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

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.

STATEMENT OF PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication in this thesis for financial gain shall not be allowed without my written permission.

Signature ____________________

Date 5/28/81

INVESTIGATION OF SELECTED BERKELEY PIT OVERBURDEN AS A

MEDIUM FOR PLANT GROWTH

by

Fred Elmer Parady III

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

of

MASTER OF SCIENCE

in

Land Rehabilitation

Approved:

Chairman, Graduate Committee

Head, Major Department

Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

May, 1981

ACKNOWLEDGEMENTS

I wish to express appreciation to the Anaconda Copper Company for developing and funding this project. Special thanks are due Roger Gordon, Senior Reclamationist at Butte Operations, for his optimism during innumerable difficulties; to John C. Spindler, now with Anaconda Copper in Denver, for obtaining the project's authorization; to Dr. Brian W. Sindelar for his editorial expertise, flexibility, and encouragement; to Dr. William M. Schafer for many great ideas; to I. Bernard Jensen for sound practical advice; and to Ron Thorson for statistical analysis.

Finally and most of all, to my wife, Anne, for accepting another two years as a student's wife.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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

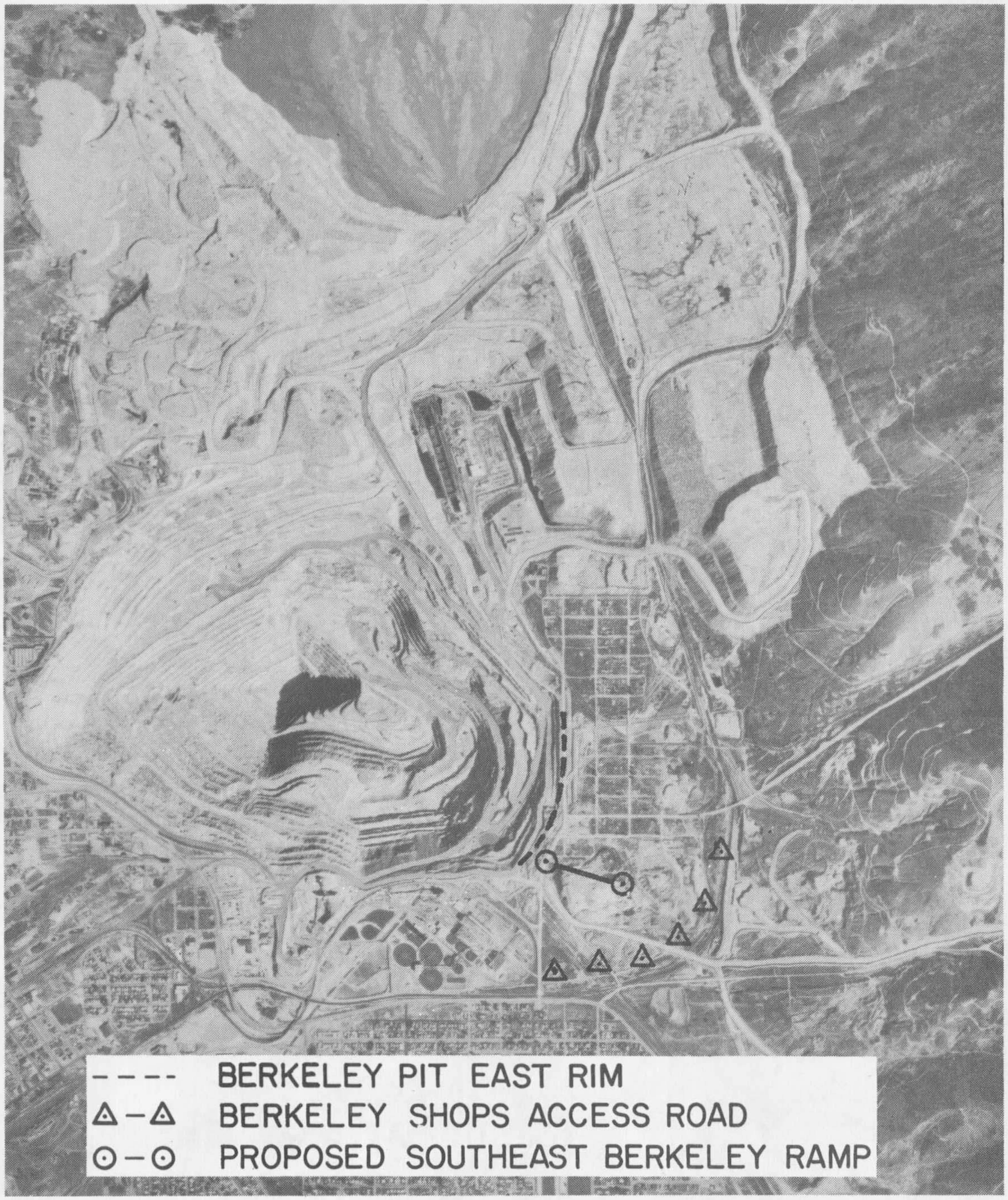

Figure 1. Aerial photograph of the Berkeley Complex.

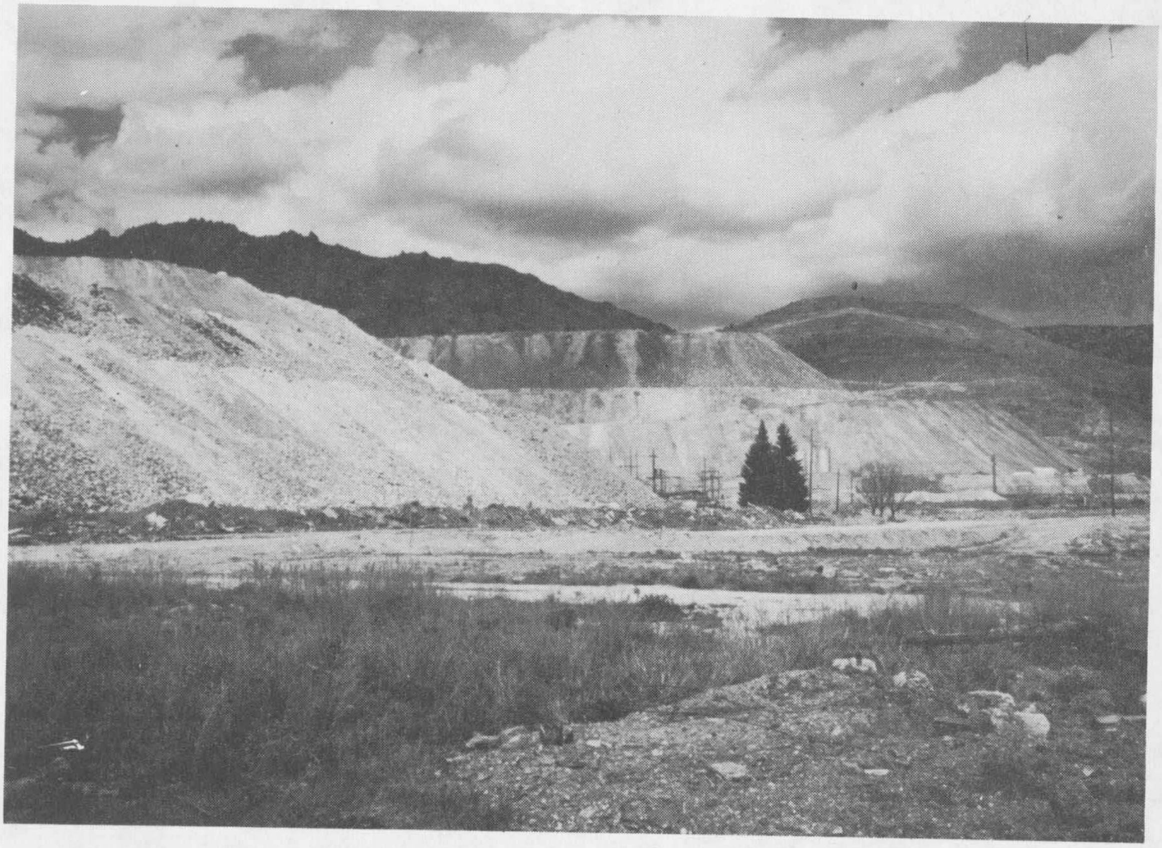

Figure 2. Typical waste dump at the Berkeley Complex.

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

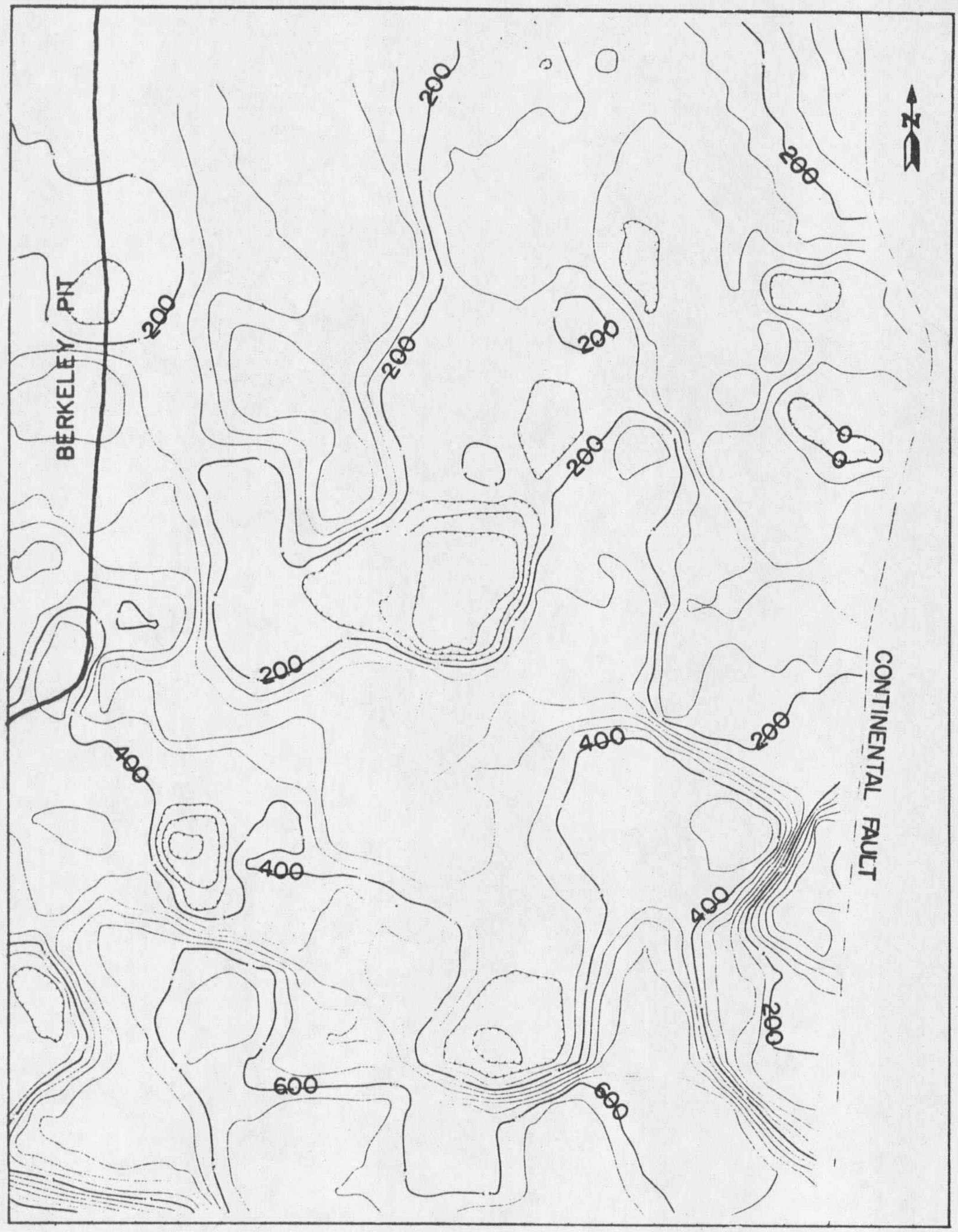

Figure 3. Isopach map showing depths of alluvial materials (derived from unpublished data).

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.

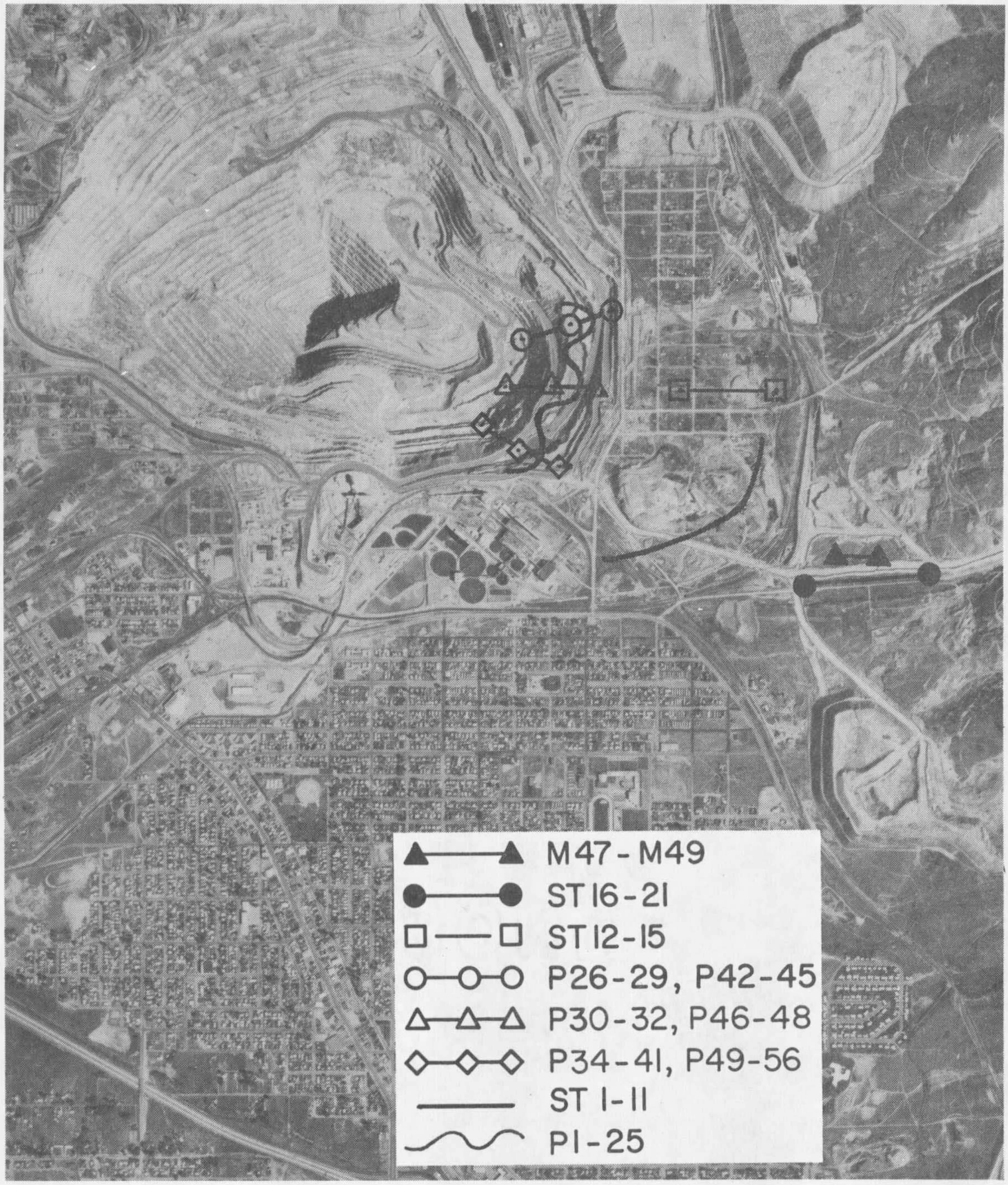

Figure 4. Alluvium sample locations.

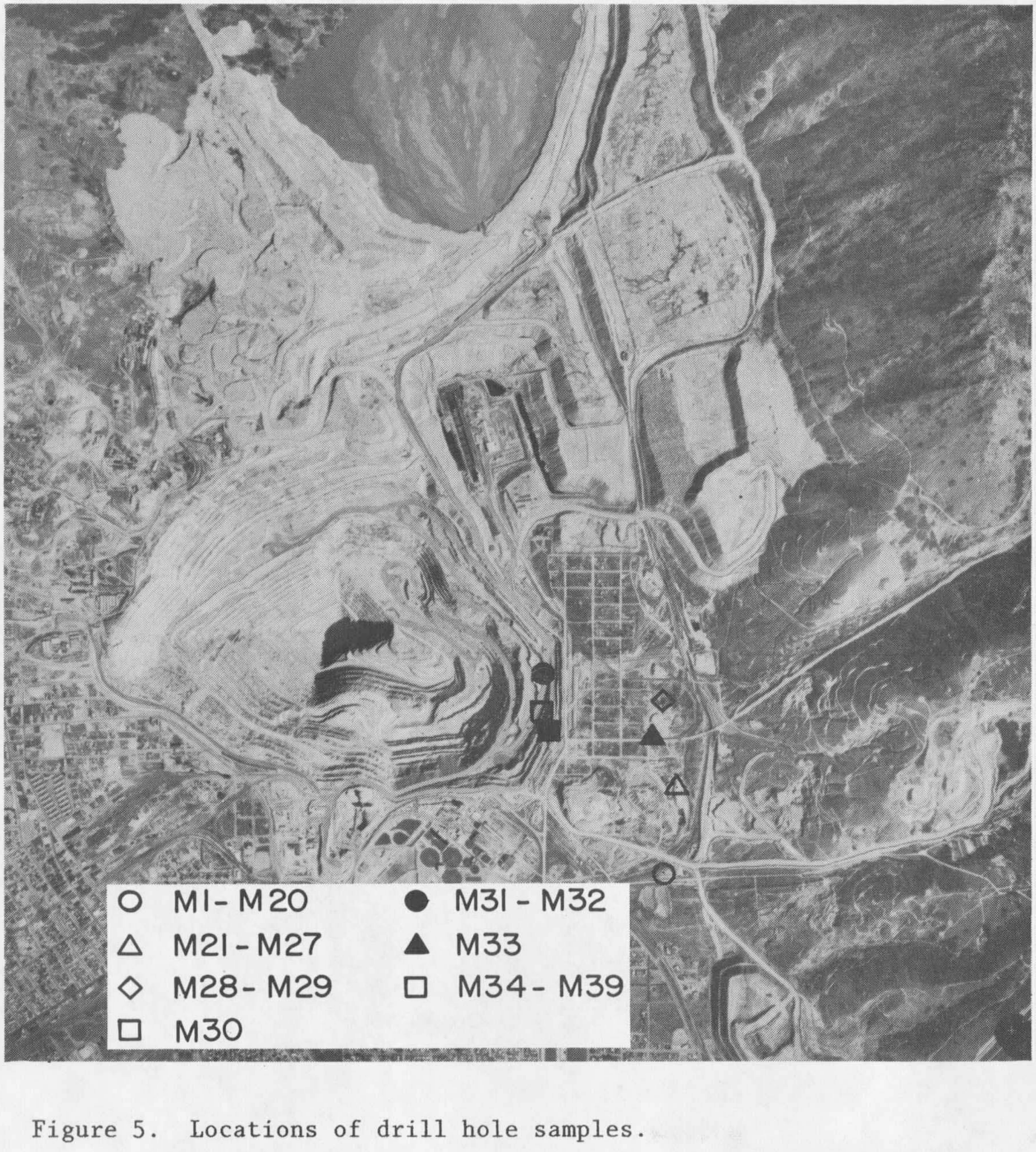

Figure 5. Locations of drill hole samples.

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