1098

0038-075X/86/1423-0173$02.00/0
SOIL SCIENCE

September 1986
Vol. 142, No. 3
Printed in U.S.A.

EVOLUTION OF STRUCTURE IN A CHRONOSEQUENCE OF ANDESITIC FOREST SOILS[1]

GODY SPYCHER,[2] SHARON L. ROSE,[2,3] PHILLIP SOLLINS,[2] JOEL NORGREN,[4]
J. LOWELL YOUNG,[5] AND KERMIT CROMACK, JR.[2]

Using scanning electron microscopy, we studied changes in soil structure in a chronosequence of four andesitic forest soils at Mt. Shasta. The soils (Xeropsamments) were 55 yr old (flow A), ~300 yr old (flow B), and an estimated several thousand years old (flows D and E).

Soil skeleton in flow A consisted of coarse particles whose accessible surface was partially or entirely covered by silt- and clay-size particles. Weathering products and organic materials were adsorbed on accessible surfaces in isolated thin patches. An abrupt boundary at the 10-cm depth separated a friable surface horizon from a cemented substratum. The boundary was deeper and more diffuse in flow B. Both flows appear to have been cemented initially, probably by interstitial sedimentation and deposition of fine particles around coarse grains as water drained from the soil. The soils were apparently further stabilized by precipitation of solutes at zones of interparticle contact as water evaporated from storage pores. Soil in flows D and E was friable throughout the profile. The main structural units were large grains entirely covered with silt- and clay-size particles and amorphous coatings stabilized by weathering products and organic matter. Discrete microaggregates were relatively uncommon. Such formation and stabilization of structure may be characteristic of andesitic parent material, which weathers mainly to allophane, halloysite, and chloritic intergrades, rather than to high-charge phyllosilicate clays.

Chronosequences of lithologically similar soils provide excellent opportunities for studying changes in soil fabric and structure during pedogenesis. Such chronosequences occur commonly in the volcanic mountains of the Pacific Rim, particularly where recurrent mudflows (lahars) have deposited material on lower slopes (Crandell 1971).

The pedogenesis of porous and unconsolidated pyroclastic parent materials begins with Entisols. Andepts develop later in the sequence and may convert to Spodosols (Simonson and Rieger 1967), Alfisols, or Ultisols (Fernandez-Caldas et al. 1981), depending on climate and vegetation. Layer-silicate clays are largely absent at the Entisol stage, and primary mineral or rock fragments may constitute the entire clay-size fraction. Unlike most parent materials, porous and unconsolidated pyroclastic materials weather primarily to allophane, halloysite, and chloritic intergrades (Shoji et al. 1982; Parfitt et al. 1983) and provide an opportunity for studying evolution of the fabric and structure of soils in which high-charge phyllosilicate and crystalline oxide clays are not the chief reactive surfaces or component particles of aggregates.

This report documents, by scanning electron microscopy, features of the evolution of aggregation and soil structure in a chronosequence of four andesitic soils derived from a sequence of mudflows designated A, B, D, and E at Mt. Shasta, California (Dickson and Crocker 1953; Sollins et al. 1983).

MATERIALS AND METHODS

At sampling, the Mt. Shasta A flow was 56 yr old (Beardsley and Cannon 1930), the B flow about 300 yr old (Jenny 1980), and the two older flows, D and E, were an estimated several thousand years old (Jenny 1980). The parent material for all flows is a coarse, sandy andesitic material that originated from a common source on the south slope of the mountain. Vegetation on flows A and B was mainly coniferous, that on flows D and E mainly black oak (Dickson and Crocker 1953; Sollins et al. 1983). Mean annual temperature and precipitation are 9.8°C

---

[1] Paper 1853, Forest Research Lab., Oregon State Univ., Corvallis 97331.

[2] Dept. of Forest Science, College of Forestry, Oregon State Univ., Corvallis 97331.

[3] Present address: Natural Resources Ecology Lab., Colorado State Univ., Fort Collins 80523

[4] Forestry Associates International, P.O. Box C-56789, Seattle, Wash. 98105.

[5] U.S. Dept. of Agriculture-Agricultural Research Service, Corvallis, Oregon 97331.

Received for publication 31 Jan. 1984; revised 13 May 1986.

and 118 cm. The soils are classified Xeropsamments (Soil Survey Staff 1975).

Thickness of the litter layer depended on the surrounding vegetation (Sollins et al. 1983). L-layers ranged from 5 to 25 mm, and F-layers from 5 to 70 mm. H-layers, 2 to 10 mm thick, occasionally occurred at flows D and E.

Soils at flows A and B had AC horizons of gravelly loamy sand that were 10 to 20 cm thick and dark gray to gray (10YR 4/1 to 6/1; dry). Dry and moist consistence was loose, and structure was absent or weak. The lower boundary was abrupt in flow A, gradual in flow B. C horizons varied in thickness from 30 cm to more than 1 m and were commonly stratified into layers of variable thickness and texture. Typically, C horizons were gray (10YR 6/2; dry) gravelly loamy sand. Dry and moist consistence was very hard and structure was massive.

Soils in flows D and E displayed A11-A12-A3 sequences based on color changes from brown or dark brown (10YR 4/3, 3/3; dry) at the top to pale brown (10YR 6/3) in horizons below about 40 cm. Thickness averaged 10 cm for the A11 horizon, 20 cm for the A12 horizon, and 40+ cm for the A3 horizon. The soil throughout the profiles was gravelly loamy sand. Consistence was soft when dry and very friable when moist, and structure was weak fine-granular. Boundaries generally were gradual.

Soil at all sites was sampled from surface horizons and from one or more subsurface horizons with bulk-density cans in spring and summer 1979. Most samples were air-dried; freeze-drying was not considered necessary because the surface morphology of the particles and aggregates did not change noticeably on drying. Intact aggregates (0.5- to 5-mm diameter) were removed from the cores, identified under a dissecting microscope (×7), mounted on Al stubs, and coated with gold-palladium alloy under vacuum. Three to five stubs, each with from one to four aggregates, were prepared from samples from each of the four sites and examined with an AMR 1200 scanning electron microscope (SEM).

RESULTS

Flows A and B

Soils from deposits A and B shared a coarse sandy texture and light-to-dark gray, low-chroma colors. The clay-size mineral fraction, about 1 to 6% by weight (Dickson and Crocker 1954), consisted largely of rock fragments (Figs. 1 and 2) rather than phyllosilicates and appeared to be well distributed throughout the soil fabric. The skeletal grains were mainly silt- and sand-size particles. Most aggregates in both flows were silt-encrusted sand-size particles (Figs. 1 and 2). Cementation, once present throughout the profile of the freshly deposited flows (Beardsley and Cannon 1930), still occurred below a depth of 10 cm in flow A and below about 15 cm in flow B.

Structure and texture of soil from surface and subsurface horizons of both flows were similar, as was the morphology of aggregates from the different soil depths, except that hyphae and rootlets were more abundant on aggregates from surface horizons than on those from subsurface horizons. Typically, accessible surfaces of particles larger than 50 μm were partially (sometimes entirely) encrusted with fine particles (Figs. 1 and 2). Most crusts were 10 to 30 μm thick. Encrusting particles were irregularly shaped, highly angular, and conchoidal (Figs. 1 and 2). Encrusted grains in friable surface horizons formed weak clusters and aggregates that were stabilized mainly by hyphae (Fig. 1). Cementation in subsurface horizons probably resulted from precipitation of solutes (see Discussion), but the mechanism could not be resolved clearly by SEM.

Adsorbed organic materials and weathering products were relatively absent from accessible surfaces of both large grains and encrusting silts, particularly in flow A (Figs. 1 and 2). However, some globular or banded materials appeared as isolated thin patches on grain surfaces. These adsorbates, usually <0.5 μm thick, occurred more extensively in flow B than in flow A, but rarely covered entire surfaces, even of small particles.

Flows D and E

Flows D and E shared similar texture, structure, color, and degree of weathering. The soil fabric appeared to be predominantly chlamydic, a fabric type in which large skeletal grains are coated with clay-plus-silt-size mineral material (Brewer 1979). Clay-size particles were clearly a more important component of the crusts in older than in younger flows, and the encrusted silts were much less angular in the old flows (Figs. 3 and 4). Coatings and organic matter were continuous around most sand- and silt-size grains.

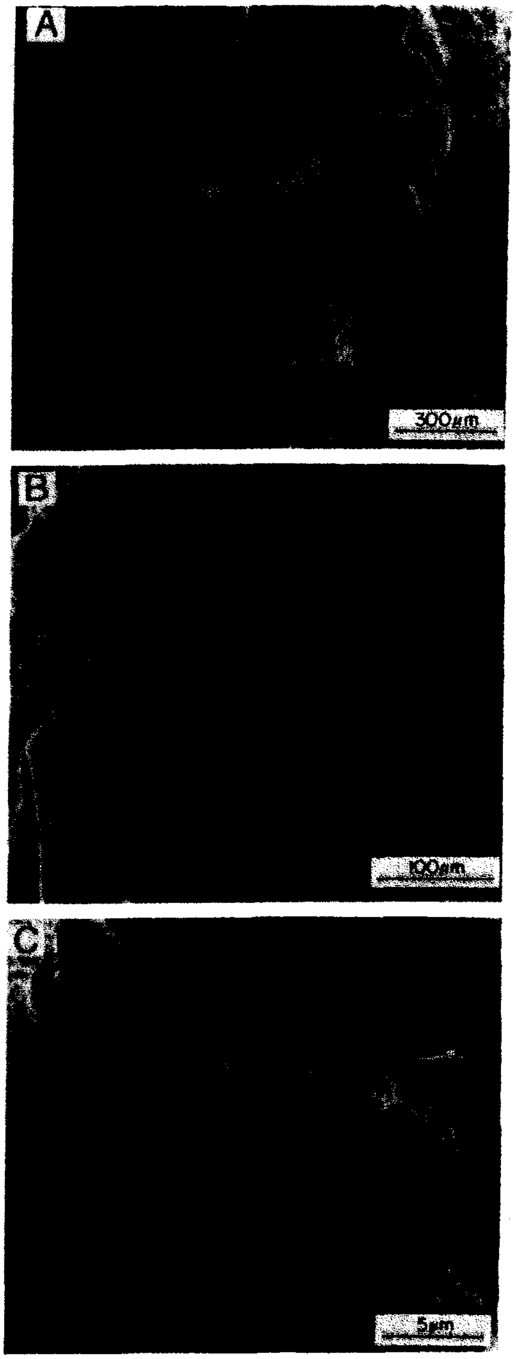

FIG. 1. Flow A. (A) Sand grains encrusted with finer particles and intergrown with hyphae, 0- to 10-cm depth. (B) Sand-grain crust as much as 30 µm thick, 20- to 40-cm depth. (C) Encrusting silts with hyphae and some isolated amorphous adsorbates, 20- to 40-cm depth.

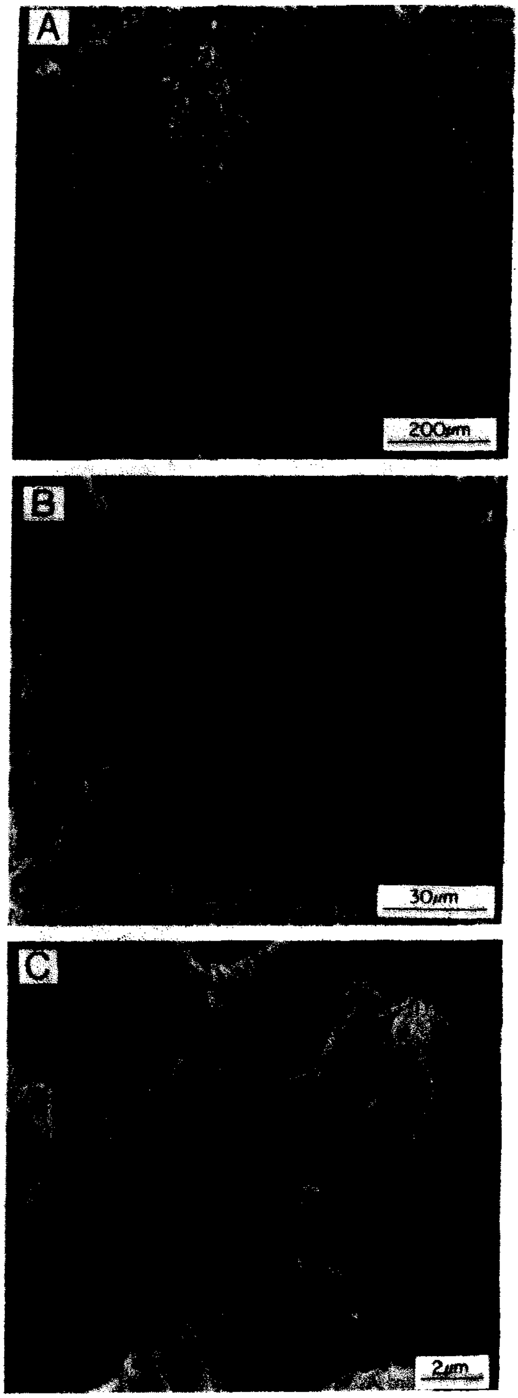

FIG. 2. Flow B. (A) Macroaggregate about 1.2 mm from the cemented subsurface horizon, 30- to 50-cm depth. (B) Continuous, mainly silty crust around sand grains, 0- to 10-cm depth. (C) Encrusting silts with hyphae and amorphous adsorbates, 30- to 50-cm depth.

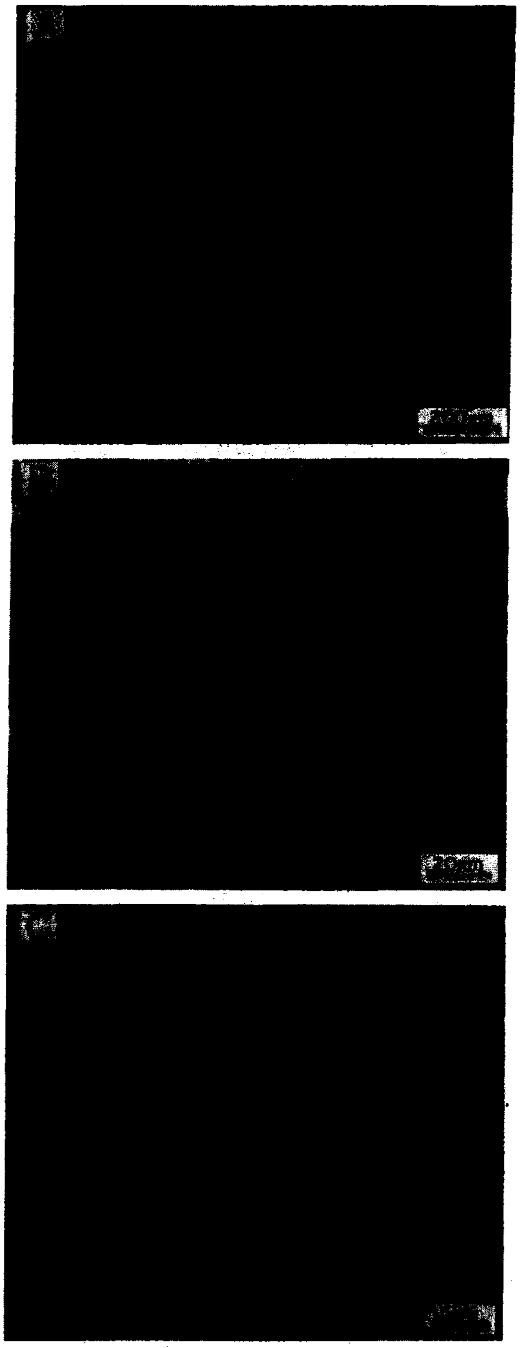

FIG. 3. Flow D. (A) Sand grain with continuous crust, 20- to 40-cm depth. (B) Silt crusts, 0- to 10-cm depth. (C) Silt grains from a crust around a larger grain with continuous coatings of clay-size particles, 20- to 40-cm depth.

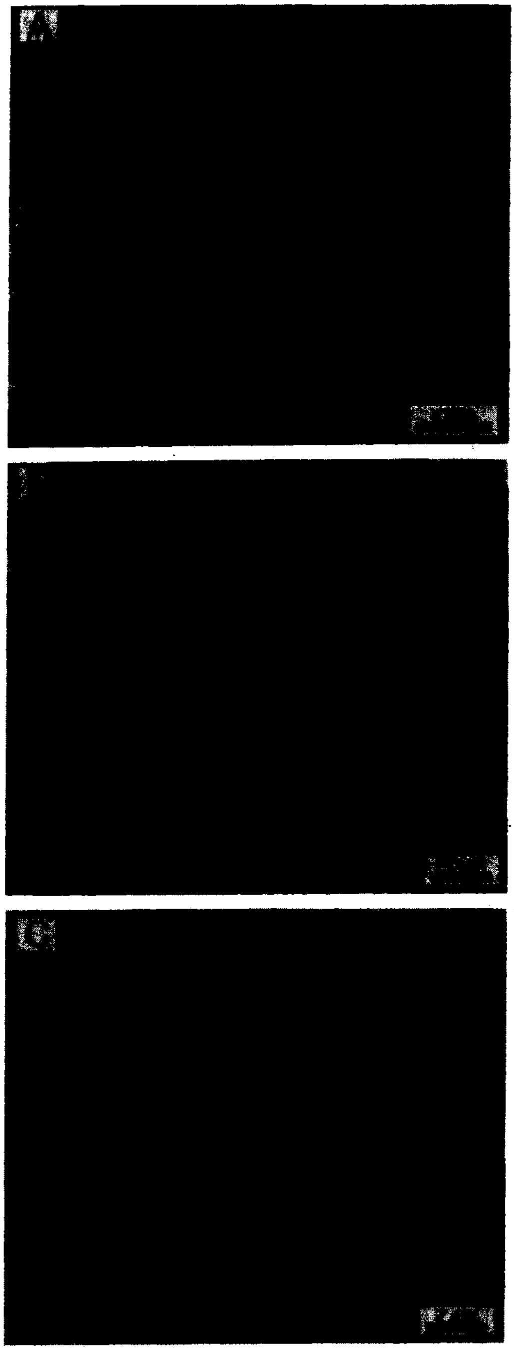

FIG. 4. Flow E. (A) Fine sand grains with continuous crust, 20- to 40-cm depth. (B) Dry root with root hairs and microaggregate, 0- to 10-cm depth. (C) Silt grains from crust coated with finer particles, 20- to 40-cm depth.

Most large aggregates (>250 μm) were simply sand-size grains with continuous crusts of silt- and clay-size particles (Figs. 3 and 4). More complex aggregates were present, but they fragmented readily and could not be examined by SEM. Smaller aggregates (10 to 250 μm) occurred as separate entities (Fig. 4), but were more often components of crusts surrounding larger particles or aggregates (Figs. 3 and 4). Most of these smaller structures were coated silt or sand grains rather than microaggregates (sensu Edwards and Bremner 1967), which was sometimes evident from their appearance (Fig. 3), or which could be inferred from the low clay content of the soil (Dickson and Crocker 1954). Only the smallest aggregates (<10 μm) appeared to consist exclusively of organic and mineral colloidal matter (Figs. 3 and 4).

DISCUSSION

Beardsley and Cannon (1930) described the A flow immediately after it occurred as approximating "concrete ready to pour." The surface consisted of fine particles that formed a hard crust upon drying; the areal extent and thickness of the crust were not noted.

When we sampled, surface layers of all flows were friable and sandy, presumably because of weathering and biological activity. Strong cementation was noted in subsurface layers, which suggests that cementation of the initial deposit extended deep into the profile. It is unlikely that the subsurface cementation was recently developed, because most indurative processes require reducing conditions and considerable time, neither of which pertained at Mt. Shasta.

We suggest that coarse particles formed an initial framework through the entire profile, and that silt- and clay-size particles encrusted accessible surfaces of coarser grains by interstitial sedimentation and deposition as water drained from the soil. Next, the fabric may have been stabilized by concentration and precipitation of solutes at zones of interparticle contact as water evaporated from storage pores. In the laboratory, silica cementation occurs at contact points between sand-size glassbeads (<500 μm) when a drop of distilled water is added and then allowed to evaporate (Gifford and Thran 1974). In addition, amorphous gel coatings forming around small particles (Uehara and Jones 1974) during the flow event should have contributed strongly to cementation under the observed packing arrangement of particles.

From the present condition of the four flows, it appears that cementation loosened at the surface during the first 50 to 60 yr of soil development, leaving an abrupt, smooth boundary between the friable surface horizon and the hard substratum. The boundary became diffuse and shifted to lower depths during the next 250 yr. This process mainly affected interaggregated contacts; silty crusts on larger grains or particles remained intact.

Continued structural development resulted in completion of crusts around larger grains. Silt and clay aggregates either were not formed because there were too few fine particles or did not persist because they were more readily destroyed than were crusts on large grains. Crusts were further stabilized as mineral matter dissolved from acute-angled exposed edges of particles and precipitated at zones of interparticle contact within the crust or at core-grain surfaces during evapotranspiration from storage pores. Single silt- and clay-encrusted sand grains are likely to remain the dominant structural units until clay formation progresses to a point where the more complex fabrics can evolve.

The early pedogenesis of the Mt. Shasta andesitic soils differs fundamentally from those beginning with nonvolcanic parent material because at no stage are layer-silicate clays dominant. The reactive surfaces appear to be provided instead by amorphous materials precipitated or adsorbed from solution onto silt- and sand-size rock fragments.

ACKNOWLEDGMENTS

Research was funded by National Science Foundation grant DEB 78-23521. We are grateful to the U.S. Forest Service Pacific Northwest Forest and Range Experiment Station (RWU-1653) and the Department of Soil Science, Oregon State University, for providing laboratory facilities and publication funds; to E. A. Paul and A. Mermut for helpful comments on the manuscript; and to B. Addison for help with the scanning electron microscope.

REFERENCES

Beardsley, G. F., and W. A. Cannon. 1930. Note on the effects of a mudflow at Mt. Shasta on the vegetation. Ecology 11:326–336.

Brewer, R. 1979. Relationships between particle size, fabric and other factors in some Australian soils. Aust. J. Soil Res. 17:29–41.

Crandell, D. R. 1971. Post glacial lahars from Mount Ranier volcano, Washington. U.S. Geol. Surv. Prof. Pap. 677.

Dickson, B. A., and R. L. Crocker. 1953. A chronosequence of soil and vegetation near Mount Shasta, California: 1. Definition of the ecosystem investigated and features of plant succession. J. Soil Sci. 4:123–141.

Dickson, B. A., and R. L. Crocker. 1954. A chronosequence of soils and vegetation near Mount Shasta, California: 3. Some properties of the mineral soils. J. Soil Sci. 5:173–191.

Edwards, A. P., and J. M. Bremner. 1967. Microaggregates in soils. J. Soil Sci. 18:64–73.

Fernandez-Caldas, E., P. Quantin, and M. L. Tejedor Salguero. 1981. Sequences climatiques de sols derives de roches volcaniques aux Iles Canaries. Geoderma 26:47–62.

Gifford, R. O., and D. F. Thran. 1974. Strength of silica cementation. *In* Soil crusts. J. W. Cary and D. D. Evans (eds.). Ariz. Agric. Exp. Stn., Tech. Bul. 214, pp. 28–30.

Jenny, H. 1980. The soil resource. Springer, New York.

Parfitt, R. L., M. Russell, and G. E. Orbell. 1983. Weathering sequence of soils from volcanic ash involving allophane and halloysite, New Zealand. Geoderma 29:41–57.

Shoji, S., Y. Fujiwara, I. Yamada, and M. Saigusa. 1982. Chemistry and clay mineralogy of Ando soils, brown forest soils, and podzolic soils formed from recent Towada ashes, northeastern Japan. Soil Sci. 133:69–86.

Simonson, R. W., and S. Rieger. 1967. Soils of the Andept suborder in Alaska. Soil Sci. Soc. Am. Proc. 31:692–699.

Soil Survey Staff. 1975. Soil taxonomy. Agric. Handbook 436. Soil Conservation Service, USDA, Washington, D.C.

Sollins, P., G. Spycher, and C. Topik. 1983. Processes of soil organic-matter accretion at a mudflow chronosequence, Mt. Shasta, California. Ecology 53:1273–1282.

Uehara, G., and R. C. Jones. 1974. Bonding mechanisms for soil crusts: 1. Particles surfaces and cementing agents. *In* Soil crusts. J. W. Cary and D. D. Evans (eds.). Ariz. Agric. Exp. Stn., Tech. Bull. 214, pp. 17–28.