteric stage, the FeO of the olivine is oxidized to Fe<sub>2</sub>O<sub>3</sub>.

The experiments on hydrothermal alteration of olivine to serpentine by Wells (1929) may throw some light on the condition under which the alteration of olivine to iddingsite may occur. The olivine from Jackson County, North Carolina, used by Wells contains 7.30 per cent of FeO. The olivine sample was treated in various solutions, under various temperature and pressure. The results of the experiments which may throw some light on the formation of iddingsite are summarized as follows:

- (1) In various solutions and temperature, but under one atmosphere pressure, olivine remains fresh and unattacked.
- (2) In 0.1 molar HCl solution contained in a sealed pyrex tube, at 200° C. and 15 atmosphere pressure, red powder of iron oxide is formed. In other solutions under similar conditions, olivine may be partly attacked but no red powder of iron oxide is formed. In a tightly sealed copper container small amount of red iron oxide is formed in HCl solution.



- (3) In a solution saturated with  $\text{SO}_2$ , at  $200^\circ \text{C}$ . and 15 atmosphere pressure, olivine disappears completely with the precipitation of pyrite and some silica.  $\text{MgO}$  and some  $\text{SiO}_2$  of the olivine are dissolved in the solution. The solubility of  $\text{MgO}$  and  $\text{SiO}_2$  is higher at higher temperature and pressure.

Therefore, it may be concluded generally that the alteration of olivine to iddingsite occurs most likely in a highly oxidizing solution containing  $\text{HCl}$ , at high temperature and under high pressure. The high pressure in a rock may be maintained in the deuteritic stage if a hard crust on the magma is formed as suggested by previous authors.

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