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FORMATION OF IDDINGSITE RIMS ON OLIVINE: A TRANSMISSION ELECTRON MICROSCOPE STUDY

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Abstract—Iddingsite rimming olivine in a basanite from the Limberg, Germany, is composed of saponite and goethite. Transmission electron microscopy of ion-thinned, oriented crystals suggests a two-stage alteration process. At first, the olivine breaks into a mosaic of 50-Å diameter {110} bounded needle-shaped domains which change to a metastable hexagonal phase having $a = 3.1$ Å and $c = 4.6$ Å, probably of close-packed, metal-oxygen octahedra. This reaction opens solution channels in the olivine which are detectable from about 20-Å diameter and are parallel to the olivine y-axis. Laths of smectite, one or two layers thick, 20 Å wide, and as much as 100 Å long parallel to their y-axis nucleate from the metastable phase and begin to fill in the solution channels. The laths orient with smectite (001) parallel to olivine (100). As the channels widen, prismatic {110} goethite crystals form directly from the metastable hexagonal phase. This first stage thus provides heterogeneous nuclei of smectite and goethite, formed epitactically and perhaps topotactically from a metastable intermediary.

In a second stage, these nuclei enlarge by deposition from solution as water migrates readily through the solution channels. A reduction in total volume allows smectite veins to form, misoriented with respect to the olivine. The reaction conserves iron, requires the addition of aluminum and water, and releases magnesium and silicon. Electron microprobe analyses of the iddingsite indicate that the smectite is saponite.

Key Words—Goethite, Iddingsite, Olivine, Saponite, Transmission electron microscopy, Weathering.

INTRODUCTION

Under hydrothermal and weathering conditions olivine is a highly reactive mineral. Iddingsite and bowlingite are familiar petrographic descriptions of olivine alteration products. Iddingsite has been shown to be a mixture of goethite and layer silicates that formed as crystallographically parallel aggregates and inherited a large degree of structural orientation from the parent olivine. Brown and Stephen (1959) showed that the layer silicates in iddingsite develop with their close-packed octahedral sheet parallel to the close packed (100) plane of olivine, and that most goethite crystals grow with X-, Y-, and Z-axes parallel to X-, Y-, and Z-axes of the parent olivine. Baker and Haggerty (1967) found that the layer silicates in iddingsites were generally interstratified smectite/chlorite or smectite/hydromica and smectite. In a survey of olivines and their pseudomorphs, Delvigne *et al.* (1979) emphasized that the composition of iddingsite is variable, both between samples and within a sample, and that the chemical changes involved in this alteration of olivine are a loss of Mg and Si, oxidation and increase in Fe content, and the addition of Al, particularly near the crystal rim.

Of special interest in hydration and oxidation reactions are the details of the reaction mechanism, including the extent of structural inheritance between primary and alteration minerals, and the nature of diffusion pathways, both of which must affect the rate of alteration. Such aspects are especially relevant to weathering studies, as they affect the process of element release and new mineral formation. Many olivines in basalts have been partly iddingsitized before exposure to weathering, and according to Baker and Haggerty (1967), weathering produces similar alteration assemblages. Iddingsite formation before weathering can therefore be thought of as a simplified example of olivine alteration, in that only the olivine is affected. In the present study, the formation of iddingsite rims around olivine crystals from Limberg, Germany, has been studied by transmission electron microscopy.

SAMPLE AND TECHNIQUES

Basanite containing well-formed olivine crystals as much as 2 mm long and titanaugite in a glassy groundmass crop out at Sasbach, Kaiserstuhl, Germany. The olivine crystals have a yellow-orange alteration rim that is thought to have formed by the reaction between olivine and water contained in the glass during the cooling of the lava. The tops of the lava flows show the development of palagonite, which has been the subject of a parallel study (Eggleton and Keller, 1982). The palagonite, which is paler yellow than the iddingsite, is monomineralic, poorly crystallized magnesian-nontronite.

Electron microprobe analyses, using an energy dispersive system (N. Ware, analyst) and a wavelength-dispersive system (K. Norrish, analyst) show the ol-

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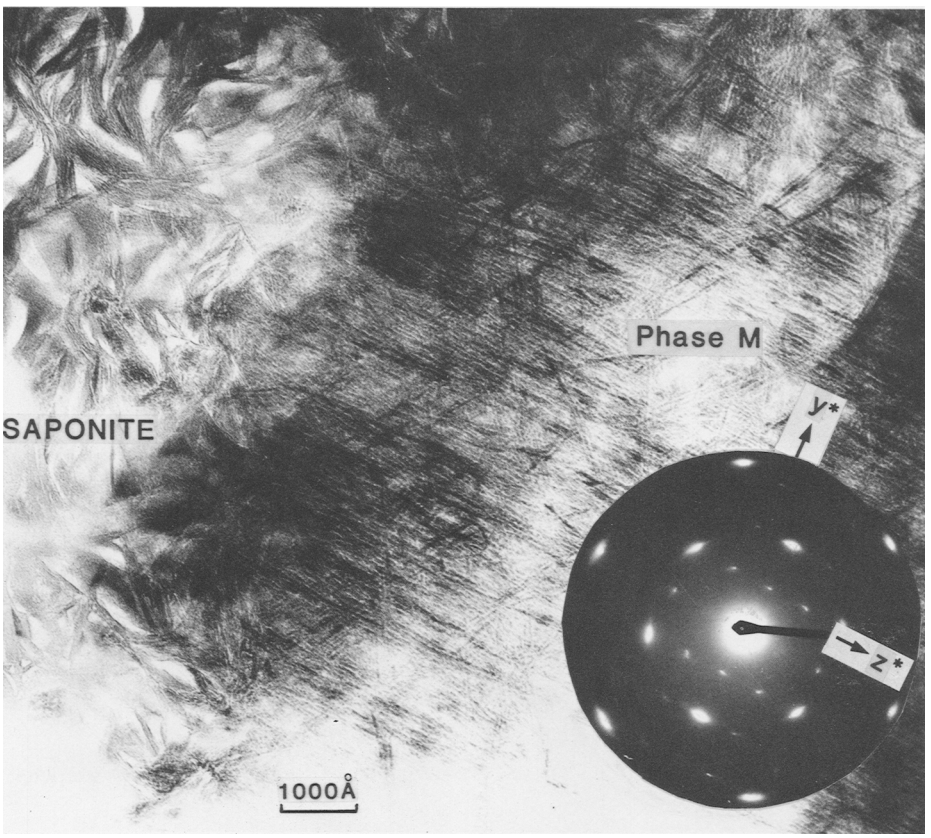


Figure 1. Transmission electron micrograph of [100] olivine projection showing the first-formed metastable phase M as needles elongated parallel to olivine *Z*. Later recrystallization forms the saponite aggregate. In the electron diffraction pattern, reflections from phase M are large and lens shaped, those from olivine are sharp. Saponite reflections were not recorded.

ivine to be zoned from Fo_{86} at the core to Fo_{81} near the rim. The alteration iddingsite has a minimum Mg/(Fe + Mg) ratio of 0.5, but 7 of 8 energy dispersive analyses show this ratio to be 0.59 + 0.01. Of 8 wavelength dispersive analyses, 6 have Mg/(Mg + Fe) ratios between 0.56 and 0.61; the other two are close to 0.48. The values listed in Table 2 are averages of the 12 analyses with Mg/(Mg + Fe) close to 0.6.

Table 1. Relation between the crystallographic axes of olivine and of saponite and goethite in iddingsite grown in an oriented aggregate.

Olivine	Goethite	Saponite
X	X	Z
Y	Y	X
Z	Z	Y
$a = 4.75$ Å	$a = 4.65$ Å	d(001) ~ (2 × 4.75) ~ 9.5 Å
$b = 10.2$ Å	$b = 10.0$ Å	$a = (10.2/2) = 5.1$ Å
$c = 6.0$ Å	$c = 3.0$ Å	$b = (6.0 \times 3/2) = 9.0$ Å

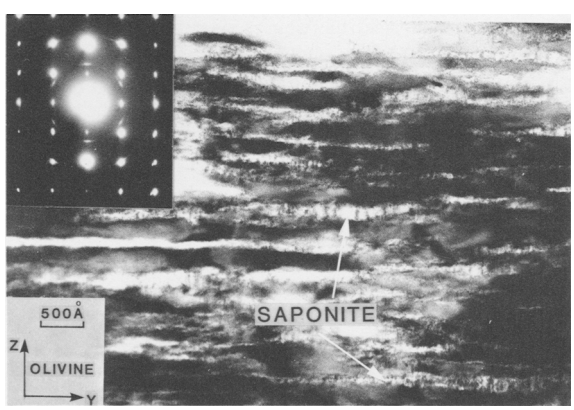


Figure 2. Transmission electron micrograph of [100] olivine projection, showing development of early layer silicate within olivine, appearing as thin strips within channels parallel to olivine *Y*. The electron diffraction pattern inset shows lens-shaped clay diffraction spots and sharp olivine reflections. Note the weak 110 and 020 saponite reflections, not present in Figure 1.

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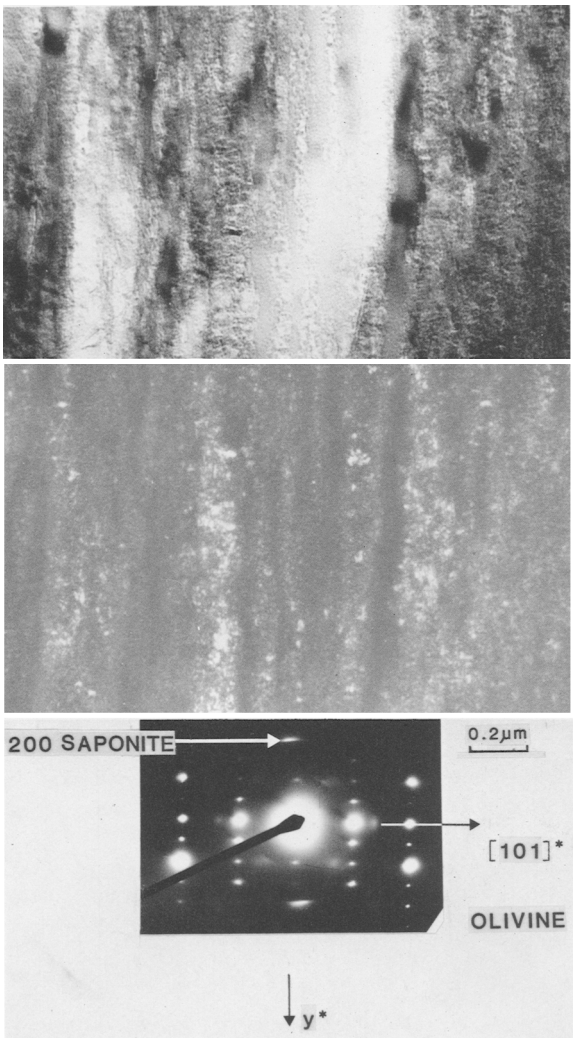


Figure 3. Transmission electron micrograph showing bright-field (upper) and dark-field images of saponite + olivine mixtures. In the bright-field image the saponite appears in mottled bands perpendicular to olivine [101]*. In the dark-field image, formed from the 200 saponite reflection with the olivine tilted a few degrees off the zone axis, the texture of the early layer silicate is revealed.

Transmission electron microscope (TEM) examinations were made using a JEOL 100CX electron microscope with a side-entry, double-tilt stage, supplemented with a JEOL 200CX with a high resolution, top-entry goniometer. Crystals were selected from optical thin sections, glued to electron microscope grids, cut out of the section, and ion-beam thinned. This process involves heating the sample to about 100°C in vacuum, a treatment which collapses smectite layers to 10 Å. The distinction between talc, mica, and smectite was generally not possible from TEM lattice images alone.

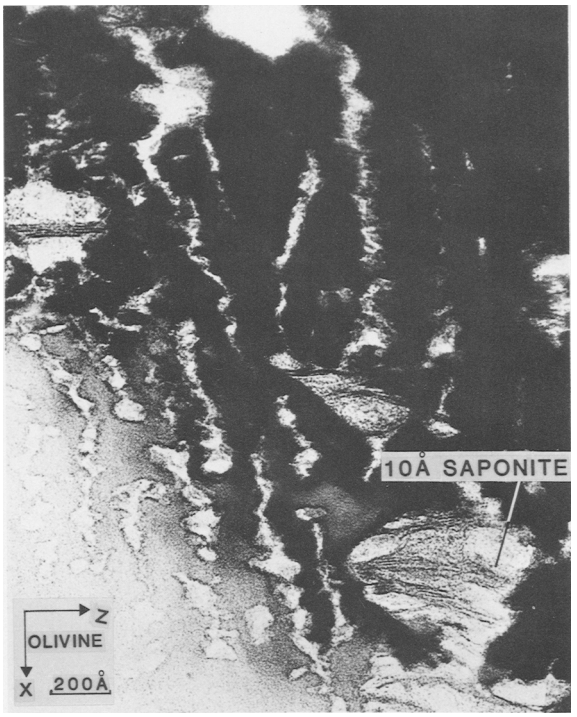


Figure 4. Transmission electron micrograph of [010] projection of altered olivine showing ragged holes, interpreted as sections across alteration channels. Larger holes enclose thin packets of 10-Å layer silicate.

ELECTRON MICROSCOPE RESULTS

[100] sections

Viewed down the olivine *X*-axis, the alteration is seen to begin as the development of thin lamellae, elongated parallel to olivine *Z*, yielding a hexagonal diffraction pattern with $a = 3.1$ Å (Figure 1). Although the prominent, broad, diffraction spots of this phase are ubiquitous in partly altered olivine, it is difficult to distinguish it from the layer silicate which appears to form next and grows as discontinuous strips and patches. The layer silicate is thought to be unexpanded (or vacuum collapsed) saponite on the basis of its 10-Å basal spacing and on chemical evidence. Composite diffraction patterns from olivine and saponite confirm the orientation relations of Table 1 (Figure 2). The alteration is at first restricted to narrow bands (<100 Å wide) extending parallel to olivine *Y* which widen as alteration proceeds. The layer silicate at this early stage is extremely vulnerable to electron beam damage, and lattice images proved to be almost unobtainable, or to be of such low contrast as to be unreproducable photographically. The original plates show that the layer silicate lattice is continuous with the olivine lattice.

Dark field imaging at lower magnification (Figure 3) reveals the shape and distribution of the neo-formed

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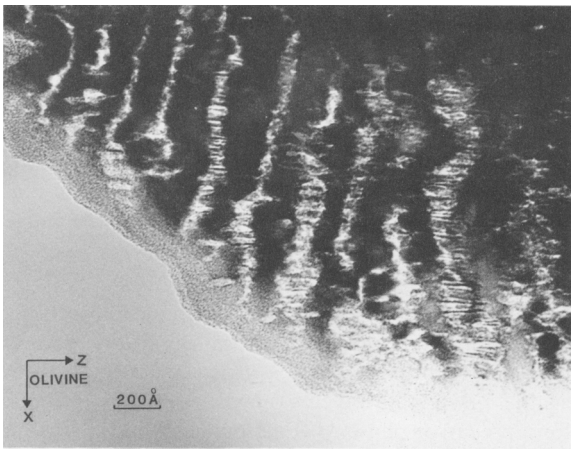


Figure 5. Transmission electron micrograph of [010] projection of altered olivine showing extension of earlier pipe-like channels to crevices filled irregularly with oriented clay layers.

saponite, strips of which are elongated across the channels (i.e., along saponite *Y* (olivine *Z*),), and it is clear that the layer silicate crystals nucleate heterogeneously throughout the olivine. On the micrometer to millimeter scale there appears to be an advancing "front" of iddingsite inwards from the crystal edge, but at the nanometer scale, alteration nuclei are randomly scattered.

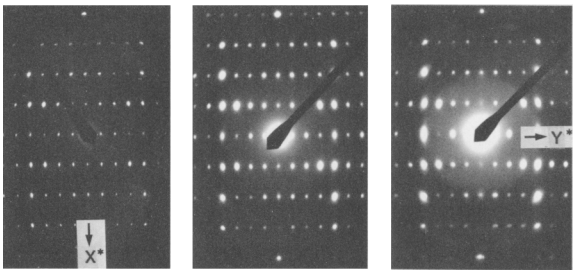


Figure 7. Transmission hk0 electron diffraction patterns of successively more altered olivine. Reduction in crystallite size is indicated by the increase in the reflection width, and the change in composition from olivine by intensity changes (for example between 020 and 040).

The hexagonal nature of the layer silicate *X*-*Y*-plane allows three choices of axes, with *Y* either parallel to olivine *Z*, or ⟨031⟩. The elongation of the earliest formed layer silicate crystals parallel to olivine *Z* gives a morphological reason for referring the layer silicate *Y* axis to this direction rather than to the pseudo-hexagonal equivalents.

[*010*] *sections*

Only one crystal was viewed down the *Z*-axis. In this crystal olivine is peppered with ragged holes across

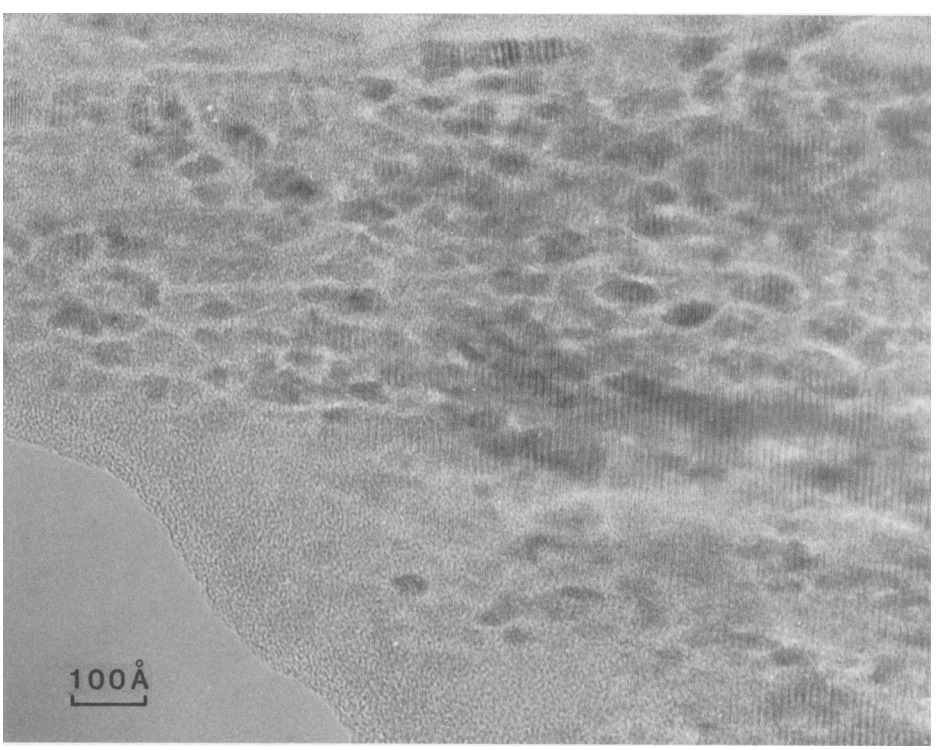


Figure 6. Transmission electron micrograph of [001] projection showing the olivine crystal breaking into a mosaic of [110]-bounded fragments.

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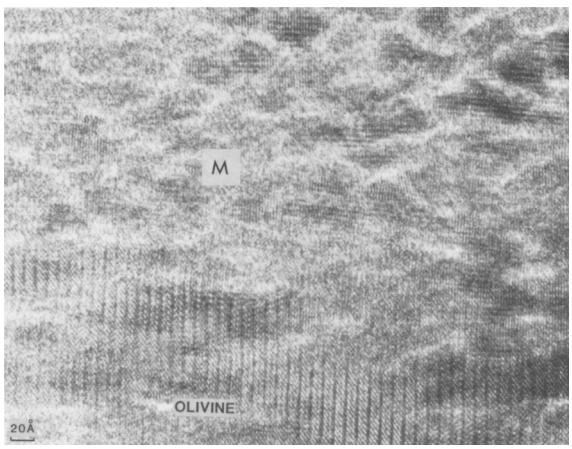


Figure 8. High-resolution transmission electron microscopy image showing phase M formed from fragmented olivine. [001] projection.

which are thin foliae of saponite (Figure 3). Thicker packets have 10-Å layer spacings, but where only two or three fringes were recorded, the spacings vary up to 20 Å (Figure 4). Calculations of electron images from two mica layers (unpublished) show that the measured fringe spacing can change by 25% with focus, hence distinction between 9- and 10-Å spacings or between 14- and 15-Å spacings requires a complete through-focus series. These clays damage so rapidly, that such extended sequences of photographs are generally not possible.

The holes, which are interpreted as cross sections of tubes, are as small as about 20 Å across. As they increase in diameter they coalesce into strips 40 or 50 Å thick and hundreds of Ångstrom units wide parallel to olivine *X* (Figure 4).

[*001*] sections

Views along the olivine *Z*-axis show the alteration mechanism with greatest clarity. At first, the olivine breaks into a mosaic of diamond-shaped domains, each about 50 Å long, bounded by {110} edges (Figure 6). A gradual change in structure is indicated by a change in the relative intensities of the electron diffraction maxima, notably an enhancement of 040, 140, and 240 and a broadening of the reflections (Figure 7). A similar progression is shown by 0k*l* reflections, where 040 and 022 strengthen and broaden as alteration proceeds (Figure 1). The olivine domains also change their lattice fringe image, with the 5.2-Å 020 repeat giving way to 2.6-Å lattice fringes, and with new fringes appearing parallel to olivine (100) spaced at about 4.5 Å. The crystals of this new phase never achieve a size greater than a few hundred Ångstrom units and are presumably metastable. The cell parameters, hexagonal, $a = 3.1$, $c = 4.5$ Å, and the presumed Mg-rich composition suggest an octahedral layer structure similar to brucite; however, until more data are available, it is unwise to call it by a mineral name. For convenience, it will be referred to here as 'phase M' (Figures 8 and 9).

The second stage in the alteration is the formation of the 10-Å layer silicate. This phase forms in intimate association with phase M; however, no micrographs are available which show structural continuity between the two. In other areas the saponite layers develop against olivine; however, no evidence has been found for a precursor phase M (Figure 10). In such areas the saponite exhibits a close, though not always exact, orientation relation to the olivine. Most commonly, 2:1 layers form with (001) parallel to olivine (100) (or parallel to the presumed octahedral layers of phase M).

By this second stage of the alteration, the solution channels seen in [010] and [100] projection are clearly developed. They pinch and swell and form discontinuous lenses as much as 100 Å across and more than 500 Å long. Wider channels contain thicker saponite packets which appear to have grown independently of the olivine structure after their initial nucleation. In some channels the saponite conforms in a general way to the early orientation relation; in others it is quite irregular. The wider channels also contain remnant diamond-shaped crystallites which are similar in appearance to microcrystals of fibrous goethite (Smith and Eggleton, 1983), and on this basis are interpreted as goethite. These crystallites, however, also resemble the initial diamond-shaped domains of phase M, and their identification as goethite must be regarded as tentative (Figures 11 and 12).

CHEMICAL RESULTS

Average electron microprobe analyses of 1-μm diameter areas are listed in Table 2. The electron microscope images and diffraction patterns show only 10-Å layer silicate and goethite in the alteration assemblage, and the analysis is therefore expressed in terms of these minerals. For the 10-Å phase, a smectite composition was assumed, with (Si + Al) = 4 in the tetrahedral layers, then Mg was allocated to the octahedral layer and interlayer. Almost enough Mg is present to fill these sites; thus, the smectite is saponite, and the Fe can be allocated to goethite. The study of palagonite from the same samples showed that the alteration of the glass proceeded without Fe loss. By assuming that the formation of iddingsite also conserves iron, a reaction can be written:

$$\underset{\text{(6.14 Olivine)(540 Å}^3\text{)}}{6.14Mg_{1.63}Fe_{0.37}SiO_4} + 12.88H^+ + 0.37Al^{3+} + 3.67H_2O + 0.55O_2 \rightarrow$$

$$\underset{\text{(Saponite)(351 Å}^3\text{)}}{Mg_{0.18}(Mg_{2.85}Fe^{3+}_{0.01})(Al_{0.37}Si_{3.63})O_{10}(OH)_2 \cdot 3H_2O} + 2.09FeO(OH) + 2.53H_4SiO_4 + 6.99Mg^{2+}$$
$$+ \underset{\text{(2.09 Goethite)(74 Å}^3\text{)}}{}$$

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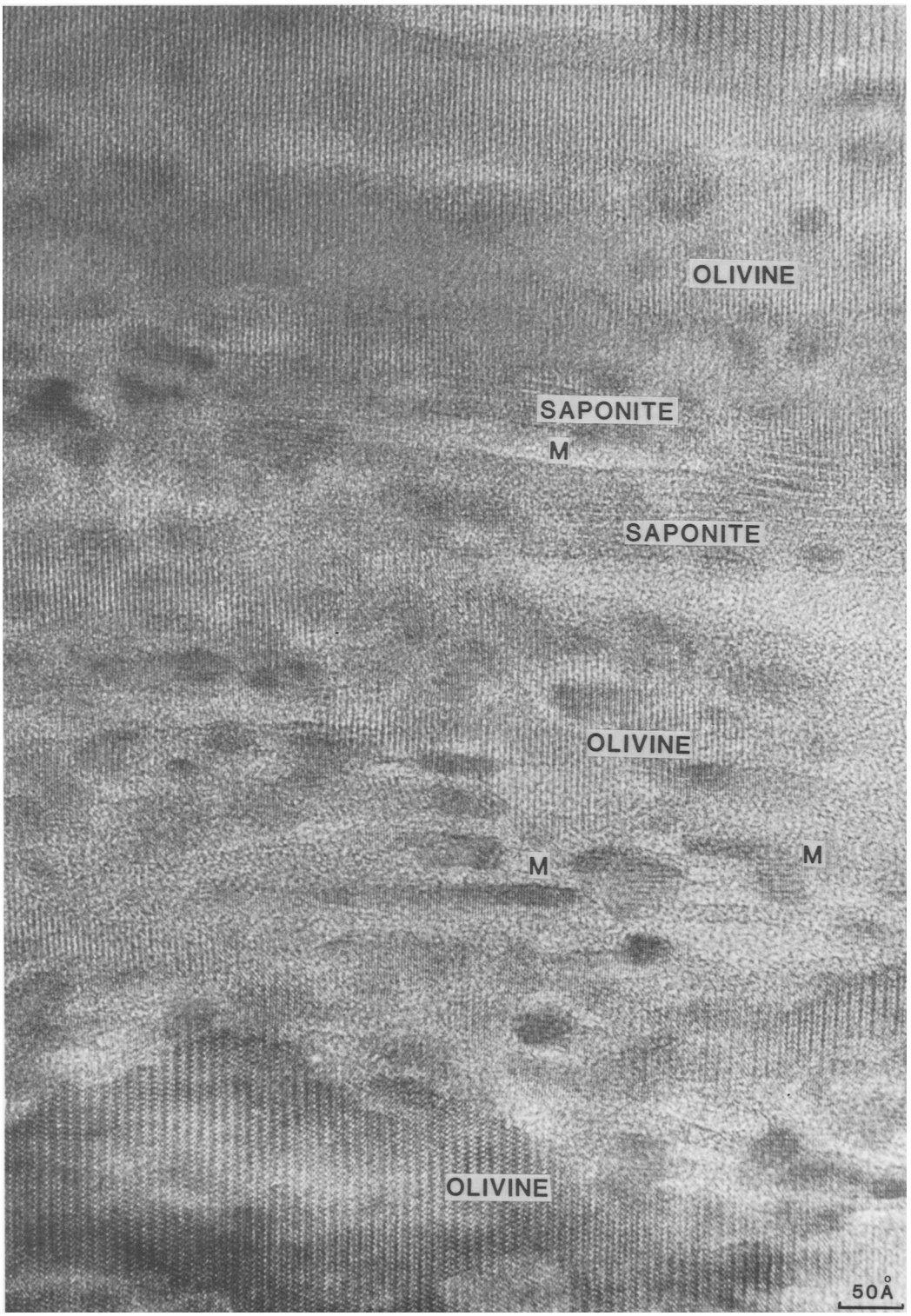


Figure 9. High-resolution transmission electron microscopy image of an alteration channel in olivine, showing phase M (2.6-Å fringes) remnant olivine (10-Å, 010 lattice fringes) and saponite (10-Å, 010 lattice fringes) roughly parallel to olivine (100)).

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Figure 10. Transmission electron micrograph of saponite layers formed on olivine. Some saponite is parallel to olivine (100), other layers are inclined at about 15° to olivine (100).

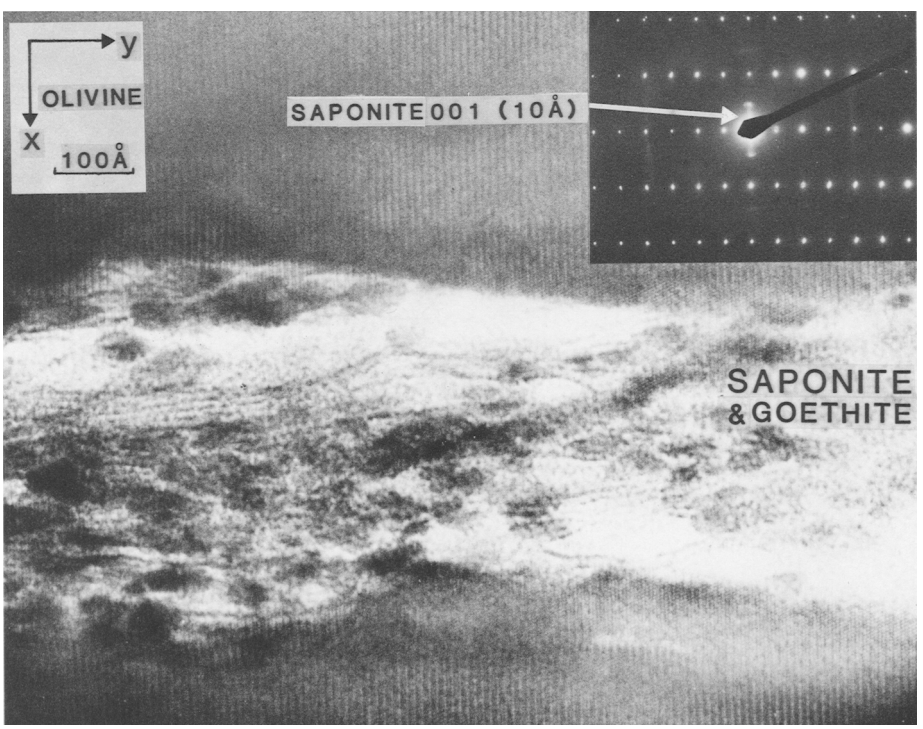


Figure 11. Transmission electron micrograph of saponite and goethite filling an alteration channel in olivine.

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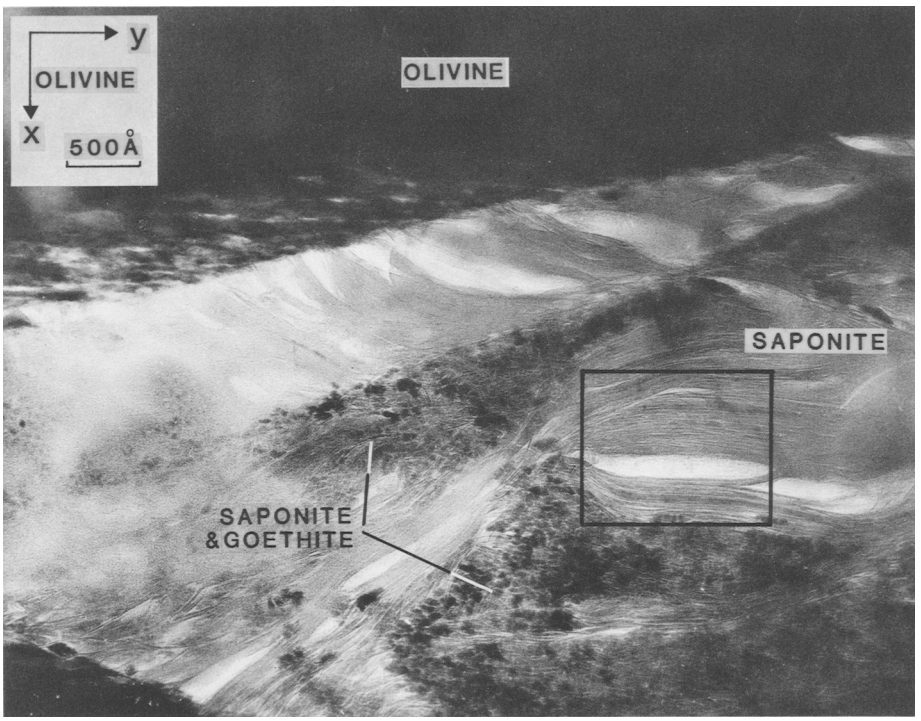


Figure 12. Transmission electron micrograph of wide alteration channel in olivine filled with recrystallized saponite and goethite.

These calculations indicate a considerable volume decrease (~20%) in this alteration process. The electron micrographs clearly show many gaps between clay and goethite in the fully altered regions, consistent with such a large change in volume. The measured density of the alteration assemblage of 2.42 g/cm³ is in agreement with the calculated density of 2.43 g/cm³. The minor and trace elements Ti, V, Cr, Mn, Co, and Ni were also analyzed at 15-μm intervals from fresh olivine to the alteration rim. As shown in Table 2, Mn increases in the alteration zone to about the same extent as Fe, thus, the reaction appears to conserve Mn as well as Fe. Mn is common in goethite, presumably substituting for Fe. Al, Ti, and V increase considerably in the iddingsite and must therefore have diffused in from the surrounding glass which contains 2.8% TiO_2 and 18.3% Al_2O_3. The other trace elements (Cr, Co, and Ni) are reduced in the iddingsite.

Table 2. Chemical data for olivine and iddingsite from the Limberg.

	Analyses		Structural formulae		
				Iddingsite	
	Olivine (wt. %)	Iddingsite (wt. %)	Olivine to 4 Si	to 1.421 Fe	to 4 (SiAl)
SiO_2	38.85	37.96	4	2.357	3.63
Al_2O_3	0.05	3.28	0.006	0.239	0.37
FeO	16.50	27.41	1.421	1.421	2.19
MnO	0.20	0.30	0.018	0.016	0.02
MgO	42.40	21.29	6.506	1.969	3.03
CaO	0.40	0.93	0.044	0.063	0.10
Total	98.40	91.17	11.995		
	(ppm)	(ppm)			
Ti	100	1200			
V	30	200			
Cr	200	80			
Mn	1500	2300			
Co	200	100			
Ni	1700	500			

The difference between columns 3 and 4 in Table 2 and the reaction equation above show the elemental gains and losses during the formation of iddingsite. Baker and Haggerty (1967) also concluded that most of the Fe released by olivine was retained as goethite, while considerable amounts of MgO and SiO_2 (as much as to 80% and 75%, respectively) were lost from the olivine. The Limberg iddingsite loses less MgO (70%) and much less SiO_2 (33%), but otherwise the reactions are comparable.

MECHANISM

The alteration of pyroxenes and amphiboles to layer silicates has been described by Veblen and Buseck (1980), Eggleton and Boland (1981), and Nakajima and

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Figure 13. Enlargement of boxed area in Figure 12. Only 10-Å layers are present, the wide gaps in this and Figure 12 probably result from collapse of the 15-Å smectite layers during preparation of the sample.

Ribbe (1980). In each work, the inheritance of a structural element (the tetrahedron-octahedron-tetrahedron I-beam) allows a topotactic transformation to take place. Near equality of the cell parameters of the primary and the alteration minerals allows large volumes of layer silicates to grow within the primary mineral without distortion. By contrast, framework silicates do not contain the structural elements of layer silicates and alter via a noncrystalline phase which in turn crystallizes to layer silicates (Eggleton and Buseck, 1980; Eggleton and Keller, 1982).

Olivine appears to fall somewhere between these extremes. The structure of olivine can be regarded as chains of metal-oxygen octahedra extending parallel to *Z* (Figures 14 and 15); these chains are also common in saponite (Figure 14) and goethite (Figure 15). Early loss of silicon may allow octahedral cations to diffuse into alternate layers of the hexagonal close-packed oxy-

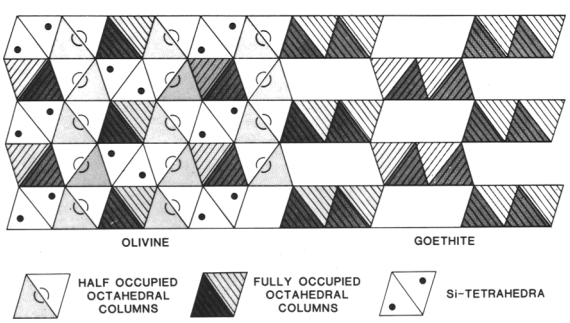


Figure 14. Idealized olivine and goethite structures viewed down *Z*, showing the close structural similarity between the two minerals.

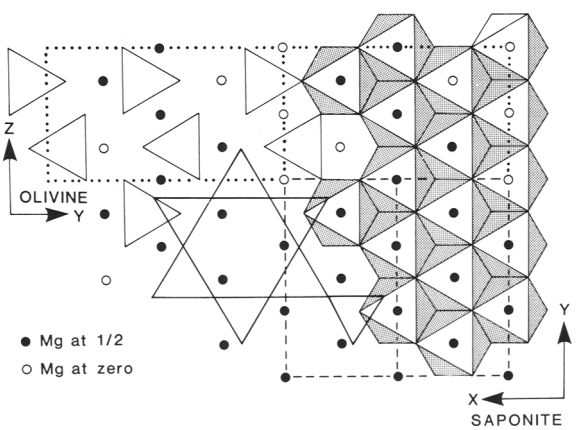


Figure 15. Idealized olivine and layer silicate structures viewed normal to the oxygen close-packed plane, showing the similarity in octahedral structure but difference in tetrahedral arrangements.

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gen structure of olivine leading to a 4.5-Å layer structure, phase M. This phase then becomes the starting point for three further processes: (1) Some of the diamond-shaped domains continue to dissolve and provide the elements for growth of smectite and goethite nearby; (2) Some exchange their magnesium for iron and become goethite; and (3) Some act as nuclei for 2:1 layer-silicate growth.

The orientation relation between olivine and smectite is established via phase M. Either bulk rearrangement of chains, or as suggested above, diffusion of cations could produce an octahedral structure with crystallites elongated parallel to olivine *Z*. It may be that such a process explains why [100] projections show early formed saponite to be in strips parallel to the original olivine octahedral chains. The silica tetrahedra of olivine and layer silicates are in different orientations when viewed perpendicular to the clay layers (along olivine *X*), and considerable structural rearrangement is needed to develop a layer silicate sheet (Figure 15). Thus, although the octahedral part of the olivine structure may remain intact over short distances, the tetrahedral sheet must be reconstructed. The incorporation of aluminum into the tetrahedral sheet is further evidence for structural reconstitution.

The initial crystallites of goethite appear to be randomly distributed. In an olivine of composition Fo_{80}, with Mg and Fe distributed essentially randomly over the octahedral sites, chance concentrations of a few Fe-bearing octahedra may act as a nucleus for the topotactic growth of goethite following oxidation of the Fe and loss of Mg and Si. The similarity in the cell parameters of olivine and goethite (Table 1), may allow goethite nuclei to form in continuity with the olivine structure (Figure 15). In the later stages of alteration the development of goethite becomes patchy suggesting some iron mobility during the formation of iddingsite.

As saponite and goethite grow, their lesser volume allows wider channels to develop, accelerating the diffusion of ions in and out of the altering olivine. Doubtless at this stage, both Mg and Si released from olivine recombine to enlarge the layer silicate crystals, giving rise to the very irregular and wispy 10-Å saponite masses within larger gaps in the olivine (Figures 1 and 12).

The formation of iddingsite, therefore, appears to proceed in two stages: an early stage of topotactic and epitactic nucleation of layer silicates and goethite; and a later stage during which these nuclei enlarge by crystallization from solution. The orientation relation between primary and alteration minerals is established in the first stage and is largely maintained thereafter.

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REFERENCES

Baker, I. and Haggerty, S. (1967) Alteration of olivine in basaltic and associated lavas. II. Intermediate and low temperature alteration: *Contr. Miner. Petrol.* **16,** 258–273.

Brown, G. and Stephen, I. (1959) A structural study of iddingsite from New South Wales, Australia: *Amer. Mineral.* **44,** 251–260.

Delvigne, J., Bisdom, E. B. A., Sleeman, J., and Stoops, G. (1979) Olivines, their pseudomorphs and secondary products: *Pedologie* **29,** 247–309.

Eggleton, R. A. and Buseck, P. R. (1980) High resolution electron microscopy of feldspar weathering: *Clays & Clay Minerals* **28,** 173–178.

Eggleton, R. A. and Keller, J. (1982) The palagonitization of limburgite glass, a TEM study: *N. Jb. Miner. Mh.* **7,** 321–336.

Nakajima, Y. and Ribbe, P. H. (1980) Alteration of pyroxenes from Hokkaido, Japan, to amphibole, clays and other biopyriboles: *N. Jb. Miner. Mh.* **6,** 258–268.

Smith, K. L. and Eggleton, R. A. (1983) Microstructures of botryoidal goethites: Clays & Clay Minerals **31,** 392–396.

Veblen, D. R. and Buseck, P. R. (1980) Microstructures and reaction mechanisms in biopyriboles: *Amer. Mineral.* **65,** 599–623.

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Резюме—Иддингсит окружающий оливин в басаните из Лимберг в Германии, состоит из сапонита и гетита. Трансмисионная электронная микроскопия направленных кристаллов указывает на двустепенный процесс изменения. Во-первых, оливин распадается на мозаику (110) иголчатой структуры диаметром 50 Å, которая изменяется в метастабильную гексагональную фазу с a = 3,1 Å и c = 4,6 Å, вероятно, октаэдр метал-кислород с плотной упаковкой. Эта реакция открывает каналы для растворителя в оливине, которые обнаруживаются от диаметра около 20 Å и которые являются параллельными к оси y. Пластинки смектита, толщиной один или два слоя, широкие на 20 Å и длиной достигающей 100 Å, параллельные к своей оси y, образуются из метастабильной фазы и начинают наполнять каналы. Пластинки ориентируются по смектиту (001), параллельно к оливину (100). Когда каналы расширяются, кристаллы призматического {110} гетита образуются прямо из метастабильной гексагональной фазы. Тогда эта начальная стадия создает неоднородные ядра смектита и гетита, которые формируются путем эпитаксии или топотаксии нз метастабильного посредника.

Во второй стадии эти ядра увеличиваются путем осаждения из раствора, в то время как вода двигается легко через каналы. Уменьшение полного объема позволяет формировать вены смектита, неориентированные по отношению к оливину. Реакция сохраняет железо, нуждаятся в добавлении алюминия и воды, и выделяет магний и кремний. Микроэлектронный анализ иддингсита указывает на то, что смехтит является в виде сапонита. [E.G.]

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Resümee—Iddingsitränder von Olivin in einem Basanit von Limberg, Deutschland, bestehen aus Saponit und Goethit. Transmissionselektronenmikroskopische Untersuchungen von "ion-thinned" orientierten Kristallen deuten auf einen Umwandlungsprozeß in zwei Abschnitten hin. Zuerst zerfällt der Olivin in ein Mosaik aus etwa 50 Å großen, {110} begrenzten, nadelförmigen Domänen, die sich in eine metastabile hexagonale Phase mit $a = 3{,}1$ Å und $c = 4{,}6$ Å umwandeln, die wahrscheinlich aus dicht gepackten Metall-Sauerstoff-Oktaedern besteht. Diese Reaktion öffnet Lösungskanäle im Olivin, die ab einem Durchmesser von 20 Å erkennbar sind und parallel zur y-Achse des Olivins verlaufen. Smektitleisten, die eine oder zwei Lagen dick sind, 20 Å breit und parallel zu ihrer y-Achse bis zu 100 Å lang sind, bilden sich aus der metastabilen Phase und beginnen die Lösungskanäle zu füllen. Die Leisten sind mit der (001) Ebene des Smektits parallel zu (100) Ebene des Olivins orientiert. Wenn die Kanäle weiter werden, bilden sich prismatische {110} Goethitkristalle direkt aus der metastabilen hexagonalen Phase. Dieses erste Stadium liefert daher heterogene Keime von Smektit und Goethit, die epitaktisch und vielleicht topotaktisch aus einer metastabilen übergangsphase entstehen.

In einem zweiten Stadium vergrößern sich diese Keime durch Ablagerung aus Lösung, da Wasser sehr leicht durch die Lösungskanäle wandern kann. Eine Verminderung des Gesamtvolumens ermöglicht es, daß sich Smektitadern bilden, die im Hinblick auf den Olivin keine bestimmte Orientierung aufweisen. Die Reaktion hält das Eisen fest und fordert eine Zufuhr von Aluminium und Wasser, während sie Magnesium und Silizium freigibt. Mikrosondenanalysen des Iddingsit deuten darauf hin, daß der Smektit ein Saponit ist. [U.W.]

Résumé—De l'iddingsite entourant de l'olivine dans une basanite de Limberg, Allemagne, est composée de saponite et de goethite. La microscopie électronique à transmission de cristaux orientés réduits à l'epaisseur d'ions, suggère un procédé d'altération à deux étapes. Tout d'abord, l'olivine se brise en une mosaïque de domaines en forme d'aiguilles, de 50 Å de diamètre limités par {110}, qui se transforment en une phase hexagonale métastable ayant $a = 3{,}1$ Å, et $c = 4{,}6$ Å, probablement d'octaèdres d'oxygène–métal très proches les uns des autres. Cette réaction ouvre des canaux de solution dans l'olivine, que l'on peut détecter d'à peu prés à partir de 20 Å de diamètre, et sont parallèles à l'axe-y de l'olivine. Des lattes de smectite, d'une ou deux couches d'épaisseur, de 20 Å de large, et jusqu'à 100 Å de longueur parallèles à leur axe-y sont formées à partir de la phase métastable et commencent à remplir les canaux de solution. Les lattes s'orientent avec la smectite (001) parallèle à l'olivine (100). En même temps que les canaux s'élargissent, des cristaux de goethite prismatiques {110} se forment directement à partir de la phase hexagonale métastable. Cette première étape fournit ainsi des noyaux hétérogènes de smectite et de goethite, formés épitactiquement, et peut-être topotactiquement à partir d'un intermédiaire métastable.

Pendant une deuxième étape, ces noyaux s'aggrandissent par déposition de solution puisque l'eau émigre facilement à travers ces canaux de solution. Une réduction de volume total permet la formation de veines de smectite, mal orientées respectivement à l'olivine. La réaction conserve le fer, exige l'addition d'aluminium et d'eau, et relâche du magnésium et de la silice. Des analyses microprobes d'électrons de l'iddingsite indiquent que la smectite est de la saponite. [D.J.]

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