



Contrasting soil development on the sedimentary Kootenai Formation and granitic Boulder batholith in southwestern Montana
by Roger Joseph Veseth

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in SOILS

Montana State University

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Abstract:

Characteristics of soils on the Kootenai Formation and Boulder batholith were compared to demonstrate relationships between soils and geologic units in Montana. The Early Cretaceous Kootenai Formation includes clayey shale, fine-grained sandstone, limestone and a basal conglomeratic sandstone. The batholith is composed of a uniform coarse-grained granitic rock, 25 pedons on each parent material were selected by point intercept transects for description, sampling and laboratory analysis.

Thirty of 44 soil properties contrasted sharply between the two parent materials. Boulder batholith soils have sandy loam or loamy sand textures; 40 percent higher frequency of a C horizon in the upper 100 cm; mean pH 0.6 unit higher; larger structure size and weaker grade; and 2-22 percent coarse fragment content. Kootenai Formation soils are more variable, having 7 textural classes ranging from sandy loam to clay and a clay content range of 3 to 74 percent. They have 20 cm greater mean solum thickness; more variable consistence; redder color hues; and a 0-65 percent coarse fragment content. There are 6 family textural classes identified in Kootenai Formation soils compared to 2 on the Boulder batholith.

Less than 10 samples (generally < 5) are required to estimate mean pH; coarse fragment content; sand fraction contents; and sand, silt and clay contents in all horizons of Boulder batholith soils within + 5 units (0.5 for pH) about the mean. Thickness of the B2t and C horizons and depth to the C are the most variable properties, requiring up to 50 samples. In Kootenai Formation soils, about 25 percent of these horizon properties require 10-35 samples and 25 percent require > 30 samples. Coarse fragment content, depth and thickness of the B2t and C horizons, and fine sand, total sand and clay contents of the C horizon require 34-72 samples; clay content being the most variable.

From laboratory analyses of five soils on each parent material, Kootenai Formation soils have 1/3 larger available water holding capacities in the B2t and C horizons; higher extractable Ca, CEC and percent BS; and more variable clay mineralogy ranging from dominantly montmorillonite to kaolinite, illite and interstratified 2:1 clays. Boulder batholith soils are dominated by illite clay with < 25 percent montmorillonite.

This documentation of soil differences related to geologic units will allow more accuracy and efficiency in soil mapping and management .

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CONTRASTING SOIL DEVELOPMENT ON THE SEDIMENTARY KOOTENAI
FORMATION AND GRANITIC BOULDER BATHOLITH
IN SOUTHWESTERN MONTANA

by

ROGER JOSEPH VESETH

A thesis submitted in partial fulfillment
of the requirements for the degree

of

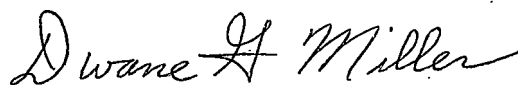
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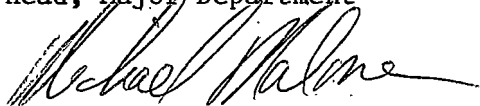
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SOILS

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ABSTRACT

Characteristics of soils on the Kootenai Formation and Boulder batholith were compared to demonstrate relationships between soils and geologic units in Montana. The Early Cretaceous Kootenai Formation includes clayey shale, fine-grained sandstone, limestone and a basal conglomeratic sandstone. The batholith is composed of a uniform coarse-grained granitic rock. 25 pedons on each parent material were selected by point intercept transects for description, sampling and laboratory analysis.

Thirty of 44 soil properties contrasted sharply between the two parent materials. Boulder batholith soils have sandy loam or loamy sand textures; 40 percent higher frequency of a C horizon in the upper 100 cm; mean pH 0.6 unit higher; larger structure size and weaker grade; and 2-22 percent coarse fragment content. Kootenai Formation soils are more variable, having 7 textural classes ranging from sandy loam to clay and a clay content range of 3 to 74 percent. They have 20 cm greater mean solum thickness; more variable consistency; redder color hues; and a 0-65 percent coarse fragment content. There are 6 family textural classes identified in Kootenai Formation soils compared to 2 on the Boulder batholith.

Less than 10 samples (generally < 5) are required to estimate mean pH; coarse fragment content; sand fraction contents; and sand, silt and clay contents in all horizons of Boulder batholith soils within ± 5 units (0.5 for pH) about the mean. Thickness of the B2t and C horizons and depth to the C are the most variable properties, requiring up to 50 samples. In Kootenai Formation soils, about 25 percent of these horizon properties require 10-35 samples and 25 percent require > 30 samples. Coarse fragment content, depth and thickness of the B2t and C horizons, and fine sand, total sand and clay contents of the C horizon require 34-72 samples; clay content being the most variable.

From laboratory analyses of five soils on each parent material, Kootenai Formation soils have 1/3 larger available water holding capacities in the B2t and C horizons; higher extractable Ca, CEC and percent BS; and more variable clay mineralogy ranging from dominantly montmorillonite to kaolinite, illite and interstratified 2:1 clays. Boulder batholith soils are dominated by illite clay with < 25 percent montmorillonite.

This documentation of soil differences related to geologic units will allow more accuracy and efficiency in soil mapping and management.

Chapter 1

INTRODUCTION

The importance of geologic parent material in soil development has long been recognized, being included by Jenny (1941) as one of the five independent soil forming factors. However, lack of knowledge of geologic weathering products and soil-geology relationships in Montana has limited the potential value of this factor in predicting soil properties. The influence of geologic parent material on soil physical and chemical properties is most pronounced in cool, dry regions and in the early stages of soil development (Birkland, 1974; Stauffer, 1935). Montana's young, often glaciated landscapes and relatively cool, dry climate should provide for a strong expression of geologic parent material properties in soils.

The writer did not find any studies that statistically compare the properties in soils developed on contrasting geologic parent materials. This study documents two contrasting examples of geologic parent material influences on soil development in Montana. It statistically compares the predictability and range in variation of selected properties in soils derived from the two parent materials. Efforts are made to explain the occurrence and variability of soil properties in relation to properties of the parent materials.

The granitic Boulder batholith was chosen as one of the parent materials because its relatively uniform composition should be reflected in uniformity of some soil properties. This study also provides baseline information for the recently initiated Butte-Whitehall soil survey which includes portions of the batholith exposure. The data are applicable to other exposures of geologic materials of similar origin and composition in the State.

The Early Cretaceous Kootenai Formation, in contrast, contains a variety of lithologies including clayey shales, sandstones, limestones and conglomeratic sandstone, and should contribute to greater soil variability. Although the Formation contains a variety of rock types, it remains fairly consistent in most exposures in the State. Soils on the Kootenai Formation elsewhere in Montana should have properties similar to those of this report.

This study will hopefully stimulate further interest in soil-geology relationships for their potential value as predictors of soil properties.

Chapter 2

LITERATURE REVIEW

Description of the Geologic Parent Materials

The Boulder batholith is an intrusive igneous body formed by the intrusion of molten magma into older geologic materials and subsequent slow cooling beneath the surface. It covers over 2850 km² of western Montana, extending 113 km along the Continental Divide between Butte and Helena (Knopf, 1957). Emplacement of the magma occurred during late Cretaceous time, roughly 78-69 million years ago (Knopf, 1957; Robinson et al., 1960; Tilling et al., 1968). Subsequent erosion, mainly during the Eocene Epoch of the Tertiary Period, removed up to 1.6 km of the overlying rock, exposing the igneous rock beneath (Perry, 1962). Figure 1 shows the exposures of intrusive rocks in Montana.

A review of the geologic studies in the area show that the most extensive rock type in the Boulder batholith is quartz monzonite with subordinate granodiorite (Becraft et al., 1963; Klepper et al., 1957; Knopf, 1957; Roberts and Gude, 1953; Robertson et al., 1960; Ruppel, 1963; Smedes, 1966). Rock mineral composition is typically plagioclase and potassium feldspar, with about 20 percent quartz and 15 percent biotite mica and hornblende. The most common grain size is very coarse sand (Wentworth scale), typically 1-3 mm (Becraft et al., 1963; Roberts and Gude, 1953; Ruppel et al., 1963).

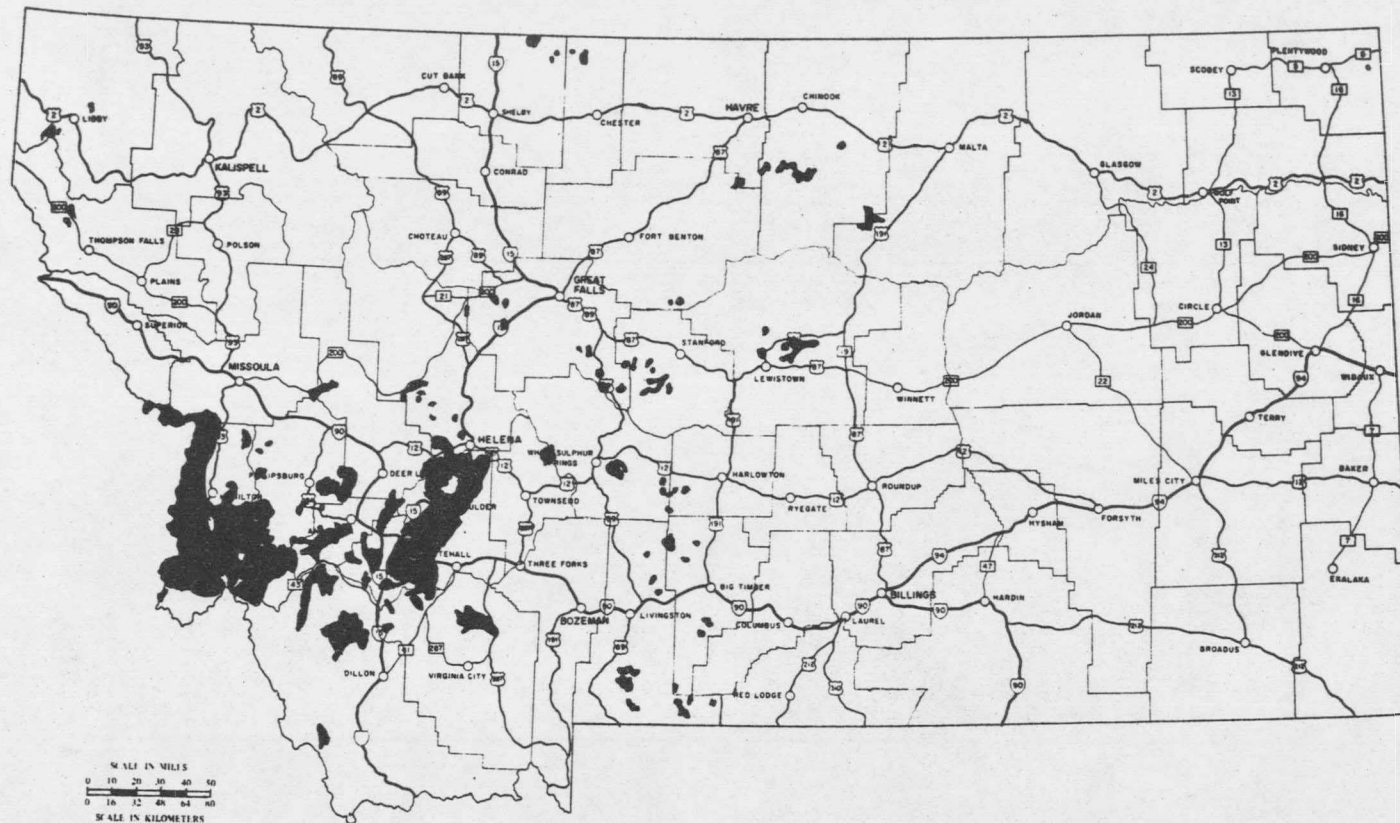


Figure 1. Exposures of coarse- to medium-grained intrusive igneous rocks in Montana (Veseth and Montagne, 1980).

Near the margins of the batholith, the rock composition tends to change somewhat. It becomes darker with an increasing content of iron, calcium and magnesium due to the assimilation of these elements from the "country rock" the igneous rock was intruded into (Perry, 1962; Sahinen, 1950; Tansley et al., 1933). The quartz content decreases and rocks become more basic, grading into granodiotite, diorite and other rock types.

Weathering and erosion along joint planes leave cores of sub-rounded boulders called tor piles, which project above the general land surface (Becraft et al., 1963; Sahinen, 1950). On a larger scale, the batholith landscapes are usually gently rounded, grass and forest covered mountains and foothills. A typical landscape is illustrated in the schematic block diagram in Figure 2.

The rocks have been variably affected by hydrothermal alteration resulting in a variable resistance to disaggregation and erosion (Becraft et al., 1963; Ruppel, 1963). Potassium feldspar and mica are often partially altered to clays by the hydrothermal activity and natural weathering processes (Becraft et al., 1963; Clayton, 1974). The batholith rock commonly disaggregates to a coarse, loose material called grus from mechanical weathering (freeze-thaw, wetting-drying, etc.) and expansion due to clay formation (Arnold et al., 1975; Becraft et al., 1963; Clayton, 1974). On the Idaho batholith to the west, illite, kaolinite and halloysite clay materials predominate in

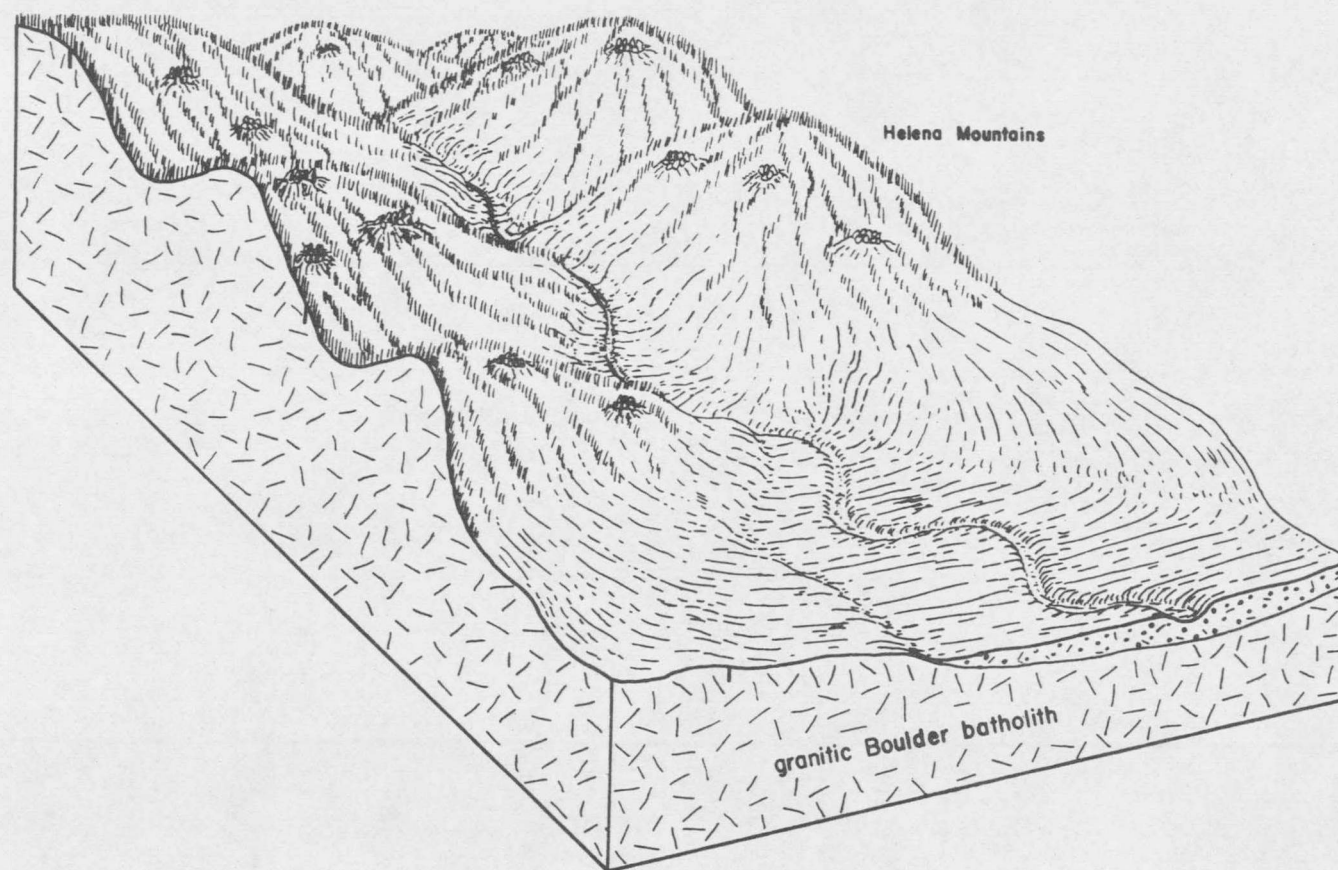


Figure 2. Schematic portrayal of Boulder batholith landscapes (adapted from Veseth and Montagne, 1980).

the soils, with some montmorillonite found at dryer, lower elevations and in poorly drained areas (Clayton, 1974).

The Early Cretaceous Kootenai Formation is commonly exposed in small outcrops in mountain and foothill areas of Montana where mountain building deformation has taken place. Figure 3 shows the exposure of the Kootenai Formation and other soft shale and hard sandstone formations of Pennsylvanian through Early Cretaceous age in Montana. The Kootenai Formation is found in most of the map delineations. It was deposited on the Jurassic Morrison Formation or older rocks and is overlain by Cretaceous marine shales (Imlay, 1952).

A composite description of the nonmarine floodplain, alluvial fan and lacustrine derived rocks of the Kootenai Formation in Montana is summarized by Veseth and Montagne (1980) from numerous geologic studies across the State. This description includes an upper unit of soft varicolored claystone or mudstone, fine-grained sandstone, freshwater limestone and a basal conglomeratic sandstone. The Formation ranges from 100 to 180 m in thickness in most Montana exposures. Of these lithologies, the basal conglomeratic sandstone is the most persistent with the others varying somewhat in proportions from one area to another. Limestones are generally absent in southern Montana east of Bozeman (Foose et al., 1958; Knappen et al., 1931; Moberly, 1960; Richards, 1957; Suttner, 1969). Exposures in the Great Falls-Lewistown area (Ballard, 1966; Fox and Groff, 1966; Harris,

1966; Vine, 1956) and the northwestern exposures (Mudge, 1972) are predominantly clayey shale and sandstone, with only a few thin limestones. In southwestern and western Montana, however, a fossiliferous "gastropod limestone" generally 15 m or less in thickness is commonly found in the upper section of the Kootenai Formation, overlying the middle shale-sandstone unit and basal conglomeratic sandstone (Hadley, 1960; Klepper et al., 1957; Robertson, 1963; Suttner, 1969; Wanek and Barclay, 1966; Witkind, 1969). Kootenai Formation exposures also thicken markedly to the west to 210-425 m (Mudge, 1972; Suttner, 1969; Wanek and Barclay, 1966). The schematic diagram in Figure 4 portrays a mountain foothill landscape of the Kootenai Formation in central Montana.

Clay mineralogy of the Kootenai Formation appears to be somewhat variable. South of Billings in the Pryor-Bighorn Mountains, the Kootenai (Cloverly) Formation seems to be dominantly montmorillonite (Moberly, 1960). In central Montana, Harris (1966) found predominantly mixed-layer illite and montmorillonite clays with some kaolinite, whereas Berg et al. (1968) show kaolinite and illite to be dominant, with some montmorillonite.

A geologic study of the Kootenai Formation area sampled in this thesis was made by Hall (1961). The Formation in this area was divided into three members. The lower member, 24-46 m thick, consists of coarse, massive, salt-and-pepper sandstone with a basal chert-

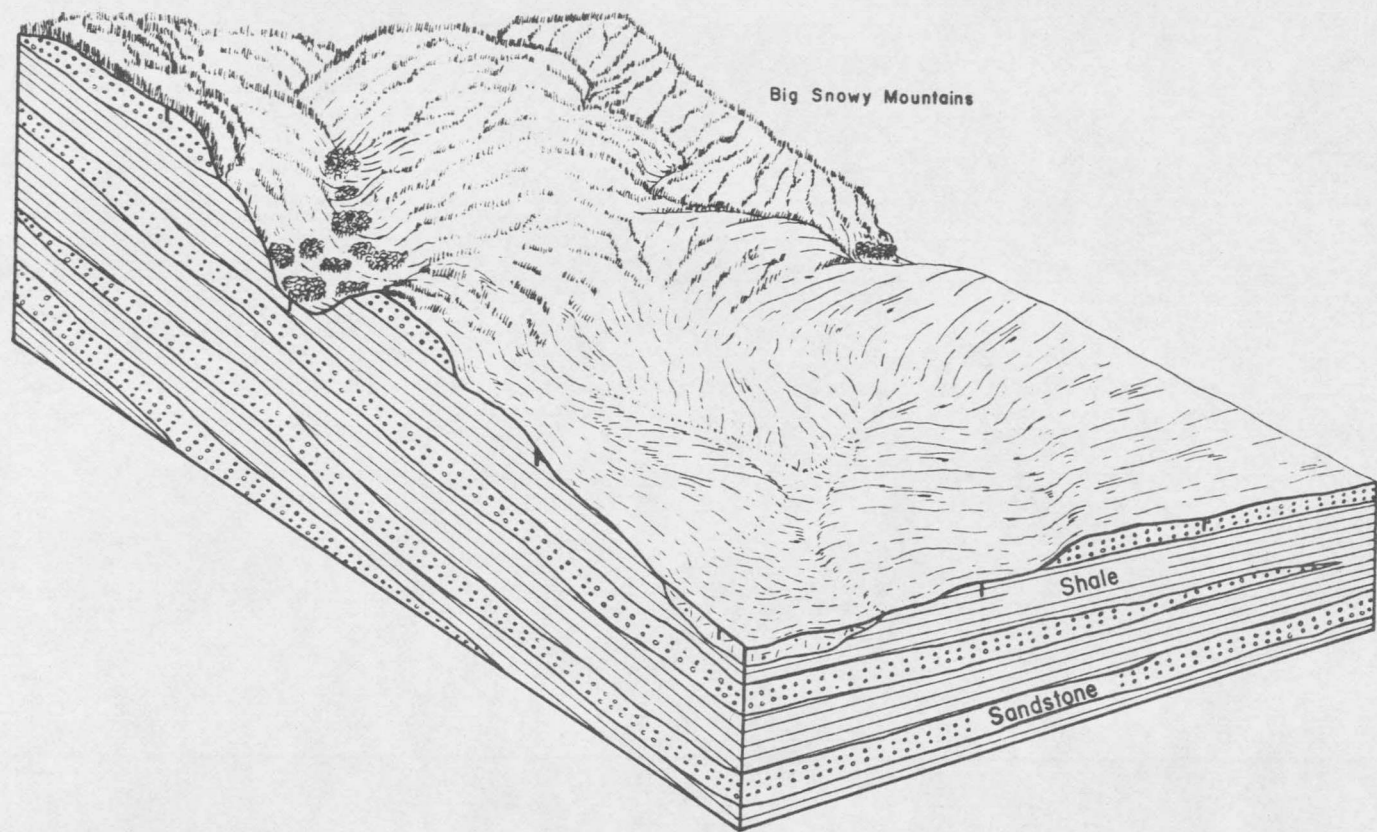


Figure 4. Schematic portrayal of Kootenai Formation landscapes in the Big Snowy Mountain foothills in Central Montana (adapted from Veseth and Montagne, 1980).

pebble conglomerate. It is quite resistant, forming prominent cliffs above the underlying soft Morrison Formation shale. A middle member about 76 m thick consists of red-maroon to yellowish tan claystone, limestones and limy siltstone at the base; 6-18 m of freshwater limestone in the middle; and more red clayey shale, limestones and limy siltstones above. Shales in this member are generally noncalcareous. The limestone in the center section of this member is correlated with the "gastropod limestone" of many other exposures in western Montana. The upper member, 15 m thick, is composed of well sorted, fine-grained, clean quartz arenite that could easily be confused with the Quadrant Sandstone of Pennsylvanian age. It weathers to a distinctive dark reddish brown color due to concentrations of hematite cement on the exposed surfaces. It is a resistant ridge forming sandstone.

The Kootenai Formation area sampled in this study is a northeasterly dipping flank of the northwest trending Buck Creek anticline. The axis area of the anticline is largely removed by erosion. The strata are gently dipping, generally at about 6-8 degrees. The Kootenai Formation extends to the highest elevation of the sampling area, so the soils should not be contaminated by material from other geologic formations.

Studies of Geology-Soil Relationships

That the properties of most soils are influenced, to some extent at least, by the nature of their parent materials has been recognized since systematic study of soils began (Stauffer, 1935). Parent material was included by Jenny (1941) as one of the five soil forming factors along with climate, organisms, topography and time, all of which are theoretically independent. The influence of parent material is particularly pronounced in more arid, cooler regions and in the initial stages of soil development (Birkland, 1974; Stauffer, 1935). However, even on the North Carolina Piedmont, one of the "oldest landscapes in the country", rock differences remain as the probable first cause of soil variability (Cady, 1950).

A review of many of the soil-geology studies reveals that soil texture and clay mineralogy are most commonly associated with parent material influences. In North Carolina, Cady (1950) found differences between soils formed on meta-gabbro and diorite to be mainly in texture and clay mineralogy. Variations in depth of weathering and certain aspects of soil structure were also found. In the Tuscahoma Sand Formation in Alabama, soils derived from a clayey geologic section had different textural and mineralogical classes at the family level of soil taxonomy than those of sandy sections (Hoyum and Hajek, 1979). Soils from the clayey strata also exhibited a higher cation exchange capacity. Gibbs and Perkins (1966) also documented the importance of

bedrock parent material to soil genesis. They noted that lithologic variations in acid crystalline rocks in Georgia resulted in different fine sand contents and clay mineralogy between the Hayesville and Cecil series.

A soil-lithosequence study on granite, pyroclastics and schist was made by Parsons and Herriman (1975) in the mountains of southwestern Oregon. Soils developed from granite have coarse textures low cation exchange capacities and base saturations, and no argillic horizons. Soils from pyroclastic rocks are fine-textured, have the highest cation exchange capacities and base saturations, and generally have argillic horizons. The soils from schist may or may not have argillic horizons and have chemical and physical properties intermediate to those from granite and pyroclastic rocks. No clay mineralogy investigations were undertaken. A higher woodland productivity and fewer watershed management and construction problems were also associated with soils developed from pyroclastic rocks compared to soils developed from schist or granite. They noted that soil landscapes underlain by schist are especially susceptible to mass movement.

In California, Harradine and Jenny (1958) found that granodiorite weathers to a sandy, relatively light-colored mantle in contrast to basalt, which weathers to a dark-colored fine-textured soil. Due to the differences in weathering rates, they pointed out that one usually finds a deep soil mantle overlying basalt and a relatively shallow

soil profile developed from granodiorite. The granodiorite, richer in quartz and potassium feldspar, decomposes more slowly than the basic igneous basalt, which contains calcium plagioclase and a higher percentage of less stable mafic minerals. The granodiorite derived soils have a higher texture variability than basalt soils and, in addition, a lower available soil moisture holding capacity and nitrogen content.

McCaleb (1959) compared soils formed from acid crystalline rocks and sandstones in North Carolina. Soils from the crystalline rocks had a higher clay content, lower cation exchange capacity and lower free iron oxide content than soils from sandstone. Clay mineralogy was dominantly kaolinite with minor vermiculite in soils of crystalline rocks, whereas soils from sandstone contained nearly equal amounts of kaolinite and vermiculite, with some illite. The higher vermiculite content in sandstone derived soils was suggested as a reason for the higher exchange capacity of these soils.

Ciolkosz et al. (1979) compared soils developed from colluvium of several geologic lithologies in the Ridge and Valley area of Pennsylvania. Contrasting soil properties include texture, color, base saturation, clay mineralogy and coarse fragment content.

In Manitoba, Canada, Ehrlich et al. (1955) found that the carbonate content of parent materials of glacial till soils has a profound effect on the type of soil profile formed. They concluded

that increasing amounts of inorganic carbonate restricted profile development and inhibited the decomposition of noncalcareous rock fragments. Also, the carbonate content in the parent material was a major factor in determining and differentiating certain great soil groups. Thickness of the solum typically decreased with increasing carbonate content. They emphasized that although pH or soil reaction is usually considered to be a reflection of the degree of base saturation of the soil absorption complex, it also may be a reflection of the composition of the material from which the soil is derived.

In a lithosequence study in Greece, Yussoglou et al. (1969) conclude that soils with argillic horizons were developed from parent material having higher initial base saturation when compared to soils with cambic horizons. Wells (1959), in New Zealand, concludes that soil developed from greywacke are low in fertility, "podzolized" with residual quartz, and are less productive when compared to soils derived from basalt.

Parent Material--Clay Mineralogy Relationships

Birkland (1974) states that all other factors being equal, the texture of the parent material has a great influence on the course of soil development. He proposes that clay formation would probably proceed more rapidly in the finer-textured material because of the greater surface area available for weathering. Constituents for clay formation are more often removed by leaching in soils of coarse-

textured parent materials resulting in lower base status. Because of this, he theorizes that soils of finer-textured material might have a higher ratio of 2:1 layer clays to 1:1 clays than those of more permeable material.

Clay minerals in a soil may originate by means of three different mechanisms: (1) inheritance from parent material, (2) alteration and degradation of primary mineral, and (3) synthesis by precipitation (Grim, 1968). For sedimentary rocks, inheritance from parent material is believed to be the predominant mode of clay origin (Grim, 1968; Van Houten, 1953). In 35 of 43 paired samples of soils and their sedimentary parent bedrock from Wyoming to Pennsylvania, Van Houten (1953) found the predominant clay mineral groups in the soils to be the same as those of their parent rock. Specific examples of soil clay mineralogy relationships to their parent materials include: montmorillonite White Store soil from montmorillonite-rich Triassic shale in North Carolina; kaolinitic Gasport soil from kaolinite-rich Pennsylvania shale in Ohio; and illitic Miami soil from illite-rich Late Wisconsin glacial till, also in Ohio.

Grim (1968) states that kaolinite is frequently the most abundant clay mineral of soils formed in sands and sandstones because they typically have a low base status and high leaching environment that is conducive to kaolinite formation. Also, kaolinite is the dominant clay mineral in ancient lacustrine sediments (such as in sections of

the Kootenai Formation of this thesis) deposited in a low pH and active water environment. In alkaline, less active waters, illite and montmorillonite are usually the dominant clay minerals.

Johnson (1970) found kaolinite as the dominant clay mineral in soil parent material from sandstones and metamorphics in Pennsylvania. He theorizes that in the sandstone derived soil, this is probably a manifestation of the inheritance mechanism. Illite was found to be the dominant clay mineral of 95 percent of the shales from Precambrian to Tertiary-Pliocene age and their derived soils.

One predication upon which inheritance of soil clay mineralogy from its parent material is based is the uniformity of the clay minerals with depth in the soil profile. Numerous recorded analyses, such as those in Iowa soils by Peterson (1946), and Russell and Haddock (1941), and those in Minnesota soils by Caldwell and Rost (1942), reveal no appreciable change in colloidal composition or clay mineralogy with depth in the profiles of soils developed on sedimentary rocks. In Manitoba, Canada, Ehrlich et al. (1955) found that montmorillonite, illite and kaolinite content of soils formed on Mankato-age glacial till is relatively uniform throughout the profile. They concluded that this indicates the clay minerals were not formed in situ by recent soil forming processes, but rather were inherited from pre-Mankato soils or geologic strata.

The clays in soils derived from crystalline rocks, both igneous

and metamorphic, are not directly inherited from the parent rock but are the products of alteration and degradation of primary minerals and thus more often reflect the environmental constraints and weathering processes of the soil forming period (Van Houten, 1953). In California, Barshad (1966) found illite to be a dominant clay mineral of soils derived from felsic intrusive igneous rock (the Boulder batholith of this study is predominantly felsic igneous rock) and attributed this to the biotite mica content of the rock and the availability of potassium. On the granitic Idaho batholith of Idaho and western Montana, which is mainly of granodiorite composition (Boulder batholith of this study is of quartz monzonite and granodiorite composition) Clayton et al. (1979) concluded that the biotite commonly weathers to degraded mica, then to a smectite-iddingsite product, and eventually to illite. Sericitic weathering products and ultimately, some kaolinization of feldspars are common. They found mixed-layer clays to be notably absent in soils of the Idaho batholith. Grim (1968) points out that felsic igneous rocks containing considerable quantities of potassium as well as magnesium will yield illite and smectite as the alteration products under weathering conditions which permit the potassium and magnesium to remain in the weathering environment. If the content of magnesium is low, illite will be the main product and if potassium is low, smectite will be the main product. Rapid removal of both elements would lead to the

formation of kaolinite. Loughon (1969) concluded that, in dryer environments, potassium feldspar in felsic crystalline rocks will generally weather to illite and montmorillonite instead of kaolinite. Birkland (1974) and Loughon (1969) point out that parent material exerts an important control on chemical weathering and the clay mineral formation. Weathering releases constituents essential to the formation of the various clays, and the inherent texture and permeability influences how fast those constituents may be removed by leaching.

In most cases clay mineralogy does vary somewhat with depth in the soil profile. Birkland (1974) suggests two possibilities for this variation. First, that clay mineral assemblages are not in equilibrium with present environmental conditions and are being altered to more stable clay minerals, such as is often the case with clay mineral inherited from the parent material. Second, some clay minerals could have formed in the past under different environmental conditions, and with reaction rates being so slow under surface conditions, these clay minerals are metastable in the present environment. He also attributed some variability to the diverse microenvironmental conditions within the soil. Johnson (1970) suggests that the three mechanisms of clay origin (inheritance, alteration and degradation of primary minerals, and synthesis) operating under different profile weathering conditions together with the process of the translocation of material

results in soil clay mineral composition becoming, to some degree, a function of soil depth. He states that weathering is most intense at the soil surface and decreases in intensity with depth. This is the horizon depth function of Jackson et al. (1948) which leads, in many cases, to the development of a profile of weathering in which clay mineral distribution and composition changes somewhat with depth.

Determining Soil Variability

Part of the objective of this study is to compare the predictability and range of variability of properties and features of soils derived from the Kootenai Formation and Boulder batholith. The literature was reviewed for site selection methods, sample size and statistical procedures. However, none of the soil-parent material studies previously cited attempt such statistical comparisons. Typically, only a few "representative" soil sites were compared with those of contrasting substrates. Since these soil-parent material studies had small sample sizes and little, if any, statistical comparisons, studies evaluating soil mapping unit composition and variability were reviewed for statistical approaches and soil property variability.

In a study of variability of soil morphological properties within three mapping units of Ohio, Wilding et al. (1965) employed a grid method for site selection. They chose ten numbers from a random

numbers table to designate sites on a numbered grid overlain on an aerial photo. This was repeated for 24 mapping unit delineations, eight delineations for each of the three mapping units, for a total of 240 observations. The density of observations per unit area was found to be relatively constant for all mapping unit delineations, thus allowing for variability comparisons between mapping units. The most variable soil properties were horizon thickness, depth of leaching of carbonates, loess thickness, depth of mottling, pH, and size class of soil structure. Clay content, soil structure grade (strength), and soil color were the least variable properties. The number of samples per delineation required to estimate the mean within 10 percent was 7-9 for all properties except depth of leaching, loess thickness and drainage class, which required, 12, 31, and 14 samples, respectively.

Crosson and Protz (1974) also used a grid system for site selection in a mapping unit composition study in Ontario, Canada. However, instead of random numbers, they sampled every 10 m on a 80 X 190 m grid. The calculated number of samples required to detect significant differences between the means of soil properties of the two mapping units at the .05 significance level was less than 60 for only six properties. These included chroma and hue of soil color, percent organic matter and percent sand, silt and clay in the Ap horizon. The number of samples required for other properties generally ranged from 118 to over 3000 (for pH).

In a statistical summary of physical and chemical properties of the Morley and Blount series in Ohio, Wilding et al. (1964) selected 59 total profile descriptions and lab analyses collected over the previous ten years in conjunction with the Ohio soil survey program. They felt that although the requirements of random sampling were not strictly satisfied, they were approximated because of the large scope of the survey program, the wide geographical scattering of sites, long time span during sampling and collection by different soil scientists. They also postulated that most characteristics would approximate a normal distribution and a range similar to those defined in each of the established series descriptions. For both series, the least variable properties were composite thickness, hue and value variables of color, depth of leaching of free carbonates, silt content and total clay content. These properties required less than ten samples to estimate the mean within 10 percent.

McCormack and Wilding (1969) investigated the variation of soil properties within eleven mapping units in Ohio. They randomly selected two delineations of each mapping unit from aerial photos and ten sampling sites in each delineation. The density of sampling sites per unit area was held relatively constant for all delineations, thus permitting reliable estimates of the aerial extent of included soil properties. Standard deviations, coefficients of variation and the number of samples required to estimate the population mean within

± 10 percent indicated that thickness of the B1, B2 and IIB horizons, depth to mottling, soil structure grade and chroma are the most variable properties. The least variable soil properties were hue, value, pH of all horizons, texture of the IIB horizon and the size and type classes of soil structure.

Nelson and McCracken (1962) made a statistical summarization of soil properties of the Norfolk and Portsmouth series in North Carolina. Central tendencies, ranges and standard deviations of the soil properties were determined from 15 randomly selected sites of each series. The soil properties were analyzed for potential criteria for soil classification and characterization, and influence on corn yield. They concluded that a sample size of 15 is inadequate for estimating most soil properties. The only factor that showed promise as a differentiating criterion of corn yield potential was the 2:1 to 1:1 layer clay ratio.

In a soil variability study on a red pine plantation in Massachusetts, Mader (1962) found exchangeable Ca and Mg to be the most variable property. Only two samples were required to estimate the mean bulk density within ± 10 percent, whereas 20 samples were required for organic matter content and over 100 samples for exchangeable Ca and Mg. He attributed this to the greater natural variability of some soil properties than others.

Steers and Hajek (1979) evaluated the accuracy of randomly

selected point intercept transects in determining map unit composition. The point intercept transect method is basically sampling at regular spacings on a straight line transect. The transect was distributed evenly throughout the mapping unit delineations for a uniform expression of variability. They concluded that many mapping units in a survey area can be characterized at an 80 percent confidence level by determining soil occurrence along less than ten transects with a minimum of ten point observations per transect. Points on the transect were located by pacing with compass orientation. The transect method was found to be particularly useful in wooded areas and in complex terrain with limited accessibility where soil boundaries and landmarks are not easily observed.

Ball and Williams (1968) also found the point intercept transect method applicable in evaluating the variability of soil chemical properties of mountain rangeland soils in North Wales. Points were located at 27 m intervals on parallel transects 260 m apart. In Michigan, Amos and Whiteside (1975) used the point intercept transect method for site selection in evaluating soil survey mapping accuracy in an urbanizing area. Randomly selected parallel transects were 152 m apart with points at 76 m intervals. A minimum of 50 samples were required to estimate the property means within ± 10 percent.

In evaluating mapping unit composition and precision in Georgia, Powell and Springer (1965) used the point intercept transect method

for site selection. Point observations were determined by pacing and compass orientation. The transects were randomly selected and transect spacing varied with size and complexity of the mapping unit. Transects were about 1.2 km in length. The point intercept transect method was used because soil boundaries were not easily discernable in the wooded and hilly topography, making random site selection infeasible.

Wicherski (1980) analyzed the variability of soils in two forest land type mapping units in Oregon with the point intercept transect method. Eight delineations of each mapping unit were sampled with randomly located transects consisting of 40 point observations each. Variability was quantified in terms of estimates of required sample sizes, ranges and coefficients of variation. He found chemical properties to be more variable than physical or morphological properties, which were about equal. The most variable chemical properties were extractable bases and organic matter content. Coarse fragment content and thickness of the O horizon were the most variable physical and morphological properties. Least variable properties in general were pH, CEC, bulk density, texture, and color. A major source of variation was attributed to sudden changes in the character of the parent material and the variety of geomorphic surfaces of varying age and stability.

Chapter 3

MATERIALS AND METHODS

Study Area Descriptions

The Kootenai Formation study area is located in the Madison Range south of Big Sky in southwestern Montana (see Figure 5). This area has a mean annual precipitation of 46-66 cm (Ross and Hunter, 1976) and mean January, July and annual temperatures of -16, 25 and 5° C, respectively (Cordell, 1960). Elevations of the Kootenai Formation exposure (outlined on the map in Figure 5) ranges from 1830 m in the northeastern portion to about 2745 m in the southwest. The Formation exposure is a smooth continuous dipslope with a northeast dip. This means that the topographic surface roughly parallels the inclined geologic strata which are plunging down to the northeast.

The Kootenai Formation exposure is predominantly forest-covered with numerous scattered meadows comprising about 30 percent of the area. Dominant tree species include Abies lasiocarpa, Pinus contorta, Pinus albicaulis, Pinus flexilis and Pseudotsuga menziesii, with understory species of mainly Vaccinium scoparium, Physocarpus malvaceus, Calamagrostis rubescens, Spiraea betulifolia and Arnica cordifolia. Meadow vegetation includes Agropyron smithii, Festuca idahoensis, Artemisia tridentata, Balsamorhiza sagittata, Lupinus spp. and a wide variety of other forb species.

The exposure of much of the Boulder batholith is outlined on the

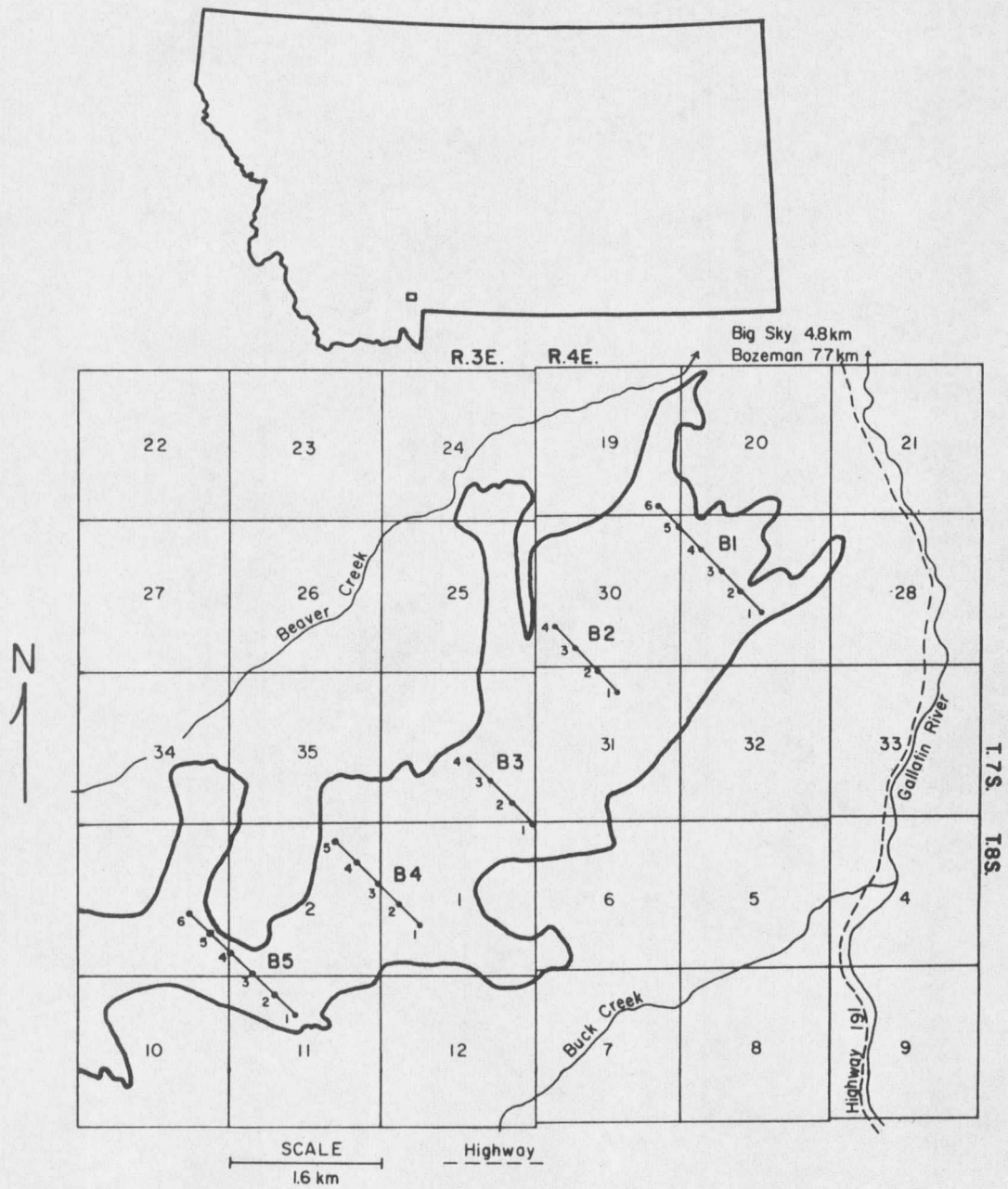


Figure 5. Kootenai Formation exposure with transect and point observation locations.

map in Figure 6. Smooth rounded mountain slopes with occasional to numerous rock outcrops called tor piles typify much of the batholith topography. The study areas on the batholith are located in portions of three mountain ranges: the Elkhorn Mountains in the northeast; Helena Mountains in the central and northwestern portions; and the Main Range in the south. Elevations of the study areas generally range between 1525 and 1920 m. Estimated mean annual precipitation is in the 36-56 cm range (Ross and Hunter, 1976). Mean January, July and annual temperatures in the study area are -14, 28 and 7° C, respectively (Cordell, 1960).

The batholith study areas are largely forested with lower mountain slopes under grass cover. Pseudotsuga menziesii and Pinus ponderosa are the dominant tree species with understory species including Agropyron spicatum, Festuca idahoensis, Berberis repens and Arctostaphylos uva-ursi, though most forested sites do not support understory vegetation. Grassland and meadow species are mainly Agropyron spicatum, Festuca idahoensis and Artemisia tridentata.

Site Selection

The soil site selection methods used on both parent materials reflect an attempt to encompass the widest range in soil variability within the constraints of limited access, time and manpower. Due to the difficulty of locating randomly selected or regular grid-selected

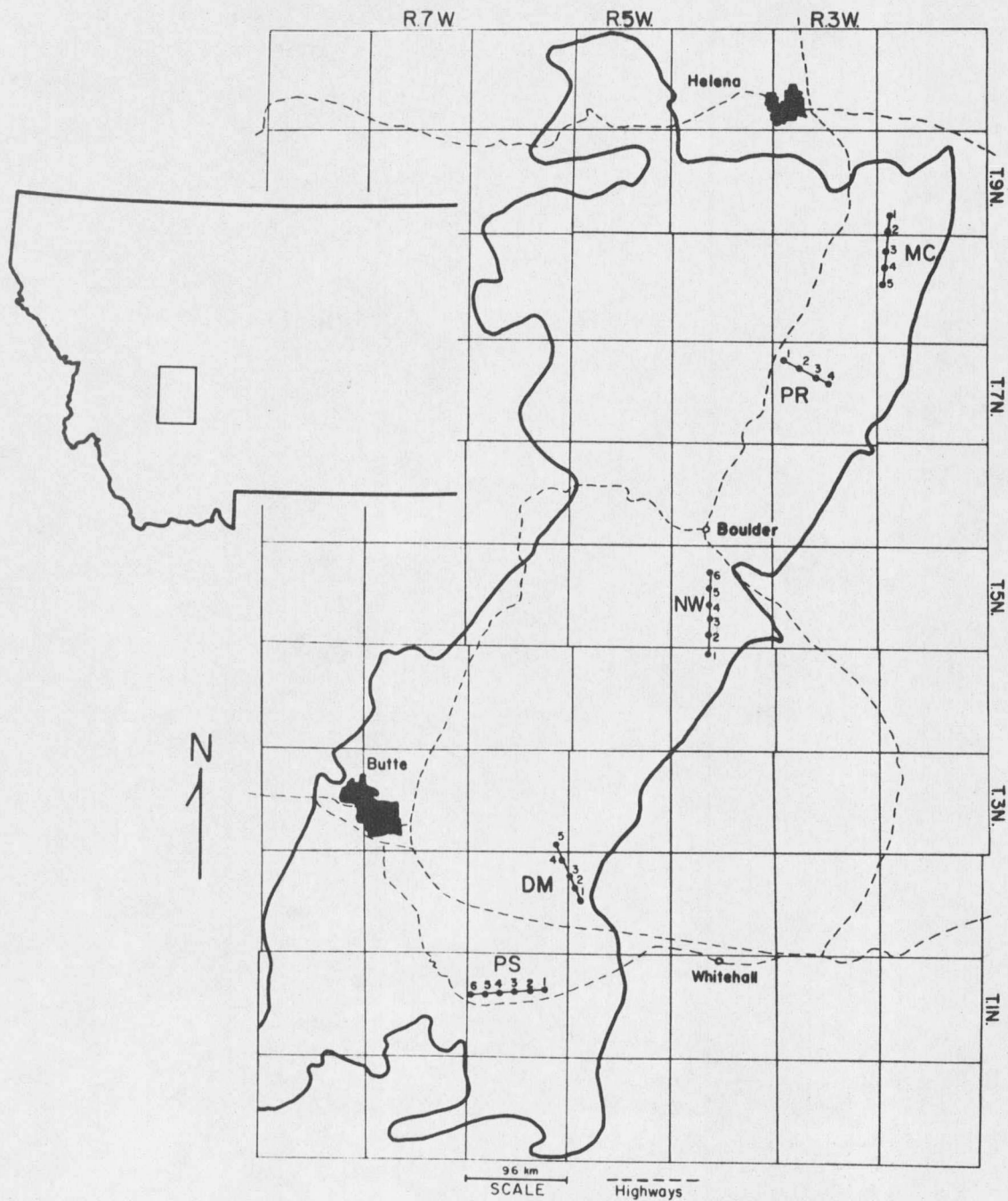


Figure 6. Boulder batholith exposure with transect and point observation locations.

points in forested terrain, a point intercept transect method was chosen. On the Kootenai Formation, five parallel transects were spaced 1.6 km apart with point observation every 322 m (5/mi). A total of 25 observations were described and sampled with 4-6 per transect. Transect lengths varied slightly with the width of the formation exposure. The transects were drawn on a topographic map and located in the field with an aerial photo. The first site on each transect was randomly selected and each successive site along the transect was located by pacing and compass orientation. Transects and point observation locations on the Kootenai Formation are shown in Figure 5.

The point intercept transect method of site selection was also used on the Boulder batholith; however, a different spacing was required. Due to the limited access on the batholith, transects were oriented along roads on the eastern half of the batholith. Transect spacing is 10-19 km. The transects were drawn on topographic maps and point observations were located every 1.6 km along the transects with spacing determined by car odometer and map reference points. Sample sites are at least 50 m from the roads. A total of 25 sites were described and sampled with 4-6 per transect. Transect and point observation locations on the Boulder batholith are displayed in Figure 6. The letter symbols near the transects indicate general points of reference; for example, PS refers to Pipestone Pass.

Soil Site Description and Sampling

All soil sites were excavated by hand to a depth of 100 cm or to bedrock. Approximately 2 kg samples were collected from each horizon for lab analyses. For each horizon, the following properties were measured by procedures of the Soil Survey Staff (1951): thickness; moist color (Munsell Color Chart); texture; structure type, class and grade; wet and moist consistence; effervescence (0.1 normal HCl); pH (Hellige-Truog field pH kit); and percent (by vol) coarse fragments > 20 mm. Slope and aspect of the sites were determined with a clinometer compass. Dominant vegetation was identified and rockiness and stoniness classes (Soil Survey Staff, 1951) were estimated within a circle with a radius of about 25 m from the point observation.

Physical Laboratory Analyses

Soil samples were air dried and measured for dry color (Munsell Color Chart) and dry consistence (Soil Survey Staff, 1951), and then ground with a flail-type grinder. Samples were hand sieved with 20 mm and 2 mm sieves for coarse fragment separation. The coarse fragment contents were estimated on a volume basis with measurements of dry total sample volumes and water displacement volumes of the coarse fragment fractions.

Soil particle size analysis was determined by the hydrometer method as described by Day (1965). Sand size fractions were determined

by decanting the suspended sediment from the hydrometer analysis cylinders, oven drying the remaining sand and passing it through a sieve stack. The sieves were placed on a reciprocating sieve shaker for three minutes at 120 strokes per minute. Sieve sizes were: .0053, .0106, .0250, .0425, .05 and .1 mm. Weights of the sieved fractions were plotted on a semilog graph along with the < 2 mm hydrometer method data for percentage conversions of the sand size fractions. Coarse (very coarse and coarse) medium and fine (fine and very fine) sand size contents were determined (Soil Survey Staff, 1951).

Soil Water Holding Capacity

Five soils on each parent material, one from each transect, were analyzed for water holding capacity. The percent soil water at 1/3 and 15 atmospheres tension was determined gravimetrically with a ceramic plate apparatus (method 30) and pressure membrane apparatus (method 31), respectively, used in Agric. Handbook 60 (Salinity Laboratory Staff, 1954). The percent available water holding capacity was estimated as the percent soil water content between those tensions.

Clay Mineralogy

The same five soil profiles on each parent material were analyzed for clay mineralogy. Samples of the < 2 mm fraction from the A and C (or B2) horizon at 100 cm depth were prepared using the methods described by Thiesen and Harward (1962). X-ray analysis methods, using a

Cu target and Ni filter, and interpretation procedures are from Whittig (1965). The relative abundance of aluminosilicate minerals in the clay fraction was determined by a semiquantitative method comparing the areas under the diffraction peaks (Klages, 1980). In this method, area weighting factors are established for the various clay minerals. The peak areas are multiplied by the weighting factors, and the respective percentages of each clay mineral calculated.

Chemical Laboratory Analysis

Chemical analyses of the five selected soil profiles on each parent material were made by the Soil Testing Laboratory at Montana State University, Bozeman. Organic matter percentages were calculated from colormetric determination (Sims and Haby, 1970). A 2:1 water-soil mixture was used for pH and electrical conductivity measurements. Extractable cations (Bower et al., 1952) and cation exchange capacity from Method 19 of Agric. Handbook 60 (Salinity Laboratory Staff, 1954) were determined by atomic adsorption spectrophotometry.

Statistical Comparisons

Statistical comparisons were made of a variety of quantitative soil properties in the A₁, A₂, B_{2t} and C horizons of all soils sampled on each parent material. These properties include: horizon depth and thickness; pH; coarse fragment content; coarse, medium

and fine sand content; and sand, silt and clay content. From Snedecor and Cochran (1973), the statistical comparisons included means, standard deviations, ranges, 90 percent confidence intervals and the number of samples (N) required to estimate the mean within a specific number of units (cm, percentage points or $\log_{10}$ units) about the mean. A .10 significance level was used for both the 90 percent confidence interval and to estimate N. Predictability of qualitative soil properties such as color, structure and consistence were estimated by frequency distributions.

The significance of differences in soil property means between parent materials was determined with the t statistic (Snedecor and Cochran, 1973) at the .10, .05 and .01 levels. Pooled variances were used since unequal sample sizes resulted with property analysis by horizon. A normal distribution was assumed. The assumption of equal variances was not completely met for all soil properties introducing possible error in significance of differences in some cases.

Chapter 4

RESULTS AND DISCUSSION

The contrasting lithologies of the Kootenai Formation and Boulder batholith, previously described, should be reflected in a variety of contrasting soil properties. Differences emphasized in this study are rockiness and stoniness; depth to bedrock; solum thickness; coarse fragment size and content; sand, silt and clay content; coarse, medium, and fine sand content; structure type, size and grade; inherited color; consistence; thickness of the B2t horizon; water holding capacity; clay mineralogy; cation exchange capacity; extractable Ca concentration; and pH as well as other soil properties. Greater soil variability in Kootenai Formation soils due to the variability of lithologies is also an important difference.

The following soil characterizations and comparison of selected soil properties indicate that there are some important differences between soils of the two parent materials. An awareness of these property and variability differences should help to improve the accuracy of soil inventories and management on the two parent material exposures.

Rockiness and Stoniness

Soil rockiness refers to the percent bedrock exposure, either as rock outcrops or soil areas too shallow over bedrock for agricultural use. Soil stoniness indicates the percent stones over 25 cm.

in diameter near or on the soil surface. A comparison of rockiness and stoniness classes of soil on the Kootenai Formation and Boulder batholith is shown in Table 1.

Only 16 percent of the Kootenai sites contained rock exposures compared to 78 percent on the batholith, with a majority of the batholith sites in rockiness classes 2 and 3. The difference in degree of stoniness, in contrast, is small, with sites on both parent materials having the same frequency of class 0 stoniness. High stoniness classes 4 and 5 include a larger percentage of Kootenai sites than those on the batholith, 20 percent as compared to 4 percent. This reflects the greater weathering resistance of some Kootenai Formation sandstones and limestones in contrast to the uniformly weathering batholith rocks.

All Kootenai sites are located on the dip slope exposures. On scarp slope exposures, where the topographic surface cuts across the bedding of the geologic strata, Kootenai soils would probably tend to have higher rockiness and stoniness classes.

Depth to Bedrock

Depth to bedrock (Table 2) in the > 100 cm class tends to be slightly greater in Kootenai soils (12 percent higher frequency). Batholith soils have an 8 percent higher frequency of being < 50 cm deep to bedrock. Frequencies of medium depth ranges are nearly the

Table 1. Frequency distribution of rockiness and stoniness classes[†] of soils on the Kootenai Formation and Boulder batholith.

Parent Material	Rockiness Classes [§]						Stoniness Classes [†]					
	0	1	2	3	4	5	0	1	2	3	4	5
	----- % -----											
Kootenai Formation	84	8	8	—	—	—	36	20	24	—	12	8
Boulder batholith	12	16	32	36	4	—	36	12	28	20	4	—

† Soil Survey Staff (1951)

§ 0 = < 2%, 1 = 2-10%, 2 = 10-25%, 3 = 25-50%, 4 = 50-90%, 5 = > 90%.

† 0 = < 0.01%, 1 = 0.01-0.1%, 2 = 0.1-3.0%, 3 = 3-15%, 4 = 15-90%, 5 = > 90%.

Table 2. Frequency distribution of the depth to bedrock in soils on the Kootenai Formation and the Boulder batholith

Parent Material	Depth Intervals [†]		
	-----cm-----		
	< 50	50-100	> 100
	-----%-----		
Kootenai Formation	4	24	72
Boulder batholith	12	28	60

† Intervals for shallow, moderating deep and deep soils (Soil Survey Staff, 1951).

same in soils of both parent materials. The greater frequency of deeper soils on the Kootenai Formation may reflect a predominance of soils derived from soft shale and an overall lower weathering resistance of Kootenai Formation strata in comparison to the crystalline batholith rocks. Some Kootenai Formation sandstones and limestones, however, are also quite resistant to weathering, resulting in soils with higher stoniness classes (previous section) and higher coarse fragment contents, which are discussed later.

Solum Thickness

Solum thickness (Table 3) is greater in Kootenai soils ($\bar{X} = 70.8$ cm) than batholith soils ($\bar{X} = 50.6$ cm) with the difference between means significant at the .05 level. Variability of solum thickness, however, is very similar between soils of the two parent materials with similar standard deviations and ranges. The 90 percent confidence intervals are nearly the same width, but they do not overlap.

Table 4 shows that a similar number of samples are required to estimate the mean solum thickness for soils of both parent materials. A confidence interval width of ± 5 cm about the mean appears to be the most feasible.

Horizon Frequency

A frequency distribution of the presence of selected soil horizons in the upper 100 cm of the profiles is shown in Table 5. The horizon

Table 3. Statistical data on solum thickness in the upper 100 cm of soils on the Kootenai Formation and Boulder batholith.

Parent Material	[*] $\bar{X}$	SD	Range	90% CI [†]
	----- cm -----			
Kootenai Formation	70.8	28.8	19-100+	61.0-80.1
Boulder batholith	50.6	27.2	11-100+	41.0-59.9

† Confidence interval at the .10 significance level.

* Difference between means significant at the .05 level.

Table 4. Number of samples (N)[#] required to estimate the mean solum thickness of soils on the Kootenai Formation and Boulder batholith.

Parent Material	Confidence Interval Width		
	±2	±5	±10
Kootenai Formation	24	4	1
Boulder batholith	22	4	1

Estimated at the .10 significance level.

Table 5. Frequency distribution of the presence of selected horizons in the upper 100 cm of soils on the Kootenai Formation and Boulder batholith.

Parent Material	Horizons [†]						
	0	A1	A2	B2t	C	Cr	R
	-----%						
Kootenai Formation	40	84	36	84	48	16	28
Boulder batholith	52	64	52	76	88	28	40

† Soil Survey Staff (1951).

with the lowest frequency in soils of both parent materials is the paralithic Cr horizon, which has a 12 percent higher frequency in batholith soils. The frequency of an R horizon or lithic contact is also fairly low (28 percent) in Kootenai soils, but includes 40 percent of the batholith soils. Almost twice the frequency (88 percent as compared to 48 percent) of a C horizon in the upper 100 cm is found in batholith soils as in Kootenai soils. This difference may reflect, in part, the lower availability of clay for development of thick B2t horizons in batholith soils. There is a high frequency of B2t horizons in soils of both parent materials, with the Kootenai soils having a slightly greater frequency, likely again because of the higher clay content of the parent material. Although there is a similar frequency of B2t horizons, large differences in clay content and thickness exist between soils of the two parent materials, as will be discussed later. Kootenai soils have a higher frequency of A1 horizons and slightly lower frequency of O and A2 horizons than batholith soils. This is likely a reflection more of the vegetative cover than parent material influences. There are 14 meadow-grassland sites on the Kootenai Formation and 10 on the Boulder batholith, which may explain, in part, the higher A1 horizon frequency and lower A2 and O horizon frequencies in Kootenai soils.

Horizon Thickness and Depth

The only significant difference (.05 level) between mean horizon thicknesses in the upper 100 cm of Kootenai and batholith soils (Table 6) is in the A1 and B2t horizons. Kootenai soils averaged 3.5 cm thicker A1 horizons and 15.2 cm thicker B2t horizons. The 90 percent confidence intervals for the mean thicknesses of these two horizons do not overlap, whereas all other horizon confidence intervals have large overlaps. Mean depths to the top of the B2t and C horizons are larger for Kootenai soils though the difference is not significant at the .10 level.

In Table 7, the 0 and A1 horizon thicknesses are the only ones that require a low number of samples to estimate the means within $\pm$ 2 cm about the mean in both Kootenai and batholith soils. The number of samples required to estimate the mean thickness and depth to the top of the other horizons are very similar for soils of both parent materials and they are generally only practical at the confidence interval of $\pm$ 10 cm about the mean. The variability in horizon thickness, particularly in surface horizons, may be more a result of changes in other soil forming factors such as vegetative cover, slope, aspect, etc. rather than parent material influences.

Soil Color

In the frequency distribution of dry soil color (Table 8), the

Table 6. Statistical data on thickness and depth to the top of selected horizons in the upper 100 cm of soils on the Kootenai Formation (KF) and the Boulder batholith (BB).

Soil Property	Horizon	$\bar{X}$		SD		Range		90% CI [†]	
		KF	BB	KF	BB	KF	BB	KF	BB
-----cm-----									
Thickness	0	4.8	3.8	1.0	1.3	3-7	2-7	4.2-5.3	2.4-5.2
	A1*	10.3	6.8	3.4	1.8	7-17	4-10	9.0-11.6	6.0-7.6
	A2	23.0	15.2	13.5	15.2	10-45	4-40	14.8-31.2	8.9-21.5
	B2t*	49.2	34.0	22.0	20.6	9-94	8-86	40.9-57.5	25.8-42.2
	C	37.0	43.0	22.3	19.7	8-60	15-76	25.4-48.6	35.8-50.2
Depth to the top	B2t	20.8	14.5	13.8	11.9	6-53	4-38	15.6-26.0	9.8-19.2
	C	47.8	38.8	16.6	17.5	19-68	11-72	39.2-56.4	32.4-45.2

† Confidence interval at the .10 significance level.

* Difference between means significant at the .05 level.

Table 7. Number of samples (N)[#] required to estimate the mean thickness and depth to the top of selected horizons in the upper 100 cm of soils on the Kootenai Formation (KF) and the Boulder batholith (BB).

Property	Horizon	Confidence Interval Width					
		cm					
		± 2		± 5		± 10	
		KF	BB	KF	BB	KF	BB
Thickness	O	1	1	1	1	1	1
	A1	9	3	1	1	1	1
	A2	153	130	25	21	6	5
	B2t	360	318	50	50	14	13
	C	401	287	64	46	16	12
Depth to the top	B2t	142	106	22	17	6	4
	C	222	227	36	36	9	9

[#] Estimated at the .10 significance level.

Table 8. Frequency distribution of dry soil color[†] by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Horizon	Parent Material	Hue			Values								Chroma							
		5 YR	7.5 YR	10 YR	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
		----- % -----																		
A1	KF	24	33	43	—	—	—	19	19	29	29	5	—	38	14	43	—	5	—	—
	BB			100	—	—	25	38	19	17	—	—	6	62	25	6	—	—	—	—
A2	KF		11	89	—	—	—	—	—	—	67	33	11	44	11	22	—	11	—	—
	BB			100	—	—	—	15	54	31	—	—	—	31	31	38	—	—	—	—
B2t	KF	23	29	48	—	—	—	4	29	29	29	9	9	—	19	29	—	43	—	—
	BB			100	—	—	—	11	32	47	—	—	—	5	26	37	—	32	—	—
C	KF	50	17	33	—	—	—	8	17	8	33	33	—	42	—	25	—	33	—	—
	BB			100	—	—	—		18	59	14	9	—	14	23	32	4	18	—	9

† Munsell Color Chart

only predictable difference is in the hue variable of color. All of the batholith dry soil colors are of hue 10 YR. Kootenai dry soil colors range from 5 YR and 7.5 YR to 10 YR in all horizons except the A2, where no hue of 5 YR is found and 89 percent of the hues are 10 YR. The red color predominant in the Kootenai Formation strata is most pronounced in the C horizon with a 50 percent frequency of the reddish 5 YR hue. No striking different or consistent pattern can be found in chroma.

Kootenai soils have higher frequencies of light color values of 7 and 8 than batholith soils. One might expect to find lighter values in forest soils that are subjected to higher leaching and lower pH environments in contrast to meadow and grassland soils. However, it does not explain the lighter values in this case, since there are four more meadow sites on the Kootenai Formation than on the Boulder batholith. The higher precipitation range and associated leaching potential of the Kootenai study area may be a factor. Since the C horizon of Kootenai soils also has a higher frequency of light values (7 and 8) than batholith soils, it appears to be an inherited color difference, possibly accentuated by climatic factors in the upper horizons.

Like dry soil color, the main difference in moist color (Table 9) between soils on the two parent materials is the hue variable. Batholith soils again are 100 percent hue 10 YR, except 95 percent in

Table 9. Frequency distribution of moist soil color[†] by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Horizon	Parent Material	Hue			Values								Chroma							
		5 YR	7.5 YR	10 YR	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
		%																		
A1	KF	24	43	33	—	9	62	19	—	—	—	—	—	33	29	38	—	—	—	—
	BB	—	—	100	—	63	38	—	—	—	—	—	56	31	13	—	—	—	—	—
A2	KF	—	22	78	—	—	—	11	49	45	—	—	—	—	44	45	—	11	—	—
	BB	—	—	100	—	—	69	23	8	—	—	—	15	31	54	—	—	—	—	—
B2t	KF	29	33	38	—	—	10	32	48	10	—	—	—	—	9	38	—	48	—	5
	BB	—	5	95	—	—	16	68	11	5	—	—	—	5	37	53	—	5	—	—
C	KF	25	42	33	—	—	—	17	25	33	25	—	—	—	50	42	—	—	—	8
	BB	—	—	100	—	—	—	27	59	9	5	—	—	5	18	63	5	9	—	—

† Munsell Color Chart

the B2t horizon. Kootenai soils are fairly evenly distributed between hues 5 YR, 7.5 YR and 10 YR. Moist soils are redder than dry soils with a higher frequency of 5 YR and 7.5 YR hues. The consistent moist and dry hues in batholith soils reflects the greater uniformity of batholith rock mineralogy in contrast to the variable Kootenai Formation lithologies.

Soil Structure

Table 10 shows the frequency distribution of soil structure grade, size and type. Structure grade distribution in the A1 horizon is roughly 2/3 moderate and 1/3 weak in Kootenai soils, whereas in batholith soils it is about 2/3 weak and 1/3 moderate. In the A2 horizon of soils of both parent materials structure grade is predominantly weak. Moderate and strong structure grades dominate in the B2t horizon of Kootenai soils, whereas batholith soils have 100 percent moderate structure grade. The C horizon of both Kootenai and batholith soils have a structureless grade because the structure type is massive. The stronger structure grade of Kootenai soils reflects the higher mean clay content, which will be discussed later.

Structure size classes for Kootenai soils are very fine, fine and medium in the A1 horizon; fine and medium in the A2; and medium and fine in the B2t. Batholith soils have medium and fine classes in the A1 horizon; very coarse and medium in the A2; and dominantly medium

Table 10. Frequency distribution of soil structure grade, size and type[†] by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Horizon	Parent Material	Grade [§]				Size Class [†]					Type [‡]						
		sl	w	m	s	vf	f	m	c	vc	gr	cr	pl	sbk	abk	pr	m
		----- % -----															
A1	KF	—	33	62	5	43	38	19	—	—	76	20	4	—	—	—	—
	BB	—	69	31	—	—	19	81	—	—	100	—	—	—	—	—	—
A2	KF	—	89	11	—	—	56	44	—	—	56	11	—	33	—	—	—
	BB	—	92	8	—	—	—	38	16	46	31	—	69	—	—	—	—
B2t	KF	—	10	52	38	—	24	76	—	—	—	—	—	48	48	4	—
	BB	—	—	100	—	—	—	89	11	—	—	—	—	84	11	5	—
C	KF	100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	100
	BB	100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	100

[†] Soil Survey Staff (1951)

[§] sl = structureless, w = weak, m = moderate, s = strong

[†] vf = very fine, f = fine, m = medium, c = coarse, vc = very coarse.

[‡] gr = granular, cr = crumb, pl = platy, sbk = subangular blocky, abk = angular blocky, pr = prismatic, m = massive.

with some very coarse structure size in the B2t. The smaller structure size in Kootenai soils may be due to the greater in situ soil movement, i.e. expansion and contraction with wetting and drying, freeze-thaw, etc. because of the higher clay content and associated higher water holding capacity. Similar reasoning for development of soil structure size has been proposed by Harper (1937 and White (1966). White (1966) also suggests that higher sand content (particularly coarse sand) in soils may increase the shear strength sufficiently to generate larger structure sizes. This appears to be the case in the coarse sandy batholith soils.

Soils of both parent materials have predominantly granular structure in the A1 horizon and 100 percent massive structure in the C horizon. Granular structure is also dominant in the A2 horizon of Kootenai soils with some subangular blocky structure. Platy structure is dominant in A2 horizons of batholith soils with the remainder being granular. Soils of both parent materials have subangular blocky, angular blocky and a small percentage (4 - 5 percent) of prismatic structure in the B2t horizon. In this horizon, Kootenai soils have half subangular blocky and half angular blocky structure, whereas batholith soils have dominantly subangular blocky structure. The higher frequency of angular blocky structure in Kootenai soils may be due to the higher inherited clay content and

associated stronger cohesive forces within the soil ped, as suggested by White (1966).

Soil Consistence

Soil consistence comparisons from Table 11 illustrate some striking differences between Kootenai and batholith soils and their predictability. Dry consistence of the A1 and A2 horizons of Kootenai soils are soft and slightly hard, respectively; B2t horizons range from loose to hard; and C horizons, slightly hard to very hard. This general increase in dry consistence hardness follows the trend of increasing clay content with depth, particularly from the B2t to C horizons in soils derived from clayey shale.

In the sandy batholith soils, dry consistence of the A1, A2 and B2t horizons is mainly soft and slightly hard with a smaller frequency of loose consistence (up to 23 percent in the A2 horizon). The C horizon, however, is a dramatic change with a 91 percent of the horizons having loose dry consistence. This again reflects the low clay content of the weathered granitic batholith rocks.

Moist consistence in the A1 and A2 horizons in both Kootenai and batholith soils is predominantly very friable and friable. There is an 80 percent frequency of very friable moist consistence in these two horizons of batholith soils and an 8 percent frequency of loose moist consistence in the A2. The B2t and C horizons in Kootenai soils

Table 11. Frequency distribution of soil consistence[†] by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Horizon	Parent Material											Wet							
		Dry [§]					Moist [†]					Stickness [‡]				Plasticity [¶]			
		lo	so	sh	h	vh	lo	vfr	fr	fi	vfi	so	ss	s	vs	po	ps	p	vp
----- % -----																			
A1	KF	—	52	48	—	—	—	62	38	—	—	5	67	14	14	—	76	10	14
	BB	6	56	38	—	—	—	81	19	—	—	94	6	—	—	88	12	—	—
A2	KF	—	51	49	—	—	—	67	33	—	—	22	44	34	—	22	56	22	—
	BB	23	64	31	—	—	8	77	15	—	—	100	—	—	—	92	8	—	—
B2t	KF	5	33	38	24	—	—	10	19	52	19	5	5	52	38	5	5	43	52
	BB	5	53	42	—	—	—	95	5	—	—	53	37	10	—	74	26	—	—
C	KF	—	—	58	25	17	—	8	34	50	8	8	8	42	42	8	8	50	34
	BB	91	—	9	—	—	86	9	5	—	—	100	—	—	—	100	—	—	—

[†] Soil Survey Staff (1951).

[§] lo = loose, so = soft, sh = slightly hard, h = hard, vh = very hard.

[‡] lo = loose, vfr = very friable, fr = friable, fi = firm, vfi = very firm.

[‡] so = nonsticky, ss = slightly sticky, s = sticky, vs = very sticky.

[¶] po = nonplastic, ps = slightly plastic, p = plastic, vp = very plastic.

have very friable to very firm moist consistence. Batholith soils have a 95 percent frequency of a friable moist consistence in the B2t horizon and an 86 percent frequency of loose moist consistence in the C.

Stickiness and plasticity in Kootenai soils range from nonsticky to very sticky and nonplastic to very plastic. Exceptions include the A1 horizon which has no nonplastic wet consistence and the A2 horizon which has neither very sticky nor very plastic wet consistence. Slightly sticky and slightly plastic are the predominant wet consistencies in the A1 and A2 horizons with sticky and very sticky, and plastic and very plastic predominating in the B2t and C horizons.

Batholith soils largely have nonsticky and nonplastic wet consistencies, except for a small percentage of slightly sticky and slightly plastic consistence (mainly in the B2t horizon). The B2t horizon is the only horizon in the batholith soils with any sticky wet consistence (10 percent frequency). The C horizon is 100 percent nonsticky and nonplastic.

Wet consistence is much more predictable in batholith soils than Kootenai soils because of the more constant soil texture, as discussed later. Moist and dry consistence are also more predictable in batholith soils than in Kootenai soils.

Field pH

The differences in mean pH between soils of the two parent materials (Table 12) are significant at the .01 level in the A2 and B2t horizons and at the .05 level in the A1. Differences in the C horizon are not significant at the .10 level. The mean pH of batholith soils are consistently about .6 units higher than those of the Kootenai soils in all horizons. Standard deviations are similar except for the C horizon of Kootenai soils which is slightly larger (1.2 vs. 0.7). This greater variability in the C horizon reflects the lithologic variability of the Formation from limestone to non-calcareous sandstone and shale. Ranges are also similar except for more acidic values in the A1 and A2 horizons of Kootenai soils. The 90 percent confidence intervals do not overlap between soils of the two parent materials except in the C horizons.

The coarse textured batholith soils might be expected to have lower pH values because of their greater leaching potential than the fine textured Kootenai soils. This is not borne out by the data, however. A possible explanation is the inherent noncalcareous nature of much of the Kootenai Formation strata in this area. Also, the higher precipitation range of the Kootenai sites (46-66 vs. 36-56 cm) associated with the higher mean elevation (2502 vs. 1676 m) may have played an important role in reducing the pH values, particularly in the upper horizons.

Table 12. Statistical data on pH by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Horizon	$\bar{X}$		SD		Range		90% CI [†]	
	KF	BB	KF	BB	KF	BB	KF	BB
	----- $\log_{10}$ -----							
A1 [*]	6.0	6.6	0.7	0.6	4.8-7.5	5.8-7.8	5.8-6.2	6.3-6.9
A2 ^{**}	5.6	6.2	0.2	0.5	5.5-6.0	5.5-7.0	5.5-5.7	6.0-6.4
B2t ^{**}	6.1	6.7	0.7	0.6	5.5-7.8	5.8-7.8	5.9-6.3	6.5-6.9
C	6.6	7.1	1.2	0.7	5.0-8.0	5.8-8.2	6.0-7.2	6.8-7.4

† Confidence interval at the .10 significance level.

* Difference between means significant at the .05 level.

** Difference between means significant at the .01 level.

Table 13. Number of samples (N)[#] required to estimate the mean pH by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Horizon	Confidence Interval Width					
	----- $\log_{10}$ -----					
	± 0.2		± 0.5		± 1.0	
	KF	BB	KF	BB	KF	BB
A1	32	27	5	4	1	1
A2	5	18	1	3	1	1
B2t	29	28	5	5	1	1
C	116	34	19	6	5	2

[#] Estimated at the .10 significance level.

Some soils in the NW and DM transects near the edge of the batholith exposure have Cca horizons. Possible sources for the calcium carbonate may include: aerial deposition, remnants of residual deposits of limestone or other calcareous strata that once overlaid the batholith, hydrothermal deposits, and inclusion of calcareous country rock into the magma at the border zone of the batholith.

The number of samples required to estimate the mean pH (Table 13) is lowest in the A2 horizon and highest in the C horizon of soils on both parent materials. Six samples or less are required to estimate the mean pH in all horizons of Kootenai and batholith soils within ± 5 units about the mean. One exception is the C horizon of Kootenai soils which requires 19 samples.

Coarse Fragment Content

Table 14 shows some statistical comparisons of coarse fragment (CF) content in soils of the two parent materials. Differences of mean > 20 mm and total CF contents between Kootenai and batholith soils are significant at the .01 level in all horizons. Differences of mean 20 - 2 mm content between the parent materials, however, are not significant at the .10 level in any horizon. Standard deviations, ranges and 90 percent confidence intervals are much larger in Kootenai soils, except in the 20 - 2 mm fraction, where they are similar to

Table 14. Statistical data on percent (by vol) coarse fragment content by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Coarse Fragment Size Fraction	Horizon	$\bar{X}$		SD		Range		90% CI [†]	
		KF	BB	KF	BB	KF	BB	KF	BB
----- % -----									
> 20 mm	A1**	10.6	0.3	13.8	0.9	0-50	0-3	5.4-15.8	0-0.7
	A2**	39.6	0.1	11.6	0.3	21-55	0-1	32.5-46.7	0-0.2
	B2t**	25.3	1.0	17.6	1.8	0-51	0-7	18.7-31.9	.3-1.7
	C**	30.4	0.4	18.4	1.4	0-53	0-6	20.8-40.0	0-0.9
20 - 2 mm	A1	3.8	5.2	2.7	3.4	1-11	2-16	2.8-4.8	3.7-6.7
	A2	4.6	5.2	2.5	2.4	1-9	1-9	3.1-6.1	4.0-6.4
	B2t	5.7	6.5	4.1	2.7	1-16	1-13	4.2-7.2	5.4-7.6
	C	10.2	12.1	6.8	7.1	3-29	1-28	6.7-13.7	9.5-14.7
Total > 2 mm	A1**	14.4	5.5	14.8	3.6	1-54	2-16	8.8-20.0	3.9-7.1
	A2**	44.0	5.2	10.7	2.4	25-59	1-9	37.5-50.5	4.0-6.4
	B2t**	31.0	7.5	18.3	3.3	3-57	1-14	24.1-37.9	6.2-8.8
	C**	37.0	12.5	17.4	7.0	8-64	1-23	28.0-46.0	9.9-15.1

† Confidence interval at the .10 significance level.

** Differences between means significant at the .01 level.

those of the batholith soils.

Figures 7, 8 and 9 illustrate the means, standard deviations and ranges of the three CF fraction contents by horizon in Kootenai and batholith soils. Dramatic differences in variability and means are shown in the total and > 20 mm fractions (Figures 7 and 8), whereas the 20 - 2 mm fraction (Figure 9) shows striking similarities. The highest > 20 mm and total CF contents in Kootenai soils is in the A2 horizon. The C horizon has the highest content of the 20 - 2 mm fraction.

In the batholith soils, the C horizon has the highest total and 20 - 2 mm CF contents. The B2t horizon has the highest > 20 mm CF content, though all horizons of batholith soils have very low percentages of this fraction. The increase in CF content with depth in the batholith soils would be expected in a uniform massive parent material such as the granitic batholith rocks where weathering intensity decreases with depth, as indicated by Jackson et al. (1948). The higher CF content in the Kootenai soils is associated with the greater weathering resistance of some bedded sandstone and limestone strata in contrast to the uniform weathering batholith rocks. Table 15 further illustrates the differences in predictability of CF contents.

Sand Size Fraction

Differences in mean coarse, medium and fine sand contents between

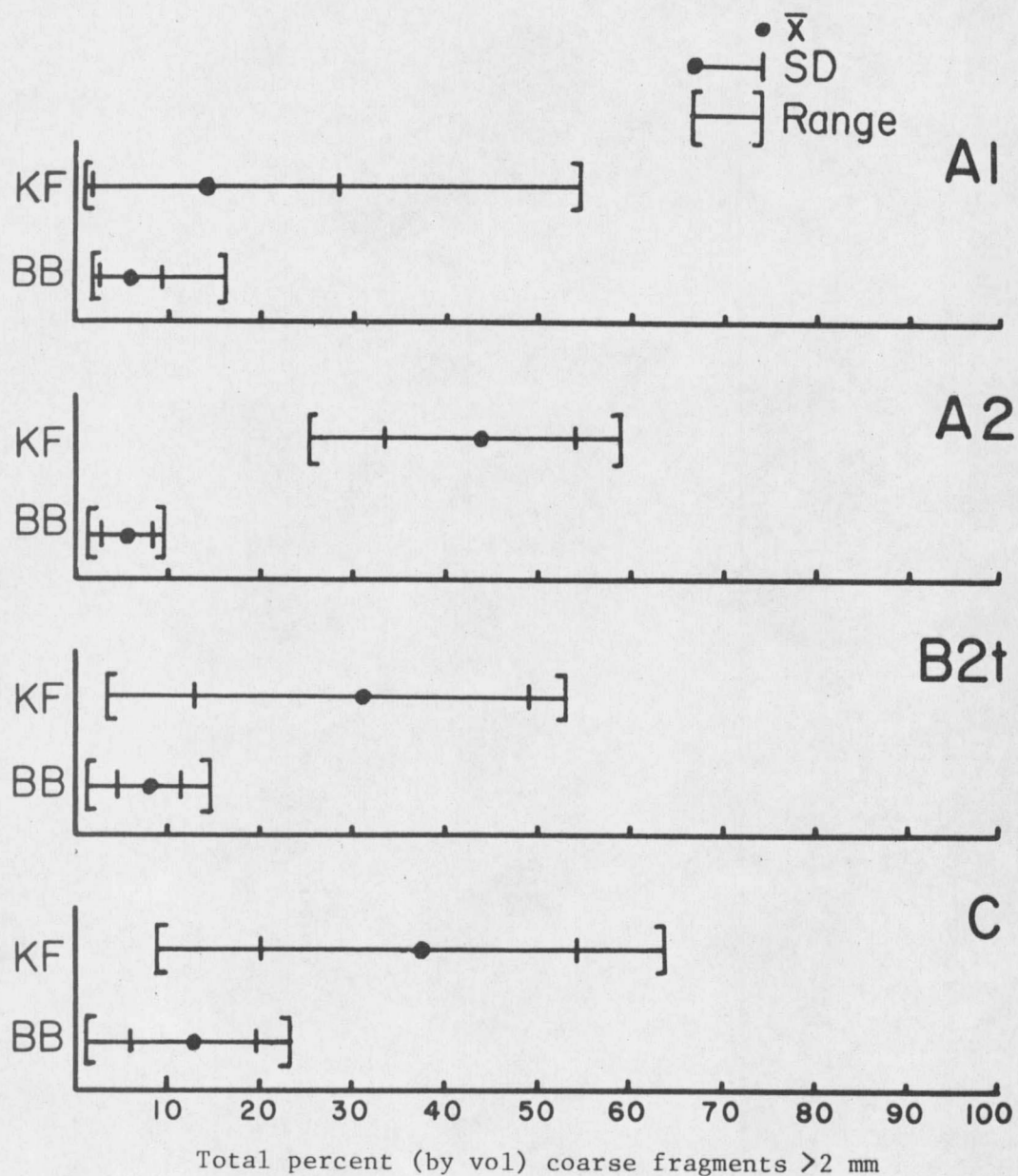


Figure 7. Means, standard deviations and ranges of the total coarse fragment content by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

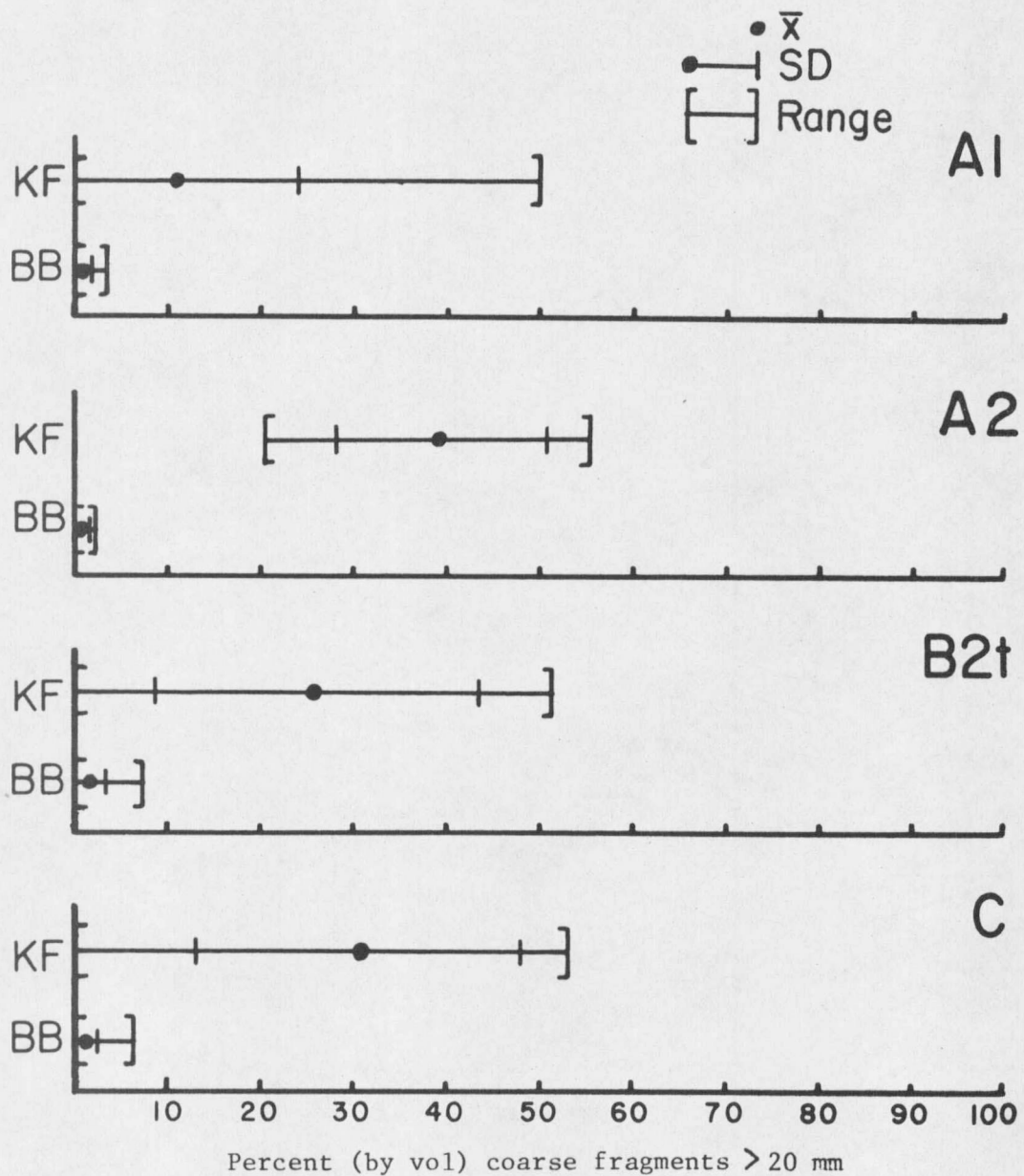


Figure 8. Means, standard deviations and ranges of the coarse fragment content > 20 mm by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

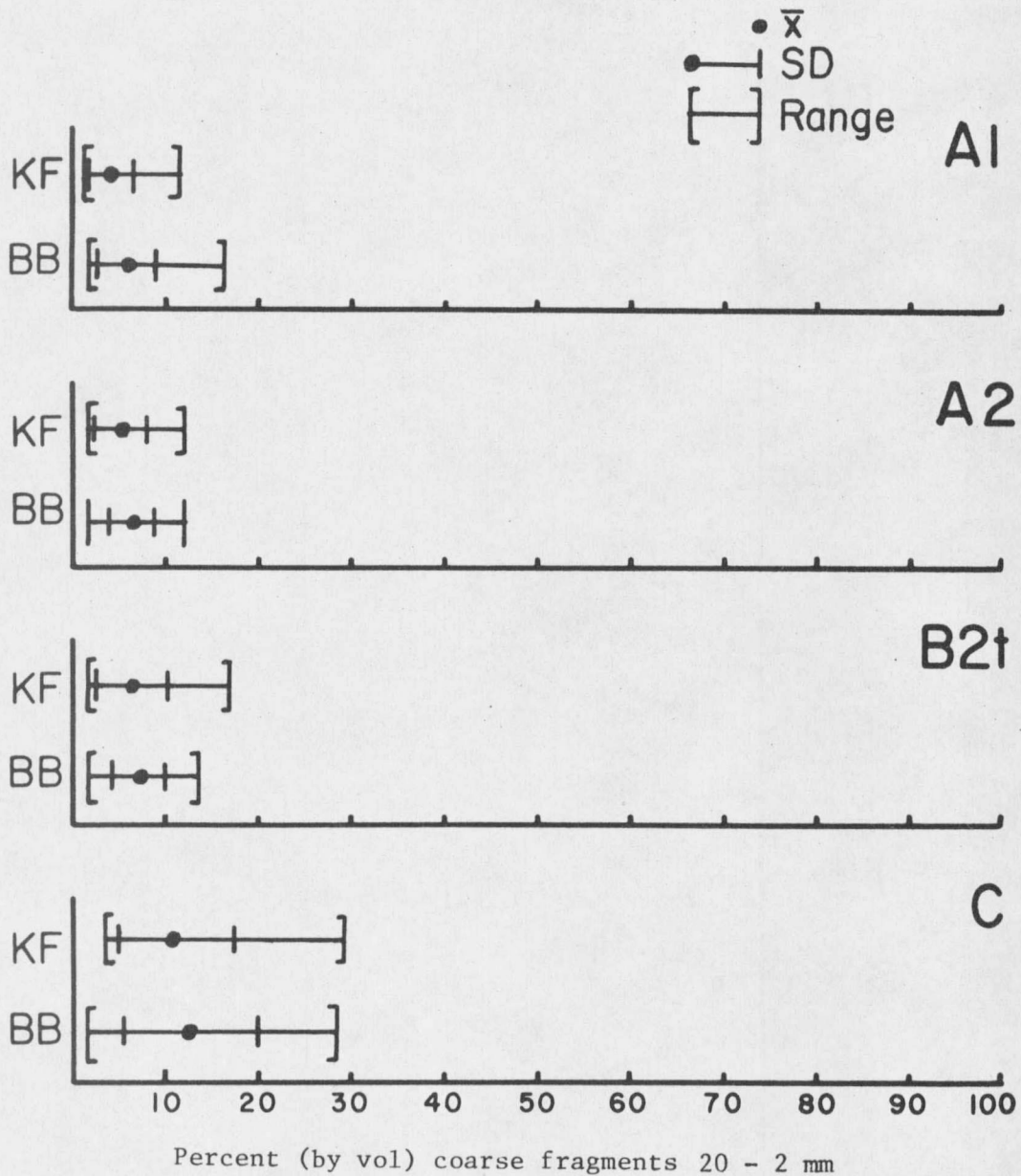


Figure 9. Means, standard deviations and ranges of the coarse fragment content 20 - 2 mm by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Table 15. Number of samples (N)[#] required to estimate the mean coarse fragment content (percent by volume for > 20 mm, 20 - 2 mm, and total) by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Coarse Fragment Size Fraction	Horizon	Confidence Interval Widths					
		- - - - - % coarse fragments - - - - -					
		± 2		± 5		± 10	
		KF	BB	KF	BB	KF	BB
> 20 mm	A1	142	1	23	1	6	1
	A2	113	1	18	1	5	1
	B2t	230	2	36	1	10	1
	C	273	2	44	1	11	1
20 - 2 mm	A1	5	8	1	2	1	1
	A2	5	5	1	1	1	1
	B2t	13	6	2	1	1	1
	C	37	37	6	6	2	2
Total	A1	163	10	26	2	7	1
	A2	96	5	15	1	4	1
	B2t	249	8	40	1	10	1
	C	233	37	39	6	10	2

[#] Estimated at the .10 significance level.

Kootenai and batholith soils (Table 16) are significant at the .01 level in all horizons. An exception is the fine sand fraction where the difference is not significant at the .10 level in the A2 horizon and only significant at the .10 level in the C horizon. Standard deviations are similar, though in the coarse sand fraction, those of batholith soils are 2-6 percentage points higher than Kootenai soils. Also, in the fine sand fraction, Kootenai soils have higher standard deviations in the B2t and C horizons than batholith soils. The 90 percent confidence intervals do not overlap between Kootenai and batholith soils in the coarse and medium sand fractions in any horizon, and in the A2 and C horizons in the fine sand fraction.

Figures 10, 11 and 12 give a visual comparison of the means, standard deviations and ranges of each sand size fraction by horizon. In the coarse and medium sand fractions (Figures 10 and 11, respectively), the ranges do not overlap and the means, standard deviations and ranges are quite consistent throughout the profile in soils of both parent materials. Extensive overlap of ranges is found in fine sand content (Figure 12) with a general increase in variability with depth.

The number of samples required to estimate the mean coarse, medium and fine sand contents are shown in Table 17. A low (< 5)

Table 16. Statistical data on three sand fraction contents (by wt) in the < 2 mm fraction by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB)

Sand Size Fraction	Horizon	$\bar{X}$		SD		Range		90% CI [†]	
		KF	BB	KF	BB	KF	BB	KF	BB
----- % -----									
Coarse (2-.5mm)	A1**	2.2	28.0	2.0	4.6	0-7	22-39	1.4-3.0	26.0-30.0
	A2**	3.1	29.8	2.3	6.0	1-8	20-39	1.7-4.5	26.8-32.8
	B2t**	1.2	25.9	1.8	7.2	0-6	14-37	0.5-1.9	23.0-28.8
	C**	1.3	34.0	2.1	8.8	0-7	13-47	0.2-2.4	30.8-37.2
Medium (.5-.25mm)	A1**	4.6	16.0	2.7	2.5	2-9	14-21	3.6-5.6	14.9-17.1
	A2**	5.3	17.9	1.8	2.8	3-9	14-22	4.2-6.4	16.5-19.3
	B2t**	3.1	18.1	2.0	3.2	1-7	13-25	2.3-3.9	16.8-19.4
	C**	2.3	18.1	2.3	2.6	0-6	10-22	1.4-3.2	17.1-19.1
Fine (.25-.05mm)	A1**	18.1	23.0	5.6	3.6	9-28	18-30	16.0-20.1	21.4-24.6
	A2	27.8	25.6	5.2	5.2	22-37	17-36	24.6-31.0	22.9-28.3
	B2t**	18.9	26.4	9.9	5.0	5-37	20-39	15.2-22.6	24.1-28.7
	C#	19.0	26.0	16.2	6.7	6-61	14-44	10.6-27.4	23.4-28.6

[†] Confidence interval at the .10 significance level.

** Difference between means significant at the .01 level.

Difference between means significant at the .10 level

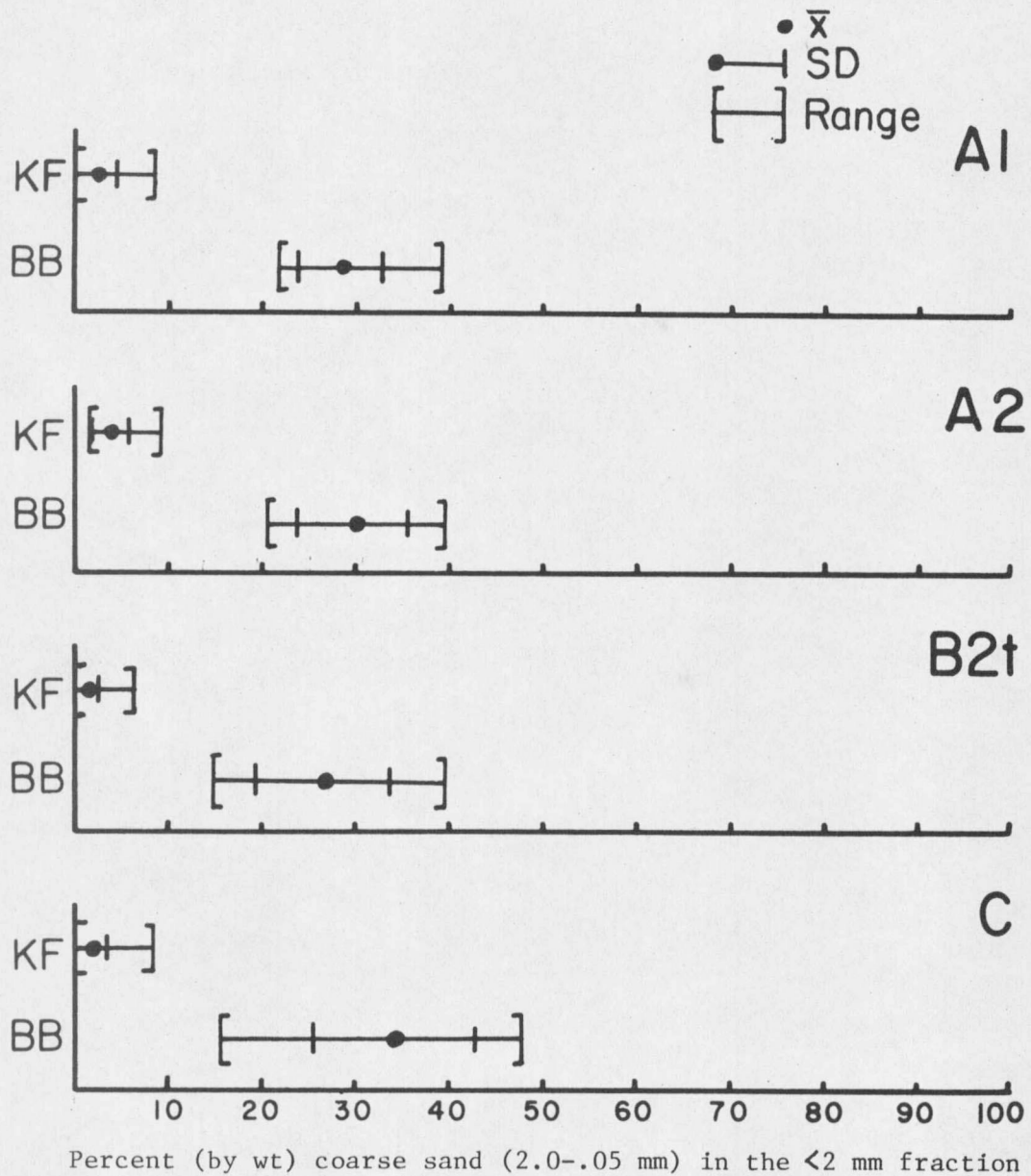


Figure 10. Means, standard deviations and ranges of coarse sand content by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

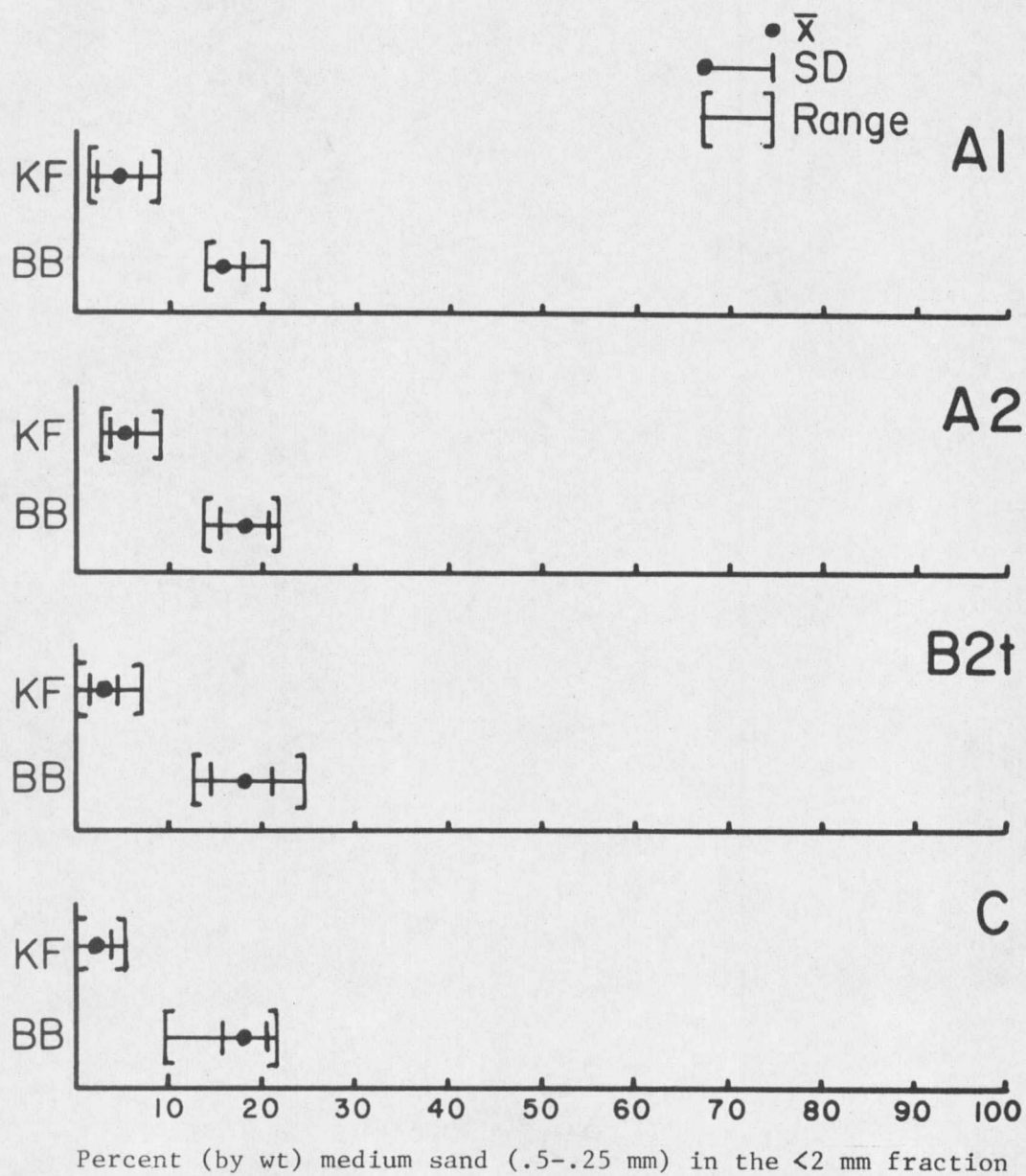


Figure 11. Means, standard deviations and ranges of medium sand content by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

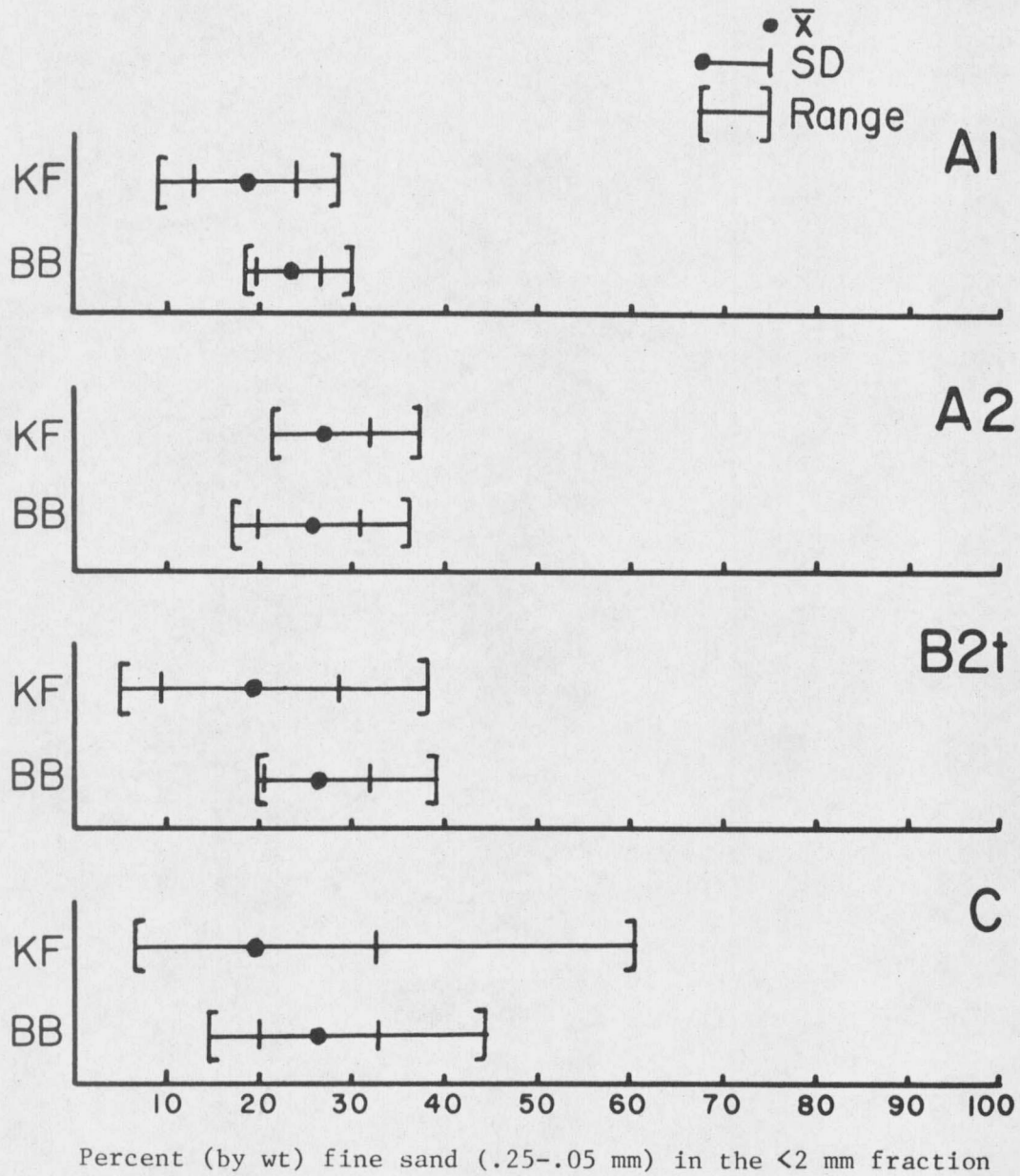


Figure 12. Means, standard deviations and ranges of fine sand content by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Table 17. Number of samples (N)[#] required to estimate the mean coarse, medium and fine sand contents (by wt) of the < 2 mm fraction by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Sand Size Fractions	Horizon	Confidence Interval Widths					
		--- % sand ---					
		± 2		± 5		± 10	
		KF	BB	KF	BB	KF	BB
Coarse sand (2 - .5 mm)	A1	3	16	1	3	1	1
	A2	5	29	1	5	1	1
	B2t	3	39	1	6	1	2
	C	4	58	1	9	1	3
Medium sand (.5 - .25 mm)	A1	5	5	1	1	1	1
	A2	3	7	1	1	1	1
	B2t	3	1	1	1	1	1
	C	5	5	1	1	1	1
Fine sand (.25 - .05 mm)	A1	23	10	4	2	1	1
	A2	23	24	3	4	1	1
	B2t	73	26	12	4	3	1
	C	211	34	34	6	9	2

[#] Estimated at the .10 significance level.

number of samples are required to estimate the mean coarse and medium sand contents within ± 2 percent about the mean in Kootenai soils. This small sample size largely reflects the predictably low coarse and medium sand contents in the Kootenai Formation strata (except the basal conglomeratic sandstone which was not exposed in the study area. The fine sand content, however, is less predictable, particularly in the B2t and C horizons. The number of samples required to estimate the mean fine sand content within ± 2 percent about the mean are 73 and 211 for the B2t and C horizons, respectively.

In batholith soils, medium sand is the only sand fraction where the mean can be estimated within ± 2 percent about the mean with 7 samples or less. Mean coarse and fine sand contents can be estimated with a low number of samples within ± 5 percent about the mean, but generally 20-30 samples or more are needed to estimate the means within ± 2 percent about the mean. The number of samples required to estimate the means increases with depth for the coarse and fine sand fraction in batholith soils, and only for fine sand in Kootenai soils.

Most Kootenai Formation sandstones are fine-grained, .125 - .250 mm (Wentworth scale), except the basal conglomeratic sandstone. Sand fractions in the shale and other strata are also typically fine. This would explain the very low content and variability of the coarse

and medium sand fractions and the higher content and variability of fine sand. The greater variability of fine sand in the C horizon of Kootenai soils also reflects the range of soils derived from clayey shale to sandstone. The higher coarse and medium sand contents of batholith soils is expected since the batholith rocks are typically coarser grained, the most common size range being 1-3 mm.

Soil Texture

One of the more dramatic differences between Kootenai and batholith soils is that of texture. Table 18 shows some statistical data on the sand, silt and clay contents by horizon. All differences of means between Kootenai and batholith soils are significant at the .01 level. Large differences in mean sand, silt and clay content exist between Kootenai and batholith soils in all horizons. Kootenai soils contain roughly 20-35 percent more silt and clay than batholith soils which, in turn, have 35-55 percent more sand. Kootenai soil standard deviations and range widths tend to be at least 2-3 times larger than in batholith soils for sand, silt and clay content in all horizons. An exception is the A2 horizon where standard deviations are similar. Standard deviations of Kootenai soils are largest in the C horizon and smallest in the A2, while the batholith soils have fairly constant standard deviations throughout the profile. None of the 90 percent confidence intervals for mean

Table 18. Statistical data on the sand, silt and clay contents (by wt) of the < 2 mm fraction by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Particle Size Fraction	Horizon	$\bar{X}$		SD		Range		90% CI [†]	
		KF	BB	KF	BB	KF	BB	KF	BB
----- % -----									
Sand (2.0 - .05 mm)	A1**	25.0	67.0	8.3	5.8	12-37	58-77	21.9-28.1	64.5-69.5
	A2**	36.4	73.0	5.4	5.4	30-46	65-86	33.1-39.7	70.3-75.7
	B2t**	23.3	70.3	12.0	7.0	6-45	56-81	18.8-27.8	67.5-73.1
	C**	22.6	77.3	17.2	5.8	3-63	67-86	13.7-31.5	75.2-79.4
Silt (.05 - .002 mm)	A1**	47.0	24.9	8.3	4.8	33-63	18-34	43.9-50.1	22.8-27.0
	A2**	51.8	19.9	4.0	4.6	47-58	9-27	49.4-54.2	17.6-22.2
	B2t**	40.9	17.9	6.5	4.0	33-50	10-24	38.5-43.3	16.3-19.5
	C**	36.0	15.8	10.5	4.8	21-60	9-28	30.6-41.4	14.0-17.6
Clay (< .002 mm)	A1**	26.8	7.3	13.8	2.8	9-50	4-14	21.6-32.0	6.1-8.5
	A2**	11.8	6.6	4.7	3.2	6-19	2-13	8.9-14.7	5.0-8.2
	B2t**	36.8	12.4	15.3	5.0	9-60	9-24	31.0-42.6	10.4-14.4
	C**	41.4	6.5	23.6	3.5	4-74	1-14	29.2-53.6	5.2-7.8

[†] Confidence interval at the .10 significance level.

** Difference between means significant at the .01 level.

sand, silt and clay contents overlap between Kootenai and batholith soils. They are also wider for Kootenai soils (5 - 24 percent) than batholith soils (2 - 5 percent). The C horizon has the widest confidence interval in Kootenai soils, while it is the narrowest in batholith soils, 11 - 24 percent and 2 - 4 percent, respectively. This further illustrates the contrast in lithologic variability of the two parent materials.

Figures 13, 14 and 15 graphically display the means, standard deviations and ranges from Table 18, giving a good representation of the contrasting predictability of soil texture. The ranges and standard deviations of Kootenai soils are consistently much wider than in batholith soils, except in the A2 horizon. Mean clay content increases from the B2t to C horizons in Kootenai soils, while it decreases in batholith soils. This is due to the high inherited clay content of the shale derived soils of the Kootenai Formation. Sand content remains about the same from the B2t to C horizon in Kootenai soils and increases in the batholith soils. Less weathering and clay formation has taken place in the C horizons of batholith soils than in the upper horizon, resulting in a proportionally higher sand content. The silt content of Kootenai soils is slightly higher in the A horizons than in the B or C horizons. This could be due to the proportional loss of clay to the lower horizons by illuviation,

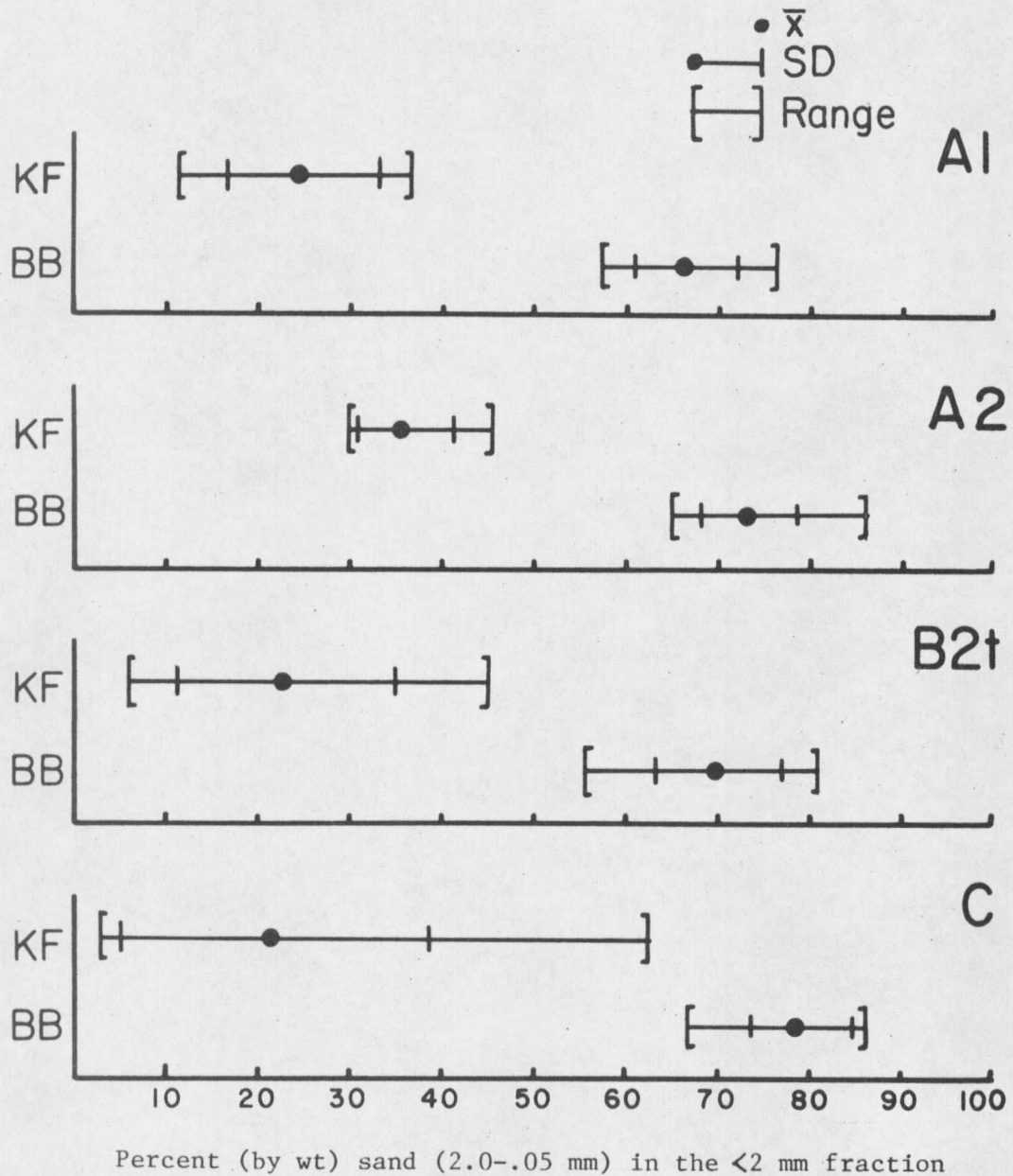


Figure 13. Means, standard deviations and ranges of sand content by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

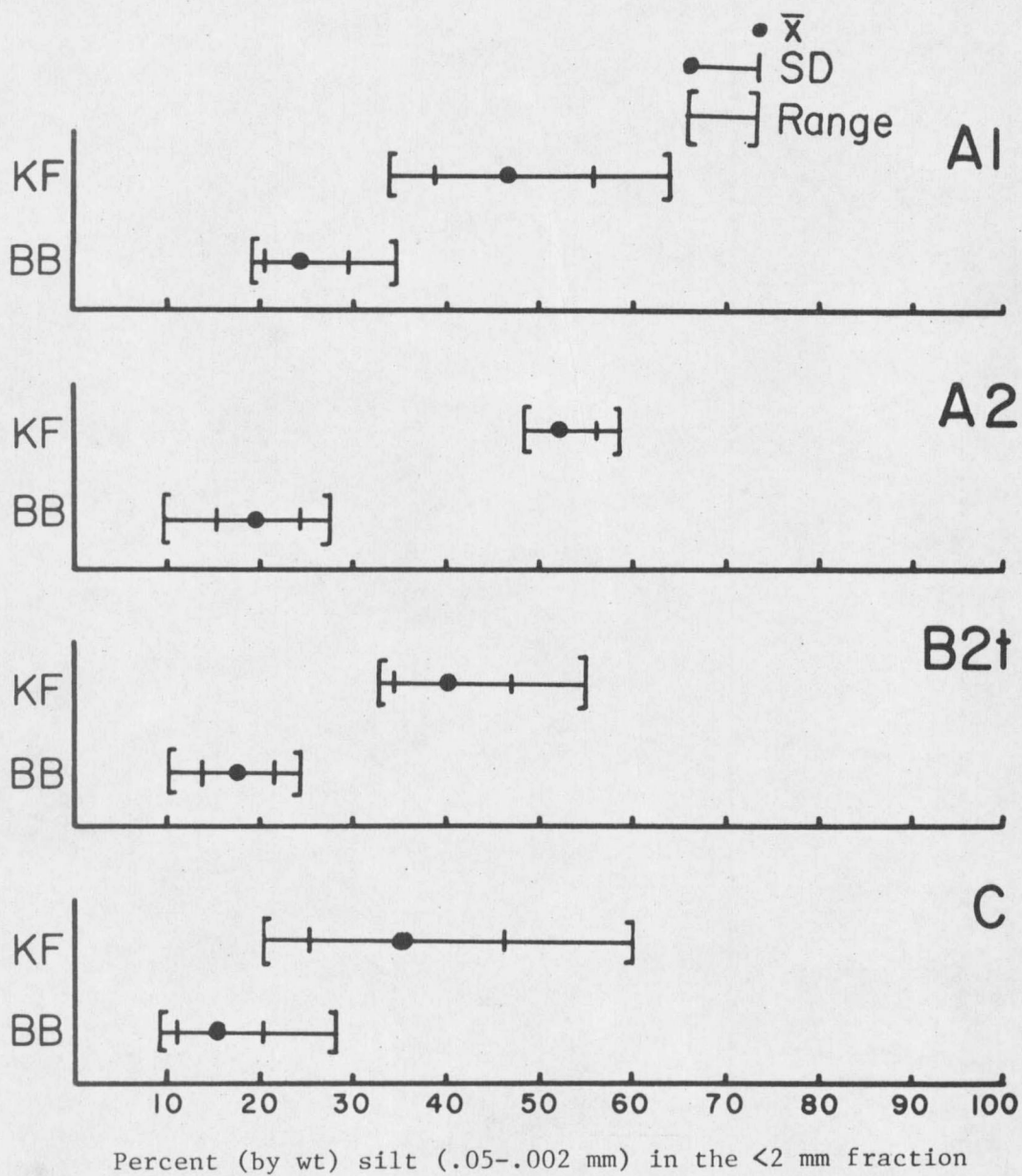


Figure 14. Means, standard deviations and ranges of silt content by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

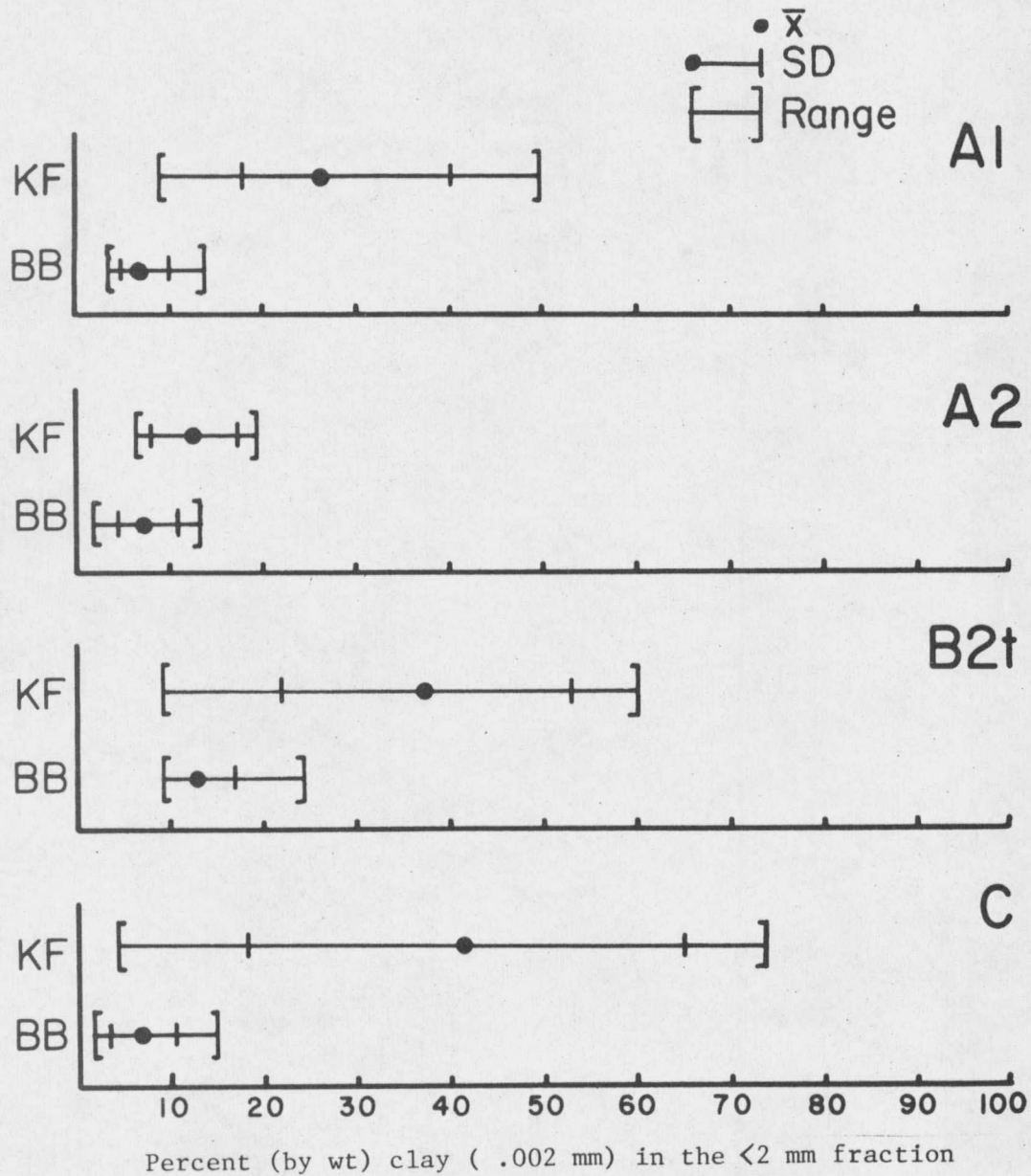


Figure 15. Means, standard deviations and ranges of clay content by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

or possibly through the addition of silt-size particles as loess deposits, or a combination of the two.

The number of samples required to estimate the mean sand, silt and clay contents (Table 19) is generally much larger in all horizons of Kootenai soils than batholith soils. An exception is the A2 horizon which requires a similar number for samples of both parent materials. Some of the more dramatic differences are in sand and clay contents of the B2t and C horizons. The number of samples required to estimate the mean sand content within ± 5 percent about the mean in the B2t and C horizons are 17 and 38 for Kootenai soils and 6 and 4 for batholith soils, respectively. For clay content, the number increases to 29 and 72 for Kootenai soils, but decreases to only 3 and 2 for batholith soils, respectively.

Table 20 shows the frequency distribution of soil textural classes of Kootenai and batholith soils. A pronounced difference in the range of textural classes and predictability is evident. All of the batholith soil textural classes in all horizons are loamy sand or sandy loam with the exception of a 5 percent frequency of a loam textural class in the B2t horizon. The A1, A2 and particularly the B2t horizons are predominantly sandy loam while the C horizon is mainly loamy sand.

Textural classes of the A1 horizon in Kootenai soils vary from loam to clay with a 43 percent frequency of silt loam and a 28 percent

Table 19. Number of samples (N)[#] required to estimate the mean sand, silt and clay contents (by wt.) in the < 2mm fraction by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Particle Size Fraction	Horizon	Confidence Interval Width					
		- - - % sand, silt or clay - - -					
		± 2		± 5		± 10	
		KF	BB	KF	BB	BK	BB
Sand (2.0 - .05 mm)	A1	51	1	8	1	2	1
	A2	25	23	4	4	1	1
	B2t	107	36	17	6	4	2
	C	239	25	38	4	10	1
Silt (.05 - .002 mm)	A1	51	18	8	3	2	1
	A2	13	17	2	3	1	1
	B2t	31	12	5	2	1	1
	C	89	17	14	3	4	1
Clay (< .002 mm)	A1	142	6	22	1	6	1
	A2	19	8	3	2	1	1
	B2t	179	19	29	3	7	1
	C	449	9	72	2	18	1

[#] Estimated at the .10 significance level.

Table 20. Frequency distribution of textural classes[†] (< 2 mm fraction) by horizon in soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Horizon	Parent Material	Textural Classes [§]										
		s	ls	sl	l	si	sil	scl	sicl	cl	sic	c
		%										
A1	KF	—	—	—	19	—	43	—	5	5	14	14
	BB	—	12	88	—	—	—	—	—	—	—	—
A2	KF	—	—	—	44	—	56	—	—	—	—	—
	BB	—	38	62	—	—	—	—	—	—	—	—
B2t	KF	—	—	—	24	—	5	—	5	24	9	33
	BB	—	5	90	5	—	—	—	—	—	—	—
C	KF	—	—	8	18	—	8	—	—	8	—	58
	BB	—	68	32	—	—	—	—	—	—	—	—

[†] Soil Survey Staff (1951).

[§] s = sand, ls = loamy sand, sl = sandy loam, l = loam, si = silt, sil = silt loam, scl = sandy clay loam, sicl = silty clay loam, cl = clay loam, sic = silty clay, c = clay.

frequency of silty clay to clay. The A2 horizon is consistently silt loam or loam. Frequencies of B2t horizon textural classes are 24 percent loam, 10 percent silt loam or silty clay loam and 64 percent clay loam or finer. A wide range of textures are found in the C horizon, from sandy loam to clay. Clay is dominant with a 58 percent frequency. Figure 16 further illustrates the contrasting textural variability of Kootenai and batholith soils in the A1, B2t and C horizons.

Soil Classification

Differences in family textural classes between soils of the two parent materials are shown in Table 21. Kootenai soils are quite variable with 52 percent of the profiles in loamy-skeletal or clayey-skeletal classes, 8 percent in coarse-loamy or fine-loamy classes and 40 percent in fine or very-fine classes. Approximately half of the batholith soils are in the sandy textural class and half are coarse-loamy; they are usually separated by only a few percentage points on the textural triangle.

The frequency distribution of soil orders, suborders and great groups (Table 22) are nearly the same in the 25 soils on each parent material. At the subgroup level, Kootenai soils have similar frequencies of Typic Cryoboralfs, Mollic Cryoboralfs and Typic Cryochrepts; 36 percent, 32 percent and 28 percent respectively.

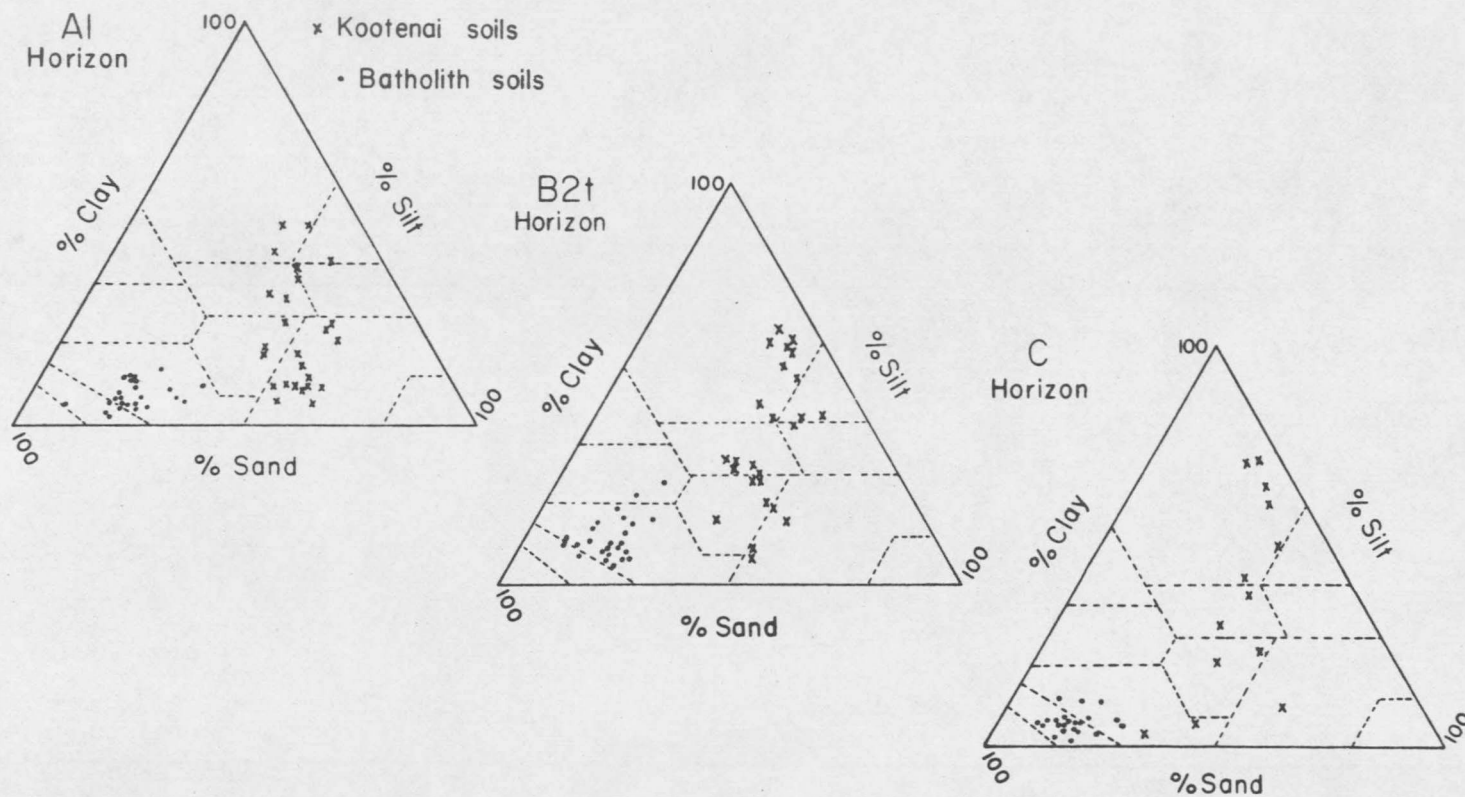


Figure 16. Textural distribution of the <2 mm fraction in the A1, B2t and C horizons in soils on the Kootenai Formation and Boulder batholith.

Table 21. Frequency distribution of family textural classes[†] of soils on the Kootenai Formation and the Boulder batholith.

Parent Material	Family Textural Classes [§]										
	frag	s-sk	l-sk	c-sk	s	co-l	fi-l	co-si	fi-si	fi	vfi
	----- % -----										
Kootenai Formation	—	—	40	12	—	4	4	—	—	28	12
Boulder batholith	—	—	—	—	52	48	—	—	—	—	—

[†] (Soil Survey Staff, 1975).

[§] frag = fragmental, s-sk = sandy - skeletal, l-sk = loamy - skeletal, c-sk = clayey - skeletal, s = sandy, co-l = coarse - loamy, fi-l = fine - loamy, co-si = coarse - silty, fi-si = fine - silty, fi = fine, vfi = very-fine.

Table 22. Frequency distribution of taxonomic classifications[†] to the soil family level of soils on the Kootenai Formation (KF) and Boulder batholith (BB).

Taxonomic Classification	Parent Material		Taxonomic Classification	Parent Material	
	KF	BB		KF	BB
	- - - % - - - -			- - - % - - - -	
<u>Family (continued)</u>					
<u>Order</u>			coarse loamy,		
			mixed	4	
Alfisol	84	72	fine, mixed	16	
Inceptisol	16	28	Mollic Cryoboralf		
			loamy-skeletal,		
<u>Suborder</u>			mixed	12	
			clayey skeletal,		
Boralf	84	72	mixed	8	
Ochrepts	16	28	sandy, mixed		24
			coarse-loamy,		
<u>Great Group</u>			mixed		36
			fine, mixed	8	
Cryoboralf	84	72	very-fine,		
Cryochrept	16	28	mixed	4	
			Lithic Mollic		
<u>Subgroup</u>			Cryoboralf		
			sandy, mixed		4
Typic Cryoboralf	48	8	fine, mixed	4	
Mollic Cryoboralf	32	60	Typic Cryochrept		
Lithic Mollic			loamy-skeletal,		
Cryoboralf	4	4	mixed	4	
Typic Cryochrept	16	24	sandy, mixed		16
Lithic Cryochrept		4	coarse-loamy,		
			mixed		8
<u>Family</u>			fine-loamy,		
			mixed	4	
Typic Cryoboralf			very-fine		
loamy-skeletal,			mixed	8	
mixed	24		Lithic Cryochrept		
clayey-skeletal			sandy, mixed		4
mixed	4				
sandy, mixed		8			

[†] Soil Survey Staff (1975)

Batholith soils, however, are predominantly Mollic Cryoboralfs (60 percent) with a smaller amount of Typic Cryochrepts (24 percent). Lithic subgroups have only a 4 percent frequency in Kootenai soils and 8 percent in batholith soils.

Kootenai and batholith soils have a great difference in predictability at the family level. Kootenai soils were classified in 13 different soil families, with the largest frequency being 24 percent loamy-skeletal, mixed Typic Cryoboralfs. If clay mineralogy had been analyzed on all sites, there would have been more soil families identified in Kootenai soils (see clay mineralogy section and Table 24). Batholith soils are much more predictable with only 7 soil families identified. Sandy and coarse-loamy, mixed Mollic Cryoboralfs accounted for 60 percent of the batholith soils with 24 percent sandy or coarse-loamy, mixed Typic Cryochrepts. Clay mineralogical analyses of selected batholith soils indicated that most of the soils will probably have mixed family mineralogies dominated by illite (see Table 24).

Water Holding Capacity

Water holding capacities of five selected soils on the Kootenai Formation and Boulder batholith are shown in Table 23. In the < 2 mm fraction, Kootenai soils consistently have higher 1/3 and 15 atmosphere water holding capacities and estimated plant available

Table 23. Percent water holding capacity (by wt) at 1/3 and 15 atmospheres tension, and available water holding capacity (AWHC) of five selected soils on the Kootenai Formation and Boulder batholith.

Soil Site	Horizon	Texture†	Total Coarse Fragment Content (by vol)	Moisture Tension				AWHC	
				----- Atmospheres -----				< 2 mm Fraction	Whole Soil
				1/3		15			
				< 2 mm Fraction	Whole Soil	< 2 mm Fraction	Whole Soil	< 2 mm Fraction	Whole Soil
----- % -----									
<u>Kootenai Formation Soils</u>									
B13	A2	sll	46	23.3	12.6	6.9	3.7	16.4	8.9
	B2t	l	41	20.0	11.8	5.0	3.0	15.0	8.8
	C	sl	45	9.1	5.0	2.7	1.5	6.4	3.5
B22	A1	sll	38	23.6	14.6	7.7	4.8	15.9	9.8
	A2	sll	36	13.7	8.8	4.1	2.6	9.6	6.2
	B2t	cl	57	18.4	7.9	9.7	4.2	8.7	3.7
B31	A1	c	1	31.9	31.6	19.4	19.2	12.5	12.4
	B21	c	3	31.6	30.6	20.0	19.4	11.6	11.2
	B22	c	2	30.2	29.6	20.0	19.6	10.2	10.0
	C1	c	2	32.8	32.1	20.7	20.3	12.1	11.8
	C2r	c	23	32.7	25.2	20.5	15.8	12.2	9.4
B41	A1	sll	9	31.0	28.2	15.7	14.3	15.3	13.9
	B21t	cl	14	25.1	21.6	14.3	12.3	10.8	9.3
	B22t	cl	37	20.3	12.8	11.1	7.0	9.2	5.8
	B23t	cl	37	17.7	11.2	11.4	7.2	6.3	4.0
	C	cl	35	20.1	13.1	10.7	7.0	9.4	6.1
B53	A1	sic	1	27.9	27.6	16.0	15.8	11.9	11.8
	B21	c	1	24.8	24.6	16.1	15.9	8.7	8.7
	B22	c	1	27.0	26.7	17.1	16.9	9.9	9.8
	B23t	c	1	30.2	29.9	16.7	16.5	13.5	13.4
	B24t	c	4	26.5	26.2	16.9	16.7	9.6	9.5
<u>Boulder batholith soils</u>									
MC4	A1	sl	2	22.1	21.7	6.1	6.0	16.0	15.7
	A2	sl	6	12.3	11.6	4.4	4.1	7.9	7.5
	B21	sl	6	12.1	11.4	4.6	4.3	7.5	7.1
	B22	sl	9	11.4	10.4	4.5	4.1	6.9	6.3
	C1	ls	13	6.7	5.8	3.4	3.0	3.3	2.8
PR4	A1	sl	4	15.9	15.3	4.1	3.9	11.8	11.4
	A21	ls	3	11.1	10.8	2.8	2.7	8.3	8.1
	A22	sl	11	10.6	8.9	2.8	2.5	7.2	6.4
	B21t	sl	5	10.7	10.2	3.4	3.2	7.3	7.0
	B22t	sl	8	13.8	12.7	5.9	5.4	7.9	7.3
NW1	A1	sl	7	16.6	15.4	5.3	5.1	11.1	10.3
	B21	sl	5	10.7	10.2	3.7	3.5	7.0	6.7
	B22	ls	5	8.5	8.1	3.1	2.9	5.4	5.3
	C	ls	8	8.1	7.4	2.8	2.6	5.3	4.8
DM5	A2	ls	1	13.1	13.0	3.2	2.3	9.9	9.8
	B21t	sl	6	10.3	9.7	3.3	3.1	7.0	6.6
	B22t	sl	8	11.0	10.1	3.7	3.4	7.3	6.7
	Cr	ls	10	5.8	5.3	2.3	2.1	3.5	3.1
PS3	A1	sl	2	14.9	14.6	5.1	5.0	9.8	9.6
	B21	sl	3	10.5	10.2	4.0	3.9	6.5	6.3
	B22	sl	9	10.6	9.6	3.8	3.5	6.8	6.1
	C1	ls	12	6.6	5.8	2.7	2.4	3.9	3.4

[†] Soil Survey Staff (1951).

water holding capacities (AWHC) than batholith soils. An exception is the C horizon of site B13 on the Kootenai Formation. This soil, developed on fine-grained sandstone, contains a very low clay content (4 percent) similar to those of the batholith soils.

High coarse fragment contents in some Kootenai soils reduced the soil water holding capacities up to nearly 50 percent. After adjusting for coarse fragments, only three of the more clayey Kootenai soils, sites B13, B41 and B53, have higher percent water contents than the batholith soils at the 1/3 and 15 atmospheres tension. Only two clayey Kootenai soils with low coarse fragment contents, sites B31 and B53, have AWHC percentages (whole soil) recognizably higher than the batholith soils, particularly in the B2 and C horizons. Even in these clayey soils, however, AWHC differences from batholith soils are relatively small, generally only 3 - 6 percent.

Water holding capacities of Kootenai soils are considerably more variable than those of the batholith soils. On a whole soil basis at 100 cm depth, the 1/3 atmosphere water holding capacity in the C (or lowest B2) horizon ranged from 5.0 to 26.2 percent compared to 5.2 - 12.7 percent in batholith soils. Similarly, at 15 atmospheres tension, ranges of water holding capacities are wider in Kootenai soils than batholith soils, 1.5 - 16.7 percent and 2.1 - 5.4 percent, respectively. Differences in AWHC and variability after adjusting for

coarse fragment content are not as large as at the 1/3 and 15 atmosphere tension, however. The AWHC of the C (or lowest B2) horizon ranges from 3.5 - 9.5 percent in Kootenai soils and 2.8 - 7.3 percent for batholith soils. Still, this difference could be reflected in productivity differences between soils of the two parent materials. A comparison of site productivity was not undertaken in this study because of the differences in elevation, precipitation and temperature of the study areas.

The higher variability of water holding capacities of Kootenai soils results from parent material and consequential soil textural variation (sandstone to clayey shale; sandy loam to clay). Batholith soils have consistent water holding capacities because of the uniform batholith rock composition. The whole soil AWHC of similar horizons in batholith soils are generally within 2 percent. Variation in AWHC between similar horizons in Kootenai soils are as high as 10 percent.

The higher organic matter percentage in the A horizons (see Table 25) also plays an important role in soil water holding capacity. The horizon with the highest AWHC (< 2 mm fraction and whole soil) in all batholith soils and all but one of the Kootenai soils is the A horizon, the horizon with the highest organic matter content.

Clay Mineralogy

The type and distribution of clay minerals in the A horizon (uppermost) and lowest horizon at 100 cm depth (C or B2 horizon) in five selected soils on both parent materials are shown in Table 24. Several interesting contrasts are illustrated. All batholith soils have high (50 - 75 percent) illite contents in the C or B2 horizons (except medium in site MC4) and very high (75 - 100 percent) illite contents in the A horizons. Only one site on the Kootenai Formation has over 50 percent illite and that is in site B13, a sandy soil formed in fine-grained sandstone. All other Kootenai soils have less than 25 percent illite, with its occurrence generally only in the C horizon.

Other investigators have attributed high illite content in soils derived from felsic igneous rocks to weathering of biotite and/or potassium feldspar in dry environments. This agrees with the pattern of illite dominance in soils on the Boulder batholith containing biotite and potassium feldspar under dry weathering environments.

"Pure montmorillonite" (not including montmorillonite interstratified with other clays) is typically only found in the C or B2 horizons of soils on both parent materials. In Kootenai soils, montmorillonite content ranges from high in the B22 and B41 sites to 0 in the B52. High montmorillonite contents have been reported in Kootenai Formation strata in exposures south of Billings (Moberly,

Table 24. Clay mineralogy of five selected soils on the Kootenai Formation and Boulder batholith.

Site	Horizon	Mineralogy [†]					Quartz	Family [‡] Mineralogy Class
		Illite	Montmorillonite	Kaolinite	Interstratified Montmorillonite, Vermiculite and Illite	Interstratified Montmorillonite and Vermiculite		
<u>Kootenai Formation Soils</u>								
B13	A2	H	—	L	—	M	Tr	Mixed
	C1	M	L	M	—	—	Tr	
B22	A2	L	—	M	—	M	Tr	Mixed
	B22t	L	H	L	—	—	L	
B31	A1	—	—	L	VH	—	L	Montmorillonitic
	C1	L	M	L	—	—	L	
B41	A1	—	—	L	VH	—	L	Mixed
	C	Tr	H	L	—	—	L	
B53	A1	—	—	L	VH	—	L	Mixed
	B24	—	—	L	VH	—	Tr	
<u>Boulder Batholith Soils</u>								
MC4	A1	VH	L	Tr	—	—	—	Mixed
	C	M	M	L	—	—	—	
PR4	A1	VH	—	Tr	—	L	—	Mixed
	B22t	H	L	Tr	—	—	L	
NWL	A1	VH	—	Tr	—	L	—	Mixed
	C	H	L	Tr	—	—	Tr	
DM5	A2	VH	—	Tr	—	L	—	Mixed
	C1	H	Tr	L	—	—	—	
PS3	A1	VH	—	Tr	—	L	Tr	Mixed
	B22t	H	L	L	—	—	L	

[†] VH = verh high (75 - 100 percent), H = high (50 - 75 percent), M = medium (25 - 50 percent), L = low (5 - 25 percent), Tr = trace (< 5 percent).

[‡] Soil Survey Staff (1975).

1969). Montmorillonite content in the C or B2 horizons of batholith soils is less variable with a range of 0 - 25 percent, except for a medium (25 - 50 percent) content in site MC4.

Nearly all of the montmorillonite clay in A horizons in soils of both parent materials is in interstratified form with vermiculite and/or illite. No interstratified clay is found in the C or B2 horizons (except in site B53). Mineralogical investigations on the soils of the Idaho batholith in western Montana and Idaho also report no interstratified clays in the C horizons (Clayton et al., 1979). Three Kootenai soils have very high percentages (74 - 100 percent) of interstratified montmorillonite-vermiculite-illite clays in the A horizons. The B24 horizon of site B53 is the only lower horizon of the soils of either parent material that contains any interstratified clay and it contains more than 75 percent. This may reflect inherited interstratified clay from a particular portion of the Kootenai Formation strata, altered clay translocated from upper horizons, or clay altered in place. Although high interstratified montmorillonite-illite clays have been reported in sections of the Kootenai Formation in central Montana (Harris, 1966), there is no conclusive evidence for support or refutation of clay inheritance in this case. The batholith soils contain no interstratified montmorillonite-vermiculite-illite clays. All A horizons of the five batholith

soils, however, have low percentages (5 - 25 percent) of interstratified montmorillonite-vermiculite clays, except site MC4. Only the A horizons of two Kootenai soils have interstratified montmorillonite-vermiculite clay, and they are in the medium percentage range.

The presence of interstratified clays in soils of both parent materials being only in A horizons (except in site B53) seems to indicate that clay alteration has taken place near the soil surface because it is not at equilibrium with the present environment. Birkeland (1974) suggests this as a major reason for contrasting clay mineralogy between the surface soil horizon and subsoil. Another possibility proposed by Jackson et al. (1948) and Johnson (1970) is the natural variation due to changing weathering intensities, moisture contents and chemistry of soil water with depth in the profile.

Kaolinite content tends to be lower in batholith soils than Kootenai soils. All A horizons of batholith soils have only a trace (0 - 5 percent) of kaolinite clay. The B or C horizons have slightly more, with 3 horizons containing up to 25 percent. In Kootenai soils, all horizons have up to 25 percent kaolinite with two lower horizons having up to 50 percent. Other investigators found a predominance of kaolinite and illite with some montmorillonite clay in Kootenai Formation strata in central Montana (Berg et al.,

1968). The higher kaolinite content of Kootenai soils may be explained by data from Grim (1968) which show an abundance of kaolinite clay in ancient lacustrine sediments where low pH prevailed. This may have been the situation for a portion of the Kootenai Formation strata in this study area as low pH predominates in the C horizons in most of the soils derived from clayey lacustrine sediments. Grim (1968) also predicts the occurrence of illite and montmorillonite clays in ancient lacustrine sediments deposited in stagnant waters and more alkaline environments. A fluctuation of pH and depositional environments of Kootenai Formation strata may be responsible for their greater variability in clay mineralogy. This is assuming that clay minerals, particularly in C horizons, are largely inherited.

The A and B2 or C horizons of Kootenai soils have a trace to a low percentage of clay-size quartz with no particular change with depth. Only four horizons of the batholith soils contain any quartz and three of those are B2 or C horizons.

Family mineralogy classes are mixed in all soils of both parent materials except one Kootenai soil which is montmorillonitic. Sites B22 and B41 would also have been classified montmorillonitic if they were in a finer particle size class. They are loamy-skeletal where site B31 is very fine.

Soil Chemistry

Chemical laboratory data on five selected soil profiles on each parent material are displayed in Table 25. Organic matter contents are similar between soils of both parent materials, particularly in the A and C (or lower B2) horizons. Higher organic matter contents are found in the upper B2 horizon of Kootenai soils than batholith soils. This may reflect the soil mixing associated with extensive gopher activity of many of the Kootenai sites, particularly in soils derived from clayey strata on transects B3, B4 and B5. Organic matter percentages are more consistent, with a more uniform decrease with depth, in the batholith soils than Kootenai soils.

Extractable cation concentrations should closely reflect exchangeable cation levels in the soils of both parent materials because of the low electrical conductivities. This reasoning is supported in Agric. Handbook 60, page 18 (Salinity Laboratory Staff, 1954) where soluble cation concentrations are found to be closely associated with total salt content which is measured as electrical conductivity. Since these soils have very low electrical conductivities (generally $< .02$ mmhos/cm), it is assumed that soluble cation concentrations are also low. Therefore, the difference between extractable and exchangeable cation concentrations due to soluble cations is considered to be minor.

Extractable K and Na levels are low in soils of both parent

Table 25. Chemical data on five selected soil profiles on the Kootenai Formation and the Boulder batholith.

Soil Site	Horizon	Texture †	Chemical Data								pH	Electrical Conductivity mmhos/cm
			Organic Matter %	Extractable Cations				Cation Exchange Capacity %	Base Saturation %			
				K	Na	Ca	Mg					
										-meq/100g-		
Kootenai Formation Soils												
B13	A2	sfl	3.6	0.6	< 0.1	4.2	0.9	8.3	69	4.9	0.2	
	B2t	l	2.6	0.4	< 0.1	3.4	0.8	6.5	72	5.5	0.2	
	C	sl	0.5	0.1	< 0.1	2.0	0.5	5.2	51	5.7	0.1	
B22	A1	sfl	3.3	0.4	< 0.1	2.6	0.7	7.8	48	5.4	0.2	
	A2	sfl	0.6	0.1	< 0.1	2.2	0.8	4.4	72	5.7	0.1	
	B2t	cl	0.5	0.4	0.1	12.6	3.6	17.8	94	5.7	0.2	
B31	A1	e	6.2	1.3	< 0.1	19.4	2.7	28.3	78	5.7	0.3	
	B21	e	5.3	0.9	< 0.1	18.0	2.6	26.1	83	5.5	0.2	
	B22	e	3.1	0.4	0.1	19.6	1.9	24.8	89	5.4	0.1	
	C1	e	1.3	0.4	< 0.1	22.0	1.9	36.5	68	5.1	0.1	
	C2r	e	0.6	0.4	0.1	34.0	1.9	38.7	94	6.3	0.4	
B41	A1	sfl	6.2	0.5	< 0.1	20.0	0.9	29.6	72	6.0	0.3	
	B21t	cl	5.6	0.3	< 0.1	19.4	0.9	29.1	71	6.0	0.2	
	B22t	cl	1.0	0.2	< 0.1	16.4	0.9	20.0	88	5.9	0.1	
	B23t	cl	0.7	0.2	< 0.1	18.2	1.0	20.9	93	5.9	0.1	
	C	cl	0.6	0.2	< 0.1	16.8	1.1	19.6	93	6.4	0.2	
B53	A1	sic	3.7	1.2	< 0.1	11.6	3.1	20.9	76	5.3	0.2	
	B21	e	3.4	0.6	< 0.1	11.4	2.6	19.6	75	4.9	0.2	
	B22	e	3.1	0.4	0.1	7.8	1.8	19.6	96	4.9	0.2	
	B23t	e	2.0	0.4	0.1	8.2	1.6	17.4	60	4.7	0.2	
	B24t	e	0.5	0.4	< 0.1	18.2	2.2	22.2	94	4.8	0.1	
Boulder batholith Soils												
MC4	A1	sl	4.1	0.8	< 0.1	7.6	1.1	12.2	78	6.1	0.6	
	A2	sl	1.5	0.4	< 0.1	4.4	0.7	9.1	61	6.2	0.2	
	B21	sl	1.3	0.4	< 0.1	4.0	0.7	6.5	79	5.5	0.1	
	B22	sl	0.9	0.4	< 0.1	6.4	0.8	8.3	92	6.3	0.2	
	C1	ls	0.4	0.1	< 0.1	4.6	0.8	7.4	75	6.1	0.1	
PR4	A1	sl	4.0	0.4	< 0.1	4.4	0.7	7.8	71	5.8	0.5	
	A21	ls	1.0	0.2	< 0.1	2.2	0.5	5.7	52	6.0	0.1	
	A22	sl	0.8	0.2	0.1	2.2	0.6	5.7	54	5.8	0.1	
	B21t	sl	0.6	0.2	0.1	3.0	0.9	6.1	68	5.9	0.1	
	B22t	sl	0.5	0.4	< 0.1	5.0	1.7	10.9	66	5.5	0.2	
NW1	A1	sl	3.7	0.6	< 0.1	6.8	1.1	10.9	78	6.0	0.2	
	B21	sl	1.6	0.3	< 0.1	5.4	1.0	8.3	82	6.2	0.1	
	B22	ls	1.0	0.3	< 0.1	4.4	1.0	7.0	82	6.5	0.1	
	C	ls	0.6	0.3	< 0.1	3.4	0.9	7.0	67	6.8	0.1	
DM5	A2	ls	3.1	0.3	< 0.1	4.2	0.5	8.3	61	6.2	0.1	
	B21t	sl	1.2	0.3	< 0.1	3.6	0.7	8.3	56	6.3	0.2	
	B22t	sl	1.2	0.3	< 0.1	4.4	0.8	8.3	67	6.2	0.1	
	Cr	sl	0.5	0.2	< 0.1	2.0	0.4	4.4	61	6.2	0.1	
PS3	A1	sl	3.7	0.3	< 0.1	5.6	0.8	8.7	78	5.8	0.2	
	B21	sl	0.9	0.3	< 0.1	4.2	0.8	8.3	64	5.8	0.1	
	B22	sl	0.6	0.2	< 0.1	5.0	1.0	8.3	75	5.7	0.1	
	C1	ls	0.4	0.2	< 0.1	4.8	0.9	7.2	83	5.5	0.1	

† Soil Survey Staff (1951)

materials. The concentrations of K appear to be slightly higher in the A horizons of most of the profiles, probably because of plant nutrient cycling. Extractable Na levels do not appear to change with depth. Concentrations of extractable Mg are low in soils of both parent materials with slightly higher levels in Kootenai soils, ranging 0.5 - 3.1 meq/100 g as compared to 0.5 - 1.1 meq/100 g in batholith soils. Extractable Ca is the cation that shows the greatest difference between soils of the two parent materials. Three of the five Kootenai soils (B31, B41 and B53) have much higher extractable Ca than any of the batholith soils. Profile B13 and the A horizons of site B22, however, have a low concentration similar to those of the batholith soils. Profile B13 is derived from fine-grained noncalcareous sandstone. The range of extractable Ca in Kootenai soils is 2.0 - 34.0 meq/100 g in contrast to the more predictable 2.2 - 7.6 range of batholith soils.

The cation exchange capacity (CEC) shows the most dramatic chemical distinction between soils of the two parent materials. Kootenai soils have quite variable CECs ranging from 4.4 to 38.7 meq/100 g in comparison to a range of 4.4 to 12.2 in batholith soils. The clayey Kootenai soils of sites B31, B41 and B53 have the highest CECs. The C2r horizon of the shale derived soil of site B31 has the highest CEC, 38.7 meq/100 g. The CEC trends also appear to reflect the extractable Ca concentrations in soils of both parent materials

in most cases.

The influence of organic matter content on CEC is illustrated by the higher CEC levels being in the A horizons, the horizon of highest organic matter content. This is particularly pronounced in the sandy batholith soils where the highest CEC is consistently found in the A horizon, except in site PR4 where the B22t horizon containing 12 percent clay had a slightly higher CEC.

Percent base saturation (BS) was determined with extractable bases which approximate exchangeable bases in these soils, as stated earlier. Kootenai soils have slightly higher BS percentages than batholith soils. All of the higher BS percentages are found in lower B2 or C horizons. This would be expected to some degree, since upper horizons should have undergone more leaching, thus losing a greater percentage of the cations. A decrease in BS percentage from the surface A horizon to the next lower horizons in all but one of the batholith soils suggests that plant nutrient cycling tends to offset the downward movements of cations by leaching.

Soil pH generally appears to be slightly higher in the batholith soils than Kootenai soils and is also more consistent throughout the profile. This was brought out earlier in comparisons of field pH by horizons of all 25 of the soils sampled on each parent material (Table 12).

Electrical conductivity is very low in all horizons of soils on

both parent materials. This is indicative of intrusive igneous rock composition and further suggests that much of the Kootenai Formation strata were deposited in nonalkaline, low pH, freshwater environments.

Chapter 7

SUMMARY AND CONCLUSIONS

The influences of parent material on soil development were evaluated by comparing properties of soils derived from the granitic Boulder batholith and sedimentary Kootenai Formation in the mountains of southwestern Montana. A total of 25 soils selected with a point intercept transect system were described and sampled on each parent material.

Frequency distribution analyses were made for qualitative soil properties. These included: rockiness and stoniness classes; depth to bedrock; presence of selected soil horizons; moist and dry color; structure type, size and grade; consistence; textural class; family textural class; and taxonomic classification to the soil family level. Quantitative soil properties were compared in the A₁, A₂, B_{2t} and C horizons through differences in means, standard deviations, ranges, 90 percent confidence intervals for the means, and the number of samples (N) required to estimate the means. The number of samples (N) is estimated at the .10 level of significance. These properties include: solum thickness; horizon thickness; depth to horizons; pH; coarse fragment contents; coarse, medium and fine sand contents; and sand, silt and clay contents.

Only 16 percent of the Kootenai soil sites contained greater than 2 percent bedrock exposures (rockiness class of 1 or more) compared to 88 percent in the batholith soil sites. Stoniness classes are similar for soils of both parent materials except for a slightly higher frequency of Kootenai soils in classes 4 and 5. Kootenai soils are slightly deeper to bedrock than batholith soils, but only by an 8 - 12 percent frequency difference. Solum thickness is also greater in Kootenai soils than batholith soils with means of 70.5 and 50.6 cm, respectively, and similar standard deviations.

The largest difference in horizon frequency between soils of the two parent materials is almost twice the frequency of C horizons in the upper 100 cm of batholith soils as in Kootenai soils, 88 and 48 percent, respectively. Batholith soils also have slightly higher frequencies of A2, Cr and R horizons. Soils of both parent materials have high frequencies of A1 and B2t horizons, 84 and 84 percent for Kootenai soils and 64 and 76 percent for batholith soils, respectively.

The A1 and B2t horizons are the only horizons with differences in mean thickness between soils of the two parent materials that are significant at the .05 level, both being thicker in Kootenai soils. Batholith soils have thinner O and A2 horizons and thicker C horizons though the differences between means are not significant at the .10 level. Mean depth to the top of the B2 and C horizons are greater in Kootenai soils than batholith soils but differences are not significant

at the .05 level. Standard deviations are similar for mean thickness and depth to horizons in soils of both parent materials in respective horizons.

The only major difference in dry and moist color between soils of the two parent materials is in hue. Nearly 100 percent of the batholith soils have a hue of 10 YR in all horizons, whereas Kootenai soils have redder hues of 5 YR and 7.5 YR, as well as 10 YR. Kootenai soils had a slightly higher frequency of lighter values, particularly in the A2 horizons. No particular difference was found in chroma.

Structure type, size and grade are less variable in A1 and B2t horizons of batholith soils than Kootenai soils. No platy structure is found in the A2 horizons of Kootenai soils whereas it has a 69 percent frequency in batholith soils. Batholith soils also consistently have larger structure size classes and weaker grades than Kootenai soils because of their lower clay and higher sand contents.

Wet soil consistence shows the most dramatic difference in predictability of soil consistence between soils of the two parent materials. Batholith soils are dominantly nonsticky and nonplastic with some slightly sticky and slightly plastic consistence when wet, whereas Kootenai soils generally range from nonsticky and nonplastic to very sticky and very plastic. Little difference in both moist and dry consistence is found between soils of the two parent materials except in the C horizon, where batholith soils are predictably loose and

Kootenai soils range from slightly hard to very hard and very friable to very firm, respectively. This again reflects the variability of clay content of soils derived from Kootenai Formation lithologies.

Mean pH of Kootenai soils is about .6 units lower than batholith soils in all four horizons. Standard deviations are similar in soils of both parent materials except in the C horizon where they are higher in Kootenai soils. All differences in mean pH are significant at the .01 level except in the C horizon.

Means and standard deviations of coarse fragment contents in Kootenai soils are much higher than in batholith soils in the >20 mm and total > 2 mm fractions. This reflects the greater weathering resistance of some of the bedded sandstones and limestones in the Kootenai Formation and the higher variability in lithology. The mean difference between soils of the two parent materials in these two coarse fragment fractions are significant at the .01 level. Little difference is found in the 20 - 2 mm fraction between soils of the two parent materials.

Coarse and medium sand contents are much higher in batholith soils with mean ranges in the profiles of 18 - 28 and 16 - 18 percent as compared to 1 - 3 and 2 - 5 percent, respectively. This reflects the predominance of these grain sizes in batholith rocks. Fine sand is the main sand-size fraction in Kootenai Formation strata, explaining

the higher fine sand content in Kootenai soils with mean ranges of 18 - 28 percent in the profiles, similar to the 23 - 26 percent mean range in batholith soil profiles. Standard deviations are low in soils of both parent materials, generally only differing by about 2 - 5 percentage points.

Variability of soil texture provides one of the most dramatic contrasts between soils of the two parent materials. Sand, silt and clay contents have much wider ranges in Kootenai soils, spanning differences up to 60 percent in sand content in the A1 horizon and 70 percent in clay content in the C horizon. Kootenai soils have much higher silt and clay contents and lower sand contents than batholith soils and also higher standard deviations, except in the A2 horizon. Batholith soils increase in mean sand content and decrease in mean clay content from the B2t and C horizons. Kootenai soils have an opposite trend with decreasing mean sand and increasing mean clay contents, except in sandstone derived soils. Mean silt content decreases with depth in soils of both parent materials.

A useful measure of the variability of soil properties with quantitative data is the number of samples (N) required to estimate the property means. Table 26 shows the ranking of variability of properties according to their N required to estimate the means within 5 units (.5 for pH) about the means. Only the thickness of the A2,

Table 26. Comparison of the relative ranking of variability of soil properties with quantitative data from soils on the Kootenai Formation and Boulder batholith.

Variability of the Property	Number of Profiles Needed [†]	Soil Properties [‡]	
		Kootenai Formation	Boulder batholith
Least	< 10	thickness of A1	thickness of A1
		pH of A1, A2 and B2t	pH of all horizons
		% CF 20 - 2 mm in all horizons	% CF > 20 mm in all horizons
		% coarse sand in all horizons	% CF 20 - 2 mm in all horizons
		% medium sand in all horizons	Total % CF in all horizons
		% fine sand in A1 and A2	% coarse sand in all horizons
		% sand in A1 and A2	% medium sand in all horizons
		% silt in A1, A2 and B2t	% fine sand in all horizons
		% clay in A2	% sand in all horizons
		—	% silt in all horizons
		—	% clay in all horizons
		—	
		—	
Moderate	10-30	thickness of A2	thickness of A2
		depth to B2t	depth to B2t
		pH of C	—
		% CF > 20 mm in A1 and A2	—
		Total % CF in A2	—
		% fine sand in B2t	—
		% sand in B2t	—
		% silt in C	—
Most	> 30	% clay in A1	—
		thickness of B2t and C	thickness of B2t and C
		depth to C	depth to C
		% CF > 20 mm in B2t and C	—
		total % CF in B2t and C	—
		% fine sand in C	—
		% sand in C	—
		% clay in C	—

[†] Number of profiles needed to estimate the property mean within ± 5 units about the mean at the .10 significance level.

[‡] CF = coarse fragments.

B2t and C horizons and depth to the B2t and C horizons in batholith soils require more than ten samples to estimate the means. All other properties require less than 10 samples and in most cases less than 5 samples to estimate the means. In contrast, nearly half of the properties in Kootenai soils require more than 10 samples to estimate means, with 10 properties requiring more than 30 samples. The C horizon of Kootenai soils tends to be the most variable horizon.

Textural classes of batholith soils are nearly all loamy sand or sandy loam. Kootenai soils have 7 textural classes ranging from sandy loam to clay. Family textural classes of batholith soils are about half sandy and half coarse-loamy. Kootenai soils are more variable with loamy and clayey-skeletal, coarse-loamy, fine-loamy, fine and very-fine family textural classes.

Kootenai soils were classified into four subgroups with Typic (36 percent) and Mollic (32 percent) Cryoboralfs, and Typic Cryochrepts (28 percent) being the dominant three. Batholith soils were classified into five subgroups, but were mainly Mollic Cryoboralfs (60 percent) and Typic Cryochrepts (28 percent). Due to the wider range of family textural classes in Kootenai soils, there were 13 different soil families identified, compared to seven in the batholith soils.

Five soils on each of the parent materials were analyzed for water holding capacity, clay mineralogy and selected chemical

properties. Soil moisture capacities (at 1/3 and 15 atmospheres tension) of Kootenai soils are all higher than batholith soils except for sandy soils derived from Kootenai Formation sandstones. Also, moisture capacities of Kootenai soils have a much wider range of variability than batholith soils because of the greater variability of soil texture. Little difference is noted between available water holding capacities in respective horizons between soils of the two parent materials. An exception is clayey Kootenai soils which have available water holding capacities that are 2 - 4 percentage points higher than batholith soils in the B2t and C horizons. This could be reflected in a productivity difference between soils of the two parent materials under similar climatic conditions. The influence of organic matter is reflected in the higher available water holding capacity generally being in the A horizons in both Kootenai and batholith soils.

Clay mineralogy in both the upper A and C (or lower B2) horizons in the upper 100 cm of batholith soils is dominantly illite (50 - 100 percent) with kaolinite (0 - 25 percent). They also have 5 - 25 percent montmorillonite in the lower horizons and 5 - 25 percent interstratified montmorillonite-vermiculite in the A horizons. All batholith soils are classified in the mixed family mineralogy. Kootenai soils are more variable, with only four soils containing illite

ranging from < 5 to 75 percent and montmorillonite ranging from 5 to 75 percent (only in the lowest horizon). Sandy Kootenai soils contained the highest illite content. Both horizons contain 25 - 50 percent kaolinite. The A horizons contain either 25 - 50 percent interstratified montmorillonite-vermiculite or 75 - 100 percent interstratified montmorillonite-vermiculite-illite clays. One montmorillonitic family mineralogy class was identified, with the other four Kootenai soils having mixed mineralogy. The higher variability of clay mineralogy in Kootenai soils suggests clay inheritance from formation strata with contrasting mineralogy. The presence of interstratified clay only in the A horizons in soils of both parent materials indicates clay alteration due to changing environments from that present when the clay was formed, whether inherited or formed in situ.

Each horizon of the five selected soils on both parent materials were analyzed for organic matter content, extractable K, Na, Ca and Mg, cation exchange capacity, percent base saturation, pH and electrical conductivity. Organic matter contents are similar in soils of both parent materials with a range of 3.1 to 6.2 percent in the A horizons. No pronounced differences are found in extractable K, Na and Mg contents, and electrical conductivity, all being low in soils of both parent materials. Similar high percent base saturation

levels are also found. Clayey Kootenai soils have higher extractable Ca and cation exchange capacities, and slightly lower pH levels than batholith soils. Sandy Kootenai soils have chemical characteristics similar to batholith soils, though pH values are slightly lower.

The results of this study on predicting selected soil properties and property variability should have direct application to inventory, use and management of soils developed on the exposures of these parent materials in Montana and neighboring states. One example would be its application to soil survey.

Because of the larger number of soil families on the Kootenai Formation, there would be more soil mapping units, and mapping unit delineations would tend to be smaller than on the Boulder batholith. Thus, with soil mapping on the same level of intensity, a greater number of samples would be required on the Kootenai Formation to achieve the same degree of accuracy. Because of the uniformity of batholith rocks, much of the soil variability is probably due to changes in landscape variables such as slope and aspect, vegetation, etc. Soil mappers should be able to use their knowledge of the influences of these factors for predicting soil variability from visual observation of the landscape-vegetation setting, with the help of aerial photos. In Kootenai soil, however, much of the soil variability (at the family level at least) reflects lithologic changes

in the Formation. These changes may or may not be reflected in landscape variations that are visually identifiable. An understanding of vegetation-soil-geology relationships may play an important role in improving the speed and accuracy of soil mapping on the Kootenai Formation. Further study is needed in this area.

This study illustrates the potential value of the knowledge of geologic parent materials for predicting soil characteristics. It advances the understanding of Montana soils in general through increased awareness of soil-geology relationships.

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APPENDICES

APPENDIX I.

EXPLANATION OF DESCRIPTIVE TERMINOLOGY IN APPENDIX II AND III

Site Location (top center): Preceding letters (or letter and number) identify the transect and the following number refers to the point observation on the transect.

Landscape Position: The first two words refer to slope curvature; the first is in the vertical plane, the second is in the horizontal, ie. convex, convex. The second part (if applicable) indicates the geomorphic structure, ie. dip slope. The last portion describes the general landform that the site is located on, ie. rolling upland or smooth valley sideslope.

Vegetation: Species listed are the main species present within a 25 m radius of the point observation.

APPENDIX II

SOIL PROFILE DESCRIPTIONS

FOR PEDONS FORMING ON THE KOOTENAI FORMATION

120

B11

CLASSIFICATION: loamy-skeletal, mixed Mollic Cryoboralf
DATE DESCRIBED: 6/26/79
LOCATION: NW $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, NE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 29, T.7S., R.4E.
ELEVATION: 2110 m
LANDSCAPE POSITION: convex, convex; dip slope; rolling upland
SLOPE AND ASPECT: 52%, N. 130^UE.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 1
VEGETATION:

Tree species- (scattered) Pseudosuga menziesii

Understory and meadow species- Festuca idahoensis, Agropyron smithii, Artemisia tridentata, Lupinus spp., Balsamorhiza sagittata

PEDON DESCRIPTION

- A1 0-15 cm; dark reddish gray (5 YR 4/2) loam, brown (7.5 YR 4/2) moist; moderate, fine, granular structure; slightly hard, very friable, slightly sticky and slightly plastic, 35% rock fragments, 30% gravel, 70% cobbles; neutral (pH 6.8).
- B2t 15-40 cm; reddish brown (5 YR 4/3) loam, dark reddish brown (5 YR 3/3) moist; moderate, fine, subangular blocky structure; slightly hard, very friable, sticky and plastic; 40% rock formations, 30% gravel, 70% cobbles, neutral (pH 7.2).
- C1 40-60 cm; reddish yellow (5 YR 6/6) clay loam, reddish brown (5 YR 5/3) moist; massive, slightly hard, friable, sticky and plastic; 45% rock fragments, 30% gravel, 70% cobbles; slightly effervescent; mildly alkaline (pH 8.0).
- G2 60-100+ cm; reddish yellow (5 YR 7/6) loam, light reddish brown (5 YR 6/4) moist; massive; slightly hard, firm, slightly sticky and slightly plastic; 50% rock fragments, 30% gravel, 70% cobbles and stones; slightly effervescent; mildly alkaline (pH 8.2).

CLASSIFICATION: clayey-skeletal, mixed Mollic Cryoboralf.
DATE DESCRIBED: 6/26/79
LOCATION: NE $\frac{1}{4}$, NW $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 29, T 7 S., R. 4 E.
ELEVATION: 2145 m
LANDSCAPE POSITION: slightly convex, convex; dip slope; upland
SLOPE AND ASPECT: 7%, N 30° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 1
VEGETATION:

Tree species- Abies lasiocarpa, Pinus contorta, Picea engelmannii

Understory and meadow species- Thalictrum occidentale, Berberis repens, Calamagrostis rubescens, Physocarpus malvaceus.

PEDON DESCRIPTION

- A1 0-6 cm; pinkish gray (5 YR 7/2) silt loam, dark reddish brown (5 YR 3/2) moist; moderate, medium, platy structure; slightly hard, very friable, slightly sticky and slightly plastic; medium acid (pH 6.0).
- B21t 6-16 cm; pink (5 YR 7/3) silty clay loam, dark reddish brown (5 YR 3/3) moist; strong, medium, prismatic structure, hard, friable, sticky and plastic; very strongly acid (pH 6.5).
- B22t 16-53 cm; pink (5 YR 7/4) silty clay, reddish brown (5 YR 4/4) moist; strong, coarse, subangular blocky structure; very hard, firm, sticky and plastic; slightly acid (pH 6.5).
- B23t 53-68 cm; pinkish gray (5 YR 6/2) clay, reddish brown (5 YR 4/4) moist; strong, medium subangular blocky structure; very hard, firm, sticky and plastic; thick continuous clay flows; 10% rock fragments, 100% gravel; neutral (pH 7.3).
- IIC 68-100+ cm; light reddish brown (5 YR 6/4) clay, light reddish brown (5 YR 6/3) moist; massive; hard, friable, sticky and plastic; 40% rock fragments, 70% gravel, 30% cobbles and stones; slightly effervescent; mildly alkaline (pH 7.7).

NOTE: rock fragments are gray, fine grained-sandstone.

122

B13

CLASSIFICATION: loamy-skeletal, mixed Typic Cryoboralf
DATE DESCRIBED: 6/26/79
LOCATION: SW $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 29, T. 7S, R.4E.
ELEVATION: 2120 m
LANDSCAPE POSITION: straight, straight; dip slope; upland
SLOPE AND ASPECT: 9%, N. 66° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 2
STONINESS CLASS: 5
VEGETATION:
Tree species- Pseudotsuga menziesii, Pinus contorta

Understory and meadow species- Vaccinium scoparium

PEDON DESCRIPTION

- 01 6-0 cm; liter
- A2 0-10 cm; light gray (10 YR 7/2) silt loam, brown (10 YR 4/3) moist; weak, fine, crumb structure; soft, very friable, nonsticky and nonplastic; 45% rock fragments, 40% gravel, 60% cobbles and stones; strongly acid (pH 5.5).
- B2t 10-19 cm; pinkish white (7.5 YR 8/2) loam, pinkish brown (10 YR 6/3) moist; weak, medium, crumb structure; slightly hard, very friable, nonsticky and nonplastic; 40% rock fragments, 40% gravel, 60% cobbles and stones; medium acid (pH 6.0).
- C 19-100+ cm; pinkish white (7.5 YR 8/2) sandy loam, pinkish brown (10 YR 6/3) moist; massive; slightly hard, very friable, non-sticky and nonplastic; 45% rock fragments, 40% gravel, 60% cobbles and stones; medium acid (pH 6.0).

B14

CLASSIFICATION: clayey-skeletal, mixed Typic Cryoboralf
DATE DESCRIBED: 6/27/79
LOCATION: SW $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 29, T. 7S., R.4E.
ELEVATION: 2185 m
LANDSCAPE POSITION: slightly convex, straight; dip slope; upland
SLOPE AND ASPECT: 11%, N. 6° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 1
VEGETATION:
Tree species- Abies lasiocarpa, Pinus contorta

Understory and meadow species- Vaccinium scoparium, Calamagrostis rubescens, Spiraea betulifolia

PEDON DESCRIPTION

- 01 5-0 cm; liter
- A21 0-12 cm; light gray (5 YR 7/1) silt loam, brown (7.5 YR 4/2) moist; weak, fine, granular structure; soft, friable, nonsticky and nonplastic; 10% rock fragments; 20% gravel, 80% cobbles; strongly acid (pH 5.5).
- A22 12-30 cm; pinkish white (7.5 YR 8/1) silt loam, light brown (7.5 YR 6/5) moist; weak, medium, subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; 25% rock fragments, 30% gravel, 70% cobbles; medium acid (pH 6.0).
- B2t 30-100+ cm; reddish yellow (7.5 YR 6/5) silty clay, strong brown (7.5 YR 5/6) moist; strong, medium, subangular blocky structure; hard, firm, sticky and plastic; thick continuous clay flows; 50% rock fragments, 80% gravel, 20% cobbles; slightly acid (pH 6.2).

NOTE: rock fragments are tan and yellow fine-grained sandstone

CLASSIFICATION: coarse-loamy, mixed Typic Cryoboralf
DATE DESCRIBED: 6/27/79
LOCATION: NE $\frac{1}{4}$, SE $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 30, T. 7S., R. 4E.
ELEVATION: 2170' m
LANDSCAPE POSITION: slightly convex, convex; dip slope; upland
SLOPE AND ASPECT: 11%, N. 16° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 2
VEGETATION:

Tree species- Abies lasiocarpa, Pinus albicaulis, Pinus contorta

Understory and meadow species- Vaccinium scoparium, Calamagrostis reubescens, Calamagrostis canadensis, Arnica cordifolia, Spiraea betulifolia

PEDON DESCRIPTION

- O1 4-0 cm; liter
 A1 0-7 cm; pinkish gray (7.5 YR 6/2) silt loam, brown (10 YR 4/3) moist; moderate, fine, subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; 15% rock fragments, 30% gravel, 70% cobbles; strongly acid (pH 5.5).
 A2 7-30 cm; light gray (10 YR 7/2) silt loam, brown (10 YR 5/3) moist; weak, medium, subangular blocky structure; hard, very friable, slightly sticky and slightly plastic; 55% rock fragments, 15% gravel and cobbles, 85% stones; medium acid (pH 5.7).
 B2t 30-58 cm; pale brown (10 YR 6/3) loam, yellow brown (10 YR 5/6) moist; moderate, medium, subangular blocky structure; very hard, firm, sticky and plastic; 35% rock fragments, 70% gravel, 30% cobbles; strongly acid (pH 5.5).
 R 58+ cm; tan to yellow, hematite-stained, fine-grained sandstone

CLASSIFICATION: loamy-skeletal, mixed Typic Cryoboralf
DATE DESCRIBED: 6/27/79
LOCATION: SW $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 19, T. 7S, R. 4E.
ELEVATION: 2170 m
LANDSCAPE POSITION: slightly convex, straight; dip slope; upland
SLOPE AND ASPECT: 9%, N. 8° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 4
VEGETATION:

Tree species- Abies lasiocarpa, Picea engelmannii, Pinus albicaulis, Pinus contorta

Understory and meadow species- Spiraea betulifolia, Calamagrostis reubescens, Vaccinium scoparium, Arnica cordifolia

PEDON DESCRIPTION

- 01 4-0 cm; liter
- A2 0-10 cm; light gray (10 YR 7/2) silt loam, brown (10 YR 5/3) moist; weak, fine, granular structure; soft, friable, slightly sticky and slightly plastic; 45% rock fragments, 20% gravel, 80% cobbles and stones; strongly acid (pH 5.2).
- B2t 10-30 cm; white (10 YR 8/1) silt loam, brown (10 YR 5/3) moist; weak, fine, subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; 50% rock fragments, 20% gravel, 80% cobbles and stones; strongly acid (pH 5.5).
- C 30-57 cm; white (10 YR 8/2) silt loam, very pale brown (10 YR 7/3) moist; massive; hard, friable, slightly sticky and slightly plastic; 60% rock fragments, 70% gravel, 30% cobbles; medium acid (pH 5.7).
- R 57+ cm; gray, hematite-stained, fine-grained sandstone.

CLASSIFICATION: loamy-skeletal, mixed Typic Cryoboralf
DATE DESCRIBED: 6/28/79
LOCATION: NW $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 31, T. 7S., R. 4E.
ELEVATION: 2340 m
LANDSCAPE POSITION: slightly convex, straight; dip slope; upland
SLOPE AND ASPECT: 18T, N. 80° E
DRAINAGE: well-drained
ROCKINESS CLASS: 1
STONINESS CLASS: 4
VEGETATION:

Tree species- Picea engelmannii, Abies lasiocarpa, Pinus contorta

Understory and meadow species- Vaccinium scoparium, Spiraea betulifolia, Berberis repens, Arnica cordifolia, Sherperdia canadensis

PEDON DESCRIPTION

- 01 5-0 cm; liter
- A1 0-7 cm; pinkish gray (7.5 YR 7/2) silt loam, dark brown (10 YR 3/3) moist; moderate, medium, granular structure; slightly hard, friable, slightly sticky and slightly plastic; 30% rock fragments, 40% gravel, 60% cobbles; strongly acid (pH 5.3).
- A2 7-30 cm; white (10 YR 8/2) loam, brown (10YR 5/4) moist; moderate, medium, granular structure; soft, friable, sticky and plastic; 40% rock fragments, 60% gravel, 40% cobbles; strongly acid (pH 5.5).
- B2t 20-100+ cm; reddish yellow (7.5 YR 6/6) clay loam, yellowish brown (10 YR 5/6) moist; moderate, medium, subangular blocky structure; hard firm, very sticky and very plastic; thin continuous clay flows; 50% rock fragments, 40% gravel, 60% cobbles; medium acid (pH 6.0).

NOTE: rock fragments are gray, hematite-stained, fine-grained sandstone

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B22

CLASSIFICATION: loamy-skeletal, mixed Typic Cryoboralf
DATE DESCRIBED: 6/28/79
LOCATION: NE $\frac{1}{4}$, NW $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 31, T. 7S., R. 4E
ELEVATION: 2377 m
LANDSCAPE POSITION: straight, slightly convex; dip slope; upland
SLOPE AND ASPECT: 14%, N. 42° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 4
VEGETATION:

Tree species- Pinus contorta, Abies lasiocarpa

Understory and meadow species- Vaccinium scoparium, Spiraea
betulifolia, Arnica cordifolia, Shepherdia canadensis

PEDON DESCRIPTION

- 01 5-0 cm; liter
- A1 0-9 cm; pinkish gray (7.5 YR 7/2) silt loam, brown (7.5 YR 4/4) moist; moderate, medium, granular structure; slightly hard, friable, sticky and slightly plastic; 35% rock fragments, 50% gravel, 50% cobbles; strongly acid (pH 5.2).
- A2 9-23 cm; very pale brown (10 YR 7/2) silt loam, brownish yellow (10 YR 6/6) moist; massive; slightly hard, very friable, sticky and slightly plastic; 35% rock fragments, 50% gravel, 50% cobbles; strongly acid (pH 5.5).
- B2t 23-100+ cm; strong brown (7.5 YR 5/6) clay loam, strong brown (7.5 YR 5/6) moist; strong, medium, angular blocky; very hard, very firm, very sticky and very plastic; thick continuous clay flows; slightly acid (pH 6.4).

NOTE: rock fragments are gray, hematite-stained, fine-grained sandstone

CLASSIFICATION: loamy-skeletal, mixed Typic Cryoboralf
DATE DESCRIBED: 6/28/79
LOCATION: NE $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 30 T. 7S R. 4E
ELEVATION: 2377 m
LANDSCAPE POSITION: straight, slightly convex; dip slope; upland
SLOPE AND ASPECT: 14%, N. 5° A.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 0
VEGETATION:

Tree species- Pinus contorta, Abies lasiocarpa, Picea engelmannii

Understory and meadow species- Viccinium scoparium, Spiraea betuli-
folia, Arnica cordifolia, Sheperdia canadensis, Juniperus communis

PEDON DESCRIPTION

- 01 5-0 cm; liter
- A21 0-23 cm; very pale brown (10 YR 7/3) silt loam, pale brown (10 YR 6/3) moist; weak, fine, crumb structure; soft, very friable, slightly sticky and slightly plastic; 40% rock fragments, 60% gravel, 40% cobbles; strongly acid (pH 5.2).
- A22 23-45 cm; very pale brown (10 YR 8/4) sandy loam, yellow (10 YR 7/6) moist; weak, medium, crumb structure; soft, very friable, slightly sticky and slightly plastic; 35% rock fragments, 50% gravel, 50% cobbles; medium acid (pH 5.8).
- B2t 40-100+ cm; very pale brown (10 YR 7/4) loam, brownish yellow (10 YR 6/6) moist; moderate, fine, subangular blocky structure, very hard, friable, sticky and plastic; thin continuous clay flows; 45% rock fragments; 40% gravel, 60% cobbles; slightly acid (pH 6.2).

NOTE: rock fragments are yellow, hematite-stained, fine-grained sandstone

CLASSIFICATION: loamy-skeletal, mixed Typic Cryochrept
DATE DESCRIBED: 6/28/79
LOCATION: SE $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 30, T. 7S., R 4E.
ELEVATION: 2340 m
LANDSCAPE POSITION: straight, slightly convex; dip slope, upland
SLOPE AND ASPECT: 14%, N. 58° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 5
VEGETATION:

Tree species- Pinus contorta, Abies lasiocarpa

Understory and meadow species- Vaccinium scoparium, Spiraea betulifolia, Arnica cordifolia, Shepherdia canadensis, Juniperus communis

PEDON DESCRIPTION

- 01 5-0 cm; liter
- A1 0-17 cm; light gray (10 YR 7/2) silt loam, dark brown (10 YR 3/3) moist; weak, fine, granular structure; soft, friable, slightly sticky and slightly plastic; 50% rock fragment, 20% gravel, 80% stones and cobbles; very strongly acid (pH 4.8).
- A2 17-60 cm; yellow (10 YR 8/7) silt loam, light yellowish brown (10 YR 6/4) moist; weak, fine, subangular blocky structure; soft, very friable, slightly sticky and slightly plastic; 50% rock fragments, 30% gravel, 70% stones and cobbles; strongly acid (pH 5.5).
- B2 60-100 cm; very pale brown (10 YR 8/3) silt loam, brownish yellow (10 YR 6/6) moist; weak, medium, angular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; thin discontinuous clay flows; 50% rock fragments, 30% gravel, 70% stones and cobbles; strongly acid (pH 5.5).

CLASSIFICATION: very-fine, montmorillonitic Typic Cryochrept
DATE DESCRIBED: 6/29/79
LOCATION: SE $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$ Sec. 36, T. 7S, R. 3E.
ELEVATION: 2535 m
LANDSCAPE POSITION: convex, slightly convex; dip slope, upland
SLOPE AND ASPECT: 11%, N. 17° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 1
VEGETATION:

Tree species-

Understory and meadow species- Festuca idahoensis, Geranium
viscosissimum, Lupinus spp., numerous forbs

PEDON DESCRIPTION

- A1 0-7 cm; pinkish gray (7.5 YR 6/2) clay, dark brown (10 YR 3/3).
 moist; moderate, fine, crumb structure; slightly hard, very
 friable, very sticky and very plastic; slightly acid (pH 6.3).
- B21 7-23 cm; light brownish gray (10 YR 6/2) clay; dark yellowish
 brown (10 YR 3/4) moist; moderate, fine, subangular blocky
 structure; slightly hard, firm, very sticky and very plastic;
 thin continuous clay flows; 2% rock fragments, 100% gravel;
 slightly acid (pH 6.5).
- B22 23-53 cm; grayish brown (10 YR 5/2) clay, dark yellowish brown
 (10 YR 4/4) moist; weak, fine, subangular blocky structure;
 slightly hard, friable, very sticky and very plastic, thin
 discontinuous clay flows; medium acid (pH 6.0).
- C1 53-60 cm; yellowish brown (10 YR 5/4) clay, brownish yellow
 (10 YR 6/6) moist; massive; hard, friable, very sticky and
 very plastic; medium acid (pH 6.0).
- C2r 60-100+ cm; white (10 YR 8/1) clay, very pale brown (10 YR 7/3)
 moist; massive; very hard, firm, very sticky and very plastic;
 20% rock fragments, 30% gravel, 70% cobbles; medium acid
 (pH 6.0).

NOTE: rock fragments in the C2r horizon are gray limestone interbedded
 with well-granulated varicolored clay

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B32

CLASSIFICATION: fine, mixed Typic Cryoboralf
DATE DESCRIBED: 6/29/79
LOCATION: SE $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 36, T. 7S., R. 3E.
ELEVATION: 2535 m
LANDSCAPE POSITION: straight, slightly convex; dip slope; upland.
SLOPE AND ASPECT: 19%, N. 95° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 0
VEGETATION:

Tree species-

Understory and meadow species- Festuca idahoensis, Geranium
viscosissimum, Lupinus spp., numerous forbs

PEDON DESCRIPTION

- A1 0-10 cm; very pale brown (10 YR 8/3) silty clay, dark yellowish brown (10 YR 4/4) moist; strong, fine, granular structure; slightly hard, firm, very sticky and very plastic, 2% rock fragments, 100% gravel; slightly acid (pH 6.3).
- B21 10-23 cm; very pale brown (10 YR 7/4) silty clay, dark yellowish brown (10 YR 4/6) moist; strong, medium, prismatic structure; hard, firm, very sticky and very plastic; thin continuous clay flows; 2% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B22 23-76 cm; very pale brown (10 YR 7/4) silty clay, yellowish brown (10 YR 5/6) moist; moderate, medium, angular blocky structure; hard, firm, very sticky and very plastic; thin continuous clay flows; 2% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B23t 76-100+ cm; very pale brown (10 YR 8/3) clay, yellowish brown (10 YR 5/8) moist; strong, medium, angular blocky structure; hard, very firm, very sticky and very plastic; thick continuous clay flows; 30% rock fragments, 30% gravel, 70% cobbles; neutral (pH 7.0).

NOTE: rock fragments are yellow calcareous siltstone and limestone.

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B33

CLASSIFICATION: very-fine, mixed Typic Cryochrept.
DATE DESCRIBED: 6/29/79
LOCATION: NE $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 36, T. 7S., R. 3E.
ELEVATION: 2512 m
LANDSCAPE POSITION: straight, straight; dip slope; upland
SLOPE AND ASPECT: 16%, N. 56° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 2
VEGETATION:

Tree species-

Understory and meadow species- Festuca idahoensis, Geranium viscosissimum, Lupinus spp., numerous forbs

PEDON DESCRIPTION

- A1 0-10 cm; brown (7.5 YR 5/3) clay, brown (7.5 YR 4/4) moist; moderate, fine, granular structure; slightly hard, friable, very sticky and very plastic; 10% rock fragments, 100% gravel; medium acid (pH 6.0).
- B21 10-28 cm; reddish brown 5 YR 4/4) clay, strong brown (7.5 YR 4/6) moist; moderate, medium, prismatic structure; slightly hard, friable, very sticky and very plastic; thin continuous clay flows; 5% rock fragments, 100% gravel; neutral (pH 6.8).
- B22 28-38 cm; yellowish red (5 YR 4/6) clay, brown (7.5 YR 4/4) moist; weak, very fine, angular blocky structure; hard, friable, very sticky and very plastic; thin discontinuous clay flows; 15% rock fragments, 100% gravel; mildly alkaline (pH 7.5).
- IICr 38+ cm; yellowish red (5 YR 4/6) clay, brown (7.5 YR 5/4) moist; granulated clay with interbedded limestones; hard, firm, very sticky and very plastic; 50% rock fragments, 100% stones and cobbles; violently effervescent; moderately alkaline (pH 8.0).

NOTE: rock fragments are gray limestone

CLASSIFICATION: very-fine, mixed Mollic Cryoboralf
DATE DESCRIBED: 6/29/79
LOCATION: NW $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 36, T. 7S., R. 3E.
ELEVATION: 2524 m
LANDSCAPE POSITION: straight, straight; dip slope; upland
SLOPE AND ASPECT: 18%, N. 0°
DRAINAGE: well-drained
ROCKINESS CLASS: 2
STONINESS CLASS: 2
VEGETATION:
Tree species- Pinus contorta, Abies lasiocarpa

Understory and meadow species- Vaccinium scoparium, Calamagrostis canadensis, Physocarpus malvaceus, Smilacina stellata

PEDON DESCRIPTION

- 01 5-0 cm; liter
- A1 0-14 cm; reddish brown (5 YR 4/4) silty clay, dark reddish brown (5 YR 3/2) moist; weak, fine, subangular block structure; hard, friable, sticky and plastic; 2% rock fragments, 100% gravel; very strongly acid (pH 5.0).
- A21t 14-25 cm; reddish brown (5 YR 5/4) silty clay, dark reddish brown (5 YR 3/3) moist; moderate, medium, angular blocky structure; hard, firm, sticky and plastic; strong acid (pH 5.5).
- B22t 25-36 cm; reddish brown (5 YR 5/4) clay, dark reddish brown (2.5 YR 3/4) moist; strong, fine, angular blocky structure; hard, very firm, sticky and plastic; 2% rock fragments, 100% gravel; medium acid (pH 6.0).
- B23t 36-65 cm; yellowish red (5 YR 5/6) clay, dark red (2.5 YR 3/6) moist; strong, coarse, prismatic structure; hard, extremely firm, very sticky and very plastic; 20% rock fragments, 100% cobbles and stones; slightly acid (pH 6.5).
- C 65-100 cm; reddish brown (5 YR 5/4) clay, dark reddish brown (5 YR 3/4) moist; granulated clay; very hard, very firm, very sticky and very plastic; 40% coarse fragment, 20% gravel, 80% cobbles and stones; slightly effervescent; moderately alkaline (pH 8.0).

B34 - Continued

NOTE: rock fragments are gray limestone in the C horizon and gray, hematite-stained, fine-grained sandstone in the B2 horizons.

CLASSIFICATION: loamy-skeletal, mixed Mollic Cryoboralf
DATE DESCRIBED: 9/27/79
LOCATION: SW $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 1, T. 8S., R. 3E
ELEVATION: 2695 m
LANDSCAPE POSITION: straight, slightly convex; dip slope; upland
SLOPE AND ASPECT: 11%, N.0°
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 2
VEGETATION:

Tree species- (scattered) Picea engelmannii, Pinus contorta

Understory and meadow species- Festuca idahoensis, Agropyron spicatum, Lupinus spp., numerous forbs

PEDON DESCRIPTION

- A1 0-9 cm; brown (7.5 YR 4/3) silt loam; dark reddish brown (5 YR 2/2) moist; weak, very fine, granular structure; soft, very friable, slightly sticky and slightly plastic; 5% rock fragments; 80% gravel, 20% cobbles; neutral (pH 7.0).
- B21t 9-18 cm; dark brown (4/5 YR 3/3) clay loam, dark reddish brown (5 YR 2/2) moist; moderate, fine, subangular blocky structure; soft, friable, slightly sticky and slightly plastic; 10% rock fragments, 80% gravel, 20% cobbles; neutral (pH 7.0).
- B22t 18-40 cm; reddish yellow (7.5 YR 6/6) clay loam, reddish brown (5 YR 5/6) moist; moderate, fine, angular block structure; moderate, firm, very sticky and plastic; 35% rock fragments, 60% gravel, 40% cobbles; mildly alkaline (pH 7.8).
- B23t 40-60 cm; light reddish brown (5 YR 6/5) clay loam, yellowish red (5 YR 4/6) moist; strong, medium, angular blocky structure; slightly hard, firm, very sticky and very plastic; 35% rock fragments, 50% gravel, 50% cobbles; moderately alkaline (pH 8.0).
- C 60-100+ cm; reddish yellow (5 YR 7/6) clay loam, reddish brown (7.5 YR 5/4) moist; massive; slightly hard, firm, very sticky and plastic; 35% rock fragments, 50% gravel, 50% cobbles; moderately alkaline (pH 8.0).

NOTE: rock fragments are tan, hematite-stained, fine-grained sandstone

CLASSIFICATION: fine, mixed Mollic Cryoboralf
DATE DESCRIBED: 9/27/79
LOCATION: NE $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 1, T. 8S. R. 3E.
ELEVATION: 2700 m
LANDSCAPE POSITION: straight, slightly convex; dip slope; upland
SLOPE AND ASPECT: 11%, N. 40° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 2
VEGETATION:

Tree species- (open timber) Picea engelmannii, Pinus contorta

Understory and meadow species- Festuca idahoensis, Agropyron spicatum, Lupinus spp., Antennaria racemosa, numerous forbs

PEDON DESCRIPTION

- A1 0-11 cm; dark reddish gray (5 YR 4/2) silt loam, dark reddish brown (5 YR 2/2) moist; moderate, fine, granular structure, soft, very friable, slightly sticky and slightly plastic; 10% rock fragments, 80% gravel, 20% cobbles; neutral (pH 7.0).
 B21t 11-22 cm; dark reddish gray (5 YR 4/2) silty clay, dark reddish brown (5 YR 3/2) moist; moderate, medium, prismatic structure; slightly hard, friable, sticky and slightly plastic; 10% rock fragments, 50% gravel, 50% cobbles; slightly acid (pH 6.2).
 B22t 22-32 cm; reddish brown (5 YR 5/4) clay, reddish brown (5 YR 4/4) moist; moderate, medium, subangular blocky structure; hard, firm, sticky and plastic; thin continuous clay flows; 35% rock fragments, 20% gravel, 80% cobbles and stones; strongly acid (pH 5.5).
 B23t 32-58 cm; reddish brown (5 YR 5/4) clay, reddish brown (5 YR 4/4) moist, strong, medium, angular blocky structure; hard, very firm, sticky and plastic; thick continuous clay flows; 35% rock fragments, 10% gravel, 90% cobbles; strongly acid (pH 5.5).
 Cr 58-100+ cm; light gray (10 YR 7/2) clay, pale brown (10 YR 6/3) moist; massive, hard, firm, sticky and plastic; 25% rock fragments, 40% gravel, 60% cobbles; very strongly acid (pH 5.0).

B42 Continued

NOTE: rock fragments are gray, fine-grained sandstone.

CLASSIFICATION: clayey-skeletal, mixed Mollic Cryoboralf
DATE DESCRIBED: 9/28/79
LOCATION: NE $\frac{1}{4}$, NE $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 2 T.8S., R. 3E.
ELEVATION: 2695 m
LANDSCAPE POSITION: straight, slightly convex; dip slope; upland
SLOPE AND ASPECT: 14%, N. 20° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 0
VEGETATION:

Tree species- (open timber) Abies lasiocarpa, Pinus contorta,
Pinus albicaulis

Understory and meadow species- Festuca idahoensis, Agropyron
spicatum, numerous forbs

PEDON DESCRIPTION

- A1 0-9 cm; light brown (7.5 YR 6/5) silty clay loam, dark brown (7.5 YR 3/4) moist; moderate, very fine, granular structure; soft, very friable, slightly sticky and slightly plastic; 5% rock fragments, 100% gravel: medium acid (pH 5.8).
 B21 9-25 cm; yellowish brown (10 YR 5/6) silty clay loam, dark brown (7.5 YR 3/4) moist; strong, medium, prismatic structure; slightly hard, firm, slightly sticky and slightly plastic; 2% rock fragments, 100% gravel; medium acid (pH 6.0).
 B22 25-43 cm; yellowish brown (10 YR 5/4) silty clay loam, brown (7.5 YR 4/4) moist; moderate, fine, subangular blocky structure; slightly hard, friable, sticky and plastic; thin continuous clay flows; 15% rock fragments, 20% gravel, 80% cobbles and stones; slightly acid (pH 6.5).
 B23t 42-59 cm; brownish yellow (10 YR 6/6) silty clay loam, strong brown (7.5 YR 4/6) moist; moderate, fine, subangular blocky structure; slightly hard, firm, very sticky and plastic; thick continuous clay flows; 60% rock fragments, 10% gravel, 90% cobbles and stones; moderately alkaline (pH 8.0).
 IIR 59+ cm; thinly bedded, gray limestone.

CLASSIFICATION: loamy-skeletal, mixed Typic Cryoboralf
DATE DESCRIBED: 9/28/79
LOCATION: NW $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, SE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 2, T. 8S., R. 3E.
ELEVATION: 2670 m
LANDSCAPE POSITION: straight, straight; dip slope; upland
SLOPE AND ASPECT: 11%, N. 0°
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 1
VEGETATION:
Tree species- (open timber) Pinus contorta, Abies lasiocarpa,
Pinus flexilis
Understory and meadow species- Vaccinium scoparium

PEDON DESCRIPTION

- A1 0-17 cm; pink (7.5 YR 7/4) silt loam, dark brown (7.5 YR 3/2) moist; weak, very fine, granular structure; soft, very friable; slightly sticky and slightly plastic; 15% rock fragments, 70% gravel, 30% cobbles; medium acid (pH 6.0).
 A2 17-49 cm; pink (7.5 YR 7/5) loam, brown (7.5 YR 5/4) moist; weak, fine, subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; 50% rock fragments, 10% gravel, 90% cobbles and stones; medium acid (pH 6.0).
 B2t 49-100+ cm; reddish yellow (7.5 YR 6/6) clay loam, strong brown (7.5 YR 4/6) moist; moderate, medium, angular block structures; hard, firm, very sticky and very plastic; thin continuous clay flows; 40% rock fragments, 50% gravel, 50% cobbles and stones; medium acid (pH 5.7)

NOTE: rock fragments are gray to yellow, fine-grained sandstone.

CLASSIFICATION: fine, mixed Mollic Cryoboralf
DATE DESCRIBED: 9/28/79
LOCATION: SW $\frac{1}{4}$, SE $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$, NE $\frac{1}{4}$ Sec. 2, T. 8S., R. 3E.
ELEVATION: 2652m
LANDSCAPE POSITION: straight, straight; dip slope; upland
SLOPE AND ASPECT: 14% , N. 98° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 1
STONINESS CLASS: 2
VEGETATION:

Tree species- (scattered) Pinus flexilis

Understory and meadow species- Festuca idahoensis, Bromus marginatus,
Agropyron spicatum, Lupinus spp., numerous forbs

PEDON DESCRIPTION

- A1 0-6 cm; reddish yellow (5 YR 6/6) clay loam, dark reddish brown (5 YR 3/2) moist; moderate, medium, granular structure; slightly hard, friable, sticky and plastic; 2% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B21t 6-23 cm; reddish brown (5 YR 5/3) clay loam, dark reddish brown (5 YR 3/3) moist; moderate, medium, prismatic structure; slightly hard, friable, sticky and plastic; 10% rock fragments, 30% gravel, 70% cobbles; slightly acid (pH 6.5)
- B22t 23-50 cm; light brown (7.5 YR 6/4) clay, reddish brown (5 YR 4/4) moist; strong, fine, angular blocky structure; hard, firm, very sticky and plastic; thin continuous clay flows; 20% rock fragments, 50% gravel, 50% cobbles; medium acid (pH 5.8).
- B23t 50-100+ cm; reddish brown (5 YR 5/4) clay, red (2.5 YR 4/6) moist; strong, coarse, angular blocky structure, very hard, very firm, very sticky and very plastic; thick continuous clay flows; 35% rock fragments, 20% gravel, 80% cobbles and stones; strongly acid (pH 5.5).

NOTE: rock fragments are gray, fine-grained sandstones; extensive gopher activity

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B51

CLASSIFICATION: loamy-skeletal, mixed Mollic Cryoboralf
DATE DESCRIBED: 9/30/79
LOCATION: SW $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$ Sec. 11, T. 8S., R. 3E.
ELEVATION: 2850 m
LANDSCAPE POSITION: slightly convex, convex; dip slope; upland
SLOPE AND ASPECT: 9%, N. 38° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 0
VEGETATION:

Tree species-

Understory and meadow species- Stipa richardsoni; Festuca idahoensis,
Antennaria racemosa, numerous forbs

PEDON DESCRIPTION

- A1 0-13 cm; yellowish brown (10 YR 5/4) silt loam, dark brown (7.5 YR 3/4) moist; weak, very fine, granular structure; soft, very friable, slightly sticky and slightly plastic; 30% rock fragments, 100% gravel; medium acid (pH 6.0).
- B21t 13-32 cm; brown (7.5 YR 5/4) loam, brown (7.5 YR 4/4) moist; weak, fine, subangular blocky structure; soft, friable, sticky and plastic; 35% rock fragments, 100% gravel; medium acid (pH 5.8).
- B22t 32-48 cm; yellowish brown (10 YR 5/4) loam, strong brown (7.5 YR 4/6) moist; moderate, coarse, angular blocky structure; soft, firm, sticky and plastic; thin discontinuous clay flows; 35% rock fragments, 60% gravel, 40% cobbles; medium acid (pH 5.8).
- C 48-56 cm; reddish brown (5 YR 4/4) loam, brown (7.5 YR 4/4) moist; massive; slightly hard, friable, sticky and plastic; 50% rock fragments, 50% gravel, 50% cobbles; strongly acid (pH 5.5).
- R 56+ cm; tan siltstone and very fine-grained sandstone.

NOTE: rock fragments are tan siltstone and very fine-grained sandstone; extensive gopher activity

CLASSIFICATION: fine-loamy, mixed Typic Cryochrept
DATE DESCRIBED: 9/30/79
LOCATION: SE $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$ Sec. 11 T. 8S, R. 3E.
ELEVATION: 2828m
LANDSCAPE POSITION: straight, slightly convex; dip slope; upland
SLOPE AND ASPECT: 14%, N. 40° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 0
VEGETATION:
Tree species- (scattered) Pinus flexilis, Abies lasiocarpa
Understory and meadow species- Stipa richardsoni, Festuca idahoensis,
Antennaria racemosa, numerous forbs

PEDON DESCRIPTION

- A1 0-9 cm; brown (10 YR 5/4) loam; dark brown (7.5 YR 3/4) moist; weak, very fine, granular structure; soft, very friable, slightly sticky and slightly plastic; 15% rock fragments, 100% gravel; medium acid (pH 5.8).
 B21 9-19 cm; light brown (7.5 YR 6/4) loam, dark brown (7.5 YR 3/4) moist; moderate, medium, prismatic structure; soft, friable, sticky and plastic; 15% rock fragments, 100% gravel; medium acid (pH 5.6).
 B22 19-39 cm; yellow (10 YR 7/5) loam, brown (7.5 YR 4/4), moist; moderate, medium, angular blocky structure; soft, friable, sticky and plastic; 15% rock fragments, 100% gravel; strongly acid (pH 5.4).
 B23 39-66 cm; yellow (10 YR 7/6) loam, strong brown (7.5 YR 5/6) moist; moderate, fine, angular blocky structure; slightly hard, friable, sticky and plastic; thin continuous clay flows; 30% rock fragments, 100% gravel; strongly acid (pH 5.2).
 R 66 + cm; yellow bedded siltstone

NOTE: rock fragments are yellow siltstone; extensive gopher activity

CLASSIFICATION: fine, mixed Typic Cryoboralf
DATE DESCRIBED: 9/30/79
LOCATION: SE $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, SW $\frac{1}{4}$, SW $\frac{1}{4}$ Sec. 2, T. 8S. R. 3E
ELEVATION: 2798 m
LANDSCAPE POSITION: straight, slightly convex; dip slope; upland
SLOPE AND ASPECT: 14%, N 38° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 0
VEGETATION:
Tree species- (scattered) Pinus flexilis

Understory and meadow species- Festuca idahoensis, Antennaria
racemosa, numerous forbs

PEDON DESCRIPTION

- A1 0-8 cm; light yellowish brown (10 YR 6/4) silty clay, brown (7.5 YR 4/4) moist; moderate, very fine, crumb structure; soft, very friable, slightly sticky and slightly plastic; medium acid (pH 6.0).
- B21 8-22 cm; brown (7.5 YR 5/4) clay, brown (7.5 YR 4/4) moist; moderate medium, prismatic structure; slightly hard, firm, sticky and plastic; thin discontinuous clay flows; medium acid (pH 5.8).
- B22 22-53 cm; yellowish brown (10 YR 5/6) clay, strong brown (7.5 YR 4/6) moist; moderate, coarse, angular blocky structure; slightly hard, friable, sticky and plastic; thin discontinuous clay flows; medium acid (pH 5.8).
- B23t 53-84 cm; brownish yellow (10 YR 6/6) clay, strong brown (7.5 YR 5/6) moist; weak, fine, subangular blocky structure, slightly hard; friable, very sticky and plastic; thin discontinuous clay flows; strongly acid (pH 5.5).
- B24t 84-100+ cm; yellow (10 YR 7/6) clay, strong brown (7.5 YR 5.6) moist; moderate, medium, angular blocky structure; hard, firm, very sticky and very plastic; thick continuous clay flows; 5% rock fragments, 100% gravel; strongly acid (pH 5.5).

NOTE: rock fragments are gray, fine-grained sandstone

CLASSIFICATION: fine, mixed Typic Cryoboralf
 DATE DESCRIBED: 9/29/79
 LOCATION: SW $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 2, T. 8S., R. 3E.
 ELEVATION: 2780 m
 LANDSCAPE POSITION: convex, straight; dip slope; upland
 SLOPE AND ASPECT: 25%, N. 40° E.
 DRAINAGE: well-drained
 ROCKINESS CLASS: 0
 STONINESS CLASS: 0
 VEGETATION:

Tree species-

Understory and meadow species- Festuca idahoensis, Antennaria
racemosa, Phleum alpinum, numerous forbs

PEDON DESCRIPTION

- A1 0-14 cm; very pale brown (10 YR 7/4) clay, dark brown (7.5 YR 3/4) moist; moderate, very fine, crumb structure; soft, very friable, slightly sticky and slightly plastic; 2% rock fragments, 100% gravel; medium acid (pH 6.0).
- B21 14-38 cm; yellow (10 YR 8/6) silty clay, brown (7.5 YR 4/4) moist; strong, coarse, prismatic structure; slightly firm, sticky and plastic; 2% rock fragments, 100% gravel; medium acid (pH 5.8).
- B22t 38-50 cm; yellow (10 YR 7/6) clay, strong brown, (7.5 YR 5/8) moist; weak, fine, angular blocky structure; slightly hard, friable, sticky and plastic; thin continuous clay flows; 5% rock fragments, 100% gravel; medium acid (pH 5.7).
- B23t 50-67 cm; yellow (10 YR 7/6) clay, reddish yellow (7.5 YR 6/8) moist; moderate, fine, prismatic structure; slightly hard, firm; very sticky and very plastic; thick continuous clay flows; 5% rock fragments, 100% gravel; strongly acid (pH 5.5).
- C 67-77 cm; yellow (10 YR 7/6) clay, reddish yellow (7.5 YR 5.8) moist; massive; slightly hard, firm, very sticky and very plastic; 5% rock fragments, 100% gravel; strongly acid (pH 5.2).
- R 77+ cm; yellow siltstone and claystone.

B54 Continued

NOTE: rock fragments are gray, fine-grained sandstone

CLASSIFICATION: fine, mixed Typic Cryoboralf
DATE DESCRIBED: 9/29/79
LOCATION: SW $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, NE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 3, T. 8S, R. 3E
ELEVATION: 2734 m
LANDSCAPE POSITION: straight, slightly convex, dip slope; upland
SLOPE AND ASPECT: 23%, N. 40° E
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 0
VEGETATION:

Tree species- (scattered) Pinus flexilis, Picea engelmanni,
Abies lasiocarpa

Understory and meadow species- Festuca idahoensis, Antennaria
racemosa, Phleum alpinum, numerous forbs

PEDON DESCRIPTION

- A1 0-9 cm; light yellowish brown (10 YR 6/4) clay loam, dark brown (10 YR 3/3) moist; moderate, very fine, crumb structure; soft, very friable, slightly sticky and slightly plastic; 5% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B21 9-28 cm; brown (10 YR 5/3) clay loam, brown (10 YR 4/3) moist; strong, medium, prismatic structure; soft, friable, sticky and plastic; 5% rock fragments, 100% gravel; medium acid (pH 6.0).
- B22 28-58 cm; yellow (10 YR 8/6) clay loam, yellowish brown (10 YR 5/6) moist; weak, fine, subangular blocky structure; slightly hard, friable, very sticky and plastic; thin discontinuous clay flows; 10% rock fragments; 100% gravel; medium acid (pH 5.8).
- B23t 58-100+ cm; yellow (10 YR 7/6) clay, brownish yellow (10 YR 6/6) moist; strong, medium, angular blocky structure; hard, firm, sticky and very plastic; thick continuous clay flows; 2% rock fragments, 100% gravel; strongly acid (pH 5.5).

NOTE: rock fragments are yellow, fine-grained sandstone

CLASSIFICATION: fine, mixed Lithic Mollic Cryoboralf
DATE DESCRIBED: 9/29/79
LOCATION: NE $\frac{1}{4}$, SE $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 3 T. 8S., R. 3E.
ELEVATION: 2713 m
LANDSCAPE POSITION: convex, slightly convex; dip slope; upland
SLOPE AND ASPECT: 14%, N. 48°E.
DRAINAGE: well-drained
ROCKINESS CLASS: 0
STONINESS CLASS: 0
VEGETATION:

Tree species- (scattered) Pinus flexilis, Abies lasiocarpa

Understory and meadow species- Festuca idahoensis, Agropyron spicatum, Antennaria racemosa, numerous forbs

PEDON DESCRIPTION

- A1** 0-9 cm; yellowish brown (10 YR 5/4) loam, dark brown (10 YR 3/3) moist; weak, very fine, granular structure; soft, very friable, nonsticky and slightly plastic; 5% rock fragments, 100% gravel; slightly acid (pH 5.5).
B21t 9-19 cm; brownish yellow (10 YR 6/6) loam, dark yellowish brown (10 YR 4/4) moist; moderate, medium, prismatic structure; soft, friable, sticky and plastic; 5% rock fragments, 100% gravel; medium acid (pH 5.8).
B22t 19-28 cm; brownish yellow (10 YR 6/6) clay loam, dark yellowish brown (10 YR 4/5) moist; moderate, fine, subangular blocky structure; slightly hard, friable, sticky and plastic; 10% rock fragments; 100% gravel; medium acid (pH 5.8).
Cr 28-38 cm; white (7.5 YR 8/2) clay; very pale brown (7.5 YR 7/3) strong, coarse, platy structure; slightly hard, firm, sticky and plastic; 30% rock fragments, 100% gravel; medium acid (pH 5.8).
R 38+ cm; gray platy shale.

NOTE: rock fragments are gray, fine-grained sandstone.

APPENDIX III

SOIL PROFILE DESCRIPTIONS

FOR PEDONS FORMING ON THE BOULDER BATHOLITH

CLASSIFICATION: sandy, mixed Mollic Cryoboralf
 DATE DESCRIBED: 10/9/79
 LOCATION: NE $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 15, T. 1N., R. 6W.
 ELEVATION: 1719 m
 LANDSCAPE POSITION: straight, convex, valley sideslope
 SLOPE AND ASPECT: 29%, N, 235° W.
 DRAINAGE: well-drained
 ROCKINESS CLASS: 1
 STONINESS CLASS: 1
 VEGETATION:

Tree species- (scattered) Pseudotsuga menziesii

Understory and meadow species- Agropyron spicatum, Festuca
idahoensis, Bouteloua gracilis, Artemisia frigida

PEDON DESCRIPTION

- A1 0-7 cm; pale brown (10 YR 6/3) sandy loamy, dark brown (10 YR 3/3) moist; moderate, medium, granular structure; slightly hard, very friable; nonsticky and nonplastic; 8% rock fragments, 100% gravel; slightly acid (pH 6.5).
 B2t 7-20 cm; yellowish brown (10 YR 5/6) loam, dark yellowish brown (10 YR 4/4) moist; moderate, medium, prismatic structure; slightly hard, friable, slightly sticky and slightly plastic; 2% rock fragments, 100% gravel; neutral (pH 7.0).
 B3ca 20-32 cm; white (7.5 YR 8/2) sandy loam, brownish yellow (10 YR 6/6) moist; moderate, medium, subangular blocky structure; slightly hard, friable, slightly sticky and nonplastic; 1% rock fragment, 100% gravel; violently effervescent; moderately alkaline (pH 8.2).
 Cr 32-62 cm; light gray (10 YR 7/2) loamy sand, yellowish brown (10 YR 5/6) moist; massive; slightly hard, loose, nonsticky and nonplastic; 20% rock fragments, 100% gravel; slight effervescent; moderately alkaline (pH 8.0).
 R 62+ cm; light gray, granite bedrock.

CLASSIFICATION: coarse-loamy, mixed Mollic Cryoboralf
DATE DESCRIBED: 10/9/79
LOCATION: SW $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 15, T. 1N., R. 6W.
ELEVATION: 1755 m
LANDSCAPE POSITION: concave, straight; rolling upland
SLOPE AND ASPECT: 40%, N. 34° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 3
STONINESS CLASS: 1
VEGETATION:

Tree species- Pseudotsuga menziesii

Understory and meadow species- Agropyron spicatum, Festuca idahoensis

PEDON DESCRIPTION

- O1 5-0 cm; liter
 A2 0-7 cm; light brownish gray (10 YR 6/2) sandy loam, very dark grayish brown (10 YR 3/2) moist; moderate, medium, granular structure; soft, very friable, nonsticky and nonplastic; 2% rock fragments, 100% gravel; slightly acid (pH 6.5).
 B21t 7-12 cm; light brownish gray (10 YR 6/2) sandy loam, very dark brown (10YR 2/2) moist; weak, medium, granular structure; soft, very friable, slightly sticky and nonplastic; slightly acid (pH 6.2).
 B22t 12-26 cm; dark grayish brown (10 YR 4/2) sandy loam, very dark grayish brown (10 YR 3/2) moist; moderate, medium, angular blocky structure; slightly hard, friable, slightly sticky and nonplastic; slightly acid (pH 6.5).
 B23t 26-51 cm; dark grayish brown (10 YR 4/2) sandy loam, brown (10 YR 4/3) moist; weak, fine, subangular blocky structure; soft, friable, slightly sticky and nonplastic; slightly acid (pH 6.5).
 C1 51-100+ cm; brown (10 YR 5/3) sandy loam, brown (10 YR 4/3) moist; massive; loose, loose, nonsticky and nonplastic; mildly alkaline (pH 7.6).

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PS3

CLASSIFICATION: sandy, mixed Typic Cryochrept
DATE DESCRIBED: 10/9/79
LOCATION: NE $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 16, T.1 N., R. 6W.
ELEVATION: 1828 m
LANDSCAPE POSITION: convex, convex; rolling upland
SLOPE AND ASPECT: 11%, N. 40°W.
DRAINAGE: well-drained
ROCKINESS CLASS: 3
STONINESS CLASS: 2
VEGETATION:

Tree species- (open timber) Pseudotsuga menziesii

Understory and meadow species- Agropyron spicatum, Festuca
idahoensis, Artemisia tridentata, sedges

PEDON DESCRIPTION

- A1 0-7 cm; dark grayish brown (10 YR 4/2) sandy loam, very dark brown (10 YR 3/2) moist; weak, medium, granular structure; soft, very friable, nonsticky and nonplastic; medium acid (pH 5.8).
- B21 7-18 cm; light brownish gray (10 YR 6/2) sandy loam, dark brown (10 YR 3/3) moist; weak, medium, subangular blocky structure; 2% rock fragments, 100% gravel; slightly acid (pH 6.2).
- B22 18-45 cm; very pal brown (10 YR 7/4) sandy loam, yellowish brown (10 YR 5/4) moist; moderate, medium, angular blocky structure; hard, friable, slightly sticky and nonplastic; 5% rock fragments, 50% gravel, 50% cobbles; slightly acid (pH 6.5).
- C1 45-100+ cm; light yellowish brown (10 YR 6/4) loamy sand, dark yellowish brown (10 YR 4/4) moist; massive; loose, loose, slightly sticky and nonplastic; 10% rock fragments, 100% gravel; neutral (pH 6.8).

CLASSIFICATION: sandy, mixed Typic Cryoboralf
DATE DESCRIBED: 10/10/79
LOCATION: SE $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 17, T. 1N, R. 6W.
ELEVATION: 1883 m
LANDSCAPE POSITION: convex, convex; dissected valley sideslope
SLOPE AND ASPECT: 23%, N. 145° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 3
STONINESS CLASS: 3
VEGETATION:

Tree species- Pseudotsuga menziesii

Understory and meadow species- Agropyron spicatum, Festuca idahoensis, Juniperus scopulorum

PEDON DESCRIPTION

- 01 2-0 cm; liter
- A21 10-12 cm; light gray (10 YR 7/1) sandy loam, brown (10 YR 5/3) moist; weak, very coarse, platy structure; soft, very friable, nonsticky and nonplastic; 2% rock fragments, 100% gravel; medium acid (pH 6.0).
- A22 12-30 cm; pale brown (10 YR 6/3) loamy sand, brown (10 YR 4/3) moist; moderate, medium, subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; 2% rock fragments, 100% gravel; medium acid (pH 6.0).
- B2t 30-72 cm; pale brown (10 YR 6/3) sandy loam, brown (10 YR 5/3) moist; moderate, medium, subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; 10% rock fragments, 100% gravel; neutral (pH 6.8).
- Cr 72-95 cm; pale brown (10 YR 6/3) loamy sand, brown (10 YR 5/3) massive; loose, loose, nonsticky and nonplastic; 10% rock fragments, 100% gravel; neutral (pH 6.8).

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PS5

CLASSIFICATION: sandy, mixed Mollic Cryoboralf
DATE DESCRIBED: 10/10/79
LOCATION: SW $\frac{1}{4}$, NE $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, SE $\frac{1}{4}$; Sec. 18, T. 1N., R. 6W.
ELEVATION: 1920 m
LANDSCAPE POSITION: convex, convex; rolling upland
SLOPE AND ASPECT: 25%, N 135° W
DRAINAGE: well-drained
ROCKINESS CLASS: 2
STONINESS CLASS: 3
VEGETATION:

Tree species- (scattered) Pseudotsuga menziesii

Understory and meadow species- Agropyron spicatum, Festuca
idahoensis, Artemisia tridentata, Juniperus scopulorum

PEDON DESCRIPTION

- A1 0-7 cm; brown (10 YR 4/3) sandy loam, very dark grayish brown (10 YR 3/2) moist; weak, medium, granular structure; soft, very friable, nonsticky and nonplastic; 15% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B1 7-22 cm; yellowish brown (10 YR 5/4) sandy loam, dark brown (10 YR 3/3) moist; moderate, coarse, subangular blocky structure; slightly hard, friable, nonsticky and slightly plastic; 2% rock fragments, 100% gravel; neutral (pH 6.8).
- B2t 22-35 cm; light yellowish brown (10 YR 6/5) sandy loam, dark yellowish brown (10 YR 4/4) moist; moderate, coarse, subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 10% rock fragments, 100% gravel; neutral (pH 6.8).
- C 35-54 cm; light yellowish brown (10 YR 6/5) loamy sand, yellowish brown (10 YR 5/4) moist; massive; loose, loose, nonsticky and nonplastic; 15% rock fragments, 100% gravel; neutral (pH 7.0).
- R 54+ cm; yellowish brown, granitic bedrock.

CLASSIFICATION: coarse-loamy, mixed Mollic Cryoboralf
DATE DESCRIBED: 10/9/79
LOCATION: NW $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 18, T. 2N., R. 5W.
ELEVATION: 1548 m
LANDSCAPE POSITION: convex, convex; rolling upland
SLOPE AND ASPECT: 36%, N. 18° W.
DRAINAGE: well-drained
ROCKINESS CLASS: 2
STONINESS CLASS: 2
VEGETATION:

Tree species-

Understory and meadow species- Agropyron spicatum, Stipa comata,
Bouteloua gracilis, Artemisia tridentata

PEDON DESCRIPTION

- A1 0-7 cm; dark grayish brown (10 YR 4/2) sandy loam, black (10 YR 2/1) moist; weak, medium, granular structure; soft, friable, nonsticky and nonplastic; 2% rock fragments, 100% gravel; mildly alkaline (pH 7.8).
- B2t 7-15 cm; brown (10 YR 4/2) sandy loam, very dark grayish brown (10 YR 3/2) moist; moderate, medium, subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 10% rock fragments, 100% gravel; moderately alkaline (pH 8.0).
- B3lca 15-30 cm; brown (10 YR 5/3) sandy loam, brown (10 YR 4/3) moist; weak, fine, subangular blocky structure; soft, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel, strongly effervescent; moderately alkaline (pH 8.2).
- B32 30-49 cm; light brownish gray (7.5 YR 6/2) sandy loam, very pale brown (10 YR 7/3) moist; moderate, medium subangular blocky structure; soft, very friable, slightly sticky and nonplastic; violently effervescent; moderately alkaline (pH 8.4).
- Crca 49-65 cm; gray (10 YR 6/1) loamy sand, grayish brown (10 YR 5/2) moist; massive; loose, loose; nonsticky and nonplastic, 5% rock fragments, 100% gravel, violently effervescent; moderately alkaline (pH 8.0).
- R 65+ cm; gray granitic bedrock.

CLASSIFICATION: sandy, mixed Typic Cryoboralf
DATE DESCRIBED: 10/10/79
LOCATION: NW $\frac{1}{4}$, SE $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 18, T. 2N., R. 5W.
ELEVATION: 1633 m
LANDSCAPE POSITION: convex, convex, rolling upland
SLOPE AND ASPECT: 12%, N. 100° W.
DRAINAGE: well-drained
ROCKINESS CLASS: 2
STONINESS CLASS: 4
VEGETATION:
Tree species- Pseudotsuga menziesii

Understory and meadow species- Agropyron spicatum, Festuca
idahoensis, Artemisia tridentata, Juniperus scopulorum

PEDON DESCRIPTION

- 01 3-0 cm; liter
- A-2 0-4 cm; brown (10 YR 5/3) loamy sand, very dark grayish brown (10 YR 3/2) moist; massive, loose, loose, nonsticky and nonplastic; 2% rock fragments, 100% gravel; slightly acid (pH 6.2).
- B21t 4-13 cm; pale brown (10 YR 6/3) sandy loam, brown (10 YR 4/3) moist; moderate, medium, subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 10% rock fragments, 100% gravel; very strongly acid (pH 5.0).
- B22t 13-22 cm; light yellowish brown (10 YR 6/4) loamy sand, yellowish brown (10 YR 5/4) moist; moderate, coarse, subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 3% rock fragments, 100% gravel; medium acid (pH 6.0).
- Cr 22-40 cm; light yellowish brown (10 YR 6/4) loamy sand, yellowish brown (10 YR 5/4) moist; massive; loose, loose, nonsticky and nonplastic, 10% rock fragments, 100% gravel; mildly alkaline (pH 7.5).
- R 40+ cm; light yellowish brown, granitic bedrock.

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DM3

CLASSIFICATION: sandy, mixed Lithic Mollic Cryoboralf
DATE DESCRIBED: 10/11/79
LOCATION: NE $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 7, T. 2N, R. 5W
ELEVATION: 1676 m
LANDSCAPE POSITION: straight, slightly convex; upland pediment
SLOPE AND ASPECT: 7%, N. 145° W.
DRAINAGE: well, drained
ROCKINESS CLASS: 0
STONINESS CLASS: 0
VEGETATION:

Tree species-

Understory and meadow species- Agropyron spicatum, Festuca
idahoensis, Artemisia tridentata, Artemisia frigida, Juniperus
scopulorum

PEDON DESCRIPTION

- A1 0-5 cm; yellowish brown (10 YR 5/4) loamy sand, dark brown (10 YR 3/3) moist; weak, medium, granular structure; loose, very friable, nonsticky and nonplastic; 3% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B2lt 5-10 cm; light yellowish brown (10 YR 6/4) sandy loam, dark brown (10 YR 3/3) moist; weak, medium subangular blocky structure; soft, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel, medium acid (pH 5.8).
- B22t 10-19 cm; yellowish brown (10 YR 5/4) sandy loam, dark yellowish brown (10 YR 4/4) moist; moderate, medium, subangular blocky structure; soft, friable, nonsticky and nonplastic; 5% rock fragments; slightly acid (pH 6.2).
- Cr 19-35 cm; pale brown (10 YR 6/3) loamy sand, yellowish brown (10 YR 5/4) moist; massive; loose, loose, nonsticky and nonplastic; 10% rock fragments, 100% gravel; slightly acid (pH 6.5).
- R 35+ cm; pale brown (10 YR 6/3) granitic bedrock.

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DM4

CLASSIFICATION: sandy, mixed Lithic Cryochrept
DATE DESCRIBED: 10/11/79
LOCATION: SW $\frac{1}{4}$, NW $\frac{1}{4}$, SE $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 1, T. 2N., R. 6W.
ELEVATION: 1707 m
LANDSCAPE POSITION: convex, convex; valley sideslope
SLOPE AND ASPECT: 27%, N. 12° W.
DRAINAGE: well-drained
ROCKINESS CLASS: 3
STONINESS CLASS: 3
VEGETATION:

Tree species- Pseudotsuga menziesii

Understory and meadow species- Agropyron spicatum, Festuca
idahoensis, Juniperus scopulorum

PEDON DESCRIPTION

- 01 3-0 cm; liter
- A2 0-4 cm; yellowish brown (10 YR 5/4) sandy loam, very dark grayish brown (10 YR 3/2) moist; weak, medium granular structure; soft, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B2 4-11 cm; brownish yellow (10 YR 6/6) sandy loam, brown (10 YR 4/3) moist; weak, medium, subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 15% rock fragments, 100% gravel; slightly acid (pH 6.2).
- Cr 11-28 cm; light yellowish brown (10 YR 6/4) loamy sand, yellowish brown (10 YR 5/4) moist; massive, loose, loose, nonsticky and nonplastic; 25% rock fragments, 100% gravel; neutral (pH 7.0).
- R 28+ cm; light yellowish brown, granitic bedrock.

CLASSIFICATION: sandy, mixed Typic Cryochrept
DATE DESCRIBED: 10/11/79
LOCATION: SE $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 35, T. 3N., R. 6W.
ELEVATION: 1828 m
LANDSCAPE POSITION: convex, convex; gently rolling upland
SLOPE AND ASPECT: 14%, N. 160° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 1
STONINESS CLASS: 2
VEGETATION:

Tree species- (open timber) Pseudotsuga menziesii

Understory and meadow species- Agropyron spicatum, Festuca idahoensis, Artemisia tridentata, Juniperus scopulorum

PEDON DESCRIPTION

- 01 2-0 cm; liter
- A2 0-6 cm; dark grayish brown (10 YR 4/2) loamy sand, very dark gray (10 YR 3/1) moist; weak, medium, granular structure; loose, very friable; nonsticky and nonplastic; strongly acid (pH 5.5).
- B21t 6-15 cm; brown (10 YR 5/3) sandy loam, very dark grayish brown (10 YR 3/2) moist; moderate, medium subangular blocky structure; hard, friable, nonsticky and nonplastic; 5% rock fragments; 100% gravel; neutral (pH 7.0).
- B22t 15-27 cm; pale brown (10 YR 6/3) sandy loam, dark brownish brown (10 YR 4/4) moist; moderate, medium, subangular blocky structure; hard, friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; neutral (pH 6.5).
- Cr 27-54 cm; light yellowish brown (10 YR 6/4) loamy sand, yellowish brown (10 YR 5/4) moist; massive; loose, loose, nonsticky and nonplastic; 10% rock fragments, 100% gravel; slightly acid (pH 6.5).
- R 54+ cm; light yellowish brown, granitic bedrock.

NW1

CLASSIFICATION: sandy, mixed Typic Cryochrept
DATE DESCRIBED: 10/5/79
LOCATION: NW $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$ Sec. 4, T. 4N., R. 4W.
ELEVATION: 1640 m
LANDSCAPE POSITION: convex, convex; rolling upland
SLOPE AND ASPECT: 11%, N. 160° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 3
STONINESS CLASS: 1
VEGETATION:
Tree species- (scattered) Psuedotsuga menziesii

Understory and meadow species- Agropyron spicatum, Bouteloua gracilis, Artemisia tridentata.

PEDON DESCRIPTION

- A1 0-8 cm; dark gray (10 YR 4/1) sandy loam, brown (10 YR 2/1) moist; weak, moderate, granular structure; slightly hard, friable, nonsticky and nonplastic; 7% rock fragments, 100% gravel; neutral (pH 7.2).
 B21 8-31 cm; dark brown (7.5 YR 3/2) sandy loam, very dark grayish brown (10 YR 3/2) moist; weak, coarse, prismatic structure; slightly hard, friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; mildly alkaline (pH 7.2).
 B22 31-52 cm; dark grayish brown (10 YR 4/2) loamy sand, dark brown (10 YR 3/3) moist; weak, medium, subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; mildly alkaline (pH 7.5).
 C 52-100+ cm; brown (10 YR 5/3) loamy sand, brown (10 YR 4/3) moist; massive; slightly hard, friable, nonsticky and nonplastic; 8% rock fragments, 100% gravel; mildly alkaline (pH 7.5).

CLASSIFICATION: sandy, mixed Mollic Cryoboralf
 DATE DESCRIBED: 10/5/79
 LOCATION: NE $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 33, T. 5N., R. 4W.
 ELEVATION: 1700m
 LANDSCAPE POSITION: convex, convex; gently rolling upland
 SLOPE AND ASPECT: 5%, N. 250° W.
 DRAINAGE: well-drained
 ROCKINESS CLASS: 0
 STONINESS CLASS: 0
 VEGETATION:

Tree species-

Understory and meadow species- *Agropyron spicatum*, *Festuca*
idahoensis, *Bouteloua gracilis*, *Artemisia tridentata*

PEDON DESCRIPTION

- A1 0-7cm; dark brown (10 YR 3/3) sandy loam, black (10 YR 2/1) moist; moderate medium granular structure; slightly hard, friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; neutral (pH 7.0).
 B21t 7-15 cm; brown (10 YR 4/3) sandy loam, dark brown (10 YR 3/3) moist; moderate, medium, subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; 20% rock fragments, 30% gravel, 70% cobbles; slightly acid (pH 6.5).
 B22t 15-32 cm; brownish yellow (10 YR 6/6) sandy loam, yellowish brown (10 YR 5/5) moist; moderate, medium, angular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; 5% rock fragments, 100% gravel; neutral (pH 7.0).
 C1 32-58 cm; brownish yellow (10 YR 6/6) loamy sand, yellowish brown (10 YR 5/6) moist; massive; slightly hard, friable, nonsticky and nonplastic; 15% rock fragments, 100% gravel; neutral (pH 7.2).
 C2 58-100+ cm; yellowish brown (10 YR 6/4) loamy sand, dark yellowish brown (10 YR 4/4) moist; massive; slightly hard, loose, nonsticky and nonplastic; 10% rock fragments, 100% gravel; mildly alkaline (pH 7.5).

CLASSIFICATION: coarse-loamy, mixed Typic Cryochrept
 DATE DESCRIBED: 10/5/79
 LOCATION: SE $\frac{1}{4}$, SW $\frac{1}{4}$, NW $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 28, T. 5N., R. 4W.
 ELEVATION: 1743 m
 LANDSCAPE POSITION: convex, convex; gently rolling upland
 SLOPE AND ASPECT: 14%, N: 20° E.
 DRAINAGE: well-drained
 ROCKINESS CLASS: 0
 STONINESS CLASS: 0
 VEGETATION:

Tree species- (open timber) Pseudotsuga menziesii

Understory and meadow species- Apropyron spicatum, Festuca idahoensis, Artemisia tridentata

PEDON DESCRIPTION

- 01 3-0 cm; liter
- A2 0-6 cm; grayish brown (10 YR 5/2) sandy loam, brown (10 YR 5/3) moist; weak, medium, platy structure; soft, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; neutral (pH 7.0).
- B2 6-25 cm; yellow (10 YR 8/6) sandy loam, brown (10 YR 5/4) moist; moderate, medium, angular blocky structure; slightly hard, friable, slightly sticky and nonplastic; 15% rock fragments, 100% gravel; slightly acid (pH 6.5).
- C1 25-58 cm; very pale brown (10 YR 8/3) sandy loam, light yellowish brown (10 YR 6/5) moist; massive; slightly hard, loose, nonsticky and nonplastic; 20% rock fragments; 100% gravel; slightly acid (pH 6.3).
- C2 58-100+ cm; very pale brown (10 YR 8/3) sandy loam, light yellowish brown (10 YR 6/5) moist; massive; hard, loose, nonsticky and nonplastic; 20% rock fragments, 100% gravel; medium acid (pH 5.8).

NW4

CLASSIFICATION: coarse-loamy, mixed Mollic Cryoboralf
 DATE DESCRIBED: 10/5/79
 LOCATION: SE $\frac{1}{4}$, NW $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 21, T.5N., R. 4W.
 ELEVATION: 1682 m
 LANDSCAPE POSITION: straight, slightly convex; greatly rolling upland
 SLOPE AND ASPECT: 7%, N. 50° E.
 DRAINAGE: well-drained
 ROCKINESS CLASS: 1
 STONINESS CLASS: 2
 VEGETATION:

Tree species-

Understory and meadow species- Agropyron spicatum, Festuca
idahoensis, Artemisia tridentata

PEDON DESCRIPTION

- A1 0-9 cm; brown (10 YR 4/3) sandy loam, black (10 YR 2/1) moist; moderate, medium, granular structure; slightly hard, friable, nonsticky and slightly plastic; 5% rock fragments, 100% gravel; neutral (pH 7.0).
- B21t 9-15 cm; dark yellowish brown (10 YR 4/4) sandy loam, dark brown (7.5 YR 3/4) moist; moderate medium angular blocky structure; slightly hard, friable, sticky and slightly plastic; 10% rock fragments, 100% gravel; mildly alkaline (pH 7.6).
- B22t 15-27 cm; brown (7.5 YR 5/6) sandy loam, brown (7.5 YR 4/4) moist; moderate, medium, prismatic structure; hard, firm, sticky and slightly plastic; 10% rock fragments, 100% gravel; mildly alkaline (pH 7.8)
- B23t 27-47 cm; dark yellowish brown (10 YR 4/6) sandy loam, brown (7.5 YR 4/6) moist; weak, medium, angular block structure; hard, friable, slightly sticky and slightly plastic; 5% rock fragments, 100% gravel, mildly alkaline (pH 7.8).
- B3ca 47-60 cm; yellowish brown (7.5 YR 5/6) sandy loam, brown (7.5 YR 5/6) moist; moderate, medium, subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 5% rock fragments; 100% gravel; slightly effervescent;

NW4 Continued

moderately alkaline (pH. 8.2).

Clca 60-100 cm; yellow (7.5 YR 7/8) sandy loam, brown (10 YR 5/6) moist; massive, hard, friable, nonsticky and nonplastic; 10% rock fragments, 100% gravel; violently effervescent; moderately alkaline (pH 8.2).

CLASSIFICATION: coarse-loamy, mixed Mollic Cryoboralf
DATE DESCRIBED: 10/6/79
LOCATION: NW $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 16, T. 5N., R. 4W.
ELEVATION: 1646 m
LANDSCAPE POSITION: concave, convex; rolling upland
SLOPE AND ASPECT: 7%, N. 15° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 2
STONINESS CLASS: 2
VEGETATION:

Tree species- (scattered) Pseudotsuga menziesii

Understory and meadow species- Agropyron spicatum, Artemisia tridentata, Juniperus scopulorum

PEDON DESCRIPTION

- A1 0-10 cm; grayish brown (10 YR 5/2) sandy loam, black (10 YR 2/1) moist; moderate, medium, granular structure; slightly hard, very friable, nonsticky and nonplastic; 3% rock fragments; 100% gravel; neutral (pH 7.0).
 B21 10-34 cm; brown (10 YR 4/4) sandy loam, brown (10 YR 4/3) moist; moderate, coarse, angular blocky structure; hard, friable, sticky and slightly plastic; 8% rock fragments, 100% gravel; mildly alkaline (pH 7.6).
 B22t 34-51 cm; pale brown (10 YR 6/3) sandy clay loam, brown (10 YR 5/3) moist; moderate, fine, prismatic structure; very hard, firm, slightly sticky and slightly plastic; thin discontinuous clay flows; 2% rock fragments, 100% gravel; mildly alkaline (pH 7.8).
 Cca 51-100 cm; yellow (10 YR 7/6) sandy loam, light gray (10 YR 7/1) moist; massive; loose, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; violently effervescent; moderately alkaline (pH 8.2).

CLASSIFICATION: coarse-loamy, mixed Typic Cryochrept
DATE DESCRIBED: 10/6/79
LOCATION: NE $\frac{1}{4}$, SW $\frac{1}{4}$, NE $\frac{1}{4}$, SE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 9, T. 5N., R. 4W.
ELEVATION: 1524 m
LANDSCAPE POSITION: straight, convex; valley sideslope
SLOPE AND ASPECT: 7%, N. 75° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 2
STONINESS CLASS: 3
VEGETATION:

Tree species- (scattered) Pseudotsuga menziesii

Understory and meadow species- Agropyron spicatum, Koeleria cristata,
Artemisia tridentata

PEDON DESCRIPTION

- A1 0-7 cm; light brownish gray (10 YR 6/2) sandy loam, black (10 YR 2/1) moist; moderate, medium granular structure, slightly hard, friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; neutral (pH 7.0).
- B2 7-23 cm; brown (10 YR 5/3) sandy loam, dark yellowish brown (10 YR 4/4) moist; moderate, medium, prismatic structure; hard, friable, sticky and plastic; 5% rock fragments, 100% gravel; slightly alkaline (pH 7.8).
- B3ca 23-30 cm; light yellowish brown (10 YR 6/4) sandy loam, dark yellowish brown (10 YR 4/3) moist; weak, medium, subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; 2% rock fragments, 100% gravel; slightly effervescent; moderately alkaline (pH 8.0).
- Clca 30-50 cm; white (10 YR 8/2) sandy clay loam, very pale brown (10 YR 7/3) moist; massive; slightly hard, friable, slightly sticky and slightly plastic; 2% rock fragments, 100% gravel; violently effervescent; moderately alkaline (pH 8.2).
- C2ca 50-85 cm; very pale brown (10 YR 7/4) sandy loam, light yellowish brown (10 YR 6/4) moist; massive; loose, loose, nonsticky and nonplastic; 5% rock fragments, 100% gravel; violently efferevescent; moderately alkaline (pH 8.2).

NW6 Continued

R. 85+ cm; very pale brown, granitic bedrock.

PR1

CLASSIFICATION: sandy, mixed Mollic Cryoboralf
 DATE DESCRIBED: 10/18/79
 LOCATION: NW $\frac{1}{4}$, SW $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 6, T. 7N., R. 3W.
 ELEVATION: 1500m
 LANDSCAPE POSITION: convex, convex; upland bench
 SLOPE AND ASPECT: 16%, N. 125°W.
 DRAINAGE: well-drained
 ROCKINESS CLASS: 2
 STONINESS CLASS: 0
 VEGETATION:

Tree species- Pseudotsuga menziesii, Pinus ponderosa

Understory and meadow species- Agropyron spicatum, Festuca idahoensis

PEDON DESCRIPTION

- A1 0-8 cm; dark grayish brown (10 YR 4/2) loamy sand, black (10 YR 2/1) moist; weak, fine, granular structure; soft, very friable, nonsticky and nonplastic; 2% rock fragments; 100% gravel; medium acid (pH 6.0).
 B2lt 8-16cm; dark grayish brown (10 YR 4/2) sandy loam, very dark gray (10 YR 3/1) moist; moderate, medium, subangular blocky structure; soft, friable, slightly sticky and nonplastic; 5% rock fragments, 100% gravel; slightly acid (pH 6.5).
 B22t 16-24 cm; dark yellowish brown (10 YR 4/4) sandy loam, dark brown moderate, medium, subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; neutral (pH 7.0).
 C1 24-100+ cm; light yellowish brown (10 YR 6/4) loamy sand, yellowish brown (10 YR 5/4) moist; massive; loose, loose, nonsticky and nonplastic; 15% rock fragments, 100% gravel; neutral (pH 7.0).

CLASSIFICATION: sandy, mixed Mollic Cryoboralf
DATE DESCRIBED: 10/18/79
LOCATION: SE¹/₄, SE¹/₄, NW¹/₄, NW¹/₄, SE¹/₄ Sec. 8, T. 7N., R. 3W.
ELEVATION: 1524 m
LANDSCAPE POSITION: straight, convex; valley sideslope
SLOPE AND ASPECT: 25%, N. 110° W.
DRAINAGE: well-drained
ROCKINESS CLASS: 3
STONINESS CLASS: 3
VEGETATION:
Tree species- Pseudotsuga menziesii, Pinus ponderosa

Understory and meadow species-

PEDON DESCRIPTION

- 01 4-0 cm; liter
- A21 0-6 cm; dark brown (10 YR 3/3) sandy loam, very dark grayish brown (10 YR 3/2) moist; weak, very coarse, platy structure; soft, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; medium acid (pH 6.0).
- A22 6-27 cm; yellowish brown (10 YR 5/4) sandy loam, dark brown (10 YR 3/3) moist; weak, very coarse, platy structure; soft, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; medium acid (pH 5.6).
- B2t 27-48 cm; brownish yellow (10 YR 6/6) loamy sand, yellowish brown (10 YR 5/4) moist; moderate, medium, subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 10% rock fragments, 100% gravel; medium acid (pH 6.0).
- C 48-63cm; brownish yellow (10 YR 6/5) loamy sand, yellowish brown (10 YR 5/5) moist; massive; loose, loose, nonsticky and nonplastic; 15% rock fragments, 100% gravel; slightly acid (pH 6.5).
- R 63+ cm; brownish yellow, granitic bedrock.

CLASSIFICATION: coarse-loamy, mixed Mollic Cryoboralf
 DATE DESCRIBED: 10/18/79
 LOCATION: SE $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 16, T. 7N., R. 3W.
 ELEVATION: 1584 m
 LANDSCAPE POSITION: convex, convex; upland ridge
 SLOPE AND ASPECT: 18%, N. 165° W.
 DRAINAGE: well-drained
 ROCKINESS CLASS: 3
 STONINESS CLASS: 0
 VEGETATION:

Tree species- Pseudotsuga menziesii, Pinus ponderosa

Understory and meadow species-

PEDON DESCRIPTION

- 01 3-0 cm; liter
- A21 0-3 cm; light brownish gray (10 YR 6/2) loamy sand, black (10 YR 2/1) moist; weak, medium, platy structure; soft, very friable, nonsticky and nonplastic; 2% rock fragments, 100% gravel; medium acid (pH 5.8).
- A22 3-14 cm; brown (10 YR 5/4) loamy sand, dark brown (10 YR 3/3) moist; weak, coarse, platy structure; loose, very friable, nonsticky and nonplastic; 2% rock fragments, 100% gravel; medium acid (pH 5.8).
- B21t 14-50 cm; pale brown (10 YR 6/3) sandy loam, yellowish brown (10 YR 5/4) moist; weak medium subangular blocky structure; slightly hard, friable nonsticky and nonplastic; 5% rock fragments, 100% gravel; medium acid (pH 6.0).
- B22t 50-100+ cm; light yellowish brown (10 YR 6/4) sandy loam, brown, (10 YR 4/3) moist; moderate, coarse, subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; medium acid (pH 6.0).

CLASSIFICATION: coarse-loamy, mixed Mollic Cryoboralf
DATE DESCRIBED: 10/19/79
LOCATION: SW $\frac{1}{4}$, NE $\frac{1}{4}$, SW $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 15, T. 7N., R. 3W.
ELEVATION: 1768 m
LANDSCAPE POSITION: convex, convex, valley sideslope
SLOPE AND ASPECT: 25%, N. 110° W.
DRAINAGE: well-drained
ROCKINESS CLASS: 4
STONINESS CLASS: 0
VEGETATION:

Tree species- Pseudotsuga menziesii, Pinus ponderosa

Understory and meadow species- Arctostaphylos uva-ursi

PEDON DESCRIPTION

- 01 4-0 cm; liter
- A1 0-4 cm; light gray (10 YR 6/1) sandy loam, very dark grayish brown (10 YR 3/2) moist; weak, medium, granular structure; soft, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; medium acid (pH 6.0).
- A21 4-17 cm; pale brown (10 YR 6/3) loamy sand, dark yellowish brown (10 YR 4/4) moist; weak, very coarse, platy structure; slightly hard, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; medium acid (pH 5.6).
- A22 17-38 cm; pale brown (10 YR 6/3) sandy loam, brown (10 YR 5/3) moist; massive; slightly hard, friable, nonsticky and nonplastic; 10% rock fragments, 100% gravel; medium acid (pH 5.8).
- B21t 38-69 cm; very pale brown (10 YR 7/3) sandy loam, brown (10 YR 4/3) moist; moderate, coarse, subangular blocky structure, slightly hard, friable, slightly sticky and nonplastic; 5% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B22t 60-100+ cm; light yellowish brown (7.5 YR 6/4) sandy loam, dark yellowish brown (10 YR 4/4) moist; moderate, medium, subangular blocky structure; hard, friable, slightly sticky and slightly plastic; 5% rock fragments, 100% gravel; neutral (pH 6.8).

MC1

CLASSIFICATION: coarse-loamy, mixed Mollic Cryoboralf
DATE DESCRIBED: 10/16/79
LOCATION: NW $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 3, T. 9N., R. 2W.
ELEVATION: 1524 m
LANDSCAPE POSITION: straight, convex; upland ridge sideslope
SLOPE AND ASPECT: 23%, N. 80° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 1
STONINESS CLASS: 2
VEGETATION:
Tree species- Pseudotsuga menziesii, Pinus ponderosa

Understory and meadow species- Arctostaphylos uva-ursi, Vaccinium
globulare

PEDON DESCRIPTION

- 01 7-0 cm; liter
- A1 0-4 cm; very dark gray (10 YR 3/1) sandy loam, black (10 YR 2/1) moist; weak, medium, granular structure; soft, very friable, slightly sticky and slightly plastic; 2% rock fragments, 100% gravel; medium acid (pH 5.8).
- A2 4-19 cm; brown (10 YR 5/3) sandy loam, very dark grayish brown (10 YR 3/2) moist; weak, very coarse, platy structure; slightly hard, friable, slightly sticky and slightly plastic; 2% rock fragments, 100% gravel; medium acid (pH 5.8).
- B21t 19-32 cm; dark brown (10 YR 3/3) loam, dark brown (10 YR 3/3) moist; moderate, medium, subangular blocky structure; hard, friable, sticky and slightly plastic; thin discontinuous clay flows; 2% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B22t 32-49 cm; dark yellowish brown (7.5 YR 4/4) sandy clay, dark yellowish brown (10 YR 4/5) moist; moderate, medium, subangular blocky structure; hard, friable, sticky and slightly plastic; thick continuous clay flows; 2% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B23t 49-60 cm; brown (10 YR 5/4) sandy loam, dark yellowish brown (10 YR 4/4) moist; weak, medium, subangular blocky structure;

MC1 Continued

hard, friable, sticky and slightly plastic; thin continuous clay flows; 5% rock fragments, 100% gravel; slightly acid (pH 6.5).

B24t 60-72 cm; yellowish brown (7.5 YR 5/8) sandy loam, dark yellowish brown (7.5 YR 4/6) moist; moderate, medium, sub-angular blocky structure; very hard, friable, sticky and slightly plastic; thin continuous clay flows; 5% rock fragments, 100% gravel; neutral (pH 6.8).

C 72-100+ cm; brownish yellow (10 YR 6/8) sandy loam, brown (10 YR 5/4) moist; massive, loose, loose, nonsticky and nonplastic; 5% rock fragments, 100% gravel; neutral (pH 6.8).

MC2

CLASSIFICATION: coarse-loamy, mixed Mollic Cryoboralf
DATE DESCRIBED: 10/16/79
LOCATION: NE $\frac{1}{4}$, SE $\frac{1}{4}$, NW $\frac{1}{4}$, SW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 30, T. 9N., R. 2W.
ELEVATION: 1584 m
LANDSCAPE POSITION: convex, convex; upland ridge sideslope
SLOPE AND ASPECT: 23%, N. 70° W.
DRAINAGE: well-drained
ROCKINESS CLASS: 2
STONINESS CLASS: 0
VEGETATION:

Tree species- Pseudotsuga menziesii, Pinus ponderosa

Understory and meadow species- Arctostaphylos uva-ursi, Calamagrostis rubescens, Berberis repens, Spiraea betulifolia

PEDON DESCRIPTION

- 01 4-0 cm; liter
- A2 0-6 cm; dark grayish brown (10 YR 4/2) sandy loam, very dark gray (10 YR 3/1) moist; weak, very fine, granular structure; soft, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B21t 6-13 cm; dark yellowish brown (10 YR 3/4) sandy loam, very dark grayish brown (10 YR 3/2) moist; moderate, coarse, subangular block structure; hard, friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; medium acid (pH 5.8).
- B22t 13-27 cm; dark yellowish brown (10 YR 4/4) sandy loam, dark brown (10 YR 3/3) moist; moderate, medium, subangular blocky structure; hard, friable, slightly sticky and nonplastic; loamy lamellae, .5 cm thick, 3 cm apart; 10% rock fragments, 100% gravel; medium acid (pH 6.0).
- C 27-100+ cm; yellowish brown (10 YR 5/6) sandy loam, dark yellowish brown (10 YR 4/4) moist; massive; loose, very friable, nonsticky and nonplastic; 20% rock fragments, 100% gravel; medium acid (pH 6.0).

CLASSIFICATION: coarse-loamy, mixed Mollic Cryoboralf
DATE DESCRIBED: 10/16/79
LOCATION: SW $\frac{1}{4}$, SW $\frac{1}{4}$, NE $\frac{1}{4}$, SE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 6, T. 8N., R. 2W.
ELEVATION: 1640 m
LANDSCAPE POSITION: convex; convex; rolling upland
SLOPE AND ASPECT: 19%, N. 120° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 3
STONINESS CLASS: 2
VEGETATION:

Tree species- Pseudotsuga menziesii, Pinus ponderosa

Understory and meadow species- Arctostaphylos uva-ursi, Calamagrostis rubescens, Vaccinium globulare

PEDON DESCRIPTION

- 01 4-1 cm; liter
- A1 0-4 cm; very dark grayish brown (10 YR 3/2) sandy loam, very dark brown (10 YR 2/2) moist; weak, fine, granular structure; soft, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; medium acid (pH 6.0).
- A21 5-22 cm; light yellowish brown (10 YR 6/4) sandy loam, dark brown (10 YR 3/3) moist; moderate, very coarse, platy structure; slightly hard, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; medium acid (pH 6.0).
- A22 22-45 cm; yellowish brown (10 YR 5/4) loamy sand, brown (10 YR 4/3) moist; weak, medium, subangular blocky structure; slightly hard, friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B21t 45-63 cm; yellowish brown (10 YR 5/6) sandy loam, dark yellowish brown (10 YR 4/4) moist; moderate, medium, subangular blocky structure; hard friable, nonsticky and nonplastic; 10% rock fragments, 100% gravel; neutral (pH 6.8).
- B22t 63-100+ cm; brownish yellow (10 YR 6/6) sandy loam, dark yellowish brown (10 YR 3/4) moist; moderate, medium subangular block structure; hard friable, nonsticky and nonplastic; sandy clay loam lamellae, 1 cm thick, 5 cm apart; 15% rock fragments, 100% gravel; neutral (pH 7.0).

CLASSIFICATION: sandy, mixed Typic Cryochrept
DATE DESCRIBED: 10/16/79
LOCATION: NW $\frac{1}{4}$, SW $\frac{1}{4}$, NE $\frac{1}{4}$, SE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 7, T. 8N., R. 2W.
ELEVATION: 1658m
LANDSCAPE POSITION: convex, concave; rolling upland
SLOPE AND ASPECT: 19%, N. 70° E.
DRAINAGE: well-drained
ROCKINESS CLASS: 2
STONINESS CLASS: 0
VEGETATION:
Tree species- Pseudotsuga menziesii, Pinus ponderosa

Understory and meadow species- Arctostaphylos uva-ursi, Calamagrostis rubescens, Festuca idahoensis, Berberis repens

PEDON DESCRIPTION

- 01 5-0 cm; liter
- A1 0-5 cm; grayish brown (10 YR 5/2) sandy loam, very dark grayish brown (10 YR 3/2) moist; weak, fine, granular structure; soft, very friable, nonsticky and nonplastic, neutral (ph. 7.0).
- A2 5-12 cm; brown (10 YR 5/4) sandy loam, dark brown (10 YR 3/3) moist; weak, very coarse, platy structure; soft, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; slightly acid (pH 6.5).
- B21 12-26 cm; brown (10 YR 5/3) sandy loam, dark brown (10 YR 3/3) moist; weak, medium, subangular blocky structure; slightly hard, very friable, slightly sticky and nonplastic; 5% rock fragments, 100% gravel; medium acid (pH 5.7).
- B22 26-53 cm; brownish yellow (10 YR 6/6) sandy loam, dark yellowish brown (10 YR 4/4) moist; moderate, coarse, subangular blocky structure; slightly hard, friable, slightly sticky and nonplastic; 10% rock fragments, 100% gravel; slightly acid (pH 6.2).
- C 53-100+ cm; brownish yellow (10 YR 6/8) loamy sand, dark yellowish brown (10 YR 4/4) moist; massive; loose, loose, nonsticky and nonplastic; 10% rock fragments, 100% gravel, slightly acid (pH 6.5).

CLASSIFICATION: coarse-loamy, mixed Mollic Cryoboralf
DATE DESCRIBED: 10/16/79
LOCATION: SE $\frac{1}{4}$, NE $\frac{1}{4}$, NW $\frac{1}{4}$, SE $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 18, T. 8N., R. 2W.
ELEVATION: 1695m
LANDSCAPE POSITION: convex, convex, upland ridge sideslope
SLOPE AND ASPECT: 21%, N. 130° W.
DRAINAGE: well-drained
ROCKINESS CLASS: 3
STONINESS CLASS: 0
VEGETATION:

Tree species-

Understory and meadow species- Festuca idahoensis, Koeleria
cristata, sedges

PEDON DESCRIPTION

- A1 0-9 cm; very dark grayish brown (10 YR 3/2) sandy loam, black (10 YR 2/1) moist; weak, fine, granular structure; soft, very friable, nonsticky and nonplastic; 5% rock fragments, 100% gravel; medium acid (pH 6.0).
- B21t 9-24 cm; dark brown (10 YR 3/3) sandy loam, very dark grayish brown (10 YR 3/2) moist; weak, medium, subangular blocky structure; slightly hard, friable, slightly sticky and nonplastic; 10% rock fragments, 100% gravel, slightly acid (pH 6.2).
- B22t 24-46 cm; brownish yellow (10 YR 6/6) sandy loam, brown (10 YR 4/3) moist; moderate, medium, angular blocky structure; hard, friable, sticky and slightly plastic; 2% rock fragments, 100% gravel, slightly acid (pH 6.5).
- B23t 46-60cm; yellowish brown (10 YR 5/6) sandy clay loam, dark yellowish brown (10 YR 4/4) moist; moderate, medium, subangular blocky structure; hard, friable, slightly sticky and nonplastic; 5% rock fragments, 100% gravel, neutral (pH 7.0).
- C 60-100+ cm; yellowish brown (10 YR 5/6) loamy sand, dark yellowish brown (10 YR 4/4) moist; massive; loose, loose, nonsticky and nonplastic; 5% rock fragments, 100% gravel, neutral (pH 7.0).

APPENDIX IV

COARSE FRAGMENT CONTENT; COARSE, MEDIUM AND FINE SAND
CONTENT; AND SAND, SILT AND CLAY CONTENT BY HORIZON IN
25 SOILS ON THE KOOTENAI FORMATION

Site	Horizon	Coarse Fragments			Sand Size Fractions			< 2 mm Fractions		
		> 20 mm	20 - 2 mm	Total	Coarse	Medium	Fine	Sand	Silt	Clay
		----- % by vol -----			----- % by wt -----			-----		
B11	A1	31	2	33	0	9	28	37	45	18
	B2t	39	3	42	0	5	26	31	43	26
	C1	39	8	47	1	2	25	28	42	30
	C2	52	2	54	2	7	31	40	40	20
B12	A1	0	1	1	0	2	16	18	58	26
	B21t	0	0	0	0	0	14	14	50	36
	B22t	0	0	0	0	1	3	4	48	48
	B23t	7	2	9	0	0	10	10	38	52
	IIC	29	12	41	0	2	21	23	37	40
B13	A2	43	3	46	1	3	36	40	54	6
	B2t	38	3	41	0	5	36	41	50	9
	C	40	5	45	0	2	61	63	33	4
B14	A21	8	6	14	2	5	26	33	62	5
	A22	25	4	29	1	4	25	30	56	14
	B2t	34	13	47	1	1	12	14	44	42
B15	A1	14	4	18	1	4	23	28	63	9
	A2	55	4	59	2	4	26	32	58	10
	B2t	32	5	37	1	2	29	32	49	19
B16	A2	0	1	45	1	5	22	30	58	12
	B2t	0	1	52	1	4	25	30	54	16
	C	3	8	64	1	1	28	30	60	10
B21	A1	29	4	32	2	7	23	32	58	10
	A2	37	3	40	3	7	28	38	48	14
	B2t	49	7	56	3	4	27	34	36	30
B22	A1	30	8	38	2	4	27	33	58	9
	A2	28	8	36	3	5	26	34	52	14
	B2t	48	9	57	0	3	30	33	36	31
B23	A21	29	11	40	3	4	31	38	52	10
	A22	30	8	38	4	6	42	52	47	1
	B2t	42	7	49	3	5	37	45	39	16
B24	A1	50	4	54	5	9	20	34	56	10
	A2	51	4	55	5	9	26	40	54	6
	B2	52	5	57	5	8	32	42	51	7
B31	A1	0	1	1	1	2	9	12	38	50
	B21	0	3	3	1	1	9	11	36	53
	B22	0	2	2	0	1	9	10	38	52
	C1	0	2	2	0	0	8	8	28	64
	C2r	19	4	23	0	0	2	2	23	75
B32	A1	2	1	3	2	1	12	15	43	42
	B21	2	1	3	0	1	8	9	46	45
	B22	1	1	2	0	1	13	14	46	40
	B23t	14	16	30	0	1	5	6	34	60
B33	A1	10	2	12	2	4	11	17	33	50
	B21	5	1	6	0	3	11	14	34	52
	B22	12	3	15	1	3	14	18	32	50
	Cr	51	3	54	0	0	8	8	31	61

Site	Horizon	Coarse Fragments			Sand Size Fractions			< 2 mm Fractions		
		> 20 mm	20 - 2 mm	Total	Coarse	Medium	Fine	Sand	Silt	Clay
		- - - - % by vol - - - -			- - - - - % by wt - - - -			- - - - -		
B34	A1	1	2	3	1	2	8	11	48	41
	B21t	0	1	1	0	2	8	10	43	47
	B22t	1	1	2	0	2	8	10	38	52
	B23t	20	2	22	0	1	4	5	29	71
	C	41	7	48	0	0	6	6	28	66
B41	A1	4	5	9	5	6	19	30	50	20
	B21t	9	5	14	2	6	20	28	42	30
	B22t	30	7	37	4	8	24	36	33	31
	B23t	24	13	37	7	5	21	33	33	34
	C	26	9	35	2	5	27	34	36	30
B42	A1	10	1	11	1	3	17	20	51	29
	B21t	10	1	11	0	2	16	18	42	40
	B22t	31	4	35	1	4	17	21	34	45
	B23t	35	3	38	1	3	19	22	32	46
	Cr	15	13	28	0	1	6	7	21	72
B43	A1	1	4	5	1	3	14	18	51	31
	B21	2	1	3	0	2	13	15	54	31
	B22	17	2	19	0	2	14	16	48	36
	B23t	58	2	60	0	2	14	16	43	41
B44	A1	8	7	15	1	5	24	30	53	17
	A2	48	5	53	8	6	24	38	47	15
	B2t	36	4	40	1	4	25	30	40	30
B45	A1	0	3	4	1	2	18	21	43	36
	B21t	11	2	13	1	4	15	20	43	37
	B22t	20	2	22	1	2	19	22	38	40
	B23t	32	3	35	0	1	11	12	38	50
B51	A1	20	11	31	4	8	24	36	54	10
	B21t	21	14	35	2	9	18	29	49	22
	B22t	24	10	34	4	5	23	32	48	20
	C	45	13	58	3	6	18	27	47	26
B52	A1	10	7	17	3	7	18	28	46	26
	B21	10	5	15	5	6	17	28	46	26
	B22	12	9	21	7	8	17	32	41	27
	B23	25	6	31	4	8	18	30	44	26
B53	A1	0	1	1	0	2	17	19	41	40
	B21	0	1	1	1	2	12	15	40	45
	B22	0	1	1	1	1	20	22	33	45
	B23t	0	1	1	1	1	11	13	39	48
	B24t	0	4	4	1	1	9	11	29	60
B54	A1	2	2	4	6	3	13	22	35	43
	B21	0	2	2	0	3	13	16	43	41
	B22t	0	5	5	1	3	11	14	34	52
	B23t	0	7	7	0	0	5	5	33	62
	C1	0	8	8	0	1	11	11	39	50
B55	A1	0	5	5	2	7	18	27	38	35
	B21	0	5	5	3	4	14	21	43	36
	B22	1	8	9	5	5	16	26	40	34
	B23t	0	3	3	0	2	11	12	33	55
B56	A1	2	4	6	7	8	21	36	45	20
	B21t	0	4	4	6	6	20	32	44	24
	B22t	0	9	9	4	7	21	32	42	36
	Cr	1	30	31	7	5	11	23	36	41

APPENDIX V

COARSE FRAGMENT CONTENT; COARSE, MEDIUM AND FINE SAND
CONTENT; AND SAND, SILT AND CLAY CONTENT BY HORIZON IN
25 SOILS ON THE BOULDER BATHOLITH

Site	Horizon	Coarse Fragments			Sand Size Fractions			<2mm Fractions		
		>20 mm	20 - 2 mm	Total	Coarse	Medium	Fine	Sand	Silt	Clay
		- - - - % by vol - - - -			- - - - - % by wt - - - - -			- - - - -		
PS1	A1	2	8	10	27	18	29	74	22	4
	B2t	0	6	6	15	18	25	58	18	24
	B3ca	0	3	3	21	18	28	68	22	10
	Cr	0	23	23	42	22	20	84	10	6
PS2	A2	0	4	4	25	22	26	73	20	7
	B21t	0	2	2	15	18	33	66	25	9
	B22t	0	0	0	15	19	35	69	22	9
	B23t	0	1	1	19	18	31	68	23	9
	C1	0	1	1	13	10	44	67	27	6
PS3	A1	0	2	2	24	19	26	69	24	7
	B21	1	2	3	21	20	28	69	25	6
	B22	7	2	9	21	20	27	68	26	6
	C1	0	12	12	36	20	25	82	13	5
PS4	A21	0	4	4	17	22	36	75	18	7
	A22	1	2	3	22	22	37	81	17	2
	B2t	7	7	14	25	20	32	77	14	9
	Cr	0	14	14	31	19	29	79	14	7
PS5	A1	0	16	16	25	21	30	76	18	6
	B1	0	2	2	21	22	32	75	20	5
	B2t	0	11	11	20	23	30	73	17	10
	C	0	20	20	25	22	34	81	18	1
DM1	A1	0	3	3	12	14	45	71	24	5
	B2t	3	8	11	14	18	39	71	14	15
	B31ca	3	6	9	21	16	33	70	15	15
	B32ca	0	1	1	14	10	34	58	28	14
	Crca	0	7	7	20	19	39	78	15	7
DM2	A2	0	4	4	26	22	30	78	20	2
	B21t	6	6	12	25	21	29	75	18	7
	B22t	0	5	5	33	25	26	84	10	6
	Cr	0	12	12	40	19	25	84	13	3
DM3	A1	0	3	3	29	18	25	72	24	4
	B21t	0	5	5	32	16	19	67	23	10
	B22t	0	9	9	24	19	24	67	24	9
	Cr	0	13	13	40	18	19	77	19	4
DM4	A2	0	7	7	33	16	17	68	20	12
	B2	0	17	17	36	12	18	66	21	13
	Cr	0	29	29	41	18	22	81	15	4
DM5	A2	0	1	1	39	17	30	86	9	5
	B21t	0	6	6	35	18	22	75	18	7
	B22t	0	8	8	31	18	25	74	19	7
	Cr	0	10	10	45	18	22	85	10	5
NW1	A1	0	7	7	32	16	20	69	22	9
	B21	0	5	5	35	16	20	71	19	10
	B22	0	5	5	30	17	28	75	20	5
	C	0	8	8	24	20	33	77	19	4

Site	Horizon	Coarse Fragments			Sand Size Fractions			<2mm Fractions		
		>20 mm	20 - 2 mm	Total	Coarse	Medium	Fine	Sand	Silt	Clay
		- - - - - % by vol - - - - -			- - - - - % by wt - - - - -					
NW2	A1	0	5	5	26	14	22	62	29	0
	B21t	7	9	16	33	13	16	73	24	13
	B22t	0	5	5	36	15	23	72	21	17
	C1	0	16	16	37	17	26	80	13	7
	C2	0	13	13	41	18	22	81	13	6
NW3	A2	0	9	9	36	15	19	70	17	13
	B2	0	18	18	33	16	23	72	13	15
	C1	0	19	19	27	17	29	73	15	12
	C2	0	23	23	38	17	19	73	15	12
NW4	A1	0	7	7	27	12	23	62	32	6
	B21t	1	12	13	27	10	21	58	26	16
	B22t	0	14	14	28	13	21	62	18	20
	B23t	0	8	8	26	15	25	66	18	16
	B3ca	1	7	8	29	16	27	72	11	17
	C1ca	4	8	12	26	18	29	73	10	17
NW5	A1	0	5	5	26	17	25	68	20	12
	B21	0	12	12	35	14	19	68	18	14
	B22t	0	2	2	14	16	25	55	20	25
	Cca	0	6	6	31	16	26	73	17	10
NW6	A1	3	5	8	27	16	18	61	25	14
	B2	0	9	9	25	18	20	63	21	16
	B3ca	0	3	3	22	14	19	55	29	16
	C1ca	0	3	3	25	13	18	56	16	28
	C2ca	0	9	9	30	14	23	67	19	14
PR1	A1	0	3	3	33	19	25	17	18	5
	B21t	0	7	7	35	18	22	75	16	9
	B22t	1	6	7	38	18	22	78	9	13
	C1	0	18	18	44	20	22	86	9	5
PR2	A21	1	4	4	30	21	24	73	18	9
	A22	0	8	8	14	21	39	75	18	7
	B2t	1	9	10	17	25	39	81	9	10
	C1	7	10	17	32	20	30	82	14	6
PR3	A21	0	3	3	28	19	27	75	24	4
	A22	0	3	3	28	18	28	74	23	3
	B21t	0	4	4	29	19	26	74	19	7
	B22t	0	5	5	25	19	29	73	21	6
PR4	A1	0	4	4	33	15	20	68	25	7
	A21	0	3	3	28	17	25	70	26	4
	A22	0	11	11	33	15	22	70	24	6
	B21t	0	5	5	36	14	20	70	18	12
	B22t	0	8	8	31	14	19	64	24	12
MC1	A1	0	4	4	21	14	19	54	36	10
	A2	0	4	4	26	15	23	64	26	10
	B21t	0	3	3	15	14	20	49	35	16
	B22t	0	2	2	15	14	20	46	18	36
	B23t	1	4	4	26	14	19	59	22	19
	B24t	2	4	4	16	17	27	60	24	16
	C	0	6	6	31	20	26	77	13	10

Site	Horizon	Coarse Fragments			Sand Size Fractions			<2mm Fractions		
		>20 mm	20 - 2 mm	Total	Coarse	Medium	Fine	Sand	Silt	Clay
		% by vol-			% by wt					
MC2	A2	0	7	7	31	14	24	69	27	4
	B21t	0	8	8	38	14	20	72	18	10
	B22t	0	10	10	33	16	22	71	20	9
	C1	0	24	24	47	17	23	67	28	5
MC3	A1	0	7	7	39	14	20	73	22	5
	A21	0	7	7	40	14	20	74	19	7
	A22	0	8	8	34	18	25	77	19	4
	B21t	0	14	14	19	26	32	77	14	9
	B22t	0	15	15	32	17	24	73	17	10
MC4	A1	0	2	2	32	14	22	68	25	7
	A2	0	6	6	35	17	21	73	20	7
	B21	0	6	6	25	19	27	71	23	6
	B22	0	9	9	28	16	25	69	25	6
	C1	0	13	13	43	17	14	74	13	3
MC5	A1	0	4	4	22	14	24	60	34	6
	B21t	0	13	13	22	16	24	62	26	12
	B22t	0	3	3	29	15	18	62	14	24
	B23t	0	5	5	16	21	30	67	18	15
	C1	0	7	7	31	19	27	77	17	6

Contrasting soil development on the sea

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