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ALTERATION OF ANDESITE IN WET, UNSTABLE SOILS OF OREGON'S WESTERN CASCADES[1]

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Abstract—Alteration products of andesite cobbles from wet soils formed in volcanic colluvial material were studied using petrographic, electron microscope, X-ray powder diffraction, and thermal techniques. Augite phenocrysts altered by congruent dissolution leaving voids which were subsequently filled with smectite. Plagioclase also altered to produce micrometer-size spheroidal aggregates of smectite. Halloysite was not observed within the altered cobbles, although it was abundant in the soil matrix. The formation of smectite in the altered cobbles was probably favored by the restrictive drainage of the microenvironment in combination with wet soil conditions.

Key Words—Andesite, Halloysite, Scanning electron microscopy, Smectite, Soil, Weathering.

INTRODUCTION

The bedrock geology of Oregon's Western Cascade Range is a complex of interbedded basaltic and andesitic lava flows, pyroclastic rocks, water-laid tuff, volcanic conglomerate, and ignimbrite (Peck *et al.*, 1964; Baldwin, 1976). Recent studies have shown that a strong relationship exists between geology, geomorphology, clay mineralogy, and landscape stability in this region (Taskey *et al.*, 1978; Taskey, 1978; Swanston and Swanson, 1976; Paeth *et al.*, 1971; Youngberg *et al.*, 1971). In evaluating the nature of the clay fraction of a number of soils formed in volcanic materials, Taskey *et al.* (1978) found that clay mineral associations and profile morphology could be used to characterize both stable and unstable land surfaces, as well as to distinguish between different types of mass movement. Numerous data were cataloged on the identity of the soil clay fraction in the Western Cascades, and genetic relationships were interpreted from analysis of major trends and associations of bulk soil mineralogy and site characteristics. In general, halloysite and noncrystalline aluminosilicate gels were associated with colluvium which mantled smectite-rich, altered pyroclastic rocks.

Much of the literature dealing with clay mineral genesis from volcanic materials has concentrated on basalt weathering in tropical environments (e.g., Eswaran, 1979; Eswaran and DeConinck, 1971; Siefferman and Milliot, 1969) or on the alteration of tephra (Kirkman, 1981; Dudas and Harward, 1975; Askenasy *et al.*, 1973). These studies have shown that allophane, halloysite, kaolinite, and gibbsite are the dominant secondary minerals produced by weathering of such materials. Smectite has also been noted as an intermediate product or as a dominant secondary phase, depending on microenvironmental conditions, and mineral transformations during near-surface rock weathering appear to be largely determined by soil microenvironmental factors with large-scale climatic factors acting as modifiers (Eswaran and DeConinck, 1971).

Genetic studies of the clay minerals in the soils of Oregon's Western Cascades are complicated by the great heterogeneity of soil parent materials. Steep slopes, high annual precipitation, short-range lithologic variability, and soil mass movement have resulted in complex volcanic colluvial deposits. The colluvium contains a mixture of basaltic and andesitic clasts, ignimbrite, altered pyroclastic materials, clayey weathering products, and Quaternary tephras. This paper describes the weathering of andesitic clasts in soils of colluvial origin in the Western Cascade Range of Oregon, characterizes the alteration products of the primary minerals in the andesites, and relates clay genesis to soil microenvironment.

MATERIALS AND METHODS

The study area is located in the Middle Santiam River drainage in the tributary drainage of Pyramid Creek (SW¼, NW¼, Sec. 19, T12S, R6E along Road 1234, at site MS-P-1 of Taskey (1978)). The area receives on average 2000–2200 mm precipitation annually and has an average annual temperature of 10.3°C (Johnsgard, 1963). Deeply altered pyroclastic rocks of the Little Butte Volcanics underlie the watershed at intermediate elevations (Peck *et al.*, 1964). The Sardine Formation, which consists primarily of basaltic and andesitic lava flows, outcrops at higher elevations. The soils at the sample site formed in colluvium containing subangular to subrounded basaltic and andesitic cobbles which overlies decomposed ash flow tuff. Varying amounts of volcanic ash are also present in the soil. Taskey *et al.* (1978) found the bulk-soil clay mineralogy of the colluvium at this location to be dominated by hydrated

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halloysite and noncrystalline aluminosilicate gel, whereas the underlying ignimbrite is characterized by smectite alteration. The smectite-rich, altered ignimbrite supports a perched water table through much of the year, resulting in wet soils, even though the slope of the study area is near 70%.

Andesitic cobbles in various stages of decomposition were sampled from the A horizon of a wet, unstable soil (site MS-P-1f, Taskey, 1978) and sealed in plastic bags. The consistence of field-moist cobbles ranged from extremely firm to extremely hard, and the cobbles could readily be removed from the soil without breakage or loss of material. The andesite cobbles were subsampled while in field-moist condition for clay mineral analysis after carefully removing adhering soil material. Subsamples were obtained by cutting or breaking off a portion of the rock, followed by gentle grinding of the rock fragments with a diamonite mortar and pestle. The ground material was dispersed in distilled water with agitation from a milkshake blender equipped with a rubber policeman instead of shearing blades. The <10-μm and clay (<2-μm) fractions were separated by centrifugation. The separates were saturated with Mg using 1 N $MgCl_2$ and freed of excess salt by three washings with distilled water. Subsamples of the Mg-saturated clay were saved in a moist state for transmission electron microscope (TEM) and differential thermal analysis (DTA) characterization. Portions of the Mg-saturated separates were used for the preparation of oriented clay films for X-ray powder diffraction (XRD) analysis using the paste method (Theissen and Harward, 1962). The remaining material was then saturated with K using 1 N KCl and distilled water washing. Slides of this material were prepared for XRD analysis. The characterization treatments used for clay mineral identification were those prescribed by Harward *et al.* (1969) and Carstea *et al.* (1970).

TEM analysis of the <2-μm fraction was performed using a Philips EM 300 operated at 80–100 kV and 7 μA. A liquid nitrogen decontamination device was employed to help minimize possible sources of contamination. Samples were prepared by dropping a dilute clay suspension onto Formvar-coated copper grids. Exposure of specimens to the electron beam was held to a minimum to avoid adverse effects of specimen-beam interaction (Jones and Uehara, 1973). DTA analyses of Mg-saturated clays equilibrated at 54% RH were done using a DuPont Model 900 Differential Thermal Analyzer.

The remaining undisturbed cobble material was further characterized by petrographic and scanning electron microscope (SEM) examination. Thin sections for petrographic study were prepared by impregnating slabs of air-dried cobbles with a polyester resin and sectioning by standard techniques. Descriptive terminology used in this study was that suggested by Stoops *et al.* (1979) for rock weathering and by Brewer (1976). Fracture surfaces of andesitic fragments for SEM observation were mounted on brass stubs and sputter coated with gold in a vacuum evaporator. A JEOL 35 or an International Scientific Instruments mini-SEM was used to analyze the specimens. The JEOL microscope was equipped with a Princeton Gamma Tech energy-dispersive X-ray elemental analyzer which permitted qualitative analyses of specimens. Elemental analyses, though subject to errors due to specimen topography and electron-capture volume, provided additional clues to aid in mineral identification by SEM. This combination of thin section and SEM observations has proven extremely useful in studying the alteration of primary minerals in soil materials (Eswaran, 1979; Eswaran and DeConinck, 1971).

RESULTS AND DISCUSSION

The samples studied are weathered pilotaxitic porphyritic to glomeroporphyritic andesites (i.e., lath-shaped microlites show sub-parallel flow orientation and phenocrysts are in places gathered together in distinct clumps, Williams *et al.*, 1954, pp. 19, 23) with megaphenocrysts of plagioclase (An_{55-60}) and augite. None are completely saprolitic; i.e., they did not consist completely of pseudomorphic secondary minerals preserving original rock fabric (Eswaran and Wong Chaw Bin, 1978a). Individual cobbles contain primary phenocrysts showing a wide range of alteration, which provides an excellent opportunity to follow the weathering sequence from its initial through its more advanced stages.

Unweathered plagioclase phenocrysts are euhedral with distinctive albite and pericline twinning. They range in length from 0.3 to 4 mm, with an average size of 1.5 mm. The plagioclase crystals show normal and oscillatory zoning, having cores of labradorite (An_{55-60}) and rims of andesine composition (An_{45-50}). The final stage of feldspar crystallization produced microlites of andesine having moderate flow orientation. Augite phenocrysts are euhedral to subhedral in form and 0.5–2.0 mm in size. The groundmass consists of feldspar microlites, interstitial glass, and accessory magnetite.

Andesite alteration progresses from the rock's surface inward along transmineral porosity. Transmineral pores traverse the rock without following grain boundaries and may develop upon cooling of the parent lavas or reflect tectonic shattering (Stoops *et al.*, 1979). Thin section observation suggests that several processes are associated with the initial phase of alteration. The interstitial glass becomes discolored and shows the development of weakly anisotropic granular forms. This change is usually associated with pale, yellowish brown staining and reduced birefringence of feldspar microlites. Such groundmass alteration is most pronounced bordering transmineral pores and decreases rapidly away from the pore. Initial phenocryst alteration consists of pellicular, congruent dissolution of augite and weak surface etching of plagioclase.

Figure 1a illustrates rock weathering which is associated with a transmineral pore system. The upper right corner of the micrograph shows a large plagioclase phenocryst bordered by a pore which trends diagonally across the photograph to the lower left corner. This pore intersects moldic porosity produced by complete congruent dissolution of augite. Hyaline material is present along portions of this porosity network. The cross polar view (Figure 1b) shows very fine-grained, highly birefringent material bordering the intermineral pore along the plagioclase phenocryst, as well as thin, discontinuous clay films on the moldic pore walls. At this magnification it is difficult to tell whether these clay films represent authigenic accumulation of clay or infiltration of pedogenic clay into the porous andesite clasts, but subsequent observations show that such features are authigenic. The groundmass bordering the pore system shows the presence of weakly anisotropic granular forms in the interstitial glass and microlites with lowered birefringence, suggesting alteration of glass to clay. Phenocryst alteration in this micrograph ranges from slight dotted alteration of plagioclase to complete, pellicular, congruent dissolution of augite.

Plagioclase alteration begins with surface etching that eventually leads to the formation of intramineral porosity as the crystals are penetrated by a network of hairline cracks (Figures 1a, 1b, 1c, 1f). Propagation of these pores probably occurs along crystal dislocations or compositional zonations (Berner and Holdren, 1977; Wilson, 1975). Once the intramineral porosity penetrates the andesine-rich surface zone, complex dotted alteration of the labradoritic core zones occurs rapidly, resulting from the alteration of discrete zones of the host material (Stoops *et al.*, 1979). Altering zones go through an isotropic, probably noncrystalline, phase prior to mineral dissolution and development of porosity, similar to the alteration sequence noted by Eswaran (1979). The resultant intramineral pores may or may not show lining with birefringent hyaline material. In more advanced stages of plagioclase alteration, the intramineral pores have broadened and coalesced to form a complex cavernous alteration pattern (Figures 1d and 2d). Figure 1d shows a plagioclase phenocryst whose interior labradoritic zones are completely altered, leaving a porous andesine rim and a central core containing zones of pseudomorphic secondary clay after the original feldspar zonation. The andesine rim and microlites commonly persist through this stage of alteration, although they are honeycombed by the development of etch porosity (Figures 1d, 1e, 1f).

Augite alteration shows a strong relationship to the proximity of transmineral porosity. Where such porosity intercepts augite phenocrysts, strong to complete pellicular dissolution has occurred. This is probably favored by rapid fluid movement through large pores which may connect to the outside soil solution and facilitate removal of dissolved constituents. However, a neighboring pyroxene surrounded by altered matrix devoid of obvious secondary porosity may show only slight pellicular alteration (Figures 1a and 2a). The alteration of interstitial glass to clay (Figure 2a), shown below to be smectite (Figure 4), may restrict fluid movement by plugging secondary porosity. While the dominant pattern of augite alteration is pellicular, some large phenocrysts, which appear to have been shattered, show irregular linear dissolution leading to the formation of randomly oriented residues.

The initial dissolution of augite produces an intricately etched surface of sharp pinnacles (Figures 2a, 2b). The surface is clear of adhering contaminants, supporting the conclusion that augite alters by congruent dissolution. Advanced dissolution produces an extremely delicate honeycombed fabric that reflects the crystal structure of the parent pyroxene (Figure 2c). Similar etch textures for augite were reported by Rahmani (1973) and were observed in altered basalts and sedimentary rocks (Glasmann, unpublished data). However, the SEM morphology of altered augite noted in this study differs markedly from the knobby, irregular surfaces illustrated by Eswaran (1979) for tropically weathered basalts. Eswaran found that noncrystalline surface coatings and pseudomorphic goethite were common alteration products of augite. The differences in alteration products and morphology between the two studies probably are due to differences in host rock geochemistry (tholeitic basalt vs. calc-alkaline andesite) and soil microenvironment (very high precipitation and very warm vs. saturated conditions and cool). The year-round wetness of the Cascade Range site apparently has a pronounced influence on

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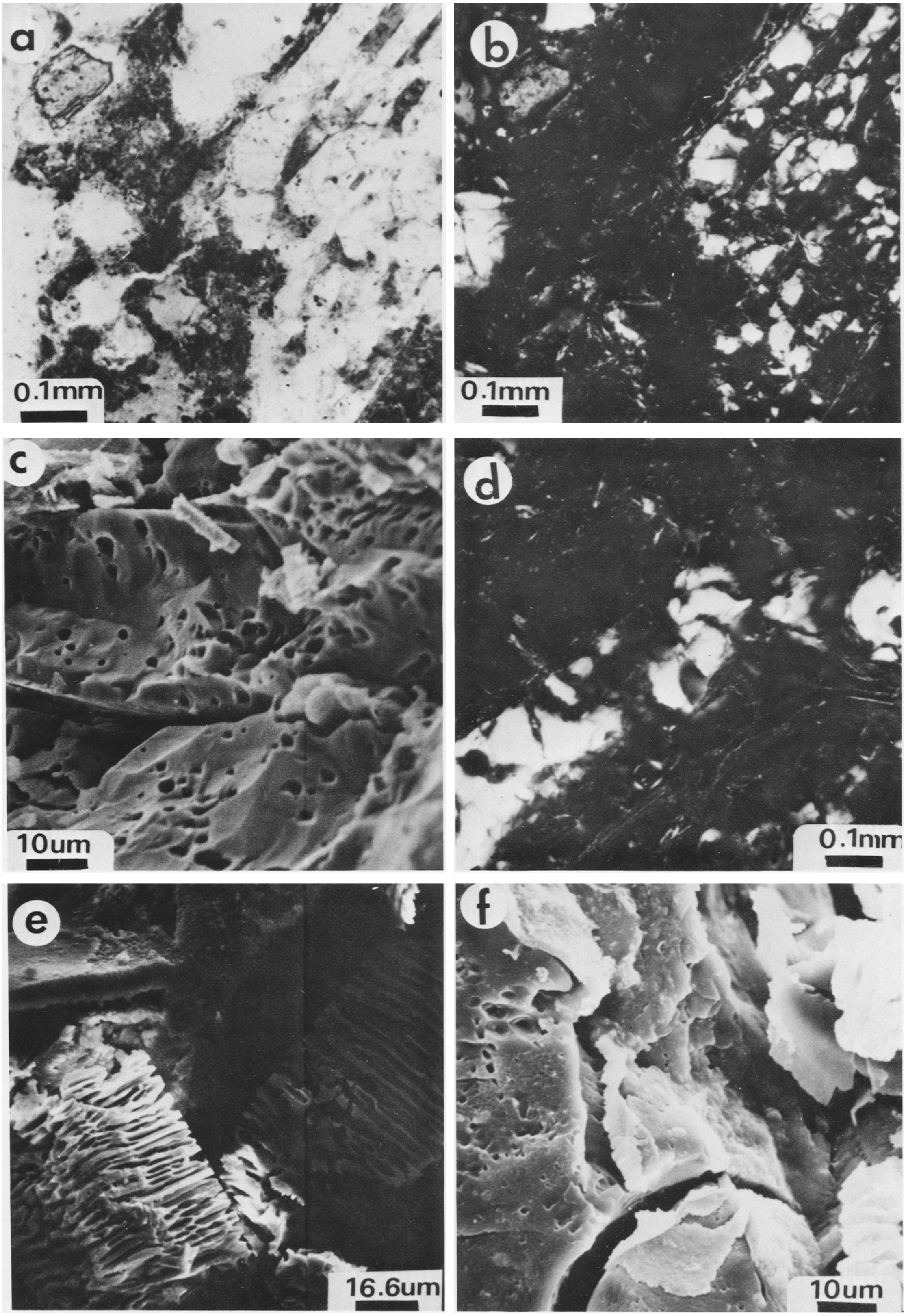
Figure 1. (a) Photomicrograph showing dotted alteration of plagioclase, pellicular alteration of augite (upper left) and transmineral porosity; (b) Cross-nichol view of Figure 1a showing cutanic material and smectite formation from feldspar; (c) Scanning electron micrograph of initial dissolution of feldspar; (d) Photomicrograph illustrating cavernous alteration of plagioclase showing andesine rim perforated by intramineral porosity and smectite pseudomorphs after plagioclase zonation; (e, f) Advanced dissolution of feldspar shown in scanning electron micrographs.

Figure 2. Scanning electron micrographs of andesite alteration: (a) Augite dissolution and unaltered feldspar microlites in matrix of smectite; (b, c) Congruent dissolution of augite; (d) Cavernous alteration of plagioclase showing convoluted sheets of smectite; (e) Higher magnification view of Figure 2d showing rectangular etch pits (upper left) and fibrous smectite sheets (center and lower right); (f) Initial stage of smectite formation on feldspar surface.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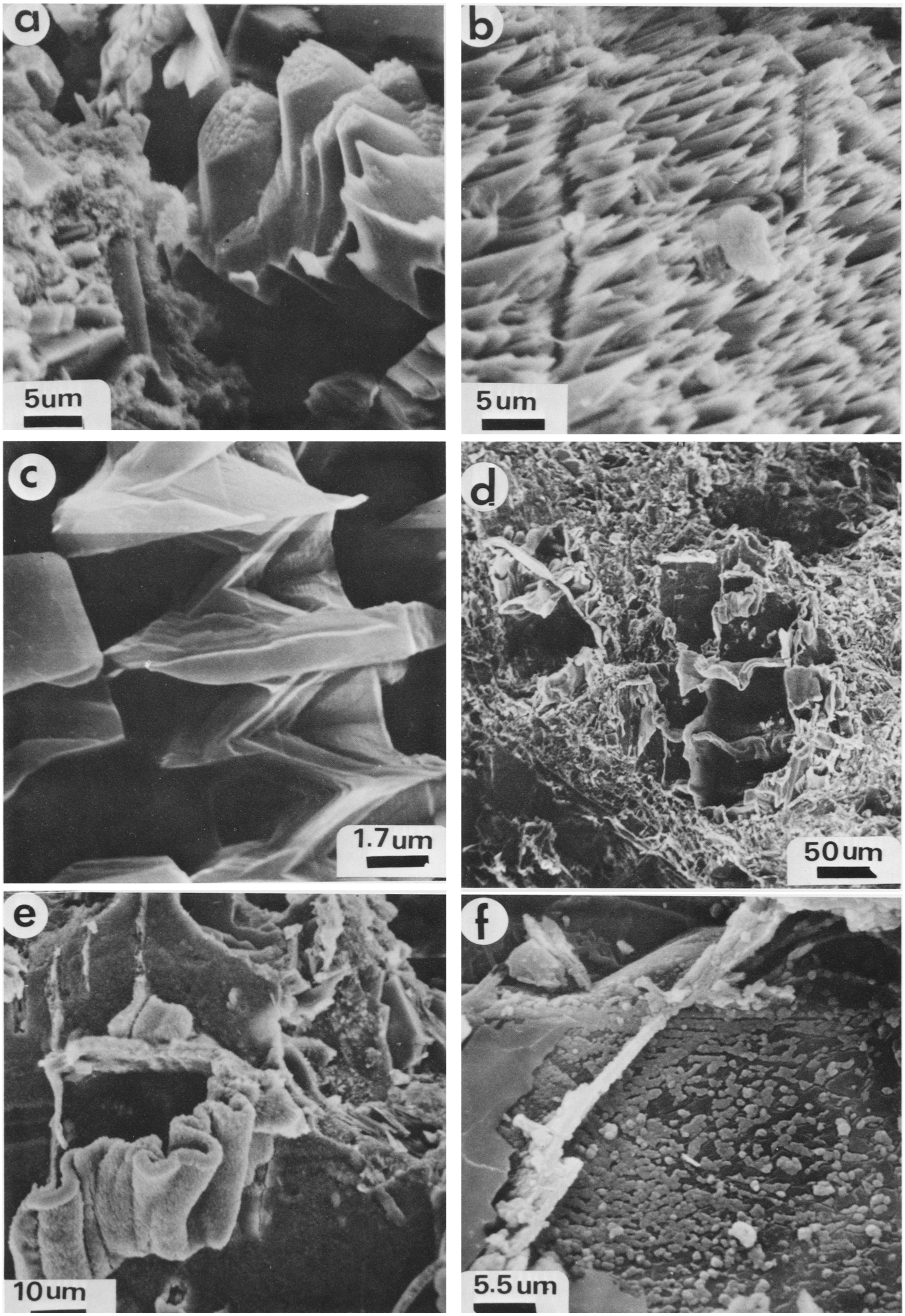
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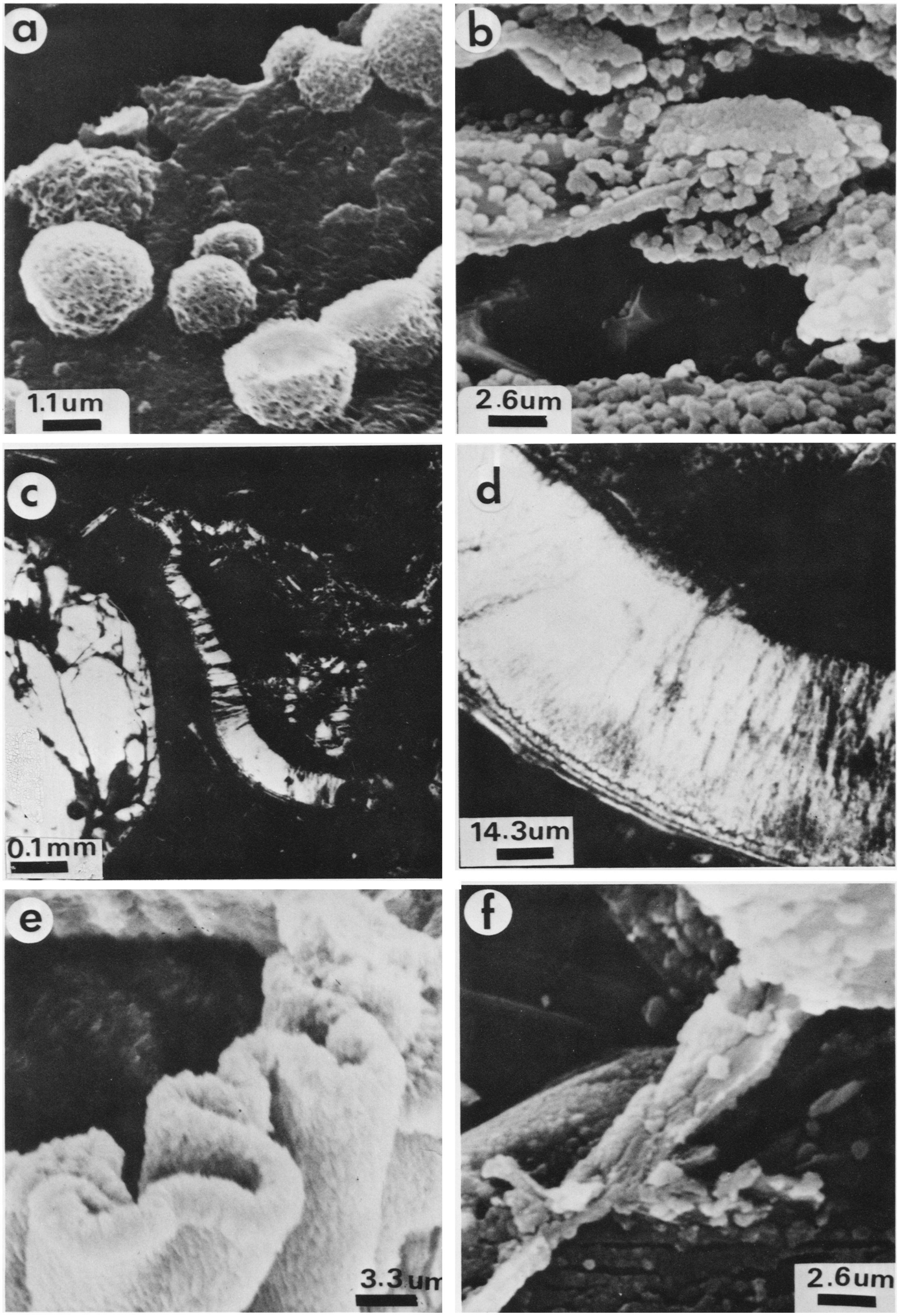
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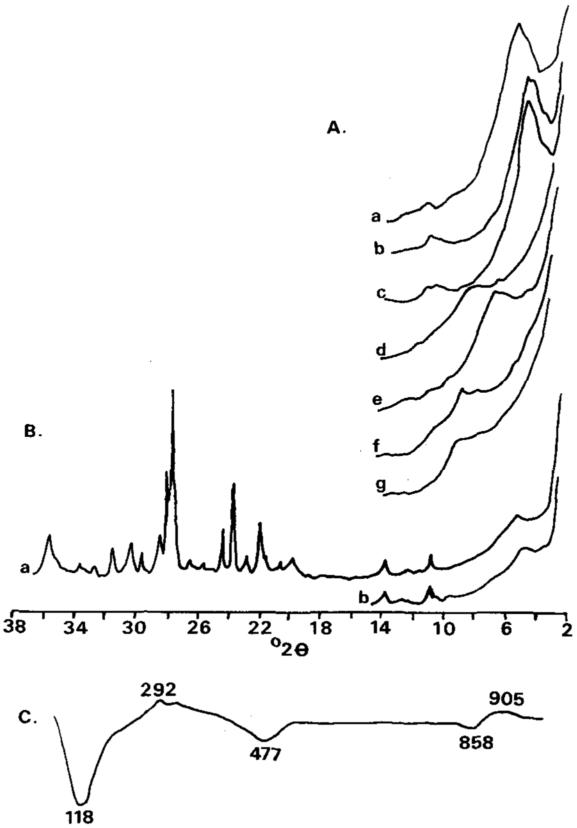

Figure 4. (A) X-ray powder diffraction patterns of <2-μm fraction of altered andesite. Treatments: (a) Mg-saturation, 54% RH, (b) Mg-ethylene glycol, (c) Mg-glycerol, (d) K-saturation, 105°C, 0% RH, (e) K-saturation, 54% RH, (f) K-saturation, 300°C, 0% RH, (g) K-saturation, 550°C, 0% RH. (B) XRD of <10-μm fraction of altered andesite showing presence of smectite, augite, plagioclase. (a) Mg-saturation, 54% RH, (b) Mg-ethylene glycol; (C) Differential thermal analysis pattern of <2-μm fraction.

augite alteration, favoring congruent over incongruent dissolution. Congruent dissolution of pyroxene is favored in an environment where oxygen is limiting and the formation of protective $Fe(OH)_3$ precipitates is hindered (Siever and Woodford, 1979). Such an environment probably exists in the wet soils at the Pyramid Creek site.

The intermediate phase of andesite alteration is characterized by advanced phenocryst alteration and the precipitation of clay minerals within the secondary porosity network. Moldic secondary pores after augite (pores retaining the outline of the original phenocryst) are partially to completely filled with pale, yellowish brown to pale green, fibrous clay. Feldspar phenocrysts show strong to complete complex cavernous alteration of labradoritic cores. Filling of internal cavernous voids by authigenic clay is incomplete, but this may be in part an artifact of thin section preparation. The extremely fine intramineral pores which cross the andesine rim and permit solution "mining" of the interior core restrict resin penetration during sample impregnation. Thus, it is possible that some of the pseudomorphic clay may be lost during thin section preparation. However, SEM observations suggest that secondary clay forms a delicate, complex, cross-linear alteration fabric which maintains high internal porosity (Figures 2d, 2e, and 3b). The clay in deformed intersecting sheets is probably produced by clay precipitation in intramineral pores which follow compositional zoning.

Close inspection of the clay films in secondary pores and channels reveals a two-stage development of authigenic clay. The first stage is characterized by the precipitation and growth of composite spherical forms on void walls or host grain surfaces (Figures 2f, 3a, 3b). The spheroids are about 1 μm in diameter and consist of a porous aggregate of much smaller particles (Figure 3a). The internal morphology of the spheroids consists of haphazard packing of extremely small plates, suggesting the possibility of smectite (Wilson and Pittman, 1977). Analyses by XRD and TEM (Figures 4 and 5) confirm the presence of montmorillonite as the major authigenic phase of the weathered andesites. However, the occurrence of montmorillonite as spherical aggregates is heretofore unmentioned in the literature. Eswaran (1979) found similar spheroids in altered plagioclase which he termed "amorphous aluminosilicates." Eswaran's globular coatings were isotropic in thin section, in contrast to the anisotropic nature of the coatings observed in this study (Figures 1b, 3c, 3d). The aggregate spheroids probably grew from a "seed" precipitated onto a suitable substrate and then merged to form irregular sheet-like structures, representing the beginning of clay film formation (Figure 2f, upper right corner; Figure 3b). This initial stage of clay precipitation is sometimes difficult to recognize due to the very small size of the spheroids. Furthermore, they are weakly anisotropic unless organized into continuous sheets.

The second phase of clay authigenesis is characterized by pore fillings of fibrous smectite. The two-phase sequence is illustrated in Figures 3c and 3d, which show

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Figure 3. Stages of smectite genesis in altered andesite: (a, b) Scanning electron micrographs showing initial formation of aggregate spheroids; (a) Spheroidal forms showing complex internal structure; (b) Development of sheet structure in smectite spheroids on grain surface; (c) Photomicrograph of fibrous smectite clay film lining a dissolution void showing multistage growth. Large plagioclase phenocryst on left; (d) Higher magnification of Figure 3c showing initial precipitation of granular smectite followed by fibrous growth. Void is in upper right corner. Growth has occurred from lower left to upper right, perpendicular to void wall; (e, f) Scanning electron micrographs of transformation of plagioclase to smectite, showing development of fibrous sheet structure.

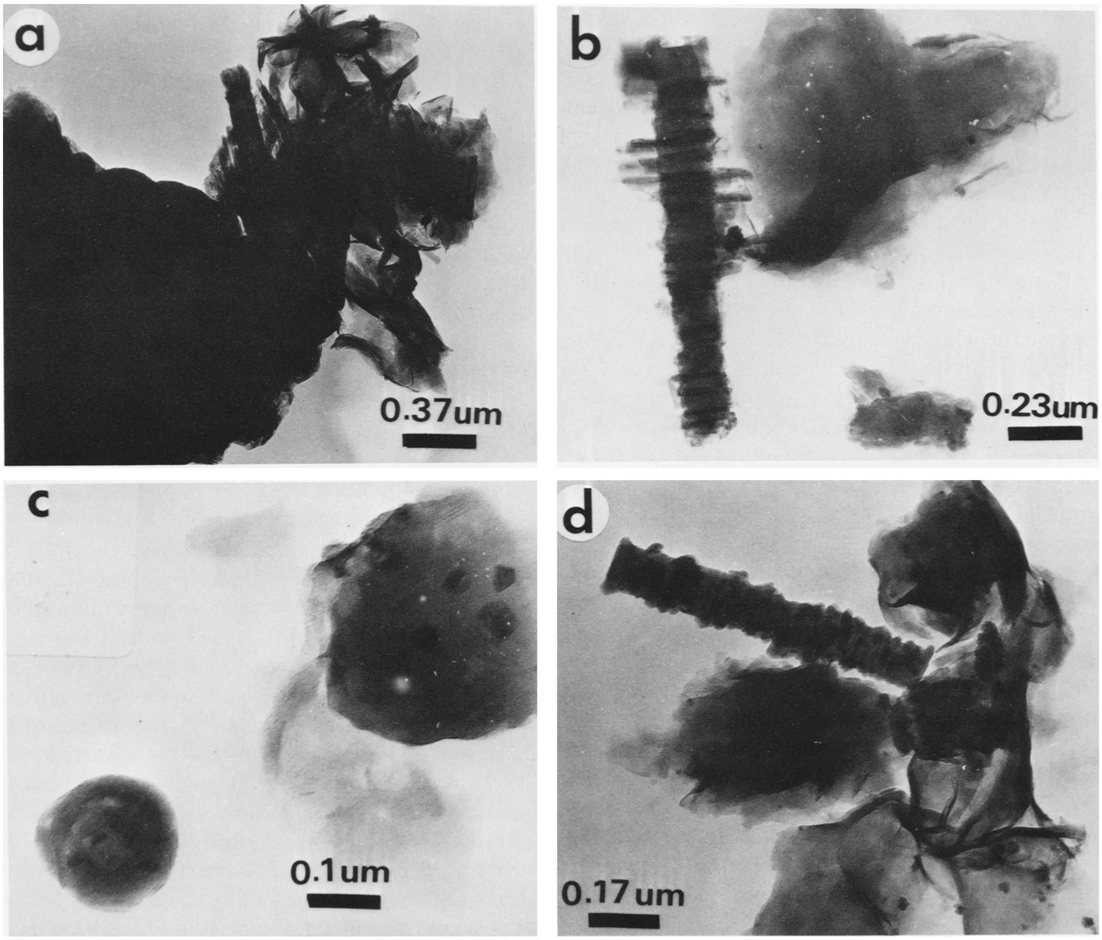

Figure 5. Transmission electron micrograph of <2-μm fraction; (a) Montmorillonite; (b, d) Montmorillonite and plagioclase fragments; (c) Spheroidal halloysite and thin flakes of montmorillonite.

a precipitation clay film partially filling a moldic dissolution pore. The clay film had at least three episodes of aggregate spheroid formation which led to the formation of continuous, overlapping sheets of clay displaying granular extinction (Figure 3d, lower left corner). Each sheet is about 1 μm thick, with the third layer showing a tendency towards fibrous growth habit. Following the precipitation of the aggregate spheroid sheets, more rapid growth of smectite occurred, producing interlocking crystals with fibrous growth habit which partially filled the void. The smectite fibers are oriented roughly perpendicular to void walls in contrast to the parallel orientation of pedologic clay films (or cutans, see Brewer, 1964, p. 206), and commonly show convolute structure (Figures 2d, 2e, and 3e). Such convolution may be an artifact of sample preparation and reflects shrinkage of clay sheets on drying.

During advanced weathering, andesine microlites undergo extensive congruent dissolution and appear as delicate, honeycombed euhedral laths encased in a smectite matrix (Figure 1e). The absence of residual surface "armor" and the dominance of selective etching during feldspar alteration agree with observations of Berner and Holdren (1977) and Wilson (1975). The alteration of plagioclase phenocrysts from the inside-out must be controlled by fluid movement through intramineral pores connecting the cavernous crystal interior to the outside environment. Fluid movement through such minute tortuous pores must be extremely slow, creating a very poorly drained microenvironment within the cavernous pore. Such a microenvironment favors the formation of smectite over other phyllosilicates (Borchardt, 1977).

None of the tubular forms of halloysite observed during plagioclase alteration in volcanic materials (Kirkman, 1981; Eswaran, 1979; Eswaran and DeConinck, 1971; Parham, 1969) or granites (Eswaran and Wong Chaw Bin, 1978c) were observed in this study. XRD analysis of altered andesites gave no indication of the presence of 1:1 phyllosilicates (Figures 4a, 4b) in either the <10-μm or clay fractions. XRD patterns characteristic of montmorillonite were obtained from the clay fraction. The possibility of halloysite is suggested in DTA patterns by an intermediate endotherm (Figure 4c), although such endotherms have also been reported for some smectites (MacKenzie, 1957). The low-temperature endotherm shows asymmetry characteristic of smectites saturated with divalent cations, and a weak high-temperature endotherm, at ~860°C, further suggests smectite (Mackenzie, 1957). TEM provides the only positive indication of the presence of halloysite in the andesite samples. Trace amounts of spheroidal halloysite were observed (Figure 5c), although the mineralogy on the whole is dominated by smectite (Figures 5a and 5d). The halloysite spheres are much smaller (~0.1 μm) than the aggregate spheroids observed by SEM (~1 μm) and lack the complex floccular internal structure of the smectite bodies. The absence of halloysite XRD peaks is probably due to its occurrence in very small amounts and in very small particles. Delicate fragments of plagioclase (Figure 5b) probably reflect phenocrystic or microlitic fragments shattered during sample preparation.

Taskey *et al.* (1978) found hydrated halloysite and noncrystalline gel to be the dominant weathering products in upper horizons of wet colluvial soils in Oregon's Western Cascades. The occurrence of smectite in upper soil horizons was related to the incorporation of subsoil material from the Little Butte Volcanics into the colluvium. The predominant formation of smectite during alteration of andesitic cobbles in a wet soil from colluvium seems at first to contradict Taskey's observations (Taskey *et al.*, 1978, Figures 3, 4). Several factors are probably responsible for the divergent mineralogy of the fine earth fraction vs. entrained, altered lithic fragments. First, the volcanic colluvium contains pyroclastic material in addition to clasts of andesite and basalt. The formation of hydrated halloysite and noncrystalline gel during alteration of tephra has been well documented (Kirkman, 1981; Dudas and Harward, 1975; Askenasy, 1973) and must be considered a likely source for the halloysite at Pyramid Creek. Second, differences in internal drainage between the soil material and the altered lithics create important differences in their respective chemical microenvironments. The weathered clasts contain different levels of microporosity which affect fluid movement between cobble and soil, as well as between individual weathering domains within the cobbles. Thus, stagnant conditions favoring retention of silica and cations probably exist on a microscale within the altering andesitic clasts, whereas the bulk soil lies in the framework of an overall leaching, though wet, environment. Smectite forms in the altering lithic fragments due to the favorable chemical microenvironment, whereas halloysite forms in the adjacent soil material. It may be possible that smectite is a precursor of the halloysite. As the cobbles decompose and alter to soil matrix, microdrainage conditions may change, causing silica and bases to be leached, favoring the transformation of smectite to halloysite. Halloysite has been observed in discrete zones in altered basaltic lithorelicts elsewhere in Oregon soils, although the initial mineral transformation of plagioclase produced smectite (Glasmann, unpublished data). This hypothesis requires further examination.

Taskey's methodology precluded the opportunity to study clay genesis on anything but a macroenvironmental scale which proved very useful in his broad study of clay mineral–landscape stability relationships. However, the present study shows that clay genesis in Western Cascade soils from colluvium is most closely tied to soil microenvironment, reaffirming conclusions reported in other recent studies of clay genesis (Gardner *et al.*, 1981; Eswaran, 1979; Meliner and Velde, 1979; Eswaran and Wong Chaw Bin, 1978a, 1978b; Eswaran and DeConinck, 1971).

CONCLUSIONS

The study of andesite alteration in Oregon's Western Cascade Range noted the following mineralogical changes: (1) Augite alters by pellicular congruent dissolution producing moldic secondary porosity. This porosity is sequentially filled by precipitation of smectite. (2) Plagioclase phenocrysts alter initially by surface etching, leading to the development of microconduits through which dotted and complex cavernous alteration of crystal interiors is facilitated. Microlites alter by congruent dissolution. (3) Interstitial glass alters to smectite and may have a protective effect on crystal alteration by restricting fluid movement through the matrix. (4) Smectite genesis follows a two-stage sequence showing initial formation of aggregate spheroids on void walls followed by a later stage of fibrous smectite growth. The formation of smectite is favored by the restrictive drainage of the microenvironment of the altering andesitic clasts and the wet soil environment of the sample location. However, the bulk soil data (Taskey *et al.*, 1978) did not show this effect.

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Резюме—Исследовались изменения продуктов андезитовых булыжников из влажных почв, формированных в вулканическом коллювиальном материале путем петрографических, электронно-микроскопических, и термических техник, а также рентгеновской порошковой диффракции. Аугитовые фенокристы изменялись путем соответствующего растворения, оставляя пустые места, которые последовательно заполнялись смектитом. Плаглиоклаз также изменялся в сфероидальные аггрегаты смектита микрометрического размера. Галлоизит не наблюдался в измененных булыжниках, хотя выступал в большом количестве в почве. Формированию смектита в измененных булыжниках, вероятно, благоприятствовал ограниченный дренаж микросреды в сопоставлении с влажными условиями почвы. [E.C.]

Resümee—Die Umwandlung von Andesitgrobkies aus nassen Böden, gebildet in vulkanischem, zusammengeschwemmtem Material, wurde mittels petrographischer Methoden, Elektronenmikroskopie, Röntgenpulverdiffraktometrie, und thermischen Methoden untersucht. Augiteinsprenglinge wandelten sich durch kongruente Auflösung um, wobei sie Hohlräume hinterließen, die im Anschluß daran mit Smektit gefüllt wurden. Plagioklas wurde ebenfalls umgewandelt, wobei sich millimetergroße kugelige Smektitaggregate bildeten. Halloysit wurde im umgewandelten Grobkies nicht gefunden, obwohl er in der Hauptmasse des Bodens reichlich vorhanden ist. Die Bildung von Smektit in dem umgewandelten Grobkies wurde wahrscheinlich durch eine allmähliche Auslaugung im kleinen Bereich zusammen mit den nassen Bodenverhältnissen gefördert. [U.W.]

Résumé—On a étudié l'altération de produits de galets de sols mouillés formés dans du matériau volcanique colluvial par des techniques petrographiques, de microscope électronique, de diffraction poudrée aux rayons-X, et thermales. Des phénocrystes d'argile se sont altérés par dissolution congruente laissant des vides qui ont été subséquemment remplis par de la smectite. La plagioclase s'est aussi altérée pour produire des aggrégats de smectite spheroïdaux de taille d'un micro-mètre. L'halloysite n'a pas été observée à l'intérieur des galets altérés, quoiqu'elle était abondante dans la matrice du sol. La formation de smectite dans les galets altérés a probablement été favorisée par le drainage restrictif du micro-environement en combinaison avec des conditions de sol mouillé. [D.J.]