ELECTRON-OPTICAL STUDY OF HYDRO-THERMAL FRINGE ALTERATION OF PLAGIOCLASE IN QUARTZ MONZONITE, BUTTE DISTRICT, MONTANA

J. M. GUILBERT and R. L. SLOANE

Departments of Geology and Civil Engineering,
University of Arizona, Tucson, Arizona

Abstract — Plagioclase feldspar is one of the outermost minerals destroyed in the hydrothermal alteration of quartz monzonite of the Butte district, Montana. Single grains of andesine plagioclase showing varying stages of fringe alteration were selected to show the sequence of events leading from the fresh plagioclase tectosilicate to the phyllosilicate montmorillonite, and to evaluate the role of petrographically-identified allophane in the alteration process.

Replicas of fresh, incipiently, and thoroughly montmorillonitized grains reveal a complex sequence of events which may follow alternate equivalent paths. Quantitatively most important is the formation of a hobnail texture composed of sparse to dense $\sim 0.5\,\mu$ discoids of amorphous material on feldspar cleavage surfaces. These discoids appear to fuse laterally to form amoeboid or lobate amorphous clusters. Some assume progressively more polygonal outlines characterizing the montmorillonite morphology, or their fringes become flake–like montmorillonite which peels away in wisps from the pitted feldspar surface. Wisps may persist singly, they may form minute ropy granules, they may develop into wispy ridges, or the entire surface may convert to ragged, wispy, or compact mont–morillonite. Far less commonly, plagioclase appears to develop without a discernible amorphous stage. The alternative paths are probably influenced by the chemical activity of magnesium in the system.

INTRODUCTION

THE BUTTE quartz monzonite host rock of the famous ore deposits of the Butte mining district, Montana, is characteristically hydrothermally altered adjacent to ore-bearing veins. This altera-tion is typically zoned from conversion of all sili-cates to quartz, sericite, and pyrite against the vein through various argillic stages to weak propylitic alteration at the outermost fringe. The alteration zones have been carefully studied petrographically, chemically, and with X-ray, but not electron-optically, by earlier workers. The fringe zone offered excellent material for an examination by electron microscopy to gain understanding of mech-anisms whereby plagioclase feldspar, a triclinic tectosilicate, breaks down into its amorphous and 2 : 1 layer montmorillonite alteration products. In spite of the importance of this transition to students of clay mineral formation in hydrothermal alter-ation, weathering, sedimentation, and soil science, no systematic studies directed at electron-optical examination of altering feldspar, other than of products separated from it, were found in a search of the literature.

Geologic setting

Hydrothermal alteration envelopes developed symmetrically about fissures in Butte quartz monzonite have been abundantly and excellently described in a series of papers by Meyer (1949), Sales and Meyer (1948, 1950), Hemley and Jones (1964), Meyer, Shea, Goddard, and Staff (1968), and others.

The unaltered quartz monzonite of the Butte district averages 36 volume per cent plagioclase, 22 per cent microperthite K-feldspar, 22 per cent quartz, about 10 per cent each of hornblende and biotite, and less than 1 per cent accessory minerals. Except for slight variations in the distribution of sparse coarse microperthite phenocrysts, the quartz monzonite is essentially homogeneous and totals over 99 per cent of the host rock of the immediate mining district. The general, essentially unvarying main stage hydrothermal alteration envelopes are schematically described in Table 1.

To those more familiar with Butte district geology, the alteration phenomena described in the body of this paper are found on the extreme mar-gins of the Central Zone or at the outer limits of

Table 1. Main Stage hydrothermal alteration mineralogy and assemblages developed in the Butte, Montana, quartz monzonite, greatly simplified

Fresh quartz monzonite	Argillized Zone			Sericitized Zone	Vein
	Fringe Subzone	Montmorillonitized Subzone	Kaolinized Subzone		
Quartz	N.C.	N.C.	N.C.	Augmented	Quartz and ore minerals
K-feldspar	N.C.	N.C. to trace ser	Trace ser	Sericite, quartz, and pyrite	
Plagioclase	Minor mont and allo; rare ser, zoisite, cal	Mont with decreasing allo yields gradationally to kaolinite			
Hornblende	Cal,ep,chl, minor allo	Nontronite yields to Kaolinite			
Biotite	Partially chl, with ru	Chloritized	Recrystallized biotite		

Allo = allophane-hisingerite, cal = calcite, chl = chlorite, ep = epidote, kaol = kaolinite, mont = montmorillonite, N.C. = no change, ru = rutile, and ser = sericite.

alteration envelopes symmetrical about veins in the Intermediate and Peripheral Zones. The portions of Table 1 which are relevent to this paper are those of the Fringe Subzone and the outer (left side) of the Montmorillonitized Subzone.

Texturally, plagioclase in the quartz monzonite occurs as tabular euhedral to subhedral grains surrounded by interstitial quartz and microperthite. The plagioclase units, commonly up to 3×6 mm, are generally of rectangular cross-section in broken rock surfaces. The whole rock texture is medium grained hypidiomorphic granular, or granitoid. Petrographically, the plagioclase is prominently twinned according to albite and combined albite-carlsbad laws. It is concentrically zoned, progressively from more calcic cores to more sodic rims, with common oscillatory zoning.

The composition of Butte plagioclase has been checked optically, in thin section, probably hundreds of times by several observers. Meyer (1949) gave its compositional range as from An_{42} to An_{50}. Subsequent determinations have run as high as An_{55}, with an average near An_{48}, 2 mole per cent on the andesine side of the andesine-labradorite composition boundary. Meyer (1949) cites a roughly compatible chemical analysis of a composite sample of plagioclase from fresh quartz monzonites containing no MgO and negligible potassium, iron, and titanium.

Plagioclase alteration

Meyer's (1949) early petrographic work revealed that an amorphous phase is intimately involved with plagioclase breakdown and the development of montmorillonite in plagioclase sites. Typically, alteration begins in the more calcic portions of the feldspar grains with the growth of centrally or zonally disposed patches of montmorillonoid flecking subordinate amounts of an optically isotropic amorphous mineraloid. Sericite flecks and calcite and zoisite granules have also been noted, but they are generally rare. Megascopically, the plagioclase passes from clear gray in color with a prominent fine grating of albite twinning in fresh rock to a light olive color with waxy luster and with destruction of twin lamellae in montmorillonitized material. Light blue tones are not uncommonly noted in pieces of the latter freshly broken from underground workings. Chemically, this propylitic alteration is a hydrogen metasomatism that concurrently frees CaO and Na_2O which are removed from the system.

The montmorillonoid mineral has been shown by several writers to be montmorillonite. Meyer (1949) and Sales and Meyer (1948) have cited dehydration, differential thermal analysis, physical, and optical support for this identification. X-ray diffractometer traces of oriented samples run in connection with this study show the (001) spacing

of air-dried material to be 14·5 Å, with even order reflections slightly suppressed and with no mixed-layer reflections in the 15–30 Å range. Glycolation shifts the entire 14·5 Å peak to 17·2 Å, denying the presence of non-expanding 14 Å vermiculite as a contaminant. Most of the (002) reflection moves from 7·2 to 8·4 Å upon glycolation, but a lesser peak indicating minor chlorite or kaolinite contamination remains at 7·2 Å. Heat treatment for 12 hr at 500°C reduces the (001) spacing to 9·7 Å and destroys the 7 Å peak, indicating that montmorillonite is accompanied by trace kaolinite or halloysite. No other minerals are discernible in the traces. Numerous film patterns indicate that montmorillonite, with the (060) spacing at 1·49 Å, is the only significant clay mineral involved. The several analytical techniques used by Meyer (1949) and X-ray studies indicate it to be a dioctahedral magnesium-bearing Al-montmorillonite. Iron appears important in aluminous nontronites developed in amphibole and pyroxene sites, and minor amounts of iron may enter octahedral positions in montmorillonites developed from plagioclase.

Sales and Meyer (1948, p. 9) briefly discuss the amorphous material that accompanies montmorillonitization. Its index of refraction is variable, ranging from about 1·50, when the allophane is broken, to nearly 1·52, rarely to 1·56, upon exposure to air. It is commonly light blue when fresh, darkening to olive or dark green tones. The index of refraction, slightly higher than that of reported values of allophane, and the color changes lead Sales and Meyer to assert that some hisingerite is probably present in the dominant allophane, the iron apparently coming from alteration of adjacent mafic minerals. The molar refraction of both CaO and Na_2O is higher than that of Al_2O_3 and SiO_2. The slightly higher index of refraction of Butte allophane may be explained by assuming CaO or Na_2O to be present in it, but the color shift remains enigmatic. Amorphous material developed directly from plagioclase should contain essentially no MgO or FeO, but the accompanying breakdown of mafic minerals liberates both of these radicals for possible involvement in the allophane phase. Sales and Meyer (1948, p. 9) say that montmorillonite is petrographically the first alteration mineral to form in plagioclase, that "the amorphous clay is always quantitively subordinate to montmorillonite"..., and that mineraloid..."decreases rapidly in relative proportion toward the vein, and its place is taken by more montmorillonite".

One of the objectives of this study was to determine the relationship between plagioclase, montmorillonite, and mineraloid at sub-micron level by electron microscopy, the precise textures of plagioclase breakdown being unresolvable even at 500× with the optical microscope.

INVESTIGATION

Specimens of nearly fresh to incipiently altered Butte quartz monzonite collected as recently as 1965 were rebroken to expose fresh surfaces. The samples were selected from several different locales in the Butte district, and all represented nearly the same alteration intensity. Several sets of freshly-exposed plagioclase tablets showing sharp, then obscure, and finally no twinning (with concomittant changes in color, hardness, and swelling characteristics) were selected at 20× with a binocular microscope, gently blown clean of debris, and carefully ringed with fingernail polish. A syrupy solution of polystyrene in ethylene dichloride was applied to the grains and permitted to dry in place overnight. The polystyrene film separated easily from the nitrocellulose surface of the fingernail polish permitting the film to be stripped from the much rougher mineral surface with relative ease. The roughly 3 × 6 mm casts were cleaned of adhering mineral particles by alternate immersion in concentrated hydrofluoric acid and 0·5 N sodium hydroxide. They were then shadowed at 30° with platinum-palladium, replicated with evaporated carbon, scored into 1·5 mm squares, immersed in ethylene dichloride for removal of the polystyrene backing, and picked up on standard 3 mm dia., 300 mesh copper support grids.

Pseudo-replicas for electron diffraction were made by sedimentation of particles on freshly-cleaved muscovite, shadowing with aluminum as an internal diffraction standard, coating with evaporated carbon, floating on distilled water, and mounting on standard support grids as above.

Replicas were scanned in an Hitachi HS-7 electron microscope at approximately 5000× magnification and 50 kV accelerating voltage. Representative areas and specific morphological features in each replica were recorded photographically on $3\frac{1}{4}$ × 4 in. sensitized glass plates.

RESULTS AND INTERPRETATIONS

Figures 1–3, *a-d*, are electron micrographs that summarize results from nearly 150 plates exposed; their description necessarily suggests some interpretation. Electron diffraction data will also be discussed.

Micrograph 1*a* shows sharp cleavage steps and chattered fracture surfaces of almost totally fresh andesine plagioclase. Close inspection reveals a few minute rounded spheroids of both positive and negative relief which may represent the initial step of hydrolytic alteration.

The striking texture of partially altered plagio-

clase is well illustrated by micrograph 1*b*. The stepped surfaces of the original plagioclase cleavage are still evident, but the smooth planes of micrograph 1*a* are shown to be covered with profuse discoid units in micrograph 1*b*. The discoids are dominantly subcircular in outline and of moderate thickness. Their diameters average about 0.5μ. They are not merely surface phenomena, but are strongly oriented, as seen in their outcrop on sloping cleavage steps, such that their short dimensions are normal to cleavage planes. This hobnail texture, apparently the first manifestation of alteration of plagioclase, is thought to result from development of amorphous material. The amorphous nature of the discoids was tested, and demonstrated, by dispersing a montmorillonite-discoid mixture and preparing pseudo-replicas of the sedimented material. The discoids, recognizable by their outlines and form, gave no electron diffraction spots. X-ray diffraction traces of discoid-rich material showed a broad hump in intermediate 2θ ranges with no lines attributable to a crystalline phase other than montmorillonite or plagioclase. Their identity with allophane, or allophane-hisingerite, can be assumed, but only indirectly shown. They are morphologically quite similar to material described as allophane in electron micrographs by Kerr *et al.* (1950), Hauser (1955), Fieldes and Williamson (1958), and Bates (1958), and they show none of the elongate or fibrous aspect of hydrated halloysite described by Sudo and Takahashi (1956). Their smooth appearance, like drops of water on a freshly-waxed surface, recalls Hauser's (1955, caption Fig. 8. p. 448) description of Lawrence County, Indiana, allophane: "The shape of the individual particles indicates . . . an amorphous aluminum silicate. The aggregates have . . . a distinctive rounded form". There is no morphological evidence suggesting a volume increase in the development even of profuse discoids in feldspar. Complementary indentations in what were overlying layers are common.

Micrograph 1*c* shows the development of a profusion of the allophane discoids on a single cleavage surface. Lineation of the discoids is rarely found, and grid-like alignment was not observed. The dipping layered structure at the left, which also contains discoids, is probably another crystal orientation of plagioclase, but it might also represent a mafic mineral. Note that several of the discoids have merged and overlapped to form dumbbell-shaped aggregates in crowded areas of micrograph 1*c*.

Micrograph 1*d* illustrates a more advanced stage in the alteration sequence. Here the discoids have begun to fuse and merge laterally to form abundant dumbbell, lobate, even amoeboid clusters. They still maintain their predominantly rounded form, with as yet no evidence of ordering or crystalline morphology. Notice the profusion of discoids protruding along the steep cleavage step at the left, again indicating strongly preferred orientation of the discoids.

Micrographs 2*a* and 2*b* show several relationships indicating still more advanced alteration. Discoids are abundant in micrograph 2*a*, but they have in large part lost the characteristic smoothly lobate form and have assumed more polygonal pseudohexagonal outlines. The field is crowded with discoids suggesting an advanced stage in the development of amorphous material, possibly with some montmorillonoid. Note that cleavage steps and surfaces are still discernible, but a more massive structure with only relict plagioclase features is evolving. Micrograph 2*b* shows generally polygonally terminated discoids which have merged so extensively that they have assumed a texture more scaly than hobnail. The material of micrograph 2*b* may be largely amorphous, but the morphology of the flakes suggests that montmorillonite, or montmorillonoid or protomontmorillonite, locally may be an important constituent.

Micrograph 2*c* shows a progression from scaly, subrounded discoids at the left to more pronouncedly polygonally terminated flakes at the upper right. In the lower right is an area of ragged, slightly curled flakes. Mineralogically, the curled flakes are thought to be montmorillonite, although hydrated halloysite, perhaps the source of the weak 7 Å line in the montmorillonite pattern described above, must be considered. Not uncommonly such ragged flakes can be traced into areas of matted, massive montmorillonite.

Micrograph 2*d* shows minute beads and ropy granules of what may be montmorillonite on plagioclase, the latter either directly converted to montmorillonite or perhaps resulting from the rolling up of such wispy flakes as those shown in micrograph 1*c*.

Micrograph 3*a* was selected for two purposes. First, close examination of the upper portion of the photo shows a surface of basin or dimple-like subcircular depressions which are dimensionally and morphologically similar to the discoids of positive relief in the lower left portions. These bowls most probably represent plucking depressions left from the separation of an originally overlying surface with discoids in positive downward relief. More importantly, micrograph 3*a* shows the development of wispy irregular ridges of montmorillonite from flakes similar to those of micrograph 2*c* at the upper left and across the top center of the photomicrograph. It appears that montmorillonite can form over a short range from
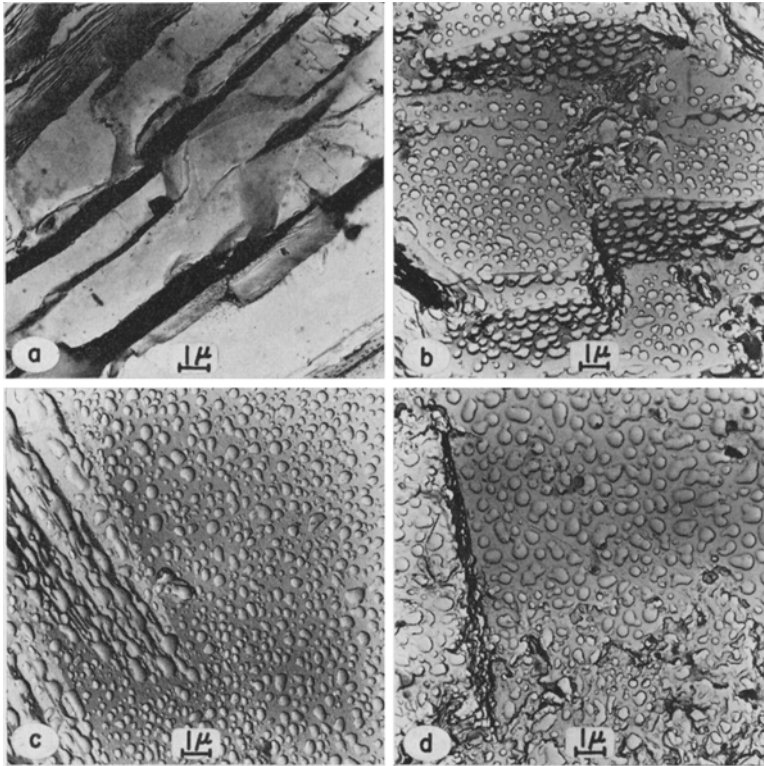
Fig. 1. (a) Sharp cleavage steps, chattered fracture surfaces, and smooth cleavage planes of fresh andesine plagioclase.

(b) Discoids of amorphous material (allophane) formed in plagioclase cleavage planes. Note preferred orientation in outcrop on cleavage steps.

(c) Allophane discoids on a plagioclase cleavage surface with overlap to form sparse dumbbell-shaped lobate aggregates.

(d) Lateral merger of discoids in more pervasively altered plagioclase with formation of amoeboid, lobate clusters of allophane.
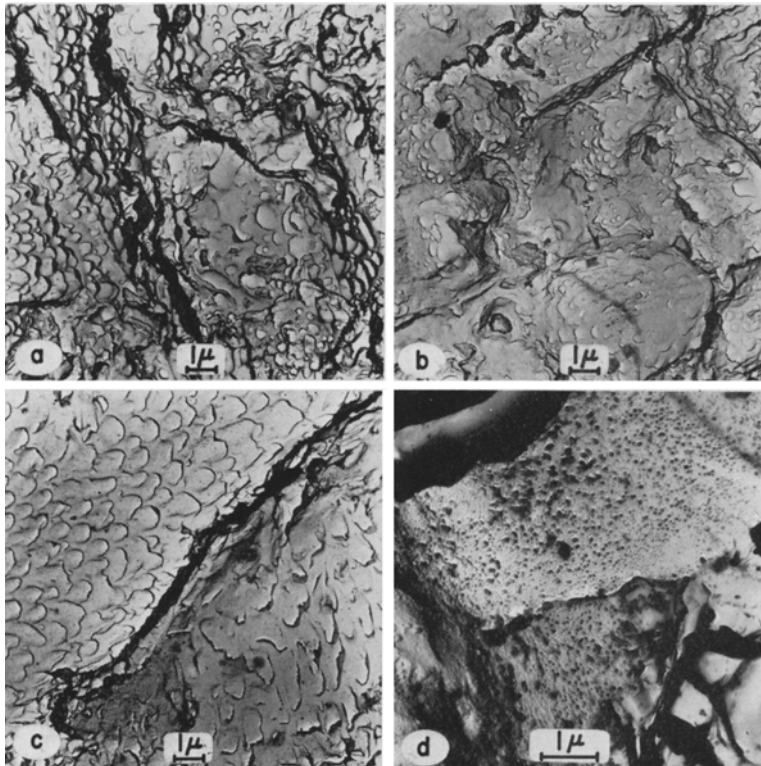
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Fig. 2. (*a*) Abundant discoids which have begun to lose their smoothly lobate form in favor of polygonal, crudely pseudohexagonal outlines. Original plagioclase cleavage discernible but subdued.

(*b*) Generally polygonally terminated discoids, probably dehydrated and peeled equivalents of the discoids in micrograph 1 (*b*).

(*c*) A progression from scaly subrounded discoids at upper left clockwise to more pronouncedly polygonally terminated, then ragged, slightly curled flakes at lower right.

(*d*) Minute beads and ropy granules of probable montmorillonite on plagioclase.
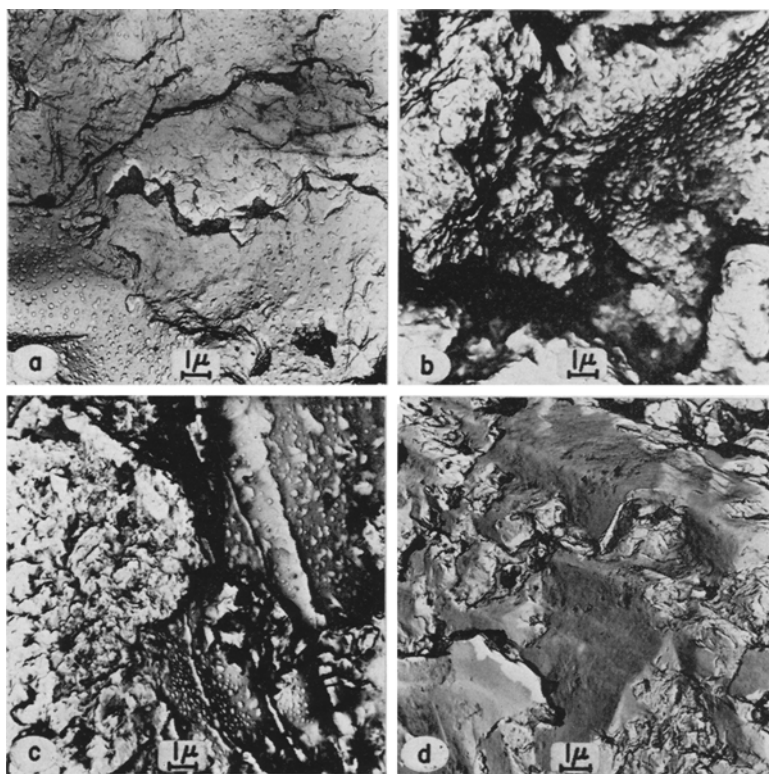
Fig. 3. (*a*) Wispy, irregular ridges of montmorillonite formed from flakes similar to those in micrograph 2 (*c*). Note subcircular depressions at top right of micrograph left by removal of discoids.

  (*b*) Ragged massive montmorillonite developing from discoid amorphous material.

  (*c*) Wispy montmorillonite developing from discoid allophane. Note relict plagioclase structures.

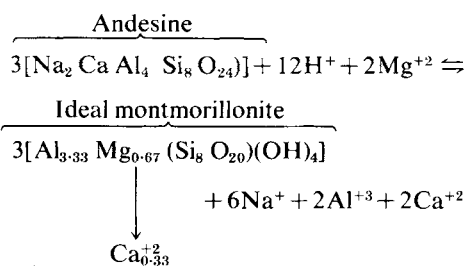 (*d*) Compact montmorillonite free from discoids and flakes.

discoids through polygonal or amoeboid masses to and through flake-like aggregation. Discoids like those plucked from the upper right field may well develop into the wispy ridges at the upper left only a few microns away.

Micrographs, 3b, c, and d were chosen to illustrate further the transition from discoid material containing relict plagioclase structures to ragged massive (micrograph 3b) and wispy (micrograph 3c) montmorillonite to the compact, discoid-free montmorillonite of micrograph 3d.

DISCUSSION AND CONCLUSIONS

Since a sound basis of chemical and mineralogical work exists for Butte alteration phenomena, some consideration of the controls of montmorillonite formation as clarified by the textural observations cited above is warranted. Replicas of many plagioclase grains selected from the Butte rocks showed textures identical to those described above, and the transition from the tectosilicate to the phyllosilicate structure appears almost universally to pass through the development of amorphous discoid textures. In a few areas, however, montmorillonite wisps and flakes appear to peel directly off sharp plagioclase units with no evident intervening amorphous material.

As indicated above, Butte andesine contains no magnesium, yet magnesium, and to a far lesser extent iron, is a constituent of the montmorillonite formed in the montmorillonitic subzone. Sales and Meyer (1948, p. 15) show that the base leaching of the Butte alteration results in early and quite abrupt removal of CaO and Na_2O from the fringe zone, but the inflection in the MgO loss curve is less abrupt, MgO being in large part retained in the fringe zone. This relationship doubtless hinges on a retention of MgO in chlorite after biotite and on the uptake in montmorillonite of MgO released during the propylitization of hornblende, biotite, and trace augite in the fresh rock (Table 1). The probable effect of the activity of MgO in the area of an altering plagioclase grain in determining the products of its alteration is indicated in the following reactions involving andesine and ideal montmorillonite with Ca occupying interstitial positions:

Andesine

$$3[Na_2\,Ca\,Al_4\ \,Si_8\,O_{24})] + 12H^+ + 2Mg^{+2} \rightleftharpoons$$

Ideal montmorillonite

$$3[Al_{3\cdot33}\,Mg_{0\cdot67}\,(Si_8\,O_{20})(OH)_4]$$
$$\downarrow \quad + 6Na^+ + 2Al^{+3} + 2Ca^{+2}$$
$$Ca_{0\cdot33}^{+2}$$

In fact, the Butte montmorillonite probably contains some Mg and trace Na in exchangeable positions, as does montmorillonite after plagioclase in quartz monzonite at Ely, Nevada (Fournier, 1965), which would slightly alter the Mg–Ca–Na distribution in the reaction. Note that although SiO_2 was probably supersaturated in whatever pore fluids were present, no silica redistribution is required in the formation of montmorillonite from andesine plagioclase. The rare development of montmorillonite seemingly directly from plagioclase suggests that the formation of allophane is at least in part chemically controlled, hinging on the availability of MgO in the system. It is an equally valid generality that altering feldspar, with negligible MgO in the local system, will generally pass through an allophane mineraloid phase, while alteration of a volcanic glass with MgO present in the local system may not, may show only brief transition, or may yield to allophane if MgO is removed. No structures suggestive of amorphous material were found in a study of alteration of latite to smectite in the Cheto, Arizona, clay deposit (Sloane and Guilbert, 1967), while textures essentially identical to those of Figs. 1–3 were found in plagioclase from specimens of quartz diorite from Highland Valley, British Columbia. The textures found in the course of this study, then, are probably general with respect to hydrothermal alteration of plagioclase in intermediate igneous rocks.

The involvement of allophane in plagioclase breakdown has been considered by many investigators, chiefly Reiche (1950), Frederickson (1951), Kanehiro and Whittig (1961), Aomine and Wada (1962), the Wisconsin group of M. L. Jackson, and more recently Snetsinger (1967). Aomine and Wada (1962) discuss the transition from feldspar through allophane to halloysite, considering the composition and "crystal" chemistry of the two phases. Too little is known about the specific compositions of the minerals involved in the Butte rocks, but the Butte sequence appears to involve the following steps.

Step 1. Outward effects of the hydrothermal solution expose plagioclase feldspar to a new environment of probably slightly elevated temperature and increased hydrogen ion activity, the principal fringe alteration effects being attributable to hydrogen metasomatism in a nearly isothermal system (Hemley and Jones, 1964). Hydrogen ions move along the cleavages of the feldspar, preferentially attacking calcium rich zones and cores and resulting in the growth of amorphous discoids which develop both upward and downward from cleavage planes. The amorphous material is certainly aluminous and may contain minor CaO

in addition to silica and water. None of the decomposition products described by Frederickson and Cox (1954) in their examination of synthetic alteration of anorthite, yielding afwillite and xonotlite, were observed. "Nucleation" points of allophane growth are fairly uniformly scattered, only rarely showing lineation developed along the intersection of two cleavages.

Step 2. Allophane discoids begin to merge laterally into dumbbell, amoeboid, or lobate forms as the feldspar is more extensively altered. Step 2 is locally concurrent with step 3.

Step 3. The mineraloid organizes to form a 2:1 layer silicate structure. Hawkins and Roy's (1963) conclusions based on experimental hydrothermal clay mineral formation are supported. They observed that gross structure of the parent material is ineffective in the formation of particular alteration minerals, for example, montmorillonite from plagioclase. Direct reactions between silicate, aluminate, and metallic ions in the amorphous state determine the structural and compositional state of the alteration product. Hawkins and Roy (1963, p. 1051) cite Iler's (1955) observation that $Mg(OH)_2$ combines readily with $Si(OH)_4$ in amorphous materials. The morphological results of this paper soundly support a mechanism of montmorillonite formation involving ordering of an aluminous, hydrous, siliceous gel, with the activity of Mg^{+2}, or a radical of magnesium, largely controlling the reactions. Iron may be subordinately involved. No evidence, electron-optical, chemical, petrographic, X-ray, or otherwise, supports the formation of more than traces of halloysite or any antigorite, while similar evidence abundantly supports the ordering of gel to form montmorillonite. Tamura and Jackson (1953) briefly discuss the formation of montmorillonoids from allophane, indicating that although the allophane-kaolinite path is generally favored (greater "ease of occurrence", p. 381), montmorillonite rather than kaolin can form in magnesium- and silica-rich environments such as in some of the dark magnesian soils of Hawaii. Again, too little is known of specific chemical changes to permit final judgements, but it appears that amorphous material dehydrates with discoids going to ragged, flakelike, commonly slightly curled, rarely apparently ropy granular units.

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Résumé – Le feldspath plagioclase est l'un des minéraux les plus extérieurs qui ont été détruits par les altérations hydrothermiques de quartz monzonite de la region de Butte, Montana. Une sélection de simples grains de plagioclase andésite qui montraient différents stades d'altérations à la frange a permis d'illustrer la chaîne d'évènements qui transforme le tectosilicate plagioclase frais en montmorillonite phylosilicate, et d'évaluer le rôle de l'allophane identifié pétrographiquement dans le processus d'altération.

Des doubles de grains frais, partiellement et totalement montmorillonitisés révèlent une série d'évènements complexes qui peuvent suivre des chemins équivalents alternés. La plus importante formation du point de vue quantitatif est celle d'une texture en clou qui se compose de discoides, parfois clairsemés, parfois compactes, de 0,5 μ de matériau amorphe sur les surfaces de clivage du feldspath. Ces discoides semblent se fusionner latéralement pour former des groupes amorphes amiboides ou lobaires. Certains prennent des formes de plus en plus polygonales, ce qui caractérise la morphologie montmorillonite; leur frange peut se transformer en montmorillonite flocconneux que l'on peut éplucher par torons de la surface de feldspath piquée. Les torons peuvent rester individuellement séparés, ou former de minuscules granulés visqueux ou prendre la forme de stries en torons, ou alors leur surface entiêre peut se changer en montmorillonite inégale, en torons, ou compacte. Il arrive parfois, mais c'est peu fréquent, que le plagioclase se mette à développer des micrograins et des torons de montmorillonite sans passer visiblement par un stade amorphe. Les chemins alternatifs résultent probablement de l'activité chimique du magnésium dans le système.

Kurzreferat – Plagioklas ist eines der äussersten Minerale, die bei der hydrothermischen Umwandlung des Quarzmonozits aus dem Butte Gebiet in Montana zerstört wurden. Es wurden Einzelkörner von Andesin-Plagioklas in verschiedenen Stadien der Randzonenumwandlung ausgewählt, um die Reihenfolge aufzuzeigen, welche vom frischen Plagioklas-Tektosilikat zum Phyllosilikat-Montmorillonit führt, und die Rolle des petrogrphisch identifizierten Allophans im Umwandlungsprozess zu bestimmen.

Nachbildungen frischer, sowie anfänglich und vollständig montmorillonisierter Körner zeigen eine komplizierte Folge von Erscheinungen, die gemäss gleichwertiger Alternativbahnen ablaufen können. Mengenmässig am bedeutendsten ist die Bildung eines schuhnagelartigen Gefüges, das aus schütteren bis dichten, 0,5 μ messenden Scheibchen aus amorphem Material auf Feldspat-Spaltoberflächen besteht. Diese Scheibchen scheinen seitlich unter Bildung von amöboiden oder lappenartigen amorphen Büscheln zusammen zu schmelzen. Manche nehmen nach und nach mehr vieleckige Kontouren an, die für die Morphologie von Montmorillonit kennzeichnend sind, oder die Ränder werden blättrigeres Montmorillonit, das sich in Bündeln von den narbigen Feldspatoberflächen ablöst. Die Bündel können vereinzelt bleiben, sie können winzige, fadenartige Körnchen formen, sie können sich zu bündelartigen Wulsten entwickeln oder die gesamte Oberfläche kann sich in unebenes, bündeliges oder kompaktes Montmorillonit verwandeln. Viel seltener scheint der Plagioklas Mikrokörner und Montmorillonit-bündel unmittelbar, ohne erkennbare Zwischenstufe, zu entwickeln. Die Alternativbahnen werden wahrscheinlich durch die chemische Aktivität des Magnesiums in dem System beeinflusst.

Резюме—Плагиоклаз это один из наиболее удаленных от центра минералов, разрушаемых в ходе гидротермальных изменений кварцевого монционита в районе ъаттс, в штате Монтана (США). Отдельные зерна плагиоклаза-андезина, показывающие разные степени изменения края, были избраны, чтобы показать последовательность явлений от свежего плагиоклаз-текто силиката до филосиликатного монтмориллонита и чтобы также предоставить оценку роли петрографически отождествленного аллофана в процессе изменения.

Модели свежих,зачаточных и тщательно подвергнутых монтмориллонизации зерен, раскрывают сложную последовательность явлений, которые могут проходить по альтернативно эквивалентным путям. Качественно наиболее важным является образование грубо сшитой структуры, состоящей из рассянных до плотных дискоидов аморфного материала размером 0,5 μ на поверхностях расщепления полевого шпата. Дискоиды эти повидимому поперечно сплавляются, чтобы создать смебоидные или лопастные аморфные скопления. Некоторые из них постепенно принимают многоугольные контуры, характерные в монтмориллонитовой морфологии или-же их края становятся чешуйчатым монтмориллонитом, который отслаи вается пучками от разъеденной поверхности полевого шпата. Пучки остаются одиночными или-же они образуют крохотные волнистые гранулы, которые могут развиться в клочковые гребни, или-же вся поверхность превращается в шероховатый клочкообразный или-же компактний монтмор иллонит. В более редких случаях, плагиоклаз повидимому развивает микроверна и клочья монтмориллонита непосредственно, без заметной аморфной стадии. Альтернативные пути вероятно находятся под влиянием химического действия магния в системе.