Nature and origin of an argillic horizon in a soil of the Boulder Batholith, Montana
by Paul Anderson McDaniel

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University

Abstract:
Some forested soils of the granitic Boulder batholith in Montana have clay-rich horizons and are poorly drained. The purpose of this project was to study a representative soil of the area and determine the processes responsible for genesis of a clay-rich argillic horizon in coarse-grained granitic parent material. X-ray diffraction, thin section, and scanning electron microscopy techniques were used to do this.

Clay fractions from the B horizons of this soil differed markedly from surface horizons in both type and amount of clay minerals present. Smectite dominated the clay fraction and accounted for up to one-fourth of the fine-earth. Soil fabric analyses indicated pedogenic processes were not responsible for the high smectite content of the B horizon. The smectite is an in situ weathering product occurring in zones of weathering similar to those characteristic of hydrothermal alteration.

Hydrothermal alteration of quartz monzonite, a geological process, is apparently responsible for most of the chemical, physical, and mineralogical properties of the B horizon. Although effects of pedogenic processes of clay formation and clay movement (lessivage) can be seen, their influence on soil properties is minimal in these soils.

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Date March 4, 1983

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ABSTRACT

Some forested soils of the granitic Boulder batholith in Montana have clay-rich horizons and are poorly drained. The purpose of this project was to study a representative soil of the area and determine the processes responsible for genesis of a clay-rich argillic horizon in coarse-grained granitic parent material. X-ray diffraction, thin section, and scanning electron microscopy techniques were used to do this.

Clay fractions from the B horizons of this soil differed markedly from surface horizons in both type and amount of clay minerals present. Smectite dominated the clay fraction and accounted for up to one-fourth of the fine-earth. Soil fabric analyses indicated pedogenic processes were not responsible for the high smectite content of the B horizon. The smectite is an *in situ* weathering product occurring in zones of weathering similar to those characteristic of hydrothermal alteration.

Hydrothermal alteration of quartz monzonite, a geological process, is apparently responsible for most of the chemical, physical, and mineralogical properties of the B horizon. Although effects of pedogenic processes of clay formation and clay movement (lessivage) can be seen, their influence on soil properties is minimal in these soils.

INTRODUCTION

This study originated, in part, as a result of field work conducted for the U.S. Forest Service. This field work involved examination and description of soils in an area of the Boulder batholith which was of particular interest to the Forest Service because of problems experienced with drainage and road bed stability.

Soils were examined in an attempt to relate their properties to unusual geomorphic features associated with poor drainage. Field work indicated zones of high clay contents in subsurface horizons of many soils in the study area. These clay zones were apparently responsible for impeded drainage in areas of the landscape.

The objective of this study was to characterize a representative soil of the area and determine the process or processes responsible for the clay-rich argillic horizon. To do this, x-ray diffraction, thin section, and scanning electron microscopy techniques were used to assess the effects of various pedogenic and geologic processes on the genesis of this soil.

LITERATURE REVIEW

Geology of the Boulder Batholith

The Boulder batholith is a large mass of igneous rock which was intruded under the earth's surface during the late Cretaceous and early Tertiary Periods, or approximately 68 to 78 million years ago (Tilling et al.,1968; Veseth and Montagne, 1980). Subsequent removal of up to 1.6 km of overlying sediments has exposed approximately 3900 square km (1500 square miles) of the batholith in southwestern Montana (Perry, 1962; Pinckney, 1965).

The predominant mineralogy of the Boulder batholith is quartz monzonite, a rock similar to granite but containing more plagioclase feldspar. The Butte quartz monzonite makes up approximately two-thirds of the exposed rock and is predominantly quartz monzonite with some granodiorite (Becraft et al., 1963; Tilling et al., 1968). In general, mineralogical and chemical compositions of different varieties of the Butte quartz monzonite are similar and differences are mainly seen in grain size, color, and fabric (Pinckney, 1965). Table 1 gives an average chemical composition for the Butte quartz monzonite based on findings of several researchers.

Table 1. Average mineral composition of the Butte quartz monzonite.

Quartz	25 %
Orthoclase	25 %
Plagioclase	35 %
Biotite	10 %
Hornblende and other minerals	5 %

(After Hood, 1963; Smedes, 1966; Becraft et al., 1963; Kaczmarek, 1974).

The quartz monzonite tends to be rather coarse-grained with individual mineral grains typically averaging 1 to 3 mm in diameter (Ruppel, 1963; Becraft et al., 1963). Phenocrysts of potassium feldspar with diameters up to 2.5 cm are common (Veseth and Montagne, 1980).

Argillic Horizon Formation on Granitic Parent Materials

An argillic horizon is defined by Soil Taxonomy (Soil Survey Staff, 1975) as "an illuvial horizon in which layer-lattice silicate clays have accumulated by illuviation to a significant extent". Since igneous crystalline rocks such as those found on the Boulder batholith generally have little or no clay-size material, some clay formation must precede or occur with argillic horizon formation. Clay formation occurs as primary minerals are altered by chemical and physical weathering processes.

Soil development on granitic parent materials is often preceded by formation of grus, a process known as grussification. The term grus refers to small, angular fragments of weathered rock which are larger than 2 mm. Chemical and physical alteration of biotite and perhaps feldspar minerals appears to be the primary mechanism by which grussification of coarse-grained igneous rock occurs.

Several researchers have demonstrated the presence of partially altered biotite in grus. Apparently, alteration of biotite to secondary illite and vermiculite and the accompanying increase in volume are responsible for fracturing the parent material (Warhaftig, 1965; Nettleton et al., 1968; Isherwood and Street, 1976; Clayton et al., 1979).

Freeze-thaw cycles are probably an especially important physical weathering process in formation of grus in cold and dry climates. Increases in volume of 9% which accompany freezing of water can provide sufficient pressures to fracture most rocks (Birkeland, 1974).

The most important process of chemical weathering of common silicate and aluminosilicate minerals is hydrolysis (Birkeland, 1974). However, in cold, dry mountainous regions, the role of hydrolysis in clay formation is minimal (Millot, 1979). Jenny (1935) reported a linear relationship between clay formation and moisture and an exponential relationship between clay formation and temperature. In view of this, little clay formation would be expected in soils of the Boulder batholith under present climatic conditions.

Time is an important factor in argillic horizon formation, since both clay formation and translocation will increase with time. Ruppel (1962) studied Pleistocene ice movement in the northern part of the Boulder batholith and concluded that glacial deposits in the area ranged in age from early-Wisconsin to late-Wisconsin. This would put an approximate age on the landscape of anywhere from 100,000 to 10,000 years. Birkeland (1974) estimated the time required for minimal expression of a textural B horizon to be on the order of 1,000 years and 500,000 years for maximal expression. He has also reported a general lack of B horizons in soils formed in late-Wisconsin tills.

Clayton et al. (1979) reported that sediment yield studies indicated erosion losses averaging 1 cm per 1,000 years under present climatic conditions on the Idaho batholith. They felt that with this rate of erosion on slopes, there had not been enough time for modal development of argillic B horizons. Soil profile descriptions from their study area seem to support this hypothesis--argillic horizons are weakly expressed and restricted to soils formed on alluvium or colluvium with slope gradients less than 10% (Clayton, 1974).

Clay Movement

Evidence for translocation of clay minerals includes the presence of clay films or argillans on surfaces of peds and individual mineral grains. Argillans can be seen in some cases with the unaided eye or by use of a hand lens as well as by thin section analysis. Argillans observed in thin section exhibit a finer, more homogenous texture and differ in their birefringence and extinction patterns compared to the soil matrix when viewed under cross-polarized light (McKeague and St. Arnaud, 1969).

However, oriented clay particles along voids and ped surfaces can be caused by stress or pressure and not illuviation of clay (Birkeland, 1974). Clay films may also be destroyed and incorporated into the soil matrix by shrinking and swelling action of 2:1 expansible clay minerals (Nettleton et al., 1969) and possibly by mixing of soil by roots and fauna.

Numerous researchers have observed clay films in portions of B horizons of soils on granitic parent materials in mountainous regions of the western United States, including the Boulder batholith. However, these argillans are generally poorly expressed, indicating the lack of development in most of these soils (Hood, 1963; Marchand, 1974; Clayton et al., 1979; Veseth, 1981).

In general, soils of the Boulder batholith show little development. The coarse texture and mineralogical composition of the parent material tends to yield soils that are coarse-textured and low in clay content. Clay-sized mica (illite and sericite) and kaolinite mineral assemblages are dominant in the clay fraction of batholith soils (Hood, 1963; Veseth, 1981).

Hydrothermal Alteration of Granitic Parent Materials

Hydrothermal alteration of granitic parent material can have a significant effect on subsequent pedogenic processes. Hydrothermal activity can greatly accelerate chemical weathering processes and alter normal weathering products. This activity has been reported over extensive areas of the Boulder and Idaho batholiths.

Sales and Meyer (1948) were among the first researchers to study hydrothermally altered granite in detail on the southern part of the Boulder batholith near Butte, Montana. They described distinct mineralogical zones or reaction rims representing zones of diminishing hydrothermal activity extending outward from joints and fractures. These distinct mineralogical zones were probably caused by changes in the composition of hydrothermal solutions as reactions occured in host rocks (Grim, 1968). Alteration most likely occurred as the batholith cooled, creating a network of fractures and cracks through which hydrothermal fluids circulated (Pinckney, 1965). Becraft et al. (1963) and Pinckney (1965) also observed similar alteration zones in central and northern portions of the Boulder batholith.

Figure 1 shows a simplified diagram of hydrothermal alteration zones in quartz monzonite. Zones shown in Figure 1 can occur over distances ranging from only a few centimeters to several kilometers and represent a horizontal extension of a larger alteration zone with vertical orientation.

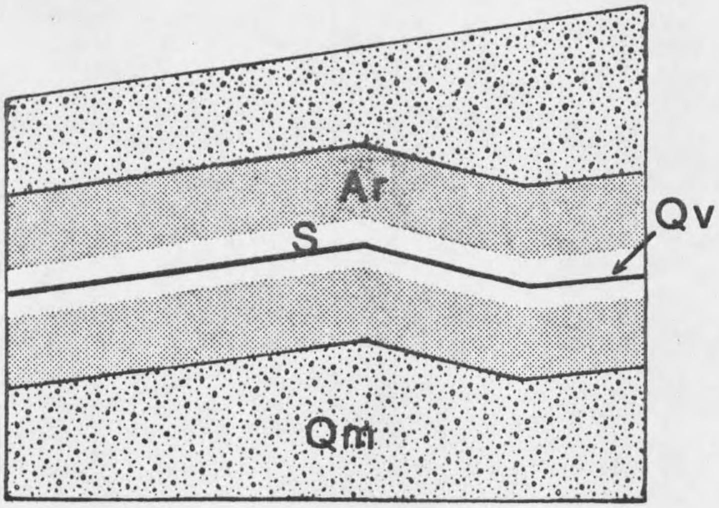

Figure 1. Zones of hydrothermal alteration in quartz monzonite. Qv = quartz or chalcedony vein; S = sericitized zone; Ar = argillized zone; Qm = unaltered quartz monzonite.

The quartz or chalcedony vein represents the zone of most intense alteration and reflects the original structure of the cracks or joints. Extending outward from the vein is a less-altered sericitized zone which contains moderately altered quartz grains, extensively altered potassium feldspars, and completely altered plagioclase, biotite, and hornblende grains. Iron pyrite, quartz, and sericite are the dominant alteration products (Sales and Meyer, 1948; Becraft et al., 1963).

An argillized zone envelopes the sericitized zone and is characterized by less intense alteration. The argillized zone is composed of a kaolinitic subzone and a less-altered montmorillonite (smectite) subzone. Quartz and potassium feldspars show little or no alteration, but plagioclases, biotite, and hornblende are extensively to completely altered to a variety of products (Guilbert and Sloane, 1968).

Montmorillonite is the dominant weathering product in the montmorillonitic subzone, occurring primarily as an alteration product of plagioclase, biotite, and hornblende (Becraft et al., 1963; Pinckney, 1965; Sales and Meyer, 1948). Illite and kaolinite also occur in this subzone in lesser amounts. The intensity of alteration in the montmorillonitic subzone is usually gradational over a distance of a few meters and is usually the widest of all alteration bands (Pinckney, 1965).

Only slight alteration is seen in quartz monzonite beyond the montmorillonite subzone. Plagioclase, biotite, and hornblende can be partially altered, with chlorite being the dominant alteration product along with minor amounts of montmorillonite (Becraft et al., 1963; Guilbert and Sloane, 1968).

Hood (1963) and Clayton et al. (1979) have described mineralogical properties of soils formed in areas of hydrothermal alteration on the Boulder and Idaho batholiths. Hood described yellow clay zones in association with areas of hydrothermal alteration. He identified this yellow clay as smectite by x-ray diffraction techniques.

Clayton et al. (1979) also found montmorillonite in the clay fraction of soils from areas of hydrothermal alteration. Kaolinite and illite dominated the clay-size fraction of soils from other areas of more intense hydrothermal alteration. Examination of soil thin sections revealed that plagioclase feldspars had undergone extensive internal alteration to sericite (koalinite, illite, and montmorillonite) and orthoclase minerals were clouded and sericitized along fractures. This alteration of feldspar was more pronounced than that seen in soils from areas of the batholith unaffected by hydrothermal alteration.

Smectite and Slope Failures

Because of a relatively low layer charge, smectites can expand and adsorb several times their weight in water (Borchardt, 1979). This along with their adhesive and cohesive properties causes smectite to frequently be associated with landslides, soil creep, and poor drainage.

Hydrothermally altered bedrock has been implicated in slope failures on the Idaho batholith (Clayton et al., 1979). Soil movement appears to be related to poor drainage associated with argillized zones and frequently occurs during spring snowmelt. Orientation of clay seams with the slope is probably important in determining the extent and type of mass movement.

METHODS AND MATERIALS

The Study Area

During the summer of 1980, 35 pedons were examined and characterized in a 10 square km area of the Deerlodge National Forest approximately 8 km southwest of Boulder, Montana. Figure 2 shows the location of the study area.

One pedon from the area was selected for this study on the basis of field characterization. This pedon contained an argillic horizon which exhibited properties representative of those of other soils occurring within the study area. These included B horizons with irregular and broken boundaries, strong chromas, the presence of "ghost rocks", and a sizeable increase in the amount of clay-size material when compared to the overlying and underlying horizons.

Field Sampling and Characteristics

A pit was dug to expose a soil profile 1.5 m across and 2 m deep. Field characterization and sampling were done using guidelines established in Soil Taxonomy (Soil Survey Staff, 1975) and Soil Survey Manual (Soil Survey Staff, 1951) with the assistance of Clint Mogen, retired USDA-SCS state soils correlator for Montana. Samples were collected from all soil horizons as well as from "ghost rock" inclusions found within the soil profile. Soil samples were air-dried, ground in a flail-type grinder, sieved to remove the greater than 2 mm

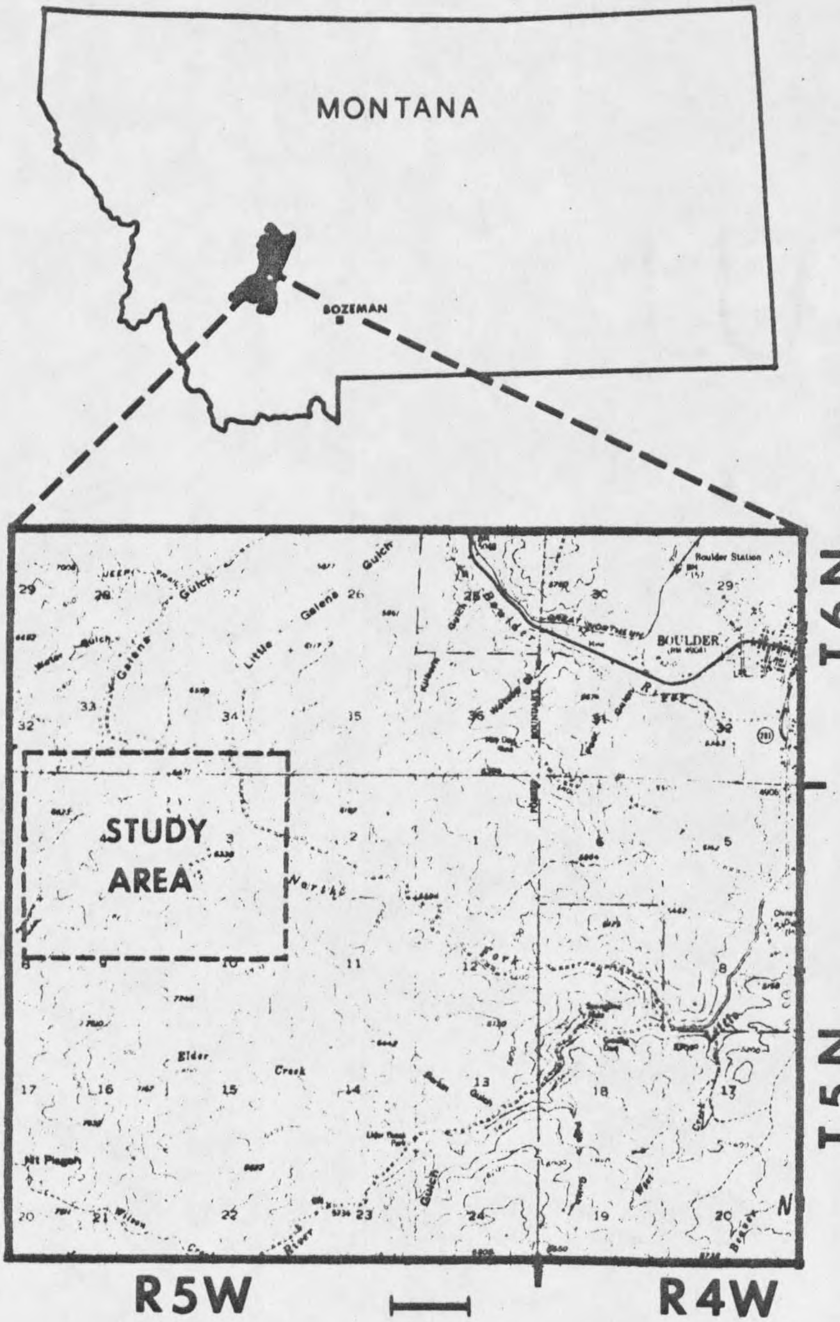

Figure 2. Maps showing location of the Boulder batholith and the study area.

fraction, and subsampled for laboratory analyses. Undisturbed samples from each horizon were used for soil fabric analysis.

Chemical Analyses

Soluble cation content, sodium adsorption ratio (SAR), electrical conductivity, pH of saturated paste, and water content at saturation were measured according to methods in Agriculture Handbook 60 (U.S. Salinity Laboratory Staff, 1969). Soil organic matter content was determined colorimetrically (Sims and Haby, 1971). A Perkin-Elmer model 303 atomic absorption spectrophotometer was used to measure soluble base cations (Ca, Mg, Na, K), extractable base cations (Chapman, 1965a), and cation exchange capacity (Chapman, 1965b). Total nitrogen was determined using a semi-micro Kjeldahl method (Bremner, 1965).

Physical Analyses

Fine earth fractions of samples were dispersed with sodium hexametaphosphate (Day, 1965) using a Blackstone BP2B ultrasound apparatus. Particle size analysis and separations were done by pipette method using particle settling time nomographs from Jackson (1956). In addition, percentages of the various sand-size fractions and coarse fragment contents were determined gravimetrically using appropriate sieves. Water content of the fine-earth fraction at 1/3 and 15 bar tension was measured using a ceramic plate apparatus and a pressure membrane apparatus, respectively (U.S. Salinity Laboratory Staff, 1969).

Clay Mineralogy

Clay mineralogy of the clay-size fraction of all samples was determined by x-ray diffraction analysis. Slides were prepared using a paste method (Thiesen and Harward, 1962), analyzed on a General Electric XRD-5 x-ray diffraction machine, and interpreted using techniques described by Whittig (1965). Semi-quantitative analysis of x-ray diffraction data was used to estimate relative amounts of various clay minerals present in each sample (Klages and Hopper, 1982).

In addition, clay mineralogy of argillans and clay-size matrix taken from the argillic horizon was determined. Clay films viewed under a binocular microscope were scraped from ped surfaces with a razor blade. Interiors of peds were sampled to obtain matrix material. Clay mineralogy of these samples was determined using x-ray diffraction techniques previously described.

Thin Section and Scanning Electron Microscopy

Thin sections of selected soil horizons were prepared by Cal-Brea Geological Services in Anaheim, California. Thin sections were examined and described under a petrographic microscope using techniques described by Moorhouse (1959) and FitzPatrick (1980).

Selected samples were examined using scanning electron microscopy (SEM). Samples of undisturbed and untreated soil material were used. Samples were prepared by Mr. Andy Blixt and examined at the Montana

Agricultural Experiment Station SEM laboratory at Montana State University in Bozeman.

RESULTS

Field Description and Characterization

The soil profile selected for this study is shown in Figures 3 and 4. Many of the features characteristic of soils in the study area are present in this profile and will be discussed in detail. A complete profile description is in Appendix I.

Based on field characterization this soil was classified as a fine-loamy over sandy, mixed Mollic Cryoboralf. Mean annual and mean summer soil temperatures were estimated using predictions of Munn and Nielsen (1979). Mollic subgroup classification was based on moist color values of 3 in the surface eluvial horizons (Soil Survey Staff, 1975).

The argillic horizon present in this soil exhibited some rather striking features. A sizeable increase in clay-sized material was observed in the argillic horizon compared with the surface eluvial horizons. The eluvial horizons were sandy loams whereas the argillic horizon was a sandy clay loam. Prismatic structure could be seen in the B22t and B23t horizons and clay films were visible on many ped faces. Boundaries of the Bt horizons and the B3 horizon were broken and discontinuous across the face of the exposed profile. The unusual diagonal orientation of the B3 boundary can be seen in Figures 3 and 4.