

Factors affecting vegetation development on mined land at Colstrip, Montana
by Patrick Leo Plantenberg

A thesis submitted in partial fulfillment of the requirements of the degree of Master of Science in Range Science
Montana State University
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Abstract:
In 1976 and 1977, six leveled, naturally revegetated 45- to 49-year-old. overburden deposits were studied near Colstrip, MT to determine factors affecting vegetation development on minesoils. Initial observations revealed plant communities on the deposits were different one from another as well as from native rangeland, although the origin, age, parent materials, microtopography, climate, and past management were apparently similar. Study objectives were to review literature on vegetation development patterns on disturbed sites, describe existing plant communities on minesoils and surrounding range-land, and analyze plant species and site differences to identify factors causing the differences in vegetation development.

Information was collected on site origins, grazing use, climatic variability, microtopography, and soil characteristics. Vegetation analyses included community mapping, species lists, canopy coverage, above and below ground productivity, frequency, density, phenology, and age-class distribution of important species. Sampling was conducted on sites, on slopes off sites, and on surrounding grazed rangeland to determine differences in plant species distribution and migrating abilities.

Plant communities on the study sites apparently developed based on responses of individual plant species to: 1) environmental gradients such as differences in season of site abandonment, parent materials, microtopography, past grazing management, and surrounding plant populations, 2) environmental modification produced by the existing vegetation on sites, and 3) the influence of climatic variability on establishment of initial vegetation. Establishment of initial vegetation may be an important process controlling the course a given plant and soil successional sequence will follow.

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A thesis submitted in partial fulfillment
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of

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ABSTRACT

In 1976 and 1977, six leveled, naturally revegetated 45- to 49-year-old overburden deposits were studied near Colstrip, MT to determine factors affecting vegetation development on minesoils. Initial observations revealed plant communities on the deposits were different one from another as well as from native rangeland, although the origin, age, parent materials, microtopography, climate, and past management were apparently similar. Study objectives were to review literature on vegetation development patterns on disturbed sites, describe existing plant communities on minesoils and surrounding rangeland, and analyze plant species and site differences to identify factors causing the differences in vegetation development.

Information was collected on site origins, grazing use, climatic variability, microtopography, and soil characteristics. Vegetation analyses included community mapping, species lists, canopy coverage, above and below ground productivity, frequency, density, phenology, and age-class distribution of important species. Sampling was conducted on sites, on slopes off sites, and on surrounding grazed rangeland to determine differences in plant species distribution and migrating abilities.

Plant communities on the study sites apparently developed based on responses of individual plant species to: 1) environmental gradients such as differences in season of site abandonment, parent materials, microtopography, past grazing management, and surrounding plant populations, 2) environmental modification produced by the existing vegetation on sites, and 3) the influence of climatic variability on establishment of initial vegetation. Establishment of initial vegetation may be an important process controlling the course a given plant and soil successional sequence will follow.

INTRODUCTION

Development of extensive coal deposits in the semiarid Northern Great Plains to supply energy for generation of electricity has increased discussion about reclamation potential. Doubt exists about the feasibility of reclamation in areas where evaporation exceeds precipitation (NAS 1974). This doubt has stimulated the passage of stringent reclamation laws.

Legislation requires establishment of vegetation cover capable of self-regeneration and succession on surface mined land [30 CFR 515 (b)(19)]. The time required to establish that cover has been repeatedly questioned (Curry 1973, 1975; Packer 1974). The presence of a 45-year-old naturally revegetated overburden deposit that exceeded present standards for reclamation success indicated that potential exists for successful reclamation in the Colstrip, MT area (Sindelar and Plantenberg 1978). However, time alone does not guarantee success, as five 48- to 49-year-old overburden deposits in the same area did not meet the requirements (Skilbred 1979).

Studies of old naturally revegetated deposits could identify and rank importance of factors affecting vegetation development on mined land. These studies are important because the number of old leveled minesoils is limited. In addition, five sites were destroyed by mining in 1977.

In 1976 and 1977, six naturally revegetated overburden deposits were intensively investigated. Study objectives were to review literature on vegetation development patterns on disturbed sites, describe existing plant communities on minesoils and surrounding rangeland, and analyze species and site differences to identify factors causing differences in vegetation development.

The deposits consisted of leveled excess overburden removed before mining in areas where overburden depth exceeded dragline capacity. Overburden was deposited on adjacent native rangeland. Preliminary reconnaissance of the deposits showed that plant communities were dissimilar on the six sites. Plant communities graded from shrub/subshrub-annual grass stands in poor range condition [using Soil Conservation Service (SCS) range condition guidelines] to stands dominated by native perennial species in good range condition. However, site origin, age, parent material, microtopography, climate, and past grazing management were apparently similar on five of six deposits. Plant communities on five of six deposits reflected changes in the relative importance of individual species rather than changes in floristic composition (Skilbred 1979).

This study was part of a study for the U.S. Department of Energy (then Energy Research and Development Administration) (Sindelar and Plantenberg 1977, 1978, 1979, 1980). Another Master of Science study was conducted on five of the six overburden deposits (Skilbred 1979).

LITERATURE REVIEW

Literature concerning vegetation development patterns on disturbed land is extensive (Haug 1970). Wali (1980) recently reviewed succession theory as it relates to mined land revegetation. He indicated problems ecologists have had relating the "orderly progression to climax" theory to observed vegetation development in areas where evaporation exceeds precipitation. Skilbred (1979) reviewed succession principles that affect natural revegetation of mined land in the Northern Great Plains. The literature review that follows seeks to clarify the role of ecological factors in development of vegetation on mined land.

Development of a climax community is not determined by an inherited design but by characteristics of the environment and of the plant species that are able to establish and maintain populations in the community (Drury and Nisbet 1973; Whittaker 1975; Pickett 1976). Initial establishment of vegetation is important to the natural revegetation process on disturbed sites (Egler 1954). The role of climatic variability in succession is important to initial establishment of vegetation after a disturbance (Lang 1971).

Significant yearly variability in precipitation occurs in the study area (NOAA 1924-1983). The vegetation present in an area may result more from climatic extremes than from average weather patterns (Egler 1977). For example, several studies indicated that drought

and precipitation greater than average influenced vegetation development more than grazing (Reed and Peterson 1961; Houston and Woodward 1966; Branson and Miller 1981).

Many vegetation studies in semiarid areas have stressed the importance of yearly precipitation amounts related to long term averages. The variation in precipitation month to month has been shown to be significant as well (Olson 1983). Protential evapotranspiration must also be considered (Toy 1979).

Minesoils are substantially different from native soils in the Colstrip, MT area. Schafer et al. (1979) reviewed differences between native soils and minesoils less than 50 years old at Colstrip. Minesoils were characterized by homogenization of the landscape, parent materials, soil texture, and soil depth, and by high coarse fragment content (Schafer 1982). Minesoils with up to 70% coarse fragments probably have more favorable moisture regimes for deep rooted plants than moderately fine to fine textured soils (Berg and Barrau 1973). Mined land has increased soil depth but often contains impermeable layers that can perch water tables (Larson 1980).

Curry (1973, 1975) speculated that rates of soil genesis may be impossible to measure with the climate that exists in the study area today. However, measurable soil formation processes have been documented on naturally revegetated minesoils under 50 years old (Schafer et al. 1979; Singleton and Barker 1980; Wali 1980).

Vegetation development on mined land is a mixture of primary and secondary succession processes (Wali 1980). Although vegetation and soil development are interdependent, the role of soil development in

primary successions probably has been exaggerated (Drury and Nisbet 1973). For example, some plant species characteristically associated with later stages of soil formation, may succeed if introduced initially by seed or vegetative transplant. In South Dakota, cool-season grasses, such as Agropyron smithii and Stipa viridula replaced warm-season grasses in native plant communities as soil structure and soil fertility (i.e. soil development) increased with time (White 1971). But on seeded mined land at Colstrip, cool-season grasses predominated regardless of minesoil age, topsoil treatment, or fertilizer regime (Depuit 1980). Mined land in the Colstrip area typically has sufficient stored soil moisture to increase initial vegetation establishment success if precipitation is normal (Sindelar et al. 1973).

Man has introduced many new species into the Northern Great Plains flora. Examples include Salsola kali which became widespread in the drought of the 1930's (Van Bruggen 1976). Melilotus officinalis is a conspicuous exotic biennial species that has become a naturalized component of disturbed native rangeland in the area (Sindelar and Plantenberg 1978). Introduced perennial species are important in native communities; examples are Poa pratensis in Agropyron smithii-Stipa viridula grasslands and Taraxacum officinale. Improved pastures are seeded with introduced plant species. Various noxious weeds such as Centaurea maculosa, Cirsium arvense, and Convolvulus arvensis occur in the study area on disturbed sites (Sindelar and Plantenberg 1978). Although man's activities have favored introduction of exotic species, the opportunity for exotic species to become established is

present even in some existing undisturbed communities (Daubenmire 1968). Disturbance, coupled with the presence of aliens, may result in a plant community different from the antecedent vegetation type (Weaver and Clements 1938). The introduction of competitive new species and varieties alters vegetation development patterns on minesoils (Sindelar and Plantenberg 1978; King 1980).

Man's use of the land may have modified existing vegetation populations in the Northern Great Plains. For example, existing vegetation in an area may not be representative of the potential vegetation because grazing may have altered it (Sedgeley 1974). The bison herds are gone. In contrast to transient bison use (England and De Vos 1969), overgrazing by livestock is extensive in different vegetation communities and occurs in all seasons of the year. The influence of livestock grazing in the past 100 years has significantly changed vegetation development patterns (Ellison 1960). In fact, grazing programs are being used today which recreate the herd effect on land without which plant, soil, and animal succession is altered (Savory 1981).

Vegetation development potentials can be substantially modified by man's choice of mining methodology. Schafer (1982) concluded that new reclamation methods had increased the overall SCS land capability classification at some mines over the capability classes that existed before mining. Different mining methods allow selective handling and placement of overburden (Dollhopf et al. 1978). Overburden with man-created improvements may form a better topsoil than the previous natural topsoil (Bradshaw and Chadwick 1980).

Mining methods and economics affect the rate and scale of mining. Size of disturbance is an important factor often overlooked in ecological studies (Burges 1960). Vegetation development patterns change as the size of disturbance changes (Egler 1954; Golley 1965; Platt 1975). The larger the disturbance the less likely the site will return to the antecedent vegetation (Connell and Slatyer 1977).

Revegetation strategies developed to meet the requirements of reclamation laws, alter vegetation development on mined land. For example, climax species depend almost solely on wind for dissemination (Weaver and Clements 1938). Today, legislation requires topsoiling and seeding of land disturbed by mining. With direct-haul topsoiling practices, propagules of relatively immobile climax species are directly transferred to sites, increasing their chance for establishment (King 1980). Establishment irrigation, seed mixture formulation, fertilization, landscape design, and other man-controlled reclamation treatments alter vegetation establishment potentials (DePuit 1980).

Following initial revegetation treatments, plant populations may be manipulated by fertilizers, herbicides, insecticides, and grazing which will influence vegetation development patterns. Reseeding and interseeding are other alternatives to establish additional plant species (Humphries 1979). Direct intervention by man to supply seed may be needed because seed of some species may be unavailable to disturbed sites (Harper 1977).

In summary, climatic variability and minesoil properties are factors that affect the process of initial establishment of

vegetation on mined land. Man has introduced new plant species into the local flora and modified existing plant species populations as well. Mining methods and revegetation strategies are other important factors that affect vegetation development on mined land.

METHODS AND PROCEDURES

Introduction

Objectives of this study were to describe existing plant communities on mined land and surrounding rangeland near Colstrip, MT and to analyze plant species and site differences. To identify and rank factors causing the differences in vegetation development among the sites, the following methods and procedures were developed.

Six overburden deposits from the same mining period on native rangeland were chosen for study to minimize variations due to mining methods, soil/parent materials, climate, grazing, and fire history in surrounding plant communities. Methods were designed to study each deposit as one site without replicates. Sampling intensity was selected to characterize adequately each site as well as the native rangeland communities surrounding each site.

Mining Methodology

Historical information concerning mining methods at the time of site formation was searched in many records:

-Western Energy Company records, Colstrip, MT

-W. B. Dean photograph collection - Forsyth, MT and Montana Historical Society, Helena, MT

-Northern Pacific Railway Company records - Minnesota Historical Society, St. Paul, MN

-Northwestern Improvement Company records - St. Paul, MN

-Foley Bros. Construction Company records - St. Paul, MN

-Forsyth Independent newspaper records - Rosebud County Museum, Forsyth, MT

-Personal interview with N. Fandrich, Town Manager, Colstrip, MT

Grazing History

Information on grazing history of the area was obtained from:

-Burlington Northern, Inc., grazing lease records, J. Bishop, BN, Inc., Miles City, MT

-Personal interview with L. Eastgate, Sarpy Creek, MT, local rancher who leased the study area and who was former purchasing agent, Foley Bros. Construction Co., in Colstrip, MT.

-Environmental impact studies done in the area (Westinghouse Elec. Corp. 1973, Bennett et al. 1976).

Literature about the area was used to supplement information on the mining and grazing history of study sites (Foley 1945, Fulmer 1973).

Species Identification

Plant lists were made for each site (see Skilbred [1979] and Sindelar and Plantenberg [1978]). Plant collections were made throughout the growing season. Specimens of each species collected were identified, characterized, and catalogued. Duplicate specimens, if available, were submitted to the Montana State University Herbarium. More than 425 vascular plant species in the Colstrip area were collected. A flora including all of the species in the study area does not exist. Scientific nomenclature for plant species was primarily

based on Hitchcock and Cronquist (1978). Nomenclature for other species was based on Booth (1950), Booth and Wright (1966), Van Bruggen (1976), and Dorn (1977). Nomenclature is based on USDA-SCS (1982).

Vegetation Mapping

Color and infrared aerial photographs and topographical maps were used to construct vegetation mosaic maps of five of the sites as well as areas immediately surrounding these sites. Surveying equipment and topographical maps were used to produce microtopographical profiles of these five sites. Regretably, a sixth site and its surrounding rangeland in another management unit, were not mapped. Numerous 35 mm photographs were taken of the sites during the study period.

On-Site Sampling

Exclosure Measurements

Exclosures (15 x 25 m) were constructed to protect permanent plots from livestock and vehicle traffic. Exclosure locations were selected on each deposit in the major plant community. The native range site was selected on an upland ridge. The ridge was an extension of the same ridge which was used to form two of the sites. Also, it was selected to match the upland nature of the sites. Vegetation sampling methods matched those of the parent study (Sindelar and Plantenberg 1978, Figure 5, p. 152). All sampling was systematic

at regular intervals along transects. Justification for random vs. systematic sampling is a matter of opinion (Daubenmire 1968).

Three permanent 20 m transects were located using galvanized wire stretched at ground level between steel posts and marked at one-meter intervals. On one transect, 10 permanent 0.75 m square quadrats were stereophotographed twice during each growing season. These stereophotographs provided a 35 mm photographic record of the vegetation. A second transect was used for standing crop estimates by the direct harvest method (Lewis 1970). Ten 0.5 m square quadrats were harvested twice during the growing season, once in late May or early June and then again in early July. These dates were chosen to sample the peak standing crop of the major cool-season and warm-season species in the area (Sindelar and Plantenberg 1977). Plant materials including shrubs were clipped to ground level and separated by species. Standing dead material and ground litter were also separated. All samples were oven dried, weighed, and averages determined. Litter samples were not ashed. As a result, litter estimates are maximum values. Shrub and cactus species with above ground perennating cambium layers and leaves were sampled differently. Only the new growth was removed and other perennating material was placed in standing dead samples. As a result, shrub estimates are minimum values.

Two transects were used for ground and canopy coverage analyses. Forty permanently located 20 x 50 cm plots were sampled twice during each growing season. Canopy and ground coverage estimates were made for each species as well as mosses, lichens, fungi, litter, rock, and bare ground with a modification of the Daubenmire (1959) canopy

coverage method. Interspaces in the imaginary polygon drawn around a plant canopy were removed to produce actual coverage values. As a result, comparisons with other studies using this method are limited and coverage values should be considered minimal. Canopy coverage estimates provided data for species composition, frequency, and species diversity. Diversity was calculated using the Shannon Index (Pielou 1975). Diversity values are reported to levels as precise as the data that were used to generate them. The indices were not calculated on a plot-by-plot basis. As a result, statistical testing was not conducted.

Summation of the largest standing crop and canopy coverage estimates for individual species from the two sampling dates in a growing season were used to compute a "maximum" value for each site. This computation is standard procedure for productivity estimates (Singh et al. 1975). For the coverage estimates, this represents a modification of the Daubenmire technique. This modification is justified for canopy coverage estimates because this study used permanently located plots with the same plants being estimated each sample date. These maximum values still lack estimates for ephemeral forbs and late developing species.

Plant density estimates were made in 20 permanently located 15 x 15 cm quadrats along one transect (Sindelar and Plantenberg 1978). Density counts of each species were recorded every two weeks during the growing season. Nine sample dates were recorded in 1976 and 15 dates in 1977.

Standing crop, canopy coverage and density differences among sites were tested using analysis of variance procedures (Nie et al. 1975). Mean separation was accomplished using Duncan's Multiple Range test (Steele and Torrie 1960). Statistical analyses were conducted even though sampling on sites was not replicated. Results should be viewed in that context.

Species frequency was used to determine whether exclosure plant communities were comparable with communities on the rest of the study sites. Frequency was sampled by modifying techniques used by Hyder et al. (1963) and Hyder et al. (1965, 1966). Presence of a species was recorded when it was overhanging or rooted in the sampling plot. Over 3,000, 4 x 10 cm plots were sampled on the six minesoil sites. For exclosure comparisons, 60 plots were sampled at one-meter intervals along transects in each exclosure. On the rest of each site, a central point was selected and transects were located in eight cardinal directions radiating from the central point. Frequency plots were sampled at one-meter intervals in eight directions, until 200 plots were recorded on each of the five sites in one management unit. On the sixth site, two central points were selected because of the large size and bilobed appearance of the site (see Figure 14). On the sixth site 1710 plots were inventoried. Frequency samples were subjected to Chi Square (X^2) analyses (Snedecor and Cochran 1971).

Slope and Exposure

Plant species on the slopes of five sites were listed and mapped. The relative abundance of each species was estimated using

the Domin-Krajina abundance scale (Mueller-Dumbois and Ellenberg 1974). Unfortunately, the slopes of the sixth site were not mapped or inventoried in any way.

Age-Class Distribution

An age-class distribution analysis was conducted for selected species populations on five sites to quantify whether or not reproduction was occurring. A central point on each site was selected and transects were established radiating in four cardinal directions. The plant closest to every five-meter mark was sampled until 25 plants were sampled per site.

Artemisia cana is rhizomatous; however, the stems are long lived. The oldest stem on each plant was sampled and the age determined by counting growth rings. Artemisia dracunculus, a perennial forb or subshrub species and Stipa comata, a perennial bunchgrass were sampled by measuring the basal and crown diameters. It was assumed that the oldest plants had the largest diameters (Daubenmire 1968). Although this is a relative criterion, an approximation of age is inventoried as well as relative plant size. The mean and 95% confidence intervals were determined. The width of the confidence interval indicated the distribution of different age and size classes in the population. If intervals did not overlap when graphed, significant differences between populations were assumed.

Phenology Studies

Seasonal development of six major species was observed in 1977 to reveal variations in development associated with litter accumula-

tions. Phenology was sampled by modifying techniques of Mueggler (1972 and Personal communication). A phenology code was used that was developed by other researchers in southeastern Montana (Taylor and Leininger 1977, Table 1). Attempts were made to locate 25 plants of each species in the canopy coverage plots. Plants were marked for repeated observations. Fifteen sample dates were observed between April 1 and October 15, 1977.

Table 1. Phenology code (Taylor and Leininger 1977).

1 cotyledon (newly germinated)	9 flowering, anthesis
2 seedling	10 late flowering
3 basal rosette	11 fruit formed
4 early greenup, veg. buds swelling	12 seed shatter, dehiscence
5 vegetative growth, twig elongation	13 vegetative maturity, summer dormancy, leaf drop
6 boot stage, flower buds appearing	14 fall greenup
7 shooting seed stalk, floral buds opening	15 winter dormancy
8 early flowering	16 dead

Soil Measurements

Soil samples were collected on each of five sites using a 7.5 cm bucket auger. From each site, six samples at five depths (N=30), 0-10 cm, 25-35 cm, 50-60 cm, 75-85 cm, and 100-110 cm were collected. Soil analyses were conducted on samples from two sites by the Montana State University Soil Testing Laboratory. Samples were then subjected to analysis of variance and mean separation techniques. Soil samples from the other four sites were analyzed by the USDA-SCS Soil Characterization Laboratory in Lincoln, Nebraska as part of a cooperative soil genesis study on the sites (Schafer et al. 1979).

Soil moisture was determined gravimetrically at biweekly intervals (Reynolds 1970). Each site was sampled in 1977 in two locations and six depths, namely 0-10 cm, 20-30 cm, 40-50 cm, 60-70 cm, 80-90 cm, and 100-110 cm.

Bulk density and root production were sampled at three sites using methods outlined by Sindelar et al. (1973). Sampling was conducted in September 1976 and July 1977. Roots were separated by washing through a #40 soil sieve. Roots were dried, weighed, and corrected for mineral matter content by ashing at 600°C. Roots and bulk density were also sampled in 1977 on all sites using a 137 cc core sampler.

Off-Site Sampling

Frequency Sampling

A total of 6075, 4 x 10 cm frequency plots were sampled near the six overburden sites on transects radiating in cardinal directions onto surrounding rangeland. Frequency was used to evaluate differences in opportunities for migration of plant species. The nearest source of propagative materials was sought when a species found on the study sites was not found within 100 m of the site on surrounding native rangeland. Between 950 and 1225 frequency plots were sampled surrounding each site.

Pioneer Species

During the 1977 field season, species lists were made on 35 one- and two-year-old man-created disturbances in the management unit

containing five of the six deposits. These disturbances were used to identify possible pioneer species on the deposits at the time of site formation. Attempts were made to determine whether the species on the recent disturbances had established from seed, vegetative transplant, or from peripheral invasion.

Age-class Distribution

Age-class distribution analyses were conducted on native rangeland surrounding five of the six sites to match the analyses conducted on the five sites. Twenty-five plants were inventoried by establishing an arbitrary point and sampling at 5 m intervals in four cardinal directions. The native range control site (NR) was used for sampling Artemisia dracunculus and Stipa comata. Due to the absence of Artemisia cana on the NR site, a swale between two of the minesoil sites was sampled.

A plowed field was sampled adjacent to one site (see Figure 10). It was abandoned in 1948, not seeded, and became dominated by Stipa comata. This is common for abandoned sandy loam cropland in southeastern Montana (D. Ryerson, 1981, Mont. State Univ., Bozeman, MT Personal communication). A soil sample was collected for textural analysis. In contrast, abandoned loamy soils in the area, can develop Aristida longiseta-Psoralea tenuiflora communities with a conspicuous component of annual Bromus spp.

Other Information

Additional vegetation data from native rangeland were obtained from other studies in the Colstrip area (Econ, Inc. 1975, 1976;

Munshower et al. 1975; Munshower and DePuit 1976; Munshower et al. 1978). Climatic data were obtained from the Colstrip weather station (NOAA 1924-1983). Parent materials and geology of the area were characterized by using Northwestern Improvement Co., mining records and overburden drill analyses conducted by Western Energy Company (1973). Table 2 summarizes sampling history of sites.

Table 2. Sampling history of sites.

DATA TYPE	SAMPLING FREQUENCY	SITE 28-1 1976	SITE 28-1 1977	SITE 28-2 1976	SITE 28-2 1977	SITE 28-3 1976	SITE 28-3 1977	SITE 28-4 1976	SITE 28-4 1977	SITE 28-5 1976	SITE 28-5 1977	SITE 30 1976	SITE 30 1977	NR SITE 1976	NR SITE 1977
Plant density	biweekly	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Cover & frequency	twice/year	5/12 6/24	6/8 7/6	6/7 6/24	6/8 7/6	5/28 ns	6/8 7/6	5/28 6/24	6/7 7/6	5/14 6/23	6/7 7/6	5/11 6/21	6/7 7/6	5/14 6/24	6/7 7/6
Standing crop	twice/year	6/17 7/20	6/15 7/13	6/7 7/20	6/15 7/13	6/7 7/20	6/15 7/13	6/7 7/20	6/15 7/13	6/7 7/20	6/15 7/13	6/7 7/20	6/15 7/12	6/7 7/20	6/15 7/13
Quadrat stereophotography	twice/year	5/24 6/23	6/16 7/20	5/24 6/23	6/16 7/20	5/24 ns	6/16 7/20	5/24 6/23	6/16 7/20	5/24 6/23	6/16 7/20	5/26 6/22	6/16 7/20	5/27 6/24	6/16 7/20
Site aerial photography	yearly	6/18 7/15	8/23	6/18 7/15	8/23	6/18 7/15	8/23	6/18 7/15	8/23	6/18 7/15	8/23	6/18 7/15	8/23	6/18 7/15	8/23
Soil moisture & temperature	biweekly	x	x	ns	x	ns	x	ns	x	ns	x	x	x	x	x
Standard soil analyses	yearly	6/1	ns	9/1	8/1	9/1	ns	9/1	8/1	9/1	8/1	6/1 9/1	ns	6/1 9/1	ns
Root biomass, soil bulk density	yearly	9/1	7/27	9/1	7/7	ns	7/7	ns	7/7	ns	7/7	9/1 (9/1/1973)	7/7	ns	7/6
Phenology	biweekly	ns[1]	x	ns	x	ns	x	ns	x	ns	x	ns	x	ns	x

[1] ns = not sampled

STUDY AREA

General Description

Location

Colstrip is in Rosebud County in southeastern Montana. It is located on the East Fork of Armell's Creek which flows northward into the Yellowstone River, 50 km away. Colstrip is in the northern part of the Powder River Basin in the Northern Great Plains physiographic province.

Geology

A detailed summary of the geology was prepared by Schafer et al. (1979). These sedimentary plains were not glaciated during Pleistocene time but changes in the climate caused downcutting of rivers and rejuvenation of much of the landscape. The area is characterized by valleys and rolling hills which are strongly dissected by intermittent stream channels and scattered bedrock outcroppings (Figure 1).

Surficial geology is dominated by the Tongue River member of the Paleocene Fort Union formation. This formation has extensive subbituminous coal reserves. At Colstrip, the Rosebud coal seam is approximately 7.5 m thick. Overburden, up to 50 m thick, is predominantly sandstone with abundant lenses of siltstone. Sediments vary laterally making sampling and characterization of overburden difficult (Dollhopf et al. 1978).

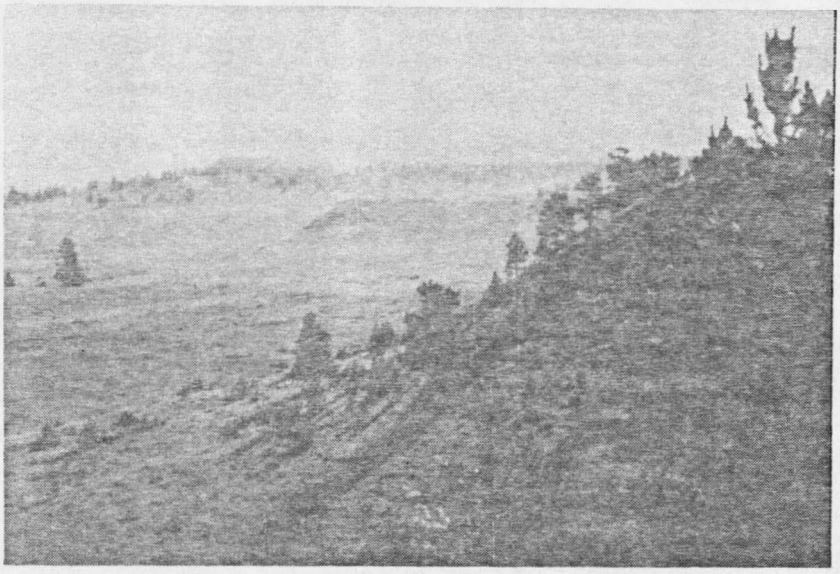


Figure 1. General view of the Colstrip, MT area.

Soils

Native soils and minesoils have been studied by Western Energy Company (1973) and Schafer et al. (1979). Most soils in the area are less than 10,000 years old. Representative soil series that develop on various parent materials at each geomorphic position in the area are illustrated in Figure 2 (modified from Econ, Inc. 1975, 1976; Schafer et al. 1979). Coarse-loamy and fine-loamy textural classes of soils dominate locally. Some fine-loamy soils occur on colluvium derived from siltstone. Skeletal and fragmental soils are common on top of sandstone, siltstone, porcelanite, or baked sandstone-capped outcrops.

Vegetation

Vegetation in the area is predominantly mixed-prairie grassland and Pinus ponderosa savanna on bedrock outcroppings (Payne 1973; Ross and Hunter 1976). A typical cross section of major plant species associations and their relation to soil, aspect, elevation, and USDA-SCS range sites is presented in Figure 2. Scientific names for plant species abbreviations used in Figure 2 are listed in Table 3.

Climate

The continental climate in the area is best described by extremes rather than means. Temperatures fluctuate between -40°C (-40°F) and 40°C (111°F). Typically, January and July are the coldest and warmest months. Precipitation averages about 40 cm but as little as 22 cm fell in the drought of 1934 while 63 cm fell in 1944. The growing season begins for many species in late September if moisture is adequate. Growth ceases with the onset of cold weather in late October and resumes again in late March as the snow recedes. Summer precipitation is variable due to localized showers and high intensity thunderstorms. Phenological differences of up to one month can occur depending on growing conditions. Vegetation production in any year is affected by fall and winter moisture from the previous year (Rogler and Haas 1947; Newbauer et al. 1980). It may also depend on moisture from the last two years (Dahl 1963). Distribution of moisture is extremely variable due to slope, exposure, wind, sublimation, drifting patterns, runoff, potential evapotranspiration, soil texture, soil

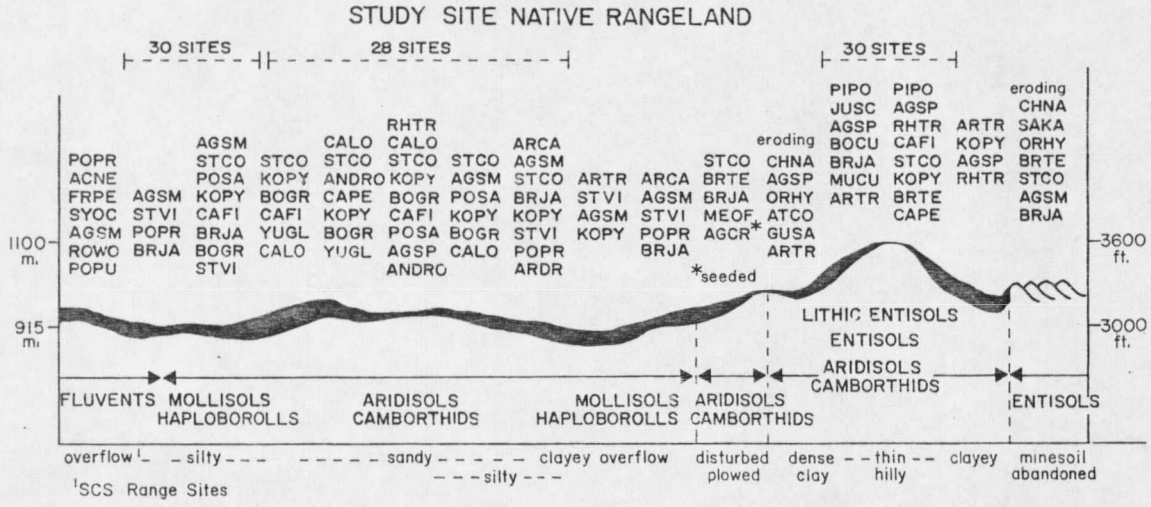


Figure 2. Cross section of major plant associations around the study sites and their relation to soil, aspect, elevation, and SCS range sites.

Table 3. Important plant species in the study area.

Grasses and sedges		Forbs	
*AGCR	Agropyron cristatum	*MEOF	Melilotus officinalis
AGSM	Agropyron smithii	*SAKA	Salsola kali + S. collina
AGSP	Agropyron spicatum		
ANDRO	Andropogon gerardii, A. g. var. paucipilus (A. hallii) & Schizachyrium scoparium		Shrubs and Trees
		ACNE	Acer negundo
BOCU	Bouteloua curtipendula	ARCA	Artemisia cana
BOGR	Bouteloua gracilis	ARDR	Artemisia dracunculus
*BRJA	Bromus japonicus	ARTR	Artemisia tridentata
*BRTE	Bromus tectorum	ATCO	Atriplex confertifolia
CALO	Calamovilfa longifolia	CHNA	Chrysothamnus nauseosus
CAFI	Carex filifolia	FRPE	Fraxinus pennsylvanica
CAPE	Carex pensylvanica	GUSA	Gutierrezia sarothrae
KOPY	Koeleria pyramidata	JUSC	Juniperus scopulorum
MUCU	Muhlenbergia cuspidata	PIPO	Pinus ponderosa
ORHY	Oryzopsis hymenoides	POPU	Populus spp.
*POPR	Poa pratensis	RHTR	Rhus trilobata
POSA	Poa sandbergii	ROWO	Rosa woodsii
STCO	Stipa comata	SYOC	Symphoricarpos occidentalis
STVI	Stipa viridula	YUGL	Yucca glauca

*introduced and naturalized species in area

infiltration rates, plant litter, and storm intensities. Potential evapotranspiration is estimated at 57 cm for the Colstrip area (Toy 1979).

Wildlife

Wildlife inventories of the area have been conducted. The most significant impact of biota observed are the periodic outbreaks of grasshoppers as in 1977. Effects of other insects, birds, and rodents on reclamation seedings and in other areas have not been adequately analyzed. Impacts of game animals on reclamation seedings at Colstrip and other areas have been documented (Sindelar et al. 1973).

Grazing History

Horses, cattle, and sheep have used the area extensively since the 1880's. The Green Mountain Stock Ranching Company was one of the first cattle operations to move into the Colstrip area (Bennett et al. 1976). Large livestock operations trailed herds through the area until the 1930's. The Fletcher Brothers (FUF Ranch) from Minneapolis, Minnesota, had a horse herd that used the length and breadth of the Armell's Creek drainage. They raised 15,000 horses for dog and cat food and had several thousand head of cattle in the early part of the 20th century. The Philbricks had a large sheep ranch headquartered east of Colstrip on Rosebud Creek until the 1930's. They sold the Colstrip townsite to Northern Pacific Railway Company (Fulmer 1973). More cattle were shipped out of Colstrip than any other place in the state in the 1930's (Eastgate, L. Colstrip, Montana, 1977. Personal communication). Cattle grazing is the dominant land use in the study area today.

SITE DESCRIPTIONS

History of Site Formation

Colstrip Mining History

Coal-powered steam locomotives powered the nation's railroads in the early 20th century. A dependable, economical source of fuel was essential. Northern Pacific Railway Company (now Burlington Northern, Inc.) had three sources of dependable but expensive coal: Roslyn, Washington; Red Lodge, Montana; and coal shipped to Duluth, Minnesota from the east (Foley 1945). Experience in midwestern coal fields showed that surface mining was more economical than underground mining. Because of government land grants, Northern Pacific owned land in southeastern Montana underlain by quantities of subbituminous coal. The coal had not been exploited because of distance from the main line. From 1917-1923 Northern Pacific developed a favorable field in the Armell's Creek drainage located 56 km southwest of Forsyth, MT which had an eight-meter thick vein of coal covered by relatively thin overburden. A branch line was completed in 1923 from the main railroad line to what was called Colstrip, MT.

In 1923, Northern Pacific Railway Company called for bids to equip and operate the new field which would be supervised by Northwestern Improvement Company, a subsidiary of Northern Pacific Railway Company. The controversial low bidder was Foley Brothers' Construction Company of St. Paul, MN which had bid for an electrified operation

rather than traditional coal-powered operations. A 150 km powerline was constructed from Billings, MT to power the mine. The operation proved to be successful and changed the coal surface mining industry (Foley 1945).

Foley Brothers Construction Company and Northwestern Improvement Company operated the mine until Northern Pacific Railway Company converted to diesel operation in 1958. Western Energy Company, a subsidiary of Montana Power Company, purchased the operations and along with Long Construction Company, commenced mining coal for electrical utilities in Montana and the midwestern states in 1968.

From 1924-1958 almost 600 ha grazing land was disturbed. Although Burlington Northern, Inc. leveled nearly all abandoned overburden in 1972-1973, some areas were not redisturbed. Several small level deposits created between 1927-1931 provided the opportunity to study nearly 50 years of natural revegetation in the area.

Excess Overburden Operations

The first pit at Colstrip was opened in the fall of 1924. A Marion 360 dragline was used that was track mounted and equipped with a 46 m boom and a 3.8 m^3 bucket (Figure 3). The dragline could handle up to 15 m of overburden. In 1925, overburden averaged only five meters thick. As mining progressed in Pit One, away from Armell's Creek, overburden continued to thicken. In areas where the dragline range was exceeded, surface material had to be removed outside the mining area. The excess overburden was jackhammered or blasted, and loaded by diesel shovel into 1927, chain driven, side-dump, Mack

trucks. The trucks hauled the material from the mine site onto adjacent rangeland (Figure 4).

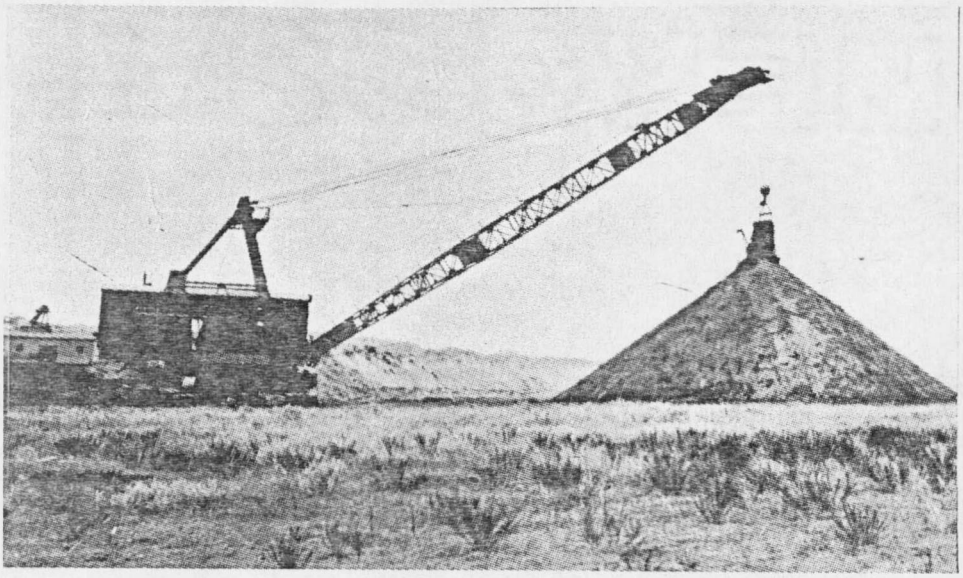


Figure 3. A Marion 360 dragline was used to mine Pit One at Colstrip in the 1920's (Dean Collection 1925).

Loading and unloading the excess overburden mixed the overburden, sorted larger rock fragments (Figure 5) and created diagonal layers in the minesoil.

Over 200,000 m^3 of excess overburden from Pit I were deposited in six dumps up to one hectare in size from October 13, 1927 until November 18, 1928. Excess overburden removal continued in Pit Two from July 26, 1929 until May 30, 1931. Removal of 1,222,000 m^3 of excess overburden from Pit II resulted in three dumps up to 10 ha in size being deposited on native rangeland.

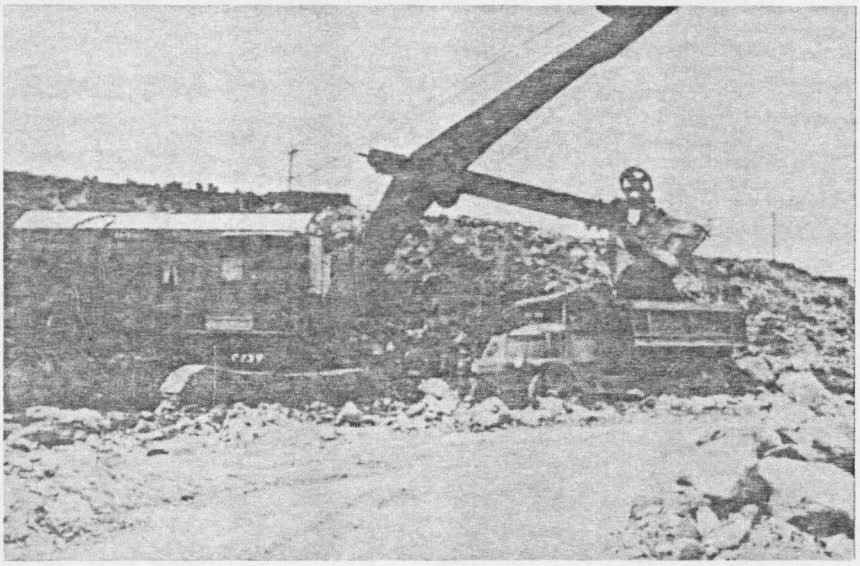


Figure 4. A Bucyrus-Erie 50-B diesel shovel loaded excess overburden on side-dump trucks (Dean Collection 1929).

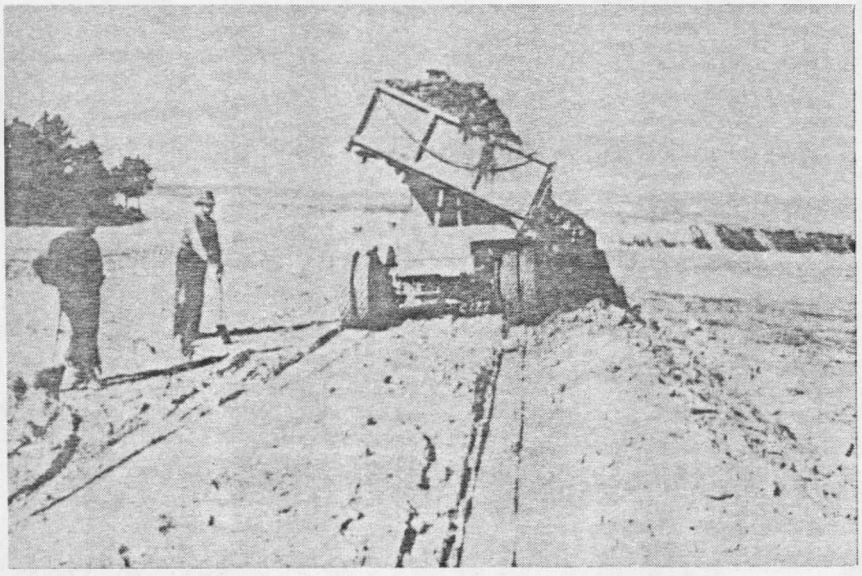


Figure 5. Side-dump trucks unloaded excess overburden on bladed dumps (Dean Collection 1929). Note the large rock fragments at the bottom of the dump.

A Bucyrus 750 shovel was assembled in 1929 which could handle more overburden than the Marion 360 dragline. The Bucyrus 750 shovel finished mining Pit One and then moved to Pit Two. Hauling excess overburden was no longer necessary.

The nine dumps created between 1927-1931 were leveled during formation and abandoned. These were the only old leveled overburden sites in the Colstrip area. The deposits had been naturally revegetated without being topsoiled, seeded, or fertilized.

Modern mining operations at Colstrip are different from those of the past. Draglines with 45 m^3 buckets can strip overburden over 50 m thick, thoroughly mixing it in the process. Bulldozers, draglines, and scrapers can reshape the overburden, forming it into topography similar to premining conditions. Topsoil can be sorted and replaced on the overburden providing a seedbed for the reclamation seeding which follows.

The old leveled deposits consisted of soil and bedrock removed from ridges (Figure 6 and 7). The overburden removed averaged less than eight meters thick. As a result, the study sites did not resemble modern-day mining sites because they contained only a portion of the overburden profile. However, the soil types and geologic materials are similar to those being placed on top of present day reclaimed minesoil profiles.

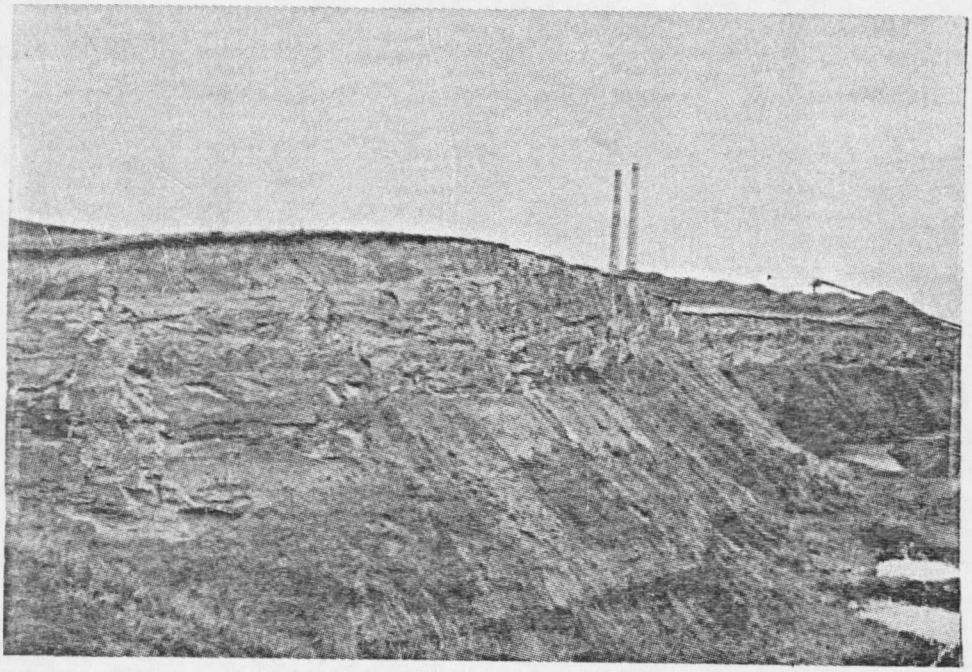


Figure 6. Surface materials from ridges that exceeded 15 m above the coal had to be removed before mining could progress.

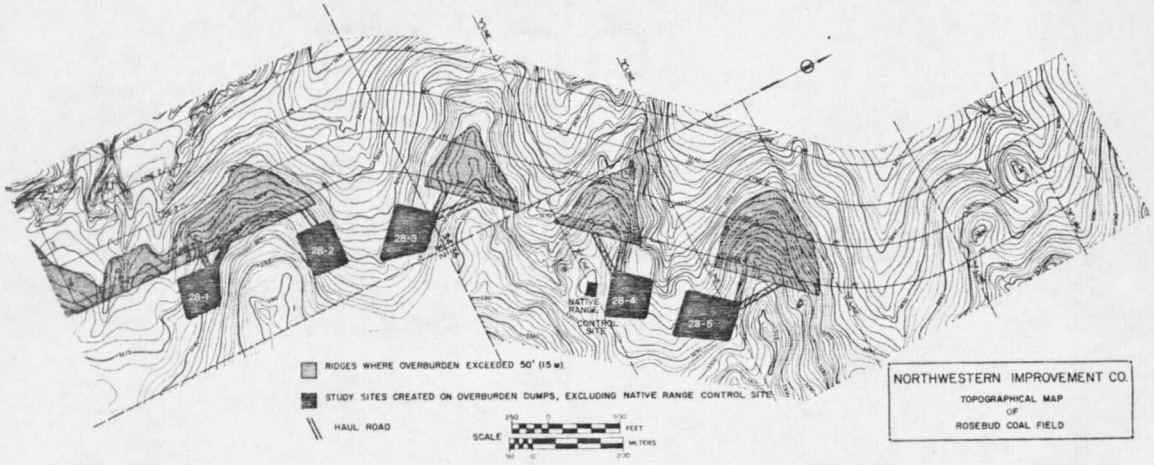


Figure 7. Topographic map of sites near Pit One.

Detailed Site Descriptions

Site Selection

Six of the nine original excess overburden deposits were chosen for study. Five of the dumps selected were created by Pit One operations between October, 1927 and November, 1928 and were called the 28-sites. As mining progressed the sites were repeatedly disturbed over a 12-month period. Sites 28-1 and 2 were completed in June, 1928; Site 28-3 was completed in September 1928; Site 28-4 was completed in July 1928; and Site 28-5 was completed in November 1928 (Figure 8). One native range control site (NR) was selected in the 28-site management unit.

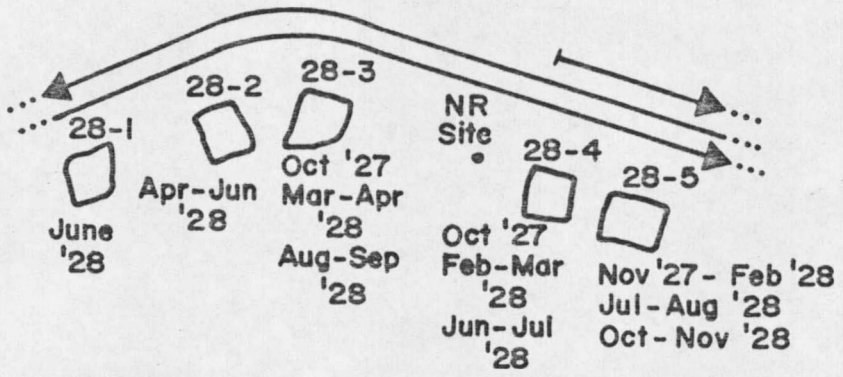


Figure 8. Chronosequence of site formation through Pit One.

One deposit from Pit Two was selected for study. It was created between July, 1929 and January, 1931 and was identified as the 30-site (Figure 9).

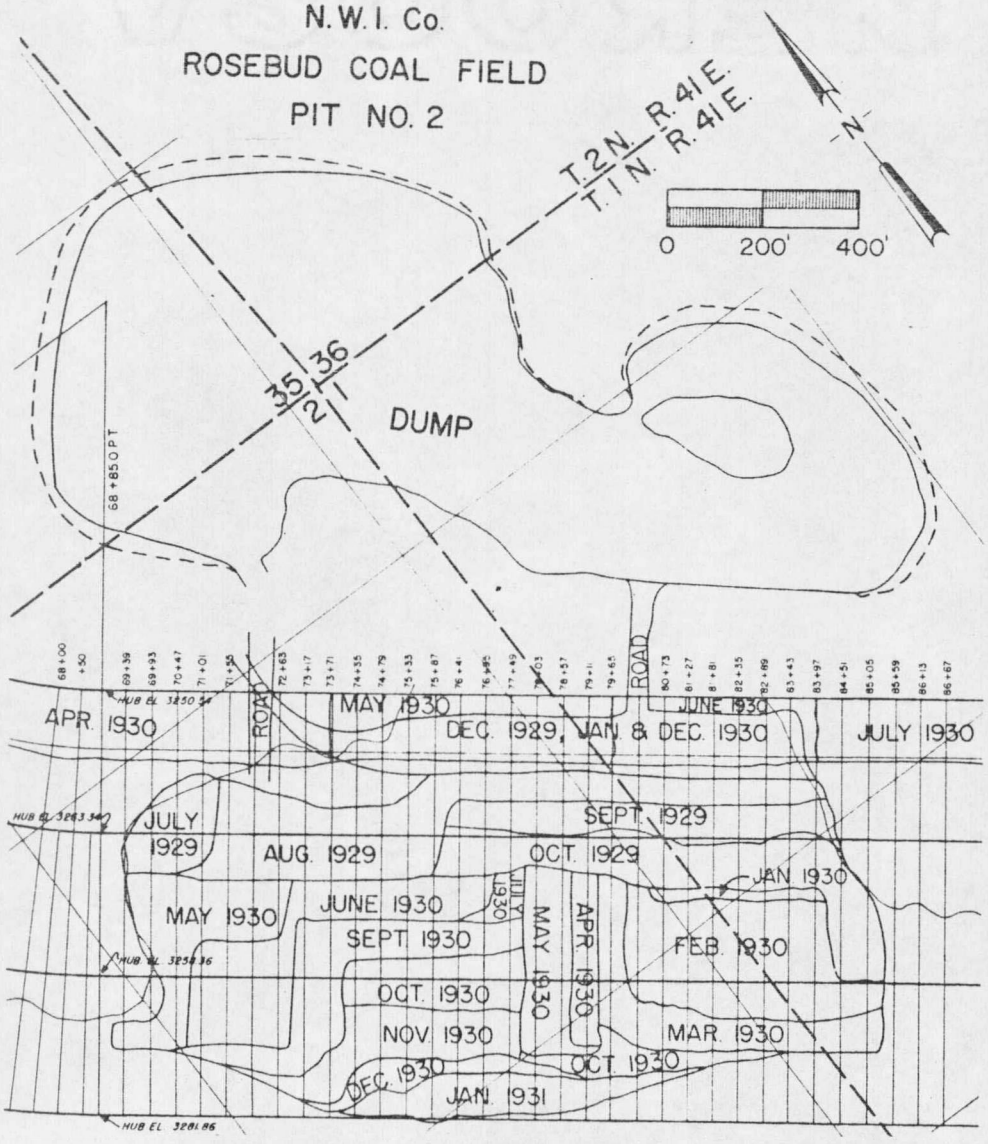


Figure 9. Northwestern Improvement Company records showed monthly removal of excess overburden from Pit Two.

Location

Sites were located 3 km southeast of Colstrip, MT on property owned by Western Energy Company. Five deposits, predominantly formed in 1928, ranged from 0.4-1.0 ha in size and were called the 28-sites. The five deposits were located within 1.4 km of each other in section 35, T2N R41E and section 3, T1N R41E (Figure 10). The native range control site (NR) was located on a ridge between two of the 28-sites. Site-30 occupied 10 ha in sections 35 and 36, T2N R41E and sections 1 and 2, T1N R41E. Other information on Figure 10 will be discussed later.

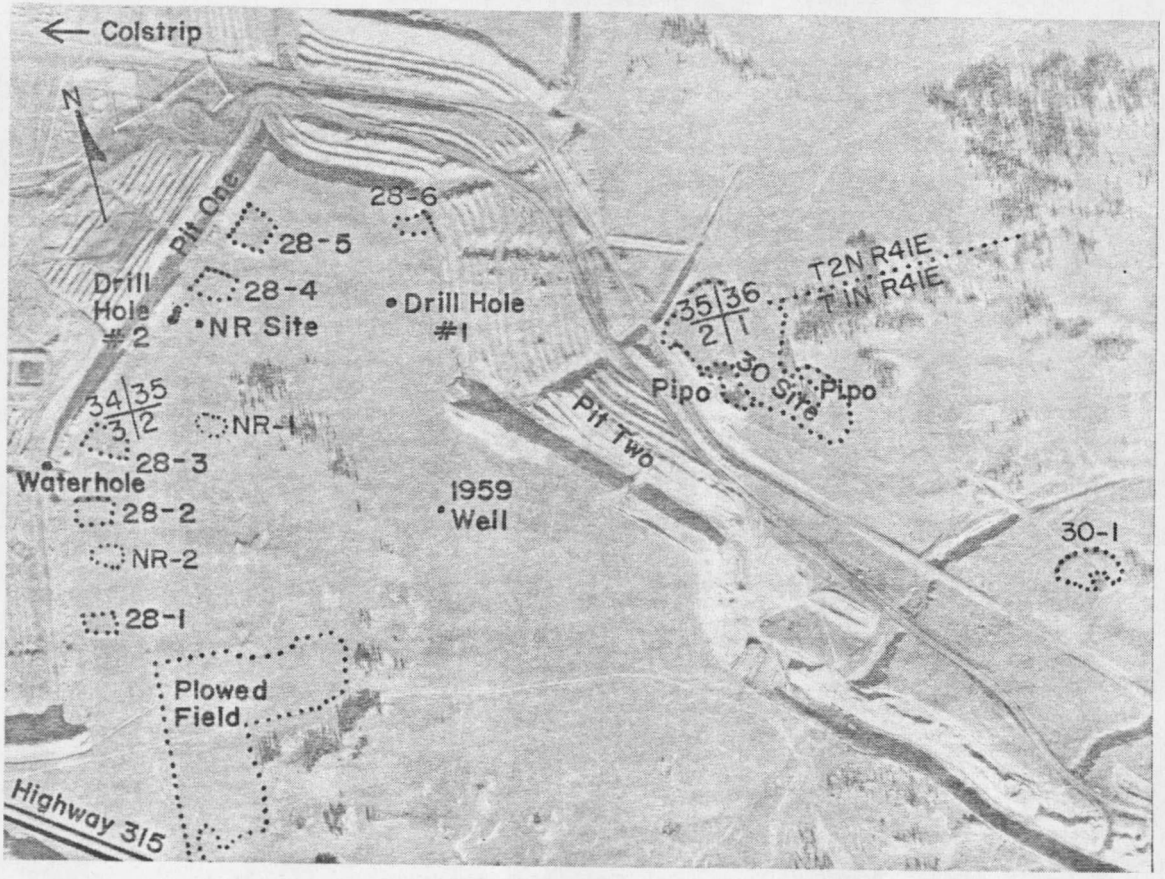


Figure 10. Location of sites (1976 photograph).

Physiography

Side-dump trucks deposited overburden on hillslopes resulting in dumps of increasing thickness as they were formed (Figure 11). The deposits were essentially level and appeared as rectangular benches or terraces on the landscape (Figures 11, 12, 13 and 14). Table 4 summarizes physical characteristics of the sites.

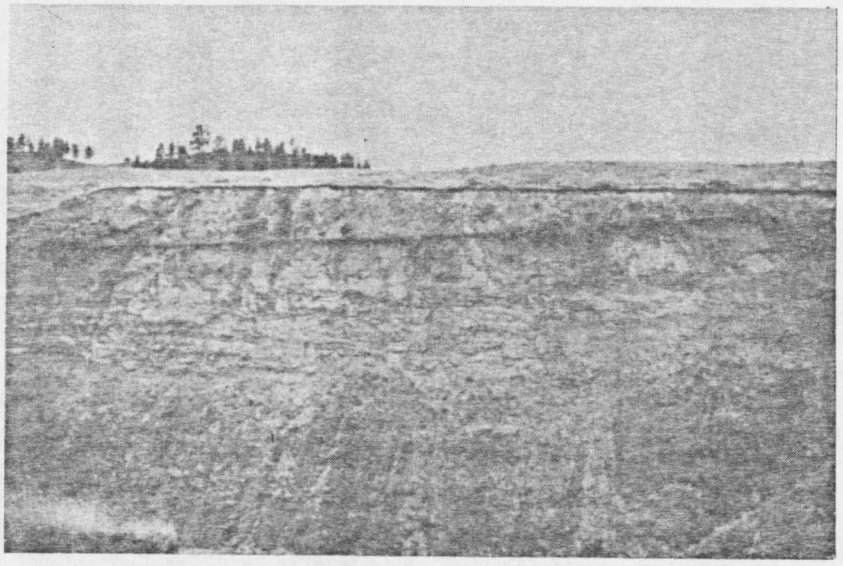


Figure 11. A cut through an excess overburden dump deposited on a hillslope showed its characteristic level surface and terrace appearance.

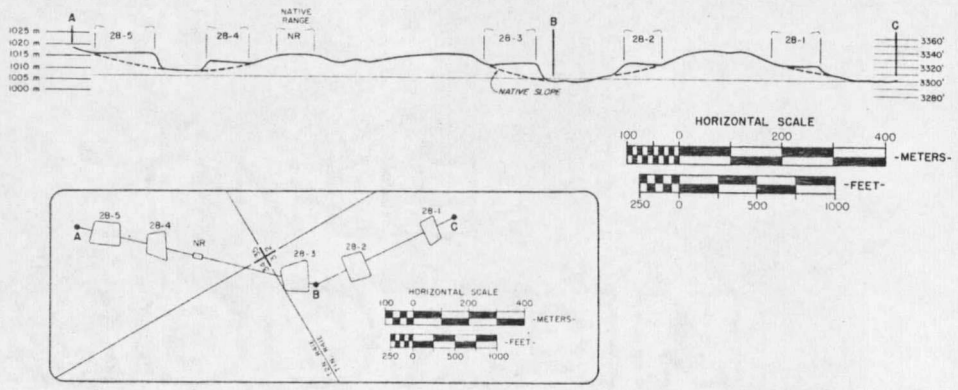


Figure 12. Topographic relationships of 28-sites.

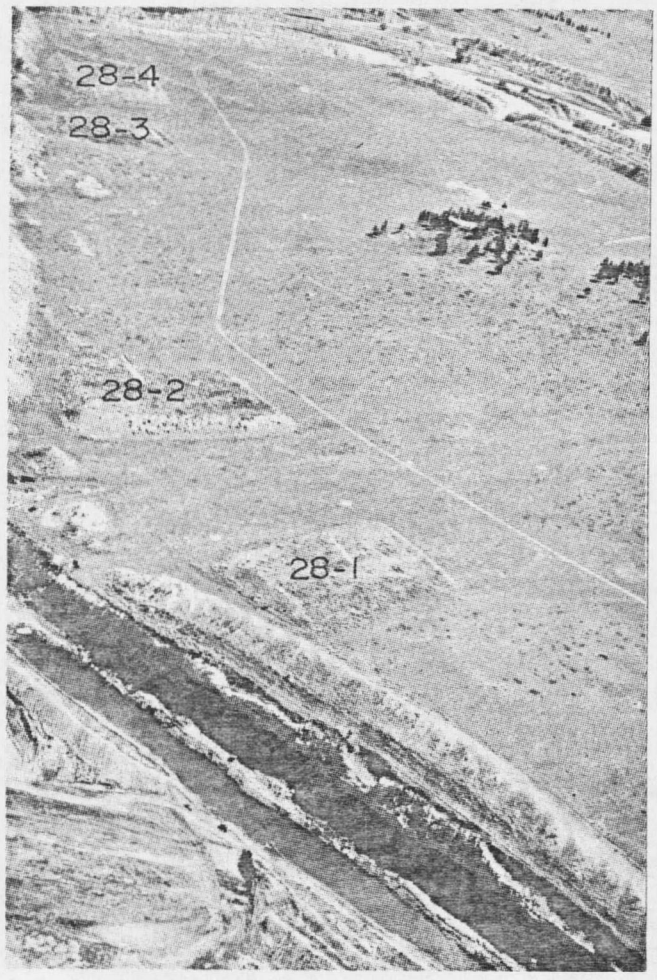


Figure 13. Aerial view of four of the five 28-sites deposited on native rangeland adjacent to Pit One. The sites appeared as benches or terraces on the landscape.

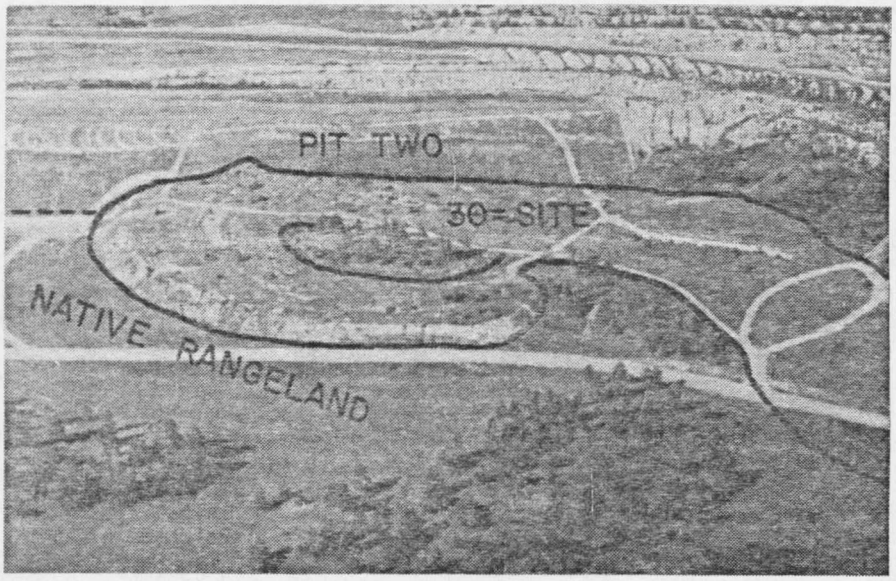


Figure 14. Aerial view of the level 30-site, a 10 ha excess overburden deposit (outlined in black) which was formed around native tree-covered outcrops.

Table 4. Physical features of sites.

			28-SITE MANAGEMENT UNIT				CHARACTERISTICS OF ADJACENT SLOPE		
SITE	LENGTH (m)	WIDTH (m)	AREA (ha)	ELEVATION (m)	SLOPE (%)	ASPECT	LENGTH (m)	SLOPE (%)	ASPECT
28-1	91	46	0.4	1010-13	0-2	W	99	8	SW
28-2	107	59	0.6	1011-15	0-4	SW	76	8	N
28-3	114	56	0.6	1011-13	0-3	NE	107	4	SW
28-4	91	59	0.5	1012-13	0-3	W	69	7	NE
28-5	91	99	0.9	1015-17	0-3	NE	84	5	SW
NATIVE RANGE GRASSLAND				1000-18	0-15	--	--	--	--
			30-SITE MANAGEMENT UNIT						
30	550	200	10.0	994-1004	0-4	--	--	61	NE
NATIVE RANGE GRASSLAND				985-1004	0-4	--	61	50	NE
NATIVE RANGE OUTCROPS				1000-1008	15-30	--	--	--	--

Postmining Use

Because of extensive premining grazing use, the composition of species in native communities was modified and presumed to be typical of a heavily grazed area in fair range condition. This was deduced from the quantities of vegetation such as Artemisia cana, Artemisia dracunculus and other increaser species observed in old photographs of the study area (Figure 3). As a result, soil materials used to form the study sites contained seeds and portions of plants characteristic of those areas. This influenced the vegetation that established. There was no evidence that management differences existed in the area prior to mining that would have affected subsequent natural revegetation on one site over another.

The 28-site management unit had been grazed periodically since mining started in the Colstrip area in 1924. The first documented use was by the Schulenberg Dairy in Colstrip, whose cattle used the area at least from 1950-55. The vegetation was in poor condition when L. Eastgate obtained the lease in 1955. Burlington Northern, Inc., leased land to Eastgate from 1951-1973 and praised his care of their land (J. Bishop, Miles City, Montana. 1977, Personal communication). Eastgate wintered 100 head of cattle and two horses on his 2,500 acre lease. In summer, the site was used by his heifers and 30 replacement cows. He also used the area for calving. Another rancher used the area almost year round from 1973-1977 for 70 head of cattle (J. Bishop, 1977, Personal communication).

The presence of well defined cattle trails to the waterhole between sites 28-2 and 3 suggested extensive cattle use (Ellison 1960).

Distance to water may have influenced grazing pressure on the five 28-sites from 1929 until 1959 when a well was drilled (Figure 10). Distance to water before mining was not a factor, as Armell's Creek ran perpendicular to the ridges that were used to form the sites. Therefore, grazing animals in the 28-site unit from 1929-1959 had to use the waterhole between sites 28-2 and 3. From 1959 until 1977 both water sources were used by cattle. Continued grazing after mining on the rangeland surrounding the 28-sites would have affected production of propagules and mobility of species characteristically grazed by cattle.

The 30-site was in another management unit which had its own water sources. It had been grazed periodically since 1931. The area was leased for spring and fall use for 60 head of cattle from 1955-1973 (L. Eastgate, Colstrip, Montana, 1977, Personal communication). In 1960, part of the area was leased by the Colstrip Gun Club for a trap-shoot. The other uses of the site have been recreational. The area was fenced in 1976 to prevent abuse by recreationists.

In 1911, the area adjacent to the 28-site management unit was described in a Northern Pacific Railway Company Land Examination report for T1N R41E. The examiner noted a "fair growth of bunch and buffalograss [any small grasses] and bluestem on rolling areas, but on the gentle slopes the growth is very poor--there being a great deal of salt sage [Artemisia cana]. What grass there is, is bluestem and wheatgrass." Andropogon gerardii was absent in 1976 on the gentle slopes. Agropyron smithii was still there although Poa pratensis had increased. Even though Yucca glauca and Artemisia cana had increased

on the rolling hills there was also more grass in 1976 and 1977 than there had been in the early part of the century (L. Eastgate, 1977, Pesonal communication). In 1969, the range was inventoried by Burlington Northern using ocular reconnaissance and classed as being in fair condition and rated from 4-5.5 A/AUM (Acres/Animal Unit Month), (J. Bishop, 1977, Personal communication). Overall, native rangeland was in better condition in 1976 than it had been for almost 100 years.

Soil/Overburden Characterization

Northwestern Improvement Company records revealed that 57% of the material hauled to the dumps was "sandrock". This agrees with overburden analyses obtained from two drill holes located within 150 m of the native range control site (NR) (Tables 5 and 6). The holes were drilled on an uphill extension of a ridge used to form two of the deposits (Figure 7). The majority of the upper 10 m of strata was sandy loam to loamy sand textured soft sandstone bedrock (Western Energy Company 1973).

Table 5. Selected overburden analyses from drill hole #1 near the native range control site (NR).

DEPTH (M)	% CLAY	% SILT	% SAND	TEXTURE	pH	EX. NH_4 ppm
0-1.5	11.6	10.6	77.8	SL	8.3	49.0
1.5-3.0	23.2	21.6	55.2	SCL	8.4	24.0
3.0-4.6	31.2	28.8	40.0	CL	8.4	22.0
4.6-6.1	5.6	17.2	77.2	LS	8.6	10.0
6.1-7.6	11.2	11.0	77.8	SL	8.6	10.0
7.6-9.1	7.8	6.6	85.6	LS	8.7	10.0
9.1-10.7	9.2	8.0	82.5	LS	8.6	14.0
10.7-12.2	6.6	8.0	85.4	LS	8.7	14.0
12.2-13.7	32.0	43.6	24.4	CL	8.2	34.0
13.7-15.2	32.0	38.8	29.9	CL	8.4	34.0

[1]SL (sandy loam), SCL (sandy clay loam), CL (clay loam), LS (loamy sand)

Table 6. Selected overburden analyses from drill hole #2 near the native range control site (NR).

DEPTH (M)	% CLAY	% SILT	% SAND	TEXTURE	pH
0-3.0	25.8	6.4	68.8	FSL[1]	8.7
3.4-6.1	12.8	4.4	82.8	LFS	8.6
6.4-9.1	10.8	2.4	86.8	LFS	8.7
9.4-11.0	10.8	2.4	86.8	LFS	8.6
11.3-11.6	28.8	38.4	32.8	CL	8.8
11.9-14.3	20.8	4.4	74.8	FSL	8.6
14.6-16.2	44.8	16.4	38.8	CL	8.7

[1]FSL (fine sandy loam), LFS (loamy fine sand), CL (clay loam)

Analyses showed no serious elemental deficiency or toxicity. All strata except deep, clay layers were described as safe to be placed on the surface after mining. Soil reaction (pH) values were moderate to high but not restrictive. The overburden contained some inherent fertility. A fertilizer adjustment was recommended because of the high levels of exchangeable ammonium (NH_4) in the overburden (Western Energy Company 1973).

The overburden was also described by the SCS Soil Characterization Laboratory in 1976 on four of the six deposits as slightly weathered, unconsolidated mineral sediments; calcareous sandstone with interbedded calcareous siltstone, and shale. Buried A_1 horizon material was common in the profiles in diagonal layers (Figure 15).

Native Soils Characterization

A soil survey of the 28-site area characterized native soils used to form the sites (Western Energy Company 1973) (Figure 16). Unfortunately, soil surrounding the 30-site were not surveyed at the same time. Topsoil used to form the 28-sites would probably have been classed as Tullock fine sandy loam with 4-15% slopes and Remitt fine

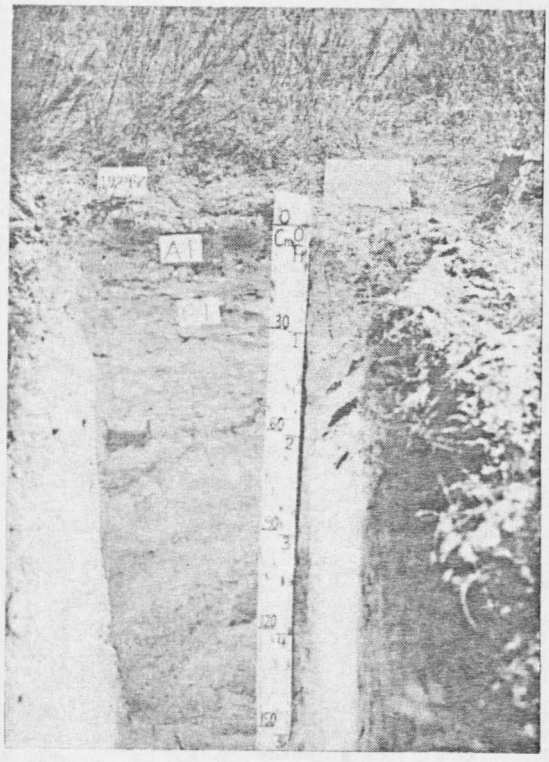


Figure 15. Minesoil at site 28-2 showing minimal A_1 horizon development and dark diagnonal layers of buried A_1 materials in the profile (Schafer et al. 1979).

sandy loam with 2-8% slopes. The grassland topsoil surrounding the 30-site was classed as Remitt fine sandy loam with 2-8% slopes and Fort Collins loam with 0-2% slopes. The 30-site also contained the Tullock complex with 2-20% slopes in the surrounding Pinus ponderosa-Agropyron spicatum type. The survey recommended that all of the soil down to bedrock could be used for stockpiling, as could the soft bedrock materials.

Two soil types were also characterized in the 28-site area by Schafer et al. (1979). The shallow upland soils were developed from

slightly weathered residual material which was either local colluvium or solifluctate calcareous sandstone. Bedrock was found as shallow as 35 cm (Figure 17). Table 7 summarizes some selected properties for the soil types used to form the sites.

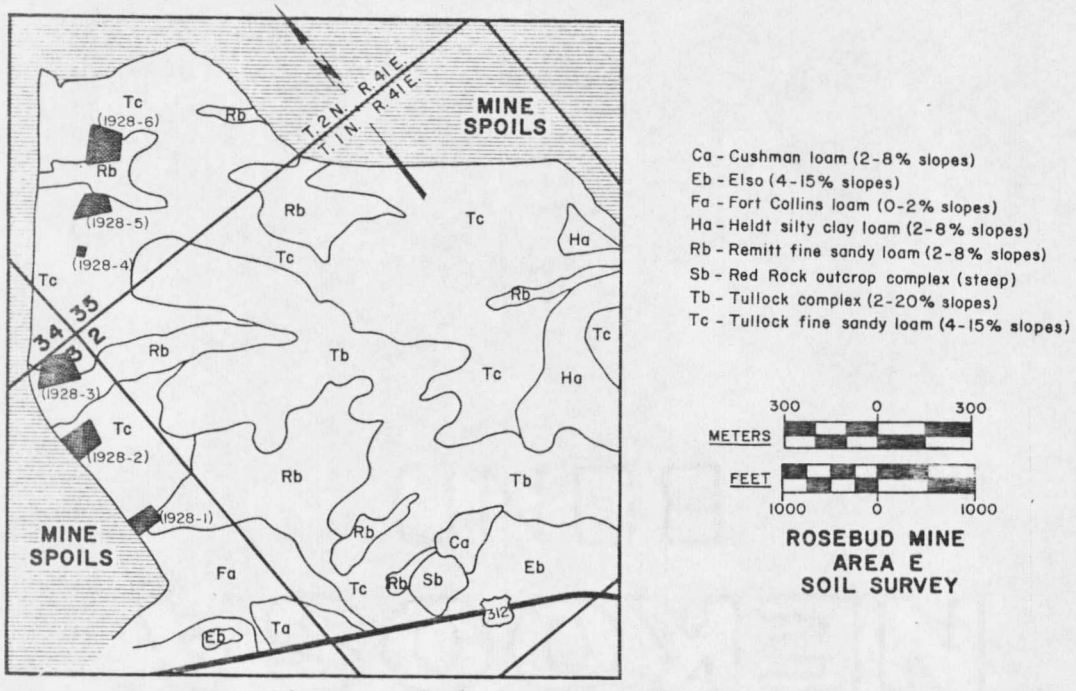


Figure 16. Soil survey of the study area (Western Energy Company 1973).

Soil Characterization on Study Sites

Table 8 lists selected minesoil properties on study sites. A minimal A_1 horizon had developed in 50 years (Figure 18). Some soil forming processes, especially near the surface, were measurable. These measurable changes included lowered bulk density, organic matter enrichment, pH reduction, weak structural development, calcium

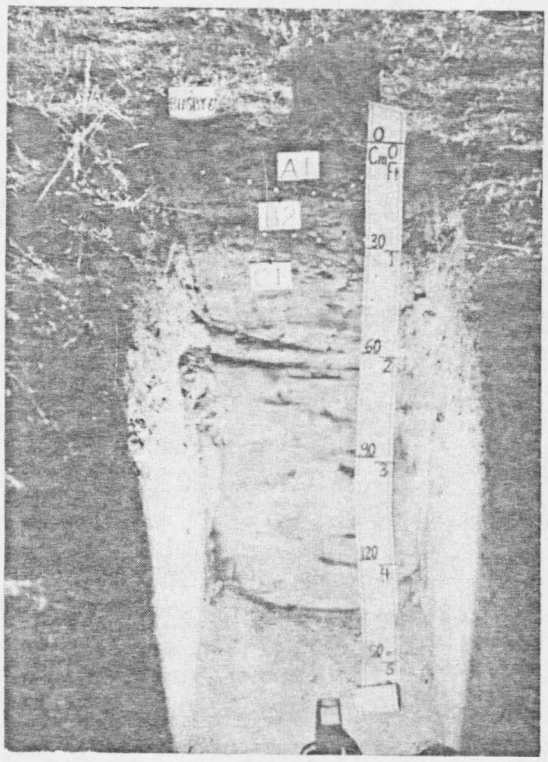


Figure 17. Native soil type (NR#2) similar to native range control site (NR) showing paralithic contact at 35 cm and sub-angular blocky structure in A_1 and B_2 horizons. (Schafer et al. 1979).

carbonate ($CaCO_3$) leaching, and rock fragment weathering (Figure 19) (Schafer et al. 1979).

Native soils and minesoils were similar in texture (coarse-loamy), bulk density (1.4-1.6 g/cc), and sodium absorption ratio (SAR = 0.5%) (Schafer et al. 1979). Minesoils had higher alkalinity (pH), electrical conductivty (EC), $CaCO_3$ percent, rock fragment contents, and lower organic carbon contents except where coal was present in the profile (Schafer et al. 1979). Fifty percent of the volume of

Table 7. Selected properties of native topsoils used to form sites.

CHARACTERISTIC	HORIZON	NATIVE SOIL TYPES REMITT	FT. COLLINS	TULLOCK		RIEDEL-6	CHINOOK-8
Slope		2-8%	0-2%	4-15%	2-20%	nearly level, concave	strongly sloping concave, SW exposure
Texture	A	FSL, LS, SL	L	SL	LS	SL	SL, LS
	B	FSL, L, LS	SCL, L	SL, LFS	S	SL	SL
	C	FSL, LFS, S	SL	SL	LS, S	SL, LS	SL
Structure	A	wk-fine crumb	mod-fine crumb	——mod-med crumb——		wk-mod med to sub ang. block	mod. coarse platy
	B	wk-coarse prism	mod-med coarse prism to mod-med to fine sub ang blocky	——		wk-mod med sub ang. blocky	vwk coarse prism and sub. ang. blocky
	C	massive	massive	——wk-mod coarse prism——		massive	vwk coarse prism and sub ang blocky
Bulk density[1] (g/cc)	A	——NS[2]——				1.26 - 1.43 (12)[3]	1.40 - 1.51 (5)
	B					——	1.46 - 1.50 (4)
	C					1.37 - 1.71 (11)	1.49 - 1.52 (4)
Effervescence ($CaCO_3$)	A	wk	noncalcareous	wk	wk	mod	noncalcareous
	B	strong	noncalc-strong	——		mod to violent	noncalcareous
	C	strong	strong	strong to violent		mod to violent	mod
pH[1]	A	7.7 - 8.3	8.0	——8.1 - 8.2——		7.4 - 8.4 (15)	6.8 - 8.0 (8)
	B	7.9 - 8.3	7.9 - 8.4	——7.9 - 8.3——		7.5 - 8.3 (4)	6.8 - 7.8 (4)
	C	8.2 - 8.9	7.9 - 8.4	——8.0 - 8.5——		7.6 - 8.6 (6)	7.5 - 8.6 (6)
Organic matter (%)	A	0.1 - 2.8	1.4	——1.4 - 2.0——		0.7 - 1.1 (4)	0.7 - 2.2 (4)
	B	0.3 - 1.4	0.8 - 1.1	——0.1 - 0.7——		0.5 - 0.8 (2)	0.4 - 0.5 (2)
	C	< 0.1	< 0.1	——< 0.1——		<0.1 - 0.6 (4)	0.1 - 0.2 (3)
C:N ratio	A	——NS——				10 - 13	11 - 17
	B					9 - 10	10 - 11
	C					6 - 13	9 - 10
Roots	A	common F + vF few mod.	common F + vF	——common F + vf——		common to many F	common fine
	B	common F + vF	common F + vF	——		common fine	common fine
	C	to few F + vF	common to few	——common F + vF——		few fine	few to common F med taproots to 1.5 m
Available Water Holding Capacity (%)	A	2.9 - 7.5	8.5	——3.4 - 5.8——		6.6 - 12.2 (2)	13.1 - 20.0 (2)
	B	2.8 - 5.9	5.1 - 8.6	——2.2 - 4.0——		9.2 (1)	5.5 - 6.0 (2)
	C	2.8 - 4.5	3.4 - 13.2	——2.2 - 3.4——		5.5 - 11.4 (2)	5.8 (1)
Drainage		well	well	—well to somewhat extensively—		well	well
Source		----------Western Energy Co. 1973----------				----------Schafer et al. 1979----------	

[1] Some variation due to different sampling methods.
[2] NS = not sampled
[3] Sample numbers in parentheses

minesoils was weakly consolidated, soft sandstone coarse fragments that were altered by weathering and mixing in the upper 30 cm (Figure 19). The coarse fragments supplied water but limited root penetration (Schafer et al. 1979). In effect, these coarse fragments probably increased the plant available soil water by reducing evaporation and increasing moisture penetration.

Table 8. Selected soil properties on minesoil sites.

CHARACTERISTIC	DEPTH (cm)	SITE 28-1[1]	N[2]	SITE 28-2[1]	N	SITE 28-3	N
Texture	0-10	SL(8), LS(4), SCL(1)	13	SL	12	SL	7
	10-200	SL(32), LS(6)	38	SL(26) LS(9), SCL(1)	36	SL(27), LS(1)	28
Structure		wk-fine platy & gran <5 cm; mod-med platy 5-20 cm; massive	10	massive 0-1 & >20 cm; wk-mod, fine-coarse platy 1-20 cm	8	NS[3]	
Consistence dry	0-10	soft	5	soft (3) - loose (1)	4		
	10-200	soft, slightly hard-firm	5	slightly hard(3)-soft(1)	4	NS	
moist	0-10	very friable	5	very friable(3)-loose(1)	4		
	10-200	very friable-friable	5	friable(3)-v friable(1)	4		
Bulk density[4] (g/cc)	0-10	1.26 - 1.60	12	1.27 - 1.52	11	1.37 - 1.40	2
	10-200	1.38 - 1.78	26	1.20 - 1.71	26	1.32 - 1.56	10
Effervescence ($CaCO_3$)	0-10	mildly (1cm)-mod calcar	5	moderately calcereous	4		
	10-200	violently calcareous	5	violently calcereous	4	NS	
pH[4]	0-10	mod (0-5 cm) pH 8.0-8.5	4	mod (0-5 cm) pH 8.2-8.4	4	(0-110cm) mod pH	20
	10-200	strong (>5 cm) pH 8.8-9.0	7	strong (5-200 cm) pH 8.6-8.9	9	strong pH/8.6-9.0	12
Organic matter (%)	0-10	0.7 - 8.0	5	1.4 - 3.8	5	0.2 - 1.2	7
	10-200	0.2 - 0.9	8	0.2 - 8.0	8	0.2 - 0.7	28
C:N ratio	0-10	13 - 17	4	12 - 16	4	NS	
	10-200	12 - 13	4	9 - 12	4		
Roots		many fine roots-20 cm	5	many fine roots-10 cm	4		
		common fine roots 10-200	5	common-many fine 10-20 cm	1	NS	
		few fine & med > 200 cm	2	few fine 10-200 cm	3		
Available water Holding capacity (%)	0-10	4.6 - 10.7	5	6.2 - 6.6	2	4.0 - 9.0	7
	10-200	6.1 - 9.1	6	4.6 - 7.7	6	3.0 - 13.0	28
Drainage		somewhat excessively		somewhat excessively		somewhat excessively	

[1] Spoil analyzed by SCS Soil Characterization Lab (Schafer et al. 1979)
[2] N = sample numbers
[3] NS = not sampled
[4] Some variation due to different sampling methods.

Table 8. Continued.

CHARACTERISTIC	DEPTH (cm)	SITE 28-4	N [1]	SITE 28-5 [2]	N	30-SITE	N
Texture	0-10	SL	8	SL(8), LS(5)	13	vF SL, SL, L(2), CL	5
	10-200	SL(25), LSa(8)	33	SL(25), LS(10)	35	vF SL(3), L(4), CL(3), C	10
Structure		NS [3]		massive 0-1 & 10-200 cm	8	mod-fine platy 0-10 cm	3
				wk-mod, very fine-very coarse platy 1-10 cm		mod-med platy (10-30) cm); massive	4
Consistence dry	0-10	NS		slightly hard(4)-soft	5	soft-slightly hard	3
	10-200			slightly hard	3	slightly hard-hard	4
moist	0-10			v friable(4)-friable	5	very friable	3
	10-200			very friable	3	very friable-hard	4
Bulk density [4] (g/cc)	0-10	1.15 - 1.30	2	1.35 - 1.62	11	1.10 - 1.80	10
	10-200	1.32 - 1.51	10	1.27 - 1.69	19	1.27 - 1.98	24
Effervescence ($CaCO_3$)	0-10	NS		mildly (1 cm)-mod calcar	5	mild-mod calcar	3
				mod calcareous	5	mod calcareous	4
pH [4]	0-10	(0-110) mod pH	17	mildly (0-1 cm) pH 7.6		mod-strong alkal (0-5 cm)	7
	10-200	8.2 - 8.5		(0-110 cm) pH 8.2	7	pH 7.7 - 7.9(3), 8.4 - 8.6(4)	
		strong pH 8.7-8.9	15	strong pH 8.6-9.1	5	mod-strong alkal pH 8.1-8.8	12
Organic matter (%)	0-10	1.0 - 1.4	8	0.5 - 2.1	6	1.2 - 8.8	4
	10-200	0.2 - 1.9	32	< 0.2	7	0.4 - 1.4	8
C:N ratio	0-10	NS		13 - 17	5	10 - 14	3
	10-200			11 - 14	3	6 - 11	4
Roots				common fine roots-10 cm	5	many fine	3
		NS		few fine 10-200 cm	3	many fine roots	4
Available water	0-10	4.0 - 6.0	8	5.8 - 9.2	3	5.6 - 12.8	4
	10-200	4.0 - 6.0	32	5.7 - 6.5	4	6.1 - 3.8	6
Drainage		somewhat excessively		somewhat excessively		well drained	

[1] N = sample numbers
[2] Spoil analyzed by SCS Soil Characterization Lab (Schafer et al. 1979)
[3] NS = not sampled
[4] Some variation due to different sampling methods.

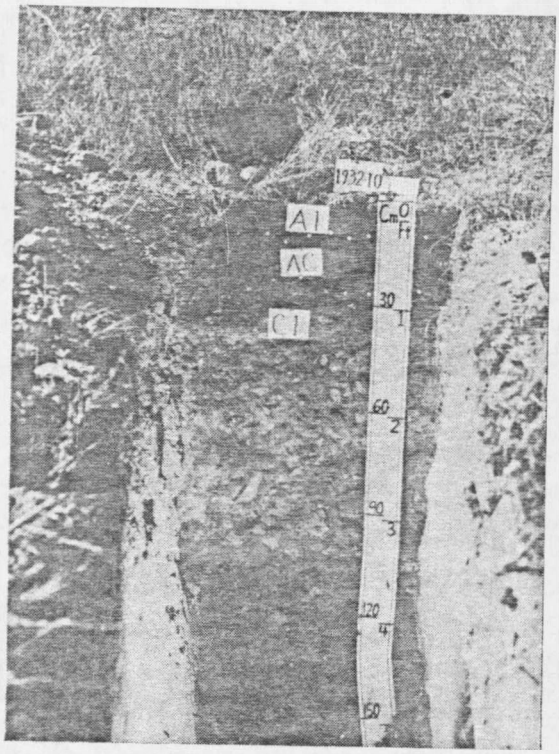


Figure 18. Minesoil at site-30 showing partially developed A_1 horizon after 47 years (Schafer et al. 1979).

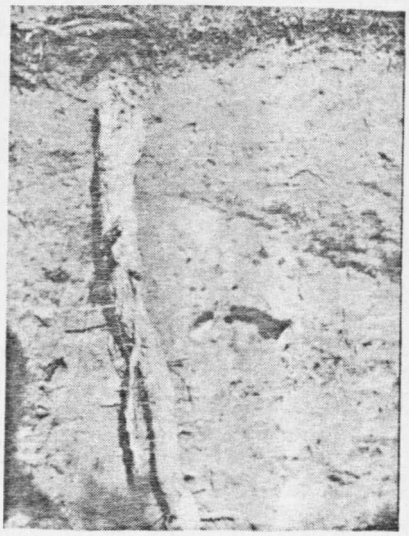


Figure 19. Minesoil at site 28-2 showing rock fragments in lower profile. After 50 years, rock fragments near the surface are weathered and not recognizable (Schafer et al. 1979).

Vegetation Communities Surrounding the Study Sites

Vegetation communities in the 28-site management unit were dominated by associations of Stipa comata, Agropyron smithii, and Calamovilfa longifolia (Figure 20-24). This agrees with mapping of the sites reported by Skilbred (1979).

Stipa comata dominated the upland ridges along with Bouteloua gracilis and Carex filifolia. These ridges ranged in elevation from 1012-1018 m and had flat to convex 0-6% slopes with shallow sandy loam textured soil. The native range control site (NR) and soil genesis study sites (NR#1, NR#2) were located in this community (Figures 10, 21, and 23). On north exposures and on level sites with increased soil development, Koeleria pyramidata (K. cristata) increased in importance. Yucca glauca, Artemisia dracunculus and Heterotheca villosa (Chrysopsis villosa) were the most visible associates in the community on the upper slopes. Artemisia cana was the most common associate on the lower slopes, especially in the south end of the unit on elevations of 1009-1012 m.

In level to concave, run-in moisture sites with slopes of 0-4% and elevations between 1006-1012 m, and with deep, loamy sand soils, Stipa comata shared dominance with Agropyron smithii. In the lowest areas of the unit on heavy soils, Stipa viridula and Poa pratensis replaced Stipa comata in the association. Artemisia cana was the most common associate in the swales, especially in the south end of the unit. A small community of Artemisia dracunculus and Carex filifolia was mapped on a deep, level, sandy loam bench adjacent to site 28-1 (Figure 20).

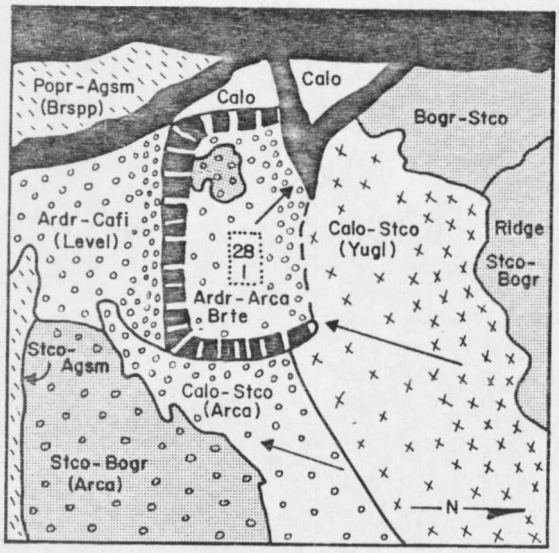


Figure 20. Plant associations on and around site 28-1.

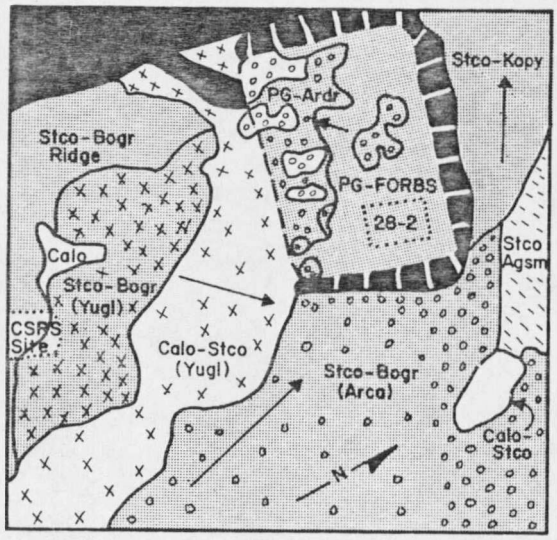


Figure 21. Plant associations on and around site 28-2.

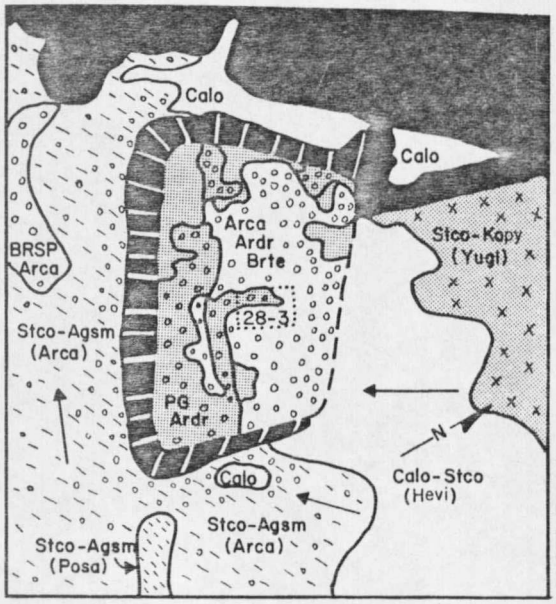


Figure 22. Plant associations on and around site 28-3.

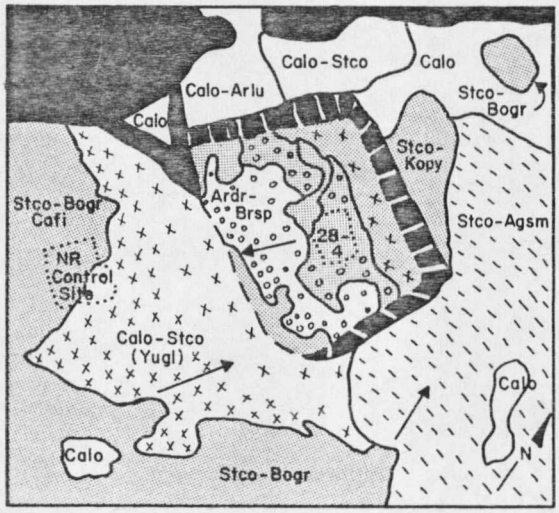


Figure 23. Plant associations on and around site 28-4.

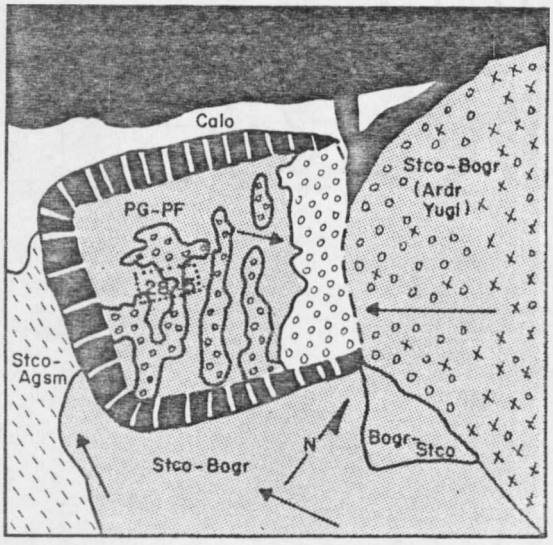


Figure 24. Plant associations on and around site 28-5.

SPECIES CODES	
PF	perennial forbs
PG	perennial grasses
AGSM	Agropyron smithii
ARCA	Artemisia cana
ARDR	Artemisia dracunculus
ARLU	Artemisia ludoviciana
BRspp.	Bromus species
BRJA	Bromus japonicus
BOGR	Bouteloua gracilis
BRTE	Bromus tectorum
CALO	Calamovilfa longifolia
CAFI	Carex filifolia
HEVI	Heterotheca villosa
KOPY	Koeleria pyramidata
POPR	Poa pratensis
POSA	Poa sandbergii
STCO	Stipa comata
YUGL	Yucca glauca

LEGEND

- STEEP, ERODING OR DISTURBED
- STUDY SITE SLOPES
- STUDY SITE BOUNDARY
- EXCLOSURE LOCATIONS
- 28-3 SITE NUMBER
- VEGETATION COMMUNITY
- DRAINAGE

NATIVE RANGE COMMUNITIES

- *Stipa comata* Communities
- *Agropyron smithii* Communities
- *Calamovilfa longifolia* Communities
- *Artemesia spp.* Communities
- *Artemesia spp.* Presence
- *Yucca glauca* Presence

STUDY SITE COMMUNITIES

- ANNUAL GRASSES
- PERENNIAL GRASSES / FORBS
- *Artemisia spp.* Presence
- *Yucca glauca* Presence

On intermediate 0-10%, straight to convex slopes between 1009-1015 m in elevation and with deep, sandy loam soil, Calamovilfa longifolia shared dominance with Stipa comata.

The entire management unit was rated in high fair (35-50%) range condition using SCS 15-19 inch precipitation zone range condition guides (Econ, Inc. 1975, 1976). The dominance of Calamovilfa longifolia, a colony forming rhizomatous grass that is commonly considered a "decreaser" species, indicated a problem with the range condition guides. This is especially true in an area that had been used as heavily as the 28-site management unit. Calamovilfa longifolia was not grazed in the area and increased in composition as other species were used.

Another common community in the study area, but not adjacent to the 28-sites, was the Pinus ponderosa-Agropyron spicatum community on sandstone outcroppings in the highest elevations in the area. This community classified in excellent condition due to the "decreaser" status of Agropyron spicatum. But Agropyron spicatum, like Calamovilfa longifolia, is not used before other species, so it increased in relative composition. Agropyron spicatum is probably used heavily if fire removes old growth.

Table 9 lists the approximate percentage of major associations around the sites as shown in Figures 20-24. The rangeland surrounding sites 28-1 and 4 was evenly split among the three major grassland communities. Sites 28-2 and 5 were surrounded by a greater percentage of Stipa comata communities even though the exposure of the native rangeland was opposite. Site 28-3 had significantly more Agropyron

smithii communities around it than the other sites. Sites 28-1, 2, and 3 had significantly more Artemisia cana around them than the sites in the north end of the unit. Finally, site 28-5 had significantly fewer Calamovilfa longifolia communities than the other sites. Elevations of rangeland surrounding the 28-sites were essentially similar (Table 9).

Table 9. Percentage of major vegetation communities around sites.

ASSOCIATION	SITES					
	28-1	28-2	28-3	28-4	28-5	30
Stipa comata	25	55	15	30	65	--
Calamovilfa longifolia	40	30	35	40	15	--
Agropyron smithii	20	15	45	30	20	60
Artemisia species	15	--	5	--	--	--
Pinus ponderosa-Agropyron spicatum	--	--	--	--	--	40
Elevation of rangeland	1006-1018	1012-1018	1006-1015	1009-1017	1007-1018	985-1008

The 30-site was surrounded by Stipa comata-Agropyron smithii grassland communities. Poa pratensis, Bromus japonicus, Bromus tectorum, and Gutierrezia sarothrae replaced Stipa comata as elevation declined, as soil texture became loamy, and as overgrazing and other disturbances increased. Soil texture varied from loamy sand to loam on grasslands surrounding the 30-site. Elevation varied from 985-995 m.

The 30-site was formed around rock outcrops dominated by the Pinus ponderosa-Agropyron spicatum type. Elevation of this type varied from 1000-1008 m. Soil texture varied but was predominantly loamy with

numerous rock fragments and shallow depth to bedrock. Bromus tectorum and Gutierrezia sarothrae were the most noticeable increasers with disturbance in this type.

The most obvious difference between the communities surrounding the 30-site compared to the 28-sites was the lack of Artemisia dracunculus and Yucca glauca around the 30 site. This may have been due to the heavy textured soil, slightly different elevations, and/or different management regimes on the 30-site. Range condition around both sites was estimated to be high fair (35-50%) using SCS range condition guidelines. In summary, the native rangeland surrounding the 30-site was significantly different from that surrounding the 28-sites in soil texture, major community types, and management regime.

Vegetation Communities on Study Sites

Three major community types dominated study sites (Table 10). On the sandy loam 28-sites, a shrub and/or subshrub-annual grass community was prevalent. It was dominated by Artemisia dracunculus and/or Artemisia cana and the commonly associated annual grasses, Bromus japonicus and Bromus tectorum. Exclosures on sites 28-1 and 3 were located in this community (Figures 20 and 22). Sites 28-1, 2, and 3 had more Artemisia cana than sites 28-4 and 5. This corresponds with Artemisia cana presence on surrounding rangeland. Dominance by Bromus japonicus and/or Bromus tectorum varied on sites and was not consistently related to slope, exposure and/or year of sampling. The 30-site did not have a shrub/subshrub-annual grass community.

Table 10. Percentage of major vegetation communities on sites.

COMMUNITY	SITES					
	28-1	28-2	28-3	28-4	28-5	30
Shrub/subshrub-annual grasses	85%	28%	55%	36%	21%	--
Perennial grasses-perennial forbs	--	60%	15%	16%	51%	70%
Perennial grasses-shrub/subshrub	15%	12%	30%	48%	28%	30%

__ indicates major exclosure community

A second community was dominated by a mixture of native perennial grasses and perennial forbs. Important grasses on the sandy loam 28-sites included Stipa comata, Koeleria pyramidata, and Agropyron smithii. Important forbs on the sandy loam 28-sites included Ambrosia psilostachya, Aster falcatus, Heterotheca villosa, Lithospermum incisum, Psoralea argophylla and Solidago missouriensis. On the loamy 30-site, Agropyron spicatum was the dominant grass and Achillea millefolium and Astragalus adsurgens were other important perennial forbs. Exclosures were located in this community on sites 28-2, 5 and 30 (Figures 21 and 24). Site 28-1 did not have enough of this community type to map. Melilotus officinalis was an important biennial forb on all sites except 28-1 and 3 in 1976.

The third community was a mixture of the other two types and was called a perennial grasses-shrub/subshrub type. This type was dominated by Artemisia cana and/or Artemisia dracunculus on the 28-sites. Yucca glauca was important on site 28-5. Important woody species on the loamy 30-site included Artemisia cana, Artemisia frigida, Gutierrezia sarothrae, and a tree species, Pinus ponderosa. The

grasses were the same as in the perennial grasses-perennial forbs type. The exclosure was located in this type on site 28-4 (Figure 23).

The 28-sites were essentially level with slopes of 0-4%. It was obvious from maps of communities on the 28-sites that the shrub/sub-shrub-annual grass type was more prevalent in the lowest, run-in portions of the sites. Artemisia cana and Artemisia dracunculus were commonly found on sandy loam minesoils in areas that received run-in moisture. In contrast, the perennial grasses-perennial forbs type was most common on the upper portions of the 28-sites especially on sites 28-2 and 5. The perennial grasses-Yucca glauca association on site 28-4 was also on the upper portion of the study site (Figure 23). Sites 28-1 and 3 were similar in species composition, as were sites 28-2 and 5.

RESULTS AND DISCUSSION

Climate During the Study Period

Significant vegetation production differences result from year-to-year precipitation variations. In 1976, annual Bromus species developed and set seed. As a result, production in 1976 was above average due to the contribution of nonperennial species. Nonperennial species usually depend on supplemental moisture (Costello 1944; Weaver and Burner 1945) or recent disturbances (Platt 1975) for their existence in any quantity. Moisture in 1976 was actually below average but the shortage came in summer and fall so production declines were not noticeable (Figure 25). Lack of moisture in 1976 limited fall regrowth.

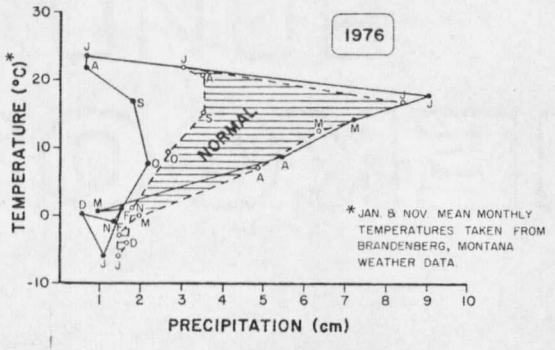


Figure 25. The 1976 climograph shows a normal year, except for a dry summer and fall.

In 1977, moisture was above average but it was so erratic as to limit its effectiveness (Figure 26). Germination after a moisture event was noticed with an almost complete die-off of new seedlings,

especially the nonperennial species, before the next event. Production in 1977 was lower than in 1976 due to the erratic nature of the moisture, which limited annual Bromus species production and Melilotus officinalis establishment. Production levels were further reduced by grasshopper populations in 1977.

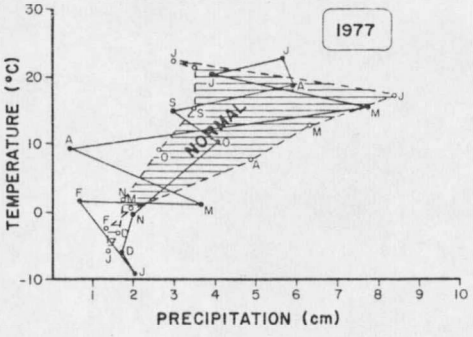


Figure 26. The 1977 climograph illustrated the erratic nature of the growing season precipitation. Colstrip had a wet March, dry April, wet May, and dry June.

Vegetation Studies

Canopy Coverage

Tables 11 and 12 list canopy coverage values, 95% confidence intervals (CI) and relative composition of species groups for sites in 1976 and 1977, respectively. Figure 27 illustrates total vegetation coverage on the sites in 1976 and 1977. The left value (black circle) for each site is for 1976 while the value on the right (open diamond) is for 1977. These symbols make sampling year variations obvious. Native range in the study area typically has from 44-53% canopy coverage, using the modified canopy coverage technique (shaded area in Figure 27) (Sindelar 1981). Another native range site (NR #1), located 150 m

Table 11. Canopy coverage percent, 95% confidence intervals (CI), and percent composition for sites in 1976.

		sandy loam					loam	sandy loam
	SITES	28-1	28-2	28-3	28-4	28-5	30	NR[1]
Perennial grasses	% cover	3.7	7.4	3.2	9.6	13.7	24.2	18.7
	± 95% CI	±1.2	±2.4	±1.2	±2.0	±2.4	±4.1	±3.1
	% comp	8	10	6	21	33	41	58
Annual grasses	% cover	6.3	9.7	9.3	2.8	2.8	0.7	0.5
	± 95% CI	±1.2	±3.4	±1.9	±1.5	±1.6	±0.3	±0.1
	% comp	13	13	19	6	7	1	2
Biennial forbs	% cover	0.8	29.8	0.5	8.0	9.1	8.6	0.4
	± 95% CI	±0.6	±9.4	±0.4	±4.1	±3.1	±1.9	±0.3
	% comp	2	40	1	17	23	15	1
Perennial forbs	% cover	8.6	8.2	6.0	9.8	8.6	4.5	2.1
	± 95% CI	±2.5	±12.6	±2.2	±2.3	±2.3	±1.5	±1.4
	% comp	18	11	12	21	22	8	7
Subshrubs	% cover	20.1	2.6	11.3	6.2	3.0	2.1	1.8
	± 95% CI	±5.8	±1.6	±4.4	±3.6	±1.4	±1.0	±1.4
	% comp	41	3	23	13	8	4	6
Shrubs	% cover	8.8	16.3	18.7	9.7	2.2	7.1	3.2
	± 95% CI	±6.7	±9.1	±10.0	±6.8	±1.2	±5.2	±3.3
	% comp	18	22	38	21	6	12	10
Trees	% cover	--	--	--	--	--	11.6	--
	± 95% CI	--	--	--	--	--	±9.7	--
	% comp	--	--	--	--	--	20	--
Total vegetation	% cover	48.6	74.4	49.2	46.4	38.7	58.9	32.2
	± 95% CI	±7.0	±11.4	±9.7	±7.8	±4.7	±10.3	±3.7
Litter	% cover	93.5	85.8	98.9	89.2	84.9	96.7	87.4
	± 95% CI	±2.6	±4.6	±0.8	±6.9	±5.8	±2.1	±5.3
Bare ground	% cover	5.2	13.1	0.9	22.4	21.7	6.0	25.0
	± 95% CI	±2.2	±5.6	±0.7	±8.4	±7.8	±3.6	±8.1

[1]NR = native range control site.

from the control site and dominated by the same species was sampled in 1977 (Figure 27).

Increased stratification and periodicity produced by the dominance of Artemisia species, along with associated increases in annual Bromus species, produced considerably more coverage on sites 28-1 and 3, especially in the dry 1977 growing season (Figures 27, 28, 29 and 30). Significant yearly variations in total coverage were noted on site 28-2 where the biennial Melilotus officinalis dominated in 1976 and not in 1977. Also, significant variations occurred on the native

Table 12. Canopy coverage percent, 95% confidence intervals (CI), and percent composition for sites in 1977.

		sandy loam					loam	--sandy loam--	
	SITES	28-1	28-2	28-3	28-4	28-5	30	NR[1]	NR #1
Perennial grasses	% cover	4.8	9.5	5.3	12.3	17.4	26.1	30.1	18.8
	± 95% CI	±1.4	±4.5	±1.8	±2.6	±3.6	±2.9	±4.2	±5.7
	% comp	7	22	8	29	51	50	62	53
Annual grasses	% cover	7.7	13.2	16.0	5.2	1.1	1.1	t[2]	0.9
	± 95% CI	±1.4	±5.3	±4.6	±1.7	±0.4	±0.3	t	±0.5
	% comp	16	30	25	12	3	2	t	3
Perennial forbs	% cover	3.5	2.8	10.9	4.8	7.5	4.7	1.4	8.2
	± 95% CI	±0.1	±1.5	±4.7	±1.8	±3.3	±1.3	±0.9	±2.8
	% comp	6	6	17	12	22	9	3	23
Subshrubs	% cover	30.7	1.7	15.5	7.8	5.6	1.9	1.5	3.6
	± 95% CI	±8.4	±1.3	±5.3	±5.2	±3.0	±0.6	±1.1	±1.8
	% comp	51	4	24	19	16	4	3	10
Shrubs	% comp	12.3	16.4	17.2	10.8	2.2	7.6	3.6	0.3
	± 95% CI	±6.6	±9.5	±8.4	±7.1	±1.9	±5.4	±4.8	±0.7
	% comp	20	37	26	26	6	15	7	1
Trees	% cover	--	--	--	--	--	10.0	--	--
	± 95% CI	--	--	--	--	--	±9.0	--	--
	% comp	--	--	--	--	--	19	--	--
Total vegetation	% cover	60.2	44.0	65.1	42.1	34.0	52.6	48.8	35.5
	± 95% CI	±7.0	±12.2	±11.4	±7.4	±5.7	±9.6	±4.8	±6.8
Litter	% cover	92.5	90.5	94.0	87.0	74.1	90.7	81.2	NS[3]
	± 95% CI	±3.1	±3.9	±3.8	±5.6	±6.4	±3.4	±4.6	NS
Bare ground	% cover	6.1	13.0	5.9	25.9	23.7	11.3	23.0	NS
	± 95% CI	±3.0	±5.2	±4.0	±8.7	6.1	±6.1	±5.4	NS

[1] NR = native range control site. NR#1 = CSRS soil site (Chinook-8)
[2] t = trace = < .5% cover, CI, and composition
[3] NS = not sampled

range control site (NR) due to the exclusion of grazing between 1976 and 1977. These significant differences are indicated by asterisks in Figure 27.

Among the 28-sites, significantly less bare ground was found on sites dominated by Artemisia species (Figure 31). Allelopathic effects of Artemisia species have been documented (Reid 1965; Schlatterer and Tisdale 1969). This may partially explain the lack of perennial grass cover on the sites dominated by Artemisia cana and/or Artemisia dracunculus. Allelopathic/competitive effects of dominance by

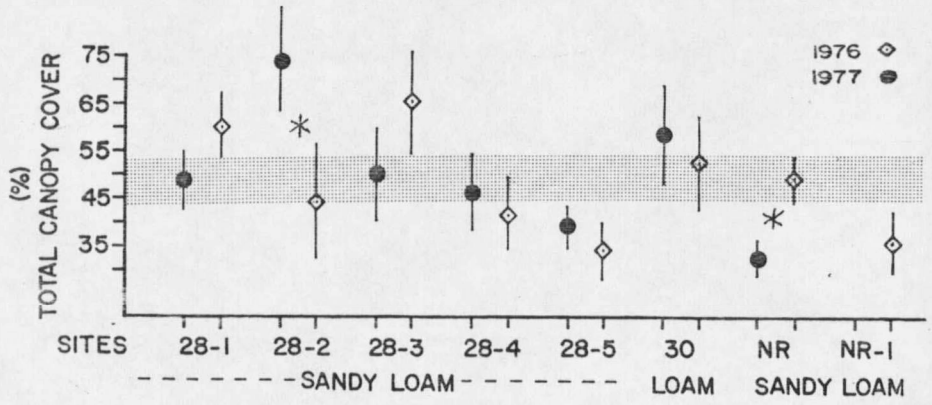


Figure 27. Total canopy coverage percent on sites in 1976 and 1977 compared with native range in the Colstrip area. Asterisks indicate sites with significant yearly differences in coverage. The shaded area indicates native rangeland coverage.

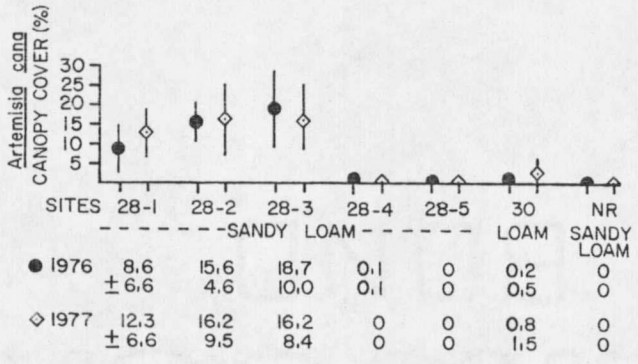


Figure 28. Artemisia cana canopy coverage percent on sites in 1976 and 1977.

Artemisia species helps explain the relative stability of coverage values on sites even though they were partially dominated by annual Bromus species.

The relative stability of annual grass coverage was partially explained by the presence of two species. On native range, Bromus japonicus is typically found in mesic microsites, while Bromus tectorum

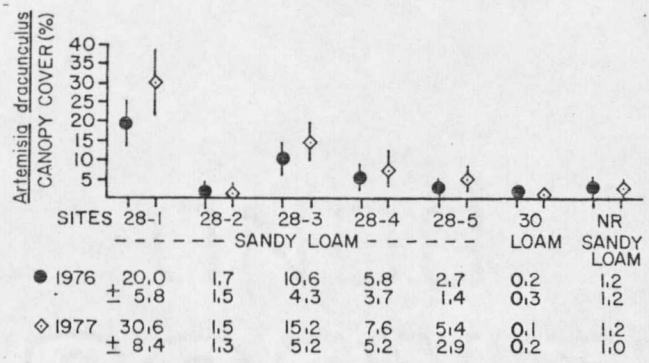


Figure 29. Artemisia dracunculus canopy coverage percent on sites in 1976 and 1977.

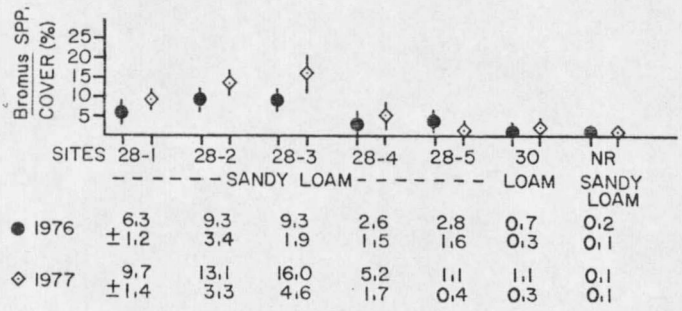


Figure 30. Annual Bromus species canopy coverage percent on sites in 1976 and 1977.

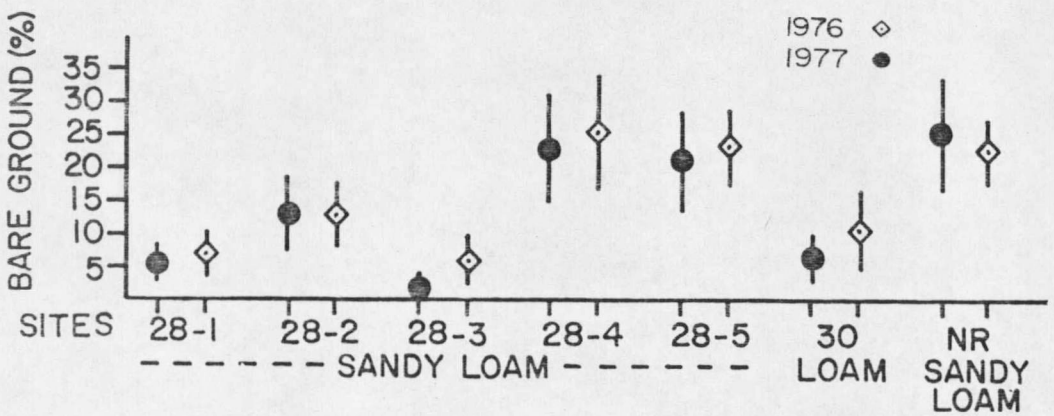


Figure 31. Bare ground percent on sites in 1976 and 1977.

is found on dry exposed locations. On most sites both annual Bromus species were found, but sampling did not separate them. Depending on precipitation patterns, one species or the other was dominant. On several of the 28-sites in 1976, Bromus tectorum dominated because of an adequate supply of moisture throughout the entire spring growing season. Bromus japonicus is phenologically about two weeks later to develop and if Bromus tectorum assumed dominance first, soil moisture could have been depleted and Bromus japonicus production was limited. In 1977, moisture was sporadic, allowing Bromus tectorum to germinate and establish, but it died before maturing. When moisture was replenished, Bromus japonicus was still alive and able to develop and dominate certain sites. This complementary effect intensified competition with other species establishing.

Table 13 summarizes the frequency of annual Bromus species on the 28-sites in 1977. Presence of one or both species on any site was not related to location, microtopography, or dominance by Artemisia species. Increased amounts of Bromus tectorum on sites 28-2 and 3 possibly reflected the increased grazing pressure in that area surrounding the waterhole. Frequency of Bromus species on native range was not separated by species, but Bromus tectorum appeared to be common on native range in the area.

Native nonperennial species do not significantly alter coverage values from year to year. With the introduction of Melilotus officinalis, Bromus tectorum, Bromus japonicus, Melilotus alba, and Tragopogon dubius into the local flora, coverage can be significantly

Table 13. Percent frequency of annual Bromus species on the 28-sites in 1977.

	SITES				
	28-1	28-2	28-3	28-4	28-5
Bromus japonicus	92	57	46	89	74
Bromus tectorum	33	85	87	24	72

altered by nonperennial life forms. This is true on disturbed sites but even occurs on unplowed, grazed native rangeland.

Coverage of perennial grasses increased as dominance by Artemisia species decreased on the 28-sites (compare Figures 28 and 29 with Figure 32). Native range in the study area has 21-27% coverage of perennial grasses and sedges (shaded areas in Figure 32) (Sindelar 1981).

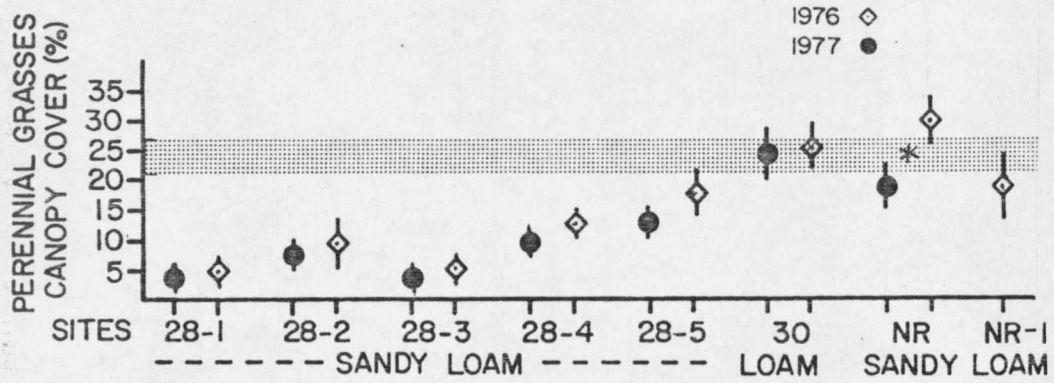


Figure 32. Perennial grass canopy coverage percent on sites in 1976 and 1977 compared with native range in the Colstrip area. Asterisks indicate sites with significant yearly differences in coverage. The shaded area indicates native rangeland coverage.

The most notable differences between native range and the overburden sites was in the Graminoid species. Minesoils lacked

warm-season species such as Bouteloua gracilis and Calamovilfa longifolia and the cool-season sedge, Carex filifolia. Of the three dominant cool-season midgrasses on the sites, coverage of Stipa comata (Figure 33) and Agropyron smithii were not significantly affected by dominance of Artemisia species. Stipa comata is dominant on shallow native range sites. With deepening of the rooting medium, amounts of Agropyron smithii were expected to increase. Only Koeleria pyramidata increased as amounts of Artemisia species decreased (Figure 34).

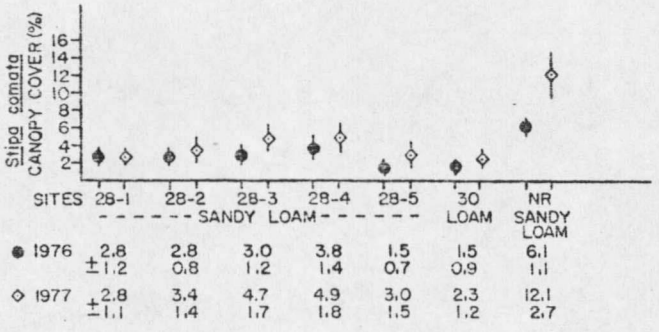


Figure 33. Stipa comata canopy coverage percent on sites in 1976 and 1977.

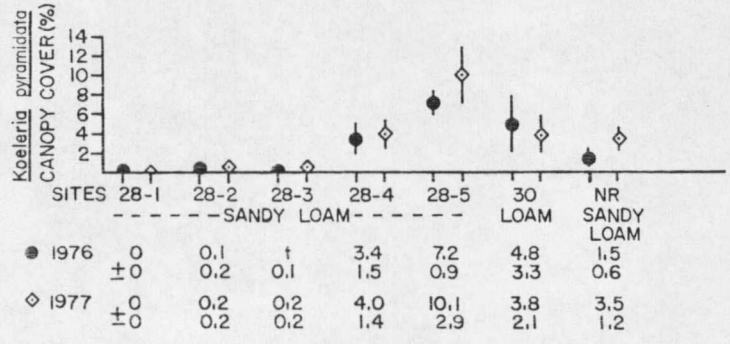


Figure 34. Koeleria pyramidata canopy coverage percent on sites in 1976 and 1977.

Significant differences in perennial forb coverage on the study sites were found only in 1977 and are indicated by asterisks in Figure 35. Typically, native range in the area has from 4-7% perennial forb coverage (shaded area in Figure 35, Sindelar 1981). The shallow native range site (NR) had significantly less forb coverage than the minesoil sites. One other native range site (NR #1) had a deep soil and had perennial forb cover similar to the overburden sites. This suggested that perennial forbs prefer deep soils. Coverage data revealed that perennial forb coverage was equal on minesoils to that of native range, but many species were lacking. Yearly differences were noted in coverage of most forb species on minesoil sites in the dry and sporadic moisture regime of 1977. This indicated that the annual, biennial, and perennial forbs as a group are much more affected by yearly weather variations than other life forms, even the annual Bromus species (compare Figures 30 and 35).

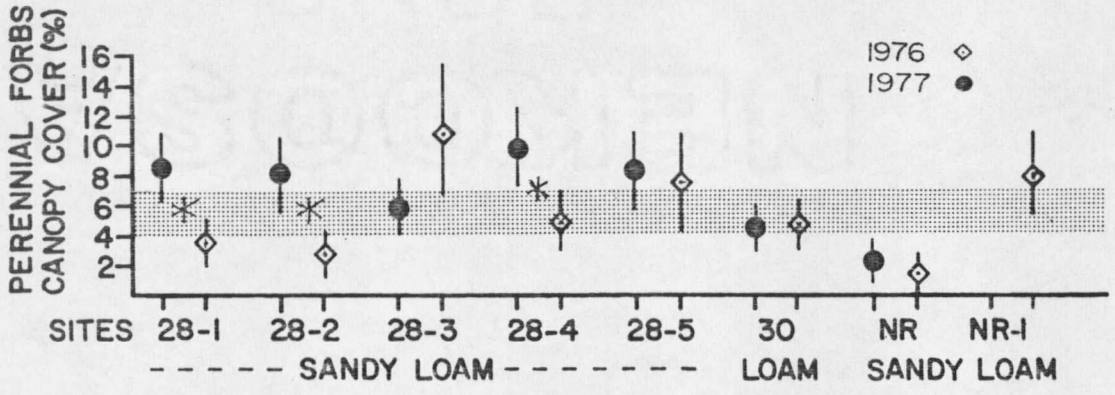


Figure 35. Perennial forb canopy coverage percent on sites in 1976 and 1977 compared with native range in the Colstrip area. Asterisks indicate sites with significant yearly differences in coverage. The shaded area indicates native rangeland coverage.

Observations in a sandy loam plowed field adjacent to site 28-1 helped interpret effects of quality and type of disturbance, grazing intensity, and age on populations of dominant species in the 28-site management unit (Figure 10). The plowed field was abandoned in 1948 and not seeded. Although the plowed field was less than 30 years old when sampled, it was dominated by an almost pure stand of Stipa comata.

The dominance of Stipa comata in the plowed field indicated that effects of mining influenced community development patterns on the 28-sites more than opportunities for migration of species or influences of heavy grazing. This conclusion was drawn because Artemisia cana, Artemisia dracunculus, and Bromus species were readily available in quantity to invade the plowed field. Also, the plowed field was in the area suspected of having been grazed as heavily as any other area of the 28-site management unit close to the waterhole.

The plowed field was younger than the 28-sites, so age may not be as important to the development of Stipa comata (i.e. succession?) as the presence of shallow soil. Stipa comata probably became dominant on the plowed field simply because the associated dominants in the vegetation type on native rangeland, namely Calamovilfa longifolia, Bouteloua gracilis, and Carex filifolia were destroyed and do not have the mechanism to migrate rapidly and/or reestablish.

In summary, disturbance alone did not necessarily increase amounts of Artemisia cana, Artemisia dracunculus, and Bromus species on sandy loam minesoils. Deepening of the rooting medium, high coarse fragment

content, and other effects of mining were more important on the 28-sites than disturbance alone.

Additional coverage analyses were conducted on the loamy 30-site to verify effects of soil texture, soil depth, coarse fragment content, allelopathic/competitive influences, proximity to source materials and microtopography on dominant species on the site. It was assumed that the loamy 30-site exclosure became dominated by Agropyron spicatum and Pinus ponderosa because of its location immediately adjacent to that community.

Table 14 summarizes the analyses conducted in a second exclosure on the 30-site (Site 30-A). Dominant vegetation on the second exclosure was Agropyron smithii-Artemisia cana, even though it was as near to the native Agropyron spicatum-Pinus ponderosa community as the other exclosure. One difference on the 30-A exclosure was its location in a concave depression with gradual slopes. Proximity to a propagule source was not as important to dominance by Agropyron spicatum and Pinus ponderosa as was level to convex microtopography. Agropyron smithii dominated on most level to concave sites with run-in moisture regardless of distance to the propagule source. Also, analyses on the site 30-A exclosure revealed that Artemisia cana is not limited to sandy loam soil.

Management differences between the 28-sites and the 30-sites were highlighted by the lack of typical "increaser"/"invader" species in the 30-A exclosure. Annual Bromus species and Poa pratensis coverage values were low even though their frequency values were high. Interestingly, these species were more important on the loamy

Table 14. Summary of canopy coverage analyses on the 30-A site exclosure.

SPECIES GROUPS	% COVERAGE	% COMPOSITION	% FREQUENCY
perennial grasses	16.0	41	100
annual grasses	1.4	4	69
perennial forbs	2.1	5	72
annual forbs	t[1]	t	3
biennial forbs	t	t	3
shrubs	18.3	46	67
subshrubs	1.7	4	42
total vegetation	39.5	100	--
IMPORTANT SPECIES			
Agropyron smithii	11.2	28	100
Artemisia cana	13.3	34	25
Rhus trilobata	3.5	9	6
Koeleria pyramidata	1.9	5	53
Poa pratensis	0.9	2	31
Bromus species	1.4	4	69

[1] t = trace < .1% coverage, 1% composition

grassland surrounding the 30-site than on the sandy loam rangeland surrounding the 28-sites.

Analyses on the site 30-A exclosure also indicated that competitive/allelopathic effects of Artemisia cana dominance do not necessarily lead to decreases in perennial grasses or increases in annual grasses, as observed on the sandy loam sites. On the 30-site, as on the 28-sites, Koeleria pyramidata was more important than Stipa comata.

In summary, naturally revegetated sites have substantial canopy coverage after nearly 50 years. Coverage of perennial grasses was significant, but disturbance reduced populations of Bouteloua gracilis, Calamovilfa longifolia, and Carex filifolia for almost 50 years.

Koeleria pyramidata was the perennial grass that generally increased after mining. However, it appeared to be limited by competition with Artemisia and annual Bromus species. Perennial forb coverage was substantial but many species were lacking. Significant yearly variations in forb coverage were noted. Mining resulted in high levels of Melilotus officinalis, but plowing did not on a shallow sandy loam site. Annual Bromus species had high coverage values on deep sandy loam minesoils. Complementary effects of two annual Bromus species intensified competition with other life forms. Coverage of shrubs on minesoils was high due to improved water relations associated with increased soil depth and coarse fragment contents. The loamy 30-site had levels of coverage for perennial life forms equalling or exceeding levels on native range in the Colstrip area.

The dominance of species on sites varied due to type of disturbance, grazing intensity, soil depth, soil texture, coarse fragment contents, proximity to source materials, microtopography, and possible allelopathic/competitive effects of existing vegetation.

Diversity

Species diversity indices are usually based on species numbers (richness) and distribution of individuals among species (evenness). Diversity measures have been correlated with successional status of developing communities (MacIntosh 1967; Whittaker 1975). Table 15 and Figure 36 summarize diversity relationships on study sites from canopy coverage data. Diversity indices were calculated using the Shannon index based on maximum coverage values for each year

Table 15. Shannon Index (H'_{Log_2}) parameters on sites in 1976 and 1977.

SITES	28-1	28-2	28-3	28-4	28-5	30	NR
	----------sandy loam----------					loam	sandy loam
SHANNON INDEX							
1976	2.8	2.9	2.6	3.7	3.6	3.6	3.4
1977	2.1	2.7	2.9	3.3	3.3	3.5	2.8
EVENNESS							
1976	.57	.56	.52	.72	.69	.69	.64
1977	.50	.55	.58	.69	.69	.69	.57
RICHNESS							
1976	29	36	31	37	38	36	40
1977	18	30	31	27	28	35	31

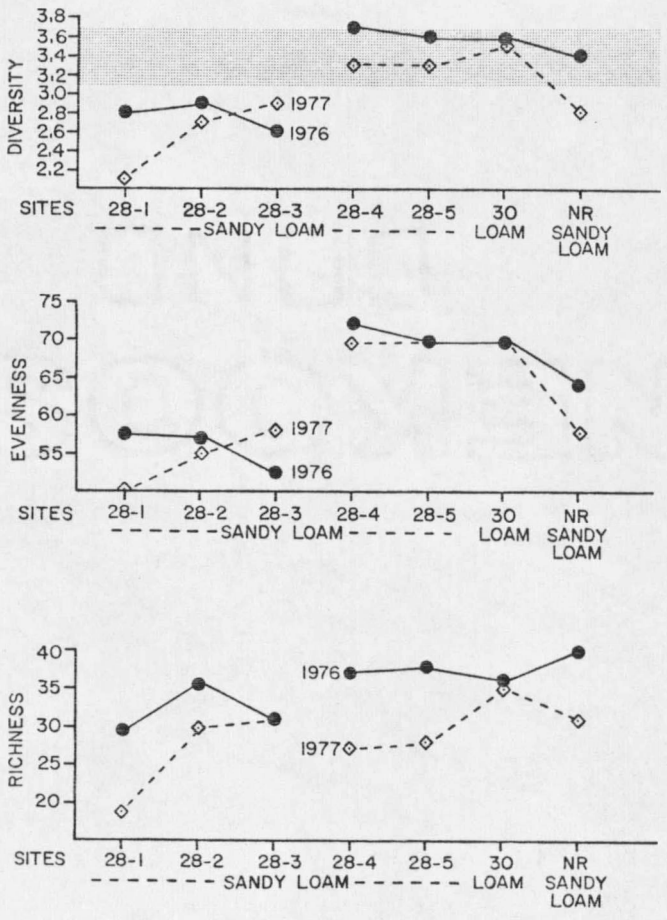


Figure 36. Shannon Index (H'_{Log_2}) parameters on sites in 1976 and 1977. The shaded area indicates native rangeland diversity.

(Pielou 1975). Evenness was calculated by dividing the diversity index by the log of the richness value. Richness was the number of species sampled on each site.

Diversity showed two distinct groupings of sites (the site groups were connected by lines in Figure 36). Sites 28-1, 2, and 3 generally had lower diversity values than sites 28-4, 5, 30 or the native range control site (NR). This was due to differences in distribution of individuals among species (evenness) rather than differences in numbers of species (richness). Diversity values in 1977 were generally lower than in 1976 due to less precipitation and an influx of grasshoppers. The 30-site was the most stable from 1976 to 1977. Diversity values reported are typical for developing plant communities. Sindelar (1981) reported 3.1-3.7 for native rangeland diversity values in the area (shaded area in Figure 36).

Diversity data suggested that gradients existed across the 28-sites. The change in dominant vegetation on each site reflected differences in the relative importance of a particular set of species rather than changes in floristic composition (Skilbred 1979). Species on the shallow native range control site (NR) were similar to the five overburden sites in the same management unit. However, two of the three dominant species on native range, Bouteloua gracilis and Carex filifolia did not establish on minesoils in any quantity. The 30-site had different soil texture, management, and species dominance which limited its comparative value with the 28-sites.

On the 28-sites, the lower diversity values, particularly on sites 28-1 and 3, may or may not have indicated a lower successional status

as concluded by Sindelar and Plantenberg (1978) and Skilbred (1979). The sandy loam minesoils had increased water availability due to increased soil depth. As a result, the deep sandy loam minesoils could have developed a shrub as well as a perennial grass dominated, managed steady state. This was especially true in the moderate to heavy grazing regime in the 28-site management unit. A lower diversity value in the relatively stable subshrub/shrub-annual grasses community on sites 28-1 and 3 may have simply been a reflection of dominance by potentially exclusionary species under a certain management program.

Standing Crop

Table 16 and 17 summarize standing crop estimates, 95% confidence intervals (CI), and percent composition in 1976 and 1977, respectively. Harvest estimates indicated that minesoils produced as much or more vegetation as native rangeland in the Colstrip area (shaded area in Figure 37) (Sindelar 1981). Standing crop Figures 37, 38, 39, 40, and 41 show estimates and confidence intervals for 1976 on the left and for 1977 on the right for each site, making year-to-year differences obvious. A superscript indicates significance across sites in 1976 using analysis of variance and Duncan's multiple range mean separation techniques. Standing crop estimates in each year followed by the same letter are not significantly different ($P < .05$). A subscript represents significance ratings in 1977. Asterisks indicate significance between sampling years for each site. Confidence intervals produced more conservative estimates of

significance while Duncan's technique helped to identify borderline differences.

Table 16. Standing crop estimates (kg/ha) for sites in 1976.

		sandy loam					loam	sandy loam
	SITES	28-1	28-2	28-3	28-4	28-5	30	NR
Perennial grasses [and sedges]								
	kg/ha	101[d1]	329[bcd]	84[d]	443[bc]	340[bcd]	1091[a]	498[b]
	± 5% CI	±65	±124	±49	±169	±224	±433	±79
	% comp	4	17	3	29	21	66	56
Annual grasses								
	kg/ha	563[a]	304[bc]	479[ab]	262[bcd]	218[cde]	15[e]	23[e]
	± 5% CI	±157	±161	±97	±206	±137	±11	±29
	% comp	20	16	19	17	13	1	3
Forbs								
	kg/ha	252[c]	1099[a]	209[c]	665[b]	451[bc]	346[b]	127[c]
	± 5% CI	±199	±786	±151	±302	±234	±106	±81
	% comp	9	58	8	42	27	21	14
Shrubs								
	kg/ha	1949[a]	182[b]	1688[a]	182[b]	638[b]	206[b]	92[b]
	± 5% CI	±715	±155	±674	±174	±666	±295	±66
	% comp	68	10	69	12	39	12	10
Total vegetation								
	kg/ha	2865[a]	1913[bc]	2460[ab]	1552[bcd]	1647[bcd]	1658[bcd]	897[d]
	± 5% CI	±697	±263	±736	±272	±714	±486	±59
Litter and standing dead vegetation								
	kg/ha	8313[ab]	4111[bc]	12152[a]	3742[c]	4371[bc]	3819[c]	1242[c]
	± 5% CI	±1914	±1419	±4644	±2185	±2080	±1475	±806

[1]Numbers in rows followed by the same letter are not significantly different ($P < .05$).

The dominance of sites 28-1 and 3 by Artemisia and Bromus species significantly elevated total vegetation production, shrub, annual grass, standing dead, and litter estimates (Figures 38, 39, and 40). In general, mining increased shrub and annual grass production on the sandy loam 28-sites compared with levels found on the upland, sandy loam, native range control site (NR). This was due to the deep minesoil on the 28-sites produced by mining. These effects of mining favored deep-rooted species and increased community stratification and seasonality which increased production potentials on the 28-sites.

Table 17. Standing crop estimates (kg/ha) for sites in 1977.

	SITES	sandy loam 28-1	sandy loam 28-2	sandy loam 28-3	sandy loam 28-4	sandy loam 28-5	loam 30	sandy loam NR
Perennial grasses [and sedges]								
	kg/ha	84[cl]	271[c]	37[c]	256[c]	281[c]	906[a]	586[b]
	± 5% CI	±64	±147	±35	±69	±168	±323	±157
	% comp	6	25	1	19	30	80	56
Annual grasses								
	kg/ha	204[ab]	252[a]	201[abc]	134[abcd]	93[bcd]	7[d]	24[d]
	± 5% CI	±68	±114	±96	±93	±73	±10	±36
	% comp	14	23	6	10	9	t	2
Forbs								
	kg/ha	179[a]	106[a]	91[a]	179[a]	162[a]	109[a]	46[a]
	± 5% CI	255	73	±65	±127	±116	±54	±34
	% comp	12	9	3	14	16	10	4
Shrubs								
	kg/ha	1039[b]	468[b]	2822[a]	756[b]	444[b]	106[b]	192[b]
	± 5% CI	±392	±441	±1327	±359	±595	±76	±223
	% comp	69	43	90	57	45	9	18
Total vegetation								
	kg/ha	1505[b]	1097[b]	3151[a]	1325[b]	994[b]	1128[b]	1255[b]
	± 5% CI	±562	±437	±1328	±297	±514	±317	±209
Litter and standing dead vegetation								
	kg/ha	7231[b]	4016[b]	22500[a]	5692[b]	3843[b]	4103[b]	1335[b]
	± 5% CI	±1710	±1568	±13252	±2432	±2053	±1002	±433

[1]Numers in rows followed by the same letter are not significantly different (P < .05).

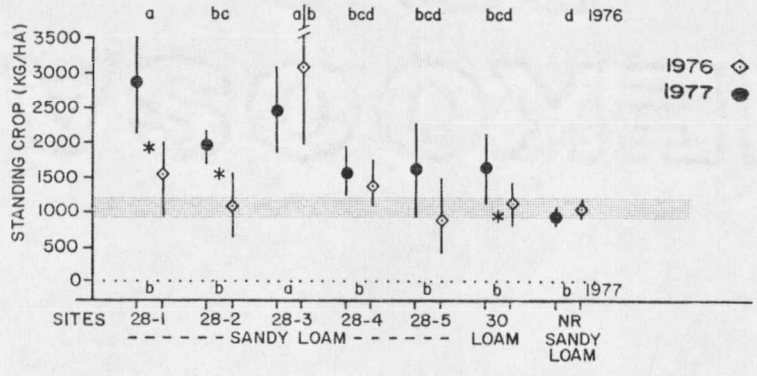


Figure 37. Standing crop estimates (kg/ha) for sites in 1976 and 1977. Asterisks indicate sites with significant yearly differences. The shaded area indicates native rangeland standing crop. Estimates in each year followed by the same letter are not significantly different (P < .05).

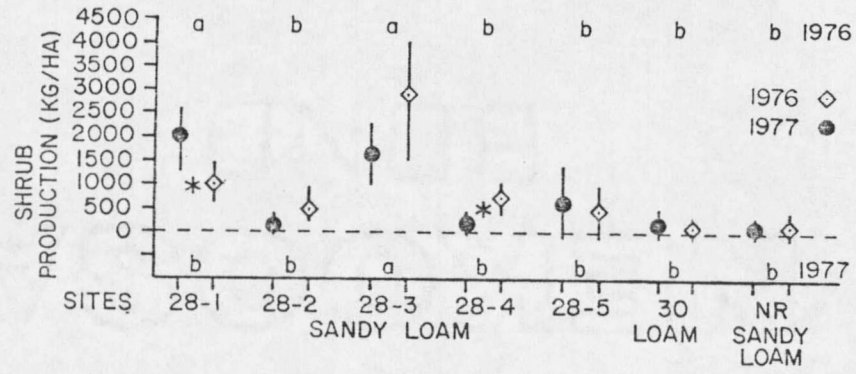


Figure 38. Shrub production estimates (kg/ha) for sites in 1976 and 1977. Asterisks indicate sites with significant yearly differences in production. Production estimates in each year followed by the same letter are not significantly different ($P < .05$).

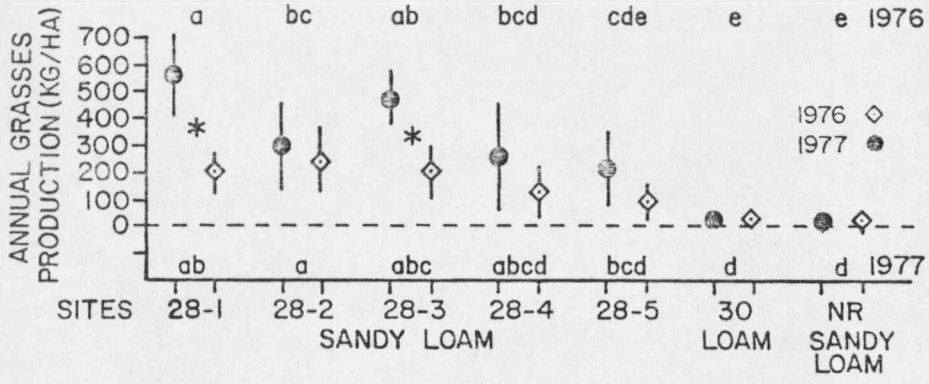


Figure 39. Annual grass production estimates (kg/ha) for sites in 1976 and 1977. Asterisks indicate sites with significant yearly differences in production. Production estimates in each year followed by the same letter are not significantly different ($P < .05$).

Litter and standing dead estimates were significantly lower on the native range control site (NR) compared with other native range sites in the area (Figure 40). This was due to the effects of grazing and complete dominance by Graminoids on the shallow soil site.

Total forb production varied between 1976 and 1977 for all sites except 28-1 and 3 (Figure 41). Sites 28-1 and 3 did not have an

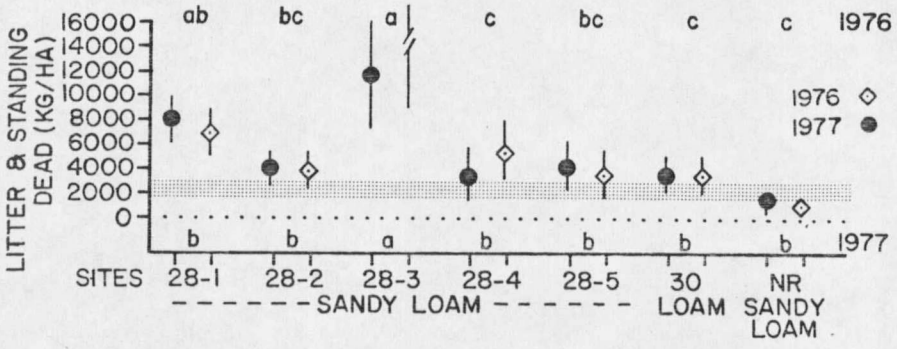


Figure 40. Litter and standing dead vegetation estimates (kg/ha) for sites in 1976 and 1977. Production estimates in each year followed by the same letter are not significantly different ($P < .05$).

important forb component. The lack of significant differences across sites in 1977 indicated the sensitivity of forbs to annual weather differences. Melilotus officinalis was responsible for the significant difference in total vegetation on site 28-2 between 1976 and 1977 (Figures 37 and 41). Annual and biennial species depend on excess moisture for their existence. The dominance of Melilotus officinalis on site 28-2 in 1976 and the lack of it in 1977 did not alter production levels of other lifeforms. This indicated its use of surplus moisture and lack of competition with other species.

Sites 28-1 and 3 had limited perennial grass production (Figure 42). The 30-site and native range site (NR) had similar levels of Graminoid production (Table 16 and 17). Mining altered the return of the sandy loam 28-sites to sites dominated by perennial grasses even though they were surrounded by perennial grass dominated communities. The only significant difference in perennial grass production between

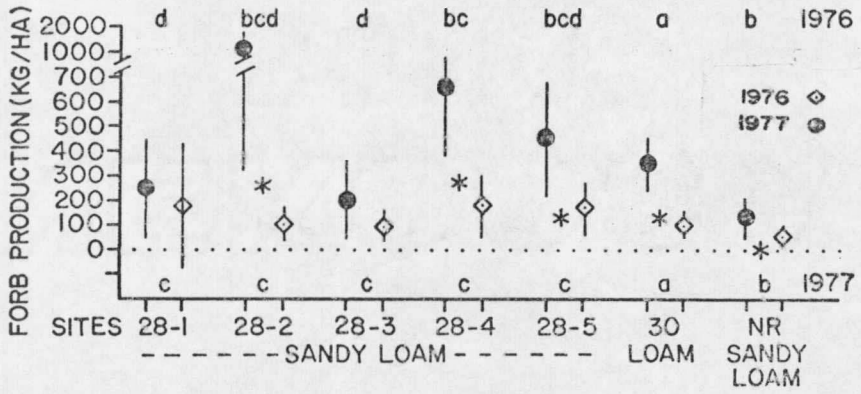


Figure 41. Forb production estimates (kg/ha) for sites in 1976 and 1977. Asterisks indicate sites with significant yearly differences in production. Production estimates in each year followed by the same letter are not significantly different ($P < .05$).

years was on the native range site where grazing was excluded between 1976 and 1977.

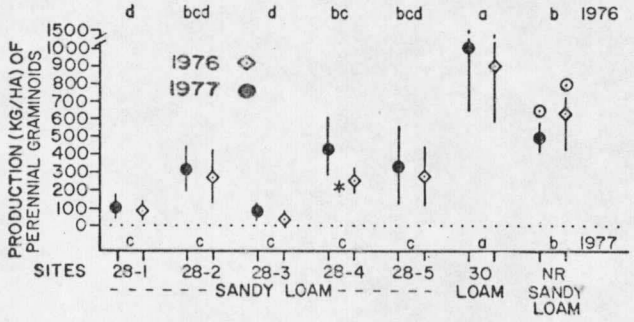


Figure 42. Perennial Graminoid production estimates (kg/ha) for sites in 1976 and 1977. Asterisks indicate sites with significant yearly differences in production. Production estimates in each year followed by the same letter are not significantly different ($P < .05$).

Analyses of individual species production essentially agreed with coverage analyses. Analyses showed that Stipa comata, the most

prevalent grass in the area, did not necessarily increase as production of Artemisia and annual Bromus species declined (Figure 43). Koeleria pyramidata had production increases across the 28-sites as Artemisia and annual Bromus species declined. This indicated its possible sensitivity to association with Artemisia and annual Bromus species and/or its obvious preference for the deep rooting medium (Figure 44). No gradients were observed in Koeleria pyramidata abundance across the 28-site unit. Stipa comata and Agropyron smithii were not favored on the sandy loam sites by the effects of mining.

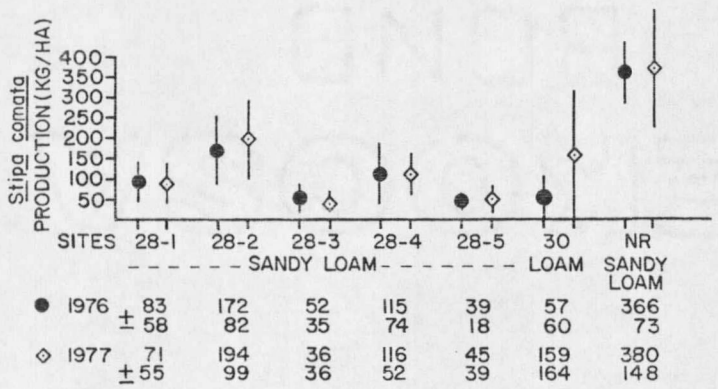


Figure 43. Stipa comata production estimates (kg/ha) for sites in 1976 and 1977.

Skilbred (1979) suggested that environmental changes on the 28-sites created by early dominants affected succession. Production on the study sites depended on the control exerted by the dominant species on their competitors. For example, litter and standing dead quantities on sites 28-1 and 3 were probably restrictive to perennial

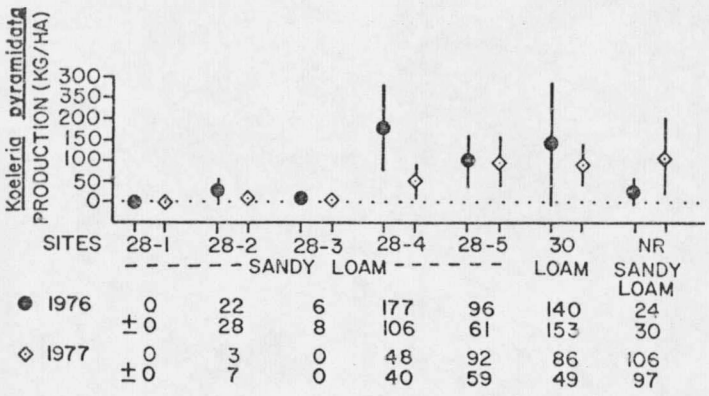


Figure 44. Koeleria pyramidata production estimates (kg/ha) for sites in 1976 and 1977.

grass seedling germination and limited forb establishment. Litter quantities would favor Bromus species (Blaisdell, 1949). Shading and possible allelopathic effects of the Artemisia species litter possibly affected Koeleria pyramidata populations. Effects of mining such as increased soil depth and coarse fragment contents changed the species able to dominate the 28-sites. These effects of mining increased stratification and production levels if those species became established. The dominant species on some of the 28-sites were restricting vegetation development rather than fostering it. This is contrary to classic succession theory.

Floristic Richness

Frequency sampling recorded 122 species on and/or within 100 m of the sites (Table 18, Figures 45-48). In these figures, the sandy loam sites are separated from the loamy sites. The number of species

Table 18. Number of species in each life form sampled on sites (ON) compared to the number sampled on native rangeland within 100 m of the sites (OFF).

SITES	sandy loam										loam				
	28-1		28-2		28-3		28-4		28-5		30		30-1		
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	TOTAL
Perennial grasses	5	11	7	11	5	13	5	13	8	10	19	15	11	17	24
Sedges	0	2	0	2	0	2	0	2	1	2	0	2	1	1	2
Annual grasses	2	3	2	2	2	3	2	3	2	3	2	3	2	2	3
Annual forbs	0	4	1	2	0	5	1	3	1	2	1	3	1	1	12
Biennial forbs	1	4	1	4	0	3	2	3	1	2	8	6	5	4	10
Perennial forbs	7	27	6	25	11	25	14	22	12	27	29	37	22	22	58
Subshrubs	1	2	2	2	2	2	2	2	2	2	2	2	1	1	2
Shrubs	2	5	2	7	2	5	3	3	2	2	9	5	9	7	10
Trees	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
Total species	18	58	21	55	22	58	29	51	29	50	71	74	53	56	122
# frames sampled	260-	1000	260-	1000	260-	1000	260-	950	260-	950	1710-	875	325-	400	= 3435 = 6175 9610

sampled in typical Daubenmire canopy coverage analyses on native range in the Colstrip area indicated by shaded areas on the figures (Sindelar 1981). Another loamy deposit from Pit Two was sampled and called the 30-1 site (Figure 10).

The 28-sites had few perennial species compared to the 30-site. This lowered the total number of sampled species on those sites compared with the 30-sites (Figures 45-48). Meanwhile, rangeland surrounding the sandy loam sites had just as many species sampled as the rangeland surrounding the loamy sites. This indicated that exclusionary factor(s) limited migration to and/or establishment of species on the sandy loam 28-sites. Intensive grazing on the 28-site management

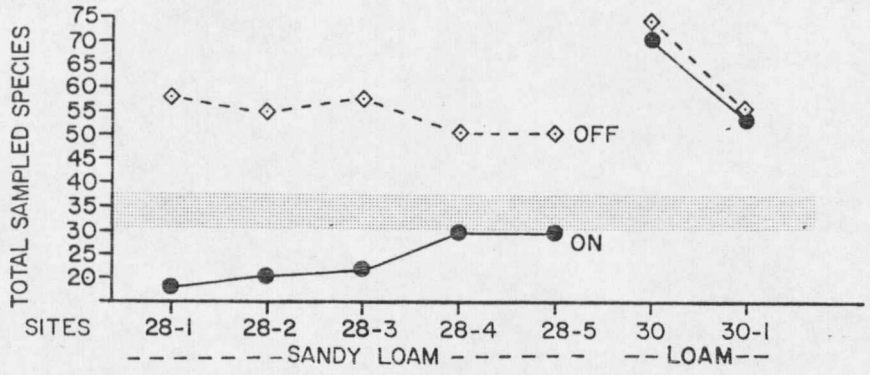


Figure 45. The total number of species sampled on-sites (ON) compared with the number sampled on native rangeland within 100 m of the sites (OFF). The shaded area indicates total sampled species on native rangeland.

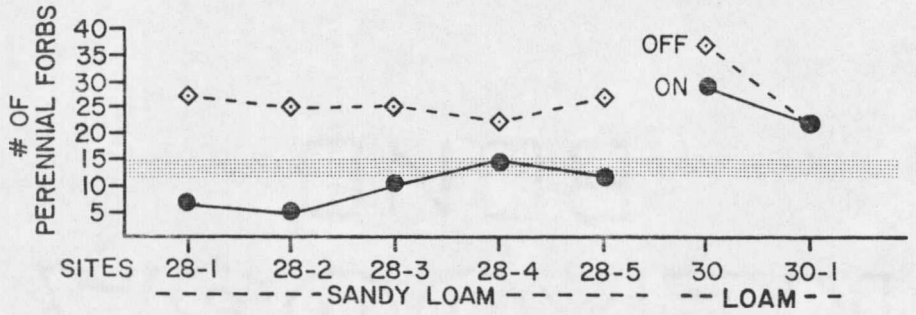


Figure 46. The number of perennial forbs sampled on-sites (ON) compared with the number sampled on native rangeland within 100 m of sites (OFF). The shaded area indicates the number of perennial forbs on native rangeland.

unit lowered the production of perennial grass propagules. This lowered the mobility of species grazed by cattle to the 28-sites.

The loamy 30-sites did not have significantly more species sampled off-site than on-site. This suggested that loamy overburden may have a greater potential for establishment of species than sandy

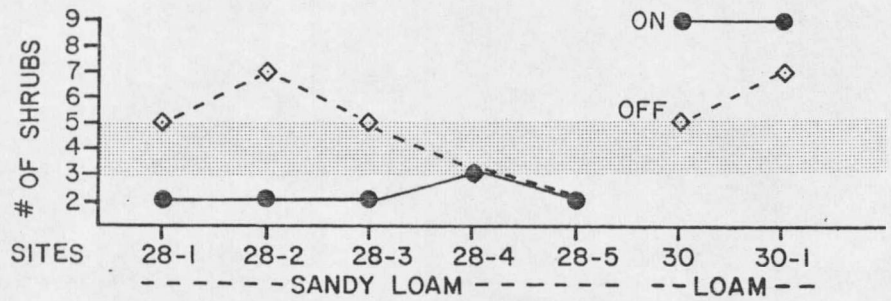


Figure 47. The number of shrubs sampled on-sites (ON) compared with the number sampled on native rangeland within 100 m of sites (OFF). The shaded area indicates the number of shrubs on native rangeland.

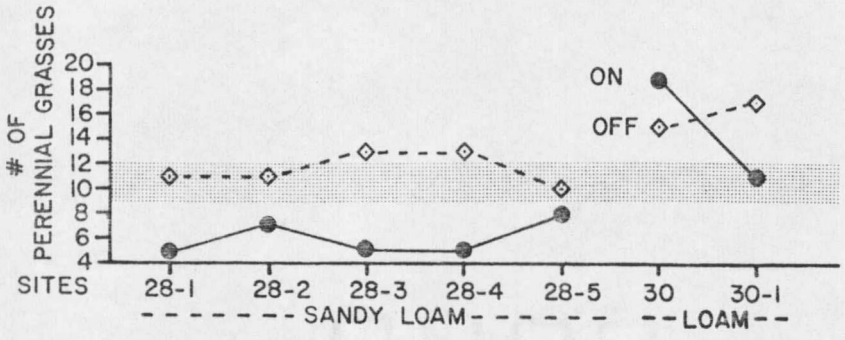


Figure 48. The number of perennial grasses sampled on-sites (ON) compared with the number sampled on native rangeland within 100 m of sites (OFF). The shaded area indicates the number of perennial grasses on native rangeland.

loam overburden, at least in a different and less intense grazing regime.

The total number of species sampled on the 28-sites decreased from the south to the north end of the unit. Meanwhile, the total number of species sampled off the sites increased in the same direction (Figure 45). This effect suggested the presence of subtle

soil, grazing, and/or competition/allelopathic gradients across the sites.

Perennial forbs accounted for most of the differences in total number of sampled species (Figure 46). On native range in the Colstrip area, only 12-15 perennial forbs are usually sampled per site (Sindelar 1981). The intensity of frequency sampling added many additional species.

Sites 28-1 and 3 had significantly fewer perennial forbs on site than the other sandy loam sites. As many as 14-25 more perennial forb species were sampled off of the 28-sites than were sampled on the sandy loam sites.

The loamy sites had significantly more perennial forbs and shrubs on- and off-site than the sandy loam sites (Figures 46 and 47). In fact, in the perennial grass, biennial forb, and shrub categories, loamy minesoils had more species on-site than surrounding rangeland (Table 18).

The total number of species sampled, especially on loamy minesoils, indicated that many species do not need substantial soil development or topsoiling to establish and persist at least in limited quantities.

The sandy loam sites had more perennial grasses off-site than on-site (Figure 48). The number of species available to each 28-site was equal but some exclusionary factor(s) limited the quantity of each species that established on the sites. The increase in number of perennial grass species on the loamy 30-site was due to the addition of species from the Pinus ponderosa-Agropyron spicatum type.

Finally, 14 species including five perennial grasses, four perennial forbs, three annual forbs, and two biennial forbs were found on minesoils that were not sampled on native range. Thirty-six species were sampled on native range that were not sampled on minesoils. In all, 91% of the species on the study sites were found within 100 m of the sites. Over 50 percent or 65 species were common to both sandy and loamy range sites.

Characterization of Native Rangeland Communities Surrounding the Sites

A unique opportunity to quantify the mobility of plant species was available because excess overburden operations produced sites surrounded by native rangeland. Over 6,000 4 x 10 cm plots were sampled on native rangeland within 100 m of the sites while 2,900 plots were sampled on the sites. Tables 19 and 20 list the important species observed on native rangeland and on the sites. Dominant species are outlined in hatchured boxes. Values in rows followed by the same letters are not significantly different ($P < .05$) using Chi Square (X^2) analyses. The large size of the 30-site and its bilobed appearance allowed the site to be sampled as two separate sites. The east lobe was called the 30-E site and the west lobe was called the 30-W site. Another small deposit from Pit Two was sampled and called the 30-1 site (Figure 10).

Within the sandy loam 28-site management unit, some subtle species population gradients were suggested by frequency data (Table 19). Bouteloua gracilis and Artemisia cana were more prevalent in the south end of the unit. This suggested differences in opportunities

Table 19. Important species (% frequency) on native rangeland surrounding the sites.

SITES	sandy loam					loam			porcelanite[3]		
	28-1	28-2	28-3	28-4	28-5	30E	30W	30-1	30E	30W	30-1
Perennial grasses											
Agropyron smithii	13d	13d	17c	14cd	11d	61a	35b	33b	3a	7a	8a
Agropyron spicatum	0c	t[1]c	1c	1c	1c	1c	6b	15a	58a	48ab	41b
Bouteloua gracilis	41a	31b	22c	18d	20cd	10e	2f	9e	3a	1a	5a
Calamovilfa longifolia	17b	9d	12c	23a	9d	3e	3e	1e	0a	3a	0a
Carex filifolia	22b	21b	11d	15c	30a	4e	2e	2e	2a	3a	2a
Koeleria pyramidata	8c	35a	20bc	36a	18b	9c	8c	23b	0b	3ab	8a
Poa pratensis	1bc	1c	2bc	0d	td	18a	15a	3b	1b	0b	11a
Stipa comata	47c	50c	49c	56b	67a	49c	62ab	14d	10a	12a	7a
Other important species											
Bromus japonicus + B. tectorum	26de	28d	41b	22e	34c	66a	60a	41b	31a	37a	9b
Artemisia cana	3c	3bc	6a	td	0d	td	0d	6ab	2a	0a	0a
Artemisia dracunculus	15a	10b	12ab	11b	12ab	0c	0c	0c	1a	0a	0a
Gutierrezia sarothrae	2c	4b	2c	2c	3bc	1c	11a	16a	8a	13a	16a
Yucca glauca	3a	1bc	2ab	3a	1bc	0c	0c	1bc	3a	1a	0a
Pinus ponderosa	0b	0b	0b	0b	0b	0b	0b	3a	15ab	21a	7b
Perennial grasses	90bc	91ab	88cd	92ab	94a	90abc	95a	84d	77a	77a	73a
Perennial forbs	31a	26b	31a	27b	32a	23b	22b	27ab	7b	20a	22a
Subshrubs	16a	11b	14a	13ab	14ab	1d	2cd	6c	5a	5a	5a
Shrubs and trees	8b	10b	10b	5c	4cd	2d	11b	26a	21a	21a	23a
number of frames	1000	1000	1000	950	950	325	250	300	175	150	100

[1] t = trace < .5% frequency
[2] Species in hatchured boxes are dominant species on a particular site.
[3] letters following numbers in porcelanite rows are from a separate statistical analysis.

for migration to the sites. Stipa comata was more important in the north end of the unit. Koeleria pyramidata was more prevalent on native rangeland with northerly exposures like that sampled around sites 28-2 and 4. These differences in populations may have indicated a subtle soil gradient that soil sampling did not uncover.

Table 20. Important species (% frequency) on minesoil sites.

SITES	sandy loam					loam		
	28-1	28-2	28-3	28-4	28-5	30E	30W	30-1
Perennial grasses[1]								
Agropyron smithii	6e	28b	6e	13cd	8de	40a	25b	17c
Agropyron spicatum	0c	0c	0c	0c	0c	18a	5b	22a
Bouteloua gracilis	1a	0a	0a	0a	0a	t[2] a	ta	0a
Calamovilfa longifolia	0c	0c	10a	6ab	4b	0c	1c	0c
Carex filifolia	0ab	0ab	0ab	0ab	1ab	0b	0b	2a
Koeleria pyramidata	0g	1fg	4ef	13d	22bc	19cd	27ab	32a
Poa pratensis	0c	1c	0c	1c	1c	20b	26a	18b
Stipa comata	34abc	40ab	41a	31bc	42a	23d	30c	26cd
Other important species								
Bromus japonicus + *B. tectorum*	86a	84ab	82ab	77b	61c	26e	25e	44d
Artemisia cana	14ab	12b	15ab	4c	0de	2cd	te	22a
Artemisia dracunculus	64a	24c	38b	39b	32bc	3d	0e	0e
Gutierrezia sarothrae	0c	3b	0c	1bc	2bc	16a	15a	17a
Yucca glauca	1b	0b	2ab	6a	2ab	2b	1bc	1b
Pinus ponderosa	0b	0b	0b	0b	0b	2a	tab	tb
Perennial grasses	38d	57c	56c	52c	59c	88a	84b	82b
Perennial forbs	16d	20cd	27bc	32b	42a	29b	43a	28bc
Subshrubs	64a	24c	40b	42b	32bc	11d	4e	10d
Shrubs	16cd	16cd	18c	10d	3e	26b	21c	43a
number of frames	200	200	200	200	200	600	975	325

[1] species in hatchured boxes are dominant species on a particular site
[2] t = trace < .5% frequency

Artemisia cana and *Bromus tectorum* were more common in the swale between sites 28-2 and 3 where cattle had access to the waterhole. *Bromus japonicus* and *Bromus tectorum* are commonly associated with *Artemisia* species in the presence of grazing abuse. Obvious cattle trails through the 28-site management unit suggested the possibility that cattle use was heavy enough in the entire unit to produce a subtle grazing gradient. This may have influenced species dominance and migration abilities to the sites (Skilbred 1979). Frequency

sampling of recent cattle use by sampling cattle "scats" did not indicate any significant patterns of preferential use across the unit. However, the well developed in 1959 may have altered recent use patterns on the sites (Figure 10).

To summarize, the plant communities surrounding the 28-sites and the 30-sites were different in range site and physiography. Frequency data verified that they were different in species dominance and composition as well. Both sets of sites were surrounded by rangeland that contained differing populations of relatively few dominant species. Differences in populations reflected subtle soil, management, and other gradients on native rangeland. These gradients presented differing opportunities for migration of species to the sites.

Analysis of Establishment Success on Minesoils

Pioneer Vegetation

Pioneer species have changed in the last 100 years. Today's important pioneers on mined land in the Colstrip area are mobile species like the tumbling annual mustards and Chenopods, biennial legumes, and windborne and other Composites (Table 21). Of these species, only four annual forbs and one shrub are native. The non-native species have increased in importance with expansion of mining, plowing, and other large disturbances.

To identify other possible pioneer species at the time of site formation, 35 small ($< 5\ m^2$) one- and two-year-old disturbances (soil test pits, etc.) were inventoried in the 28-site management unit in 1977. Table 22 lists 20 frequently observed species. Old photographs

Table 21. Commonly observed pioneer species on large disturbances on minesoils in the Colstrip area.

CRUCIFERAE (BRASSICACEAE)		LEGUMINOSAE (FABACEAE)	
Camelina microcarpa	AIF	Melilotus alba	BIF
Descurainia pinnata	ANF	Melilotus officinalis	BIF
Descurainia sophia	AIF		
Sisymbrium altissimum	AIF	COMPOSITAE (ASTERACEAE)	
Sisymbrium loeselii	AIF		
		Chrysothamnus nauseosus ssp. graveolens	PNS
CHENOPODIACEAE		Helianthus annuus	ANF
		Helianthus petiolaris	ANF
Chenopodium album	AIF	Lactuca serriola	BIF
Chenopodium leptophyllum	ANF	Taraxacum officinale	PIF
Kochia scoparia	AIF	Tragopogon dubius	BIF
Salsola collina	AIF		
Salsola kali	AIF		

A=annual; B=biennial; P=perennial; N=native; I=introduced; F=forb; S=shrub.

of Pit One showed overburden covered with Salsola kali (Dean Collection 1929).

The size of disturbance influences pioneer vegetation patterns. Only five annual forbs were commonly observed on small disturbances. These annual forbs were the only species common to both large and small disturbances. The importance of mobile nonperennial forbs on small disturbances was reduced by other species which established early. For example, Bromus japonicus and Bromus tectorum are relatively immobile. However, on small disturbances annual Bromus species were the most commonly observed species.

Most perennial species were tolerant of shallow burial. These species were able to establish within the boundaries of the small disturbances by peripheral invasion by resprouting through up to 15 cm of soil. Rhizomatous species had a competitive edge by establishing

Table 22. Twenty commonly observed pioneer species on small disturbances in the 28-site management unit.

SPECIES	% FREQ	LIFEFORM	MOST COMMON ESTABLISHMENT METHODS
*Bromus japonicus	91	annual grass	seed
Agropyron smithii	80	rhizomatous grass	resprout after burial
Ambrosia psilostachya	72	rhizomatous forb	seed and rhizome transplant
*Bromus tectorum	72	annual grass	seed
Helianthus petiolaris	57	annual forb	seed
Lygodesmia juncea	54	rhizomatous forb	seed and rhizome transplant
Aster falcatus	46	rhizomatous forb	resprout after burial
Lithospermum incisum	43	perennial forb	seed, resprout after burial
Solidago missouriensis	40	rhizomatous forb	resprout after burial
Stipa comata	37	perennial grass	seed, resprout after burial
Calamovilfa longifolia	37	rhizomatous grass	resprout after burial
*Salsola species	37	annual forbs	seed
Gaura coccinea	37	perennial forb	resprout after burial
Psoralea argophylla	37	rhizomatous forb	resprout after burial
Camelina microcarpa	31	annual forb	seed
Artemisia dracunculus	29	subshrub	resprout after burial
Yucca glauca	26	shrub	root transplant
Heterotheca villosa	26	perennial forb	resprout after burial
Cirsium undulatum	23	biennial forb	seed
Chenopodium leptophyllum	20	annual forb	seed

* indicates introduced and naturalized species in the study area

through peripheral invasion, rhizome transplants, and seed. Stipa comata was the most important perennial grass establishing from seed. Yucca glauca was the most common transplanted shrub.

From the inventory of small disturbances, it was assumed that Salsola kali, Helianthus petiolaris, and Chenopodium leptophyllum were the most common pioneers at the time of 28-site formation. It was also assumed that perennial species established early on the 28-sites by peripheral invasion of rhizomes and seed because of the relatively small size of the deposits and the proximity of surrounding rangeland. Another process affecting early establishment of perennial species on the 28-sites was direct transplantation of propagules and vegetative materials. This occurred because materials used to form

the sites came from the upper eight meters of the native soil profile and contained a considerable portion of A_1 horizon material.

Establishment Success from Frequency Analyses

Frequency data verified that Bouteloua gracilis and Carex filifolia, which are two of the dominant species in the area, did not migrate and/or establish in any quantity after almost 50 years (Table 23). Calamovilfa longifolia was the only important warm-season grass species on the minesoil sites. Rhizome transplants during site formation were probably responsible for its presence. The only other important species with warm-season growth characteristics were the "all"-season Composites such as Artemisia species and Gutierrezia sarothrae.

Table 23 lists important species on native rangeland that did not establish on minesoils in any quantity. Bouteloua gracilis was more prevalent on sandy rather than silty native range sites. It may require additional soil structure before it can establish in plant communities (Judd and Jackson 1939; White 1971). Stipa viridula, a cool-season grass, was common on loamy soils. USDA-Forest Service (1971) concluded that Stipa viridula needed $CaCO_3$ removal before it would dominate on native soil. Topsoiling may enhance Stipa viridula and Bouteloua gracilis establishment on minesoils.

The 28-sites resembled upland terraces with a deeper rooting medium than is found on other upland sites in the unit. This increased soil depth opened the sites to dominance by other species in

Table 23. Important species on native rangeland that did not establish on minesoils in nearly 50 years.

SPECIES	Minesoil Percent Frequency		Native Range Percent Frequency		
	sandy	loamy	sandy	loamy	porcelanite
Perennial grasses					
Bouteloua gracilis	t[1]	t	26	8	10
Bouteloua curtipendula	-	t	-	6	8
Muhlenbergia cuspidata	-	-	-	1	4
Stipa viridula	-	1	1	5	-
Sedges					
Carex filifolia	t	-	20	3	3
Carex pensylvanica	-	-	5	1	-
Perennial forbs					
Sphaeralcea coccinea	-	t	2	3	2
Phlox hoodii	-	-	3	-	-
Asclepias pumila	-	-	1	t	-
Lichens					
Paramelia chlorochloa	-	-	3	1	-
number of frames	1300	2035	4900	875	425

[1] t = trace < .5% frequency

the local flora. Resultant communities that developed were partially dominated by species associated with deep soil and/or swale locations.

Some species on the 28-sites indicated that gradients existed across the management unit (Table 20). Artemisia cana populations on the sites reflected its availability on native rangeland. Associated with the increases in Artemisia cana in the south end of the unit were increased levels of annual Bromus species. As Bromus species and Artemisia cana dominance declined across the unit, Koeleria pyramidata and total perennial grasses increased. Also, Aster falcatus, total perennial forbs, and Yucca glauca increased from the south to the north end of the unit. These differences in species populations on versus off the sites suggested that various gradients

affected distribution and establishment. These gradients were not just a result of availability of propagules.

The loamy 30-sites became dominated by species from two native communities surrounding the sites. Dominance depended on microtopography and proximity to source materials. Dominant species included Agropyron smithii, Koeleria pyramidata, Poa pratensis, Stipa comata, and annual Bromus species from the grassland community and Agropyron spicatum, Yucca glauca, Gutierrezia sarothrae, and Pinus ponderosa from the bedrock outcroppings. Pinus ponderosa and Agropyron spicatum were competitive on loamy minesoils with level to convex shaped slopes close to the outcroppings. On level to concave shaped slopes, regardless of texture or proximity to a particular native community, Agropyron smithii and Poa pratensis dominated.

The overall dominance of the 30-sites was characterized by species from the deep loamy grasslands surrounding the sites. Mining of loamy materials did not alter the dominance of species as it did on the shallow upland sandy loam sites. Data from the 30-sites indicated the potential exists to recreate the two native communities surrounding those sites in the Colstrip area.

The loss of Bouteloua gracilis and Carex filifolia populations indicates that reestablishment of communities dominated by warm-season Graminoids and/or cool-season Carices may require special techniques.

Tables 24 and 25 list important species that established on minesoils which favored loamy or sandy loam minesoils. Koeleria pyramidata was less frequent on sandy loam minesoils than on sandy loam native rangeland. However, it was more frequent on loamy

minesoil than on loamy native rangeland surrounding the 30-sites. Evidently, it prefers loamy soil with an increased coarse fragment content, sandy loam soil with some development, northerly exposures, and/or it is especially susceptible to allelopathic/competitive effects of Artemisia and annual Bromus species.

Table 24. Established species that favored loamy textures.

SPECIES	Minesoil Percent Frequency		Native Range Percent Frequency		
	sandy	loamy	sandy	loamy	porcelanite
Perennial grasses					
Agropyron smithii	15	30	14	44	6
Koeleria pyramidata	8	26	23	13	3
Agropyron spicatum	-	13	-	7	51
Poa pratensis	t[1]	22	1	12	3
Perennial forbs					
Solidago missouriensis	3	6	1	1	1
Aster falcatus	8	13	7	4	3
Oxytropis serecia	t	2	-	t	-
Achillea millefolium	-	3	t	4	1
Astragalus adsurgens	t	3	t	t	-
Woody species					
Artemisia frigida	1	7	2	3	4
Gutierrezia sarothrae	1	15	3	9	12
Pinus ponderosa	-	2	-	6	14
number of frames	1300	2035	4900	875	425

[1] t = trace < .5% frequency

Annual Bromus species were more prevalent on sandy loam minesoils than on sandy loam native uplands. The loamy sites had just the opposite effect, with more annual Bromus species on loamy native communities than on loamy minesoils. This indicated the management differences between the two sites or simply the preference of Bromus species for deep sandy loam materials. Analyses in the plowed field

Table 25. Established species that favored sandy textures.

SPECIES	Minesoil Percent Frequency		Native Range Percent Frequency		
	sandy	loamy	sandy	loamy	porcelanite
Perennial grasses					
Stipa comata	35	27	53	41	10
Calamovilfa longifolia	4	t[1]	14	2	1
Annual grasses	79	30	30	56	30
Perennial forbs					
Psoralea argophylla	1	1	2	1	-
Heterotheca villosa	2	2	6	t	1
Lithospermum incisum	4	1	3	t	-
Ambrosia psilostachya	6	t	3	t	2
Artemisia ludoviciana	2	1	1	2	-
Woody species					
Artemisia dracunculus	39	1	12	-	t
Artemisia cana	10	5	3	2	1
Yucca glauca	2	1	2	t	1
number of frames	1300	2035	4900	875	425

[1] t = trace < .5% frequency

adjacent to site 28-1 showed that Bromus and Artemisia species cannot compete on the shallow, sandy loam, Stipa comata-Bouteloua gracilis-Carex filifolia vegetation type even after plowing destroyed the Carex filifolia and Bouteloua gracilis populations.

To summarize, mining favored species naturally found on deep soil types. Some species seemed to require further soil development or topsoiling to become established. The large number of species that migrated and established on minesoils without topsoiling and other reclamation treatments suggested that the need for soil development has been exaggerated. Natural revegetation favored the cool-season grasses.

Importance of Initial Establishment (Initial Floristics)

Vegetation development is a mixture of initial floristics and relay floristics processes with initial floristics being more important (Egler 1954). Anderson and Holte (1981) found support in the literature that vegetation change over time is often adjustment in existing plant populations and not species replacement as expected from classic succession theory (initial floristics versus relay floristics). The relative stability/initial floristics concept (Egler 1954) suggests that many different assemblages of the same species could form relatively stable communities on the same site (Anderson and Holte 1981).

Initial floristics implies that species participating in a successional sequence are already present on the site at the start of that sequence. Initial floristics has been underestimated and is significant in sharpening the prediction of successional sequences (Muller-Dumbois and Ellenberg 1974). Costello (1944) noted that small populations of climax species in initial stands after a disturbance are often overlooked in sampling. Species composition may be determined in large part by the species that first colonize the site (Futuyma 1973). Early-establishing perennial species may be the controlling factor in determining the course a given succession will follow mainly because of their ability to invade and hold space (Davis and Cantlon 1969).

The initial floristics process on the 45-to-49 year-old naturally revegetated plant communities could not be directly evaluated. However, certain factors that influence the initial establishment of vegetation, namely the season of site abandonment and climatic

variability in the study area were identified as especially important to vegetation development on mined land. It is believed that the observed differences in special composition, particularly across the homogeneous sandy loam 28-sites, were due to the influences of the initial floristics process.

Autecological characteristics of the dominant species on the study sites were other important factors affecting initial establishment of plant species after a disturbance. Recent Montana Agricultural Experiment Station studies on seeded mined land have been reviewed by DePuit (1980). Regardless of seed mixture diversity, relatively few species with autecological properties favoring early establishment (i.e. germination characteristics, rapid growth, cool-season growth habit) have had long lasting effects on site vegetation development and have persisted at the expense of many other, supposedly equally adapted species. Establishment of desired initial combinations of species may be the most important process controlling the course a given plant and soil succession sequence will follow.

Other Vegetation Sampling

Density sampling revealed that the 30-site had as many annual Bromus species plants/m^2 as the 28-sites, even though coverage and production estimates for Bromus species were extremely low. This indicated that management and/or a preference for deep sandy loam minesoils were probably responsible for differences between annual Bromus species production on the 28-sites and the 30-site.

A phenology study was conducted in 1977 to quantify effects of litter accumulations on Artemisia and Bromus communities. Perennial grass phenology was different across the sites but did not relate to dominance by Artemisia species, management, or microtopography.

Population analyses were conducted for three important species on adjacent native range and on an abandoned plowed field adjacent to site 28-1 (Table 26). A significant difference was found for Stipa comata basal diameter and probably age among the 28-sites, the native range control site (NR), and the plowed field. All age-classes were sampled on the 28-sites including adults, young adults, and seedlings. No seedlings were found on the plowed field or native range site. Data indicated that Stipa comata was able to establish on minesoil and that some factor(s) limited its growth on the 28-sites. Although West et al. (1979) found little relation between plant size and age in Stipa comata because of year-to-year plasticity in basal area, at least some factor was limiting plant size on the 28-sites.

Table 26. Summary of age-class distribution analyses conducted on selected species in 1977 on sites.

SITES	28-1	28-2	28-3	28-4	28-5	NATIVE RANGE	PLOWED FIELD
	sandy loam						
Stipa comata							
basal diameter (cm)	2.0 c[1]	2.1 c	3.0 bc	3.2abc	3.0abc	5.7a	5.0ab
± 95% CI	±0.7	0.8	0.7	1.4	1.4	1.6	1.2
Artemisia dracunculus							
crown diameter (cm)	9.5ab	7.7 bc	14.8a	12.4ab	10.6ab	4.7a	-
± 95% CI	±2.5	2.6	3.4	4.6	3.4	2.0	
Artemisia cana							
oldest stem (years)	6.7ab	7.7ab	9.1 c	5.4 b	7.4ab	7.1ab	-
± 95% CI	±1.8	1.7	1.5	1.2	2.2	1.2	

[1]Numbers in columns followed by the same letters are not significantly different ($P < .05$).

Confidence intervals from population analyses of Stipa comata, Artemisia dracunculus and Artemisia cana revealed that all three populations were reproducing and not relics of past grazing abuse. Stipa comata obviously favored shallow soil, even if it had been disturbed, as it was in the plowed field.

Physiography Studies

Microtopography

Infrared photographs of the 28-sites, taken in 1976 during a Melilotus officinalis bloom, revealed the importance of microtopographical differences on vegetation establishment. Obvious strips of vegetation were observed. In 1977, mapping of the vegetation only revealed this pattern on site 28-5 (Figure 24). The strips were blading patterns created as the sites were being formed. A horse-drawn blade was used to smooth the sites while creating small ridges and swales two to three meters apart. A transit revealed that as little as 15 cm relief between a ridge and swale had produced the vegetation patterns. Percentages of bare ground and increased amounts of Melilotus officinalis and Aster falcatus were characteristic components of convex microridges. Litter amounts were high, as were amounts of Artemisia dracunculus, Bromus japonicus and/or Bromus tectorum in the concave microswales.

Slopes on the 28-sites ranged from 0-4%. Even with these gentle slopes and sandy loam textures, runoff was observed during a typical summer thunderstorm. Vegetation maps of the 28-sites consistently showed increased amounts of Artemisia species in the run-in

collection areas on the sites (Figures 20-24).

Slope shape was possibly another factor influencing vegetation distribution. Most upland grassland sites in the Colstrip area are flat to convex in shape. Slopes below outcroppings are concave. Mining generally produces slopes with convex configurations and minor concave areas where settling occurs. Subsidence on the large 30-site produced small depressions with minimal concave slopes that became dominated by rhizomatous grasses. Meanwhile, convex slopes on the 30-site became dominated by bunchgrasses and primarily nonrhizomatous species.

Microtopographical differences on minesoils were probably important enough to affect initial establishment of species. This altered the eventual dominance on sites even on soils with the same textures.

Slope and Exposure Studies

Excess overburden operations created deposits on native rangeland with three sloping sides that stabilized at the angle of repose (Figure 13). Peripheral slopes of the five, 28-sites were inventoried to identify species preferring different slopes and exposures and to quantify natural revegetation potential on steep sandy loam slopes. Table 27 summarizes characteristics of each slope. Dominant species on each slope are in parentheses.

A total of 80 species was inventoried, with 28-40 species present on any one slope. No consistent pattern was found relating slope percent, aspect, total coverage, bare ground, and number of species;

but as expected, the northerly exposures generally had more species, more coverage, and less bare ground (Table 27).

Table 27. Summary of slope and exposure studies on 28-sites slopes.

ASPECT	---west---		northwest	north	northeast			------east------			southeast		south	southwest	
SITES	28-1	28-2	28-3	28-4	28-2	28-4	28-5	28-1	28-2	28-3	28-4	28-5	28-1	28-3	28-5
SLOPE %	35	47	44	43	60	46	42	33	44	48	41	48	36	63	62
BARE GROUND %	80	80	69	45	67	35	45	45	65	85	76	55	85	90	65
NUMBER OF SPECIES	34	29	28	37	37	40	37	31	31	28	34	32	32	35	31
TOTAL COVER	14	10	12	18	18	33	16	33	16	10	15	22	17	11	16
Dominant species (% composition)															
Stipa comata	3	(10)[1]	(8)	2	6	1	3	1	t[2]	1	1	2	1	1	1
Oryzopsis hymenoides	3	4	(9)	2	2	3	(12)	t	1	1	1	2	1	4	3
Calamovilfa longifolia	(7)	(10)	(16)	(27)	(11)	3	(31)	3	3	1	3	t	-	4	1
Agropyron smithii	3	(10)	t	t	2	1	3	t	1	1	3	2	1	1	1
Bromus tectorum	3	1	4	2	2	t	3	(61)	(65)	(53)	(32)	(22)	(59)	(17)	3
Salsola kali	1	(10)	4	2	-	-	(18)	-	-	-	3	2	2	4	9
Bromus japonicus	3	4	(9)	2	2	t	3	6	3	-	3	2	1	t	1
Helianthus petiolaris	1	1	t	t	-	t	1	t	3	5	(31)	(50)	1	4	(57)
Artemisia ludoviciana	(13)	-	-	5	-	1	-	t	-	-	3	2	-	1	-
Artemisia dracunculus	(27)	4	t	2	(41)	(74)	3	(24)	3	5	3	2	(11)	4	1
Artemisia cana	(20)	(19)	(33)	t	2	t	t	3	3	5	-	t	2	4	t
Rosa woodsia	1	t	-	-	(16)	t	-	-	-	-	-	-	-	t	-
Yucca glauca	-	1	t	(38)	t	1	1	t	-	-	3	t	6	(26)	1

[1] ( ) indicates dominant species
[2] t = < .05% composition

It appeared that many species were adapted to different slopes and exposures and moved up and down the slopes to get proper conditions. Species quantities present on native range affected the quantities present on the slopes, particularly for shrub and subshrub species.

Soil Studies

Introduction

The Cooperative States Research Service (CSRS) funded a Montana State University-Montana Agricultural Experiment Station soil genesis

study in the Colstrip area in 1976-1977. The soil genesis study group sampled four of the minesoil sites used in this study. They also sampled two native sandy loam range sites near the five 28-sites (Figure 10). The following is a summary of selected soil analyses on those six sites as reported by Schafer et al. (1979), and compared with data collected in this study.

Soil Temperature

Exposure is often a critical factor affecting soil temperature. Differences in soil temperatures on study sites appeared to be more related to effects induced by the dominant vegetation, rather than the small slope and exposure differences observed. For example, sites 28-1 and 3 generally had the coldest soil temperatures, due to litter accumulations on the sites. A minesoil could be warmer or colder than native soils with similar textures, grazing use, and slope and exposure conditions because of differences in plant community dominance.

Soil Texture

The major difference between the 28- and 30-site minesoils was textural (Table 8). The 28-sites were almost exclusively sandy loam to loamy sand in texture. Essentially, soil texture across the 28-sites was homogeneous. Differences in plant community dominance on the 28-sites were therefore not related to inherent differences in soil texture.

On the 30-site soil texture varied from very fine sandy loam to clay. As a result, the 30-site had different microhabitats for plant

community development. Textural differences on the 30-site made generalizations about plant community development cause and effect difficult.

Bulk Density

Bulk density on study sites was sampled in 1977 using a 137 cc core sampler. Bulk density differences between sites were insignificant because of the small core sampler and large coarse fragment content of minesoils.

Other bulk density sampling on study sites used the volume displacement-excavation method as outlined by Sindelar et al. (1973). Soil volumes 6-20 times larger than the core samples produced significant differences in 1976 and 1977 on three study sites. As Schafer et al. (1979) reported, bulk density reductions had occurred in the upper layer of minesoils and a compacted layer occurred at 30 cm (Table 8). Bulk density values decreased below 30 cm. The 28-sites were not significantly different in bulk density.

The 30-site had significantly higher dry bulk density values than the 28 sites (Table 8). Bulk density values were large enough to restrict root growth at 30 cm. This effect produced obvious mats of roots above the siltstone fragments. Essentially, root growth was limited to the upper 30 cm and to cracks between rock fragments in the compacted zone. Stark (1982) reported that a compacted layer at 18-20 cm on another portion of the 30-site was acting like a rock layer, holding water near the surface.

The layer at 30 cm was possibly compacted enough to temporarily

perch available water on the 30-site. In fine textured soil such as that on the 30-site, a given amount of rainfall will not penetrate as deeply as in coarser soils. Water held near the soil surface can be lost by evaporation from the soil surface. This effect coupled with seasonal moisture distribution patterns in the Colstrip area would favor cool-season species with large concentrations of roots in the upper 30 cm. This effect was favoring the growth of Pinus ponderosa on the site with its extensive rooting system and cool season growth habit (Richardson 1981). Taprooted species that could penetrate the compacted layer by following cracks between siltstone fragments would also be favored because of the moisture available below 30 cm. This helped explain the dominance of the 30-site by Melilotus officinalis in 1976.

Schafer et al. (1979) reported that the 30-site had the largest range in infiltration rates. Although infiltration rates for all sites were rapid (6-15 cm/hr) and slopes were less than 4%, substantial runoff and erosion was observed during typical precipitation events on the sites.

Soil Moisture

Soil moisture can be misinterpreted when conclusions are based on the inherent soil available water holding capacity (AWHC). The AWHC is the soil water held at field capacity (1/3 bar tension) minus the moisture held at the wilting point (15 bar tension). Table 28 summarizes soil texture and AWHC values on study sites. Sindelar and Plantenberg (1978) and Schafer et al. (1979) concluded that the loamy 30-site was successionally advanced because of the increased AWHC.

Table 28. Texture and soil AWHC values on study sites.

SITES	TEXTURE	AWHC (1/3-15 bar)	N[1]
28-1	SL[2]	7.7 b[3]	(9)
28-2	SL	6.3 bcd	(8)
28-3	SL	5.3 de	(35)
28-4	SL	4.9 de	(40)
28-5	SL	6.8 bc	(10)
30	L	11.5a	(8)
NR	SL	3.7 e	(5)

[1]N= sample number [2]SL = sandy loam, L = loamy
[3]AWHC column values followed by the same letter are not significantly different ($P < .05$).

Data from this study suggested that differences in plant communities and evaporation on sites influenced plant available moisture more than inherent soil AWHC. Table 29 graphically displays available soil moisture for the study sites in 1977. Plant available soil moisture is defined as the percent by weight of soil moisture (gravimetric) measured on a particular date minus the wilting point (15 bar) moisture level for that soil. This value indicated the plant available soil moisture that remained in the soil on that date. Therefore, it is a measure of evapotranspiration for the plant community on a site. This plant available soil moisture value differs from the AWHC. Shaded areas in the table indicate sample dates and soil depths where plant available soil moisture dropped below 0.1%.

Even though the five 28-sites had similar inherent soil AWHC values (4.9-7.7%) the plant available soil moisture measured varied substantially due to plant community differences (Table 29). The 30-site, with a larger inherent AWHC (11.5%), was drying at the soil

Table 29. Plant available soil moisture (% soil water by weight - 15 bar water) on study sites in 1977. Values are the mean of two replicates. Shaded areas indicate when moisture dropped below 0.1%.

SITES	SOIL DEPTHS (cm)	SAMPLING DATES 4/6	4/20	5/3	5/17	6/1	6/16	6/27	7/13	7/26	8/4	8/23	9/10	9/19	10/1	10/15
28-1	20-30	8.6	5.8	4.2	4.5	3.2	1.2	0.7	-0.4	-0.9	-0.4	-1.1	0.7	-0.1	-0.3	4.4
	40-50	8.0	4.8	4.4	2.9	3.8	1.3	0.3	-0.5	-0.2	0.5	-0.7	0.4	-1.0	0.2	3.0
	60-70	6.9	5.3	5.4	3.7	3.6	3.0	-0.4	-0.4	-1.0	0.1	-1.1	-0.9	-0.2	-0.8	0.0
	80-90	-1.0	7.1	4.9	5.2	3.0	1.3	1.0	-0.6	-1.0	0.3	-1.3	-0.4	0.3	-0.7	-1.4
	110-110	-0.7	6.2	5.6	4.6	1.0	0.8	-0.2	-0.4	-0.4	-0.4	-1.4	1.4	-0.3	-0.6	-0.4
28-2	20-30	8.4	4.5	4.7	5.0	4.3	1.7	1.3	-0.9	0.3	0.3	0.6	0.9	0.3	0.6	5.4
	40-50	0.4	5.5	5.1	4.1	5.1	3.4	2.5	-0.4	0.9	1.0	1.0	-0.3	0.9	0.7	2.8
	60-70	4.2	6.1	4.8	3.1	5.6	3.5	2.8	0.1	1.4	1.5	1.2	1.5	1.2	1.0	-0.3
	80-90	-0.2	3.7	2.9	2.3	5.3	5.0	4.2	1.9	1.2	0.8	1.7	1.8	3.6	1.2	1.4
	100-110	0.1	1.7	-0.1	2.4	5.0	5.0	3.3	1.1	0.8	1.8	2.2	2.7	2.1	0.5	0.2
28-3	20-30	9.5	6.9	3.7	4.6	5.1	1.7	2.3	0.8	0.9	0.2	-0.4	1.1	0.5	0.4	5.4
	40-50	9.1	4.8	4.4	4.1	5.8	2.5	2.0	0.5	0.1	0.5	0.0	0.3	-0.3	-0.2	4.1
	60-70	6.4	5.5	5.3	4.2	4.9	1.9	2.1	0.3	0.1	0.1	-0.7	0.0	0.0	-0.3	1.1
	80-90	6.1	5.8	5.3	4.9	4.5	2.5	4.4	0.3	0.3	-0.1	0.0	0.0	-0.4	0.0	0.7
	100-110	1.1	4.5	4.7	5.3	4.3	2.4	2.7	0.3	0.2	-0.4	0.7	0.1	-0.6	0.1	0.4
28-4	20-30	8.9	5.5	4.7	5.3	4.8	3.9	1.2	1.1	-0.8	1.2	-0.6	1.4	1.4	0.6	5.2
	40-50	9.1	6.6	4.6	3.6	4.8	3.3	1.5	0.8	0.4	4.2	-0.1	0.5	2.5	0.4	2.7
	60-70	8.7	6.4	4.4	3.8	4.6	4.6	2.1	0.6	1.7	2.2	0.1	1.4	3.8	1.0	2.5
	80-90	6.9	6.9	5.9	5.1	5.5	5.3	2.9	0.3	1.5	6.0	0.3	1.7	2.0	0.3	3.6
	100-110	6.4	3.7	5.5	5.1	3.9	4.8	3.5	1.0	1.9	4.1	0.6	2.0	2.0	1.8	3.6
28-5	20-30	7.6	6.5	4.7	5.4	5.7	2.8	1.3	2.3	1.9	2.1	1.1	1.2	0.6	0.5	5.4
	40-50	8.3	7.7	5.5	4.8	5.9	4.3	2.5	3.2	3.7	2.2	0.4	1.1	0.8	1.2	2.5
	60-70	6.6	7.0	6.9	4.8	5.7	5.4	3.2	3.0	3.1	2.1	1.2	2.2	0.6	1.5	3.0
	80-90	7.2	6.6	6.2	5.8	5.8	5.2	4.2	3.4	3.0	2.3	2.2	2.3	0.5	1.3	2.1
	100-110	6.6	5.0	4.6	5.4	6.0	6.1	8.0	4.1	3.7	2.2	2.9	2.8	0.6	2.9	2.3
30	20-30	-	8.7	6.1	1.2	4.6	0.6	-0.4	-2.7	-1.0	-1.6	-3.6	-2.5	-1.1	-1.7	3.5
	40-50	-	8.3	5.7	3.6	4.4	2.1	0.1	-1.1	-1.0	-0.3	-3.3	-1.7	-0.9	0.3	-0.5
	60-70	-	7.0	5.7	3.0	5.1	3.8	1.3	0.6	1.7	0.9	-1.9	-0.9	-0.5	1.5	-0.1
	80-90	-	4.9	3.6	1.2	4.1	1.2	3.3	4.2	1.3	2.7	-2.3	2.9	0.8	2.0	2.9
	100-110	-	1.4	3.7	0.5	1.7	4.0	4.4	2.1	1.8	3.8	-0.7	2.4	2.3	2.1	1.2
NR	20-30	7.7	3.9	3.4	5.8	3.8	2.1	0.8	-0.2	0.7	-0.7	-1.2	-0.2	-0.6	-0.1	4.8
	40-50	4.7	4.4	6.4	3.5	5.1	7.1	0.5	-1.9	-0.8	-0.2	-1.0	-0.9	-1.4	0.0	1.2
	60-70	-0.2	4.4	5.8	2.8	5.2	0.8	0.3	-1.3	-1.4	0.8	-1.2	-1.6	-1.6	-0.2	-0.6
	80-90	2.2	4.0	3.5	1.2	1.0	0.1	0.3	0.1	-0.9	1.2	-0.9	-1.6	-0.8	-1.4	-0.4
	100-110	1.8	2.9	2.8	0.7	0.8	0.3	0.9	1.4	1.7	0.6	-0.5	-1.0	-0.2	-0.3	-0.1

surface three weeks earlier than the 28-sites. High AWHC soils such as that on the 30-site hold water near the surface, where in dry years, a large amount can be lost by evaporation. Only in years that precipitation exceeds AWHC, does the extra storage capacity of fine textured soils make increased water available to the plant community.

The potential extra storage capacity on the 30-site was limited by high bulk density values which restricted rooting depths. The

compacted layer on the 30-site restricted soil moisture movement downward and favored cool-season species with extensive shallow rooting systems. Only taprooted species such as Melilotus officinalis, that could find cracks in the compacted zone, could take advantage of the soil moisture available below the compacted layer on the 30-site (Table 29).

Table 30 summarizes 1976-1977 plant available soil moisture (% soil moisture - 15 bar level) on six soil genesis study sites. The volumetric soil moisture data was converted to percent by weight (gravimetric) by dividing it by the bulk density value at each soil depth. Shaded areas in the table indicate relative dry zones with less than 3% plant available soil moisture at different depths throughout the season.

Soil moisture sampling showed that plant available soil moisture was not limiting perennial grass establishment (i.e., succession?) on the sandy loam 28-sites even in the dry 1977 growing season. This indicated that other factors, primarily litter accumulations, were limiting perennial grass establishment in subshrub/shrub-annual grass communities, such as those on sites 28-1 and 3. Annual Bromus species seedlings can establish in litter better than perennial grass seedlings can (Blaisdell 1949).

The plant communities dominated by "all"-season shrub, subshrub, and cool-season annual grass species used more soil moisture than cool-season perennial grass dominated communities. (Compare plant available soil moisture on site 28-1 and 3 with 28-2, 5, and 6 [Table 29]). On the native range sites, NR#1 and 2, moisture was available, but

Table 30. Plant available soil moisture (% soil water by weight - 15 bar water)on sites in 1976-1977 from Schafer et al. (1979). Shaded areas indicate when levels dropped below 3.0%.

SITES	SOIL DEPTHS (cm)	SAMPLING DATES 6/9	6/29	7/11	8/11	8/24	9/15	10/22	11/24	1/11	2/12	3/13	4/6	4/14	5/2	5/15	5/29	6/15	7/8	7/19	7/31
		1976								1977											
28-1	15	8	7	4	-1	-1	-1	2	5	12	21	11	7	12	1	7	7	12	-	-	-
	30	9	12	8	4	3	3	3	6	7	11	11	16	14	11	8	12	9	-	-	-
	45	11	12	9	4	3	3	4	4	6	9	16	14	13	9	12	8	-	-	-	
	60	11	11	9	4	3	2	3	3	4	4	12	13	11	8	11	8	-	-	-	
	75	11	10	9	3	2	2	2	2	2	1	7	10	11	7	9	6	-	-	-	
	90	11	10	9	3	2	2	1	2	3	1	5	6	9	5	7	4	-	-	-	
	120	14	13	12	5	4	4	2	4	4	3	3	4	5	2	5	4	-	-	-	
	150	9	9	8	2	2	2	0	2	2	2	1	2	1	2	0	2	2	-	-	-
	180	3	4	4	2	1	1	0	1	1	2	1	1	1	1	0	1	1	-	-	-
	210	1	1	1	1	1	1	-1	1	1	1	0	1	1	1	0	0	0	-	-	-
28-2	15	4	2	-1	-2	-2	0	3	4	8	16	10	16	12	4	6	8	6	-	-	-
	30	10	8	2	2	2	2	4	6	6	10	10	16	14	14	7	12	7	-	-	-
	45	11	8	4	3	2	2	3	3	3	5	8	15	13	16	8	11	8	-	-	-
	60	11	9	5	3	3	1	3	3	2	3	5	11	11	16	6	10	8	-	-	-
	75	10	8	4	2	2	0	2	2	1	2	2	5	6	15	3	8	6	-	-	-
	90	10	8	5	2	1	1	1	1	1	1	1	2	4	9	3	5	4	-	-	-
	120	10	9	5	3	3	2	2	3	1	3	1	2	2	5	2	3	3	-	-	-
	150	10	9	6	5	4	3	4	4	4	4	4	4	4	6	3	3	4	-	-	-
	180	9	9	8	6	5	4	5	6	4	5	4	4	4	6	3	4	4	-	-	-
	210	7	7	8	6	6	4	5	6	5	6	4	5	4	6	4	4	4	-	-	-
	240	6	6	7	6	6	5	6	6	5	6	5	5	5	5	4	5	4	-	-	-
28-5	15	-	6	7	2	0	-1	-5	1	5	8	12	10	14	10	1	4	2	4	-	-
	30	-	8	10	6	4	2	2	2	5	6	6	10	14	12	7	9	7	4	-	-
	45	-	9	11	9	5	3	3	2	4	5	5	9	15	12	10	8	11	7	-	-
	60	-	10	12	3	6	3	3	3	3	4	6	8	15	17	11	10	12	6	-	-
	75	-	11	13	10	7	4	4	0	4	4	4	7	13	13	11	10	11	9	-	-
	90	-	11	11	10	6	4	4	2	4	4	4	6	9	10	10	9	10	8	-	-
	120	-	11	12	11	9	6	5	2	5	4	4	5	9	8	8	9	9	8	-	-
	150	-	12	12	12	10	7	7	2	7	6	6	6	7	9	9	8	7	7	-	-
	180	-	12	12	12	11	9	8	4	8	7	7	7	7	8	9	7	7	7	-	-
30	15	8	12	4	-3	-4	-5	-1	2	5	15	9	15	12	2	6	6	3	2	-4	-4
	30	11	24	8	1	0	-2	-2	3	4	12	10	17	14	11	8	11	6	3	0	0
	45	11	15	9	2	1	0	-1	1	1	8	8	16	13	11	7	11	6	3	1	1
	60	12	15	9	4	3	2	-2	2	1	8	5	12	12	11	7	9	7	4	2	2
	75	12	14	10	5	4	2	1	2	2	8	4	7	9	9	7	8	7	5	3	3
	90	11	12	9	6	5	3	2	4	2	8	4	5	5	6	5	6	5	4	2	3
	120	7	9	6	5	4	2	1	3	1	4	2	2	2	2	1	2	2	2	2	2
	150	6	7	6	6	6	4	3	6	2	5	3	3	3	2	2	2	3	3	2	2
	180	5	6	8	6	6	4	1	5	3	5	4	4	4	1	3	4	4	4	3	3
	210	5	5	4	6	5	4	2	5	3	6	0	4	4	4	2	4	4	4	3	3
	240	4	4	4	4	4	4	1	4	2	-1	3	4	3	4	3	-	-	-	-	-
NR#1	15	4	6	2	-3	-1	-2	3	4	10	16	9	15	10	5	3	5	5	-	-	-
	30	9	11	6	0	0	1	1	6	9	12	10	17	12	10	10	10	5	-	-	-
	45	16	10	9	3	2	0	1	6	6	7	9	16	12	11	6	10	6	-	-	-
	60	9	8	9	5	4	2	3	4	6	6	6	14	12	10	8	8	7	-	-	-
	75	11	10	10	7	7	4	8	5	7	7	7	14	12	12	9	8	12	-	-	-
	90	13	10	11	8	8	6	6	7	8	8	8	12	12	14	10	10	12	-	-	-
	120	13	11	13	10	10	8	6	7	9	9	10	9	12	14	11	10	14	-	-	-
	150	15	12	15	11	11	10	9	9	10	10	10	10	12	15	12	11	12	-	-	-
	180	17	14	19	13	14	12	10	10	12	12	14	10	12	15	13	12	12	-	-	-
	210	22	19	22	17	17	12	12	11	14	15	13	13	14	17	16	14	16	-	-	-
	240	-	19	19	17	17	17	16	15	-	-	-	-	-	-	-	-	-	-	-	-
NR#2	15	6	5	0	-2	-3	-3	-1	2	4	16	6	10	6	-8	2	4	0	-1	-2	-3
	30	11	11	6	2	1	0	0	3	3	16	10	15	10	5	7	9	6	2	0	0
	45	13	13	10	4	3	2	1	3	3	14	10	17	13	9	10	11	8	3	3	2
	60	14	14	11	5	4	3	1	4	3	11	9	17	14	11	10	11	9	4	3	2
	75	14	13	11	6	4	4	1	4	3	7	7	14	13	11	9	10	9	6	4	9
	90	14	11	11	6	5	4	2	4	3	7	5	10	11	10	11	9	7	6	4	4
	120	16	16	16	14	11	9	6	9	8	9	10	10	11	11	11	11	11	9	7	6
	150	15	15	16	13	11	9	6	9	9	9	9	9	9	10	8	11	10	11	10	10
	180	13	13	13	15	10	9	4	9	7	9	7	7	8	8	14	8	8	9	9	9
	210	13	13	13	11	11	9	6	9	7	7	7	8	8	7	6	7	6	14	6	8
	240	11	11	11	11	10	9	5	9	6	8	7	12	7	7	6	7	6	7	7	6

annual grasses, Melilotus officinalis, and other species which depend on that moisture were limited by factors besides soil moisture availability and litter accumulations (Table 30). These sites dominated by perennial grass communities on native range that have plant available soil moisture are subject to invasion if disturbed.

The sandy loam 28-sites were not inherently droughty and did not have limited growing seasons as concluded by Schafer et al. (1979). A plant community with a mix of warm- and cool-season species with different rooting habits can produce different growing season and production profiles. Dominance of perennial grasses (i.e., succession?) on the 28-sites was not limited by AWHC or soil texture.

Organic Carbon:Nitrogen (C:N) Ratios

Schafer et al. (1979) reported organic carbon, nitrogen, and C:N ratios for the soil genesis study sites. Minesoils and native range had similar values at all depths.

Root Production

The bulk density core samples were washed through a #40 soil sieve to sample root production. The roots were dried, weighed and ashed. Differences were not significant because of large standard deviations due to small volumes, large coarse fragment contents of the minesoils, and small sample numbers. Core sampling produced significantly higher root production figures in the surface 10 cm than other sampling methods on the sites. The volume displacement-excavation method bulk density samples were also analyzed for root production. These data essentially agreed with data reported by Wyatt et al. (1980) on the

soil genesis study sites. Schafer et al. (1979), Wyatt et al. (1980), and Schafer and Nielsen (1981) reported root production, root count, and root size data comparing old minesoils with native soils averages. Root production data were too variable from site to site to draw conclusions.

Soil Sampling Summary

Overall soil analyses in this study and those reported by Schafer et al. (1979) did not reveal any serious soil chemical or physical limitations to plant growth. Measurable soil alterations in less than 50 years were observed. This agreed with conclusions reported by Schafer et al. (1979).

Variations in interpretations between this study and the soil genesis study were apparent. Conclusions by the soil genesis study group based on average soil characteristics across sites were mainly responsible for the differing interpretations. This was especially true if the averages were generated across soil textural boundaries and/or on sites with different plant communities. This study indicated that most data, even on sites with similar textures, bulk densities, and AWHC were too variable for generalizations.

The 28-sites were different from the 30-sites in plant community dominance and management as well as in soil texture, bulk density, AWHC and possibly evaporation. Vegetation and soils data from this study suggested that loamy minesoils were not inherently better than sandy loam minesoils in terms of vegetation production, plant available soil moisture, and/or dominance by Graminoids (i.e., succession?).

Soils on the 28-sites were essentially homogeneous in texture, bulk density, and AWHC. Differences in successional status of the 28-sites, as interpreted by dominance of perennial Graminoids, were not as related to inherent soil differences (i.e., AWHC, bulk density, and texture) as they were related to differences in soil characteristics produced by the dominant vegetation on the site (i.e. plant available soil moisture, soil temperature).

The variety of species present, differences in plant community dominance, and variations in soils measured on the 28-sites with similar soils, indicated that plants affect soil genesis (i.e. organic matter enrichment, soil temperature) more than soil genesis (i.e. $CaCO_3$ removal, structural development) limits plant development on minesoils. The dominant vegetation on the 28-sites appeared to be hindering vegetation change rather than fostering it, as expected from succession theory. Control of plant available soil moisture and production of standing dead vegetation and litter particularly affected vegetation development on the 28-sites.

SUMMARY

The presence of six 45-to-49-year-old naturally revegetated overburden deposits in the Colstrip, MT area presented the opportunity to study factors affecting vegetation development on surface mined land. In 1976 and 1977, a study was conducted to describe existing plant communities on minesoils and surrounding rangeland and to analyze plant species and site differences. This would identify and rank factors responsible for differences in vegetation development. These deposits consisted of excess overburden removed before mining in those areas where overburden thickness exceeded dragline capacity. Excess overburden was deposited on adjacent native rangeland, leveled, and abandoned. Initial observations revealed plant communities on the deposits were different from one another as well as from native rangeland, although the origin, age, parent materials, microtopography, climate, and past management were apparently similar.

In addition to an intensive vegetation sampling program, information was collected on site origins, grazing use, climatic variability, microtopography, and soil characteristics. Analyses indicated that community differences may have been due to the differential responses of individual species to: 1) environmental gradients; primarily differences in season of site abandonment, surrounding species populations, physiography, and microtopography; 2) environmental modification of the site produced by the existing vegetation,

and 3) the influence of climatic variability on establishment of initial vegetation.

Plant communities on the sites varied from shrub/subshrub-annual grass stands in poor range condition (using SCS range condition guidelines) to stands dominanted by native perennial species in good range condition. Natural revegetation produced different communities on the 30-site than the 28-sites. Differences were correlated with soil texture, grazing management, and surrounding plant communities. Although textural variations were reported on the 30-site, differences in vegetation dominance across the site appeared to be most affected by distance to a propagule source and microtopography. Significant differences in plant species dominance among the 28-sites indicated that different combinations of the same species can produce relatively stable communities on amorphous parent materials with uniform soil texture.

Because vegetation development of mined land is a combination of primary and secondary succession processes, and because classic successional concepts are questionable in semiarid areas (Wali 1980), ranking importance of factors affecting succession is difficult. Although a number of factors were identified as influencing succession on the sites, it is probable that climatic variability and season of site abandonment were most important. These factors are critical because they affect initial establishment of vegetation.

The initial floristics process on the 45- to 49-year-old naturally revegetated plant communities could not be directly evaluted. It is believed that the observed differences in species composition,

particularly across the homogeneous sandy loam 28-sites, were due to the influence of the initial floristics process. Establishment of desired initial combinations of species may be the most important process controlling the course a given plant and soil succession sequence will follow.

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