Investigation of selected Berkeley Pit overburden as a medium for plant growth
by Fred Elmer Parady

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Land Rehabilitation
Montana State University
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Abstract:
Lack of suitable native soil for covering waste dumps poses a critical reclamation problem at the Berkeley Complex in Butte, Montana. The purpose of this study was therefore to determine the capabilities of alluvial overburden materials for use as a coversoil.

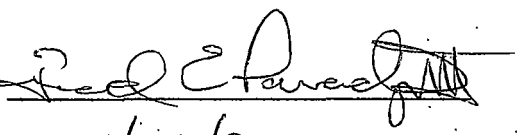
A greenhouse study used wheat as a growth indicator to evaluate manure and lime amendment levels on three alluvium sources. The alluvium was intensively sampled and analyzed in the laboratory to characterize its physical and chemical properties. Further greenhouse study assessed the response to the stress of crust formation of cicer milkvetch, thickspike wheatgrass, sheep fescue, and slender wheatgrass grown in an alluvium control or alluvium treated with manure, hay, or crimped straw. Field observation identified a surface crusting problem in alluvial materials applied to a dump slope. A scanning electron microscope was utilized to determine the mechanisms of crust formation.

Results indicated that alluvium from the east rim of the Berkeley Pit was the best plant growth medium evaluated. Added lime was not of significant benefit. Manure mixed with alluvium at a 1:4 volumetric ratio provided the greatest increase in wheat yields. Moisture contents high enough to insure plant germination within the alluvium reduced crust strength below levels inhibitory to plant emergence, except for species with small seeds such as sheep fescue. Crusting problems were shown to be a physical phenomenon caused by grain packing and clay adhesion within the sand fraction. Low percentages of expanding clays limit the tendency for cracks to develop in the crust. Organic matter addition decreases crust strength by aiding formation of stable soil aggregates and decreasing clay adhesion in the sand fraction.

Berkeley Pit alluvium can be used as a coversoil with a good suitability classification for pH, electrical conductivity, texture, and sodium adsorption ratio. Rock fragment percentage is easily estimated in the field and should be used as a selection criterion for the alluvium, with < 35% rock fragment content providing for coversoil with at least a fair suitability classification. Levels of selenium, arsenic, mercury, nickel, lead, and cadmium in the alluvium did not exceed suspected toxic levels. Copper, manganese, and zinc levels were elevated in the alluvium, but localized toxicities to plants can be ameliorated by liming, addition of organic matter, or fertilization.

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by

Fred Elmer Parady III

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

of

MASTER OF SCIENCE

in

Land Rehabilitation

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ABSTRACT

Lack of suitable native soil for covering waste dumps poses a critical reclamation problem at the Berkeley Complex in Butte, Montana. The purpose of this study was therefore to determine the capabilities of alluvial overburden materials for use as a coversoil. A greenhouse study used wheat as a growth indicator to evaluate manure and lime amendment levels on three alluvium sources. The alluvium was intensively sampled and analyzed in the laboratory to characterize its physical and chemical properties. Further greenhouse study assessed the response to the stress of crust formation of cicer milkvetch, thickspike wheatgrass, sheep fescue, and slender wheatgrass grown in an alluvium control or alluvium treated with manure, hay, or crimped straw. Field observation identified a surface crusting problem in alluvial materials applied to a dump slope. A scanning electron microscope was utilized to determine the mechanisms of crust formation.

Results indicated that alluvium from the east rim of the Berkeley Pit was the best plant growth medium evaluated. Added lime was not of significant benefit. Manure mixed with alluvium at a 1:4 volumetric ratio provided the greatest increase in wheat yields. Moisture contents high enough to insure plant germination within the alluvium reduced crust strength below levels inhibitory to plant emergence, except for species with small seeds such as sheep fescue. Crusting problems were shown to be a physical phenomenon caused by grain packing and clay adhesion within the sand fraction. Low percentages of expanding clays limit the tendency for cracks to develop in the crust. Organic matter addition decreases crust strength by aiding formation of stable soil aggregates and decreasing clay adhesion in the sand fraction.

Berkeley Pit alluvium can be used as a coversoil with a good suitability classification for pH, electrical conductivity, texture, and sodium adsorption ratio. Rock fragment percentage is easily estimated in the field and should be used as a selection criterion for the alluvium, with < 35% rock fragment content providing for coversoil with at least a fair suitability classification. Levels of selenium, arsenic, mercury, nickel, lead, and cadmium in the alluvium did not exceed suspected toxic levels. Copper, manganese, and zinc levels were elevated in the alluvium, but localized toxicities to plants can be ameliorated by liming, addition of organic matter, or fertilization.

INTRODUCTION

Intensive mining in the Butte area began with the discovery of gold in 1864 (Smith, 1953). The Berkeley Pit opened in 1955 and now uses large scale truck and shovel operations to mine low grade copper ore. The mining site, presently known as the Berkeley Complex, occupies approximately 3250 ha in the northeast corner of the Summit Valley (Figure 1).

Lack of suitable native soil for covering waste dumps poses a critical reclamation problem at the Berkeley Complex. Undisturbed soils in the area are quite shallow, ranging from 25 to 100 cm deep (Boettcher, 1970). The area has been highly disturbed by mining activity, decreasing the limited quantities of native soil available for salvage. Construction of mine waste dumps has increased land surface area, causing a concomittant increase in the need for coversoil materials. Coversoil is defined as any material used on final reclamation surfaces as a plant growth media (Schafer, 1979). Waste dumps contain a variety of materials (Figure 2), including ore mixed with waste materials. Further, geological materials overlying mineral ore deposits frequently contain low concentrations of disseminated pyritic minerals. Pyritic minerals oxidize upon exposure to air and water, acidifying the spoil materials and potentially solubilizing toxic quantities of heavy metals (Sorensen et al., 1980). Heterogeneity of the coarse materials at the dump surface and the presence of pyritic

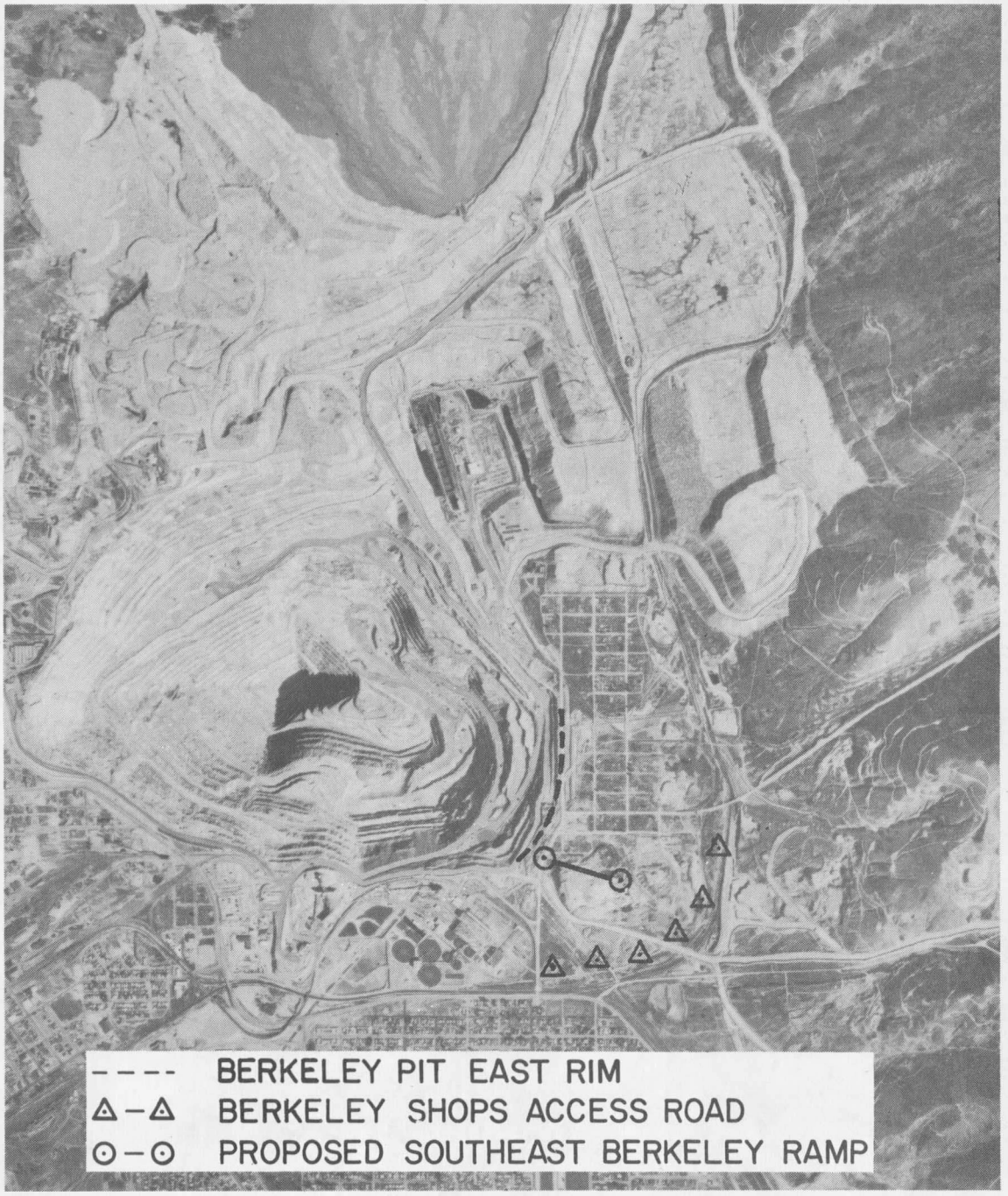


Figure 1. Aerial photograph of the Berkeley Complex.

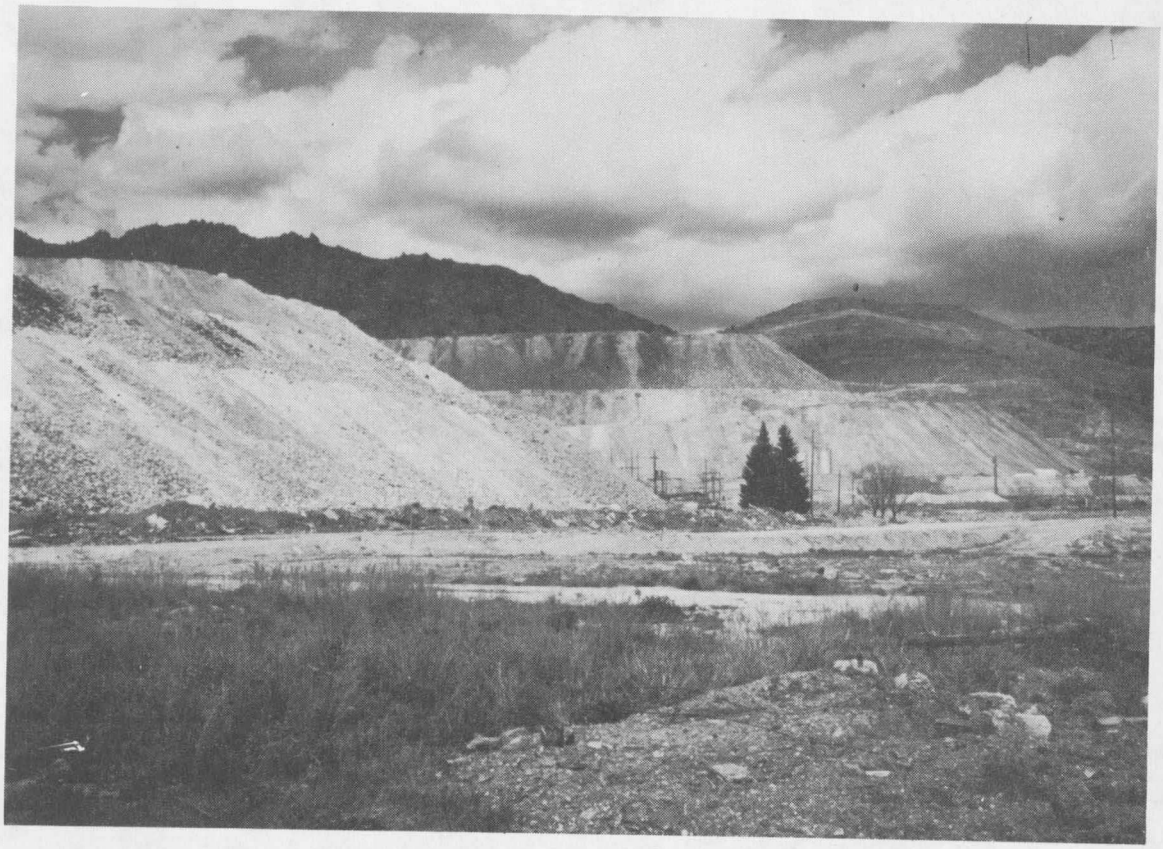


Figure 2. Typical waste dump at the Berkeley Complex.

minerals necessitates the burial of these materials with an acceptable depth of suitable coversoil.

Soil physically supports plants while providing the water and nutrient reservoirs necessary for growth (Brady, 1974). Selecting overburden materials for use as coversoil thus requires evaluation of the range of physical and chemical properties known to affect plant growth. Since plant communities reflect the range of stresses present in the environment over time, the material selected should accommodate the vegetation envisioned for the post mining land use. Field trials are needed to demonstrate the ability of the coversoil to support plant communities over time and over the range of natural stresses.

A substantial deposit of alluvial materials covers a large portion of the Berkeley Complex. These materials offer promise for use as a coversoil and will be made available by the eastward expansion of the Berkeley Pit. However, field observation identified a surface crusting problem in alluvial materials placed on a dump slope. The purpose of this study was to determine the capabilities of alluvial overburden materials for use as coversoil on areas which must be reclaimed in accordance with reclamation plans approved by the Montana Department of State Lands.

Specific project objectives include:

1. Characterization of the chemical and physical properties of the alluvial material.
2. Determination of plant response to amendment treatments for enhancing alluvial suitability for use as a coversoil.
3. Identification of crust formation mechanisms.
4. Determination of plant response to the stress of crust formation.

LITERATURE REVIEW

Use Of Overburden As Coversoil

The single most important factor in successful reclamation is the nature of the material left at the surface following mining (McCormack, 1976). Species seeded on mined land face an environment of interrelated limiting factors or stresses, including drought, low nutrient availability, accelerated erosion, extremes of temperature, and competition (Sindelar and Plantenberg, 1980). Where the amount of topsoil is limited, as in areas mined in the past when topsoil salvage was infrequent, an adequate depth of coversoil can potentially be provided by mixing available topsoil with selected spoil material (Schuman and Taylor, 1978). Use of selected overburden materials as coversoil has received little investigation, although studies of a variety of overburden materials and abandoned spoils have been reported.

Extensive evaluations of plant succession and soil genesis have been conducted on a range of 1 to 50 year old coal mine spoils in southeastern Montana. Schafer et al. (1979) reported that three to four years were required before root systems and levels of microbiological activity in minesoils resembled those in native soils; that only 50 years were required for organic matter content and structure of minesoils to attain levels common in the top 5 cm of native soils; and that as long as 500 years may be necessary before organic matter

content and structure of deeper layers resemble natural soils. Although minesoils are different from native soils, the study pointed out that they are not necessarily inferior. The authors of the study concluded that due to limited water availability in the arid West, minesoils should be selected for high water-holding capacity. Study of plant succession on coal mine spoils abandoned in 1928 and 1930 revealed spoil texture to be a major factor affecting rate of succession. Highly advanced communities occurred on spoil higher in silt and clay and less advanced communities were found on spoil very high in sand content (Sindelar and Plantenberg, 1979).

Greenhouse studies in Arizona using forage species grown in coal mine spoils and native soils indicated that the spoil material had a lower fertility level. Spoils and native soils had nearly equal yields of alfalfa, barley, and wheat when optimum soil moisture and plant nutrients were supplied (Day et al., 1979a). A national questionnaire found corn yields on mine soils to be 4 to 90 percent less than on adjacent native soils, varying with topsoil applications and special treatments of reclaimed areas (Nielson and Miller, 1980). Study of an open pit uranium mine in New Mexico correlated the degree of plant establishment on spoils abandoned between .5 and 20 years, finding that favorable pH, electrical conductivity, and soil texture were closely related to successful vegetation establishment (Reynolds

et al., 1978). Investigation of the reclamation potential of overburden materials from the Fruitland formation in New Mexico concluded that high sodicity and salinity levels, along with low phosphorous contents and possible boron problems, would preclude use of overburden materials as coversoil without significant amendments (Gould et al., 1976). A study of the revegetation potential of acid mine wastes in northeastern California defined low pH as the factor most inhibitory to revegetation, and suggested liming and surface mulch would be necessary for the establishment of seeded grasses and legumes (Butterfield and Tueller, 1980).

Field experiments in Colorado demonstrated that leached, processed oil shale, mulched with peat and sawdust and then fertilized, provided an excellent growth medium for tall wheatgrass (Agropyron elongatum) and Russian wildrye (Elymus junceus) (Schaal, 1973). However, a subsequent study recommended a minimum of 30 cm of soil be placed over the shale due to resalinization following leaching (Harbert and Berg, 1978).

Depths of Coversoil

Coversoils should provide a root zone deep enough to support the post-mining plant community, and the root zone should be free of inimical zones and physical barriers to growth (Schafer et al., 1979).

In general, roots decrease in size and abundance with depth (White and Lewis, 1969). However, Singh and Coleman (1974) found root growth below 40 cm was most rapid early in the growing season and postulated that growth of deep roots was important for utilization of soil water. Weaver and Darland (1949) noted that many roots extended more than a foot below the solum into the parent material. Coupland and Johnson (1964) pointed out that differences in distribution of roots with depth were significant in determining the competitive ability of each species and in explaining species distribution in relation to climate and microclimate.

In an exhaustive study of rooting depths on prairie grasslands, Weaver (1958) used the trench method to identify maximum rooting depth of a variety of grasses. Roots of needlegrass (Stipa spartea), buffalo grass (Buchloe dactyloides), and western wheatgrass (Agropyron smithii) reached depths of 2 m. Big bluestem (Andropogon gerardii) roots attained depths of 4 m. Green needlegrass (Stipa viridula) and Canada wildrye (Elymus canadensis) were shallow rooted, with roots penetrating to only 1 m. The author concluded that for each of the dozen grasses studied (except Junegrass, Koeleria cristata), all attained root depths of at least 1.2 m in the variety of soil types which were examined. Albertson (1937) found similar rooting depths for western wheatgrass and Canada wildrye in Kansas.

Sturges (1977) studied big sagebrush (Artemisia tridentata) rooting patterns in southcentral Wyoming. He concluded that the primary water reservoir for an individual plant extends 91 cm laterally from the trunk and 91 cm deep. Moisture use zones shifted outward and downward as the season progressed. Maximum root penetration was 1.8 m. Roots at one site extended less than 1.5 m deep, reflecting limited water supplies and rocky substrata.

A North Dakota study of crop and native grass yields concluded that 75 to 100 cm of coversoil placed over unsuitable overburden was required to reconstruct productive minesoils (Agricultural Research Service, 1977). Further study of wheat, alfalfa, crested wheatgrass, and native warm season grasses yields on a wedge of topsoil and subsoil of varying depths concluded that all crops studied responded to increased soil thickness up to a total of 75 to 120 cm (Power et al., 1981). All crops extracted water from the spoil below the replaced coversoil in this study.

Standard soil profile description, root biomass, and radioactive tracer techniques were used to characterize root distribution in a study near Colstrip, Montana (Wyatt et al., 1980). One purpose was to determine required depths for burial of toxic overburden material based on maximum rooting depth. Rooting depths on old spoil, new spoil, and native soil were compared. Results from all methods

indicated old spoil had more roots below 100 cm, a difference attributed to an overstory dominated by deeper rooting half shrubs on the old spoil. Root biomass in the upper 100 cm of new spoil was 40% less than in old spoil or native soils, due to the relatively short time the new spoils had been vegetated. Maximum rooting depth was measured for 15 species, with tall wheatgrass (Agropyron elongatum) and needleandthread (Stipa comata) both having the deepest roots at 183 cm. Roots below 76 cm comprised 5% or less of total root biomass, but these deep roots were extremely important for water uptake and plant growth late in the growing season. A minimum of 2 m of non-toxic and non-compacted material was therefore recommended for a post mining root zone.

Soil Crusting

Studies of crusting problems have dealt with soils rather than overburden materials. Crust formation in overburden materials may influence seed germination, emergence, and chemical and physical processes in the same manner as soil crusts.

Although sandy materials do not typically form crusts (Ferry and Olsen, 1975), crusting of materials low in organic matter has been observed (Ahmad and Roblin, 1971). In Queensland, Australia, sandy alluvial soils are low in organic matter due to continuous cropping

and consequently have poor soil structure. Soil particles slaked upon wetting, forming a non-aggregated layer resulting in a strong crust upon drying, with the degree of crust development depending upon rainfall intensity and total precipitation (Gunton and Kerr, 1972). Short, intense rains on a sandy loam soil in California caused crusts up to 7 cm thick upon drying (Timm et al., 1971). Ibanga et al. (1980) reported that in soils with equal amounts of clay, those with the highest amounts of sand formed the hardest crusts. Large particles of a sand mixture have a low total surface area and therefore less clay is necessary to bind the sand grains into a hard aggregate. Edwards (1977) noted that crusting was most severe on tilled soils lacking protective vegetative cover.

A primary response of the soil surface to intense rainfall is the formation of a crust through the consolidation of surface particles (Farres, 1978). McIntyre (1958) suggested two mechanisms involved in crust formation: washing-in of fine particles and compaction of the surface by raindrop impact. Radiant energy is also highly significant in developing crust strength (Goyal et al., 1979). Crust formation may thus be caused by raindrop impact and subsequent drying (Epstein and Grant, 1973).

Holder and Brown (1974), working with a loam textured soil, found an inverse relationship between mechanical impedance and soil water

content of the crust between 2.8 and 20%. Maximum impedance was found in a narrow range of 2.2 to 2.8% soil water, and crust strength increased initially as the soil dried and then declined as surface cracking increased. Busch et al. (1973) reported that irrigation may weaken a crust, and that lower sprinkler application rates produced a consistently weaker crust strength.

Surface crusts in soils may reduce infiltration and increase runoff (Duley, 1939). Crusts can also decrease gaseous diffusion (Ahmad and Roblin, 1971). The effect of these changes is to inhibit seedling germination and emergence (Evans and Buol, 1968). Crusts can also cause loss of seedlings due to heat girdling (Arndt, 1965).

A modulus of rupture test has been the standard method for measurement of soil crust strength (Allison, 1923; Carnes, 1934; Richards, 1953). The modulus of rupture is an intrinsic physical property which is expressed in standard units independent of method of measurement. The method has been modified so that briquet preparation simulates seedbed preparation and wetting and drying cycles under field conditions (Rao and Bhardwaj, 1976). Arndt (1965) has correctly noted that proof of a causal relationship between modulus of rupture and seedling emergence has not been established. The problems in applying laboratory results from this technique to field practices have also been analyzed (Lemos and Lutz, 1957). Arndt (1965) developed a

technique for direct measurement of mechanical impedance. A comparison of the modulus of rupture test with the Fishing Line method and the Shear Vane penetrometer showed good correlation between methods but only .6 correlation with turnip seedling emergence (Page and Hole, 1977).

Scanning electron microscopy has been used to analyze crusts (Chen et al., 1980). The scanning electron microscope utilizes an electron probe synchronized with a cathode ray tube and is well adapted to surface examination of materials, with advantages in minimum sample preparation and changes in magnification not necessitating changes in focus (Kimoto and Russ, 1969).

Seedling emergence through crusts is affected by seed size and weight, soil and crust water content, soil temperature and cumulative degree days (Edwards, 1977). Hadas and Stibbe (1977) reported that the deeper a seed is placed, the harder the soil crust will be when reached by the coleoptile. Morton and Buchele (1960) demonstrated that the energy necessary for emergence, as measured by a mechanical seedling, increased directly with seedling diameter. Emergent force is also directly correlated with seed weight of selected forage seedlings (Jensen et al., 1972). Previous studies indicated that small seeded legumes experience difficulty in emergence (Williams, 1956). Williams (1956) reported the emergence force of small seeded legumes

to be closely correlated to seed weight. Frelich et al. (1973) showed decreasing seedling emergence with increasing soil crust strength for six grass species; tall fescue (Festuca arundinacea) had the smallest seeds and lowest emergence through all crusts. A curvilinear relationship between seedling emergence of wheat, guar, and grain sorghum and crust hardness was demonstrated by Taylor (1962). A special transducer was used to measure seedling emergence force of a variety of plants, including corn and tall wheatgrass, with a positive correlation shown between seed size and emergence force (Gifford and Thran, 1969). Research with wheat showed that crust strength limited seedling emergence at the lower end of the available moisture range, and that the limiting crust strength of 200 to 500 millibars appeared to decrease as available moisture decreased (Hanks and Thorp, 1956). Bennet et al. (1963) showed cotton seedling emergence to be negatively correlated with crust strength and positively correlated with moisture content of the top 8 cm of soil.

Mulches and Soil Amendments

Mulches protect soil by reducing wind velocity, shielding it from raindrop impact, retarding water flow and soil movement by acting as a trap, and by increasing water infiltration; at the same time mulches may enhance seedling establishment by holding seed and fertilizer in

place, modifying temperatures, retaining moisture, and preventing crusting (Kay, 1978a). Kay also pointed out the need for soil mulch or seed coverage to limit germination before sufficient moisture is present for continued growth.

Organic surface residues increase water infiltration rates, reduce evaporation rates, and reduce spring and summer soil temperatures, with the combination of lower temperatures and lower evaporation rates reducing soil crusting (Black and Siddoway, 1979). Nearly any plant material residue can be used as a mulch. An evaluation of wild oat straw showed that straw was effective in reducing splash, blocking sediment movement, delaying runoff initiation, reducing total runoff loss, and reducing crust formation (Singer and Blackard, 1977). Greenhouse studies on coal mine spoil in Arizona demonstrated that a mulch of Russian thistle was as effective as barley straw in reducing soil moisture loss (Day et al., 1979b).

Jensen et al. (1971) reported the need to anchor organic mulches to limit loss by wind or runoff. However, a comparison of crimped straw and standing stubble at a uranium mine in the Shirley Basin of Wyoming concluded that small grain stubble gave longer lasting protection because it was not susceptible to being blown out (Schuman et al., 1980).

Wheat straw mulch increased the percentage of stable soil aggregates over that found in a bare soil in a Colorado study (Smika and Greb, 1975). The authors attributed this effect to aggregation of individual soil particles by a substance not present in bare soil. One effect of mulch in reducing evaporation is due to the decrease in convective vapor loss from the soil surface, which hastens formation of a dry layer and reduces both liquid and vapor flow to the atmosphere (Papendick et al., 1973).

The amount of mulch to be applied varies with site erodability (Kay, 1978b) and the kind of mulch (Grib, 1967). Recommended application rates range from one to four tons per acre (Meyer et al., 1970). A study conducted on a silt loam soil concluded that mulch application rates of 1, 2, and 4 tons per acre maintained very high infiltration rates resulting in essentially no erosion (Mannering and Meyer, 1963).

Microclimate provided by mulch treatment was shown to be the major factor in determining plant survival in a study in Australia on gradients steeper than 18° (32%) with limited topsoil (Reynolds and Lang, 1979). Total vegetation production and ground cover were determined primarily by topsoil application.

Various chemical amendments and plastic emulsions, such as polyvinyl alcohol, have been utilized in attempts to reduce crust strength

(Chaudhri et al., 1976). Page and Quick (1979) reported that materials investigated as soil conditioners (including polyvinyl alcohol) suffer from high viscosity and low solubility, making spray applications difficult. Another limitation is the high cost of the chemicals necessary to achieve the desired results (Moe et al., 1971).

Organic soil amendments have met with more success than chemical amendments in improvement of soil crusts. Gauer et al. (1971) showed favorable effects of organic materials such as manure on humic acid content, organic carbon, total nitrogen, and available nutrients. Application of animal wastes is effective both in providing nutrients and disposal of waste (Lund and Doss, 1980). A Nigerian study demonstrated that a combination of NPK fertilization and cattle feedlot manure applied to a subsoil caused equivalent dry matter yields for the subsoil and topsoil (Aina and Egolum, 1980). A study on clay soils in Vermont showed that manure counteracted the effect of ammonical-N fertilizer in lowering pH (Magdoff and Amadon, 1980). Lund and Doss (1980) reported that manure application increased pH through the addition of cations from the manure and the resultant removal of acid-forming constituents from the profile. They also reported that large applications of manure increased the cation exchange capacity of soils. Annual application of 270 metric tons/ha for three years caused a four-fold increase in CEC.

Heavy Metals As Environmental Contaminants

Copper, zinc, and manganese are essential plant nutrients that can also be phytotoxic at excessive concentrations (Bidwell, 1974). Understanding a heavy metal toxicity problem requires knowledge of naturally occurring baseline concentrations, levels of the metal in contaminated soils, critical levels in plant tissue, the reactions of the metal in the soil, and the physiologic effects of the metal in the plant. Potential rehabilitation methods depend on these factors as well as interactions among metals. Heavy metal toxicity problems are difficult to precisely define because of variation between sites and the plants growing on them. In any toxicity situation, the response of vegetation will vary with the degree of stress from other factors and the plant's tolerance to that toxicity (Rosen et al., 1978).

Copper content in native soils is reported to range from 2 to 100 ppm (Tisdale and Nelson, 1975). Soils within 1 mile of a copper smelter in Superior, Arizona averaged 5000 ppm copper at the surface (Cannon and Anderson, 1971). The upper critical level, which is the minimum concentration in actively growing tissue that reduces yields, is 20 ppm copper in barley (Davis et al., 1978). The amount of exchangeable copper within the soil decreases with increasing pH (Tisdale and Nelson, 1975). Copper is a constituent of a number of

proteins, including cytochrome oxidase (Price et al., 1972). Excessive amounts of copper in the plant depresses iron activity and may cause iron deficiency symptoms to appear in plants (Tisdale and Nelson, 1975).

Organic matter complexes with copper, in some cases tightly enough to restrict its availability to plants (Lee, 1950). Thus, organic matter additions may possibly have a role in reducing locally high levels of copper. Liming to increase the pH of an acid soil may also be an effective means of limiting copper availability to plants (Lucas and Knezek, 1972). Copper deficiencies are more frequent in sandy soils than medium and fine textured soils (Russell, 1973).

Zinc content of normal soils ranges from 10 to 300 ppm (Rosen et al., 1978). Zinc content of the upper 3 cm of soils within 900 m of zinc smelters in Japan, Poland and England ranged up to 12,200 ppm, with appreciable downward movement observed (National Academy of Sciences, 1979). The upper critical level is 290 ppm zinc for barley (Davis et al., 1978). The distribution of zinc between oxidation states or mineral forms is influenced by soil pH and redox potential. Zinc solubilized by low pH and reducing conditions is associated with the exchangeable and organic fractions of the soil (Sims and Patrick, 1978). Corn grown on soils high in zinc exhibited severe chlorosis and stunting. High zinc levels interfered with chlorophyll

metabolism, possibly through zinc competition with iron for a particular site on a chlorophyll biosynthetic enzyme (Rosen et al., 1978).

Zinc deficiencies have been reported in soils that have received frequent or heavy phosphorous applications (Paulsen and Rotimi, 1968). Reduction in zinc adsorption with increasing phosphorous levels is apparently due to the formation of soluble zinc-phosphorous compounds, with the highest reduction in adsorption occurring in the soil with the lowest carbonate content (Saeed, 1977). Phosphorous could therefore be used to alleviate zinc toxicities in soils with high zinc levels. The solubility of zinc decreases with increasing pH, so lime is a potential amendment to alleviate zinc toxicities (Saeed, 1977). Iron and manganese both cause depressed zinc absorption by roots and translocation in soybeans (Reddy et al., 1978). The suggested mechanism was competition by iron and manganese for absorption sites.

Total manganese content of most soils is reported to range from 200 to 3000 ppm (Swaine, 1960). Manganese exists in soil in three valence states, with the exchangeable divalent ion taken up by plants favored by a pH below 6.5 (Tisdale and Nelson, 1975). Manganese is a nonspecific activator for a number of enzymes (Price et al., 1972). High levels of organic matter are known to depress levels of exchangeable manganese (Murphy and Walsh, 1972). Therefore, application of organic matter may alleviate local toxicity problems. Liming of an

acid soil also decreases the amount of manganese a crop will take up (Chambers and Gardner, 1951).

ALLUVIUM CHARACTERIZATION

Study Site Description

The Berkeley Complex lies next to the Continental Divide at an elevation of 1750 to 2000 m. Two-thirds of the 290 mm annual precipitation recorded at the Butte airport falls during the growing season (National Oceanic and Atmospheric Administration, 1977). Precipitation at the Berkeley Complex is probably higher due to its higher elevation. The frost free period averages sixty days, ranging from forty to ninety days.

Ross and Hunter (1976) described the climax vegetation of Montana. They classified the Summit Valley Floor as a silty range site (indicating soils more than 50 cm deep of fine sandy loam, loam, or silt loam in texture) receiving 380 to 480 mm of annual precipitation. The species expected on a climax site in this area are listed in Table 1 in order of decreasing dominance (adapted from Ross and Hunter, 1976). The moderately to very steep mountain slopes of the East Ridge would support subalpine fir (Abies lasiocarpa) and douglas-fir (Pseudotsuga menziesii). Douglas-fir climax forests would occur at elevations of 1,830 to 1,980 m on south and west facing slopes.

The present vegetation of the Summit Valley does not approach climax due to historic overgrazing (especially from large numbers of horses associated with mining prior to the turn of the century), timbering activities, and damage from at least eleven different smelters

Table 1. Dominants in the climax vegetation of a silty range site in the 380 to 480 mm precipitation zone.[1]

Scientific Name	Common Name	Category
Festuca scabrella	rough fescue	decreaser
Festuca idahoensis	Idaho fescue	increaser
Agropyron spicatum	bluebunch wheatgrass	decreaser
Stipa columbiana	Columbia needlegrass	decreaser
Elymus cinereus	basin wildrye	decreaser
Hesperochloa kingii	spike fescue	decreaser
Danthonia parryi	Parry danthonia	decreaser
Agropyron trachycaulum	slender wheatgrass	decreaser
Lupine spp.	lupine	increaser
Geranium viscossisimum	sticky geranium	decreaser
Balsamorhiza sagittata	arrowleaf balsamroot	increaser
Geum triflorum	prairiesmoke	decreaser
Artemisia tridentata	big sagebrush	increaser
Delphinium occidentale	tall larkspur	decreaser
Koeleria cristata	prairie junegrass	increaser
Danthonia intermedia	timber danthonia	increaser
Poa ampla	big bluegrass	decreaser

[1]Adapted from Ross and Hunter, 1976.

(Montana Department of State Lands, 1975). Two vegetation types currently dominate the Berkeley Complex. The rubber rabbitbrush (Chrysothamnus nauseosus)/grassland type is in poor range condition, with bluegrass (Poa spp.), slender wheatgrass (Agropyron trachycaulum), tufted hairgrass (Deschampsia caespitosa), and rough bentgrass (Agrostis scabra) being the dominant grasses (ECON INC., 1980). The forest type is dominated either by lodgepole pine (Pinus contorta) or aspen (Populus tremuloides) and is in fair range condition (ECON INC., 1980).

Soils of the Berkeley Complex are youthful soils developed from alluvial and colluvial materials (Moshier and Noel, 1981) derived from granitic Boulder Batholith parent materials. Veseth and Montagne (1980) described three tentative soil series on a landscape setting of the Boulder Batholith south of Helena. The Comad series is a sandy-skeletal, mixed, Alfic Cryochrept formed in coarse residuum, colluvium, or glacial till on steep mountain slopes at elevations of 1,525 to 1,980 m (5,000 to 6,500 ft.), characterized by high coarse fragment content (60-80%) with a sand or loamy sand texture in the < 2 mm fraction. The Woodgulch series is a sandy, mixed, Dystric Eutrochrept formed in coarse residuum and colluvium on moderately steep slopes at 1,370 to 1,675 m (4,500 to 5,500 ft.), characterized by 5-30% angular granite pebbles and a sand to loamy sand fine fraction texture. The

Baxendale series is a coarse-loamy, mixed Typic Haploboroll formed in residuum and alluvium on gently to steeply sloping foothills and alluvial fans at elevations of 1,370-1,525 m (4,500 to 5,000 ft.), characterized by 5 to 35% coarse fragment content and 5 to 10% clay content in the B horizon.

Alluvium blankets bedrock as the topographic surface leaves Butte Hill and plunges to the ancient Silver Bow Creek valley floor. The deepest alluvium lies in the area southeast of the Berkeley Pit (Figure 3). Parent material of the alluvium is medium to coarse grained granitic quartz monzonite of the Boulder Batholith (Alusow, 1978). The alluvium is primarily stream sedimentary material. Alluvial deposits and floodplain sediments are deposited in one of two ways: overbank sedimentation outside the natural levee of the river channel and channel derived point or channel bar sediment bars (Davies and Lewin, 1974). Alluvial fans generally form in arid environments at the base of a mountain front where a steeper slope abruptly passes into a gentle slope. Alluvial fans from adjacent drainages commonly coalesce laterally into a broad sloping plain or alluvial apron. Thick deposits of poorly sorted, coarse detrital sediments are often produced in tectonically active areas where the mountains are being elevated and the alluvial fans are sinking (Reineck and Singh, 1975), as is the case in the Summit Valley (Ratcliff, 1973). Three zones can be

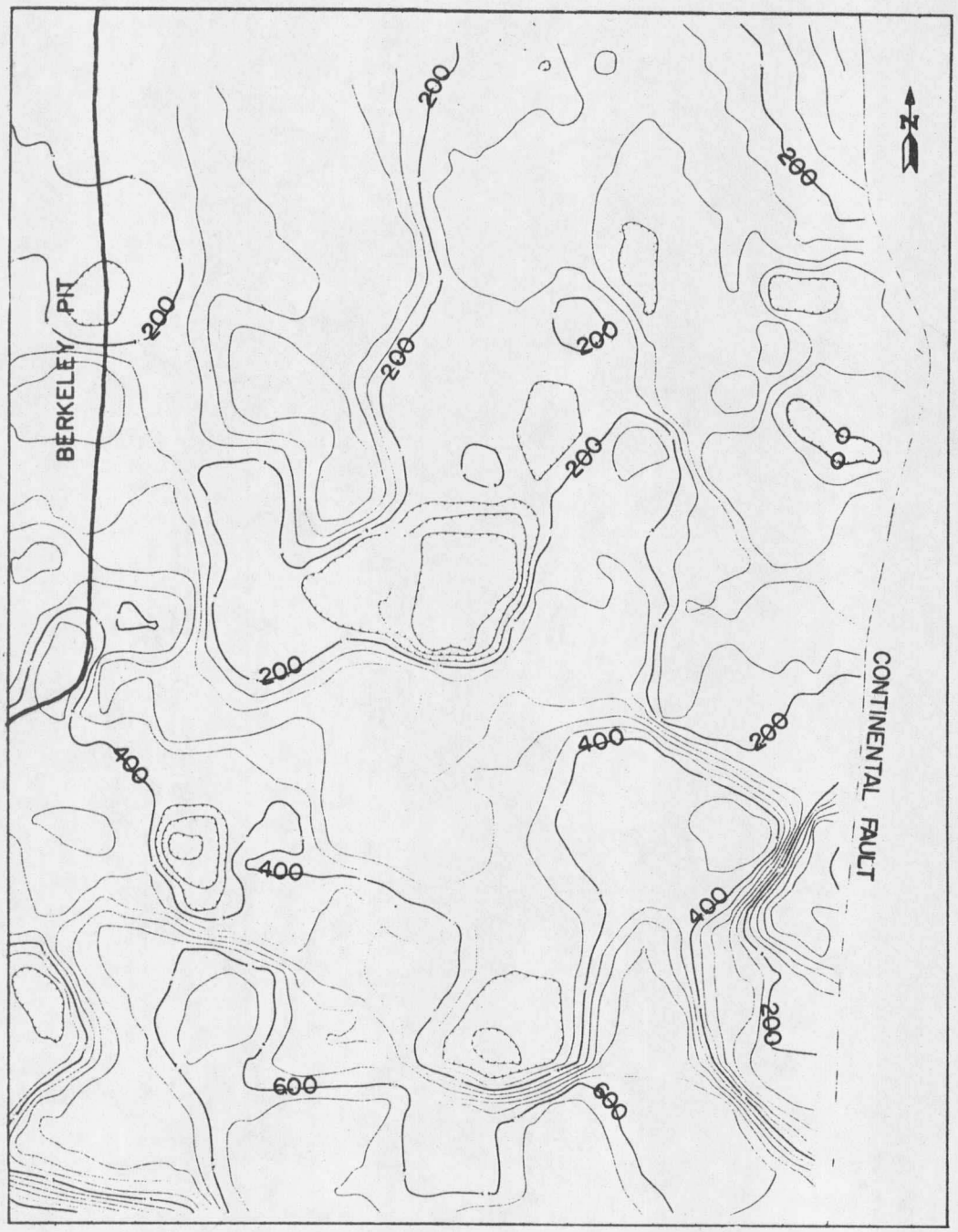


Figure 3. Isopach map showing depths of alluvial materials (derived from unpublished data).

distinguished in alluvial fans, with the coarsest and thickest deposits occurring near the fanhead or apex. The fanhead is dominated by masses of unsorted coarse material from colluvial flow or mud flow (Hooke, 1967). Maximum grain size and sediment thickness decrease from the fanhead through the midfan to the base or outermost area of the fan (Blissenbach, 1954).

The depositional environment of an alluvial fan is complicated, consisting of interstratified fluvial and mudflow sediments (Reineck and Singh, 1975). Sediments of alluvial fans are deposited under oxidizing conditions and organic matter is consequently rare. Sorensen et al. (1980) noted that geological materials overlying ore deposits often contain low concentrations of finely disseminated pyritic minerals. Field observation has confirmed the presence of disseminated pyrites in the alluvium.

Methods and Procedures

A series of 86 alluvium samples was collected over a two year period. Sample locations are shown in Figure 4. Locations of ten samples are not known because of collection on previously transported fill materials. An additional 39 samples were selected from drill core and chip materials. Recovery of alluvial materials was poor until drilling mud was used (Golder Associates, 1980). Drill hole locations are presented in Figure 5.

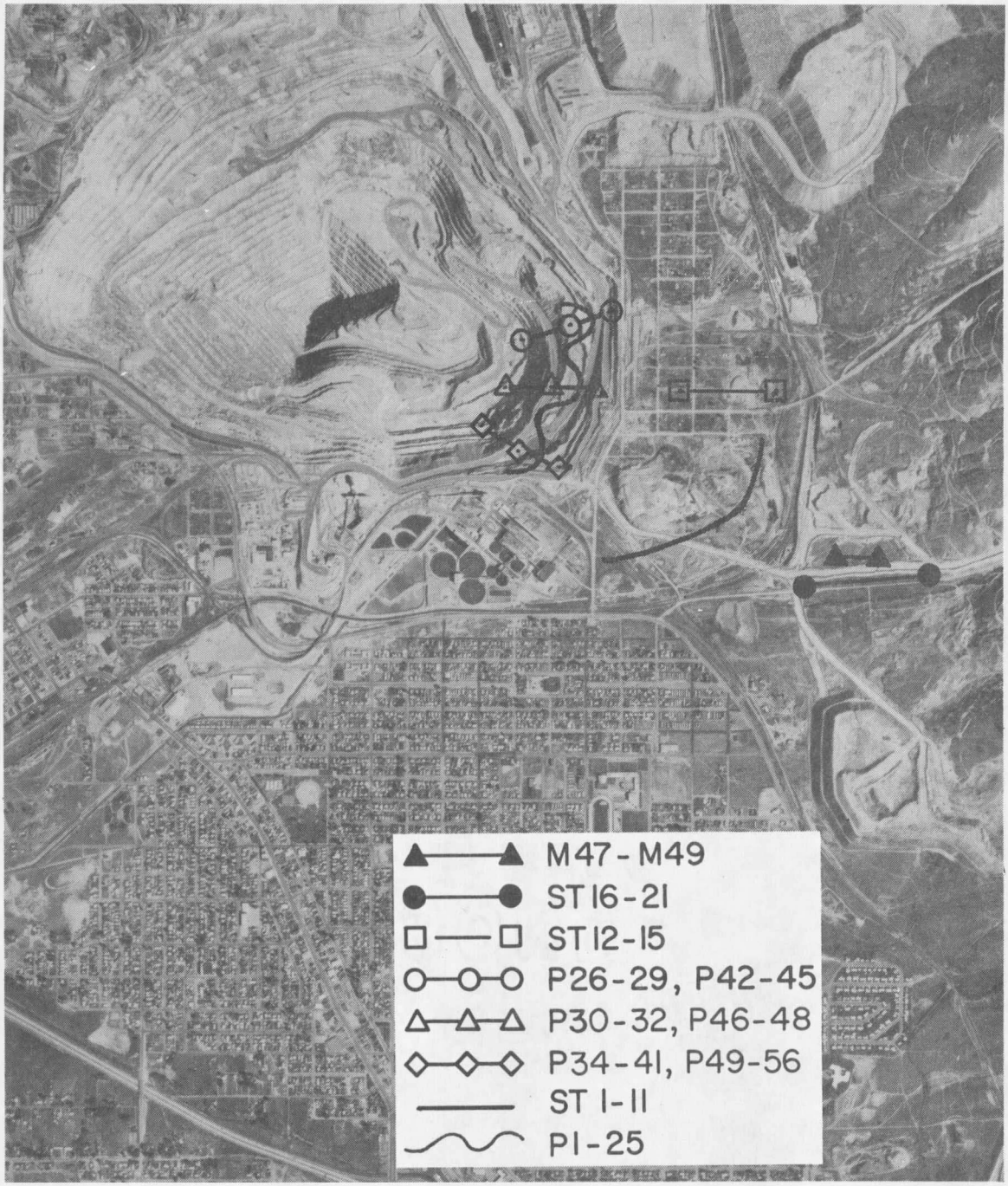


Figure 4. Alluvium sample locations.

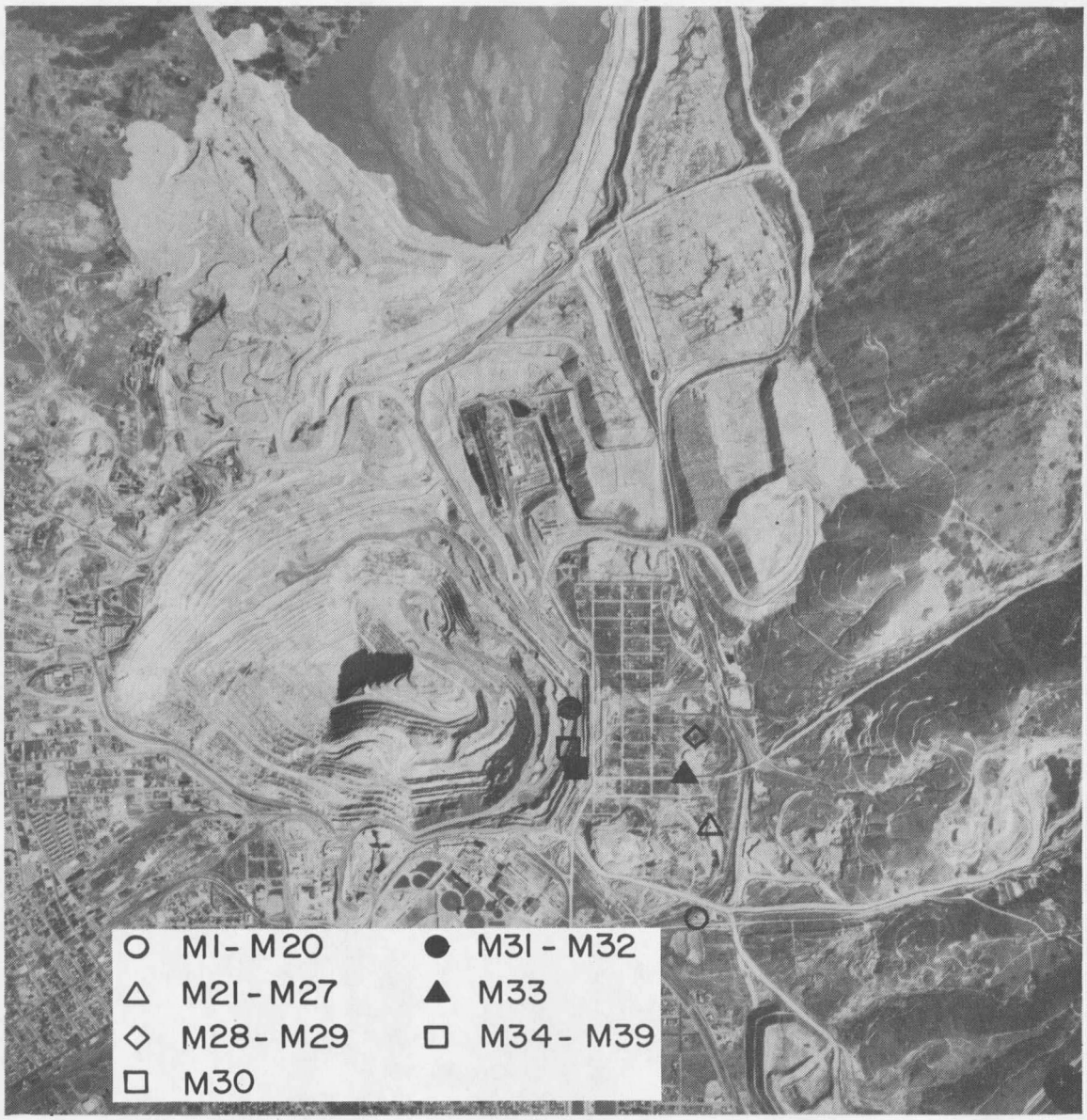


Figure 5. Locations of drill hole samples.

Samples P1-P56 were taken from the east rim of the Berkeley Pit. Samples M1-M39 are from the drilling program. Samples ST1-ST20 were taken from areas adjacent to the Berkeley Shop access road. Samples M40-M59 are miscellaneous samples collected from a variety of areas. Samples P1-P41, ST1-ST20, and M43-M59 were analyzed by the Environmental Engineering Laboratory of the Anaconda Copper Company in Butte. Samples M1-M42 and P42-P56 were analyzed by Northern Testing Laboratories, Inc. in Billings.

Samples were passed through a 2 mm sieve and oven dried at 55°C for 24 hours. An extract of a saturated paste was used for determination of calcium, magnesium, and sodium, by atomic absorption spectroscopy, and for electrical conductivity and pH analysis with the appropriate probe (United States Salinity Laboratory Staff, 1969). A neutral one normal ammonium acetate extraction was used for atomic absorption analysis for potassium (United States Salinity Laboratory Staff, 1969). Particle size analysis utilized a standard hydrometer technique (Day, 1965). Phosphorous was extracted with the sodium bicarbonate method (Olsen and Dean, 1965).

Northern Testing Laboratories used a DTPA extraction (Follet and Lindsay, 1971) prior to atomic absorption analysis for zinc, iron, manganese, copper, cadmium, lead, and nickel. Anaconda's laboratory used a neutral one normal ammonium acetate extraction prior to atomic

absorption analysis for copper (Fiskell, 1965), zinc (Viets et al., 1965), manganese (Adams, 1965), cadmium, and lead, as a measure of the availability of the metal to plant roots.

Fifteen additional samples were collected in March, 1981 and dry sieved for rock fragment percentage (Soil Conservation Service, 1967).

Selenium content was determined by the gaseous hydride method (Fine, 1965) after hot water extraction. Mercury levels were determined by atomic absorption spectroscopy cold vapor generation after acid extraction of the sample (Hatch and Ott, 1968). Arsenic was determined by atomic absorption spectroscopy of an acid extraction (Forehand et al., 1976).

Results and Disscussion

A summary of results of analysis for properties where methodology was uniform is presented in Table 2. Schafer (1979) utilized a literature review to propose guidelines for rating the suitability of topsoil, subsoil, and overburden materials for use as coversoil material in stripmine reclamation. A summary of the relevant criteria for key soil properties is presented in Table 3 (adapted from Schafer, 1979).

Table 2. Statistical Analysis of Selected Parameters.

Property	Mean	Standard Error	Range	Number of Samples
Calcium (ppm)	933	99	66-4600	104
Magnesium (ppm)	218	25	4-2420	125
Sodium (ppm)	66	6	2-520	124
Clay (%)	13	.6	3-34	98
Silt (%)	20	.8	8-46	98
Very Fine Sand (%)	8	.3	1-18	57
Sand (%)	67	1.2	29-87	98
pH	6.0	1.1	3.3-8.1	125
Lime requirement (kg/ha)	3095	477	0-13,450	44
Electrical conductivity (mmhos/cm)	.82	.09	.15-1.5	76
Cation exchange capacity (meq/100g)	10.4	1.6	4-36	19
Potassium (ppm)	139	6	4-388	125
Phosphorous (ppm)	23	4	1-247	101

Table 3. Selected criteria for rating materials for use as coversoil.

Factor	Good*	Fair**	Poor†
Texture class	vfsl,fsl,sl, l,sil	lfs,ls,cl, scl,sicl	s,c,sc,sic
Electrical conductivity (mmhos/cm)	< 4	4-8	> 8
pH	5.6-7.8	4.5-5.6, 7.8-8.4	< 4.5, > 8.4
Rock fragments (%)	< 15	15-35	> 35
Sodium Adsorption Ratio (meg/ℓ)	0-5	5-15	>15

*Good is ideal plant growth media.
**Fair is acceptable plant growth media.
†Poor should not be used or should be amended.

Farmer et al. (1976) reported good growth and root development of grasses on spoils limed to a pH of 5.0; however, additional liming was necessary to prevent reacidification. Plant growth is commonly restricted by pH levels below 5.0 (Vlamis, 1952). Slightly over thirty percent of the Berkeley Pit alluvium samples have a pH lower than the 5.6 needed to receive a good suitability rating. Only eight percent fall into the poor category with a pH below 4.5. Only three percent of the samples exceed the pH level of 7.8 necessary for a good rating, and they are within the pH level of 8.4 required for a fair rating.

Overall, the bulk of the material (with a mean pH of 6.0) received a good suitability classification for pH.

Lime requirement and pH exhibited significant correlation, as expected. The curve and equation describing the relationship are presented in Figure 6. The equation describing the relationship can be used to predict lime requirement from pH for the Berkeley Pit alluvium. The standard deviation of lime requirement predicted from pH with this equation is approximately 2000 kg/ha.

For texture, 82% of the samples rated a good suitability classification (sandy loam or loam) and the remaining 18% of the material receives a fair classification (sandy clay loam or loamy sand) under the guidelines. Electrical conductivity of all samples was below 4 mmhos/cm, and all sodium adsorption ratios (SAR) were below 5, indicating a good suitability for these properties.

Eight samples taken from the east rim of the Berkeley Pit had a mean rock fragment percentage of 24.4 (S.E. = 2.79), rating a fair suitability classification. For three samples taken from the vicinity of the Berkeley Shops access road, the mean rock fragment percentage was 42 (S.E. = 4.39), classifying in the upper end of the poor category. For three samples taken from the area of the proposed southeast Berkeley extension ramp, mean rock fragment percentage was 59.5 (S.E. 7.5), rating a poor suitability classification.

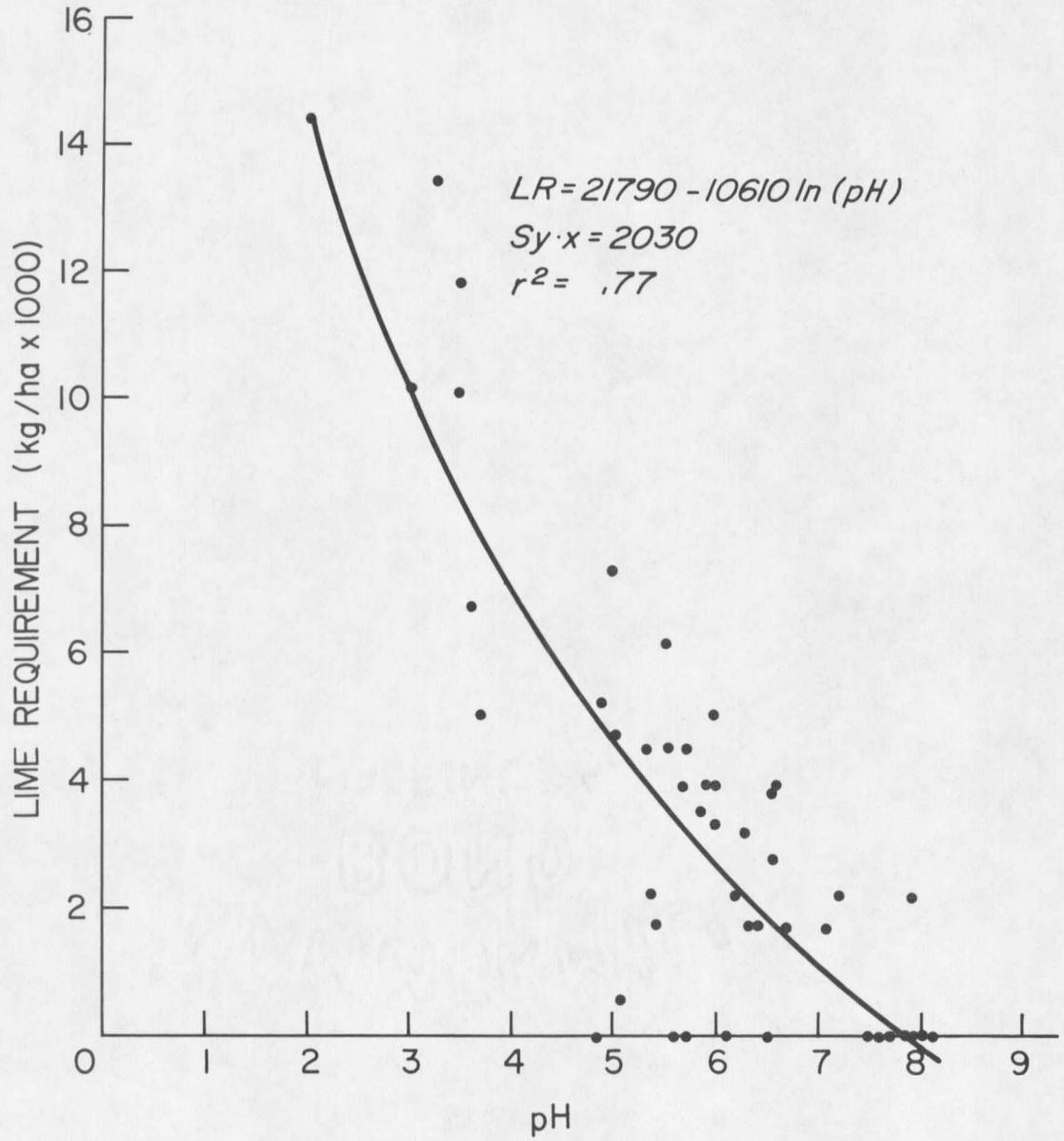


Figure 6. Relationship between lime requirement and pH for Berkeley Pit alluvium.

None of the samples analyzed for selenium, mercury or arsenic exceeded the suspected toxic levels established for these elements in Montana (Dollhopf et al., 1977). Eleven samples exceeded the red flag level for nickel of 1 ppm, but only 1 sample was over 2 ppm at 8.52 ppm. Only two samples exceeded the suspected toxic levels for lead of 10-20 ppm, those being 22.5 and 34.5 ppm. Finally, only two samples exceeded the 1 ppm red flag level for cadmium, at 1.3 and 1.99 ppm.

The levels of copper, manganese, and zinc in Berkeley Pit alluvium were not correlated with depth of sample, texture, or pH. The presence of disseminated pyritic minerals throughout the alluvium deposit probably accounts for the variability in trace element levels presented in Table 4. Use of low grade ore or leach rock as road bed material in the Berkeley Pit is a complicating factor. A statistical summary of analytical results for extractable trace elements in the Berkeley Pit alluvium and agricultural soils is presented in Table 5 with the recommended suspect levels for these elements in Montana.

Table 4. Comparison of DTPA extractable levels of copper, manganese, and zinc in agricultural soils and Berkeley Pit alluvium with suspected toxic levels in Montana (ppm).

	Suspected Toxic[1]	Agricultural Soils	Berkeley Pit Alluvium	
			Range	Mean
Copper	40	.14-3.68[2] 1.06-19.30[3]	1.2-192	44.0
Manganese	60	.6-39.5[2] 0-78.5[4]	7.1-322	100.9
Zinc	40	.13-14.2[2]	2.7-110	30.7

[1]Dollhopf et al., 1978.
[2]Follet and Lindsay, 1970 (Colorado).
[3]Gupa and MacKay, 1966 (eastern Canada).
[4]Walker and Barber, 1960 (Indiana).

Table 5. Statistical summary of copper, zinc, and manganese values by source, extract, and pH (all values in ppm, except N = number of samples).

			Copper				Zinc				Manganese			
Source	Extract	pH	$\bar{X}$	STD Error	Range	N	$\bar{X}$	STD Error	Range	N	$\bar{X}$	STD Error	Range	N
Berkeley Pit East Rim	Ammonium acetate	5.5	43.6	9.3	.5-280	42	47.6	11.9	.4-462	42	26.8	10.6	.1-371	41
	DTPA	6.3	44.0	9.1	1.2-126	14	30.7	7.7	2.7-108	14	100.9	11.4	15.6-176	14
Miscellaneous	Ammonium acetate	5.7	57.4	10.1	3.0-127	17	77.9	23.3	.9-351	17	64.8	26.6	1.0-355	17
	DTPA	6.2	45.5	7.7	1.7-192	42	30.2	4.3	3.8-110	42	121.9	15.9	7.1-332	42
Southeast Berkeley Ramp	Ammonium acetate	7.7	7.5	2.0	1.0-41	20	2.6	.6	.1-4.5	20	.7	.2	.1-3.0	20

Of the samples extracted with DTPA, 40% exceeded the suspect level used in Montana for copper, 25% exceeded the level for zinc, and 65% exceeded the level for manganese. It should be noted that trace element levels are commonly elevated above ore deposits, providing the basis for the process of geobotanical prospecting (Viktorov et al., 1964).

In any toxicity situation, the response of vegetation will vary with the degree of environmental stress and the plant's tolerance to that toxicity (Rosen et al., 1978). Local toxicity situations which may occur in the alluvium for copper, manganese, and zinc could possibly be alleviated by liming to raise soil pH and decrease metal availability (Lucas and Knezek, 1972; Saeed, 1977; Chambers and Gardner, 1951). Organic matter additions may decrease copper and manganese availability (Lee, 1950; Murphy and Walsh, 1972). Increasing phosphorous levels through fertilization increases the formation of zinc-phosphorous compounds and may be a means to ameliorate a zinc toxicity situation (Saeed, 1977).

A question exists as to whether the alluvium has been adequately sampled to obtain a representative range of values. In the Fort Union formation, drill holes placed 300 m or more apart yield no better information than a single drill hole in each mine area (Dollhopf et al., 1978). Location of unsuitable overburden materials required

drill holes placed every 30 to 50 m (Dollhopf et al., 1978). A study by the United States Geological Survey in Big Horn County, Montana concluded that the range of elemental concentrations increased only slightly by sampling multiple drill holes compared to a single drill hole, and that only a slight risk existed of missing rocks of unusual geochemistry by sampling a single hole (Hinkley et al., 1978). Similarly, the range of DTPA-extractable copper values within any of four drill holes (Table 6) largely includes the overall range for all samples of 1.2-192.0 ppm copper.

Table 6. Range of values for copper within four drill holes

	Drill Hole			
	1	2	3	4
Copper (ppm)	2.2-186.0	8.8-71.9	3.4-68.9	1.2-103.0

Thus, the variety of sampling locations in this study should insure adequate representation of the range of characteristics of the alluvium.

Summary and Conclusions

The alluvium rates a good suitability classification for pH, electrical conductivity, texture, and sodium adsorption ratio. Rock fragment percentage should be used as a selection criterion to insure

the use of material with at least a fair suitability classification. Levels of selenium, mercury, arsenic, nickel, lead, and cadmium in the alluvium do not present toxicity problems. Copper, manganese, and zinc levels are elevated in the alluvium, but local plant toxicity situations can be dealt with by liming or organic matter and fertilization management. The alluvium has been adequately sampled to insure representation of the range of values present in the alluvium for different properties. Soil tests performed on the alluvium should be abbreviated and standardized. For comparison purposes with suspected toxic levels in Montana, a DTPA extract should be used. Soil analyses on the alluvium need only include pH, texture, copper, manganese, and zinc.

AMENDMENT LEVELS

A study to determine optimum levels of lime and manure amendments for enhancing the capability of alluvial overburden materials to support plant growth was initiated in the Montana State University greenhouse on July 19, 1979. Wheat yields (g/pot) were used as an indication of the value of soil amendments. Pots contained one of a combination of three alluvium types, three liming rates, and four levels of manure application. The greenhouse portion of the study was completed October 4, 1979.

Methods and Procedures

The alluvium for the study was collected from the Berkeley Complex and placed in 125 ℓ containers on July 17, 1979, as described in Table 7:

Table 7. Description of alluvial sources

Alluvium Source	Approximate Depth from Surface	Location
Berkeley Pit East Rim	60 m	North of the dragline below the 5400 sump.
Berkeley Shops Access Road	7.5 m	South wall of the access road east of the super tube.
Southeast Berkeley Ramp	3.6 m	East rim of the pit, south of the water tank.

The alluvium materials were sorted by hand and rocks greater than 2.5 m in diameter were removed. Samples of the three alluvium types were sieved through a 2 mm sieve and oven dried at 55° C. The samples were analyzed by the Reclamation Research Laboratory at Montana State University in Bozeman, Montana.

Agricultural lime was applied to the three alluvium types at zero, normal, and double rates. The actual amount of lime applied was based on eight-tenths of the indicated lime requirement for the samples (Peech, 1965). The manure was obtained from the Montana Livestock Auction in Butte, Montana. It was shredded using a Linden Soil Shredder and mixed on a dry volume basis. Fertilizer was applied to all pots based on a rate of 336 bulk kg/ha of 16-20-0, resulting in application of 54 kg/ha actual nitrogen and 67 kg/ha actual P_2O_5.

The pots were 2450 cm^3 in volume, and were seeded with wheat on July 20, 1979. Seedlings were thinned to five per pot on August 2, 1979. Pots were randomly placed on a greenhouse bench initially and were rearranged twice during the study. Soil moisture levels were maintained at or near field capacity throughout the growth period. Plants in each pot were clipped to ground level on October 3, 1979, individually bagged, placed in a drier for 48 hours, and then weighed.

Production data were analyzed using a standard analysis of variance technique and a Duncan Multiple Range Test (Ostle, 1963) with the

aid of Dr. Ervin Smith, Agricultural Experiment Station Statistician at Montana State University.

Results and Discussion

All three alluvial materials were sandy loam in texture, with the Ramp and Super Tube materials containing a higher percentage of larger rocks. The results of the chemical analysis of these materials are summarized in Table 8.

Table 8. Summarized results of chemical analysis of alluvial materials

Test	Berkeley Shops Access Road	Berkeley Pit East Rim	Southeast Berkeley Ramp
pH	6.1	6.5	7.5
EC (mmhos/cm)	1.01	.59	1.10
% Saturation	28.8	30.0	33.8
CEC (meq/100g)	8.7	7.2	16.4
Pb (µg/g)[1]	< .40	< .40	< .40
Cd	< .20	< .24	< .20
Cu	26.9	1.6	30.7
Zn	4.3	14.9	2.8
K	71.2	126.0	180.0
Ca	888	1084	1820
Mg	162	260	404
As	.44	.79	.73
Total S (µg/g)[2]	2449	1605	822
N - NO_3 (µg/g)[3]	5.5	4.9	5.6
Organic Matter %	0	0	0
P (µg/g)	1.4	1.9	0.8

1 1 N NH_4OA_c extraction. AA analysis of extractant solution.
2 Chaudhry and Cornfield, 1966.
3 Phenoldisulfionic acid method.

The normal rate of lime treatment was based upon lime requirement test results from the Anaconda Copper Company Environmental Laboratory, shown in Table 9.

Table 9. Lime requirement in kg/ha.

Alluvium Type:	Southeast Berkeley Ramp	Berkeley Pit East Rim	Berkeley Shops Access Road
Lime Requirement:	3000	2500	2500

These test results do not indicate plant toxic levels of heavy metals. Cadmium levels in a variety of nonpolluted soils have been reported as less than 1 ppm (Haghiri, 1973), while the cadmium content of nonpolluted soils of the Gallatin Valley were reported as .5 ppm or less using a hydrochloric acid extraction (Munshower, 1977). Total lead content of apparently uncontaminated soils in Great Britain ranged from 10 to 150 ppm (Colbourn and Thornton, 1978). The test values reported are within these ranges, and below the suspect levels used as a guide for rating materials for use as a plant growth medium in Montana (Dollhopf et al., 1977).

Wheat yields increased with increasing manure level for all alluvium types, as shown in Table 10. These results demonstrate that

Table 10. Production means by alluvium type and manure level measured as grams per pot of aerial biomass.

Manure Level (in cm):	0	8	15	23
Alluvium Type: Berkeley Pit Access Road	2.6a[1]	3.5b	4.4c	5.4d
Berkeley Pit East Rim	2.4a	5.5b	5.8c	7.3c
Southeast Berkeley Rim	1.7a	4.1b	4.8c	5.1c

[1]Means in the same row followed by the same letter are not significantly different at the .05 probability level as determined by Duncan's Multiple Range Test.

under greenhouse and optimum soil moisture conditions, the greatest gain in yield occurs with the initial addition of manure, and that the benefit in terms of production from the third additional increment of manure is minimal. However, plant color and vigor were visibly best at the highest level of added manure. The only plants which flowered during the study were both treated with the highest manure level used. Under field conditions the benefits of additional organic matter in increasing the cation exchange capacity and water holding capacity may be significant.

Added lime was not a significant factor in increasing production, as shown in Table 11. These results could be expected, given the

Table 11. Production means by alluvium type and lime level measured grams per pot of aerial biomass.

Lime Level:		None	Normal	Double
Alluvium Type:	Berkeley Shops Access Road	3.9a[1]	4.0a	4.0a
	Berkeley Pit East Rim	5.2a	5.7a	5.6a
	Southeast Berkeley Ramp	3.6a	3.9ab	4.3b

[1]Means in the same row followed by the same letter are not significantly different at the .05 probability level as determined by Duncan's Multiple Range Test.

initial pH of the materials. However, the presence of disseminated disulfides and pyrites could cause later acidification of the materials upon exposure to surface weathering. The total sulfur levels (refer to Table 8) indicate that acidification might be a potential long term problem requiring a lime application.

The overall mean production of the Berkeley Pit East Rim material, 5.5 grams of aerial biomass per pot, was significantly greater ($P<.05$) than those of the Berkeley Shops Access Road and Southeast Berkeley Ramp materials, 3.91 and 3.96 grams per pot, respectively.

Summary and Conclusions

A greenhouse experiment was conducted with three alluvium types, three levels of lime, and four levels of manure application. All treatments were fertilized. Wheat was grown under optimum soil moisture conditions and used as a growth potential indicator. Under these conditions, the results indicated that the Berkeley Pit east rim material is the superior growing medium of the three, the 7.6 cm manure treatment produced the greatest increment of increased yield, and neither of the two lime levels shown significant benefit.

MECHANISMS OF CRUST FORMATION

A study site located on a west facing 24° (40%) slope of the Continental East waste dump was covered with a 60 cm layer of alluvium in November of 1979. After lying fallow over winter, formation of a surface crust of sufficient strength to impair seedling emergence was observed the following spring. Determination of the mechanism of crust formation and identification of possible techniques for mitigating the crusting problem was the objective of this portion of the research.

Methods and Procedures

Samples of crusted alluvium were taken from three locations on a regraded mined area at the Continental East waste dump study site on July 10, 1980. The alluvium had been in place without surface cover for eight months. The samples were air dried prior to analysis. Each of the three crust samples was subsampled at the surface, middle (approximately 3 cm) and bottom of the crust. Twenty samples were measured for depth of crust. An unconsolidated sample from below the crust was also collected.

Samples were prepared for scanning electron microscope examination to identify fabric and porosity changes within the crust. Specimens approximately 1 mm thick were mounted in colloidal carbon on clean copper specimen holders. All specimens were coated with gold for 4 1/2 minutes in a PELCO Sputtercoater to enhance the images.

The samples were then analyzed on a JEOL 100CX Transmission Electron Microscope with a ASID-4D scanning attachment. Images of one location on each specimen were taken at three magnifications: 200 x, 800 x, and 2000 x.

Modulus of rupture tests (Richards, 1953) were performed on five untreated alluvium samples and five samples treated with manure mixed at a 1:4 volumetric ratio. Clay mineralogy was analyzed using standard x-ray diffraction techniques (Whittig, 1965).

Results and Discussion

The following results are based upon qualitative interpretation of the SEM photographs. The mechanism of the crust appears to be grain packing, with clays and silts filling in between sands, as shown in Figure 7. Duley (1939) observed that soil crusting was caused by fitting of finer particles between larger ones. A study of a range of artificially produced textures showed that for soils with equal amounts of clay, the sandier soils produce the strongest crusts (Ibanga, 1980). The suggested mechanism was that since the larger particles of a sandier texture have a lower surface area, less clay is required to bind the sand grains into a hard aggregate. The images display no evidence of gypsum crystals, carbonates, or soluble salts, eliminating chemical cementation as a mechanism of crust formation from consideration.

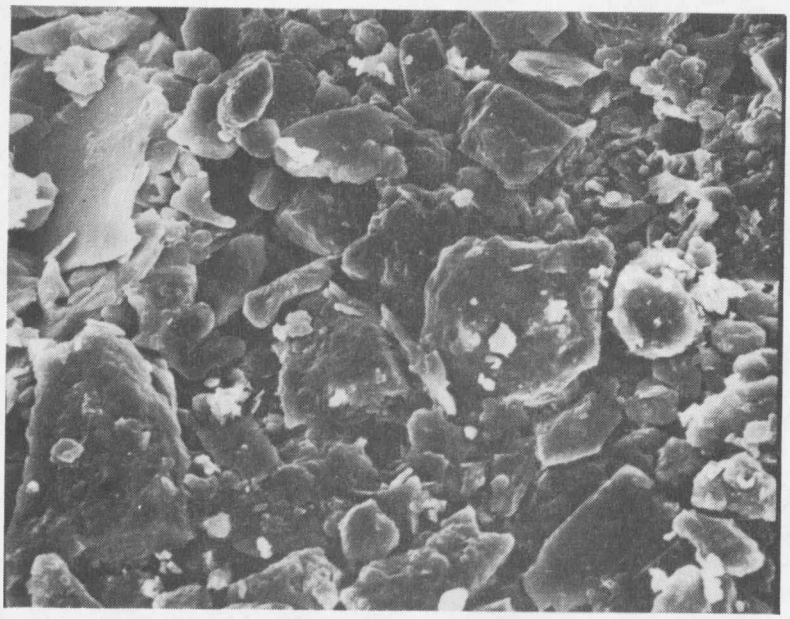


Figure 7. Surface sample photographed at 800x.

The images presented in Figure 8 create a crust profile with images of the surface, middle, and bottom of the crust at 200 x magnification. The images demonstrate an increase in porosity and mean grain size with depth. The surface also exhibits less jointing or cracking than lower depths.

The average modulus of rupture tests of untreated alluvium samples was 1.2 bars (S.E. = .03). The alluvium samples treated with manure had a modulus of rupture of .19 bars (S.E. = .01) which was significantly different at $p < .01$. Thus, the addition of organic matter caused a six-fold decrease in crusting strength.

X-ray diffraction tests showed the clay fraction of the alluvium to be approximately 30% smectite, 50% illite, 10% kaolinite, and 10% quartz. The low percentage of expanding clays reduces the tendency for cracks to develop in the crust, decreasing opportunities for seedling emergence. Crust thickness averaged 7.25 cm (S.E. = .38).

Summary and Conclusions

Surface crusting of alluvial overburden materials is a physical problem caused by grain packing and clay adhesion within the sand fraction. Low percentages of expanding clays limits the tendency for cracks to develop in the crust. Organic matter addition decreases crust strength by aiding formation of stable soil aggregates and decreasing clay adhesion in the sand fraction.

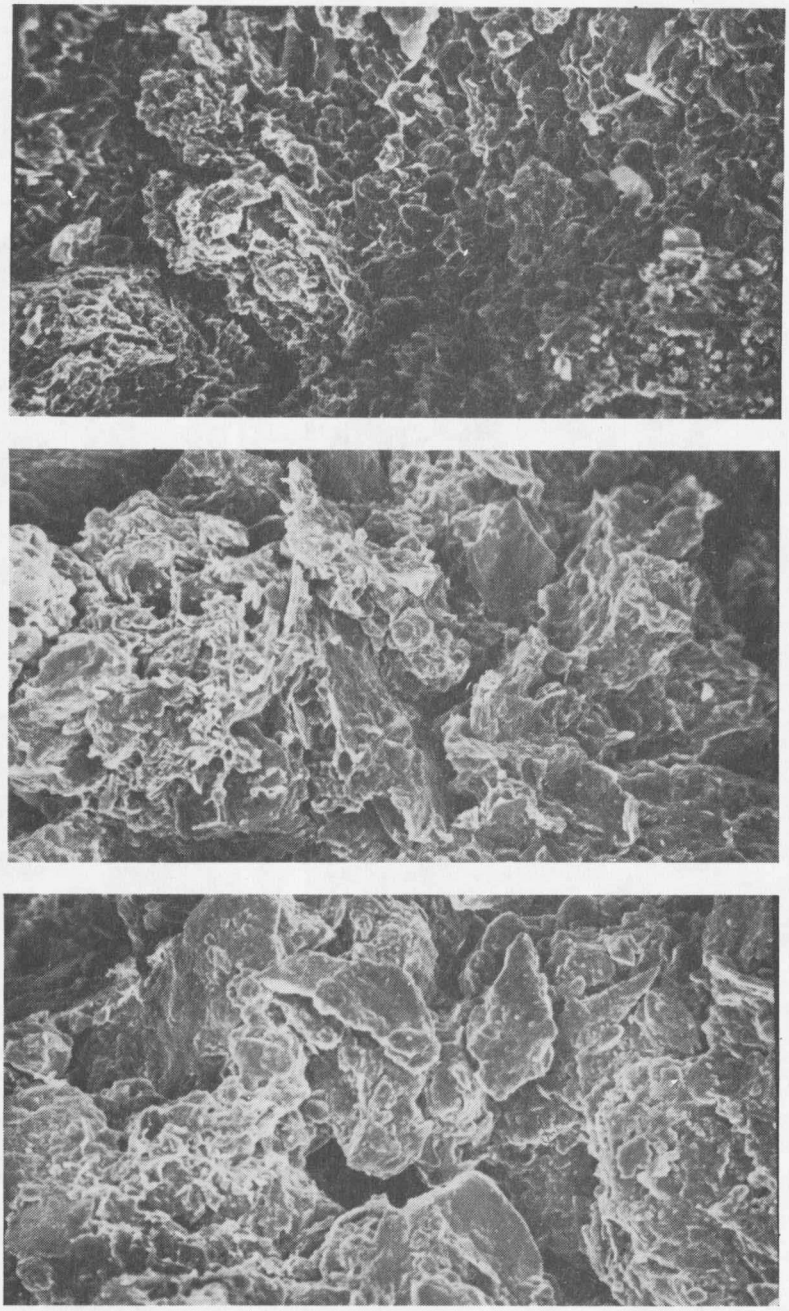


Figure 8. Surface, middle, and bottom of a 7 cm thick crust photographed at 200 x.

EFFECTS OF CRUST FORMATION

A greenhouse experiment designed to assess plant response to the stress of crust formation was initiated in the spring of 1981. Four plant species were used in a factorial design with five replicated treatments.

Methods and Procedures

Plants were grown in trays 20 x 30 cm and 10 cm deep. Trays contained the following soil materials: Bozeman silt loam as a soil control, alluvium control, manure mixed with alluvium at a 1:4 volumetric rate, hay incorporated into the surface at a 2.25 kg/ha rate, and straw crimped in at a 4.5 kg/ha rate. Rocks larger than 5 cm were handpicked from the alluvium during tray preparation. Figure 9 presents a view of one tray of each treatment.

Species selected for the study were Lutana cicer milkvetch (Astragalus cicer), Covar sheep fescue (Festuca ovina), Revenue slender wheatgrass (Agropyron trachycaulum), and Critana thickspike wheatgrass (Agropyron dasytachum). Cicer milkvetch is a strongly rhizomatous, herbaceous, perennial legume with medium size seeds (269 per gram) that have extremely hard seed coats requiring scarification (Wiesner et al., 1978). Lutana is tolerant of slightly acid soils, frost, drought, and performs best on moderately coarse textured soils (Stroh et al., 1978). Sheep fescue is a tenacious understory bunchgrass with small seeds (1500 per gram) (Soil Conservation Service,



Figure 9. Soil control, alluvium control, and incorporated hay, manure, and crimped straw treated trays.

1972). Covar is cold and drought tolerant, and particularly successful on sandy and gravelly soils (Lilley and Bensen, 1979). Revenue slender wheatgrass, with approximately 352 seeds per gram, is a drought tolerant, cool season, native, perennial bunchgrass adapted to most soil textures (Long, 1981). Critana thickspike wheatgrass has 410 seeds per gram and is a native, perennial, rhizomatous grass adapted to dry sandy sites (Dubbs et al., 1974).

Seed was tested to ascertain seed quality. Lutana was mechanically scarified so that 47% of the seed swelled, which is in the 30-50% range recommended with a quick swell test (Wiesner et al., 1978). Six replicates of 50 seeds each were germinated at 20°C for 14 days (Wiesner et al., 1978). Six replicates of 50 seeds each of sheep fescue and thickspike wheatgrass were placed on a blotter soaked with .2% KNO_3 in a germinator at 25°C for 28 days. Six replicates of 50 seeds each of slender wheatgrass were placed on blotter soaked with .2% KNO_3, prechilled for five days, and then placed in a germinator at 25°C for 14 days. Germination was counted at the conclusion of these treatments, and used for comparason purposes as a control for the greenhouse portion of the study.

Seedling emergence in the greenhouse was counted, trays were weighed for gravimetric soil moisture content, and trays were rerandomized every 2 or 3 days. After 45 days, the plants were allowed

to wilt to determine wilting point and were then clipped at ground level for production data. Upon completion of the greenhouse portion of the study the trays were placed in a drier at 60°C for three days. Five readings each with a Procter penetrometer with a 3.2 cm^2 tip and a Soil Test pocket penetrometer with a .3 cm^2 tip were taken on each tray.

A separate experiment utilized 25 trays 26 cm^2 x 6 cm deep to obtain a curve relating crust strength to moisture content. The alluvium was passed through a 19 mm sieve to remove rocks and then oven dried at 30°C for 3 days prior to filling each tray with 2040 g of alluvium. Three wet-dry cycles occurred during which the alluvium was placed in the sunlight in the afternoons and surface temperatures exceeding 35°C were measured with a Cole-Parmer Model 8520-50 Digi-Sense Thermocouple Thermometer. Trays were wet to 20% moisture content and crust strength measured using a Proctor penetrometer with a 3.2 cm^2 tip at successively drier moisture increments. Bulk density of 5 crust samples collected in the field was determined using a saran resin technique (Brasher et al., 1966).

Results and Discussion

Germination of 30% of the Lutana cicer milkvetch seed was obtained in the laboratory. Critana thickspike wheatgrass, Revenue

slender wheatgrass, and Covar sheep fescue germinated 96, 80, and 94%, respectively. No significant differences among treatments (including the seed laboratory control) were observed for germination of cicer milkvetch, slender wheatgrass, or thickspike wheatgrass. Optimum soil moisture conditions (approximately 16% gravimetric soil moisture content) were maintained during the first half of the study and probably masked treatment differences. Germination of sheep fescue did vary with treatment, as shown in Table 12.

Table 12. Germination from equal number of seeds of sheep fescue under varying treatments (number of seeds).

Treatment	Germination	
Laboratory Control	28	a[1]
Hay	23	b
Manure	21	bc
Crimped Straw	18	bcd
Soil Control	16	d
Alluvium Control	15	d

[1]Means followed by same letter are not significantly different at the .05 probability level as determined by Duncan's Multiple Range Test.

Sheep fescue had the smallest seed used in the study, probably accounting for the difficulty it encountered in emerging in the greenhouse as compared to the seed laboratory.

Gravimetric soil moisture levels were recorded when the seedlings exhibited signs of mortality such as marked color changes. Results of these measurements are presented in Table 13. No differences

Table 13. Gravimetric moisture content at mortality for four species by treatment (measured in percent).

Treatment	Cicer milkvetch	Thickspike wheatgrass	Sheep fescue	Slender wheatgrass
Soil Control	2.8 a	1.9 a	2.1 b	2.3 a
Alluvium Control	2.7 a	1.5 a	3.0 a	1.6 b
Manure	3.0 a	1.1 a	1.2 c	.8 c
Hay	3.1 a	1.2 a	1.2 c	1.1 bc
Crimped Straw	3.0 a	1.4 a	1.3 c	1.2 bc

[1]Means in the same column followed by the same letter are not significantly different at the .05 probability level as determined by Duncan's Multiple Range Test.

attributable to treatment in the moisture level at which mortality occurred were observed for cicer milkvetch or thickspike wheatgrass. Mortality of sheep fescue seedlings was earliest (highest moisture content) on the alluvium control. Slender wheatgrass seedlings died earliest on the soil control and latest (lowest moisture content) on the manure treatment. Thickspike wheatgrass and slender wheatgrass appeared to be the most drought tolerant species. Cicer milkvetch was the least drought tolerant.

Production means for all species by treatment are presented in Table 14. Aerial biomass from the soil control was significantly

Table 14. Aerial biomass production means by species and treatment measured as milligrams per seedling.

Treatment	Cicer milkvetch	Thickspike wheatgrass	Sheep fescue	Slender wheatgrass
Soil Control	60 a[1]	165 a	44 a	217 a
Manure	52 a	56 b	20 b	154 b
Hay	25 a	20 b	12 b	22 b
Crimped Straw	32 a	15 b	8 b	30 b
Alluvium Control	19 a	20 b		17 c

[1]Means in the same column followed by the same letter are not significantly different at the .05 probability level as determined by Duncan's Multiple Range Test.

greater than all other treatments for all species except cicer milkvetch. Cicer milkvetch showed no differences in production with any treatment. Aerial biomass of slender wheatgrass grown in the alluvium control was significantly lower than with other treatments. Aerial biomass produced by the manure treatment was not statistically different from production with the other alluvium treatments. However, production of the manure treatment was second to the soil control, an apparent difference observed for all species.

Results of penetrometer tests on the soil control, alluvium control, and incorporated hay, manure, and crimped straw treated trays are presented in Table 15. Crimped straw treatment values were also divided into between row or within row groups.

Table 15. Comparasion of pocket and Proctor penetrometer test results (in bars).

Treatment	Pocket Penetrometer	Proctor Penetrometer
Soil control	.22 a[1]	1.09 a
Manure	.27 a	1.11 a
Hay	2.58 b	4.42 b
Crimped straw	3.26 c	6.29 c
Within rows	2.56 b	5.69 d
Between rows	3.72 d	6.69 c
Alluvium control	3.76 d	5.36 d

[1]Means in the same column followed by the same letter are not significantly different at the .05 probability level as determined by Duncan's Multiple Range Test.

Penetrometer measurements of soil strength for trays with manure mixed into alluvium at a 1:4 volumetric ratio were statistically similar to results from the soil control for both the pocket and Proctor penetrometers. When measured with a pocket penetrometer, crust strength of the hay, straw, and alluvium control treatments was significantly and

successively greater than the soil control and manure treatments. Pocket penetrometer readings within rows of the crimped straw treatment were statistically similar to the hay treatment, while the values between rows were similar to the alluvium control. Procter penetrometer measurements of crust strength were similar except that the values for the crimped straw were greater than the alluvium control. Also, the within rows results were statistically similar to the alluvium control, and the between rows values were similar to the values of the crimped straw treatment itself. The divergence in values measured with pocket or Proctor penetrometers probably reflects differences in configuration of the instruments (Voorhees et al., 1975). The pocket penetrometer presumably measured crust strength within the crimped straw rows more accurately because it is much smaller and therefore could be placed entirely within the row.

Figure 10 represents the logarithmic relationship between crust strength and gravimetric moisture content. Crust strength increases with decreasing moisture content. Gerard et al. (1972) reported root elongation of peas and cotton decreased with increasing strength, as measured with a penetrometer, particularly for soil strength values > 10 bars. Wheat, grain sorghum, and soybean seedlings were reported to emerge from soils with crust strengths as high as 1.4 bars (Hanks and Thorpe, 1956).

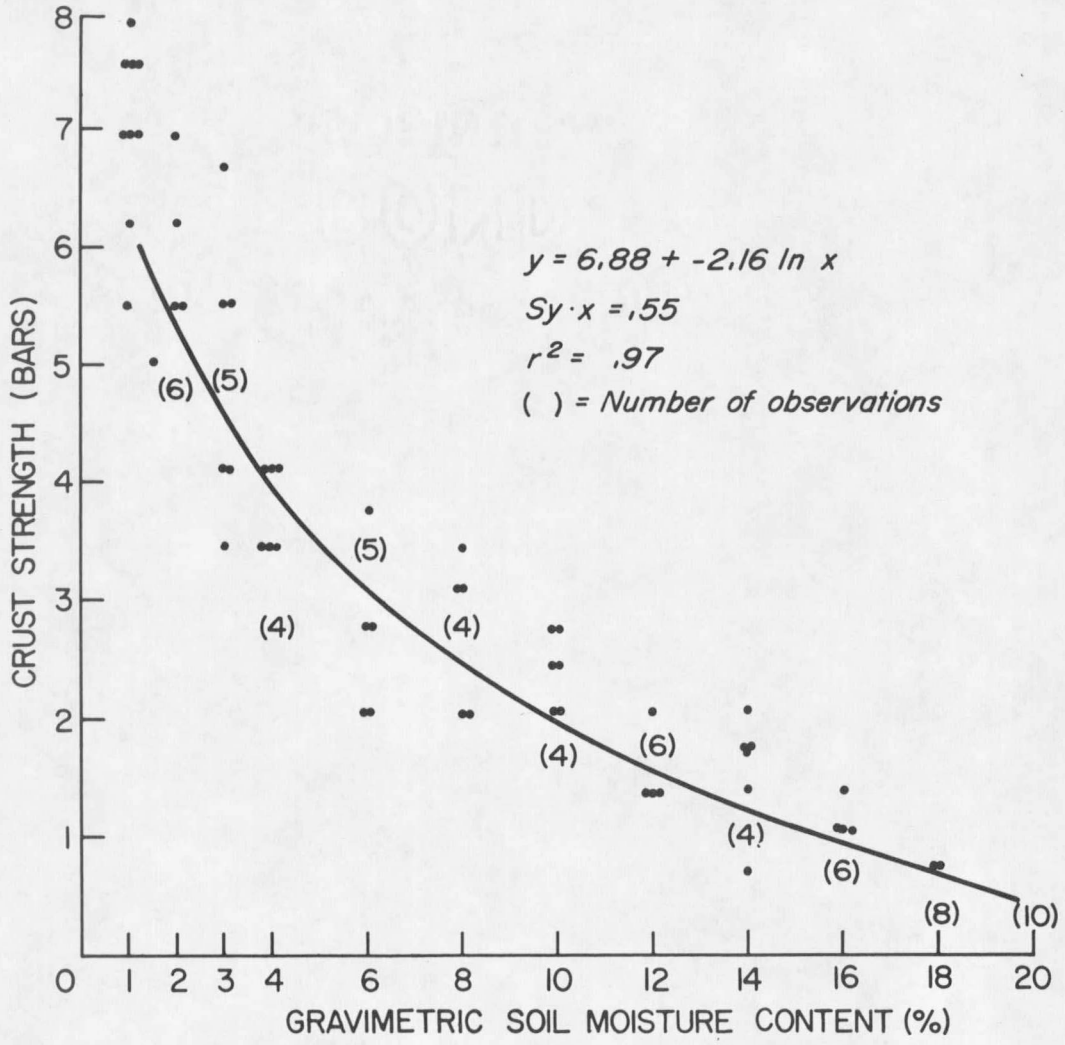


Figure 10. Relationship between crust strength and moisture content.

Bulk density of crusted alluvium averaged 2.0 (S.E.=.05), ranging from 1.89 to 2.17. Golder Associates (1980) reported bulk density of drill core alluvium samples as 2.10 (S.D.=.1). Bulk density of sand or loamy sand textured soils range from 1.2 to 1.8 g/cm^3, and subsoil densities of agricultural soils can exceed 2.0 g/cm^3 (Brady, 1974). Plant root activity is generally reduced by bulk densities higher than 1.88 g/cm^3 (Veihmeyer and Hendrickson, 1948). Morphological changes occur in roots elongating through high strength soils, with root tips becoming narrower and the proximal part becoming wider than usual (Barley, 1968). Radial root pressure from this form of growth enables the root to deform or crack the soil ahead of the root tip and thereby reduce mechanical impedance and promote root elongation (Gerard et al., 1972). High bulk density levels can decrease water infiltration rates, reduce aeration, increase cloddiness, and increase the mechanical strength of the soils (Feldman and Domier, 1970, and Flocker et al., 1958). High bulk densities cause chemical alterations in roots, resulting in an increase in the cation exchange capacity of the root on both a unit weight and unit surface area basis (Kulkani and Savant, 1977). Bulk density levels can be lowered by amendment with manure and management practices such as minimum tillage (Brady, 1974).

Summary and Conclusions

Moisture contents high enough to insure plant germination also reduce crust strength below levels inhibitory to plant emergence, except for species with very small seeds. The alluvium, regardless of treatment or species produced less aerial biomass than the soil control. The soil strength of alluvium amended with manure is statistically similar to the soil control. Crust strength of the alluvium increases with decreasing moisture content. Bulk density of the alluvium without amendment is high enough to inhibit plant root activity.

SUMMARY AND CONCLUSIONS

Lack of suitable native soil for covering waste dumps poses a critical reclamation problem at the Berkeley Complex. Alluvial overburden materials from the Berkeley Pit were investigated for their potential use as a coversoil. An intensive field sampling design was implemented to determine the range of chemical and physical properties present in the alluvium. A greenhouse study using wheat as a growth indicator was used to evaluate three sources of alluvium, three liming rates, and three manure application rates. A surface crust was observed in the alluvium after it laid fallow for one year, and led to a study of the crusting phenomenon with a scanning electron microscope. Further greenhouse study used cicer milkvetch, thickspike wheatgrass, sheep fescue, and slender wheatgrass grown in alluvium with control, manure, hay, and straw treatments to evaluate crust effects on seedling germination, emergence, and establishment.

Berkeley Pit alluvium can be used as a coversoil with a good suitability classification for pH, electrical conductivity, texture, and sodium adsorption ratio. Rock fragment percentage is easily estimated in the field and should be used as a selection criterion for the alluvium, with < 35% rock fragment content providing for coversoil with at least a fair suitability classification. Levels of selenium, mercury, arsenic, nickel, lead, and cadmium in the alluvium do not present toxicity problems. Copper, manganese, and zinc levels are

elevated in the alluvium, but localized toxicity problems to plants can be ameliorated by liming, addition of organic matter, or fertilization. The alluvium has been adequately sampled to insure representation of the range of values present for different properties.

The greenhouse study using wheat as a growth indicator for amendment levels and alluvium sources indicated that material from the east rim of the Berkeley Pit was the best plant growth medium evaluated. Manure mixed into alluvium at a 1:4 volumetric ratio produced the greatest increment of increased yield. Added lime was not of significant benefit.

Scanning electron microscopy showed that the surface crusting of alluvial materials was a physical problem caused by grain packing and clay adhesion within the sand fraction. Low percentages of expanding clays limit the tendency for cracks to develop in the crust. Organic matter addition decreases crust strength by aiding formation of stable soil aggregates and decreasing clay adhesion in the sand fraction.

The greenhouse study of seedling success of four species grown under various treatments demonstrated that moisture contents high enough to insure plant germination generally reduced crust strength below levels inhibitory to plant emergence. Small seeded species such as sheep fescue were the exception, as it experienced difficulty in emergence from the alluvium under all treatments. All species grown

in the alluvium, regardless of treatment, produced less aerial biomass than the soil control. Soil crust strength of alluvium amended with manure and the soil control were statistically similar. Crust strength of the alluvium increased with decreasing moisture content. Bulk density of the alluvium without amendment was high enough to inhibit plant root activity.

Berkeley Pit alluvium is generally suitable for use as a cover-soil. The amount of time the alluvium lies fallow following surface application should be minimized. Lack of cover during periods of fallow exacerbates temperature extremes and raindrop impact and splash, the physical processes which contribute to crust formation and determine the strength of the crust in the field. Addition of organic matter over time should alleviate physical problems inherent in the alluvium. Further research is needed to demonstrate the ability of the alluvium to support plant communities in the field over time.

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