SELECTIVE PLACEMENT OF COAL STRIPMINE OVERBURDEN IN MONTANA

I. Data Base

Prepared for

United States Department of the Interior
Bureau of Mines

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MONTANA AGRICULTURAL EXPERIMENT STATION
Reclamation Research Program
Montana State University
Bozeman, Mt 59717

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Overburden Strata on Soil and Hydrology Relationships

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The specific objective of this three year study is to investigate the means of re-establishing non-polluted hydrologic systems in areas where surface mining directly impacts shallow ground-water resources. The research area chosen for the study is located near Colstrip, Montana at a new mine site where chemical analysis of core samples from the overburden suggested that excessive concentrations of several elements would be encountered during the mining process. This report discusses local vegetation; soils; and regional geology, and hydrology.

Stratigraphic cross sections and regression analyses were used to study the litho-chemical relationships in the overburden. Cross sections indicated inimical material may be related to both rock type and position within the overburden profile. In over-burden zones where clay content was high, there was a greater probability that Pb, Cu, Ni, and Mn concentrations would also be higher than average; similarly, the likelihood of overburden exceeding a suspect level became less as the sand content increased. Highest values of conductance were usually found within a few meters of the surface. High concentrations of clay, nickel, and zinc were frequently found directly above and below the Rosebud coal. Regression analysis indicated overburden SAR was predictable with only a Na analysis. A strong relationship also existed in the overburden between conductance, Ca, and Mg.

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FOREWORD

This report was prepared by the Montana Agricultural Experiment Station Reclamation Research Program, Montana State University in Bozeman under USBM Contract Number H0262032. This contract was initiated under the Advancing Coal Mining Technology Program. It was administered under the technical direction of the Spokane Mining Research Center with Mr. Lewis M. McNay acting as the Technical Project Officer. Mrs. Darlene Wilson was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period January, 1976 to June, 1977. This report was submitted by the authors in June, 1977.

We gratefully acknowledge Dr. R. Abbott, Assistant Professor of Mathematics, Montana State University, for his help in the statistical analyses presented in this report. We extend our appreciation to staff of the Western Energy Company for their cooperation and suggestions during the overburden drilling phase of this study. Lastly, a special acknowledgement is due to the Montana Department of State Lands and the Bureau of Land Management, Miles City for their cooperation in permitting access onto lands for this overburden research.

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INTRODUCTION

Abundant coal deposits of the Fort Union Formation in Montana are an important source of raw energy for the nation and the state. This coal is particularly attractive because of its low sulfur content and because its widespread, near surface location lends itself to the more economic surface extraction methods. There is concern, however, that large scale mining operations may adversely affect the quality of important ground-water resources both locally and on a more regional extent.

The concern stems from the fact that, in places, the coal seams themselves are aquifers which are currently utilized as sources for domestic and agricultural water supplies. At locations where the coal seam is a subsurface water bearing unit, the aquifer is effectively eliminated during the mining process and replaced by overburden material from an adjacent mine cut. Typically, inimical material is dumped in the bottom of the mine pit and covered with overburden. This is done in an attempt to keep the undesirable material far from the surface where it could pose problems for revegetation. Unfortunately, under certain hydrogeologic conditions this technique may place the inimical material directly in contact with the inflowing ground water in the developing spoils aquifer. The extent to which this material will influence the water quality is not known at this time, however, the potential exists for both local and, in time, regional changes.

A more logical approach to the prevention of this potential problem may be to selectively replace overburden in the mine pit. This, in fact, is the specific objective of the current research, i.e., to investigate the means of re-establishing non-polluted hydrologic systems through detailed overburden chemical analysis and selective handling of the overburden material. Obviously, it would be more desireable to place material with highest permeability and lowest pollution potential within the anticipated saturated zone and to isolate the inimical material above the water table but sufficiently below the surface so as not to inhibit revegetation efforts. This is in line with current reclamation concepts in Montana which are to strive for total reclamation rather than placing all emphasis on a revegetated surface.

The control of percolation down from the surface is also a means of preventing the leaching of inimical material into the developing spoils aquifer. Techniques to minimize leaching are additional objectives of this project. It is planned to investigate the following methods: 1) designing the recontoured spoils in a manner that will divert most surface water runoff away from areas known to be underlain by inimical material; 2) consumption of shallow subsurface water through evapotranspiration; and 3) capping the buried undesirable strata with an impermeable layer of shale or clay.

The research area is located near Colstrip, Montana at a new mine site where core analysis suggest that excessive concentrations of several elements in the overburden will be intercepted by mining. The mine is operated by the Western Energy Company and the site is referred to as Area B. Overburden will be moved with a Marion 8050 dragline which has a 46.2 m^3 (60 $yard^3$) bucket and 99 m (325 ft) boom. This combination of bucket and boom allows a versatile working radius of 87.2 m (286 ft), which is nearly twice the width of the pit (45 m). This provides the necessary freedom to select overburden materials and the capability to place them as spoils within specific zones, either close to or far from the machine body.

Coal producers and users in the Western States are cognizant of environmental degradation resulting from surface mining practices. Public attitudes are influencing the enactment of more stringent legislation of surface mining operations. Several states are now considering additional modifications requiring the segregation and burial of toxic stratigraphic horizons, toxicants which may tend to degrade the local and regional ground and surface water resources. The research discussed herein is designed to develop, demonstrate, and evaluate alternative surface coal mine overburden handling techniques by which inimical materials may be efficiently identified, segregated, and specifically placed.

This first project report is divided into two major parts: (1) Baseline Resource Data, and (2) Overburden Chemistry and Stratigraphy.

PART I - BASELINE RESOURCE DATA

VEGETATION

Colstrip Area

Most native vegetation of the Colstrip area of southeastern Montana can be characterized as within either mixed prairie or coniferous woodland plant associations, although scattered intrusions of riparian vegetation do occur along more mesic to hydric drainages and streamcourses. Payne (1973) classified the area in general as within the eastern Montana ponderosa pine savannah vegetative type, which contains scattered open stands of ponderosa pine interspersed among broad expanses of northern mixed prairie vegetation. Vegetation of the Colstrip area has been described at length previously (e.g. Sindelar et al., 1974, 1973; Meyn, Sundberg and Young, 1976; Munshower, Sindelar and Neuman, 1975; Munshower and DePuit, 1976; Lewis and Lefohn, 1976; Lewis, Glass and Lefohn, 1976).

Mixed prairie is the most prevalent class of native vegetation in the Colstrip area, and is composed of a diverse mixture of cool and warm season perennial grass, forb and shrub species. Mixed prairie plant communities are typically encountered on dry, level to steeply sloping uplands (i.e. sites with insufficient available moisture to support coniferous woodland or riparian vegetation). Plant species composition, cover and production of specific sites varies markedly depending on soils, topography and microclimate (i.e., range site) and pattern-history of land use. Properly grazed or relatively ungrazed areas may be classified as within good to excellent range condition classes, and are typically dominated by a mixture of native perennial grasses. Floristics of such relatively pristine or good to excellent condition areas have been discussed previously (e.g. Ross, Murray and Haigh, 1973; Wright and Wright, 1948; Morris, 1946; N.G.P.R.P., 1975). However, in the Colstrip region such relatively undisturbed sites are the exception rather than the rule since much of the area's rangeland has been rather continuously and sometimes excessively grazed by livestock. Overgrazing generally tends to promote development of various increaser or invader native shrub, half-shrub and weedy forb species as well as certain introduced annual grasses and weeds. Hence, much native mixed prairie has retrogressed considerably from climax, being presently composed of a variable admixture of climax-decreaser, increaser, and invader plant species. A listing of common grass and shrub species of mixed prairie plant communities of the Colstrip area is presented in Table 1; forb species diversity is rather excessive for presentation here, but is available in other reports (e.g. Munshower et al., 1975; Munshower and Depuit, 1976; Lauenroth et al., 1976).

Coniferous woodland vegetation is scattered and rather sporadic in distribution in the Colstrip area, in general occupying sites of higher elevation, high relief, rough topography and/or northerly exposure.

Table 1. Major grass and shrub species of mixed prairie plant communities of the Colstrip, Montana area.

Scientific name	Common name
Perennial grasses and grasslikes:	
Agropyron smithii	Western wheatgrass
Agropyron spicatum	Bluebunch wheatgrass
Aristida longiseta	Red threeawn
Bouteloua curtipendula	Side oats grama
Bouteloua gracilis	Blue grama
Calamovilfa longifolia	Prairie sandreed
Carex eleocharis	Needle-leaf sedge
Carex filifolia	Threadleaf sedge
Koeleria cristata	Prairie junegrass
Poa pratensis	Kentucky bluegrass
Poa sandbergii	Sandberg bluegrass
Schizachyrium scoparium	Little bluestem
Stipa comata	Needle & thread
Stipa viridula	Green needlegrass
Annual grasses:	
Bromus japonicus	Japanese brome
Bromus tectorum	Cheatgrass
Hordeum jubatum	Foxtail barley
Vulpia octoflora	Sixweeks fescue
Shrubs and Half-shrubs:	
Artemisia cana	Silver sagebrush
Artemisia frigida	Fringed sagewort
Artemisia tridentata	Big sagebrush
Gutierrezia sarothrae	Broom snakeweed
Rhus trilobata	Three-leaf sumac

Ponderosa pine (*Pinus ponderosa*) usually dominates, growing in open to moderately dense stands, although on certain sites Rocky Mountain juniper (*Juniperus scopulorum*) may be conspicuous. Understory vegetation consists of a variety of mixed prairie grasses, shrubs and forbs as well as occasionally, more mesophytic broad-leaved shrubs.

Riparian vegetation is encountered on sites with relatively greater available moisture, such as along stream courses, drainages or on subirrigated areas. If sufficient moisture is available, plant communities may be dominated by broad-leaved trees such as plains cottonwood (*Populus deltoides*), boxelder (*Acer negundo*) and green ash (*Fraxinus pennsylvanica* var *lanceolata*). On other sites, dominance may be exhibited by various broad-leaved shrubs or smaller trees, including American plum (*Prunus americana*), western chokecherry (*Prunus virginiana* var *demissa*), snowberry (*Symphoricarpos* spp), willow (*Salix* spp.), rose (*Rosa* spp.) and hawthorn (*Crataegus* spp.). Although rather sporadic and localized in distribution, this type of vegetation is nonetheless a conspicuous feature of the Colstrip area.

Livestock grazing constitutes the prime current land use of most areas of native vegetation of the Colstrip region. Payne (1973) assigned a mean estimated livestock carrying capacity for the eastern Montana ponderosa pine savannah vegetative type of 4.0 acres (1.6 ha) per animal unit month (A/AUM). Locally, carrying capacities may be greater or less than this level depending on range site and condition. Carrying capacities of higher condition mixed prairie range sites of the Colstrip area were noted between 1.5 and 3.0 A/AUM by Munshower and DePuit (1976), while lower condition or less productive sites were as low as 13.2 A/AUM. Coniferous woodland carrying capacities for this region have been generally noted between 5 and 8 A/AUM (Munshower and DePuit, 1976; Depuit, Willmuth and Coenenberg, 1975). Total aboveground plant productivity also varies widely according to range site and condition. In general, mixed prairie sites produce between 1000 and 1800 Kg/ha/year, with mean production levels in the range 1200-1300 Kg/ha/year (Munshower and DePuit, 1976; Lauenroth et al., 1976). Aboveground production by non-tree species within coniferous woodland plant communities may range roughly between 700 and 900 Kg/ha/year (Munshower and DePuit, 1976; Depuit et al., 1975. Livestock carrying capacity and aboveground plant production for any given site also tend to vary, sometimes sizably, from year to year depending on yearly weather fluctuations.

A limited conversion of native rangeland into agricultural cropland has occurred in the Colstrip area, although the total acreage of agricultural lands is rather small relative to acreage of native vegetation. Principal agricultural land uses include hay-pasture and cereal grain production. Irrigated or dryland pastures are utilized as livestock pasturage or as sources of hay. Major pasture species include alfalfa (*Medicago sativa*), crested wheatgrass (*Agropyron cristatum*), smooth brome (*Bromus inermis*), yellow sweetclover (*Melilotus officinalis*) and timothy (*Phleum pratense*).

Barley and winter wheat comprise the major cereal grain crops of the area, with typical average yields of 60 and 47 bushels per acre (.4 ha) respectively (Meyn, et al., 1976).

In summary, most vegetation of the Colstrip locale can be characterized as sub-climax mixed prairie interspersed with considerable areas of ponderosa pine woodland on high relief, high elevation or northerly exposed sites and with limited areas of riparian vegetation on more moist sites. Livestock grazing comprises the major land use of this native vegetation. A limited portion of the area has been converted into agricultural land, principally for use for hay-pasturage for livestock and production of the cereal grains barley and wheat.

The Study Area

The study area covers a portion of the Western Energy Company mining area B, and in pursuance of current State of Montana mine site baseline study requirements the Company in 1975 contracted a study to document existent vegetation of this area. This study was conducted by personnel of Ecological Consulting Service, Helena, Montana under the direction of W.F. Schwarzkopf, and is summarized in the report of E.C.S. (1975). Methods employed by E.C.S. in this study are described at length in the above report, and will not be reiterated in detail here.

Results

Based upon the two to three plant species exerting aspect dominance, the study area portion of area B was found to possess five grassland, five shrub-grassland and three timber-grassland plant communities. Four non-natural area classes were also present in the study area. Each plant community type was placed within a standard S.C.S. range site class and rated according to standard methods (USDA, 1971) for range condition and recommended livestock carrying capacity. Plant communities were then mapped using infra-red aerial photographs. Table 2 contains a listing of all study area plant communities/land classifications with approximate size, range site designation, range condition and recommended carrying capacity. The distribution of these vegetation types is portrayed in the map of Figure 1.

To provide an index of plant species composition and distribution within and between the defined study area plant communities, sampling transects were analyzed within each of the major nonagricultural vegetation types for plant species constancy and frequency (E.C.S., 1975). Constancy refers to the percentage of plant species occurrence among sampling transects within a given plant community, whereas frequency represents the percentage of plant species occurrence among sampling points along the sampling transects. These data are presented in Table 3.

Table 2. Vegetation types/land classification units of the study area portion of Western Energy Company mining area B with respective areas, range site classification, estimated range condition and carrying capacity, 1975.

Code Number		Area (ha)	% of Total Study Area	Range Site Occupied[1]	Range Condition	Recommended Carrying Capacity (A/AUM)[2]
Grassland Communities						
111.1	*Agropyron smithii-Bromus* spp.-*Poa* spp.	92.6	2.12	Overflow	Good (55)[3]	1.7
111.2	*Agropyron smithii-Koeleria cristata-Carex filifolia*	182.3	4.18	Silty	Fair (47)	3.3
111.3	*Stipa comata-Carex filifolia-Koeleria cristata*	504.0	11.54	Silty	Fair (32)	3.3
111.4	*Calamovilfa longifolia-Schizachyrium scoparium*	104.5	2.39	Sandy	Good (70)	2.2
111.5	*Bromus tectorum*	55.8	1.28	--	--	--
Shrub-grassland Communities:						
211	*Artemisia tridentata-Koeleria cristata-Agropyron spicatum*	495.3	11.34	Clayey	Fair (31)	3.3
212.1	*Artemisia cana-Agropyron smithii-Stipa viridula-Poa* spp.	328.3	7.52	Overflow	Good (55)	1.7
212.2	*Artemisia cana-Agropyron smithii-Stipa viridula-Bromus* spp.	1341.5	30.72	Silty	Fair (41)	3.3
213	*Rhus trilobata-Stipa comata-Agropyron smithii*	317.5	7.27	Sandy	Fair (37)	3.3
214	*Chrysothamnus nauseosus-Agropyron spicatum-Oryzopsis hymenoides*	85.7	1.96	Dense Clay	Poor (16)	10.0
Timber-grassland Communities:						
220	*Arer negundo-Fraxinus pennsylvanica-Poa* spp.-*Agropyron smithii*	55.3	1.27	--	--	--
351	*Pinus ponderosa-Agropyron spicatum*	19.4	0.44	Thin-hilly	Excellent (76)	2.0
352	*Pinus ponderosa-Juniperus scopulorum-Agropyron spicatum*	5.5	0.12	Thin-hilly	Fair (49)	4.0
Non-natural Vegetation Classification Units:						
530	Agricultural	555.5	12.72	--	--	--
543	Stock Ponds	0.7	0.02	--	--	--
651	Disturbed Grassland	193.3	4.42	--	--	--
653	Residential	14.4	0.32	--	--	--
5	Sandstone Outcrops	15.6	0.36	--	--	--

[1] Follows USDA, S.C.S. (1971) criteria (Base data from E.C.S., 1975)

[2] Acres per animal unit month

[3] Follows USDA, S.C.S. methods: Poor = 0-24 Fair = 25-49 Good = 50-74 Excellent = 75-100

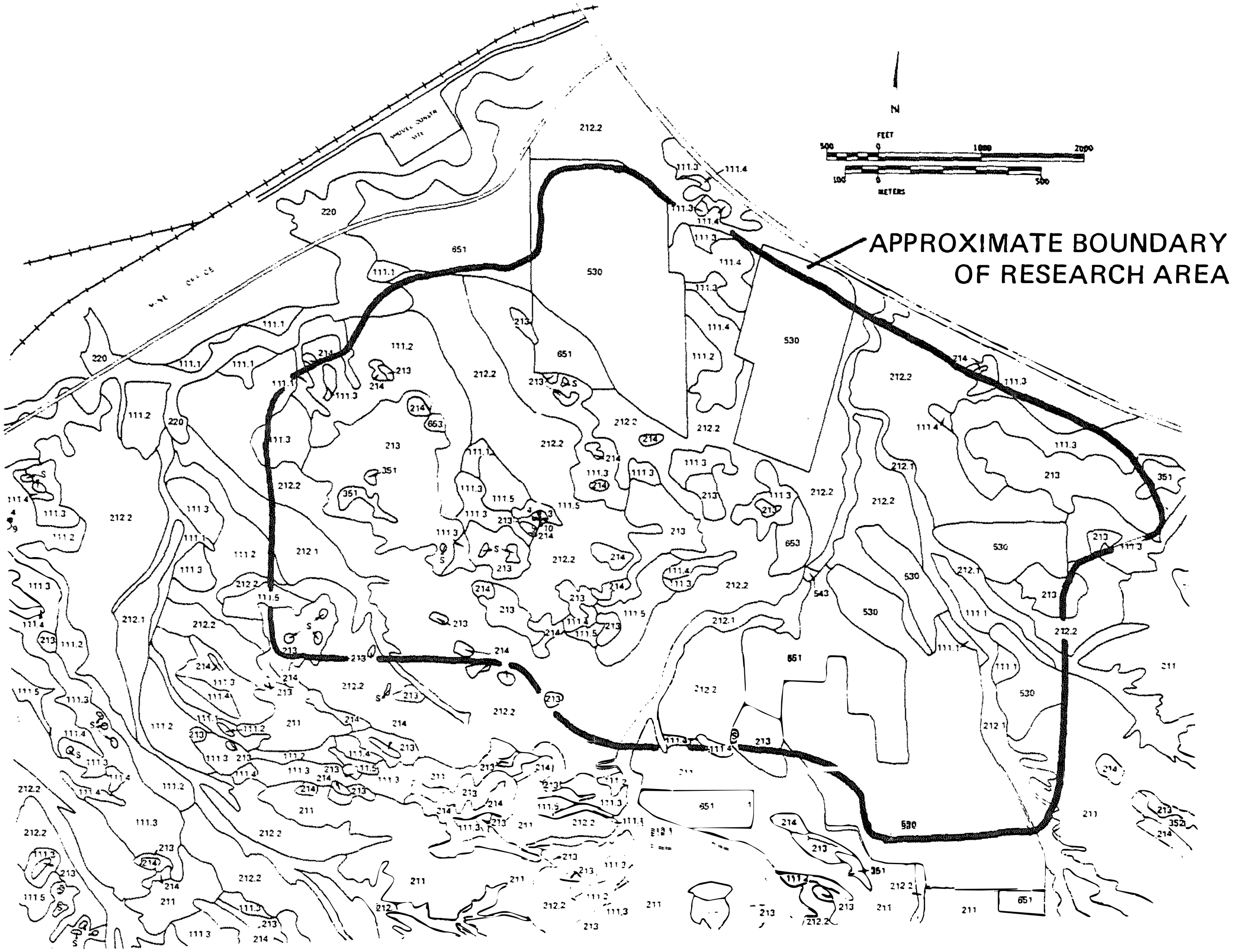


Figure 1. Vegetation map of a portion of Western Energy Company's mine area B Colstrip, Montana. (Ecological Consulting Serv., 1975).

Table 3. Constancy/frequency[1] of plant species within three plant classes for thirteen plant communities present on study area portion of Western Energy Company mining area B, 1975 (Table I of E.C.S., 1975).

Plant Taxa	Plant Community Code Number												
	111.1	111.2	111.3	111.4	211	212.1	212.2	213	214	220	351	352	651
Grasses:													
Agropyron cristatum	--	--	--	--	--	--	--	--	--	--	--	--	100/100
Agropyron smithii	100/95	100/84	50/23		80/34	100/67	100/58	67/58	25/5	100/85	25/3	33/8	100/10
Agropyron spicatum	--	29/6	33/3	--	100/64	--	--	33/15	100/44	--	100/89	100/88	--
Agropyron trachycaulum	--	--	--	--	--	--	50/15	--	--	--	--	--	--
Andropogon gerardi	--	--	--	50/5	--	--	--	--	--	--	--	--	--
Aristida longiseta	--	29/4	50/8	--	20/1	--	--	33/3	--	--	--	--	--
Bouteloua curtipendula	--	--	--	--	20/2	--	--	33/2	--	--	--	33/5	--
Bouteloua gracilis	--	86/45	67/33	100/33	80/19	33/2	50/10	67/33	--	--	--	--	--
Bromus spp.	--	--	--	--	--	--	50/18	--	--	--	--	--	--
Bromus japonicus	100/100	86/56	100/41	100/40	60/34	100/75	100/55	67/33	--	--	25/21	33/2	100/5
Bromus tectorum	--	71/31	50/20	--	60/22	33/17	100/73	33/33	--	--	25/11	33/5	100/5
Calamovilfa longifolia	--	--	17/3	100/98	20/2	--	--	33/10	--	--	--	--	--
Carex filifolia	--	57/14	67/44	50/5	60/21	--	--	--	--	--	25/21	33/3	--
Carex viridula	--	14/1	33/13	100/23	--	--	--	33/7	--	--	25/4	--	--
Festuca idahoensis	--	--	--	--	--	--	--	--	--	--	--	--	100/15
Koeleria cristata	--	86/49	67/33	100/70	100/71	--	--	100/55	--	--	75/23	100/10	--
Muhlenbergia cuspidata	--	--	--	--	--	33/2	--	--	--	--	--	33/3	--
Oryzopsis hymenoides	--	--	--	--	--	--	--	--	50/5	--	--	--	--
Poa pratensis	100/100	14/14	--	--	--	33/25	50/43	--	--	100/95	--	--	--
Poa scabrella	--	14/2	17/6	--	40/5	--	--	--	--	--	--	--	--
Poa sandbergii	--	43/20	33/5	--	60/23	33/3	50/40	100/37	--	--	25/1	67/7	100/5
Schizachyrium scoparium	--	--	33/2	50/5	--	--	--	--	--	--	--	--	--
Stipa comata	100/5	71/21	100/85	100/78	80/30	67/8	--	100/57	--	--	75/14	67/7	--
Stipa viridula	100/95	29/20	17/1	--	40/9	100/80	100/43	33/8	--	--	25/4	--	--
Vulpia octoflora	--	43/9	67/10	50/23	--	--	--	--	--	--	--	--	--
Total Grasses	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/100	100/48	100/100	100/95	100/93	100/100

[1] Constancy (% occurrence among sites)/Frequency (% occurrence among frames).

(Continued)

Table 3 Continued

Plant Taxa	111.1	111.2	111.3	111.4	211	212.1	212.2	213	214	220	351	352	651
	Plant Community Code Number												
Total Forbs[2]	100/100	100/100	100/95	100/98	100/84	100/98	100/65	100/40	100/60	100/75	100/87	100/83	100/100
Shrubs; half-shrubs and trees:													
Artemisia cana	--	14/1	17/1	50/5	20/1	100/72	100/48	33/18	--	--	25/93	--	--
Artemisia tridentata	--	--	--	--	100/70	--	--	33/7	50/6	--	--	67/8	--
Atriplex confertifolia	--	--	--	--	--	--	--	--	25/5	--	--	--	--
Chrysothamnus nauseosus	--	--	--	--	--	--	--	--	100/19	--	--	33/2	--
Ceratoides lanata	--	14/1	--	--	--	--	--	--	--	--	--	--	--
Gutierrezia sarothrae	--	57/25	50/29	50/40	100/28	67/13	--	33/2	100/16	--	25/3	67/23	--
Juniperus horizontalis	--	--	--	--	--	--	--	--	--	--	--	33/5	--
Juniperus scopulorum	--	--	--	--	--	--	--	--	--	--	50/6	67/32	--
Pinus ponderosa	--	--	--	--	--	--	--	--	--	--	75/8	67/10	--
Prunus virginiana	--	--	--	--	20/1	--	--	--	--	--	--	--	--
Rhus trilobata	--	--	--	--	--	--	--	100/38	25/1	--	75/15	100/13	--
Ribes cereum	--	--	--	--	--	--	--	--	--	--	25/1	--	--
Rosa arkansana	--	--	--	--	--	--	50/8	33/7	25/1	100/35	50/13	67/8	--
Symphoricarpos spp.	--	--	--	--	--	33/11	50/18	--	--	100/20	75/8	67/23	--
Total Shrubs	--	71/26	50/30	50/40	100/86	100/77	100/50	100/75	100/48	100/50	100/40	100/90	--

[2] Listed as forage class only.

Aboveground plant annual production is another important descriptive parameter useful in characterizing rangeland plant communities. Accordingly, plant production samples were collected using harvesting techniques (E.C.S., 1975) within eleven of the defined nonagricultural plant community types of the study area. Harvested plants were separated into five plant catagories (perennial grasses, annual grasses, shrubs, forbs and lichens), oven-dried and weighed, and results expanded into production per unit area. Data thus derived are presented in Table 4.

The following paragraphs will discuss characteristics of each of the defined plant community types of the study area in light of the data presented in Tables 2 through 4.

Type 111.1: *Agropyron smithii-Bromus* spp.-*Poa* spp. Type 111.1 covered only 2.12 percent (92.6 ha) of the study area, and was encountered only on localized bottomland sites with heavy soils. Western wheatgrass (*Agropyron smithii*), Japanese brome (*Bromus japonicus*), Kentucky bluegrass (*Poa pratensis*) and green needlegrass (*Stipa viridula*) were dominant grass species, while shrub cover was negligible (Table 3). Perennial grass production (1402.8 Kg/ha, Table 4) was higher for this vegetation type than for any other, which in part accounts for the relatively high recommended livestock carrying capacity of 1.7 A/AUM (Table 2). Total biomass production was 1612.9 Kg/ha. Range condition was evaluated as good for this type.

Type 111.2: *Agropyron smithii-Koeleria cristata-Carex filifolia.* Type 111.2 was found at slightly higher, more xeric sites than Type 111.1 and may have represented an ecotone between Type 111.1 and 111.3. Slopes were rather gradual in general, and Type 111.2 occupied silty range sites. Range condition was classed as only fair, with dominance exerted by western wheatgrass, Japanese brome, prairie junegrass (*Koeleria cristata*), blue grama (*Bouteloua gracilis*), cheatgrass (*Bromus tectorum*) and threadleaf sedge (*Carex filifolia*) (Table 3). Broom snakeweed (*Gutierrezia sarothrae*) was a common invader half-shrub species in this type indicative of excessive grazing pressure, and forbs were a conspicuous feature of the plant community. Perennial grass and total annual production were only moderate, while forb production was relatively high (Table 4). Recommended livestock carrying capacity was 3.3 A/AUM. Type 111.2 covered 182.3 ha, or 4.2 percent of the study area (Table 2).

Type 111.3: *Stipa comata-Carex filifolia-Koeleria cristata.* This important and widely distributed vegetation type constituted the largest of the grassland types, covering approximately 504 ha (11.5 percent of the study area). Type 111.3 generally occurred on silty range sites on dry upper benches, knolls and ridges. Perennial grass species again dominated, with needle-and-thread (*Stipa comata*), threadleaf sedge and prairie junegrass most prominant, followed by blue grama and western wheatgrass. Range condition was

Table 4. Aboveground plant production (oven-dried weight basis) of eleven major plant communities within the study area portion of Western Energy Company mining area B, 1975 (after Table III of E.C.S. 1975).

Plant Community	Plant Class	Estimated Aboveground Production (Kg/ha)
Agropyron smithii-Bromus spp.-*Poa* spp. (111.1)*	Perennial grass	1402.8
	Annual grass	124.4
	Forbs	85.7
	Total	1612.9
Agropyron smithii-Koeleria cristata-Carex filifolia (111.2)	Perennial grass	565.7
	Annual grass	83.9
	Forbs	571.3
	Shrubs	171.2
	Total	1392.1
Stipa comata-Carex filifolia-Koeleria cristata (111.3)	Perennial grass	589.2
	Forbs	205.0
	Shrubs	100.7
	Lichens	52.4
	Total	947.3
Calamovilfa longifolia-Schizachyrium scoparium (111.4)	Perennial grass	1294.9
	Annual grass	19.9
	Forbs	379.5
	Shrubs	2.9
	Total	1697.2
Artemisia tridentata-Koeleria cristata-Agropyron spicatum (211)	Perennial grass	419.5
	Annual Grass	62.4
	Forbs	70.9
	Shrubs	832.2
	Total	1385.0
Artemisia cana-Agropyron smithii-Stipa viridula-Poa spp. (212.1)	Perennial grass	1066.5
	Annual grass	51.2
	Forbs	258.7
	Shrubs	566.6
	Total	1943.0
Artemisia cana-Agropyron smithii-Stipa viridula-Bromus spp. (212.2)	Perennial grass	323.9
	Annual grass	231.1
	Forbs	1283.7
	Shrubs	485.3
	Total	2324.0
Rhus trilobata-Stipa comata-Agropyron smithii (213)	Perennial grass	364.2
	Annual grass	79.3
	Forbs	189.6
	Shrubs	895.5
	Lichens	9.0
	Total	1537.6
Chrysothamnus nauseosus-Agropyron spicatum-Oryzopsis hymenoides (214)	Perennial grass	65.4
	Forbs	109.9
	Shrubs	142.6
	Total	317.9
Pinus ponderosa-Agropyron spicatum (351)	Perennial grass	338.8
	Annual grass	17.8
	Forbs	124.7
	Shrubs	87.2
	Total	568.5
Pinus ponderosa-Juniperus scopulorum-Agropyron spicatum (352)	Perennial grass	114.0
	Forbs	40.5
	Shrubs	16.6
	Total	171.1

*code number from Table 2

assessed as only fair, as suggested by significant concentrations of the invading annual grasses, Japanese brome and cheatgrass, and the half-shrub, broom snakeweed (Table 3). Total biomass production (845 Kg/ha, Table 4) was rather low, with only moderate perennial grass production. Recommended livestock carrying capacity (3.3 A/AUM) was the same as for Type 111.2.

Type 111.4: *Calamovilfa longifolia-Schizachyrium scoparium.* This small (e.g. 104.5 ha, Table 2) grassland type was rather localized in occurrence, being found primarily on toe or foot-slopes of sandy-soiled hills or ridges. Dominance was generally exhibited by either or both prairie sandreed (*Calamovilfa longifolia*) or little bluestem (*Schizachyrium scoparium*) in association with needle-and-thread, prairie junegrass, blue grama and sedges (*Carex* spp.) (Table 3). Range condition was evaluated as good with a relatively high livestock carrying capacity of 2.2 A/AUM. This carrying capacity was supported by an unusually high perennial grass production level (1155.1 Kg/ha, Table 4).

Type 111.5: *Bromus tectorum.* On isolated, severely overgrazed or otherwise degraded sites within the study area, plant communities dominated in large by the invading annual grass cheatgrass (and, at times, Japanese brome) occurred. Such plant communities owe existance to disturbance and hence may be found on nearly every type of range site. Due to its small size within the study area (55.8 ha) and general undesirability in terms of reestablishment following mining, Type 111.5 was not quantitatively sampled by E.C.S.(1975).

Type 211: *Artemisia tridentata-Koeleria cristata- Agropyron spicatum.* This sizable shrub-grassland vegetation type covered approximately 495 ha (11.3 percent, Table 2) of the study area, occurring on clayey range sites of upper slopes and benches. Type 211 often appeared to be overgrazed, and range condition was rated only as fair. Big sagebrush (*Artemisia tridentata*) dominated site aspect, although apparent vigor was often low, followed by the half-shrub, broom snakeweed. Perennial grass cover was moderate, principally by such species as bluebunch wheatgrass (*Agropyron spicatum*), prairie junegrass, western wheatgrass and needle-and-thread, while Japanese brome was a common annual grass species (Table 3). Perennial grass production (419.5 Kg/Ha, Table 4) was low to moderate, and recommended carrying capacity was 3.3 A/AUM. Shrub production, as expected, was relatively high within Type 211 (832.2 Kg/ha, Table 4).

Type 212.1: *Artemisia cana-Agropyron smithii-Stipa viridula-Poa* spp. Type 212.1 was characteristic of mesic draws and coulees within the study area, and was classed as occupying overflow range sites. Roughly 328 ha, or 7.5 percent, of the study area was covered by this type. Type 212.1 was typically dominated by dense stands of silver sagebrush (*Artemisia cana*), which are reflected in rather high shrub production levels (Table 4). However, the relatively moist sites of Type 212.1 also supported suprisingly high perennial grass production (1066.5 Kg/ha, Table 4), a reflection of generally good range condition and resultant high carrying capacity of 1.7 A/AUM. Principal grass species of the type were western wheatgrass, green needlegrass, Japanese brome and Kentucky bluegrass *(Poa pratensis)*. Overall biomass production was high (1943 Kg/ha, Table 4), primarily due to perennial grass and shrub productivity.

Type 212.2: *Artemisia cana-Agropyron smithii-Stipa viridula-Bromus* spp. This type was fairly similar floristically to Type 212.1, but occurred on slightly higher, drier sites such as lower benches adjacent to the drainage bottoms and coulees of Type 212.1. Range site classification for Type 212.2 was silty rather than overflow. Vegetation of Type 212.2 was quite similar to that of Type 212.1 except that the dominant silver sagebrush was noticeably less dense, perennial grass cover and production was far lower (Table 4) and forb cover-production extremely high (e.g. 1283.7 Kg/ha, Table 4). The high forb productivity was largely due to the invasion and development of yellow sweetclover *(Melilotus officinalis)*, and caused total annual plant productivity to be misleadingly high in view of the range condition rating of only fair for this type. The rather depressed, fair condition classification for Type 212.2 is supported by relatively low perennial grass and abnormally high annual grass production levels (Table 4). This shrub-grassland vegetation type was the largest single type noted within the study area, covering over 1341 ha, or 30.7 percent of the area (Table 2). Recommended S.C.S. livestock carrying capacity for such fair condition silty range site vegetation was 3.3 A/AUM, although this approximation may indeed be rather high in view of the noted low perennial grass production level.

Type 213: *Rhus trilobata-Stipa comata-Agropyron smithii*. Type 213 was commonly located on sandy range sites on ridges, hills or south-facing slopes, sometimes in association with ponderosa pine. Three-leaf sumac *(Rhus trilobata)* was the aspect-dominant shrub species, although other shrub species were often present in sizable concentrations, such as big and silver sagebrush and prairie rose *(Rosa arkansana*, Table 3*)*. Shrub productivity of Type 213 (895.5 Kg/ha, Table 3) was higher than that within any other vegetation type of the study area. Perennial grass cover and production, however, was rather low (Table 4) although diversity was considerable with western wheatgrass, needle-and-thread, prairie junegrass, prairie and bluebunch wheatgrass all more or less common (Table 3). Range condition was assessed as fair. Type 213 covered 317.5 ha (7.3 percent of the study area).

Type 214: *Chrysothamnus nauseosus-Agropyron spicatum-Oryzopsis hymenoides*. This small and relatively unimportant vegetation type was usually located on scattered, often steeply sloping hills, knolls and ridges with dense heavy ("gumbo") clays. Type 214 only covered roughly 2 percent of the study area (85.7 ha). Vegetation was very sparse, no doubt a reflection of poor soils in conjunction, possibly, with overgrazing. Various hardy shrubs, such as rubber rabbitbrush *(Chrysothamnus nauseosus)*, shadscale *(Atriplex confertifolia)*, broom snakeweed and big sagebrush, tended to dominate such sites, although a sparse cover of certain perennial grasses, principally bluebunch wheatgrass and Indian ricegrass *(Oryzopsis hymenoides)*, did occasionally occur (Table 3). Biomass production was extremely low within all plant classes, and range condition was rated as poor with a very low livestock carrying capacity of 10.0 A/AUM.

Type 220: *Acer negundo-Fraxinus pennsylvanica-Poa* spp.*-Agropyron smithii.* This riparian vegetation type consisted of broad-leaved tree dominated plant communities on mesic to hydric bottomlands along the East Fork Armell's Creek. Overstory trees were primarly boxelder *(Acer negundo)*, green ash *(Fraxinus pennsylvanica* var. *lanceolata)* and, sporadically, plains cottonwood *(Populus deltoides)*. Understory vegetation, typically consisting of a dense cover of Kentucky bluegrass and western wheatgrass, was quite similar to that of overflow site Type 111.1 communities, except that various broad-leaved shrubs tended here to be more common, such as prairie rose and snowberry *(Symphoricarpos* spp.*)* (Table 3). Range site and condition may also have been similar to Type 111.1. Type 220 was very limited in extent within the study area, being confined to only approximately 55.3 ha adjacent to the East Fork Armell's Creek.

Types 351 and 352: *Pinus ponderosa-Agropyron spicatum* and *P. ponderosa-Juniperus scopulorum-A. spicatum.* These two ponderosa pine timber-grassland vegetation types are both quite similar and limited in extent within the study area (collectively covering less than 1 percent of the area), and therefore will here be discussed together. Both types occupy thin-hilly range sites, typically at higher elevations, on steeper slopes or broken topography and/or on northerly exposures. Within Type 351 ponderosa pine dominated the overstory, growing usually in rather open stands, with a variably developed understory of bluebunch wheatgrass, needle-and-thread, threadleaf sedge, three-leaf sumac, silver sagebrush and prairie rose (Table 3). Overall nontree productivity was rather low (Table 4), although sufficient perennial grass production occurred for range condition for this type of range site to be judged as excellent (although the recommended S.C.S. carrying capacity of 2.0 A/AUM was undoubtedly far too high).

Type 352 was very limited in extent in the study area (covering less than 6 ha) and was quite similar to Type 351 except that Rocky Mountain juniper *(Juniperus scopulorum)* became the most common dominant tree species. The juniper and pine overstory of this type was always quite open. Type 352 occurred in general on more severe sites, and nontree productivity was the lowest observed within any of the sampled study area vegetation types (Table 5). Range condition was assessed as fair.

Type 530: Agricultural: Roughly 555 ha (or 12.7 percent of the study area was classed as agricultural. Wheat production was the prime use of most of this land, although hay-pasturage and fallow areas also occurred. No quantitative data were collected on agricultural land by E.C.S. (1975).

Type 651: Disturbed Grassland: Areas disturbed from native state by past, albeit discontinued, cultivation were categorized as within this type, which covered 193.3 ha (4.4 percent) of the study area. Such cultivation has apparently been variable in intent, ranging from rangeland improvement plantings to old agronomically cropped areas. More recently cultivated rangeland seedling areas tended freqeuently to be dominated by crested wheatgrass *(Agropyron cristatum)*, whereas progressively greater cover by native mixed prairie species occurred on progressively older sites. Invading annual grasses such as cheatgrass and Japanese brome were often present in conspicuous concentrations within Type 651. Due to the man-caused nature of its existence, no uniform range site and condition classification could be made for this type. However, most Type 651 sites appeared to be severely overgrazed.

Summary

Three broad categories of natural plant communties were found within the study area portion of Western Energy Company mining area B. Approximately 21.5 percent (939 ha) of the area was collectively covered by five grass dominated plant communities (Types 111.1 through 111.5), generally in fair to good range condition. Five shrubland-grassland vegetation types (Types 211 through 214) collectively comprised the largest portion of the area - 2568 ha, or 58.85 percent of the area. Condition of shrub-grassland vegetation types varied widely from poor to good depending on degree and history of grazing use. Timber-grassland communities covered only 1.8 percent (80.2 ha) of the study site.

These natural vegetation types occurred over a variety of S.C.S. range sites, ranging from overflow to thin-hilly. Excluding all non-natural vegetation classification units, silty appeared to be the most widespread range site, covering approximately 57.4 percent of the area, followed by clayey (14.0 percent), overflow (13.5 percent), sandy (12.0 percent), dense clay (2.5 percent) and thin-hilly (0.7 percent). Roughly 3.2 percent of the range sites were in poor range condition, 65.2 percent in fair condition, 13.3 percent in good condition and only 0.4 percent in excellent condition. The S.C.S. recommended livestock carrying capacity for natural vegetation types of the study area varied from 1.7 to 10 A/AUM.

Agricultural land and disturbed (i.e., cultivated) grassland together covered approximately 17.1 percent (749 ha) of the study area. Less than 1.0 percent of the area consisted of nonvegetated sandstone outcrops or cultural features (residential, stock ponds, etc.).

The range resource thus comprises the major land resource of the study area portion of mining area B, and although mainly in only fair condition due to livestock overgrazing, this resource still has definite value in terms of local livestock production. It would appear that re-establishment of suitable rangeland vegetation capable of withstanding and supporting grazing livestock will be the ultimate reclamation goal for most of this area according to present State of Montana regulations. The presence of a limited acreage of agricultural land within the pre-mining area, however, may complicate reclamation goals somewhat if exact restoration of premining conditions is desired.

SOILS

Regional Distribution

Colstrip lies in a soil transition zone of Aridisols, Alfisols, and Mollisols. Aridisols or desert soils are dominant in the Southern Powder River Basin in a somewhat drier climate. Mollisols, prairie soils, are common in the moister Great Plains of North and South Dakota. Alfisols or forest soils occur in the neighboring Big Horn mountains and Black Hills regions. Entisols which are young, undeveloped soils are locally common due to steep terrain (Figure 2).

Packer (1974) characterized soils in the Colstrip area as fine-loamy, loamy-skeletal, Lithic Haploborolls. Field research at Colstrip indicates that the soil landscape is comprised primarily of Ustic Torriorthents, Borollic Camborthids, Aridic Haploborolls, Ustollic Haplargids, and Ustic Torrifluvents.

Soil-Forming Factors

Soils in the Colstrip area result from the interaction of several soil-forming factors. Climate, organisms, parent material, relief, and time all have had an effect in determining the properties of soils in this region. These soil properties in turn also affect vegetation, hydrology, and land-use patterns. Information on the distribution of soil types and their individual properties is therefore basic in characterizing the natural resources of an area.

The climate in Colstrip is characterized as continental, warm in summer, cold in winter. Average annual precipitation for the period 1941-1970 was 40.1 cm (15.8 inches) (U.S. Dept. of Commerce, NOAA, Figure 3). Three-fourths of this precipitation falls during the April to September growing season with 15 cm of the total coming in the early growing season. Summer precipitation occurs as showers and thunderstorms, some of which are of high intensity accompanied by hail.

As a result of low precipitation, run-off during snowmelt and high-intensity thunderstorms, and high evapo-transpiration rates, soils in the Colstrip area are dry in the root zone during much of the growing season. Many coarse-textured soils are dry long enough to have an aridic moisture regime which is typical of desert soils. Finer-textured soils with more clay and organic matter retain moisture longer into the summer and have a ustic moisture regime. Mean annual soil temperature is such that soils at low elevations have a mesic temperature regime while soils in the uplands have frigid temperature regimes (mean annual soil temperature less 8°C) (47°F). These facts suggest that climate plays an important part in the classification of soils in the Colstrip area.

Vegetation is another important soil-forming factor (see Vegetation Section, page 3). The region is dominated by mixed grass prairie with small areas of ponderosa pine uplands. Soils under grassland tend to build up thick A horizons high in organic matter due to the contribution of grass root systems (Mollisols). Soils under forest usually have an O horizon of relatively undecomposed organic matter with an underlying mineral A horizon low in pH. Argillic B horizons (clay accumulation) are also common in forest soils (Alfisols).

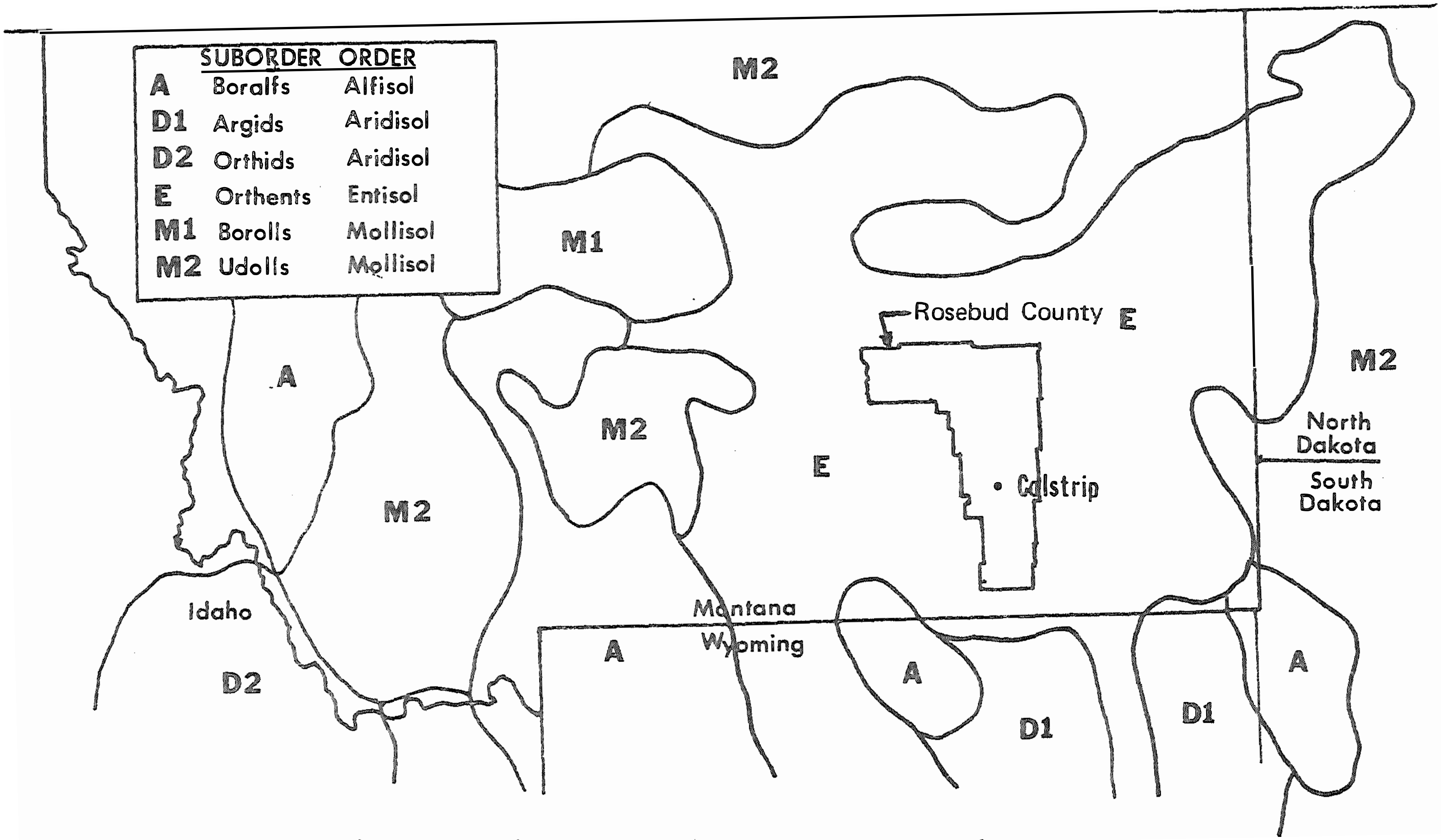


Figure 2. Regional distribution of soils in the Missouri Plateau and northern Powder River basin (from Buckman and Brady, 1971, p312).

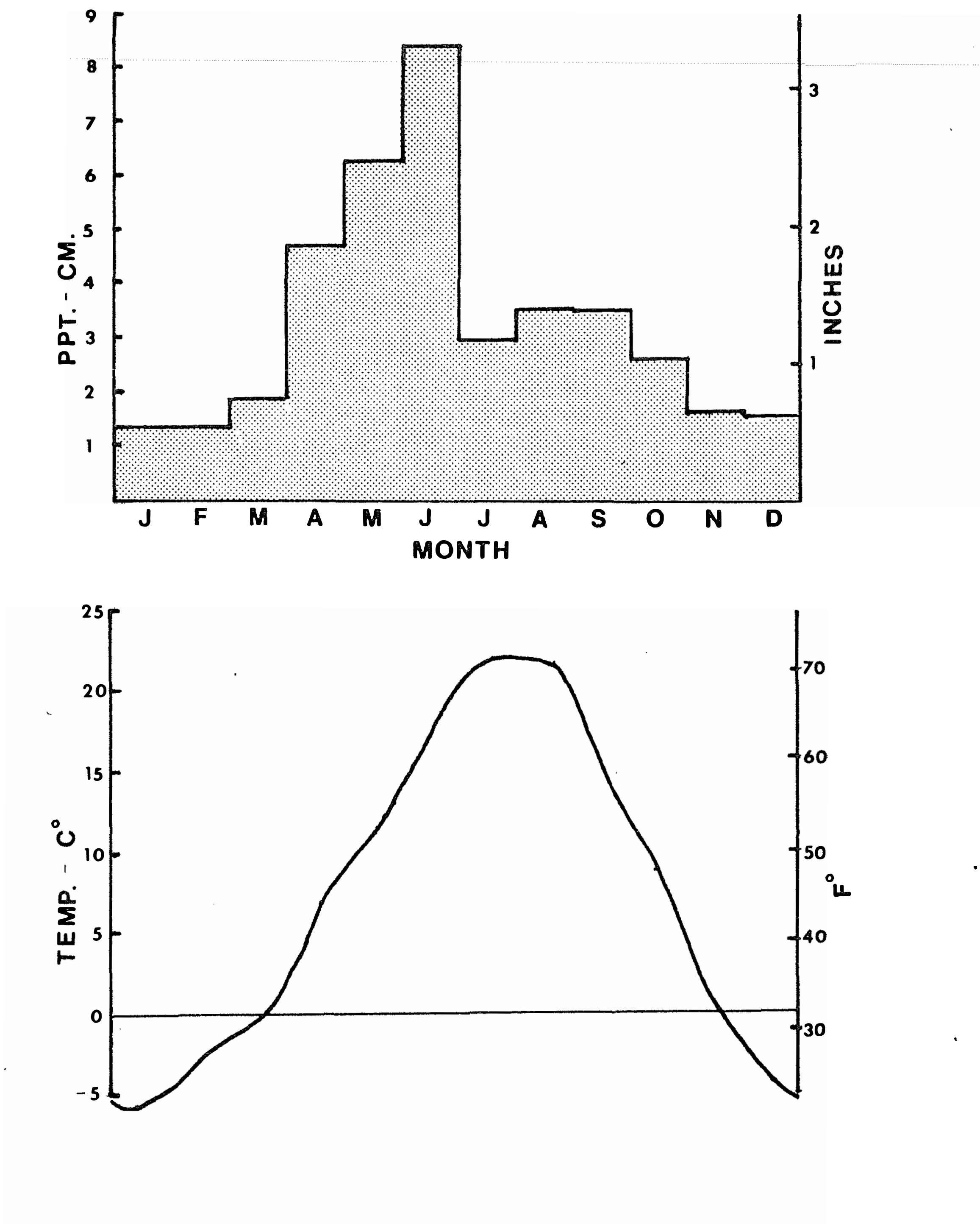


Figure 3. Average monthly precipitation and temperature at Colstrip, Montana (NOAA Climatological Summary for Colstrip, period 1942-1970).

Parent material composition and texture also plays an important role especially in "young" soils. The Tongue River member of the coal-bearing Fort Union formation outcrops throughout the Colstrip area. This member is predominantly sandstone with common lenses of siltstone. Baked sandstone (porcelainite) caps many of the buttes in the area. Prominent shale units lie above the coal seam and come to the surface in some drainages (see Geology Section). As a result, coarse-loamy particle-size is dominant in Colstrip area soils. Fine-loamy soils are found where residuum from sandstone and siltstone are mixed. Fine-silty soils occur on siltstone. Some fine soils (more than 35% clay) occur on shale in alluvial valleys and other topographic lows. Skeletal and fragmental soils are common on top of scoria (porcelainite) buttes.

Relief is another soil-forming factor which plays an important role in determining the properties of soils in the Colstrip area. The relief factor includes the effect of both slope and aspect on soils. Due to the sufficiently steep gradient of streams draining the region, and the weakly consolidated nature of the Fort Union materials, a moderately steep dissected topography has resulted. Slopes range from nearly level in the alluvial valleys to steep (over 25% slope) in the scoria uplands.

At this latitude, differences in aspect can have a strong effect on microclimate which in turn affects soil development through vegetation differences. Soils on north-facing slopes tend to be colder and wetter because less incident energy is available to warm and dry these soils. Organic matter tends to accumulate to higher levels under these conditions. Soils on south-facing slopes are lower in organic matter.

The rate of geologic erosion is high on steep slopes in the uplands. As a result these soils cannot accumulate thick A horizons as the soil surface is slowly deflated. Steep surfaces are not stable long enough for cambic B horizons (horizon of alteration) to form. The resulting soils are classified as Entisols. On the midslopes, erosion is less and surfaces are more stable. Cambic B horizons form and slightly thicker A horizons accumulate. The solum (A and B horizon) is thicker than on steep upper slopes. The dominant soils are Borollic Camborthids. On the lowest part of the slopes, gradients are shallow. Material that may be carried by overland flow from upslope is deposited here due to a loss in energy of the moving water. This material is often high in organic matter if it derived from A horizons of upland soils. Over-thickened mollic epipedons can result (A horizons high in organic matter). Due to the accumulation and retention of surface run-off in these geomorphic positions, more water moves through these profiles. Thus the solum is thickest in these locations. If enough fine clay is present in the deposited material or in the residual parent material, argillic horizons may also form. Aridic Haploborolls and Borollic Haplargids dominate on the lower slopes. In the river channels and flood plains, soils are constantly reworked. Normal pedologic processes are often disturbed as material is deposited or removed by alluvial action. These soils with no B horizon are classified as Fluvents (Figure 4).

Time is the last important soil-forming factor. The Colstrip region is within the unglaciated portion of the Missouri Plateau so there have

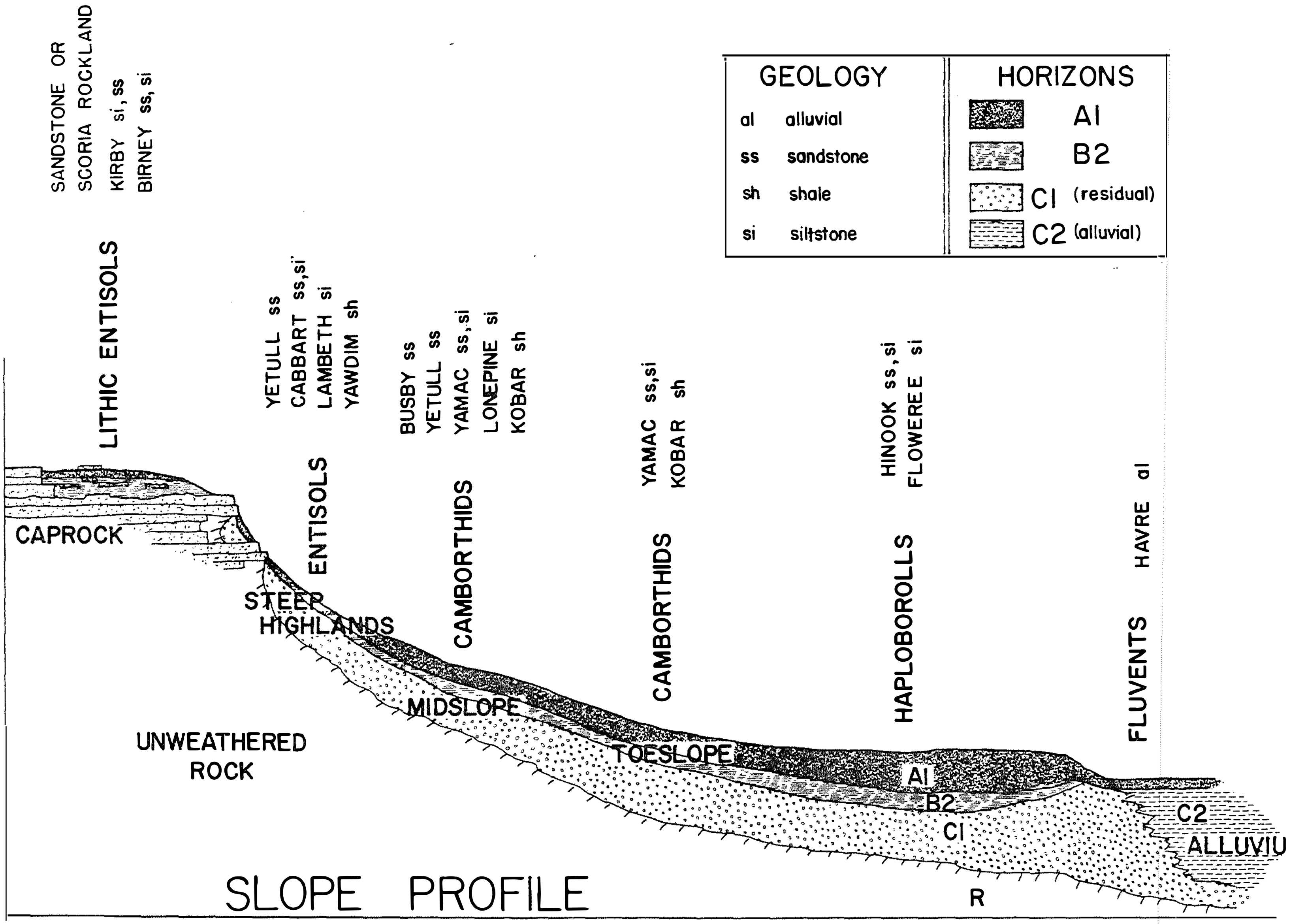


Figure 4. Typical slope profile in the Colstrip, Montana area showing soil distribution.

been no major surface disturbances in the area in geologically recent times. However, the downcutting of the rivers, which is evidenced by the numerous steep-sided coulees in the area, keeps the soil surface rejuvenated. Absolute dating of soils is extremely difficult so soils are termed "young" or "old" according to their profile development. Pronounced horizonation indicates an "old" soil. In the Colstrip area, young soils (Entisols) are common on the least stable upper slopes. All other soils in the area have medium development.

Dominant Soil-Forming Processes

Each soil unit mapped in the Colstrip area is a result of an unique association of soil-forming factors. The combination of the climate, organisms, parent material, and relief unique to the Colstrip area has resulted in several dominant soil-forming processes. These processes acting through time has given rise to the soil landscape seen today.

Some components of soil are mobile in percolating water. These components may differ somewhat in their mobility giving rise to bands or horizons of accumulated material at different depths. In the order of decreasing mobility are soluble salts > carbonates > clay. Mogen et al. (1959) found successive layers of carbonate, gypsum, and soluble salts with increasing depth. Redmond and Omodt (1967) studied three till-derived prairie soils in eastern North Dakota. The dominant soil development processes included organic matter accumulation and associated structure changes, redistribution of carbonates and soluble salts, color changes, and formation of argillic B horizons.

Similar soil development processes occur in the Colstrip area. On steep slopes, less water moves through the soil due to rapid surface run-off. As a result, carbonates and salts will not be leached deeply if at all. Lack of surface stability prevents thick A horizon development, and no cambic B horizons form. Midslope soils with more percolating moisture and more stability have deeper $CaCO_3$ horizons and very deep salt accumulation. More pronounced A horizons develop and color changes and soil structure formation lead to Cambic B horizon development. A lack of fine clay in the parent material prevents argillic horizon development in this position. On the lower slopes $CaCO_3$ horizons are deepest. Salts may be leached completely out of the soil. Since shale often occurs here in the Colstrip area, fine clay may be present in the parent material. This clay can be moved by water through the soil. It accumulates several inches below the surface in an argillic horizon.

Soil Mapping

The Colstrip area soils have been mapped by the Soil Conservation Service in their soil survey of Rosebud County which is not yet finished (Figure 5).

For mapping and management purposes, "soil series" are established which consist of all soils that are similar in arrangement, number, depth, thickness, and kind of horizons, depth to rock, texture, pH, structure, and other properties. Soil series are given a common name by which they can be referred to easily. Occasionally soil series are further divided on the basis of surface texture, slope, stoniness, degree of erosion, or other properties that may be important for management but do not modify the soil series criteria. The soil type is a subdivision of a series based on surface texture while a soil phase is subdivided because of some other property.

The simplest soil-mapping units consist of one soil series, soil type, or soil phase. Due to the variability inherent in soils, 15 percent of the area of a mapping unit is allowed to contain a different soil series. If more than 15 percent of a mappable area consists of a different soil, then the mapping unit is called a soil association. A soil association is a combination of two or more taxonomically dissimilar soil series that occur in a geographic pattern too intricate to map. In a soil association the dominant soil series is listed first.

Legend and Soil Description

The following soil map and mapping legend were produced by the Soil Conservation Service during their survey of Rosebud County, Montana (Table 5, Figure 5).

Table 5. Soil mapping legend for a portion of Western Energy Company mine area B, Colstrip, Montana.

Map Unit	Area (Hectares)	Description
127F	178	Birney-Kirby-Cabbart complex, moist, 25-70% slope
128E	60	Birney-Yawdim-Cabbart complex, 15-25% slope
13C	130	Busby, fine sandy loam, 2-8% slope
13D	207	Busby, fine sandy loam, 8-15% slope
132D	260	Busby-Cabbart complex, 8-15% slope
132E	109	Busby-Cabbart complex, 15-25% slope
183E	260	Cabbart-Busby-rock complex, 15-25% slope
184F	104	Cabbart-Yawdim-rock complex, 25-70% slope
37C	12	Lonepine silt loam, 2-8% slope
37D	67	Lonepine silt loam, 8-15% slope
37E	-	Lonepine silt loam, 15-25% slope
371C	276	Lonepine silty clay loam, 2-8% slope
372E	63	Lonepine-Cabbart-Yawdim complex, 15-25% slope
373D	-	Lonepine-Yamac complex, 8-15% slope
49A	-	Yamac loam, 0-2% slope
49C	311	Yamac loam, 2-8% slope
49D	138	Yamac loam, 8-15% slope
491C	170	Yamac-Havre complex, 2-8% slope
491D	1339	Yamac-Havre complex, 8-15% slope
492D	3	Yamac-Busby complex, 8-15% slope
493C	2	Yamac-Cabbart complex, 2-8% slope
498D	32	Yamac-Yawdim-Cabbart complex, 8-15% slope
498E	43	Yamac-Yawdim-Cabbart complex, 15-25% slope
59A	156	Kobar silty clay loam, 0-2% slope
59C	89	Kobar silty clay loam, 2-8% slope

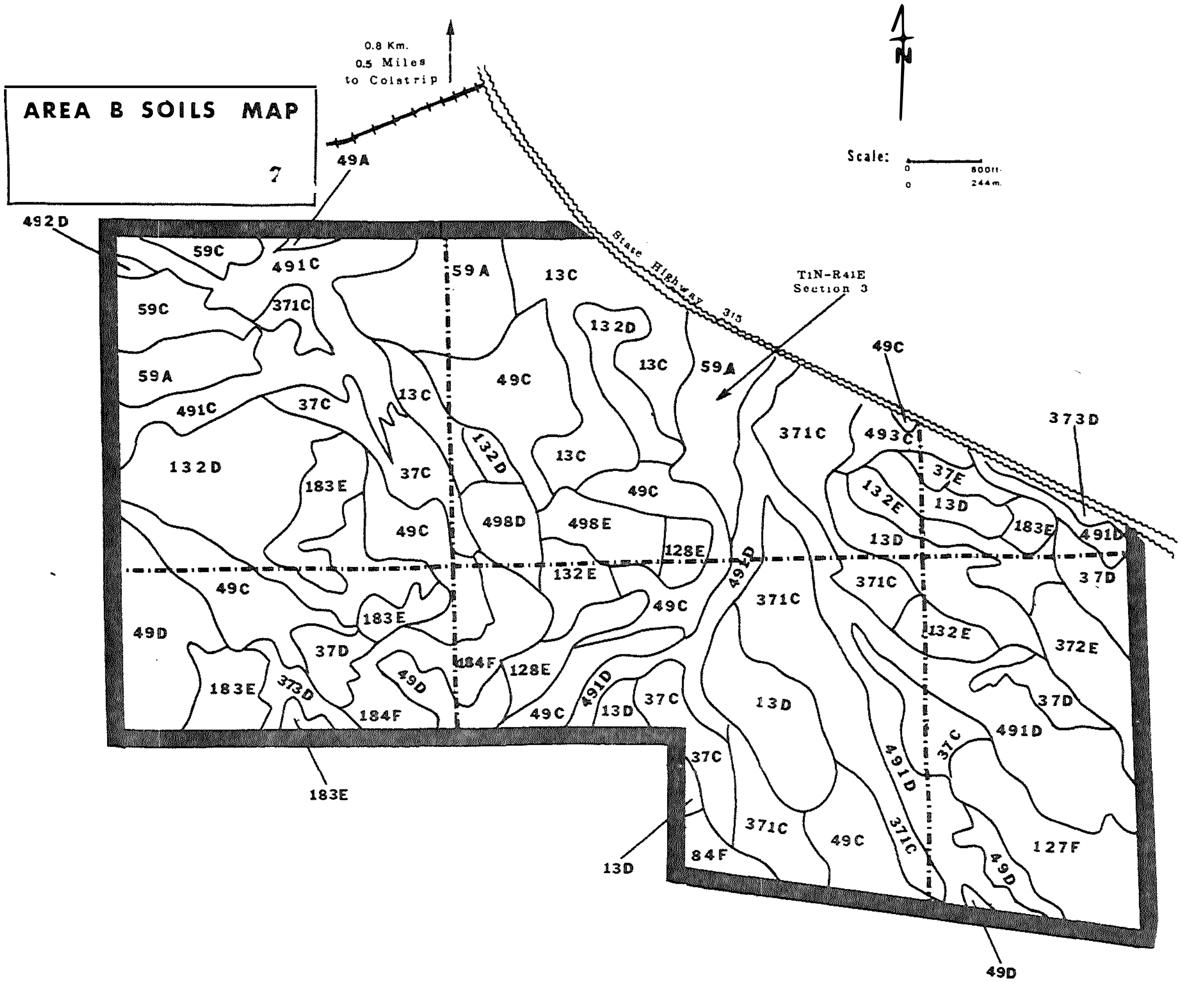


Figure 5. Soils map for a portion of Western Energy Company's mine area B Colstrip, Montana. (from Soil Conservation Service maps).

Classification of soils mapped in Western Energy Company mining area B are listed in Table 6. Complete soil series description of these

Table 6. Classification of soils mapped in Western Energy Company mining Area B, Colstrip, Montana.

Birney	loamy-skeletal, mixed, Borollic Camborthid
Busby	course-loamy, mixed, Borollic Camborthid
Cabbart	loamy-mixed, (calc), frigid, shallow, Ustic Torriorthent
Havre	fine-loamy, mixed, frigid, Ustic Torrifluvent
Kirby	fragmental, mixed, Borollic Camborthid
Kobar	fine montmorillonitic, Borollic Camborthid
Lonepine	fine-silty, mixed Borollic Camborthid
Yamac	fine-loamy, mixed, Borollic Camborthid
Yawdim	clayey, mixed (calc) frigid, shallow, Ustic Torriorthent

soils are available from the Soil Conservation Service. Soil chemical and physical properties of selected soils in mining Area B are presented in Table 8. In summary, we can deduce the following generalities about soils in mining Area B (Table 7).

Table 7. Basic properties which characterize the chemical and physical properties of soils in mining Area B.

pH: All of these soils have moderately alkaline pH at the surface which becomes alkaline below about 75 cm. pH values in this range are common in many agricultural soils throughout Montana and should provide a suitable reaction for plant growth.

EC: Electrical conductivity in all soils at all depths is below the level which could damage salt sensitive species.

SAR: Sodium levels in saturation extracts were less then 1.0 meq/100 gm and SAR values greater than 10 were not encountered. Sodium usually only creates physical problems in soils when SAR exceeds 10.

Texture: Soils contained very few coarse fragments due to the weakly consolidated nature of Fort Union sediments. Textures ranged from sandy loam to clay but soils coarser than clay loam predominate. Available water-holding capacity is low in these soils due to their coarse texture.

Organic matter: Soils slightly exceed 1.0% organic matter in the surface 15 cm, but drop as low as 0.1% below this depth. Organic matter content generally increases as texture becomes heavier.

Macro-nutrients: Levels of nitrate nitrogen were generally less than 20 pounds/acre. Phosphate was less than 30 ppm, and potassium less than 125 ppm. Sulfur is less than 5 ppm in most soils. These values are common in many range soils.

Table 8 Soil Chemical and physical properties[+] of selected soils in mining area B, Colstrip, Montana (from Westinghouse, 1973b)

Soil Series	Map Unit	Depth (cm)	pH	OM %	NO_3-N (ppm)	PO_4-P (ppm)	K (ppm)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	EC mmhos/cm	Lime* (est)	S (ppm)	Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)	0.3 atm (% H_2O)	15 atm (% H_2O)	SAR	Clay %	Silt %	Sand %	Texture
Busby	132D	0-15	8.1	1.4	-	1.0	188	5.3	2.7	0.1	0.3	0	2.1	0.3	28.8	2.9	10.4	6.0	3.4	-	10.8	9.4	80.8	LS
		15-30	7.9	0.4	-	0.8	113	5.8	2.5	0.1	0.3	0	1.4	0.2	25.5	3.2	6.4	4.4	2.2	-	6.8	2.4	90.8	S
		30-58	8.0	0.1	-	0.8	63	35+	2.2	0.1	0.3	M+	2.8	0.4	20.8	2.8	5.2	5.6	2.8	-	8.8	4.4	86.8	LS
		58-111	8.3	0.1	-	1.0	88	28.9	2.2	0.1	0.2	M+	3.4	1.9	10.6	3.0	13.8	4.5	2.2	-	6.8	4.4	88.8	S
Cabbart	184F	0-13	8.0	1.4	0.3	7.7	188	28.9	3.4	0.1	0.4	M	1.4	0	4.6	1.8	10.2	10.3	5.2	-	16.8	42.4	40.8	L
		13-28	8.2	1.2	1.3	14.5	150	28.9	3.2	0.1	0.4	M+	6.1	0	5.8	1.6	5.2	9.1	4.6	-	14.8	46.4	38.8	L
		28-71	8.4	0.1	0.5	33.5	113	24.5	5.9	0.3	0.7	M+	105	0	5.5	1.2	3.6	10.3	5.1	-	16.8	4.4	78.8	SL
Kobar	59A	0-15	8.3	1.0	-	4.3	300	28.9	8.2	0.1	0.3	0	9.1	0.2	9.8	2.4	8.2	20.7	10.4	2.4	34.8	24.4	40.8	CL
		15-25	8.0	0.8	-	2.3	300	9.5	0.3	0.1	0.3	0	138+	0.2	11.5	2.2	3.6	9.1	4.6	0.2	14.8	36.4	48.8	L
		25-50	8.3	0.1	1.3	0.5	150	35+	16.4	0.1	0.4	M+	138+	0	14.4	2.3	2.4	26.3	13.3	0.6	44.8	22.4	32.8	C
		50-71	8.6	0.1	0	2.7	150	30.7	14.3	0.1	0.4	M+	138+	0	12.8	1.8	12.0	14.9	7.5	0.1	24.8	36.4	38.8	CL
		71-122	8.2	0.1	1.3	4.3	188	35+	12.9	0.5	1.1	M+	138+	0.3	14.4	2.6	12.8	27.7	13.8	0.1	46.8	24.4	28.8	C
		122-152	8.0	0.1	0	3.5	188	35+	14.9	1.3	4.3	M+	138+	0.2	18.4	2.5	6.7	8.0	4.0	0.1	12.8	54.4	32.8	SiL
Yamac	49C	0-15	8.0	1.2	9.0	17.5	238	9.1	3.6	0.1	0.4	0	0.7	0	6.3	1.1	10.2	14.9	7.5	-	24.8	34.4	40.8	L
		15-30	8.0	1.0	6.3	7.7	113	27.5	5.3	0.1	0.4	M	0.7	0	5.8	1.8	5.2	11.8	5.9	-	26.8	34.4	38.8	L
		30-91	8.2	0.5	3.0	5.0	113	34.9	6.9	0.1	0.4	M+	8.5	0	4.4	1.4	4.0	10.2	5.1	-	16.8	44.4	38.8	L
		91-152	8.4	0.1	0.3	12.5	63	32.4	8.7	0.1	0.4	M+	0.7	0	3.9	1.4	2.8	9.0	4.5	-	14.8	10.4	74.8	SL

* - Lime estimated by effervesence with 10% HCl (0 = None, M = Moderate)

\+ - pH (1:2 paste)
electrical conductivity (EC) (1:2 paste)
sodium adsorption ratio (SAR)
cation exchange capacity (if SAR exceeds 10)
mechanical analysis (hydrometer)
organic matter (wet combustion)
nitrate nitrogen (phenoldisulfonic acid method)
phosphate-phosphoros (weak Bray method)
Ca, Mg, Na, K (ammonium acetate soluble)
sulfate-sulfur (ammonium acetate soluble)
Zn, Fe, Mn, Cu (DTPA extracted)
B (hot water soluble)

L - LOAM
S - SAND
C - CLAY
CL - CLAYEY LOAM
SL - SANDY LOAM
SiL - SILTY LOAM
LS - LOAMY SAND

REGIONAL GEOLOGY

Physiography

The research area is located southwest of the town of Colstrip, Rosebud County, in southeastern Montana (Figure 6) and is within the unglaciated Missouri Plateau, a division of the Northern Great Plains Province (Fenneman, 1931). East Fork Armells Creek and Rosebud Creek provide drainage for the immediate Colstrip area and flow north to the Yellowstone River. These creeks and rivers together with numerous intermittent streams are part of the upper Missouri Drainage Basin.

The topography is developed on essentially flat laying sediments of the Fort Union Formation. Where surface material is soft clay, uplands consist of rolling barren hills with some badland features. In areas with rocks more resistant to erosion, broad somewhat level areas exist with local buttes topped by resistant clinker (porcelainite) materials. Despite being within the Missouri "plateau", the Colstrip area contains considerable relief. Uplift of the entire region and downcutting of the drainage has resulted in a steeply dissected topography in many areas.

Landforms in the northern Powder River Basin (Figure 7) are classified as open high hills (local relief of 150 to 300 meters and 50-80% of the land area with slopes over 8%) (Keefer, 1974). Elevation in the northern Powder River Basin ranges from 650 meters above sea level near the Yellowstone River to nearly 1500 meters in the Little Wolf Mountains West of Colstrip (Westinghouse, 1973a). The Armells Creek floodplain is at 990 meters above sea level near Colstrip.

History and Structural Framework

The geologic history of the area since Precambrian time includes periods of deposition, deformation and erosion. During the Paleozoic and Mesozoic Eras, a sequence of carbonates, sandstones and shales were deposited throughout Montana and Wyoming reaching a thickness of as much as 11,500 feet near Buffalo, Wyoming (U.S. Dept. of the Interior, 1977). This sequence of sedementary rocks in the Colstrip region is shown in Figure 8.

The region was relatively stable during these periods as evidenced by thick accumulations of limestone, dolomite and evaporite deposits. The presence of these marine deposits indicates that, during most of this time, the area was covered by shallow epicontinental seas. There are, however, intermittent deposits of sandstone within the marine sediments suggesting brief periods of sea level retreat and continental deposition. Permanent withdrawal of marine water from the basin area began after deposition of sediments forming the Bearpaw Shale. Broad regional uplift in central Montana is believed to have been the cause of the final withdrawal of the sea (Gill and Cobban, 1973). The Late Cretaceous Hell Creek Formation overlies the Bearpaw Shale and is the oldest non-marine formation in the region (Figure 9). The continental origin of deposits in the Hell Creek are indicative of various fluvial and lacustrine environments (Lewis and Roberts, 1977).

Tectonic events which occurred during the Late Cretaceous and Tertiary periods shaped the Powder River Basin into its present structure. During

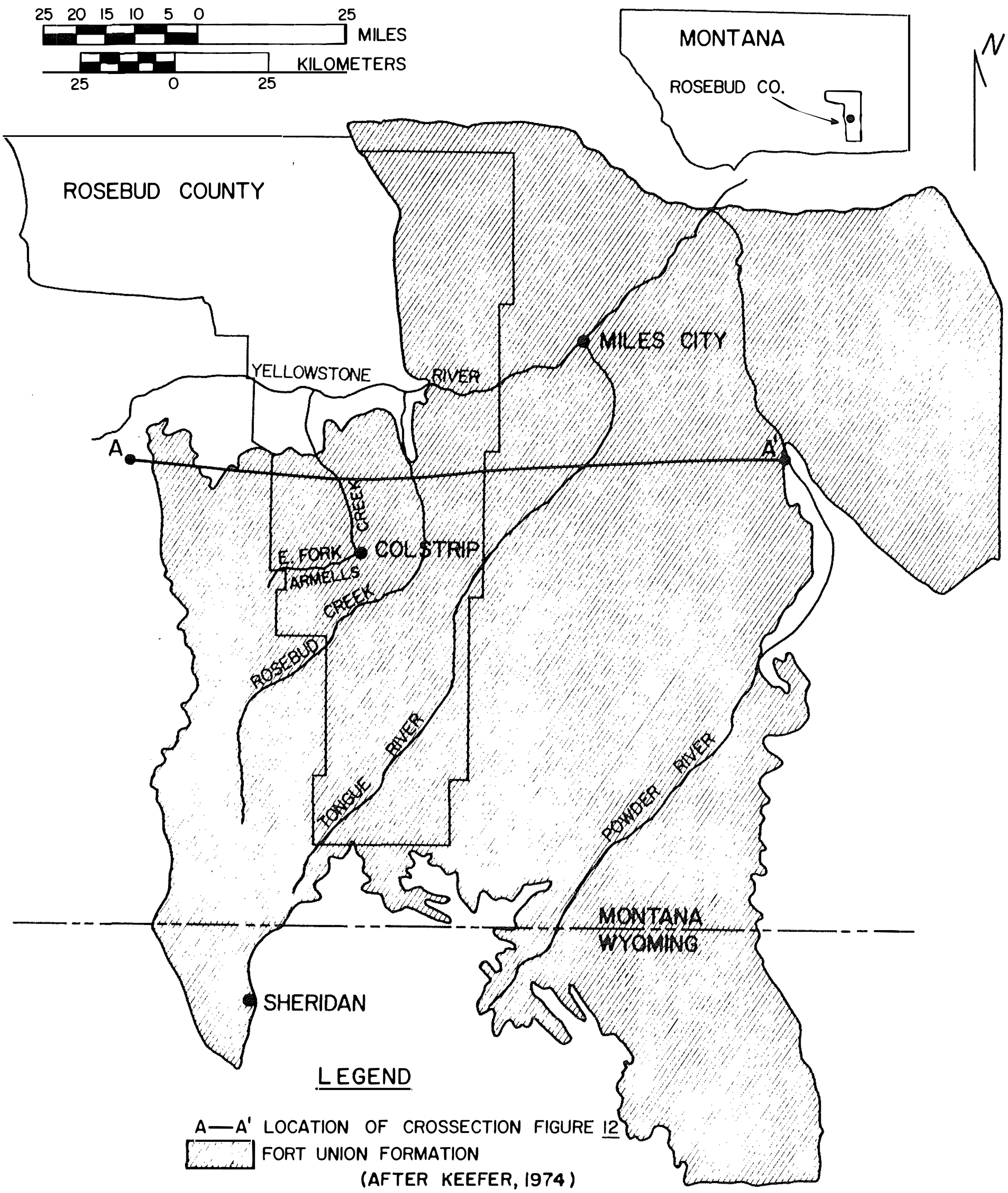


Figure 6. Location map.

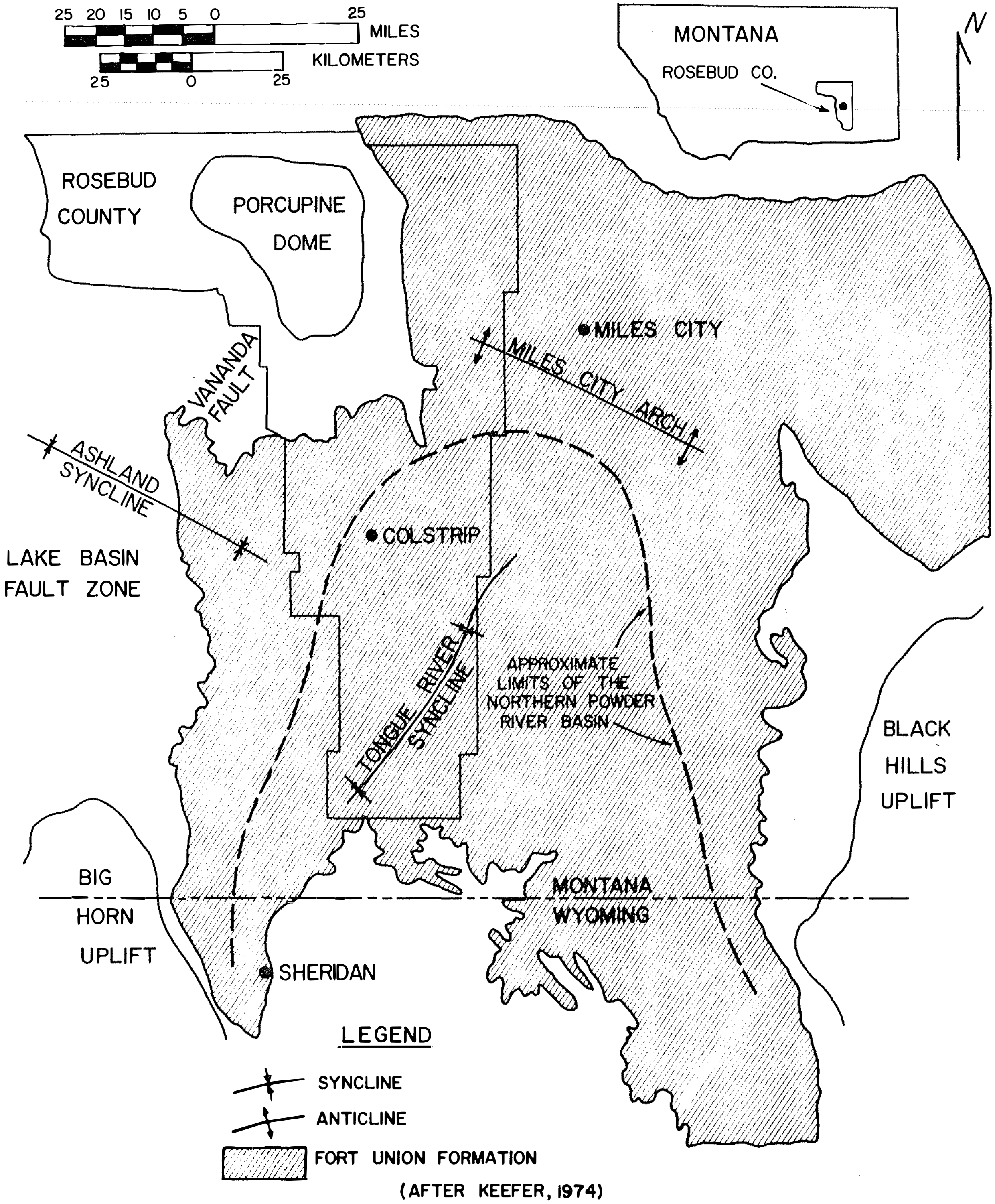


Figure 7. Structural framework of the Northern Powder River Basin area, southeastern Montana (after Keefer, 1974; Lewis and Roberts, 1977).

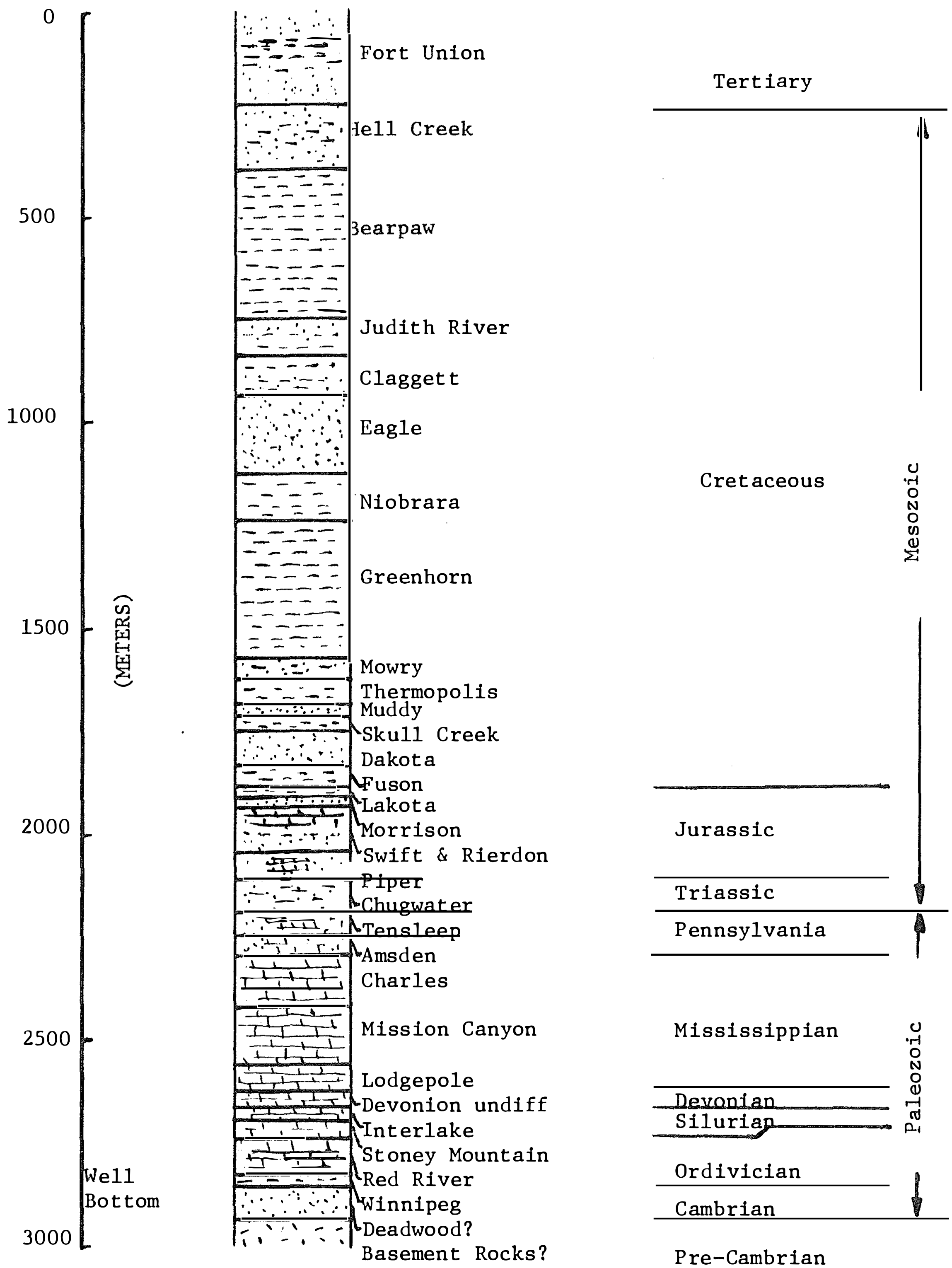


Figure 8. Complete section of sediments underlying Colstrip, Montana. (from water-well drillers log. Montana State Department of Natural Resources and Cons., 1974).

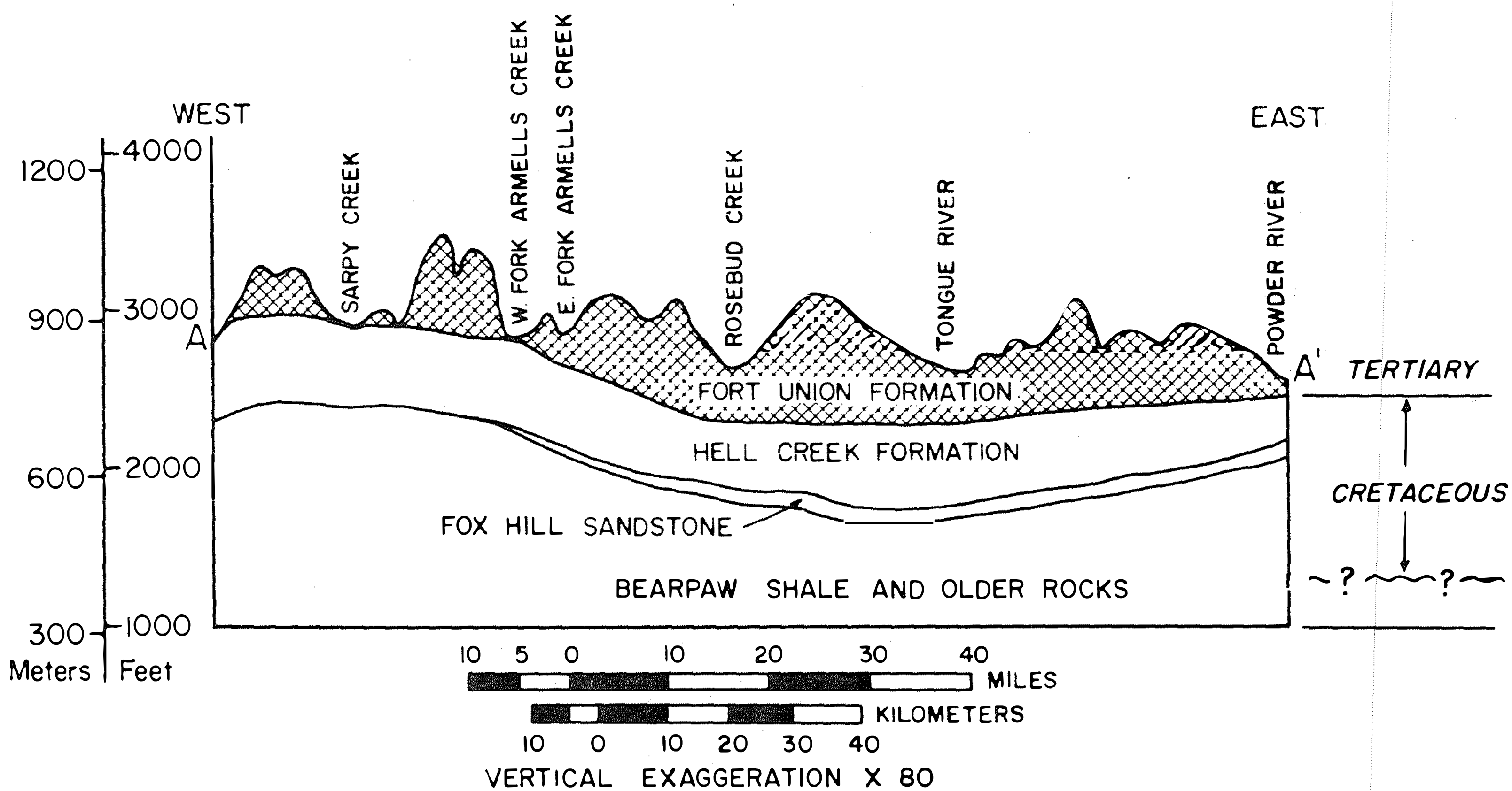


Figure 9. Generalized west-east cross section (A-A^1, Figure 6) showing regional stratigraphy in the northern Powder River Basin in Montana (after Lewis and Roberts, 1977).

Hell Creek deposition, relatively strong subsidence of the basin area was the first indication of the Laramide orogeny. This subsidence was concurrent with uplift of the bordering Big Horn Mountains in Montana and Wyoming and the Black Hills in Wyoming and South Dakota. (Figure 7) Following Hell Creek deposition, large volumes of Fort Union Formation were being transported into the swampy flood plain environments of the newly formed Powder River Basin (Lewis and Roberts, 1977).

The Fort Union Formation is divided into the Tullock, Lebo Shale and Tongue River Members (Figure 10). The Tullock and Lebo Shale Members were deposited along stream courses and in temporary ponds and marshes over an area of low topographic relief (Parker and Andrews, 1939). Intervals of nondeposition and erosion of these members are inferred from lenticularity of the beds, the abrupt truncation of the cross bedding and the channel depressions filled with sandstone that cut across coal and shale beds. Locally, in the northeast part of the basin, lacustrine deposition is indicated by the varied character of the sediments (Lewis and Roberts, 1977). The thickest and most extensive coal deposits are found interbedded with heterogenous, discontinuous mixtures of fine lenticular sand, silty sandstone, siltstone, silty shale, and shale deposited in fluvial and lacustrine environments (Balster, 1971). Part II of this report contains a more detailed discussion of overburden stratigraphy at the research site.

Most of the major structural features in the area were formed or partly formed by completion of Fort Union deposition at the end of the Paleocene. Early Eocene was a time of strong folding and faulting (Glaze and Keller, 1965) which resulted in the formation of most of the present day structural features of southeastern Montana (Figure 7). In late Eocene, uplift renewed in the Black Hills (Robinson and others, 1964) and the Powder River Basin was tilted to the west creating an asymetric structure with the deepest part on the west adjacent to the Big Horn Uplift near the Montana-Wyoming border (Lewis and Roberts, 1977). During Oligocene and Miocene time, the area is thought to have been buried by tuffaceous debris from increased volcanic activity to the west (Glaze and Keller, 1965).

Near the end of Pliocene time, a major regional uplift took place (Glaze and Keller, 1965), with many of the structures near the basin, such as the Miles City Arch, becoming more prominent. Extensive normal faulting occurred, altering structures to their present form. Examples of this faulting are the Vananda fault and the Lake Basin Fault Zone (Figure 7) (Lewis and Roberts, 1977).

Subsurface structure northwest of the basin is dominated by the gently southeast-plunging Ashland syncline (Figure 7). This feature probably developed as a trough between the Bighorn uplift to the south and the Porcupine dome to the north during their formation. Subsequent subsidence within the Powder River Basin accompanying continued uplift of the Bighorn Mountains caused the syncline to plunge into the basin (Lewis and Roberts, 1977).

The major regional uplift near the end of Pliocene time caused streams to be rejevenated and erode through the ash cover, uncovering buried mountains and re-excavating basins. Erosion continued until Pleistocene time and formed most of the present landscape (Glaze and Keller, 1965).

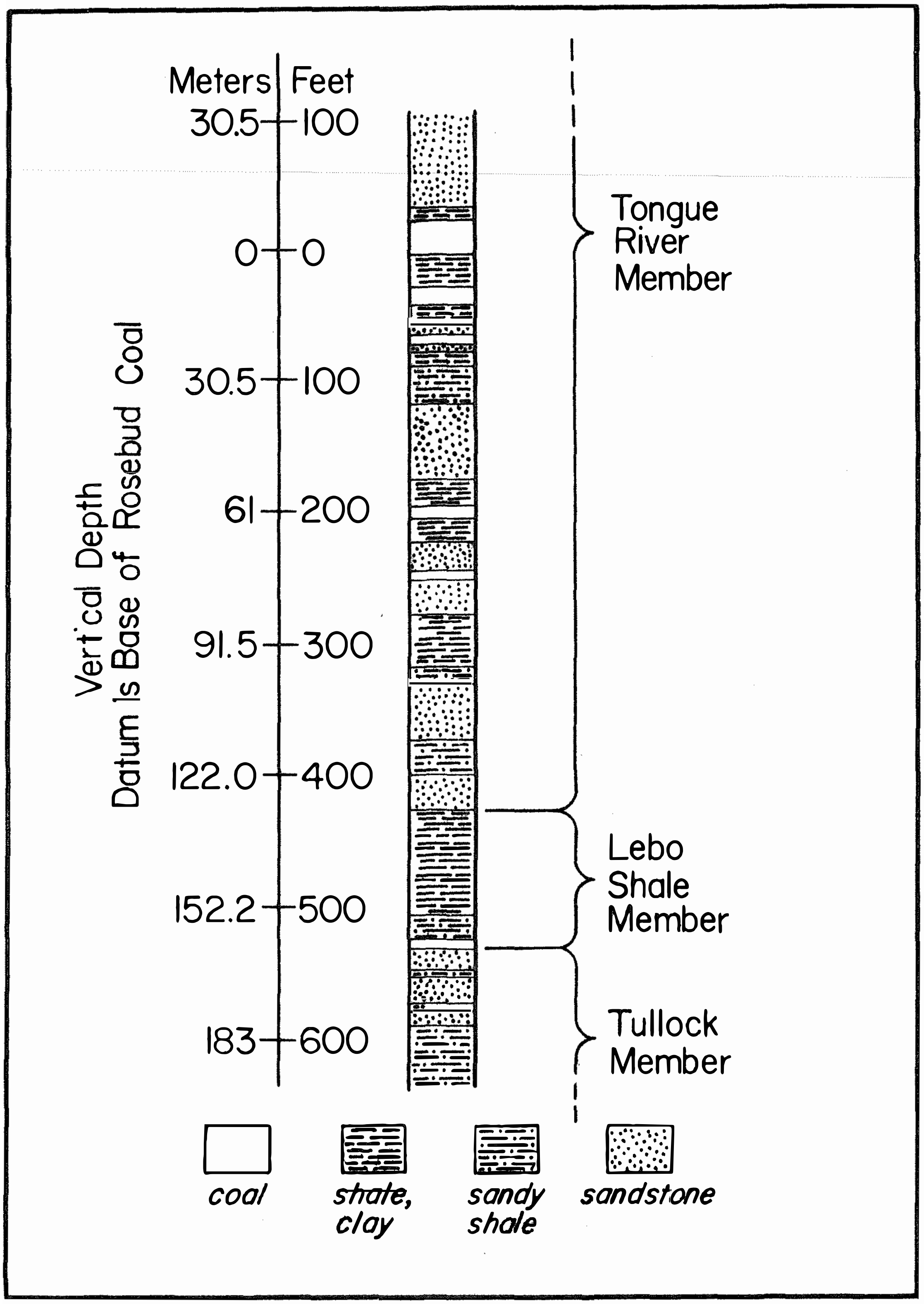


Figure 10. Generalized stratigraphic column of part of the Fort Union Formation near Colstrip, southeastern Montana (after Van Voast and Hedges, 1976).

Geologic units probably have been folded locally since the inception of the basin. However, local deformation generally associated with the burning of a coal deposit and subsequent baking of the overlying units is of a more recent age. Subsidence and slumping generally followed this process, which account for many small structural features in the area, particularly in the Tongue River Member of the Fort Union Formation (Lewis and Roberts, 1977).

HYDROLOGY

Water Use

Local agricultural operations depend heavily on surface and ground water for domestic and livestock uses. Small surface water impoundments and wells provide stockwater for area ranchers. Until recently, the city of Colstrip obtained its water supply from four wells. City water is now pumped from the Yellowstone River along with water for the electric power generating plants, Colstrip I and II. Armells Creek which becomes a series of ponds in late summer is also used for stock water.

Since Colstrip lies in a semiarid region, water availability may be a limiting factor in agricultural production and thus deserves considerable attention. The Rosebud coal seam which is mined near Colstrip is a major aquifer in parts of the area. Therefore, mining has a potentially large effect on the region through disruptance of the Rosebud aquifer. Previous research on the hydrology of the Colstrip region include Renick (1929), Hodder et al. (1970), Hodder and Sindelar (1972), Westinghouse (1973a), (1973b) Montana Department of Natural Resources and Conservation (1974), and Van Voast and Hedges (1974) and (1976).

Surface-Water Hydrology

Only one perennial stream, Rosebud Creek, occurs within 10 miles of Colstrip (Van Voast and Hedges, 1974). Armells Creek and its tributaries and tributaries of Rosebud Creek are ephemeral, flowing in spring and in early summer. Occasional discharges also occur during exceptionally high intensity thunderstorms.

Low rainfall accounts for the ephemeral nature of drainages around Colstrip (see Figure 3). Runoff in the Rosebud Creek drainage which is adjacent to the Armells Creek watershed averages only 0.65 cm per year, but has ranged from 0 to 16.3 cm in six years of record. Runoff from upland areas of these watersheds will be up to 12.7 cm in an average year (Montana Department of Natural Resources and Conservation, 1974).

Stripmining in the area may affect surface hydrology through disturbance of the vegetation, alteration of existing drainages, and reshaping of slopes. Montana law requires that no water impoundments exist within mine areas, thus surface runoff from mines will enter the existing drainage system but only after passing through settling basins located off mined land. The effects of mining on surface hydrology is an area that needs further study.

Surface-Water Quality

Armells Creek has a calcium-magnesium-sulfate type water in its upper reaches near Colstrip. The creek grades into a sodium-sulfate water in its lower reaches where it flows through the Lebo shale member of the Fort Union Formation. The water is hard and has high specific conductance indicating large amounts of dissolved solids. Iron and manganese exceed U.S. Public Health drinking-water standards. Specific conductance ranges from 5,000 micromhos/cm in Armells Creek headwaters to 1,000 micromhos/cm at its mouth. These values increase during low flow. Turbidity and suspended solids generally increase downstream (Montana Department of Natural Resources and Conservation, 1974; Tables 9 and 10).

Water analyzed from ponds in strip mine spoils (Hodder et al., 1970; and Hodder and Sindelar, 1972, Tables 9 and 10) indicates that these waters are more mineralized than Armells Creek. Calcium, magnesium, and sulfate are the dominant ions. Hydrogen ion concentration (pH) is slightly higher in spoil-impounded water, specific conductance is 50 percent higher, magnesium concentrations are two to three times higher, and calcium is 20 to 50 percent higher than in Armells Creek. Sulfate concentrations are nearly the same and sodium concentrations are 50 percent less in spoil ponds than in Armells Creek. Waters in spoils are generally more mineralized during the warm wet months (April-July) than other times in the year. pH in summer and fall (8.7) is higher than in early spring (8.4) (Westinghouse, 1973b).

Other data and discussion of surface water quality can be obtained in Hodder et al. (1970); Hodder and Sindelar (1972); Van Voast (1974) and (1976), Montana Department of Natural Resources and Conservation (1974), Renick (1929), and Westinghouse (1973a and 1973b).

Ground-Water Hydrology

Clinker, coal, and sandstone units in the Fort Union Formation and recent alluvium along Armells Creek comprise the principal aquifers in the Colstrip region. These aquifers provide a large segment of the water used consumptively in the area due to the lack of permanent surface water supplies.

Shallow wells in recent alluvium produce clearly the best quality water in the area, however, the areal extent of this aquifer is limited to thin bands along the Armells Creek drainage (Renick, 1929). A thick sandstone unit 12.2 to 30.5 meters thick occurs locally above the Rosebud coal. Where this sand is extensive and lies below the water table, it can be an important local aquifer. However, the water is generally hard (Renick, 1929).

The Rosebud coal seam is one of the most important regional aquifers. It has a relatively high permeability at some locations due to the fractured nature of the coal and it is a continuous unit over large areas. The Rosebud ranges from 6.1 to 8.8 meters in thickness and thus can hold a large volume of water. Along most of the northern and northeastern outcrop of the Rosebud bed, clinker (porcelainite) has formed from the burning of the coal. The clinker is highly permeable. The coal is usually overlain by a clay layer from 15 cm to 2 meters thick and underlain by a prominent underclay which separates it from the McKay coal. The McKay coal seam also serves as an aquifer near Colstrip but because it is deeper, thinner, and less continuous, it is not as extensively used. McKay water is more highly mineralized than that from the Rosebud aquifer (Westinghouse, 1973b).

Table 9. Some chemical, physical, and biological analyses of water samples near Colstrip, Montana.

SAMPLE SITE	LOCATION	DATE	FLOW (cfs)	TEMPERATURE C°	pH	SPEC. COND. µmhos/cm-25°	DISS. O_2 (mg/L.)	FECAL COLIFORM (counts/100ml)	B.O.D. (mg/l)	TOT. HARDNESS (mg/l)	HCO_3 (mg/l)	CO_3 (mg/l)	ALKALINITY (mg/l)	SAR	TURBIDITY (JTV)	SUSP. SOLIDS (mg/l)	DISS. SOLIDS (mg/l)	REFERENCE
E. Fork Armells Cr.	T1N,R41E,S.3	10/24/73	0.2	–	8.2	3850	–	–	–	2200	644	0	528	2.5	1	–	3679	1
at Colstrip		1/25/74	0.1	2.0	7.2	2826	1.9	0	1.9	1555	602	0	494	1.8	39	39.0	2584	1
		4/16/74	0.2	11.8	7.8	3055	10.7	0	2.4	1728	599	0	491	1.8	4	7.2	2845	1
E. Fork Armells Cr.	T3N,R41E,S.28	3/14/74	0.9	4.1	8.0	5043	12.5	1	5.0	2520	592	0	485	4.6	11	26.0	4885	1
N. of Colstrip		4/16/74	2.0	15.0	8.1	4848	11.9	36	2.8	2480	558	0	458	4.3	8	18.0	4686	1
E. Fork Armell Cr.	T4N,R40E,S.22	1/25/74	2.8	2.2	8.0	2096	10.5	0	4.0	682	285	0	234	3.8	2	3.8	1639	1
at Hwy. 315		4/16/74	2.2	24.0	8.3	4460	8.0	0	1.7	1412	506	0	419	7.7	20	28.0	4002	1
Upper W.Fk.ArmellsCr	T3N,R39E,S.26	4/14/74	1.6	15.0	8.2	5440	9.5	6	1.5	1720	640	0	533	9.3	17	16.8	5026	1
W. Fork near Hwy.	T4N,R40E,S.16	1/25/74	3.1	2.0	7.9	3272	11.0	0	4.4	962	412	0	338	6.6	2	10.5	2769	1
315		4/15/74	2.8	11.6	8.2	4190	11.3	190	4.0	1116	522	0	436	8.8	18	28.0	3604	1
W. Fk. at Hwy. 315	T5N,R39E,S.36	1/25/74	4.5	0	8.0	2280	11.7	0	6.0	540	318	0	261	6.0	15	37.3	1734	1
		4/16/74	4.2	13.5	8.2	3210	11.3	32	3.6	710	413	0	339	8.8	16	38.0	2634	1
Armells Cr. W. of	T6N,R39E,S.23	12/14/73	1.9	3.1	8.3	3880	13.3	2	2.1	–	–		–	–	8	24.8	–	1
Forsyth		1/22/74	9.2	0	7.8	1006	11.6	1120	11.0	178	194	0	159	4.5	72	180	701	1
		3/1/74	2.3	4.7	8.2	2914	11.8	260	4.7	447	512	0	420	10.8	33	64.0	2301	1
		4/16/74	4.2	14.0	8.2	2628	11.0	212	3.5	504	380	0	312	8.5	43	93.0	2095	1
		4/17/74	4.2	13.5	8.3	3304	10.9	50	3.6	656	463	6.0	389	10.3	26	64.0	2796	1
		6/20/74	18.3	27.2	8.2	650	8.4	–	–	152	134	0	110	–	270	380	–	1
Spring in spoils	SW end pit 1	1970				2500								10.1				2
Pond (at 2.4m)	Mine pit 1	1970				6000								2.4				2
Pond (surface)	Mine pit 2	1970				4300								0.8				2
Pond (var. depth)	Mine pit 3	1970				4000								0.4				2
Coal seepage	Mine pit 6	1970				5000								1.0				2
Pit bottom seepage	Mine pit 6	1970				4000								0.3				2
Pond (surface)	Mine pit 1	6/15/71		24.7	8.7	4800												3
Pond (surface)	Mine pit 1	8/15/71		27.8	9.3	5225												3
Pond (surface)	Mine pit 1	10/23/71		8.1	9.1	4925												3
Pond	Mine pit 1	6/15/71		22.2	8.7	4850												3
Pond	Mine pit 1	8/15/71		23.6	9.0	5175												3
Pond	Mine pit 1	10/23/71		8.3	8.9	4825												3
Pond	Mine pit 1	6/15/71		18.8	8.5	5025												3
Pond	Mine pit 1	8/15/71		21.3	8.7	5150												3
Pond	Mine pit 1	10/23/71		8.1	8.7	4875												3
Pond (surface)	Mine pit 2	6/15/71		24.1	8.4	2967												3
Pond (surface)	Mine pit 2	8/15/71		25.4	8.8	4067												3
Pond (surface)	Mine pit 2	10/23/71		7.9	8.7	4000												3
Pond	Mine pit 2	6/15/71		21.3	8.3	4133												3
Pond	Mine pit 2	8/15/71		22.4	8.4	4000												3
Pond	Mine pit 2	10/23/71		6.8	8.8	4050												3
Pond	Mine pit 2	6/15/71		14.4	8.3	5200												3
Pond	Mine pit 2	8/15/71		19.4	8.1	5333												3
Pond	Mine pit 2	10/23/71		7.9	8.5	4300												3
Pond (surface)	Mine pit 3	6/15/71		21.8	8.3	3733												3
Pond (surface)	Mine pit 3	8/15/71		23.3	8.5	4200												3
Pond (surface)	Mine pit 3	10/23/71		8.7	8.2	3867												3
Pond	Mine pit 3	6/15/71		21.3	8.4	3667												3
Pond	Mine pit 3	8/15/71		22.6	8.4	4133												3
Pond	Mine pit 3	10/23/71		7.9	8.7	3800												3
Pond	Mine pit 3	6/15/71		19.8	8.3	4067												3
Pond	Mine pit 3	8/15/71		22.2	8.2	4267												3
Pond	Mine pit 3	10/23/71		7.6	8.7	3833												3

1. Mont. Dept. of Nat. Res. and Cons., 1974
2. Hodder et al., 1970
3. Hodder and Sindelar, 1971

Table 10. Some elemental chemical analyses of water samples near Colstrip, Montana.

SAMPLE SITE	LOCATION	DATE	Ca (mg/1)	Mg (mg/1)	Na (mg/1)	SO_4 (mg/1)	Cl (mg/1)	F (mg/1)	NO_3 (mg/1)	PO_4 (mg/1)	Fe (mg/1)	Mn (mg/1)	Zn (mg/1)	Cu (mg/1)	Cd (mg/1)	Pb (mg/1)	Hg (mg/1)	Cr (mg/1)	REFERENCE
E. Fork Armells	T1N,R41E,	10/24/73	285	362	272	2078	38	0.3	0.5	0.9	0.4	-	.04	<.01	<.01	<.01	-	-	1
Cr. at Colstrip	S.3	1/25/74	261	220	160	1328	12.8	-	0.8	0.3	2.7	3.0	.06	.01	<.01	-	<.001	-	1
		4/16/74	228	281	173	1563	0.2	0.3	0	0	0.4	1.5	.03	.01	<.001	-	<.001	-	1
E. Fork Armells	T3N,R41E,	3/14/74	207	487	525	3048	26	0.3	0.2	0.1	0.8	0.3	.02	.01	<.01	<.01	<.001	-	1
Cr. N. of	S.28	4/16/74	248	452	488	2904	35	0.2	0	0	0.4	0.2	.01	.01	<.001	-	<.001	.02	
Colstrip																			
E. Fork Armells	T4N,R40E,	1/25/74	124	91	228	891	20	-	0.8	0.1	0.1	0	.01	.03	<.01	-	<.001	-	1
Cr. at Hwy. 315	S.22	4/16/74	216	212	669	3286	9.0	0.3	0.2	0	0.3	0.2	.01	.03	<.001	-	<.001	-	1
Upper W. Fk.	T3N,R39E,	4/14/74	192	301	888	2999	0.2	.27	0	<.03	.25	.07	.01	.01	<.001	-	<.001	-	1
Armells Cr.	S.26																		
W. Fork near	T4N,R40E	1/25/74	167	132	468	1570	17.8	-	1.6	.17	.39	.26	<.01	.02	<.01	-	<.001	-	1
Hwy. 315	S.16	4/15/74	176	164	675	2049	12.0	.44	0	<.03	.65	.15	.01	.01	<.001	-	<.001	.04	1
W. Fork at	T5N,R39E,	1/25/74	104	68	323	908	13.3	-	0.7	.11	.61	.20	.01	.01	<.01	-	.004	-	1
Hwy. 315	S.36	4/16/74	124	97	538	1444	17.0	.27	0.1	.03	.35	.33	.02	.01	<.001	-	<.001	.05	1
Armells Cr. W.	T6N,R39E,	12/14/73	-	-	-	-	-	-	-	-	.16	-	.02	.01	<.01	<.01	-	-	1
of Forsyth	S.23	1/22/74	62	58	138	292	8.2	-	1.4	.23	3.4	.15	.01	.02	<.01	-	.01	-	1
		3/1/74	63	70	525	1118	12.0	-	0.3	.49	1.8	-	.02	<.01	<.01	<.01	<.001	.01	1
		4/16/74	92	67	441	1100	14.0	-	0.3	.06	1.8	.21	.02	<.01	<.001	-	<.001	.05	1
		4/17/74	99	99	606	1500	23	-	-	-	-	-	-	-	-	-	-	-	1
		6/20/74	39	13	82	204	5.5	-	0.6	.17	9.2	.32	.03	<.01	<.001	-	<.001	.01	1
Spring in spoils	SW end																		
	pit 1	1970	226	198	858	804					0.3								2
Pond (at 2.4m)	Mine pit 1	1970	125	7	322	4262					3.7								2
Pond (surface)	Mine pit 2	1970	226	605	98	2426					6.3								2
Pond (var.depth)	Mine pit 3	1970	428	183	43	2884					3.7								2
Coal seepage	Mine pit 6	1970	192	239	63	3317					4.3								2
Pit bottom																			
seepage	Mine pit 6	1970	555	253	35	2587					14.7								2
Pond (surface)	Mine pit 1	6/15/71	124	633	240	803													3
Pond (surface)	Mine pit 1	8/15/71	124	780	316	1033													3
Pond (surface)	Mine pit 1	10/23/71	130	716	302	1070													3
Pond (1.5-3m)	Mine pit 1	6/15/71	131	640	247	841													3
Pond (1.5-3m)	Mine pit 1	8/15/71	110	789	317	912													3
Pond (1.5-3m)	Mine pit 1	10/23/71	128	728	298	1048													3
Pond (3-5m)	Mine pit 1	6/15/71	151	670	261	906													3
Pond (3-5m)	Mine pit 1	8/15/71	128	788	312	978													3
Pond (3-5m)	Mine pit 1	10/23/71	137	740	302	1086													3
Pond (surface)	Mine pit 2	6/15/71	190	347	47	413													3
Pond (surface)	Mine pit 2	8/15/71	288	560	92	663													3
Pond (surface)	Mine pit 2	10/23/71	320	581	92	857													3
Pond (1.5-3m)	Mine pit 2	6/15/71	294	519	82	713													3
Pond (1.5-3m)	Mine pit 2	8/15/71	284	561	92	697													3
Pond (1.5-3m)	Mine pit 2	10/23/71	311	596	98	919													3
Pond (3-5m)	Mine pit 2	6/15/71	365	742	98	1051													3
Pond (3-5m)	Mine pit 2	8/15/71	372	809	138	1014													3
Pond (3-5m)	Mine pit 2	10/23/71	342	627	104	930													3
Pond (surface)	Mine pit 3	6/15/71	239	426	85	668													3
Pond (surface)	Mine pit 3	8/15/71	309	555	131	683													3
Pond (surface)	Mine pit 3	10/23/71	306	517	124	858													3
Pond (1.5-3m)	Mine pit 3	6/15/71	246	422	87	688													3
Pond (1.5-3m)	Mine pit 3	8/15/71	300	463	129	703													3
Pond (1.5-3m)	Mine pit 3	10/23/71	312	480	131	1221													3
Pond (3-5m)	Mine pit 3	6/15/71	283	488	99	788													3
Pond (3-5m)	Mine pit 3	8/15/71	327	488	124	740													3
Pond (3-5m)	Mine pit 3	10/23/71	303	533	129	822													3

1. Mont. Dept. of Nat. Res. and Cons., 1974
2. Hodder et al., 1970
3. Hodder and Sindelar, 1971

When these aquifers are absent, one of the many sandstone units below the McKay coal and above the Lebo shale are used for well-water. The city of Colstrip obtained its water from these aquifers until recently when Yellowstone River Water was piped in for Colstrip power units I and II.

Deep aquifers also exist in the area. They have been penetrated by oil and gas drilling operations and construction of an exploratory deep well at Colstrip. The Mississippian carbonates are the primary deep aquifers. They are most likely recharged in the Big Horn Mountains and Black Hills. A well within this aquifer at Colstrip was tested for water production. After a long freeflow period, the Colstrip well produced 908 liters/minute (240 gallons per minute) (gpm) with no pumping. The water temperature was 97.2°C. Static pressure in the confined aquifer was 14,000 kg/m^2 (200 lbs/in^2) (Montana Department of Natural Resources and Conservation, 1974). Little is known about the performance of this aquifer when producing.

Ground-water flow in shallow aquifers is controlled by water courses, geologic structure, area of the aquifer, nature of the recharge area, and permeability of surrounding hydrogeologic units. East Fork Amells Creek intercepts the Rosebud coal aquifer and diverts the ground water into surface flow. Where the Rosebud outcrops, water production is enough to be useable at only a few locations. Most shallow aquifers in the area are bounded by relatively impermeable aquicludes so that movement of water out of the aquifer is limited. However, hydrostatic level of aquifers decreases with depth indicating that there is a downward component of ground-water flow (Westinghouse, 1973b).

Depth to water in several drill holes penetrating the Rosebud or Rosebud and McKay seams was measured in March, 1976 (Table 11). The holes were drilled as part of an extensive overburden chemistry investigation program. Since specific water-bearing zones were not isolated or sealed off in the holes, the depth to water measurements when contoured may not be truly representative of ground-water movement patterns within a particular aquifer. Water level on piezometric surface maps based on these data were not, therefore, included in this report. The impact of the exploratory borings on the ground-water regime in the site area is currently under study.

Yields of wells around Colstrip average 37.8 liters per minute (10 gpm) in shallow aquifers. Deeper wells in the Tongue River member have produced as much as 189 liters per minute (50 gpm) (Van Voast and Hedges, 1974). From the limited data available, a maximum transmissivity for the Rosebud aquifer of 12.4 m^2/day (134 ft^2/day) has been calculated (Westinghouse, 1973b). Test hole injections in Pit 1 mine spoils showed transmissivity ranging from 2.3 m^2/day (25 ft^2/day) to 4.1 m^2/day (44 ft^2/day).

Ground-Water Quality

Water from the Rosebud coal seam (Table 12) is dominated by calcium and bicarbonate and is the least mineralized in the Colstrip area. pH is slightly alkaline. Water from the McKay coal seam is characteristically

Table 11. Depth to water measurements in drill holes located near Colstrip, Montana in mine area B (sites denoted as cased were drilled and cased to the bottom of the Rosebud coal seam. All other sites were drilled through both the Rosebud and McKay coal seams March, 1976, M.A.E.S.).

Location	Depth to Bottom	Collar Elev(m)	Depth to Water (m) Mar 2	Mar 9	Mar 10	Mar 19	Mar 24	Apr 27	Jn 1	Jn 28	Aug 9
1 N48E55	11.0 cased	995	4.7					4.5	4.3	4.3	-
2 N47E56	40.5	1009	13.0								
3 N46E56	44.8	1014	19.1								
4 N46E57	36.6	1007	12.0								
5 N45E58	38.7	1012	16.8								
6 N46E58	39.6	1010	15.8								
7 N46E59	53.3	1021	18.0								
8 N44E57	39.6	1014	18.3								
9 N44E56	47.2	1021	23.5	23.8							
10 N43E56	56.4	1028	21.0	21.1							
11 N44E55	61.0	1033	37.0	37.0							
12 N43E55	68.6	1038	35.1	34.4							
13 N44E54	79.2	1045	38.3								
14 N45E56	51.2	1022	27.1	27.1							
15 N46E55	28.2 cased	1013	17.5	17.5				17.6	17.5	17.5	17.6
16 N44E53	56.4	1026	24.5	24.5							
17 N44E52	54.9	1023	19.7		19.4						
18 N45E52	38.9 cased	1010	12.2		12.1			12.2	12.2	12.1	12.1
19 N45E53	73.2	-	39.3		39.2						
20 N45E54	50.3	1019	21.7		21.6						
21 N46E54	38.1	1009	13.6		13.6						
22 N46E53	48.9	1016	18.5		18.6						
23 N46E52	41.1	1006	10.0		9.9						
24 N47E53	18.3	997	3.6		3.5						
25 N47E54	30.5	1005	11.8		11.7						
26 N45E59	48.8	1019	24.8				24.8				
27 N43E58	34.3	1031				32.6	33.5				
28 N44E58	34.3 cased	1018				22.3	23.2	22.4	22.3	22.4	22.3
29 N43E57		1025				29.0	29.4				
30 N43E59	48.8	1023				28.3	28.3				
31 N42E58	67.1	3401				41.6	40.0				
32 N42E59	62.5	1034				35.5	35.5				
33 N44E59	44.2	1016				24.1	24.3				

Table 12. Chemical analyses of some groundwater samples near Colstrip, Montana (from Westinghouse, 1973).

WATER SOURCE	DATE	TEMPERATURE C°	SPEC. COND µmhos/cm	pH	DISS. SOLIDS mg/l	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	NO_3	Fe	SiO_2	PO_4
						mg/l											
Rosebud drainage, Pit 6	3/24/73	19	624	8.2	535	45	47	20	3	244	0	104	3	47	0.1	21	.13
Rosebud well	3/18/73	9	869	7.5	802	72	74	26	3	451	0	147	6	4	0.1	19	.08
SS 350' below Rosebud	3/19/73	13	2610	8.0	2032	14	3	603	4	413	0	978	8	0.1	0.6	7	.09
SS 200' below Rosebud	3/20/73	10	3460	7.4	3155	103	153	550	10	547	0	1704	13	0.2	1.3	13	<.05
Rosebud	7/31/23	-	-	-	334	13	17	20	-	63	0	56	6	24	6.9	38	-
Rosebud	7/22/23	-	-	-	366	54	45	16	-	320	19	49	3	Tr.	Tr.	14	-
SS 250' below Rosebud	7/15/23	-	-	-	1884	104	92	346	-	390	0	1003	9	2.2	1.2	13	-
SS 300' below Rosebud	7/15/23	-	-	-	1160	14	9	380	-	371	0	531	8	1.9	Tr.	10	-
Recent alluvium	7/15/23	-	-	-	2428	194	172	296	-	547	0	1300	20	1	8	18	-
Recent alluvium	7/20/23	-	-	-	1304	90	122	143	-	593	0	537	6	2	0.8	18	-
Lower Tongue River SS	9/14/23	-	-	-	1454	143	160	63	-	464	0	716	8	5	2.5	23	-
Tullock member	7/30/23	-	-	-	732	4	2	305	-	732	36	3	18	Tr.	0.4	9	-
Rosebud	7/30/23	-	-	-	1351	144	135	92	-	517	0	634	11	1.5	5.3	28	-
SS 250' below Rosebud	1923	-	-	-	2029	67	12	233	-	1210	-	1045	20	10	-	-	-
Rosebud (spring)	1923	-	-	-	718	114	51	33	-	357	-	268	5	-	-	-	-
Rosebud (mine shaft)	1923	-	-	-	1102	98	87	153	-	794	-	259	10	-	-	-	-
SS 100' below Rosebud	3/16/73	5	1040	7.1	-	120	73	-	-	465	0	312	-	5.2	0	-	-
Rosebud seep, Pit 6	3/24/73	12	600	7.8	-	50	52	-	-	378	0	131	-	46	0	-	-
Rosebud	3/18/73	9	875	7.4	-	93	62	-	-	468	0	212	-	0.9	0.1	-	-
Rosebud	3/15/73	-	1380	7.2	-	120	153	-	-	526	0	788	-	0	-	-	-
McKay	3/18/73	-	1680	7.6	-	140	153	-	-	366	0	887	-	6	1.0	-	-
McKay	3/16/73	8	2400	6.9	-	204	216	-	-	294	0	1625	-	0.3	0.2	-	-
McKay	3/16/73	-	2500	7.7	-	133	317	-	-	585	0	1625	-	0.5	1.8	-	-
SS 200' below Rosebud	3/20/73	10	3400	7.4	-	162	154	-	-	564	0	1875	-	0	1.5	-	-
SS 350' below Rosebud	3/19/73	13	2300	7.8	-	20	0	-	-	431	0	1440	-	0.3	1.0	-	-
Recent alluvium	3/23/73	-	1500	7.4	-	126	131	-	-	262	0	775	-	0.3	0.4	-	-

higher in calcium and magnesium with magnesium the dominant cation. Sulfate is the dominant anion. Water from sandstone units near the base of the Tongue River member are sodium-sulfate dominated with specific conductance ranging from about 2500-3500 micromhos/cm.

A comparison of 1923 water quality data with more recent analyses (1973) indicates that no major changes in water quality have occurred due to commercial mining of the Rosebud coal seam (Westinghouse, 1973b).

Ground water in the Colstrip area is generally less mineralized than Armells Creek which in turn is less mineralized than surface impounded water on spoils.

PART II- OVERBURDEN CHEMISTRY AND STRATIGRAPHY

INTRODUCTION

As stated earlier, this three year research project is concerned with the development of overburden handling techniques that will reduce the potential for water quality degradation in re-establishing spoils aquifers. The potential for this pollution results from the post-mining interaction between inimical materials in the spoils, surface water infiltration-percolation, and the lateral inflow of ground water. The present legal criteria used for evaluating whether overburden material is inimical or acceptable has been outlined by the Montana Department of State Lands (Table 13).

Table 13. Montana Department of State Lands guideline for suspect levels in overburden material. Corresponding analysis procedures are listed in Table 14.

Analysis	Suspect Level
Conductance	> 4-6 mmhos/cm
Sodium adsorption ratio	> 12
Mechanical Analysis	Clay > 40%
	Sand > 70%
Saturation %	None
pH	> 8.8-9.0
PO_4-P	None
NO_3-N	> 10-20 ppm
NH_4-N	> 10-20 ppm
Cd	> 0.1-1.0 ppm
Cu	> 40 ppm
Fe	Unknown
Pb	pH < 6, > 10-15 ppm
	pH > 6, > 15-20 ppm
Mn	> 60 ppm
Hg	> 0.4-0.5 ppm
Se	> 2.0 ppm
Mo	> 0.3 ppm
B	> 8.0 ppm
Zn	> 30-40 ppm
Ni	DTPA Extraction, > 1.0 ppm
	Acid Extraction, > 5.0 ppm

These criteria, as applied to the overburden material, are based on reviews of national literature. The literature has demonstrated or suggested that in soils having concentration above these "suspect levels" plant production has been restrained. The literature also shows that in some cases soil concentrations above these levels resulted in degradation of associated water resources. The use of the national literature was necessary due to an absence or shortage of this type of information for the Fort Union Coal region. Since in many cases,

Table 14. Overburden laboratory analysis procedures.

Sodium Adsorption Ratio (SAR)

This determination is made on the extract from a water saturated soil paste. Agriculture Handbook No. 60, United States Dept. of Agriculture, Feb. 1954, p. 84-88.

SAR= meq/L Na/ [(meq/L Ca+ meq/L Mg)/2]$^{\frac{1}{2}}$

Calcium, Magnesium, Sodium

Determination by Atomic Absorption Spectroscopy using saturation extract. Agriculture Handbook No. 60, United States Dept. of Agriculture, Feb. 1954, p. 84-88.

Conductance

This determination is made on the extract from a water saturated soil paste using a Thomas Serfass Conductivity Bridge Model RCM 1581. Agricultural Handbook No. 60. USDA, Feb. 1974, p. 89.

pH

This determination is made in a water saturated soil paste using a Corning Model 110 digital pH meter. Agricultural Handbook No. 60. USDA, Feb. 1954, p. 102.

Saturation Percentage

Ref. Agricultural Handbook No. 60, USDA, 1954 (84), method 2 and 3a.

Mechanical Analysis

Bouyoucos method with hydrometer. Textural triangle was used for texture class identification (Soil Survey Manual, 1951, USDA, p. 209.

Nitrate

Phenoldisulfonic acid method. Reference- Black, C.A. 1965. Methods of Soil Analysis, American Society of Agronomy, p. 1216.

Boron

Hot water extraction, Plasma Emission Spectrometer Analysis, Agricultural Handbook No. 60. USDA (1954), P. 142, method 73b.

Copper, Cadmium, Iron, Lead, manganese, Zinc, and Nickel

Atomic Absorption analysis of DTPA extract. Soil Science Soc. of American Proceeding, Vol. 35, No. 4 (1971), p. 600-602.

Molybdenum

This element is extracted with Tamm's solution and analysed on the Plasma Emission Spectrometer. Reference: Black, C.A. 1965. Methods of Soil Analysis. American Society of Agronomy. p. 1056.

Selenium

Inorganic Se in soils is determined by the gaseous hydride method after hot water extraction. The Se is reduced from +6 oxidation state to +4 oxidation state by addition of $NaBH_4$ solution to produce H and convert Se to SeH_2. The gaseous SeH_2 is swept into N flame of AA for determination. EPA, Methods for Chemical Analysis of Water and Waste, 1974.

Mercury

Acid extraction determined by cold Hg vapor generation and Atomic Absorption spectroscopy. Anal. Chem. vol. 40, No. 114 (1968).

Exchange NH_4

Extraction with sodium Chloride, distillation and titration. Reference: Jackson, M.A. 1958. Solid Chemical Analysis, Prentice Hall, Inc. p. 19, 194-195.

Phosphorus

Colorimetric determination of $NaCO_3$ extraction. ASA Agronomy Monography No. 9 Method 73-4.4, p. 1044-1047.

these chemical studies were based on conditions different from those normally found in Montana, their applicability to any one specific region or mine site is questionable. There are exceptions to this statement for such well known parameters as sodium adsorption ratios, conductance, and nitrate; however, in general, the limits are somewhat arbitrary, expecially with regard to the trace elements. This problem is clearly recognized by those who administer the guidelines as well as by those who must comply. For this reason, application of the guidelines requires a thorough understanding of the overall situation, since toxicity of many of the trace elements may depend on other soil factors such as pH. Although problems are inherent in any regulation of this type, the need for some type of control over deposition of inimical materials in the spoils is clearly necessary at least until data are developed to indicate otherwise.

A detailed understanding of overburden chemistry and stratigraphy is essential for a successful selective handling program. Knowledge of the presence and both the vertical and lateral extent of the inimical zones must be available prior to the stripping operation. Local hydrogeologic characteristics, especially the shallow groundwater regime, must be understood for the pre and post-mining conditions to make optimum use of the dragline during overburden stripping and spoil placement. To gain this information a preliminary exploratory drilling and sampling program was conducted in the spring of 1976. The field work and the resulting data are presented in the following sections. More intense drilling and installation of additional observation wells are planned for the next phase of the research. It is anticipated that this research will eventually provide insight into: 1) the relationship of texture and stratigraphy to chemical characteristics in the overburden; 2) rapid field analytical techniques; 3) necessary overburden drilling intensities; 4) selective handling, procedures, and costs; and 5) methods to monitor the effectiveness of selective handling.

The presence of inimical materials in the following figures does not necessarily infer that these materials be specially handled. It is expected that, in most cases, sufficient dilution will occur during the normal course of extraction and spoil placement. Current plans are to test this hypothesis by calculations and by field sampling.

DATA COLLECTION

The data discussed in the following sections are based on overburden samples collected during an exploratory drilling program conducted in the spring of 1976. A total of 38 exploratory holes were drilled on a 305 meter grid pattern covering an area of about 2000 hectares in Mine area B (Figure 11). The Montana Agricultural experiment Station supervised the drilling and sampling at 33 of these sites. These samples were then analyzed by Montana Testing Laboratory in Great Falls, Montana. Data for the other five sites, identified as N45E55, N45E57, N45E59, N47E55, and N47E57, were supplied by the Western Energy Company and analyzed by Northern Testing Laboratories, Billings, Mont. Overburden analysis procedures used were those recommended by the Montana Department of State Lands (Table 14).

During the drilling operation the compressed air method was used. Samples were collected throughout the depth profile at each different strata. The maximum sampling interval was three meters. The minimum was not less than 0.6 meters. Generally, samples were collected every 1.5 meters. Following the drilling, gamma, gamma-gamma density, spontaneous potential, and resistivity logs were run in the open hole. Water levels were measured and four of the holes (N48E55, N46E55, N45E53, N44E58) were cased with PVC pipe to serve as preliminary water level monitoring wells. The remaining holes were backfilled and sealed with a surface plug.

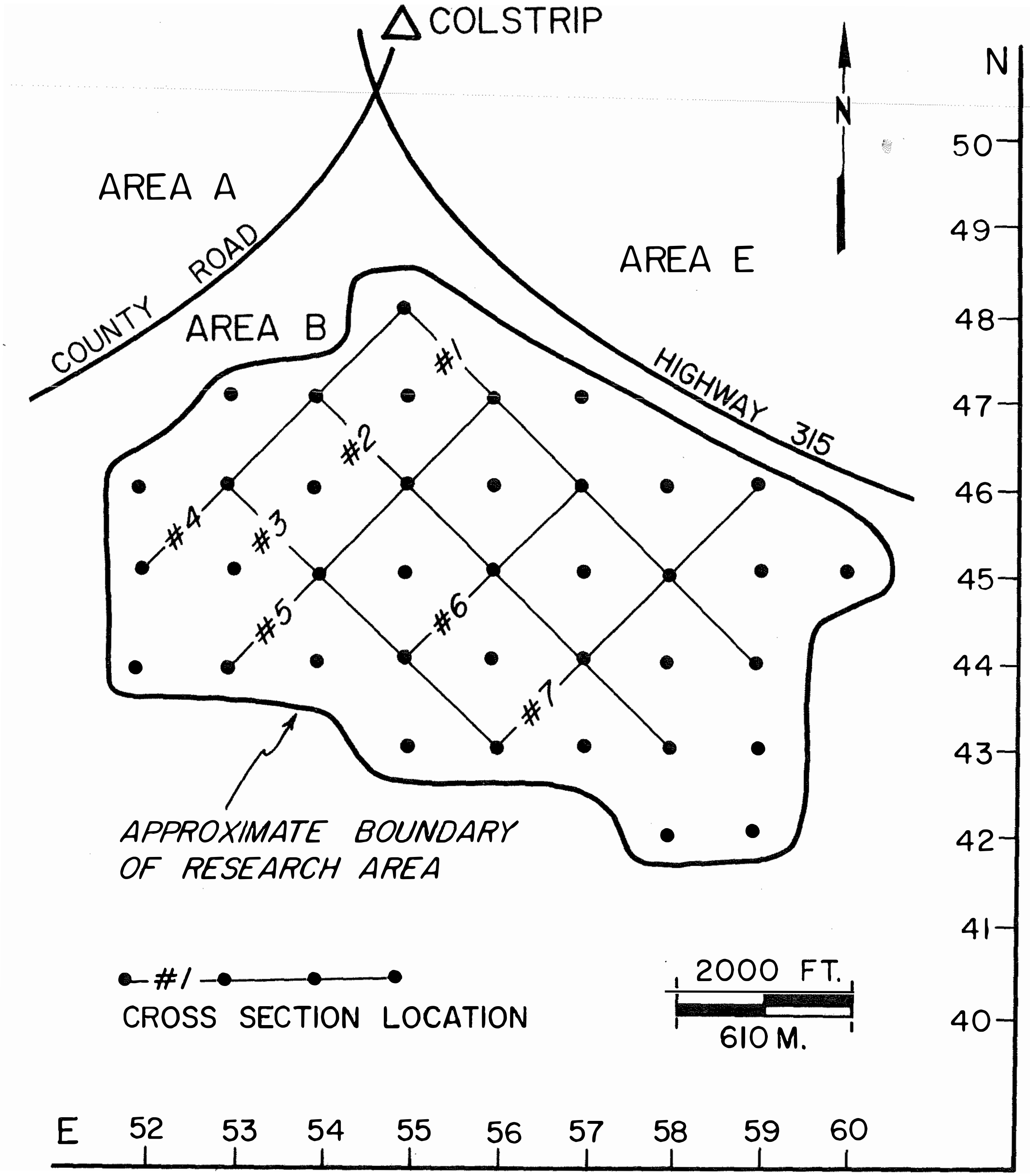


Figure 11. Drill hole and cross section location map, Western Energy Company, Mine Area B.

OVERBURDEN CHEMISTRY

Results of the laboratory chemical and mechanical analysis for Mine Area B are summarized in Table 15. It should be realized that the chemical analysis methods used are those which extract the readily soluble and exchangeable constituents in a mine soil, and do not necessarily reflect results one might obtain with total chemical analyses procedures. The procedures, then, were designed to determine the concentration of constituents that would be available to plant life. The concentration of elements readily extractable by water, i.e. ground water, could be comparatively less than values in this report. Summary statistics for individual drill hole analysis are presented in Appendix A. Also, these summary statistics include the interburden between the Rosebud and McKay Coal seams. Although only summary statistics are presented in this report the entire data base is available from Montana State University to individuals on a request basis.

Table 15. Summary of overburden chemistry and mechanical analysis data from Western Energy Company Mine Area B.

Analysis	Mean	±	Standard Deviation	Range Min	-	Max	Number of Samples
pH	8.0	±	0.4	5.0	-	9.6	887
Saturation %	36.80	±	7.77	18.90	-	74.40	887
Conductance (mmhos/cm)	1.83	±	1.65	0.23	-	14.80	887
Ca (meq/L)	6.26	±	6.69	0.30	-	78.84	887
Mg (meq/L)	11.76	±	15.54	0.30	-	118.42	887
Na (meq/L)	4.68	±	6.17	0.04	-	60.87	887
SAR	1.48	±	1.07	0.01	-	8.68	886
Zn (ppm)	13.44	±	36.67	0.08	-	650.00	890
Fe (ppm)	26.43	±	21.53	0.05	-	104.00	891
Cu (ppm)	1.37	±	1.11	0.05	-	6.30	890
Mn (ppm)	3.18	±	2.56	0.05	-	23.80	891
Ni (ppm)	0.83	±	0.73	0.05	-	5.21	893
Cd (ppm)	0.15	±	0.30	0.05	-	3.75	893
Pb (ppm)	2.80	±	2.17	0.10	-	11.90	893
Hg (ppm)	0.026	±	0.269	0.0005	-	0.278	893
Se (ppm)	0.013	±	0.007	0.005	-	0.110	891
Mo (ppm)	0.863	±	0.687	0.005	-	4.65	893
B (ppm)	0.460	±	0.507	0.005	-	3.95	879
PO_4 (ppm)	2.65	±	4.69	0.10	-	38.00	810
NO_3 (ppm)	0.67	±	1.06	0.05	-	10.60	874
NH_4 (ppm)	13.77	±	9.91	0.50	-	80.02	892
Sand (%)	44.71	±	22.35	3.60	-	92.40	826
Silt (%)	29.53	±	14.77	1.00	-	83.00	824
Clay (%)	25.72	±	13.85	1.80	-	77.60	825

A comparison of the analysis summary (Table 15) with the suspect levels (Table 13) indicated the overburden did not contain any excessive concentrations of copper, lead, manganese, mercury, selenium, or boron. Sodium was not a problem since its concentration was relatively low and the maximum sodium adsorption ratio (SAR) was only 8.68. Although the concentration of nitrate-nitrogen (NO_3-N) was very low, mean of 0.67 ppm, a few samples exceeded the 10.0 ppm suspect level.

Several parameters exceeded the suspect level including the trace elements nickel, cadmium, zinc, and molybdenum. Levels of pH, conductance, ammonium, sand, and clay were also found to exceed suspect levels in this overburden material. The statistical mean for both ammonium and molybdenum exceeded the suspect level indicating a considerable volume of overburden in Area B may be adversely affected by these elements. The statistical mean for zinc, cadmium, and nickel plus one standard deviation exceeded the respective suspect levels. This indicated a considerable number of overburden samples contained excessive concentrations of these elements. Interpretation of cadmium results must be qualified. The minimum analytical sensitivity for cadmium was 0.10 ppm during this laboratory work. Therefore, cadmium concentration results reported by the lab as something less than 0.10 ppm were for statistical purposes divided in half. Thus interpretations regarding cadmium will include this error.

According to Montana Department of State Lands criteria, therefore, the research area contained a number of chemical and physical characteristics that could be harmful to the area water and plant resources. Briefly, the following statements will allude to the environmental consequences if the plant and water resources are subjected to such excessive levels. High conductance values indicate excessive salt concentrations. If this soil is used as a root growth medium, the plant will be required to expend a greater amount of metabolic energy to take up water, thus adversely influencing the plant-water relationship. Excessively high concentrations of trace elements (Ni, Cd, Zn, Mo) can cause a direct metabolic interference in plant cell physiology. A soil with greater than 40% clay will likely have characteristics unfavorable for root penetration and water infiltration. A soil with greater than 70% sand will likely transmit water fast thus limiting water retention for plant use. Also, such a soil has little capacity for plant nutrient storage. Excessively high ammonium (NH_4) values should have a positive influence on plant production. If placed in the root zone, NH_4 will partially oxidize to nitrate (NO_3). Plant life can utilize both these forms of nitrogen in substantial amounts. The concern about NH_4, however, is its association with ground water.

The concern between ground water and overburden chemistry stems from the belief that ground water will take on, to a certain extent, the chemical characteristics of its flow medium. Excessive salt or trace elements in ground water may reduce the desirability of the aquifer for domestic purposes, or if unknowingly used, these waters may create metabolic problems in animal life. The specific concern with high NH_4 levels in overburden stems from its potential oxidation transformation to NO_3 during the mining process which subjects overburden in a chemically reduced state to oxygen in the earth's atmosphere. Thus a relatively sudden source of NO_3 may be made available to the areas water resources.

OVERBURDEN STRATIGRAPHY

The stratigraphy and lithic characteristics of the overburden in the research area were studied using drillers logs, geophysical logs (natural gamma, gamma-gamma density, spontaneous potential and resistivity), and mechanical analyses of samples collected at 1.5 m (5 ft) intervals during the drilling program. Use of the natural gamma logs in combination with the mechanical analyses data provided a means for rather consistent delineation of rock types throughout the research area. Where there were apparent differences between the lab data and the geophysical logs, the logs were followed. These data were the basis for preparation of the individual stratigraphic columns (Appendix A) as well as cross sections 1 through 7, Figures 12-18. Locations of these cross sections are shown on Figure 11.

The terminology used in this report to describe the stratigraphy and lithic variation of the overburden in the research area is summarized in Table 16.

Table 16. Stratigraphic Terminology

% sand (1)	terminology of overburden materials as used in this report (2)	inclusive terms (3)
-90- -80- -70- -60-	silty sand (st sd)	sand, sandstone, clayey sand, muddy sand, silty sand
-50- -40- -30- -20-	sandy shale (sd sh)	sandy clay, sandy claystone, sandy clay shale, sandy mud, sandy mudstone, sandy mud-shale, sandy silt, sandy siltstone, sandy silt-shale
-10-	shale (sh)	clay, claystone, clay-shale, mud, mudstone, mud-shale, silt, siltstone, silt-shale

(1) Data from laboratory mechanical analysis. Sand size ranges from 0.05 mm-2 mm.

(2) Because of the complexity of the overburden stratigraphy and overburden chemistry in the research area an attempt was made in this report to simplify stratigraphic terminology. More detailed descriptions may be necessary in following reports.

(3) After Folk, R.L. 1968.

Generally, three major types of material were delineated: 1) silty sand (greater than 50% sand); 2) sandy shale (10-50% sand); and 3) shale less than 10% sand). Although a more detailed description may be warranted in future reports, the need to reduce the number of variables for correlation with geochemical data required a more simplified stratigraphic framework for use in the inital stages of this study. In addition to the rock types mentioned above, thin deposits (less than .15 m) of clinker (porcelainite) and coal stringers were occassionally encountered during drilling.

Thickness of the overburden in the research area ranges from approximately 5 m (15 ft) to 65 m (210 ft). The overburden is generally composed of alternating beds of shale, sandy shale and silty sand. There are however, locations composed almost entirely of shale and sandy shale (boring 4556, Figure 13) or almost entirely of silty sand (boring 4655, Figure 13). Individual bodies of silty sand range in thickness from less 0.3 m (1 ft) to almost 21 m (70 ft). This variability makes stratigraphic correlation difficult and will certainly increase the complexity of planning large scale selective overburden handling operations. One rather consistent characteristic however, is the general presence of shale or sandy shale at the base of the overburden directly above the Rosebud coal.

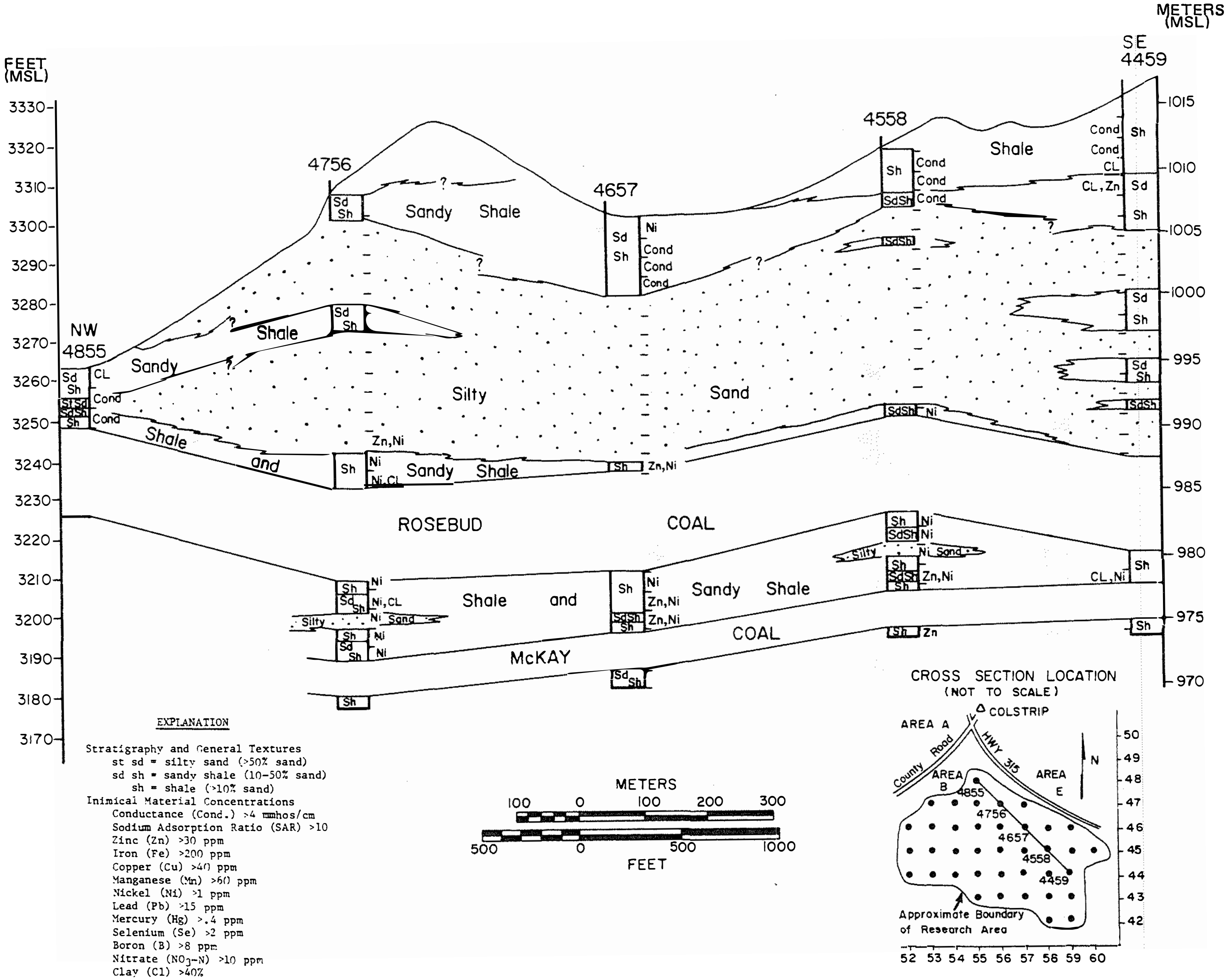


Figure 12. Cross section #1, Western Energy Company Mine Area B.

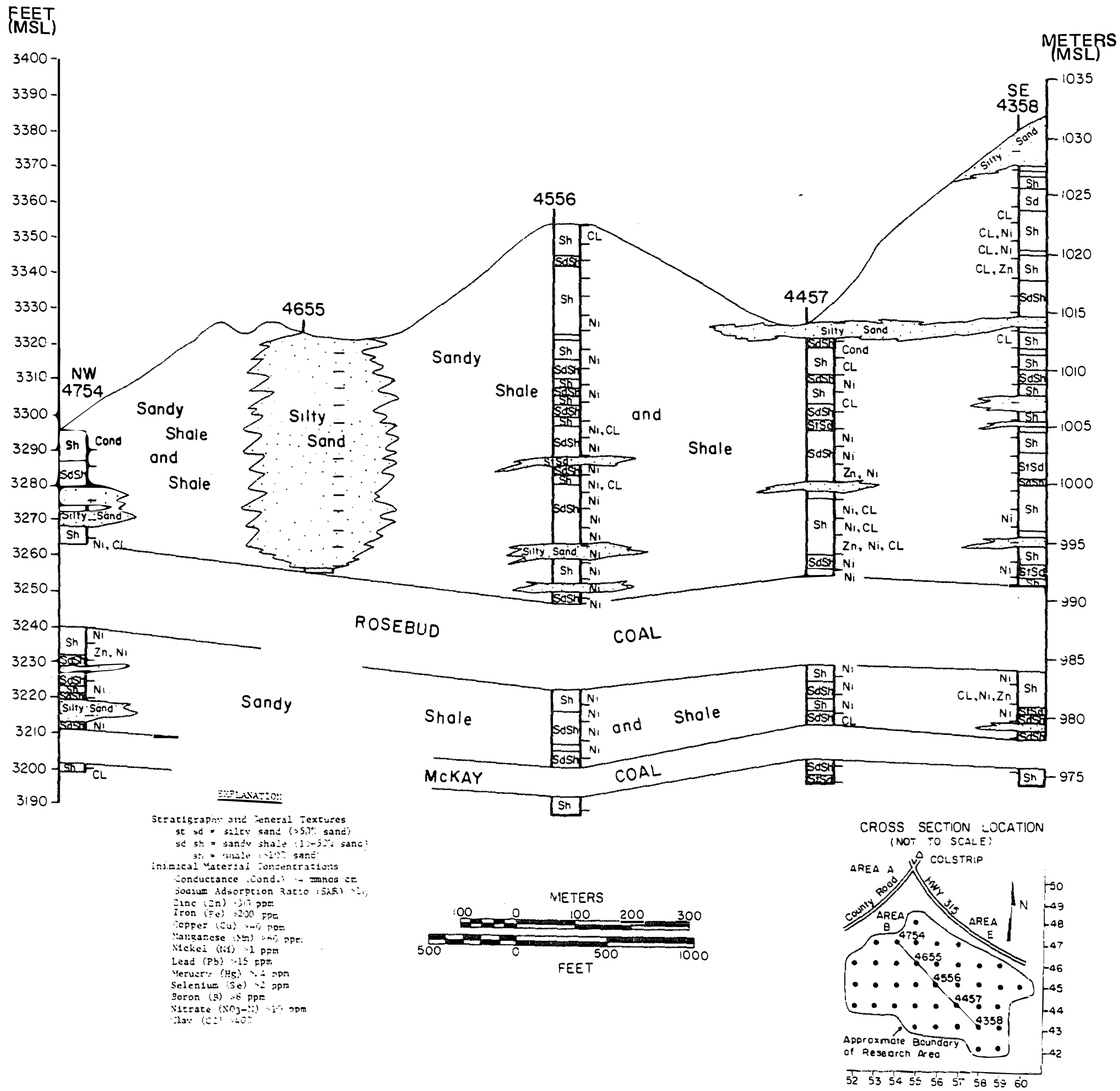


Figure 13. Cross section #2, Western Energy Company Mine Area B.

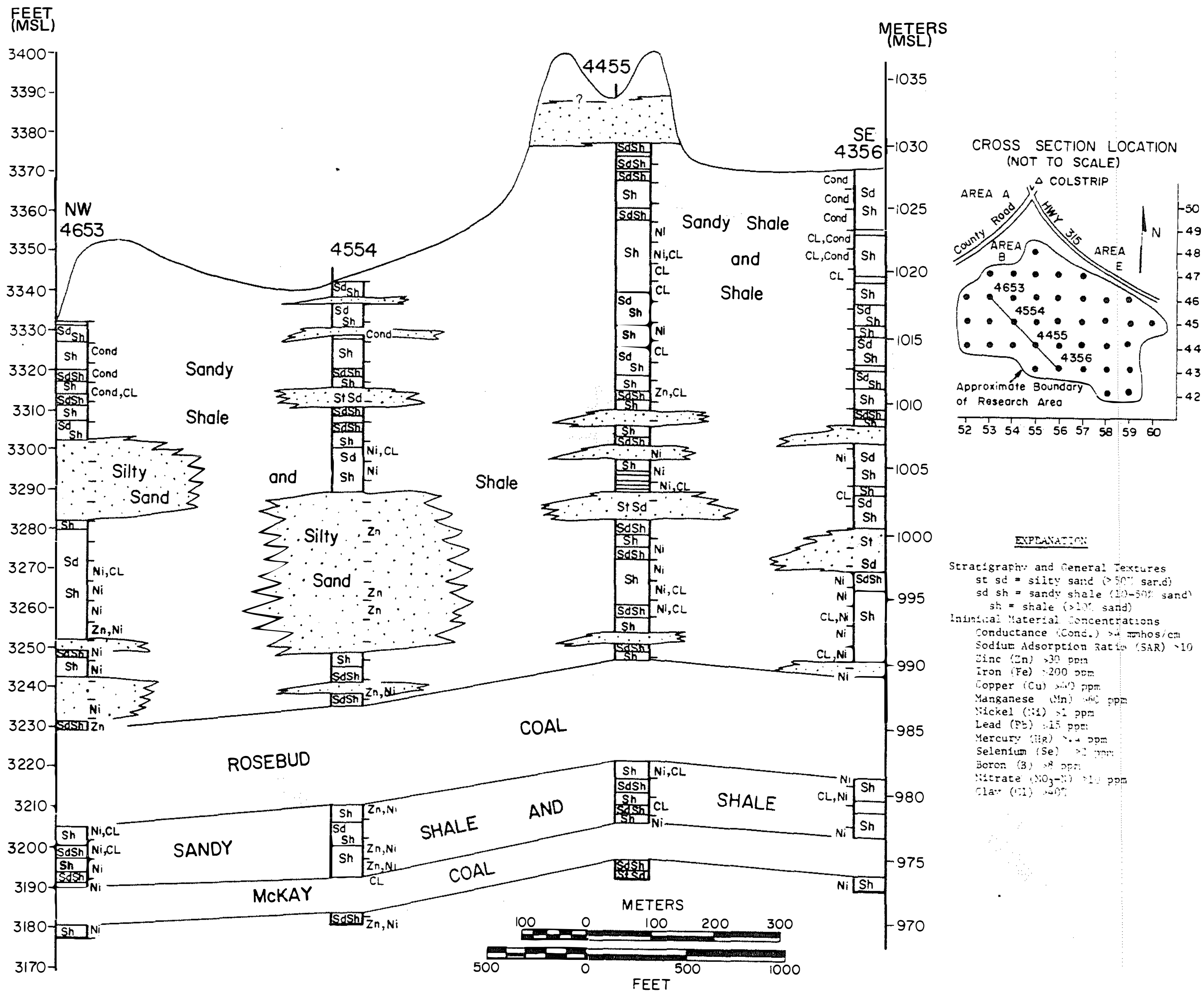


Figure 14. Cross section #3, Western Energy Company Mine Area B.

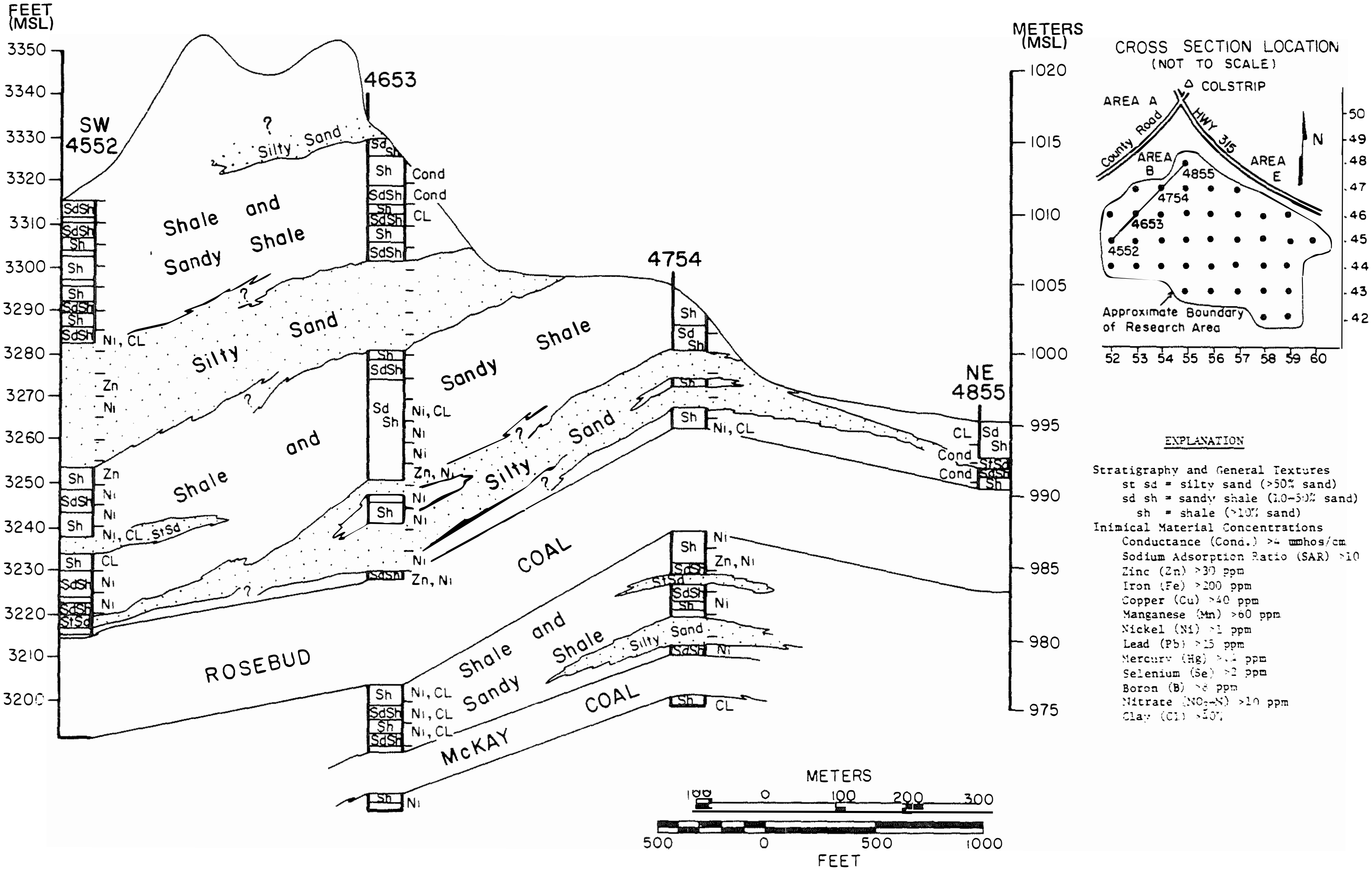


Figure 15. Cross section #4, Western Energy Company Mine Area B.

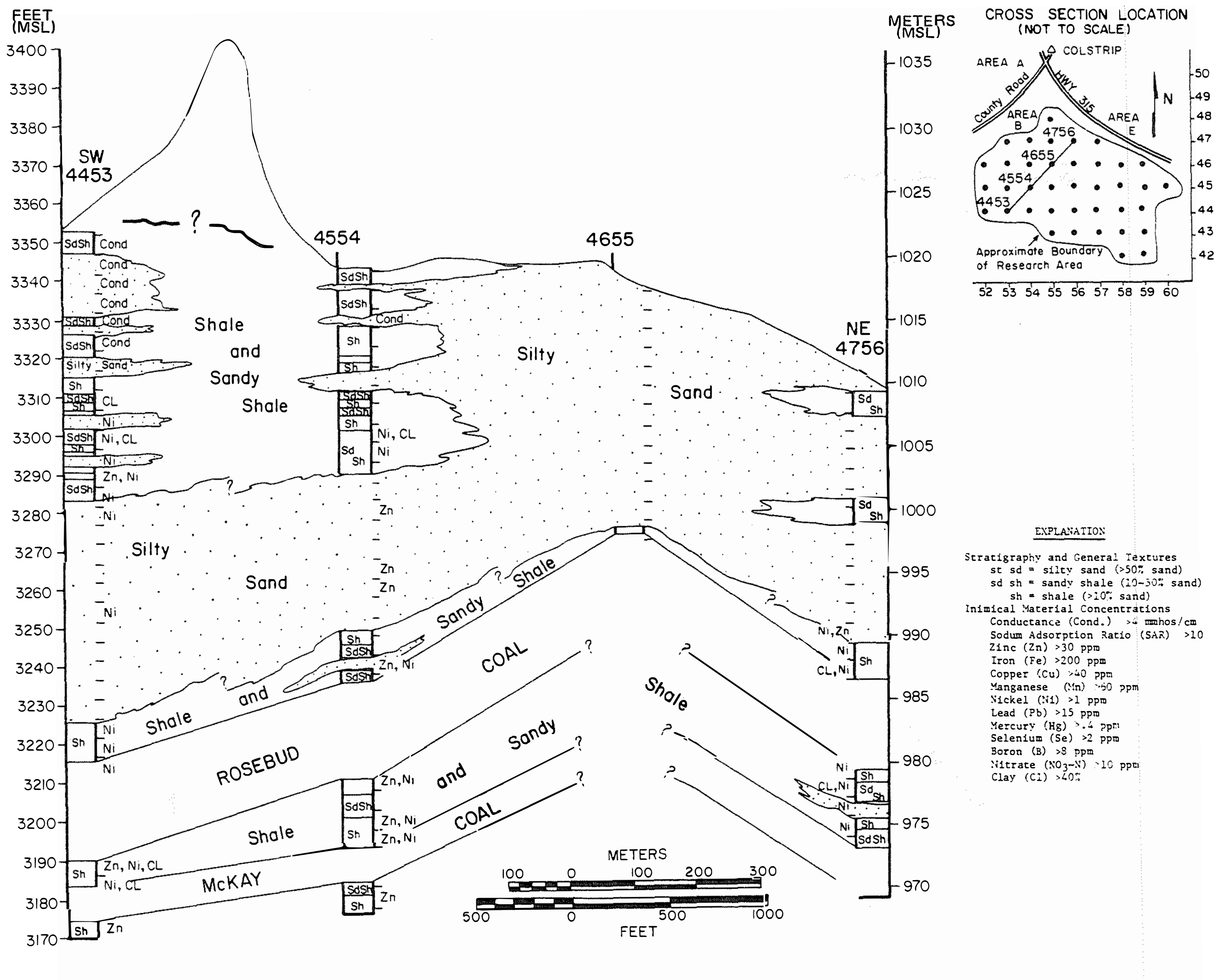


Figure 16. Cross Section #5, Western Energy Company Mine Area B.

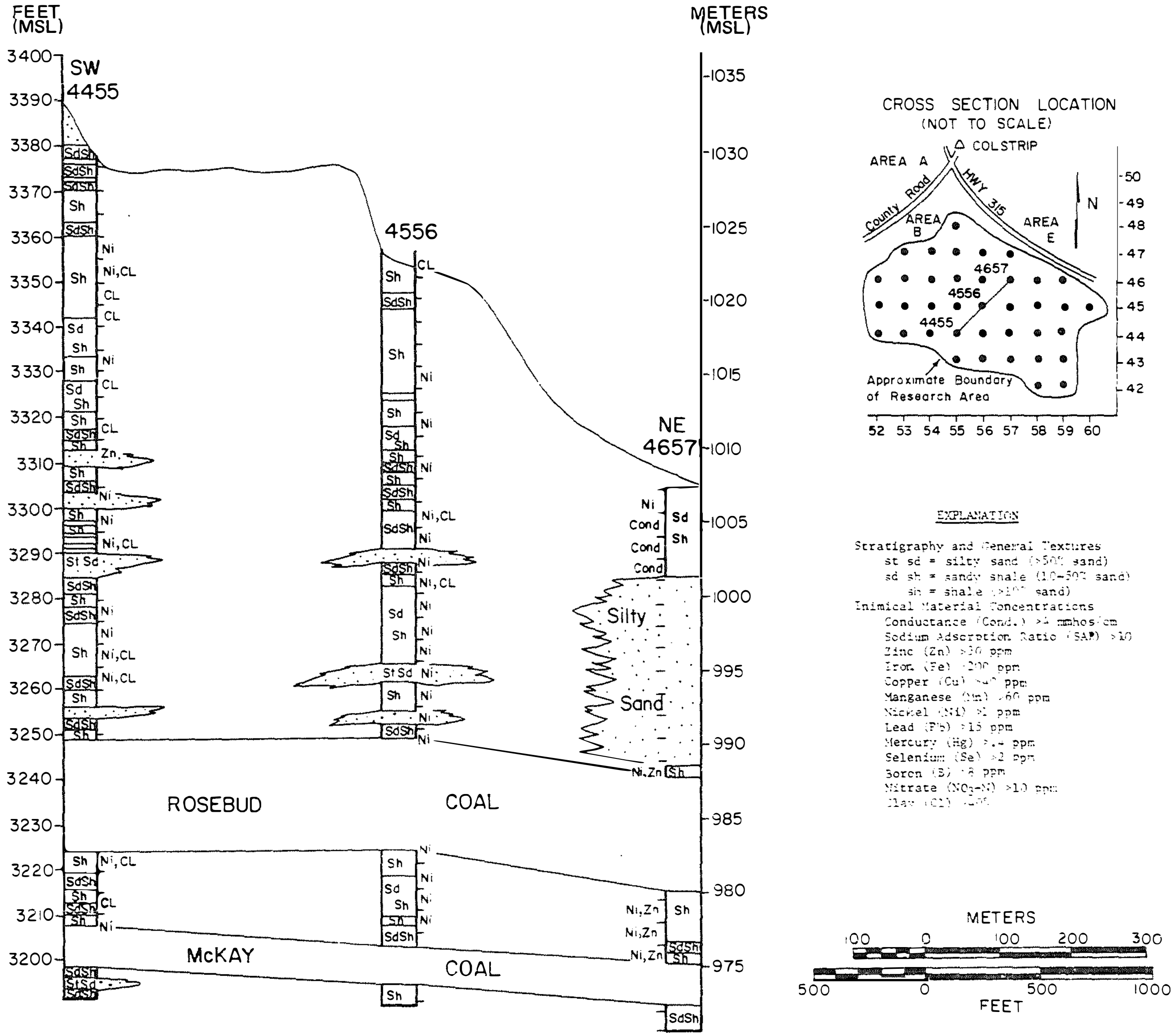


Figure 17. Cross section #6, Western Energy Company Mine Area B.

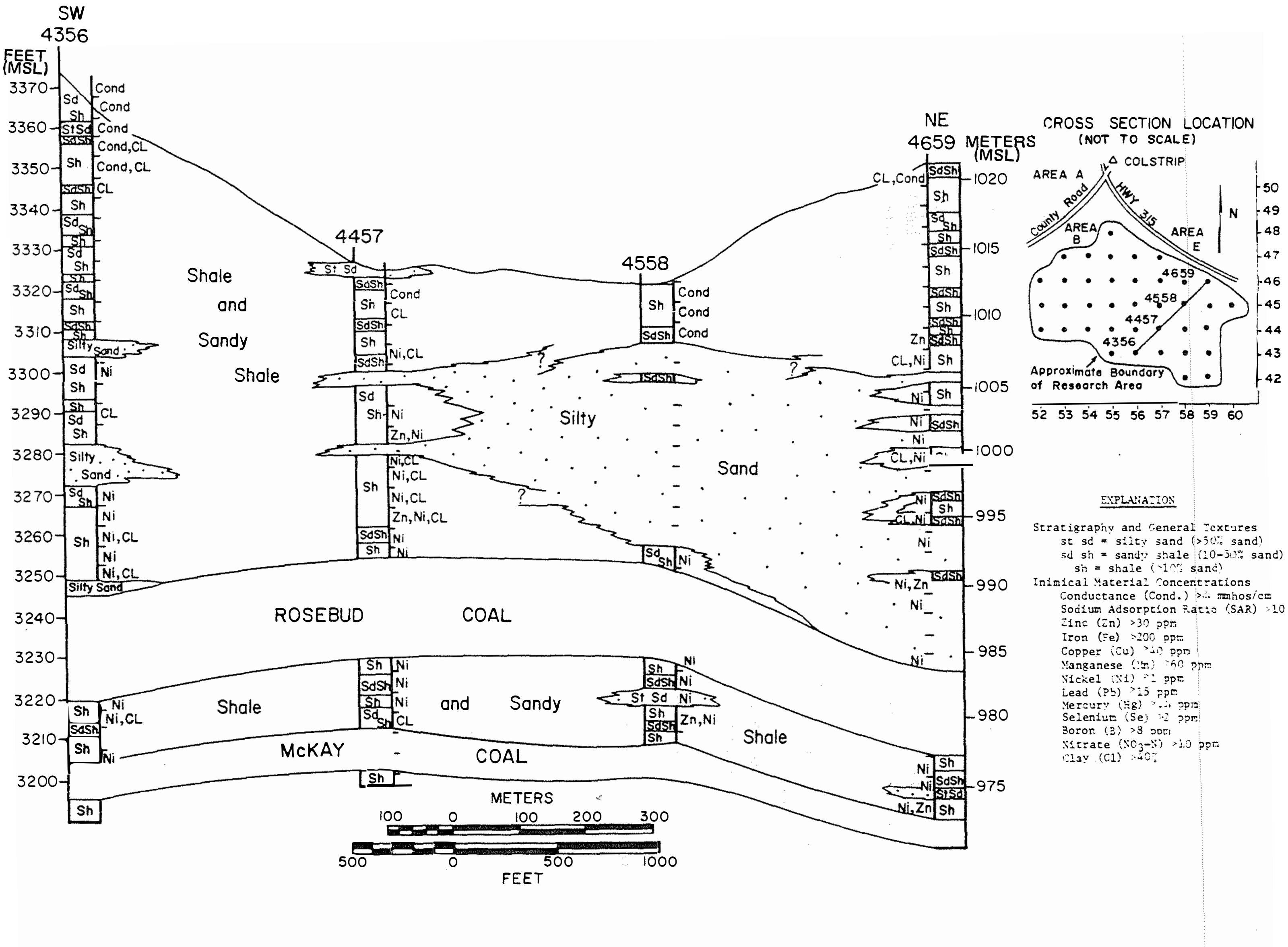


Figure 18. Cross section #7, Western Energy Company Mine Area B.

LITHO-CHEMICAL RELATIONSHIPS IN THE OVERBURDEN

Overburden chemical data for the research area were plotted on stratigraphic cross sections (Figures 12 through 18) to investigate the relationship between the location of inimical material and the local stratigraphy. This initial, qualitative approach focused on four parameters: electrical conductance (Cond.); nickel (Ni); zinc (Zn); and clay content (CL). With the exceptions of molybdenum (Mo) and ammonium (NH_4-N) these were the parameters found most frequently in excess of "suspect levels". Molybdenum with a recommended limit of .3 ppm exceeded this limit so often that it was not included in this initial evaluation. The same was true for ammonium. Cadmium could not be plotted since its red flag level (.1 ppm-1.0 ppm) was less than the sensitivity of the instrument used for analysis.

The initial review of data suggests that the location of inimical material may have some relationship to both rock type and to vertical position within the overburden profile. With regard to rock type, the preliminary analysis indicates a positive relationship between inimical material and the shale and sandy shale material. The inimical material appears to be less frequently found associated with the silty sand than with these lithic types. To check this observation, the percentage of silty sands within the overburden for each exploratory boring was calculated and then plotted. A fifty percent silty sand content was chosen as a dividing line (Figure 19). The portions of the research area believed to contain greater than 50% silty sand in the overburden are indicated by the dot pattern on the figure. A similar approach was used to evaluate inimical concentrations. The percentage of 1.5 meter sampling intervals within the overburden for each test hole containing any inimical material was calculated and then plotted. The lined areas in Figure 19 indicate areas of overburden in which inimical material was identified in more than fifty percent of the sampled intervals. As shown on the figure, the areas with greater than fifty percent silty sand in the overburden profile are areas with the fewest inimical materials. This suggests the possibility that the silty sands are relatively "clean" compared with the shales and sandy shales. Although this could well have been predicted prior to the analysis, the technique may have some use in the prediction of problem areas on a more regional scale.

A review of the cross-section data indicates a possibility that the location of inimical material may be related to position within the overburden profile. Highest values of electrical conductance are usually found within a few meters of the surface. This suggests a possibility that a surface feature or process such as ponding or evapotranspiration may influence the location of these inimical zones. Also, there frequently appears to be concentrations of clay, nickel, and zinc directly above the Rosebud coal and within the interburden. Reasons for this are not understood at this time.

Multiple regression techniques were used to further investigate overburden chemical and physical parameters (Table 17). Each of the 25 overburden measures were compared by a computerized stepwise regression program to all of the remaining measures. This program first finds the single vari-

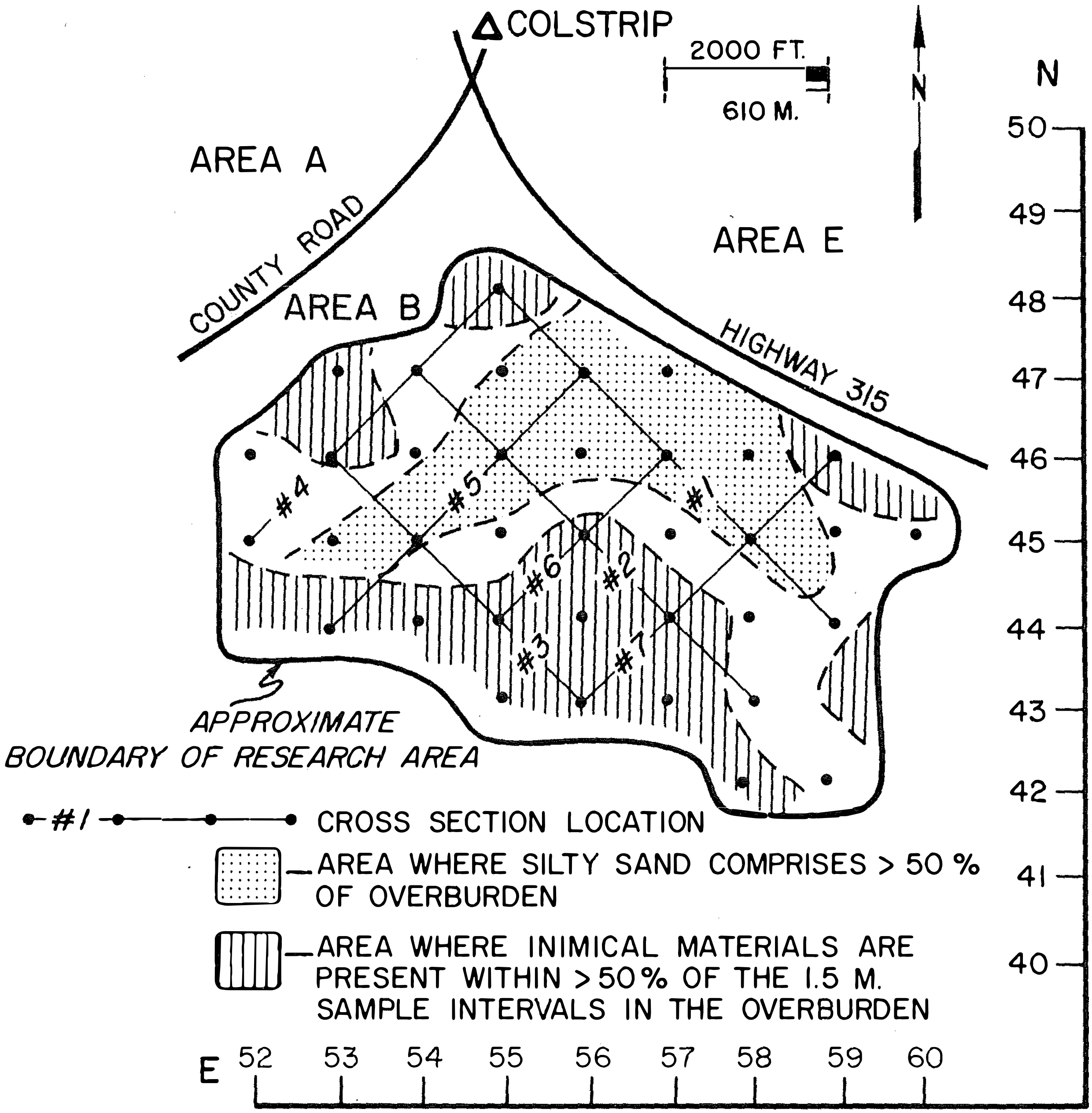


Figure 19. Areal relationship of overburden lithic composition and geochemical characteristics.

Table 17. Relationship between overburden chemical and physical parameters in Mine Area B as indicated by the square of the multiple correlation coefficient, Colstrip, Montana, 1977.

Overburden Parameter (y)	Square of the Multiple Correlation Coefficient (R^2) Total R^2	Individual Contributions to Total R^2 Value from Most Significant Predictive Measures (x_i)+
Conductance mmhos/cm	.95*	Mg (.88), Ca (.04), SAR (.03)
Na (meq/L)	.89*	SAR (.71), Mg (.18)
Mg (meq/L)	.88*	Cond (.88)
SAR	.79*	Na (.71), Mg (.08)
Ca (meq/L)	.75*	Cond (.67), SAR (.05), Mg (.03)
Cu (ppm)	.60*	Pb (.47), Clay (.09), Mn (.04)
Pb (ppm)	.60*	Cu (.47), Ni (.10), Clay (.03)
Ni (ppm)	.48	Pb (.44), Depth (.04)
Saturation %	.47	Clay (.47)
Clay %	.45	Cu (.41), Pb (.04)
Sand %	.43	Cu (.32), Pb (.05), Ca (.03), Mn (.03)
pH	.41	Depth (.23), Ca (.09), Hg (.06), Ni (.03)
Mn (ppm)	.38	Fe (.30), Cu (.08)
Depth (meters)	.35	Ni (.23), pH (.09), Mg (.03)
Fe (ppm)	.31	Pb (.31)
Hg (ppm)	.17	pH (.12), Pb (.05)
Silt %	.17	Fe (.09), Cond (.08)
B (ppm)	.13	pH (.10), Cu (.03)
Cd (ppm)	.12	Cu (.08), PO_4 (.04)
NH_4-N (ppm)	.08	Mn (.05), Hg (.03)
An (ppm)	.06	Depth (.06)
PO_4-P (ppm)	.05	Cd (.05)
NO_3-N (ppm)	.03	Na (.03)
Mo (ppm)	.03	Fe (.03)
Se (ppm)	.03	Cd (.02)

+ Predictive measures (x_i) included in the table are those that cause more than a (0.025) increase in R^2. See text for further discussion.

* Indicates regression with substantial degree of relationship. No tests of significance were performed on the R^2 values because measurements performed on drill-hole samples were not statistically independent.

able most highly correlated to the measure being analyzed. Next, the variable which accounts for the most remaining variation in the analyzed measure is chosen. This process continues until all variables are included. The degree of association between the analyzed measure and all remaining measures in the regression is indicated by the square of the multiple correlation coefficient (R^2). An R^2 of 0 indicates no association (random) and an R^2 of 1.0 indicates perfect correlation. Multiple regression techniques indicate which overburden measures are most highly correlated (R^2 near 1.0), but can also be used for predictive purposes. For example, lead, clay, and manganese are all components of a regression equation which is correlated with copper (R^2 = .60, Table 17). Therefore, if lead, nickel, and clay contents are known, then copper could be predicted with perhaps a high degree of accuracy.

As additional predictive measures are added into a regression equation, R^2 increases. However, since the most highly correlated measures are included in the regression equation first, successive increases in R^2 become smaller and smaller. Thus, after the most significant variables have been included in a regression, changes in R^2 become negligible. In this study, measures which did not add more than .025 to the preceding value of R^2 were considered non-significant and were excluded from the final regression equation. A more formal description of the multiple regression procedure is given in Appendix B.

There were several overburden parameters which had essentially no relationship to other chemical or physical measures. These included zinc, cadmium, mercury, selenium, molybdenum, boron, phosphate, nitrate, ammonium, and silt (Table 17). Levels of these properties were not predicted by any other overburden measures (x_i), as indicated by the low multiple correlation coefficient squared ($R^2 < .20$).

Several overburden parameters showed only weak relationships to other chemical and physical measures ($.30 < R^2 < .50$). For example, the predictability of soil depth was low; Ni had some correlation to depth ($R^2 = .23$) and pH and Mg improved the total correlation ($R^2 = .35$). This statistical result was somewhat disappointing since trends with depth were frequently observed in the data. In particular, conductance near the surface and trace elements (i.e., Ni, Pb, Cd) near the pit base showed an apparent relationship to depth. The relationship between saturation % and other parameters was weak but some correlation to clay % was present ($R^2 = .47$). It was expected that this correlation would be greater since saturation % in soil material is largely a function of clay content, particularly in non-sodic soil material.

Conductance in the overburden was highly correlated to magnesium ($R^2 = .88$), while the additions of Ca and SAR improved the total multiple correlation ($R^2 = .95$). Thus in the mine Area B study area, the relationship between Mg and conductance was strong and either one would be useful in predicting the other.

The sodium adsorption ratio (SAR) was highly correlated to Na ($R^2 = .71$). This might be expected since SAR is a mathematical ratio of sodium to calcium plus magnesium, but it is interesting to note that magnesium contributed little ($R^2 = .08$) to the prediction of SAR, and calcium did not contribute to this multiple correlation. Thus SAR may have been estimated with only the sodium analysis in this overburden material. Calcium concentration in the overburden was correlated to conductance ($R^2 = .67$), while the addition of SAR and Mg improved the predictability of Ca ($R^2 = .75$). Therefore, both calcium and magnesium concentrations may have been predictable by conductance, and SAR may have been predictable by sodium concentration. In this overburden material, then, analysis of conductance and sodium could have, by regression equations, been used to characterize the SAR, calcium, and magnesium characteristics of the overburden.

Lead in the overburden was correlated to copper ($R^2 = .47$), while the addition of Ni and clay improved the ability to predict Pb concentrations ($R^2 = .60$). Copper in the overburden was correlated to Pb ($R^2 = .47$), while the addition of clay and Mn improved the ability to predict Cu ($R^2 = .60$). Therefore, there was an association between lead and copper, and a general association between Pb, Cu, Ni, Mn, and clay. In other words, in zones where clay content is high, there is a greater probability that Pb, Cu, Ni, and Mn concentrations will also be higher than average. This type of relationship was shown earlier during the discussion on stratigraphy where zones of shale tended to be associated with trace elements; realizing the terms shale and clay in a qualitative sense are used synonymously.

The following multiple regression equations summarize the above relationships where an overburden variable (y) was strongly correlated to predictive measures (x_i). The accuracy of these equations is re-

R^2	
.95	Conductance, mmhos/cm = .106 + .064(Mg, meq/L) + .328 (SAR)
.75	Ca, meq/L=1.1=5.17 (Cond, mmhos/cm)-1.84 (SAR)-.154 (Mg, meq/L)
.88	Mg, meq/L = - 4.349 + 8.952 (Conductance, mmhos/cm)
.89	Na, meq/L = - 2.739 + 3.548 (SAR) + .181 (Mg, meq/L)
.79	SAR = .855 + .205 (Na, meq/L) - .029 (Mg, meq/L)
.60	Cu, ppm = - .187 + .210 (Pb, ppm) + .024 (Clay, %) + .116 (Mn,ppm)
.60	Pb, ppm = .094 + .567 (Cu, ppm) + 1.112 (Ni, ppm) + .040 (Clay, %)

flected by the R^2 value. If $R^2 = 1$ the prediction of the overburden parameter (e.g. conductance) by the predictive measures (e.g. Mg, Ca, SAR) would contain no error. The further R^2 is from 1, the greater is the associated error of the regression equation. Therefore, R^2 qualitatively describes the accuracy of these equations. No attempt will be made in this report to quantitatively describe the error of each equation with confidence intervals.

During the discussion on stratigraphy the lithic material was classified into three groups; silty sand (>50% sand), sandy shale (10-50% sand), and shale (< 10% sand). Table 18 shows the frequency with which each overburden parameter exceeded the suspect level in each group. When all chemical and physical parameters were considered, overburden composed of silty shale, sandy shale, and silty sand exceeded the suspect level 21.0%, 20.6%, and 13.4% of the time, respectvely. Thus, the likelihood of overburden exceeding the suspect level became less as the sand content increased. The parameters which contributed to this result most substantially were Cd, Ni, and NH_4. These parameters exceeded the suspect levels at an increased rate when the sand content was less than 50%. Although Mo exceeded the suspect level more frequently as percent sand decreased, the number of toxic occurances was very high at all percentages of overburden sand content.

These data from bore holes on a 305 m grid provided some insight into litho-chemical relationships in overburden. Future reports shall include similar multiple regression statistical analysis on a data set composed of bore holes on a 60 m grid basis. Perhaps a more intense data set will reveal additional relationships and more strongly confirm those correlations described in this report.

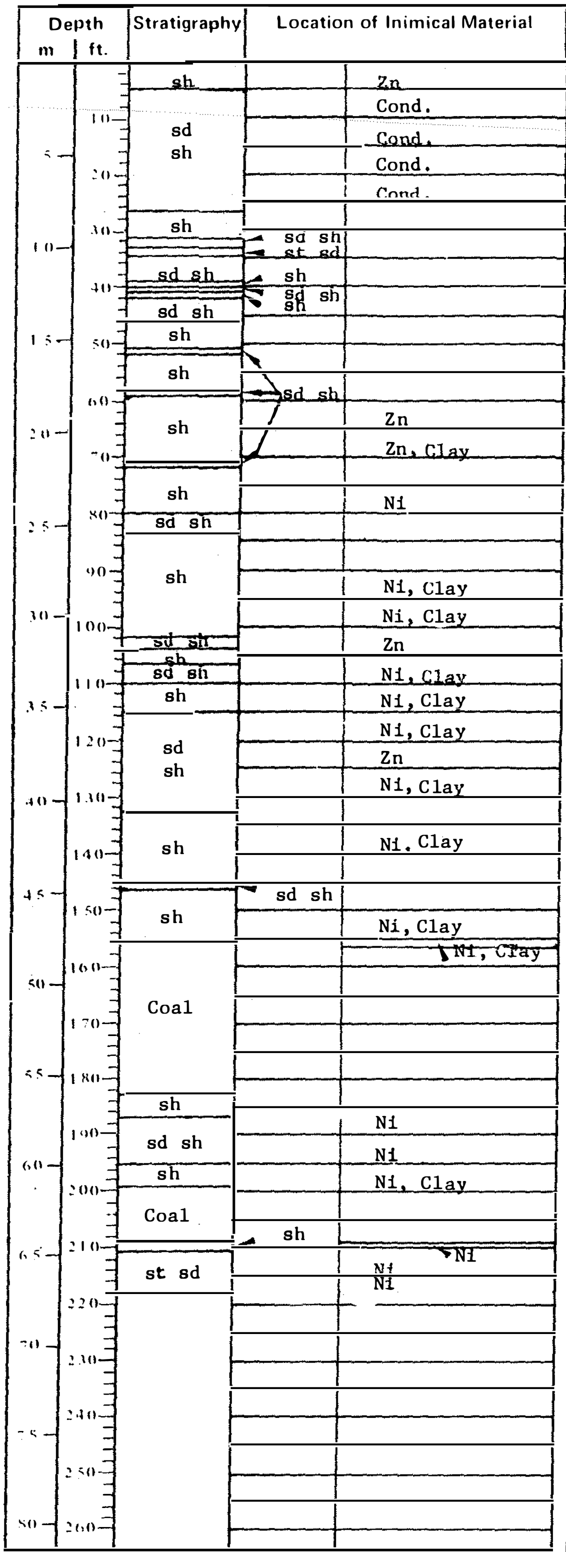
Table 18. Frequency of occurrence* when chemical and physical parameters exceeded suspect levels+.

Parameter	Suspect Level	Overburden Sand Content: < 10%	10-50%	> 50%	Total
pH	Exceeded	0	0	2	2
	Not Exceeded	9	498	311	818
Conductance	Exceeded	0	43	20	63
	Not Exceeded	9	455	293	757
SAR	Exceeded	0	0	0	0
	Not Exceeded	9	497	313	819
Clay	Exceeded	5	146	0	151
	Not Exceeded	4	355	315	674
Zn	Exceeded	0	61	25	86
	Not Exceeded	9	440	290	709
Cu	Exceeded	0	0	0	0
	Not Exceeded	9	502	314	825
Mn	Exceeded	0	0	0	0
	Not Exceeded	9	502	315	826
NO_3-N	Exceeded	0	1	0	1
	Not Exceeded	9	501	314	824
NH_4	Exceeded	7	372	157	536
	Not Exceeded	2	129	158	289
Ni	Exceeded	4	247	45	296
	Not Exceeded	5	255	270	530
Cd	Exceeded	5	344	157	506
	Not Exceeded	4	158	158	320
Pb	Exceeded	0	0	0	0
	Not Exceeded	9	502	315	826
Hg	Exceeded	0	0	0	0
	Not Exceeded	9	502	315	826
Se	Exceeded	0	0	0	0
	Not Exceeded	9	501	314	824
Mo	Exceeded	9	439	267	715
	Not Exceeded	0	63	48	111
B	Exceeded	0	0	0	0
	Not Exceeded	8	501	315	824
Total exceeded		30	1653	673	2356
Total not exceeded		113	6361	4358	10,802
% Exceeded		21.0	20.6	13.4	17.9

* An occurrence is an overburden analysis, generally representing a 1.5 m depth increment.

\+ Suspect levels are listed in Table 13.

APPENDIX A - Stratigraphy and geochemistry of the exploratory borings from Western Energy Company Mine Area B, Colstrip, Montana

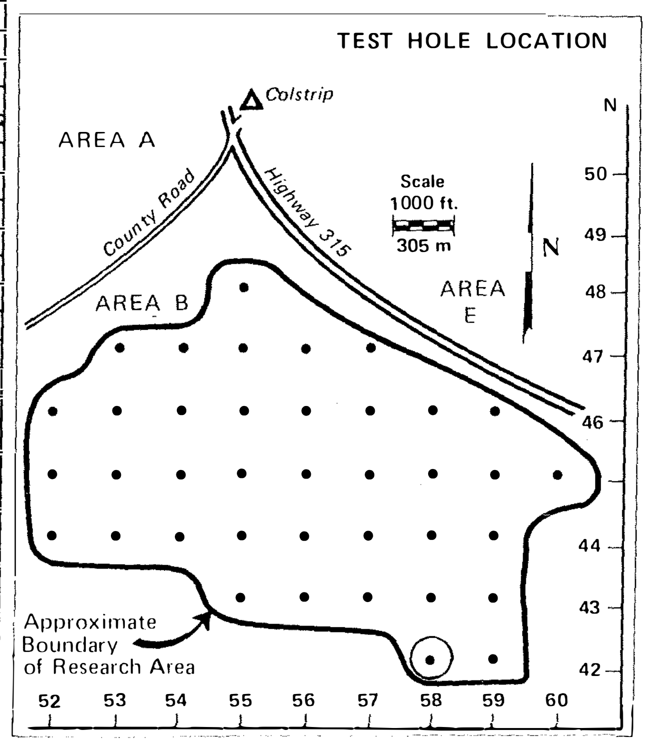


TEST HOLE DESIGNATION N42-E58

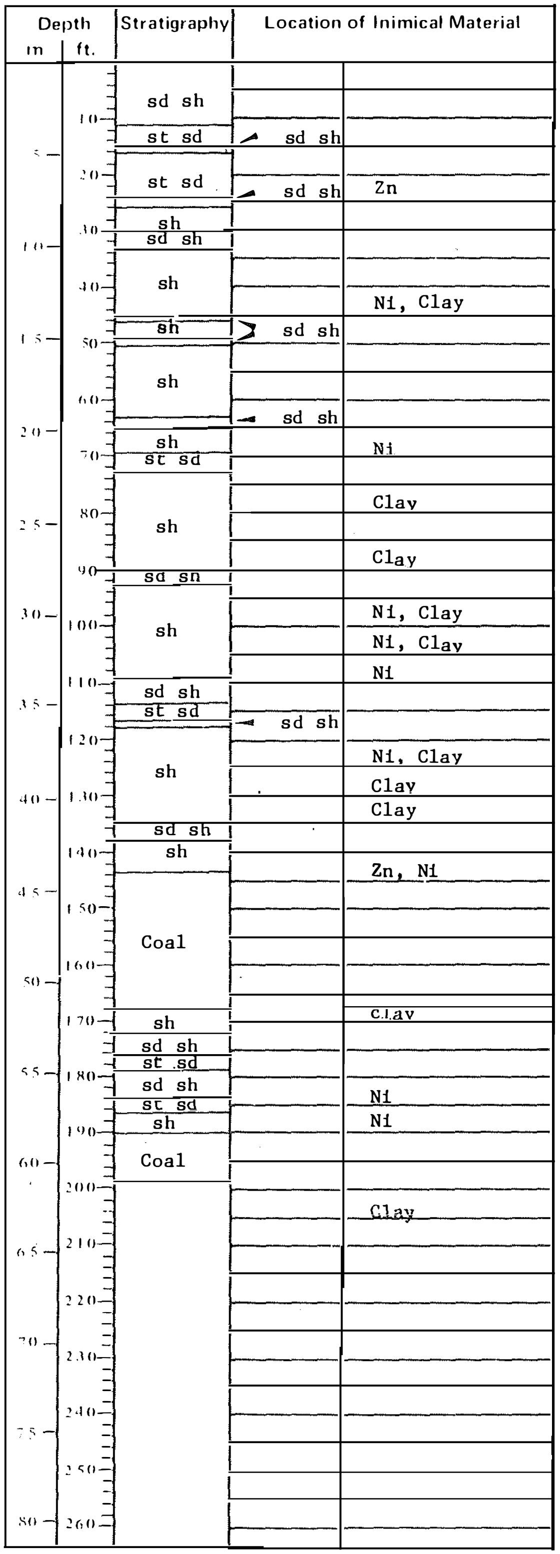
STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	8.1 ± 0.3	7.3 - 8.6
Saturation	%	39.1 ± 6.6	28.7 - 51.8
Cond.	mmhos/cm	2.28 ± 1.51	0.65 - 7.50
Ca	meq/L	3.98 ± 3.77	0.90 - 18.71
Mg	meq/L	16.23 ± 17.28	3.70 - 84.90
Na	meq/L	6.36 ± 6.27	1.61 - 28.35
SAR	---	1.97 ± 0.97	0.69 - 4.28
Zn	ppm	15.48 ± 21.76	0.70 - 92.00
Fe	ppm	29.2 ± 30.5	2.2 - 99.6
Cu	ppm	2.18 ± 1.26	0.40 - 4.60
Mn	ppm	2.9 ± 2.5	0.2 - 8.2
Ni	ppm	0.94 ± 0.78	0.06 - 3.14
Cd	ppm	0.20 ± 0.13	0.06 - 0.46
Pb	ppm	4.49 ± 2.98	0.50 - 10.81
Hg	ppm	0.020 ± 0.021	0.004 - 0.096
Se	ppm	0.010 ± 0.002	0.01 - 0.02
Mo	ppm	0.72 ± 0.49	0.07 - 2.5
B	ppm	0.53 ± 0.39	0.01 - 1.99
PO_4-P	ppm	4.02 ± 8.56	0.10 - 38.00
NO_3-N	ppm	0.60 ± 0.71	0.15 - 2.20
NH_4-N	ppm	9.22 ± 5.51	0.50 - 16.88
Clay	%	31.8 ± 17.0	2.4 - 59.4
Silt	%	27.0 ± 13.2	5.9 - 53.2
Sand	%	41.0 ± 24.9	10.8 - 36.0

TEST HOLE LOCATION



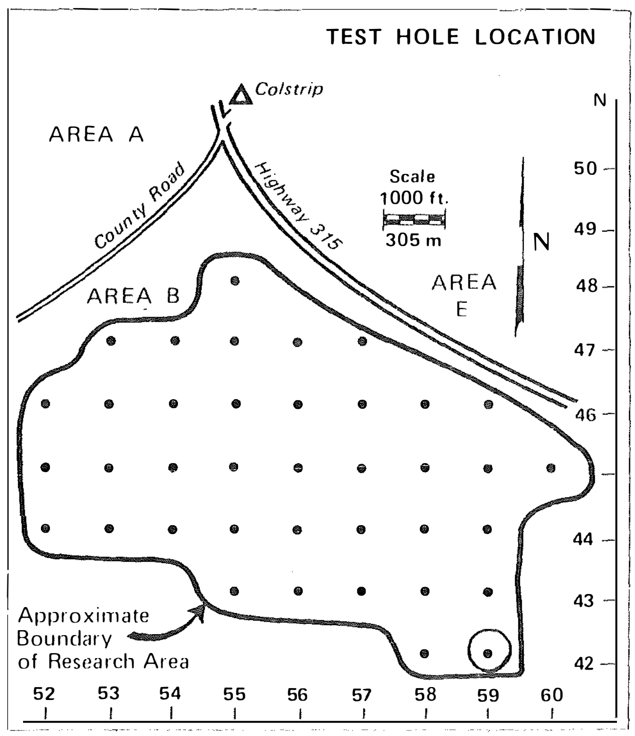
Appendix A-1. Stratigraphic and chemical data for test hole N42-E58. (st sd=silty sand, sd sh=sandy shale, sh=shale).



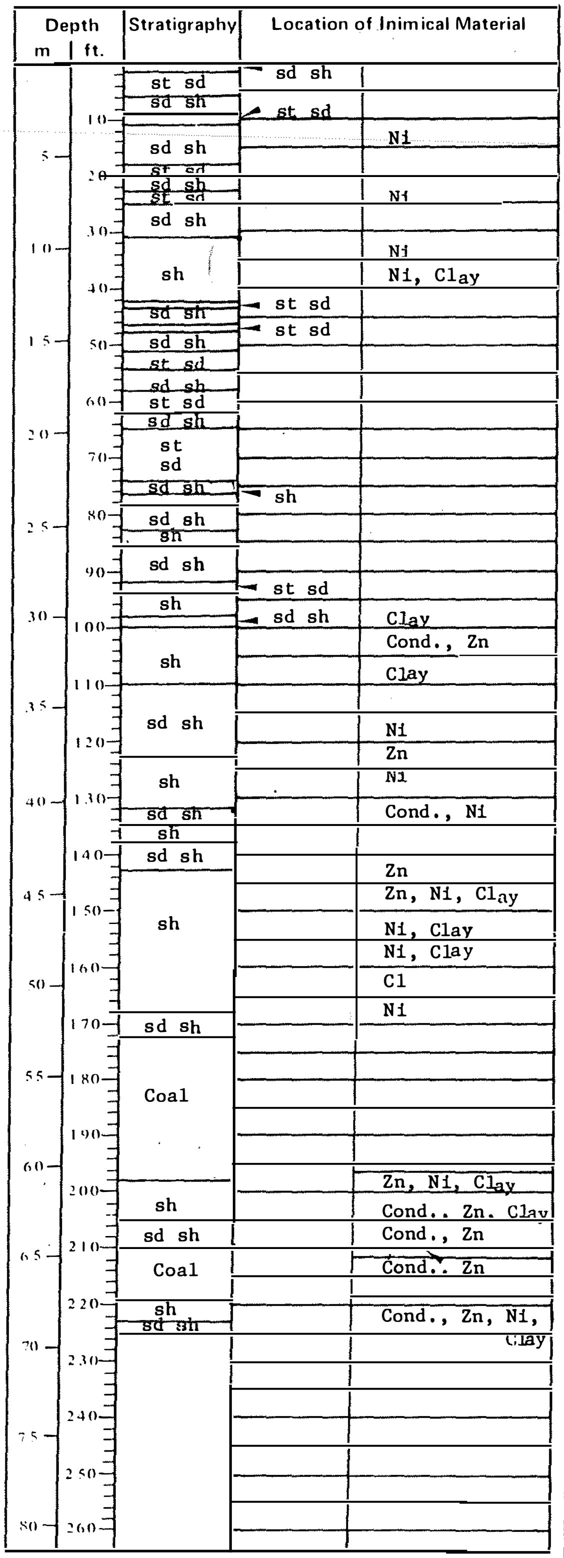
TEST HOLE DESIGNATION N42-E59

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min--Max
pH	– – –	7.9 ± 1.5	6.8 - 8.9
Saturation	%	37.8 ±10.5	24.8 - 56.1
Cond.	mmhos/cm	1.33 ± 0.63	0.29 - 2.6
Ca	meq/L	4.90 ± 3.15	0.50 - 13.47
Mg	meq/L	7.08 ± 4.41	0.30 - 17.48
Na	meq/L	3.20 ± 1.69	0.48 - 5.87
SAR	– – –	1.30 ± 0.66	0.01 - 2.35
Zn	ppm	10.69 ±22.12	1.36 - 126.00
Fe	ppm	21.6 ±13.6	2.4 - 66.0
Cu	ppm	1.70 ± 1.37	0.05 - 5.00
Mn	ppm	4.3 ± 3.5	0.9 - 18.0
Ni	ppm	0.84 ± 0.79	0.15 - 4.55
Cd	ppm	0.18 ± 0.41	0.06 - 2.50
Pb	ppm	1.77 ± 1.26	0.12 - 3.75
Hg	ppm	0.029 ±0.021	0.001 - 0.096
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	0.80 ± 0.46	0.16 - 2.14
B	ppm	0.35 ± 0.22	0.06 - 0.88
PO_4-P	ppm	1.4 ± 1.6	1.0 - 4.0
NO_3-N	ppm	0.71 ± 1.64	0.15 - 9.15
NH_4-N	ppm	18.23 ± 8.32	3.38 - 33.77
Clay	%	29.7 ±14.9	11.8 - 56.4
Silt	%	23.7 ±12.4	5.0 - 42.2
Sand	%	46.6 ±22.7	18.8 - 82.4



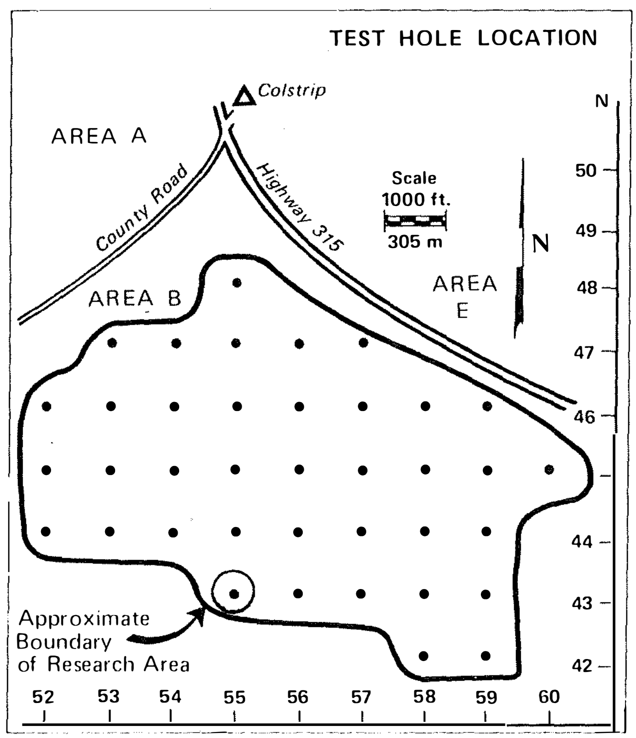
Appendix A-2. Stratigraphic and chemical data for test hole N42-E59. (st sd=silty sand, sd sh=sandy shale, sh=shale).



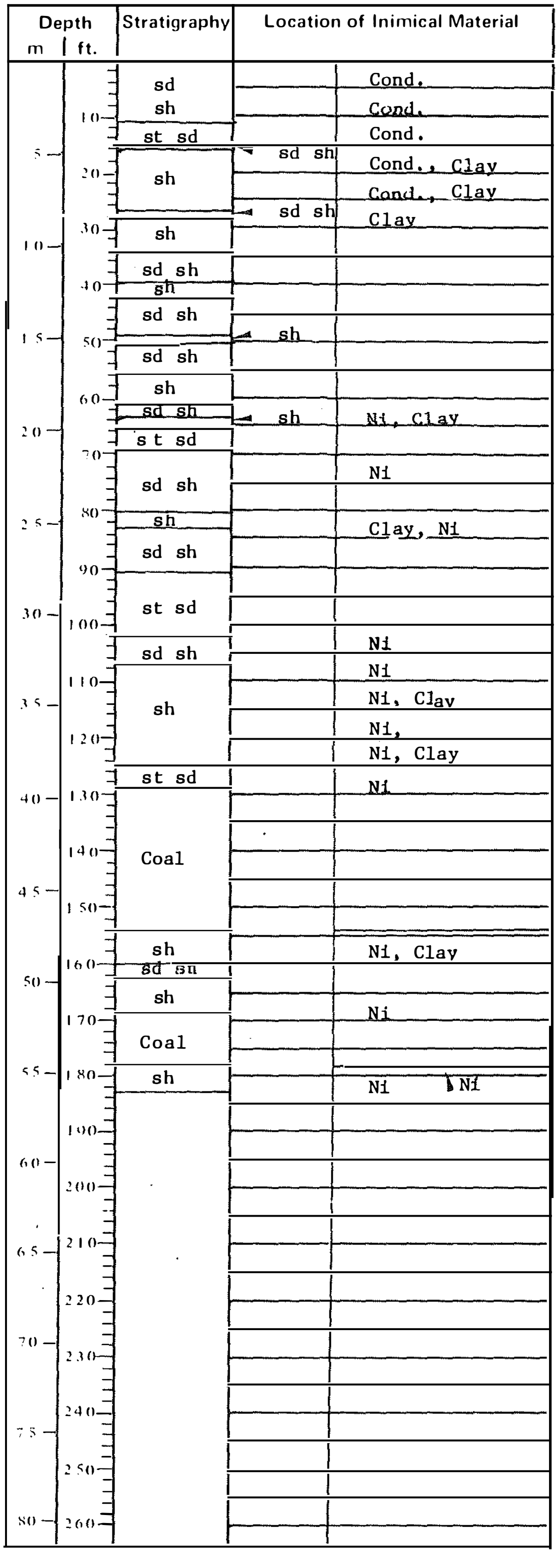
TEST HOLE DESIGNATION N43-E55

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min.–Max
pH	---	8.1 ± 0.4	7.2 - 8.9
Saturation	%	36.9 ± 6.6	23.9 - 56.2
Cond.	mmhos/cm	2.73 ± 2.60	0.50 - 14.80
Ca	meq/L	9.42 ±13.16	0.30 - 78.74
Mg	meq/L	18.82 ±21.10	0.85 - 104.24
Na	meq/L	2.98 ± 2.17	0.04 - 8.17
SAR	---	0.87 ± 0.36	0.01 - 1.71
Zn	ppm	39.06 ±108.32	0.40 - 650.00
Fe	ppm	31.6 ±26.0	2.0 - 87.0
Cu	ppm	1.85 ± 1.29	0.05 - 5.50
Mn	ppm	3.3 ± 2.4	0.2 - 9.2
Ni	ppm	0.87 ± 0.39	0.12 - 1.58
Cd	ppm	0.19 ± 0.11	0.06 - 0.58
Pb	ppm	3.27 ± 1.97	0.23 - 7.02
Hg	ppm	0.028 ± 0.018	0.004 - 0.090
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	0.94 ± 0.39	0.40 - 1.71
B	ppm	0.54 ± 0.68	0.01 - 3.49
PO_4-P	ppm	6.5 ± 9.7	0.1 - 32.5
NO_3-N	ppm	0.42 ± 0.61	0.15 - 3.5
NH_4-N	ppm	15.00 ± 7.93	0.50 - 33.77
Clay	%	28.5 ±13.1	8.4 - 54.8
Silt	%	25.2 ±13.0	1.0 - 44.0
Sand	%	46.2 ±23.2	14.4 - 84.2



Appendix A-3. Stratigraphic and chemical data for test hole N43-E55.
(st sd=silty sand, sd sh=sandy shale, sh=shale).

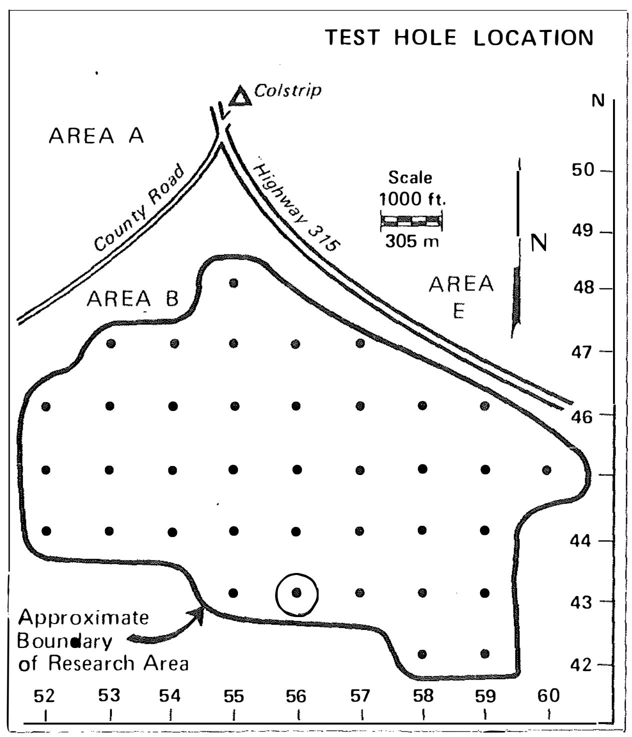


TEST HOLE DESIGNATION N43-E56

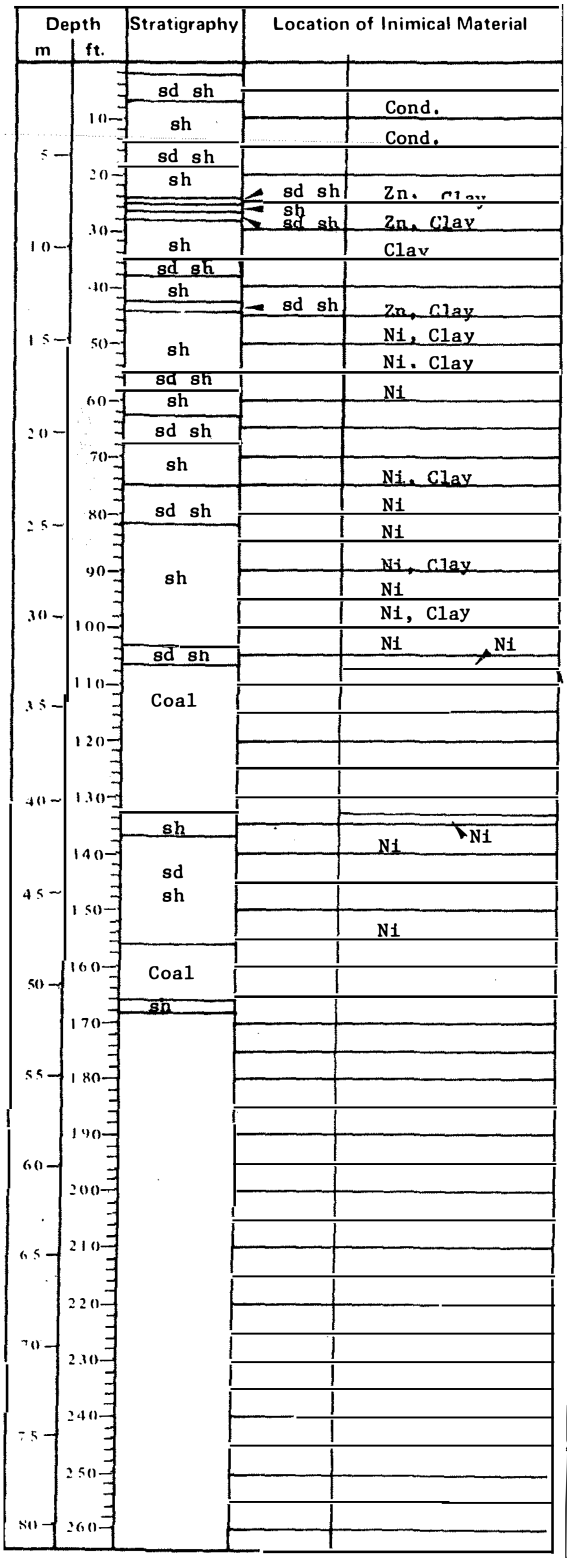
STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	– – –	7.7 ± 0.4	7.0 - 8.3
Saturation	%	37.8 ± 7.1	18.9 - 52.9
Cond.	mmhos/cm	2.64 ± 1.77	1.00 - 8.60
Ca	meq/L	10.53 ± 9.90	3.12 - 56.14
Mg	meq/L	20.24 ± 19.65	6.17 - 81.21
Na	meq/L	8.28 ± 9.56	3.09 - 44.35
SAR	– – –	1.93 ± 1.23	0.58 - 5.45
Zn	ppm	2.95 ± 2.29	0.58 - 10.50
Fe	ppm	15.2 ± 13.8	2.0 - 51.0
Cu	ppm	2.23 ± 1.62	0.20 - 6.30
Mn	ppm	3.7 ± 2.7	0.8 - 10.8
Ni	ppm	1.00 ± 0.59	0.12 - 2.25
Cd	ppm	0.14 ± 0.08	0.06 - 0.35
Pb	ppm	2.31 ± 1.69	0.40 - 8.20
Hg	ppm	0.04 ± 0.03	0.01 - 0.13
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	1.11 ± 0.49	0.54 - 2.75
B	ppm	0.70 ± 0.71	0.01 - 2.61
PO_4-P	ppm	8.01 ± 5.76	4.00 - 37.00
NO_3-N	ppm	0.40 ± 0.50	0.15 - 2.35
NH_4-N	ppm	14.41 ± 5.74	3.38 - 27.01
Clay	%	31.0 ± 17.1	6.0 - 54.4
Silt	%	27.5 ± 15.9	8.2 - 65.4
Sand	%	41.5 ± 21.9	16.4 - 80.8

TEST HOLE LOCATION



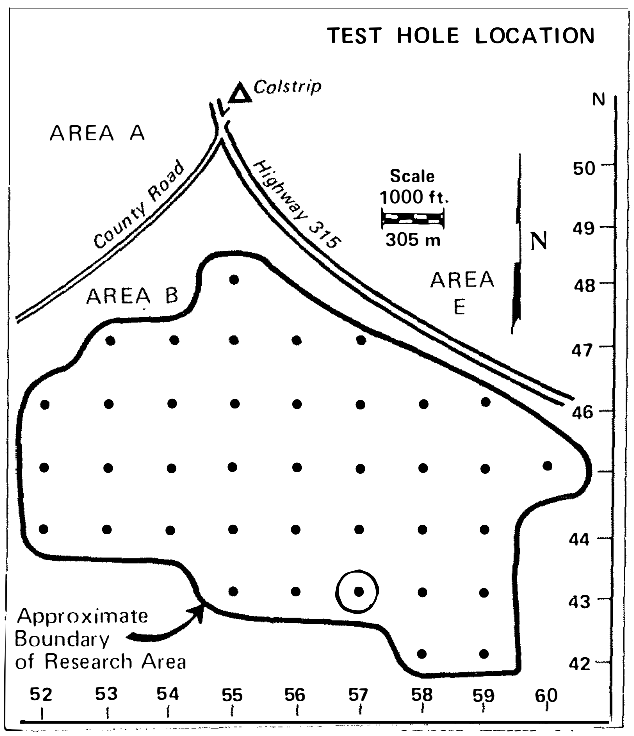
Appendix A-4. Stratigraphic and chemical data for test hole N43-E56. (st sd=silty sand, sd sh=sandy shale, sh=shale).



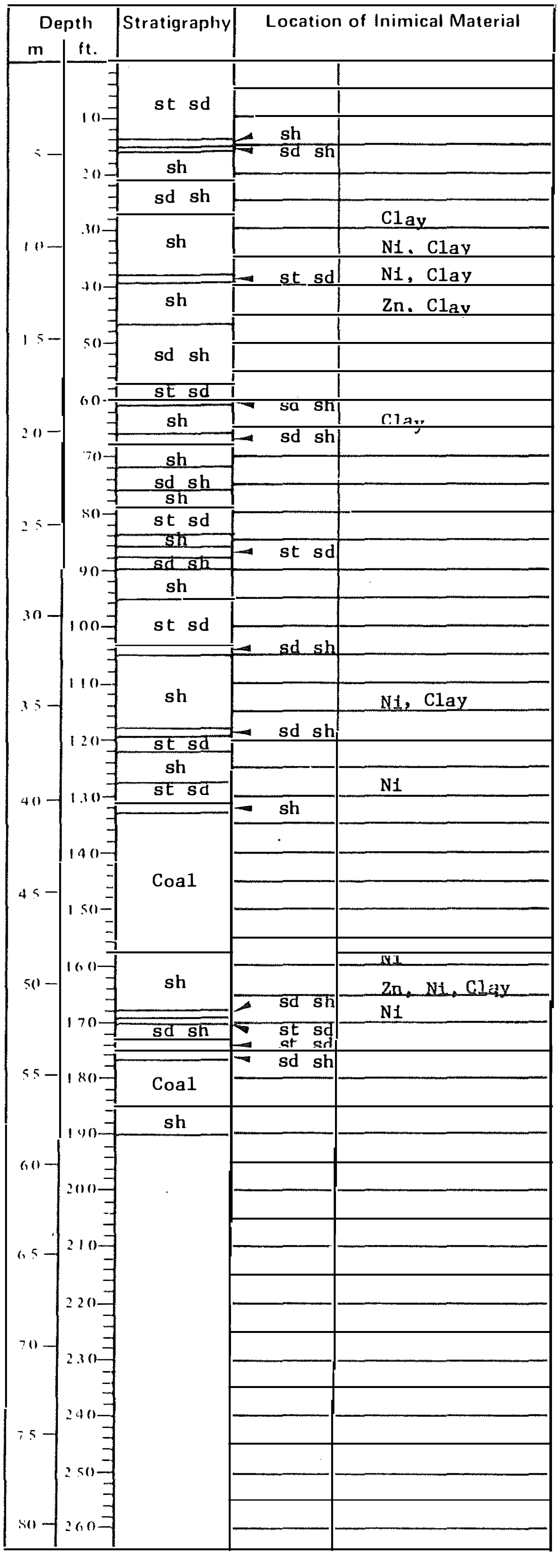
TEST HOLE DESIGNATION N43-E57

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min.–Max
pH	———	8.0 ± 0.3	7.3 – 8.6
Saturation	%	40.2 ± 7.0	28.7 – 56.9
Cond.	mmhos/cm	1.67 ± 1.14	0.43 – 5.30
Ca	meq/L	3.17 ± 1.89	0.90 – 8.38
Mg	meq/L	11.49 ± 11.88	2.57 – 54.29
Na	meq/L	4.96 ± 3.42	0.70 – 13.48
SAR	———	1.79 ± 0.81	0.53 – 3.13
Zn	ppm	10.10 ± 9.53	0.10 – 39.00
Fe	ppm	37.3 ± 30.1	2.6 – 84.0
Cu	ppm	2.10 ± 1.10	0.50 – 5.20
Mn	ppm	2.7 ± 1.8	0.2 – 7.4
Ni	ppm	1.00 ± 0.73	0.06 – 2.28
Cd	ppm	0.16 ± 0.09	0.06 – 0.35
Pb	ppm	4.94 ± 2.47	1.32 – 10.81
Hg	ppm	0.029 ± 0.015	0.002 – 0.062
Se	ppm	0.01 ± 0.004	0.01 – 0.02
Mo	ppm	0.72 ± 0.33	0.11 – 1.38
B	ppm	0.97 ± 0.63	0.46 – 3.16
PO_4-P	ppm	1.2 ± 0.7	0.5 – 3.5
NO_3-N	ppm	0.35 ± 0.62	0.15 – 3.50
NH_4-N	ppm	9.06 ± 4.83	0.50 – 20.26
Clay	%	33.0 ± 14.9	3.2 – 60.2
Silt	%	29.8 ± 10.8	16.6 – 60.8
Sand	%	37.1 ± 18.2	8.8 63.6



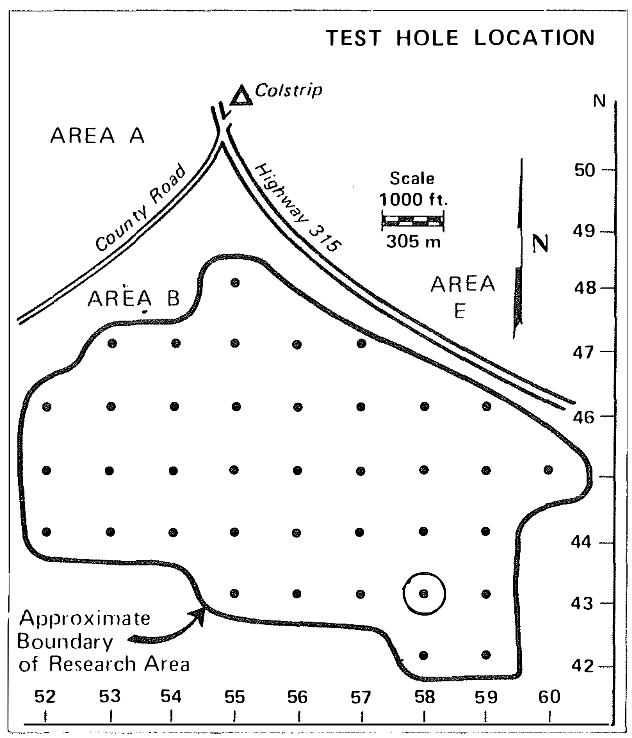
Appendix A-5. Stratigraphic and chemical data for test hole N43-E57. (st sd=silty sand, sd sh= sandy shale, sh=shale).



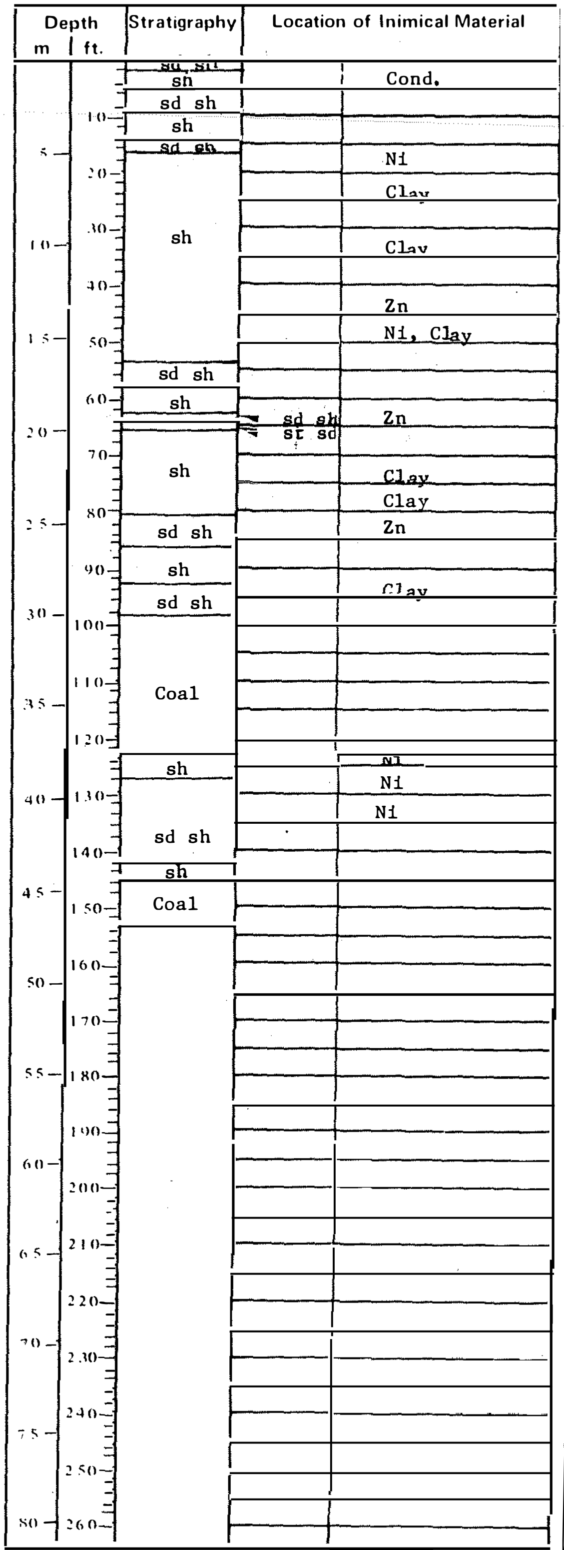
TEST HOLE DESIGNATION N43-E58

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	– – –	7.9 ± 1.5	6.9 - 8.7
Saturation	%	36.2 ± 9.4	19.7 - 53.9
Cond.	mmhos/cm	1.53 ± 0.81	0.34 - 3.20
Ca	meq/L	5.85 ± 4.43	0.90 - 21.96
Mg	meq/L	7.46 ± 4.39	1.44 - 19.54
Na	meq/L	3.27 ± 1.77	0.78 - 5.83
SAR	– – –	1.26 ± 0.50	0.49 - 2.10
Zn	ppm	11.96 ±18.96	1.94 - 100.00
Fe	ppm	31.9 ±20.8	2.2 - 70.0
Cu	ppm	1.58 ± 0.87	0.20 - 2.90
Mn	ppm	3.0 ± 1.3	1.2 - 7.4
Ni	ppm	0.63 ± 0.44	0.06 - 1.72
Cd	ppm	0.18 ± 0.15	0.06 - 0.93
Pb	ppm	2.75 ± 1.82	0.23 - 6.74
Hg	ppm	0.020±0.012	0.006 - 0.068
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	2.24 ± 1.19	0.25 - 4.47
B	ppm	0.26 ± 0.28	0.01 - 1.36
PO_4-P	ppm	0.5 ± 0.4	0.1 - 2.0
NO_3-N	ppm	0.82 ± 0.90	0.15 - 3.50
NH_4-N	ppm	12.62 ± 6.66	0.50 - 27.01
Clay	%	28.9 ±14.9	6.3 - 60.2
Silt	%	26.9 ±15.5	1.3 - 68.6
Sand	%	44.2 ±24.9	16.2 - 92.4



Appendix A-6. Stratigraphic and chemical data for test hole N43-E58.
(st sd=silty sand, sd sh=sandy shale, sh=shale).

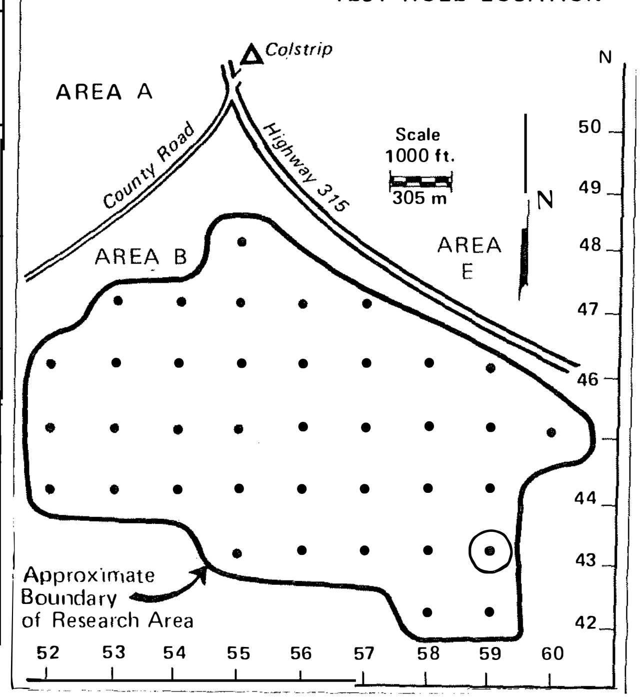


TEST HOLE DESIGNATION N43-E59

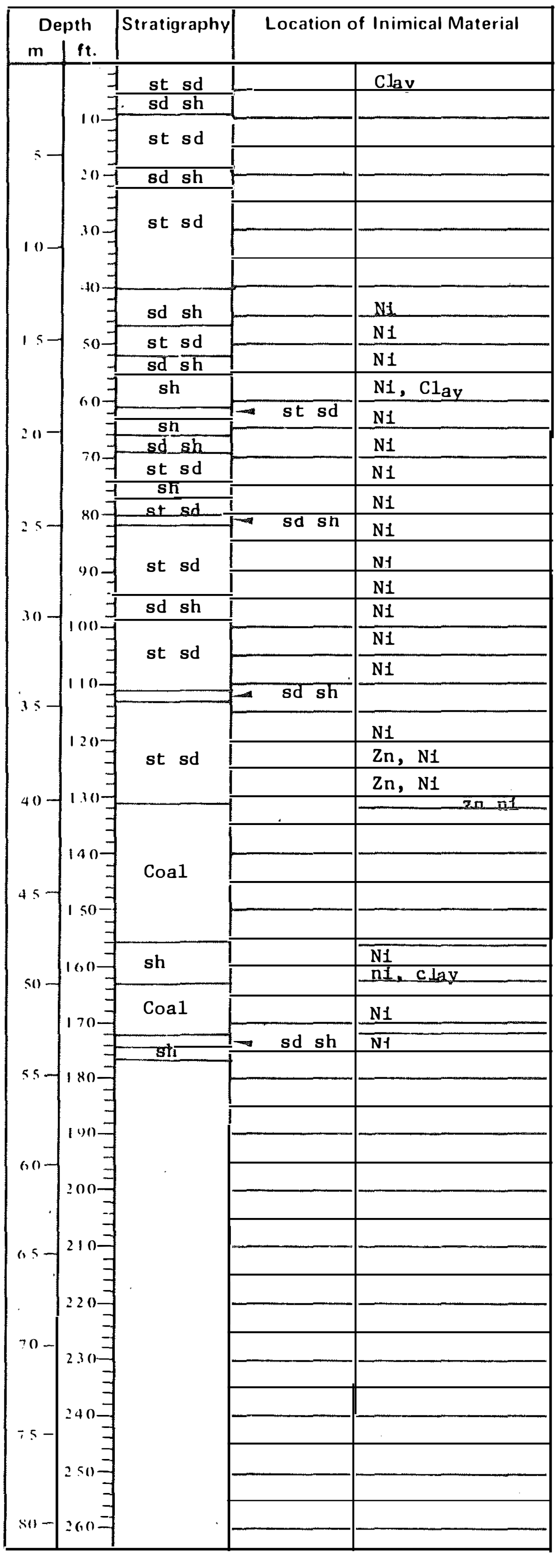
STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min--Max
pH	---	7.8 ± 0.2	7.5 - 8.3
Saturation	%	44.5 ± 9.2	64.9 - 25.0
Cond.	mmhos/cm	2.10 ± 0.81	0.51 - 5.00
Ca	meq/L	5.78 ± 3.30	2.17 - 19.16
Mg	meq/L	9.76 ± 6.90	2.37 - 34.55
Na	meq/L	4.87 ± 2.35	1.61 - 14.78
SAR	---	1.75 ± 0.56	0.82 - 3.29
Zn	ppm	15.44 ± 30.13	1.36 - 130.00
Fe	ppm	44.3 ± 21.9	2.2 - 82.0
Cu	ppm	1.82 ± 1.09	0.40 - 5.50
Mn	ppm	3.7 ± 1.6	0.9 - 6.7
Ni	ppm	0.74 ± 0.44	0.06 - 1.72
Cd	ppm	0.70 ± 1.17	0.06 - 3.75
Pb	ppm	2.41 ± 1.76	0.10 - 6.20
Hg	ppm	0.03 ± 0.03	0.004 - 0.15
Se	ppm	0.01 ± 0.002	0.01 - 0.02
Mo	ppm	0.77 ± 0.58	0.11 - 3.11
B	ppm	0.53 ± 0.63	0.13 - 2.59
PO_4-P	ppm	1.30 ± 2.30	1.00 - 2.00
NO_3-N	ppm	0.82 ± 0.56	0.05 - 2.20
NH_4-N	ppm	11.95 ± 8.70	0.50 - 33.77
Clay	%	30.5 ± 14.39	15.2 - 69.8
Silt	%	31.0 ± 13.8	9.8 - 63.8
Sand	%	39.4 ± 18.3	3.6 - 76.0

TEST HOLE LOCATION



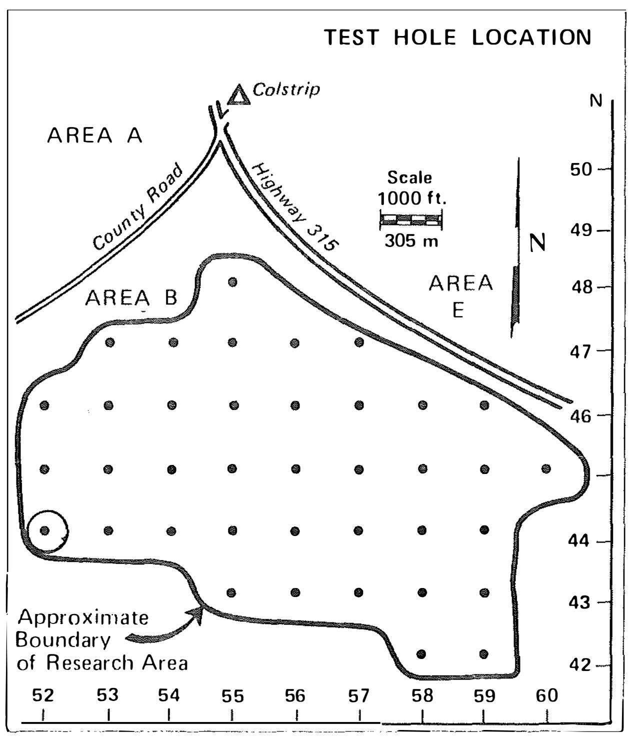
Appendix A-7. Stratigraphic and chemical data for test hole N43-E59. (st sd=silty sand, sd sh= sandy shale, sh=shale).



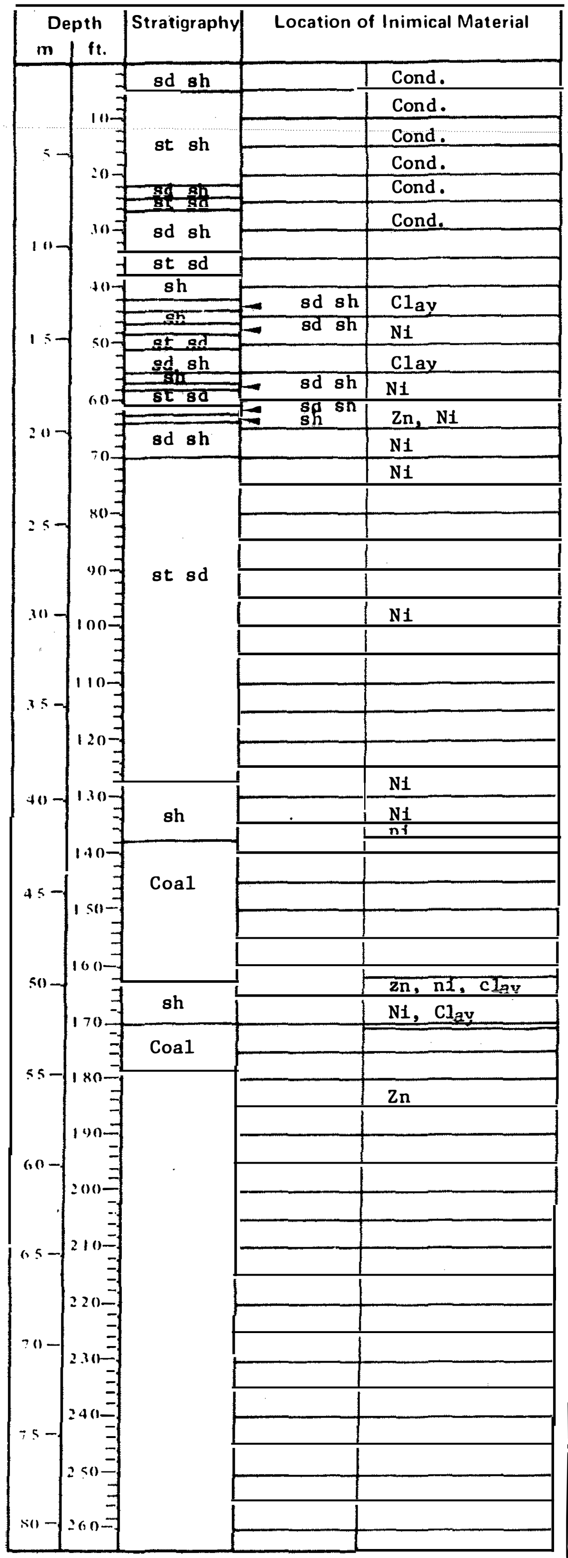
TEST HOLE DESIGNATION N44-E52

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	8.2 ± 2.4	7.3 - 8.8
Saturation	%	36.5 ±11.9	30.1 - 50.4
Cond.	mmhos/cm	0.88 ± 5.7	1.97 - 26.00
Ca	meq/L	4.52 ± 2.93	1.90 - 11.48
Mg	meq/L	5.11 ± 3.84	0.93 - 15.25
Na	meq/L	1.38 ± 1.26	0.17 - 5.57
SAR	---	0.62 ± 1.51	0.12 - 2.38
Zn	ppm	6.51 ± 9.72	0.28 - 49.80
Fe	ppm	20.4 ±11.6	4.6 - 40.0
Cu	ppm	0.74 ± 0.75	0.10 - 3.10
Mn	ppm	1.4 ± 0.7	0.4 - 3.2
Ni	ppm	1.17 ± 0.83	0.06 - 3.00
Cd	ppm	0.09 ± 0.05	0.06 - 0.23
Pb	ppm	2.54 ± 2.30	0.50 - 10.00
Hg	ppm	0.03 ± 0.04	0.001 - 0.19
Se	ppm	0.01 ±0.003	0.01 - 0.02
Mo	ppm	0.63 ± 0.19	0.14 - 0.93
B	ppm	0.57 ± 0.28	0.32 - 1.82
PO_4-P	ppm	0.87 ± 0.82	0.10 - 2.50
NO_3-N	ppm	0.87 ± 0.72	0.15 - 2.85
NH_4-N	ppm	10.24 ± 7.02	0.50 - 23.64
Clay	%	19.6 ±12.2	5.2 - 45.2
Silt	%	30.0 ±14.2	9.6 - 62.4
Sand	%	50.4 ±22.6	24.8 - 82.4



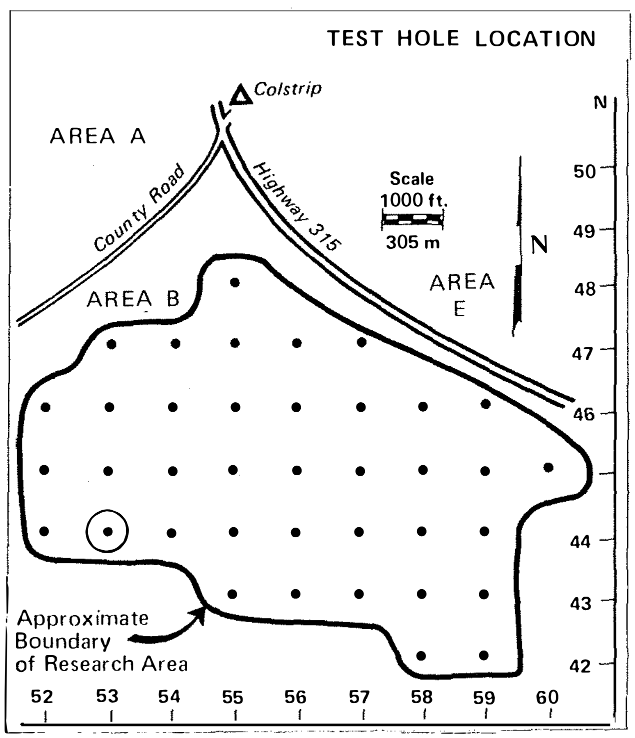
Appendix A-8. Stratigraphic and chemical data for test hole N44-E52. (st sd=silty sand, sd sh=sandy shale, sh=shale).



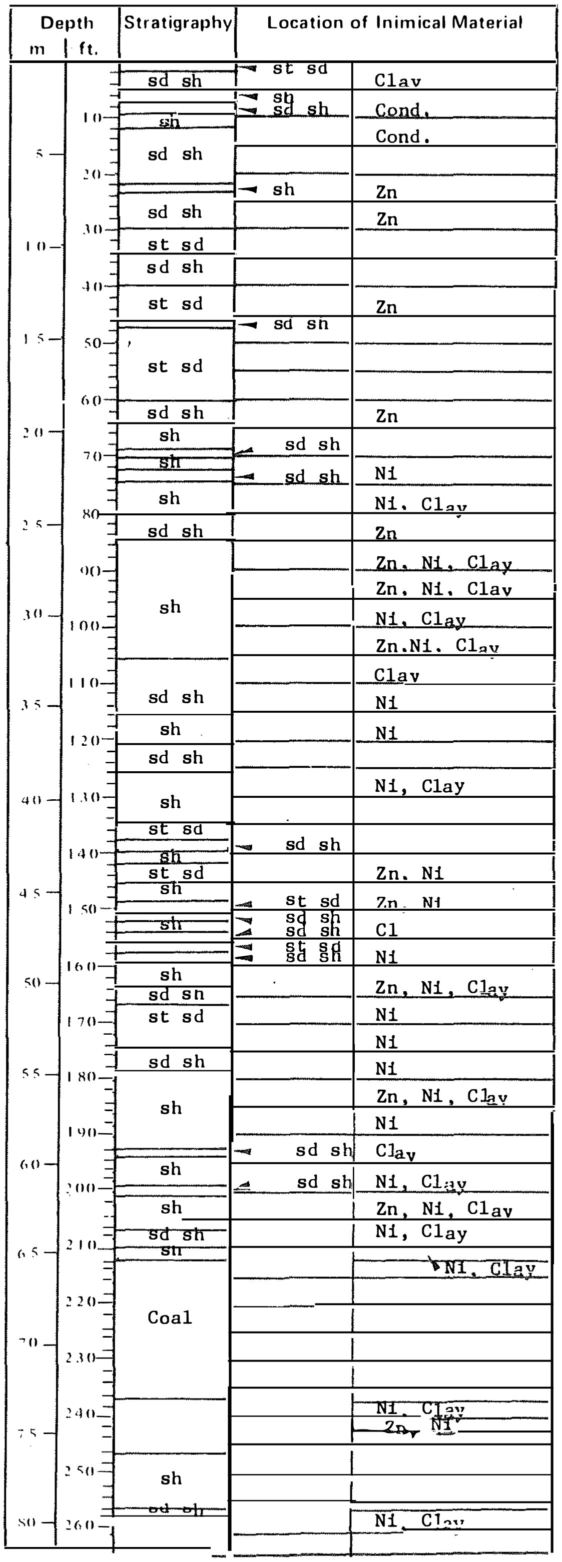
TEST HOLE DESIGNATION N44-E53

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	7.9 ± 0.3	7.3 - 8.3
Saturation	%	35.5 ± 5.9	27.5 - 49.1
Cond.	mmhos/cm	2.68 ± 2.63	1.08 - 9.37
Ca	meq/L	9.27 ± 7.60	2.92 - 26.95
Mg	meq/L	22.74 ± 33.02	4.73 - 117.19
Na	meq/L	7.69 ± 9.37	1.67 - 34.78
SAR	---	1.77 ± 1.02	0.66 - 4.19
Zn	ppm	14.58 ± 23.36	1.40 - 128.00
Fe	ppm	30.3 ± 19.3	5.2 - 72.0
Cu	ppm	1.12 ± 0.91	0.10 - 3.60
Mn	ppm	2.8 ± 1.9	1.0 - 10.2
Ni	ppm	0.97 ± 0.73	0.12 - 3.29
Cd	ppm	0.09 ± 0.06	0.06 - 0.38
Pb	ppm	3.10 ± 2.74	0.23 - 11.90
Hg	ppm	0.043 ± 0.057	0.001 - 0.278
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	0.41 ± 0.16	0.15 - 0.80
B	ppm	0.19 ± 0.22	0.01 - 0.78
PO_4-P	ppm	1.94 ± 1.59	0.50 - 7.80
NO_3-N	ppm	0.16 ± 0.04	0.15 - 0.35
NH_4-N	ppm	24.94 ± 18.01	3.64 - 80.02
Clay	%	22.8 ± 14.8	3.8 - 48.8
Silt	%	32.9 ± 16.7	12.6 - 83.0
Sand	%	44.4 ± 21.9	13.4 - 80.2



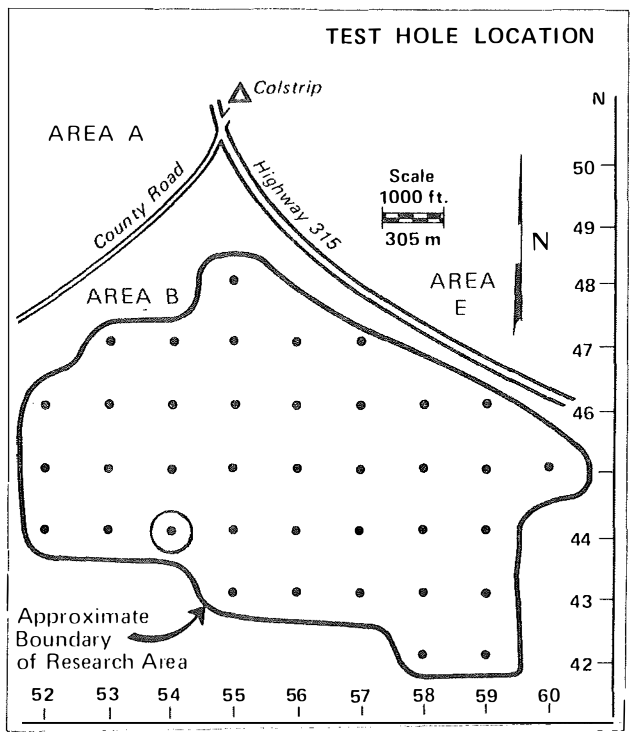
Appendix A-9. Stratigraphic and chemical data for test hole N44-E53. (st sd=silty sand, sd sh=sandy shale, sh=shale).



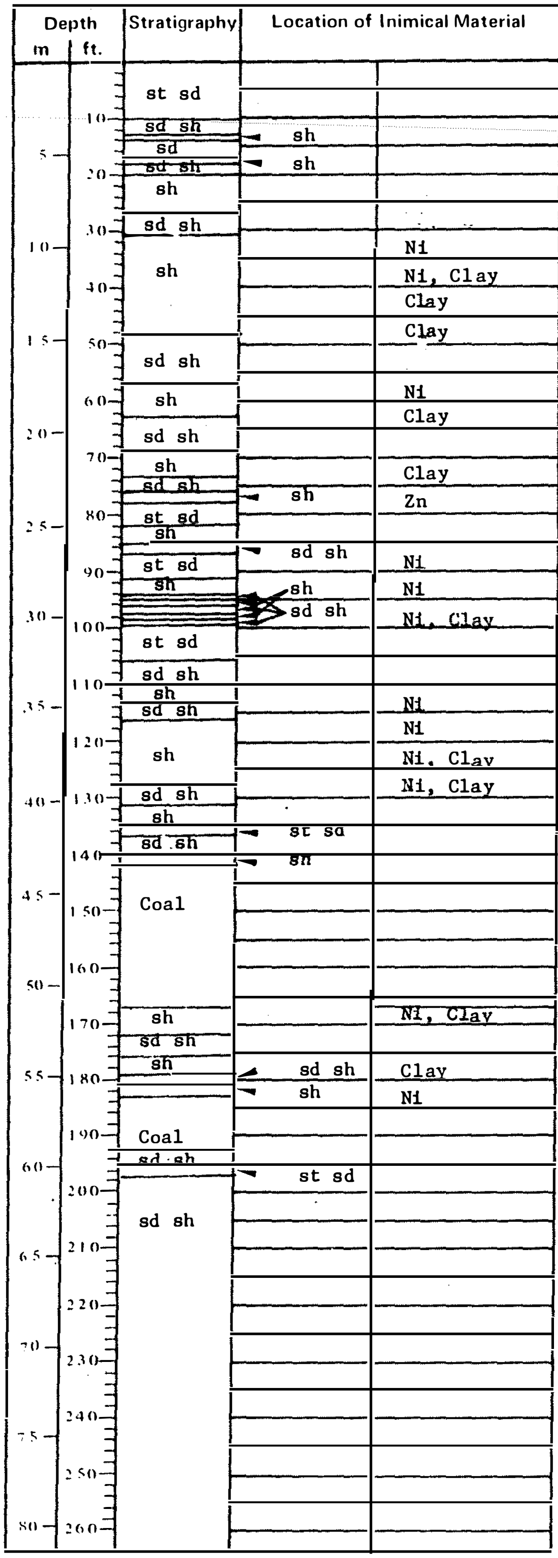
TEST HOLE DESIGNATION N44-E54

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	8.0 ± 0.6	5.0 - 8.5
Saturation	%	41.2 ±10.4	26.3 - 74.4
Cond.	mmhos/cm	1.33 ± 0.92	0.48 - 4.32
Ca	meq/L	5.49 ± 3.42	1.82 - 17.76
Mg	meq/L	7.89 ± 8.55	0.95 - 42.76
Na	meq/L	2.57 ± 2.83	0.39 - 19.13
SAR	---	0.97 ± 0.70	0.21 - 4.53
Zn	ppm	32.60 ±71.25	1.36 - 480.30
Fe	ppm	23.0 ±12.4	2.2 - 40.5
Cu	ppm	1.70 ± 1.14	0.10 - 3.70
Mn	ppm	3.0 ± 1.8	0.4 - 7.6
Ni	ppm	1.18 ± 0.97	0.06 - 5.21
Cd	ppm	0.11 ± 0.06	0.06 - 0.23
Pb	ppm	3.37 ± 1.88	0.50 - 9.19
Hg	ppm	0.019± 0.013	0.004 - 0.056
Se	ppm	0.01 ± 0.00	0.01 - 1.01
Mo	ppm	0.92 ± 0.63	0.07 - 3.01
B	ppm	0.65 ± 0.57	0.07 - 3.26
PO_4-P	ppm	0.96 ± 0.93	0.10 - 5.10
NO_3-N	ppm	1.06 ± 0.61	0.15 - 2.20
NH_4-N	ppm	11.45 ± 5.92	3.38 - 30.39
Clay	%	32.6 ± 15.5	5.2 - 60.2
Silt	%	26.9 ± 11.3	5.4 - 54.0
Sand	%	39.8 ± 21.1	13.6 - 83.8



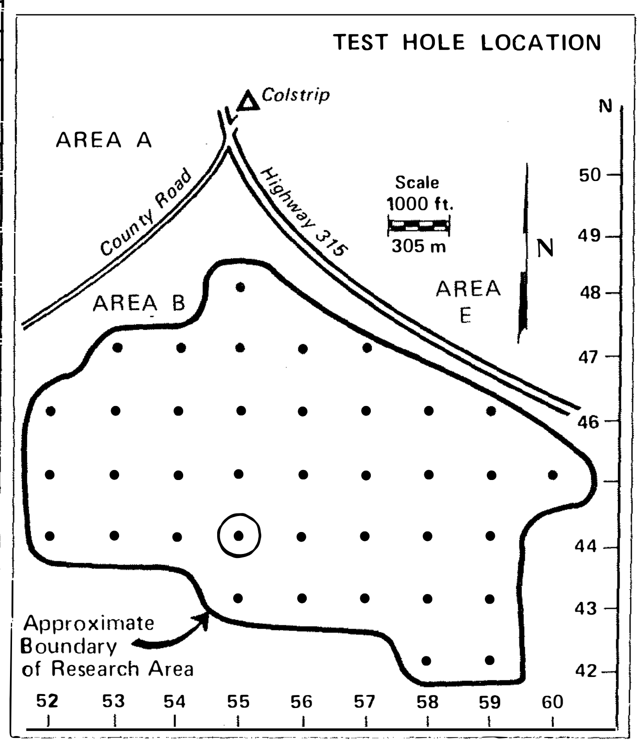
Appendix A-10. Stratigraphic and chemical data for test hole N44-E54. (st sd=silty sand, sd sh=sandy shale, sh=shale).



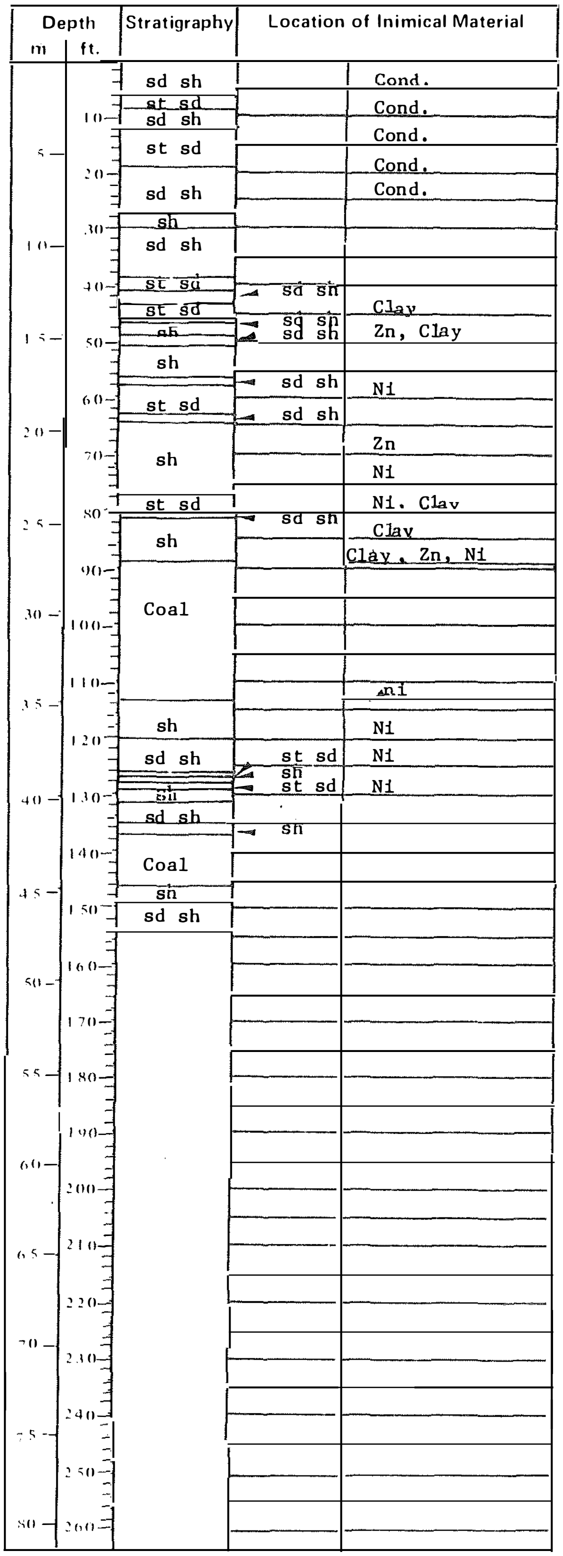
TEST HOLE DESIGNATION N44-E55

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	7.8 ± 1.4	7.0 - 8.5
Saturation	%	39.3 ± 9.6	27.7 - 53.5
Cond.	mmhos/cm	1.58 ± 0.75	0.35 - 3.30
Ca	meq/L	5.17 ± 2.58	0.90 - 14.77
Mg	meq/L	7.74 ± 3.56	1.65 - 14.40
Na	meq/L	3.32 ± 1.94	0.61 - 7.30
SAR	---	1.31 ± 0.70	0.41 - 3.40
Zn	ppm	6.48 ± 6.07	0.78 - 34.6
Fe	ppm	41.2 ± 25.6	2.8 - 93.0
Cu	ppm	1.36 ± 0.85	0.05 - 3.20
Mn	ppm	3.2 ± 1.7	1.0 - 8.6
Ni	ppm	0.65 ± 0.42	0.06 - 1.31
Cd	ppm	0.13 ± 0.06	0.06 - 0.23
Pb	ppm	2.92 ± 1.65	0.23 - 5.93
Hg	ppm	0.021 ± 0.016	0.001 - 0.080
Se	ppm	0.01 ± 0.002	0.01 - 0.02
Mo	ppm	1.21 ± 0.88	0.04 - 4.65
B	ppm	0.36 ± 0.34	0.02 - 1.61
PO_4-P	ppm	0.64 ± 0.44	0.10 - 1.00
NO_3-N	ppm	0.31 ± 0.69	0.15 - 4.10
NH_4-N	ppm	11.78 ± 6.07	0.50 - 27.01
Clay	%	33.3 ± 15.6	10.9 - 77.6
Silt	%	27.8 ± 12.1	8.9 - 54.8
Sand	%	39.6 ± 18.1	15.4 - 80.2



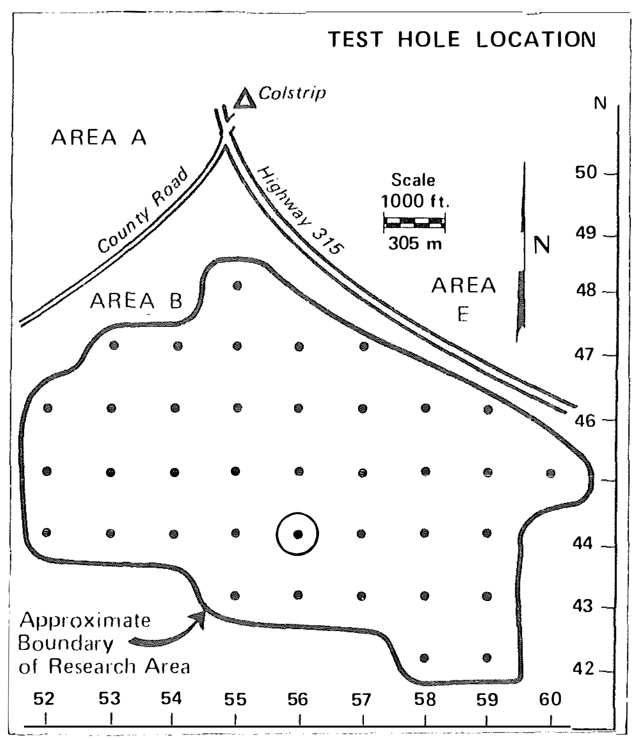
Appendix A-11. Stratigraphic and chemical data for test hole N44-E55. (st sd=silty sand, sd sh=sandy shale, sh=shale).



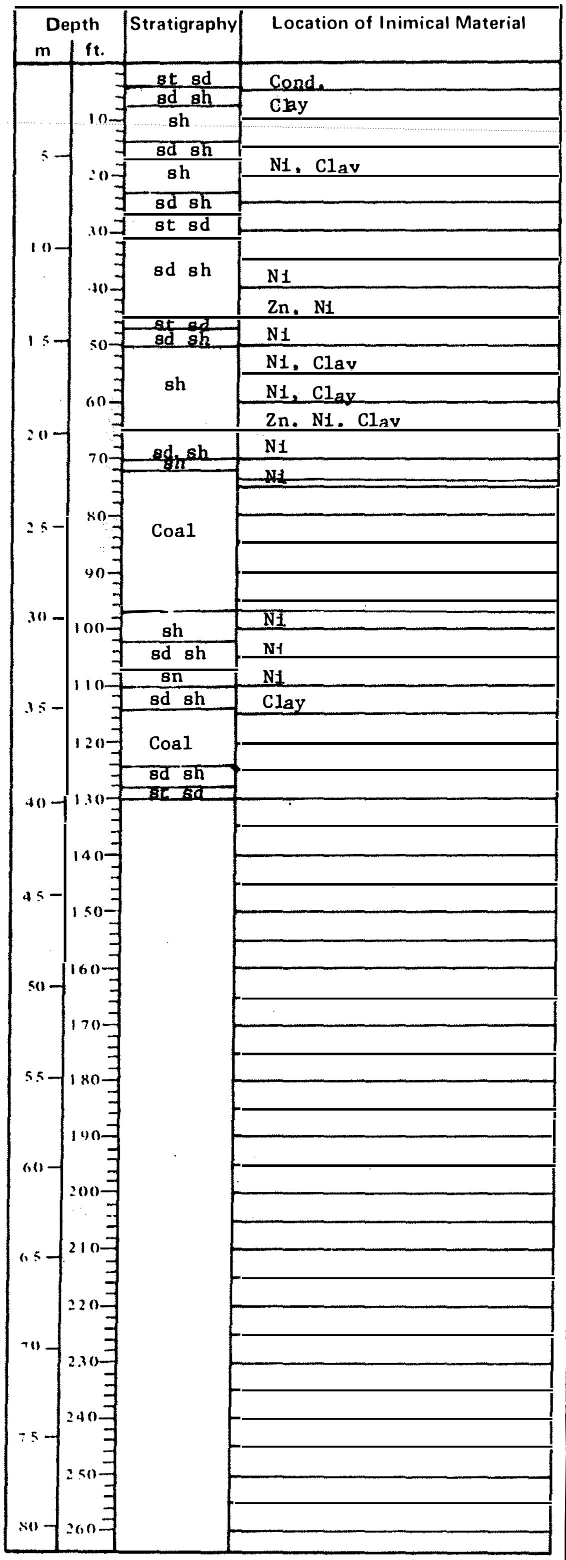
TEST HOLE DESIGNATION N44-E56

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min--Max
pH	---	8.1 ± 0.1	7.6 - 8.3
Saturation	%	38.6 ± 5.0	30.4 - 47.8
Cond.	mmhos/cm	2.85 ± 2.15	1.10 - 8.0
Ca	meq/L	5.37 ± 4.21	1.9 - 21.21
Mg	meq/L	22.26 ± 23.08	5.35 - 79.96
Na	meq/L	8.35 ± 9.70	2.22 - 38.87
SAR	---	2.05 ± 1.29	0.94 - 5.57
Zn	ppm	13.72 ± 18.80	2.00 - 74.00
Fe	ppm	36.1 ± 28.8	3.8 - 83.0
Cu	ppm	1.50 ± 0.85	0.50 - 3.70
Mn	ppm	2.8 ± 2.0	0.2 - 7.4
Ni	ppm	0.82 ± 0.57	0.06 - 2.00
Cd	ppm	0.14 ± 0.08	0.06 - 0.35
Pb	ppm	3.35 ± 1.86	0.70 - 7.83
Hg	ppm	0.031 ± 0.018	0.002 - 0.064
Se	ppm	0.01 ± 0.003	0.01 - 0.02
Mo	ppm	1.50 ± 0.62	0.67 - 3.10
B	ppm	0.52 ± 0.32	0.10 - 1.55
PO_4-P	ppm	3.72 ± 7.41	0.10 - 32.50
NO_3-N	ppm	0.46 ± 0.84	0.15 - 3.50
NH_4-N	ppm	7.80 ± 6.23	0.50 - 20.26
Clay	%	27.6 ± 17.1	2.2 - 52.0
Silt	%	41.3 ± 17.9	14.0 - 63.2
Sand	%	31.2 ± 18.3	12.8 - 68.2



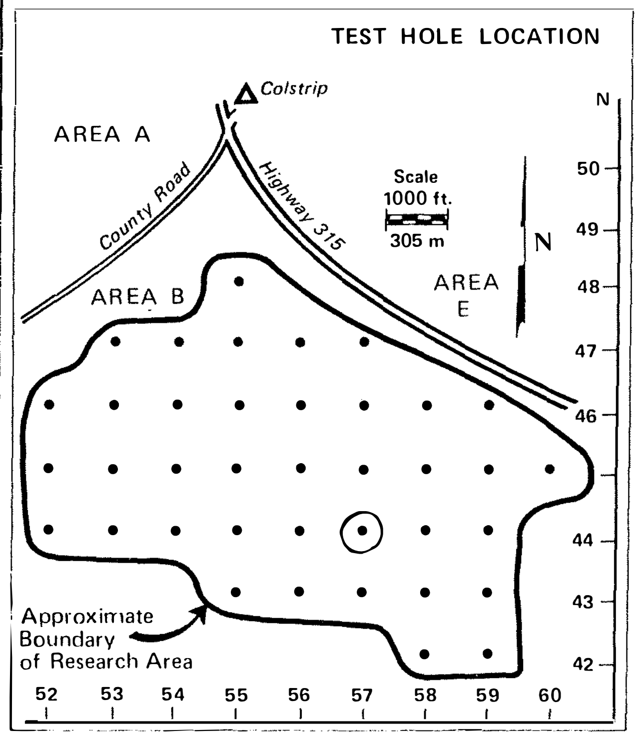
Appendix A-12. Stratigraphic and chemical data for test hole N44-E56. (st sd=silty sand, sd sh=sandy shale, sh=shale).



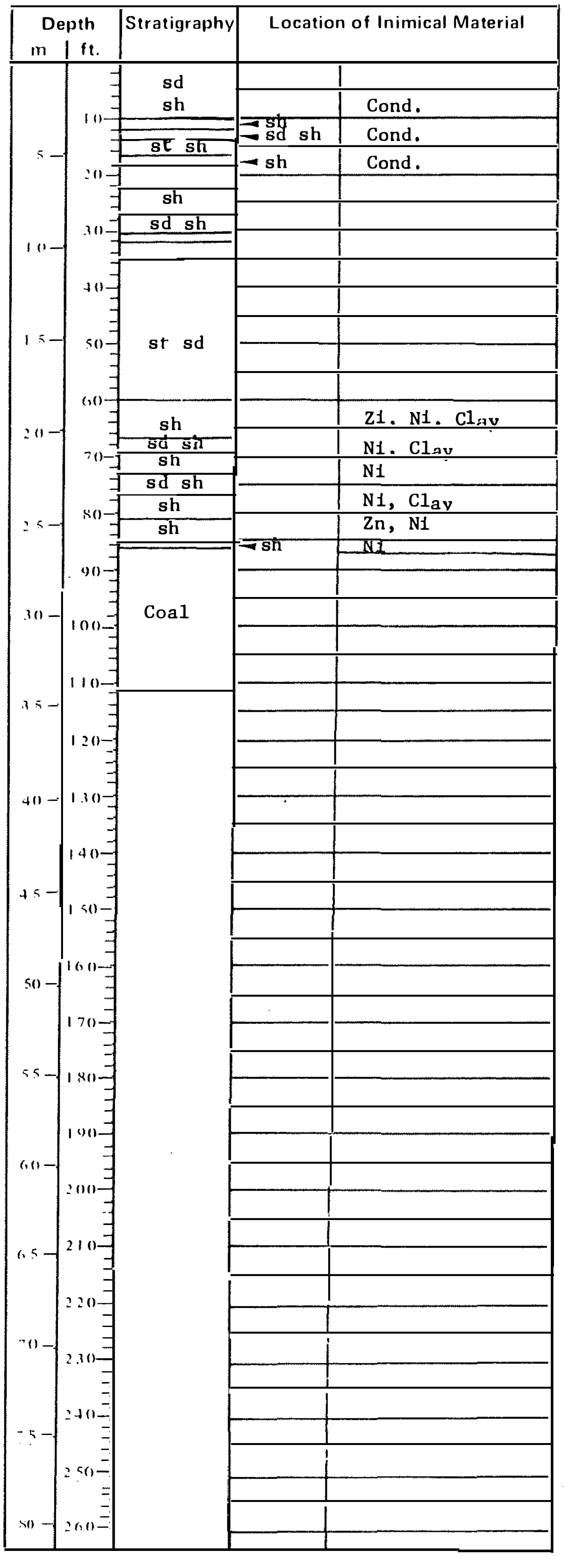
TEST HOLE DESIGNATION N44-E57

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	– – –	7.9 ± 0.3	7.3 - 8.3
Saturation	%	37.5 ± 6.4	29.4 - 47.6
Cond.	mmhos/cm	2.02 ± 1.00	0.90 - 5.60
Ca	meq/L	7.62 ± 4.82	2.17 - 21.56
Mg	meq/L	11.66 ± 11.81	2.47 - 57.36
Na	meq/L	4.87 ± 2.24	1.72 - 8.57
SAR	– – –	1.67 ± 0.92	0.66 - 4.44
Zn	ppm	15.39 ± 17.46	1.94 - 79.8
Fe	ppm	40.8 ± 25.9	5.5 - 92.0
Cu	ppm	2.31 ± 1.00	0.40 - 4.20
Mn	ppm	4.8 ± 2.8	1.2 - 13.0
Ni	ppm	1.30 ± 0.84	0.12 - 2.57
Cd	ppm	0.19 ± 0.12	0.06 - 0.46
Pb	ppm	4.03 ± 2.02	0.78 - 7.83
Hg	ppm	0.03 ± 0.02	0.003 - 0.07
Se	ppm	0.01 ± 0.004	0.01 - 0.02
Mo	ppm	1.18 ± 1.07	0.04 - 3.82
B	ppm	0.38 ± 0.25	0.10 - 0.87
PO_4-P	ppm	2.14 ± 0.99	0.50 - 4.40
NO_3-N	ppm	0.65 ± 0.57	0.15 - 1.55
NH_4-N	ppm	19.83 ± 11.30	6.80 - 49.69
Clay	%	30.5 ± 12.4	13.0 - 52.2
Silt	%	37.4 ± 10.2	19.4 - 59.0
Sand	%	32.1 ± 15.7	12.4 - 67.3



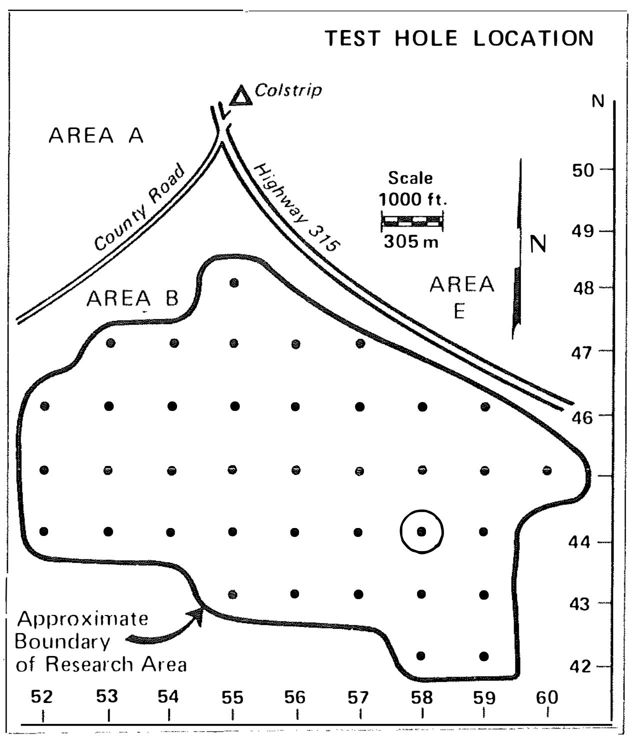
Appendix A-13. Stratigraphic and chemical data for test hole N44-E57. (st sd=silty sand, sd sh=sandy shale, sh=shale).



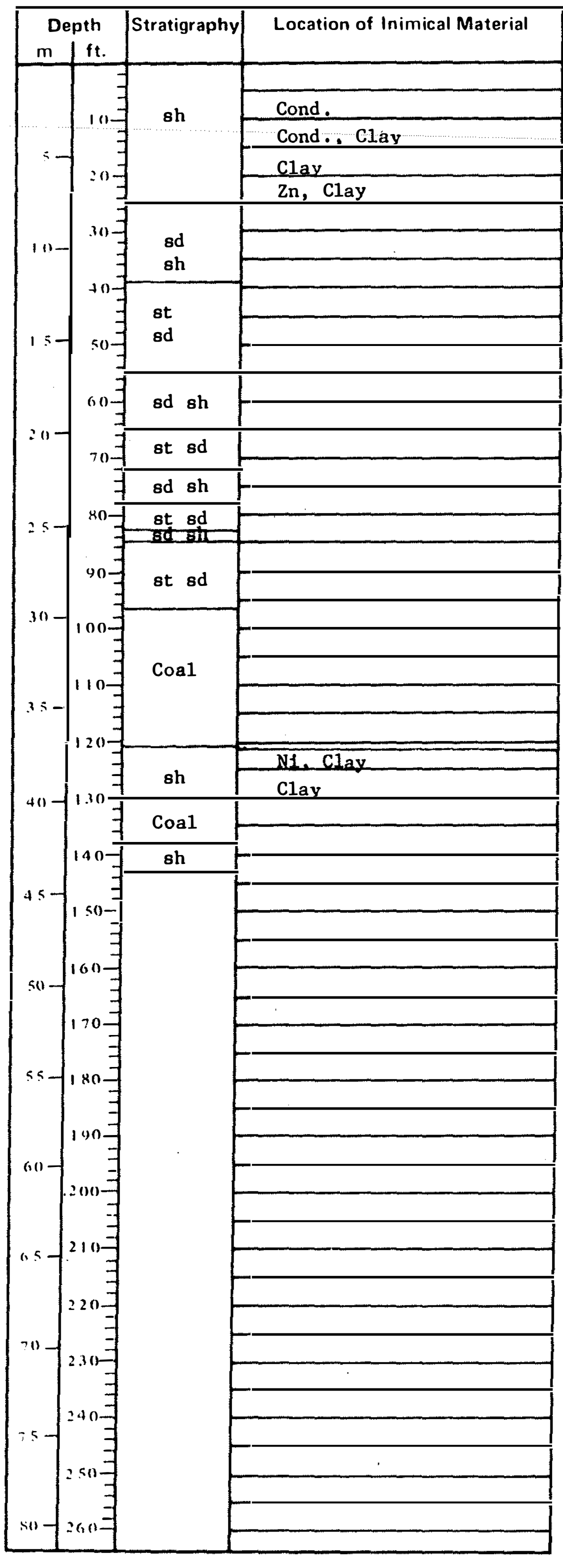
TEST HOLE DESIGNATION N44-E58

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	8.3 ± 0.3	8.0 - 8.8
Saturation	%	38.4 ± 6.6	28.7 - 48.2
Cond.	mmhos/cm	2.31 ± 2.8	0.46 - 10.20
Ca	meq/L	6.36 ± 6.74	1.30 - 21.71
Mg	meq/L	15.20 ±21.79	2.39 - 75.02
Na	meq/L	8.70 ±15.24	0.78 - 56.00
SAR	---	1.98 ± 2.24	0.54 - 8.13
Zn	ppm	13.24 ±19.36	0.86 - 84.60
Fe	ppm	27.7 ±27.9	4.0 - 88.0
Cu	ppm	1.49 ± 1.14	0.20 - 3.20
Mn	ppm	2.8 ± 2.0	1.0 - 6.7
Ni	ppm	0.89 ± 0.75	0.12 - 2.14
Cd	ppm	0.17 ± 0.12	0.06 - 0.58
Pb	ppm	3.16 ± 3.12	0.50 - 9.73
Hg	ppm	0.040± 0.027	0.001 - 0.128
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	1.37 ± 0.70	0.15 - 3.12
B	ppm	0.39 ± 0.30	0.01 - 1.20
PO_4-P	ppm	1.42 ± 1.62	0.10 - 6.00
NO_3-N	ppm	1.30 ± 0.74	0.15 - 2.20
NH_4-N	ppm	9.94 ± 5.49	3.38 - 16.88
Clay	%	27.4 ±15.9	3.2 - 56.8
Silt	%	28.8 ±15.7	6.3 - 60.6
Sand	%	43.8 ±21.7	15.2 - 80.9



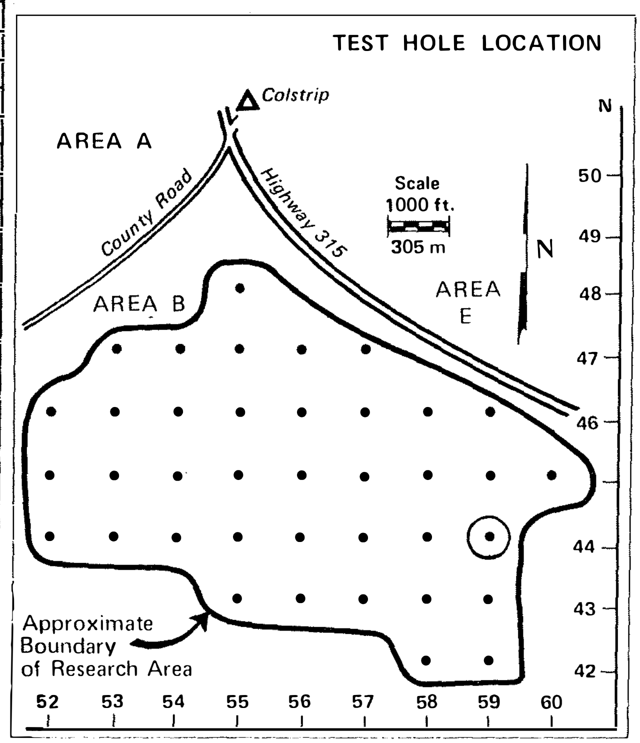
Appendix A-14. Stratigraphic and chemical data for test hole N44-E58. (st sd=silty sand, sd sh=sandy shale, sh=shale).



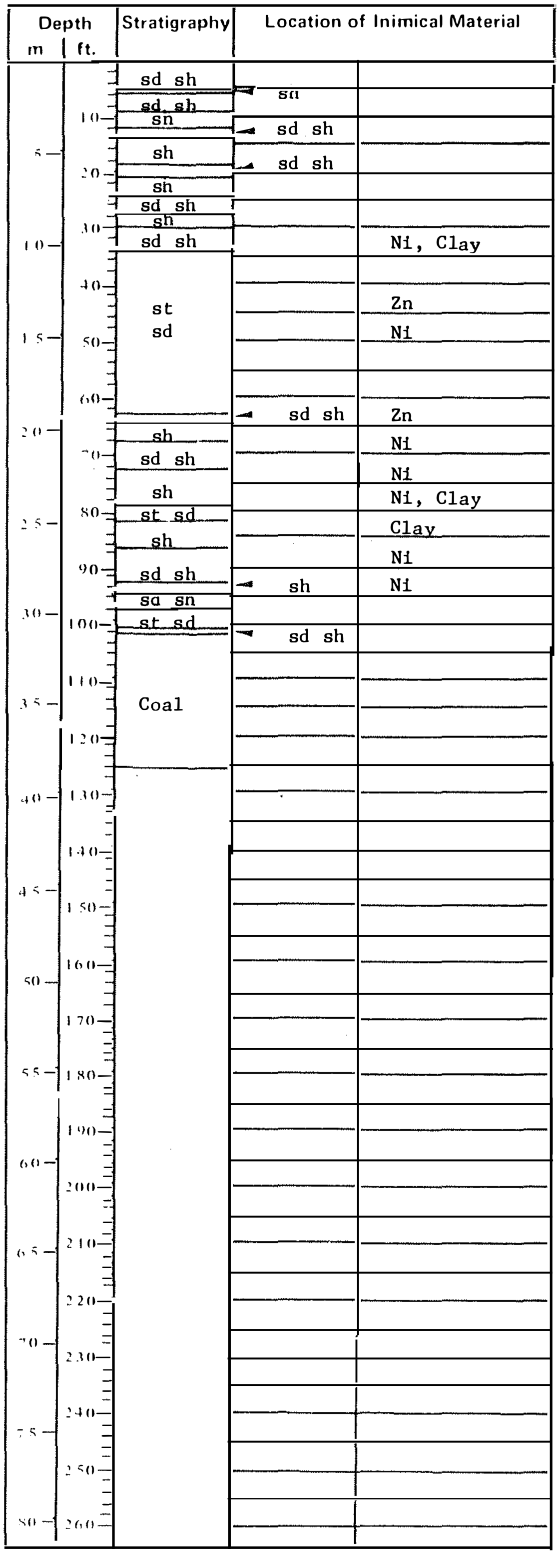
TEST HOLE DESIGNATION N44-E59

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min--Max
pH	---	7.65 ± 0.47	6.50 - 8.40
Saturation	%	36.57 ± 10.24	24.30 - 58.60
Cond.	mmhos/cm	2.46 ± 1.62	0.70 - 8.20
Ca	meq/L	7.70 ± 6.53	2.31 - 27.45
Mg	meq/L	19.97 ± 20.43	2.15 - 99.71
Na	meq/L	6.35 ± 5.30	2.70 - 25.91
SAR	---	1.64 ± 0.58	1.18 - 3.25
Zn	ppm	7.63 ± 10.07	1.08 - 50.00
Fe	ppm	8.26 ± 4.55	4.00 - 25.00
Cu	ppm	1.30 ± 1.68	0.05 - 4.80
Mn	ppm	1.82 ± 0.68	0.80 - 4.10
Ni	ppm	0.54 ± 0.29	0.25 - 1.60
Cd	ppm	0.12 ± 0.07	0.05 - 0.30
Pb	ppm	1.38 ± 1.36	0.40 - 6.25
Hg	ppm	0.04 ± 0.01	0.001 - 0.06
Se	ppm	0.01 ± 0.003	0.01 - 0.02
Mo	ppm	0.69 ± 0.25	0.39 - 1.38
B	ppm	0.52 ± 0.66	0.04 - 2.10
PO_4-P	ppm	6.65 ± 6.31	1.00 - 30.00
NO_3-N	ppm	1.14 ± 1.26	0.15 - 5.95
NH_4-N	ppm	15.26 ± 11.11	3.38 - 53.77
Clay	%	22.70 ± 16.22	5.20 - 61.00
Silt	%	19.56 ± 16.71	4.80 - 71.00
Sand	%	56.86 ± 28.47	10.40 - 84.00



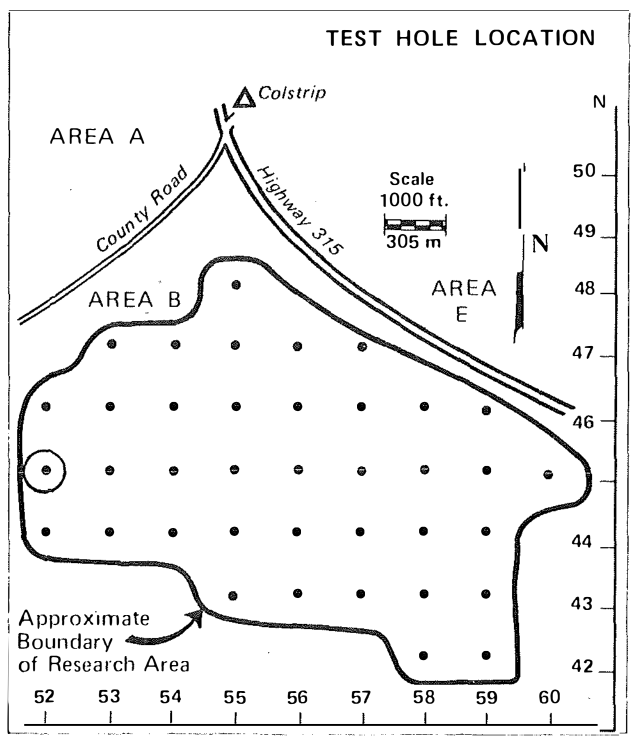
Appendix A-15. Stratigraphic and chemical data for test hole N44-E59. (st sd=silty sand, sd sh=sandy shale, sh=shale).



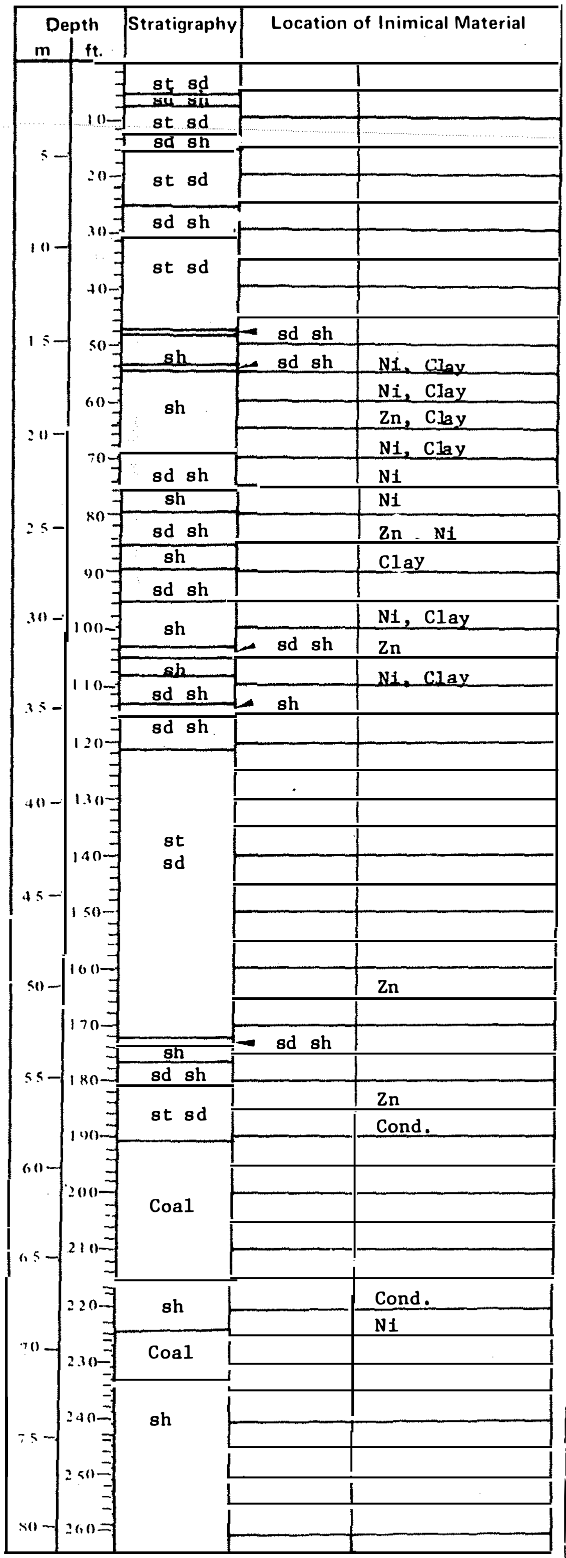
TEST HOLE DESIGNATION N45-E52

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	— — —	8.3 ± 0.2	7.9 - 8.6
Saturation	%	41.3 ± 9.1	30.9 - 63.1
Cond.	mmhos/cm	1.34 ± 0.72	0.46 - 3.15
Ca	meq/L	6.10 ± 5.95	2.42 - 23.75
Mg	meq/L	8.25 ± 5.26	1.85 - 22.20
Na	meq/L	2.43 ± 1.08	0.39 - 4.43
SAR	— — —	0.97 ± 0.40	0.24 - 1.69
Zn	ppm	8.59 ± 11.27	0.08 - 36.00
Fe	ppm	18.6 ± 12.4	3.8 - 49.0
Cu	ppm	0.85 ± 0.64	0.10 - 2.20
Mn	ppm	2.2 ± 1.4	0.40 - 7.1
Ni	ppm	0.76 ± 0.64	0.06 - 2.00
Cd	ppm	0.46 ± 0.91	0.06 - 3.45
Pb	ppm	2.35 ± 1.71	0.10 - 7.02
Hg	ppm	0.018 ± 0.018	0.0005 - 0.064
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	1.63 ± 0.29	1.30 - 2.35
B	ppm	0.57 ± 0.34	0.36 - 1.90
PO_4-P	ppm	6.08 ± 10.00	0.80 - 30.80
NO_3-N	ppm	0.48 ± 0.36	0.15 - 0.95
NH_4-N	ppm	7.30 ± 6.57	0.50 - 29.10
Clay	%	25.4 ± 13.8	7.2 - 51.8
Silt	%	32.0 ± 13.3	12.8 - 57.4
Sand	%	43.1 ± 23.0	12.8 - 80.0



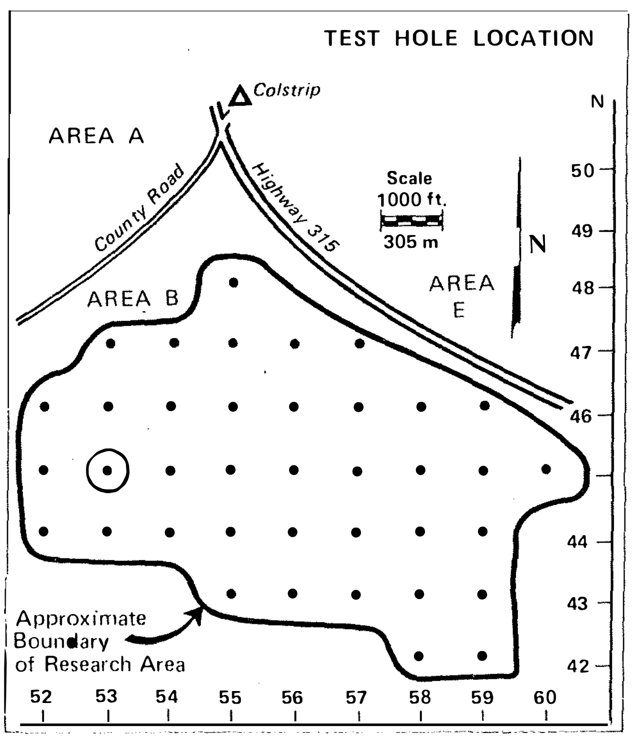
Appendix A-16. Stratigraphic and chemical data for test hole N45-E52. (st sd=silty sand, sd sh=sandy shale, sh=shale).



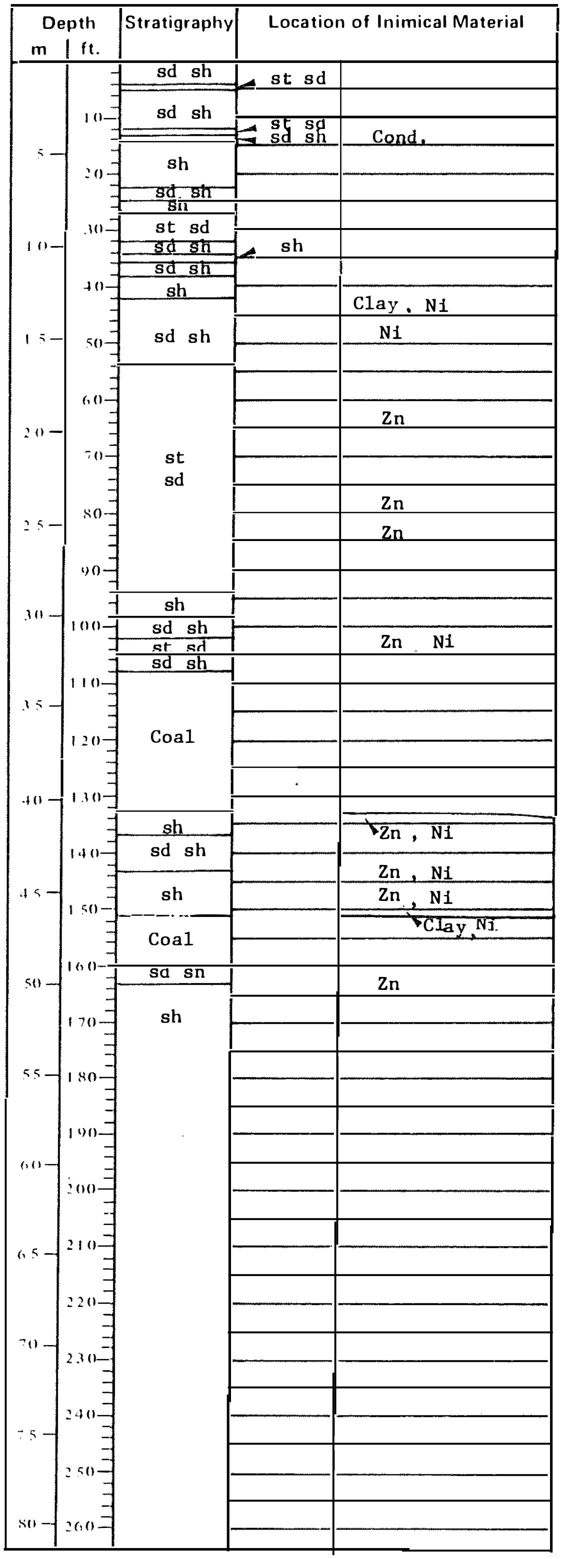
TEST HOLE DESIGNATION N45-E53

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min.–Max
pH	---	8.0 ± 0.3	7.1 - 8.5
Saturation	%	36.0 ± 8.6	24.8 - 63.6
Cond.	mmhos/cm	1.50 ± 1.78	0.27- 10.70
Ca	meq/L	5.78 ±10.09	1.07- 65.87
Mg	meq/L	9.82 ±12.64	0.82- 62.34
Na	meq/L	2.33 ± 2.50	0.39- 12.61
SAR	---	0.88 ± 0.73	0.31- 4.46
Zn	ppm	11.01 ±13.58	0.20- 51.48
Fe	ppm	23.3 ±13.4	3.2 - 52.0
Cu	ppm	1.02 ± 0.89	0.05- 3.10
Mn	ppm	1.9 ± 1.1	1.0 - 7.3
Ni	ppm	0.66 ± 0.43	0.06- 1.58
Cd	ppm	0.15 ± 0.09	0.06- 0.35
Pb	ppm	2.61 ± 2.29	0.12- 8.37
Hg	ppm	0.031 ±0.024	0.004- 0.108
Se	ppm	0.01 ± 0.00	0.01- 0.01
Mo	ppm	1.06 ± 1.14	0.07- 3.64
B	ppm	0.34 ± 0.50	0.01- 3.01
PO_4-P	ppm	3.76 ± 5.19	0.10- 19.30
NO_3-N	ppm	0.54 ± 0.70	0.15- 2.85
NH_4-N	ppm	17.77 ± 12.61	0.50- 80.02
Clay	%	23.2 ± 15.4	6.6 - 52.4
Silt	%	23.2 ± 19.9	4.6 - 51.0
Sand	%	53.6 ± 26.7	14.8 - 87.2



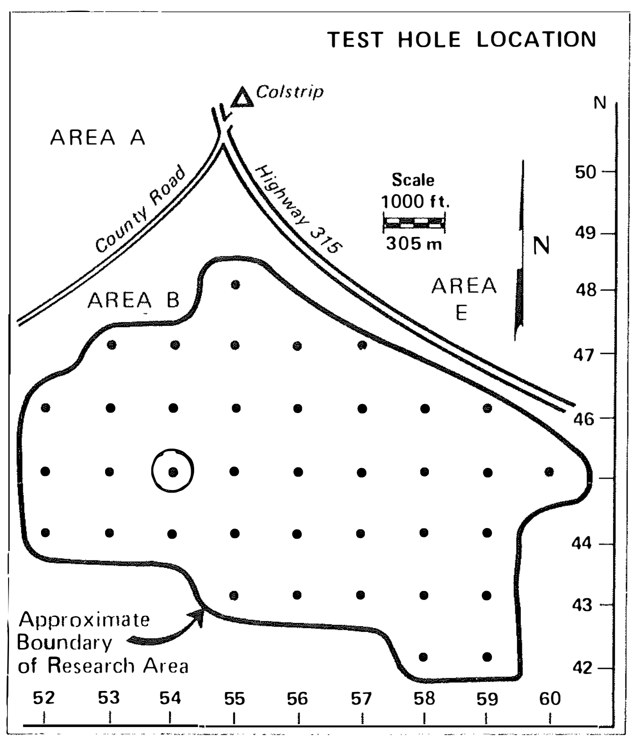
Appendix A-17. Stratigraphic and chemical data for test hole N45-E53. (st sd=silty sand, sd sh=sandy shale, sh=shale).



TEST HOLE DESIGNATION N45-E54

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	– – –	8.1 ± .4	6.7 - 8.6
Saturation	%	35.3 ± 7.4	25.6 - 51.3
Cond.	mmhos/cm	1.58 ± 1.29	0.57 - 7.29
Ca	meq/L	5.82 ± 5.92	1.40 - 29.94
Mg	meq/L	9.99 ±13.90	2.88 - 76.48
Na	meq/L	3.60 ± 3.94	0.91 - 21.74
SAR	– – –	1.25 ± 0.72	0.49 - 3.40
Zn	ppm	44.51 ±86.93	0.36 - 332.00
Fe	ppm	15.4 ±12.0	2.4 - 52.0
Cu	ppm	0.70 ± 0.68	0.05 - 2.3
Mn	ppm	2.2 ± 1.3	0.4 - 5.2
Ni	ppm	0.71 ± 0.65	0.06 - 3.14
Cd	ppm	0.18 ± 0.10	0.06 - 0.35
Pb	ppm	2.60 ± 1.96	0.12 - 7.29
Hg	ppm	0.020 ± 0.012	0.004 - 0.10
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	0.28 ± 0.13	0.07 - 0.61
B	ppm	0.36 ± 0.20	0.05 - 0.82
PO_4-P	ppm	1.18 ± 0.55	0.50 - 2.50
NO_3-N	ppm	0.47 ± 0.60	0.15 - 2.85
NH_4-N	ppm	10.68 ± 8.57	3.64 - 43.66
Clay	%	21.5 ±10.8	7.2 - 45.2
Silt	%	31.2 ±14.3	10.8 - 64.0
Sand	%	47.8 ± 21.5	10.4 - 80.0



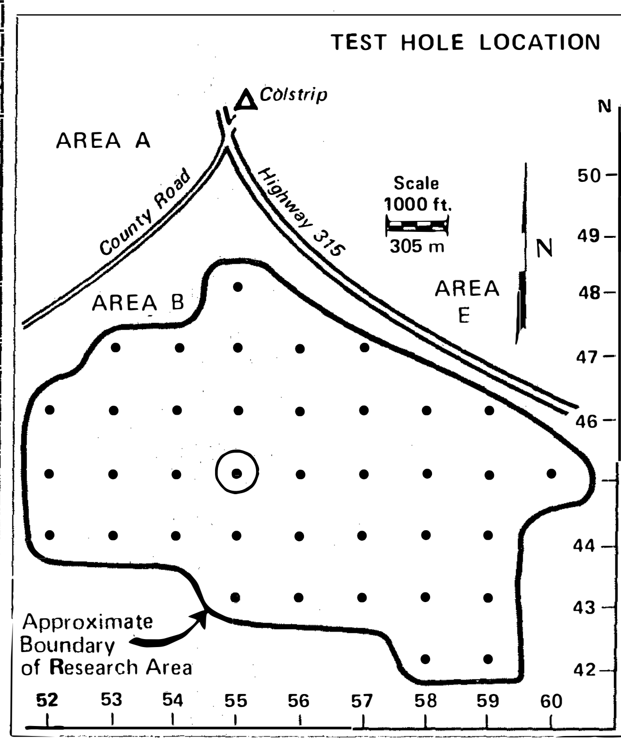
Appendix A-18. Stratigraphic and chemical data for test hole N45-E54. (st sd=silty sand, sd sh=sandy shale, sh=shale).

TEST HOLE DESIGNATION N45E55

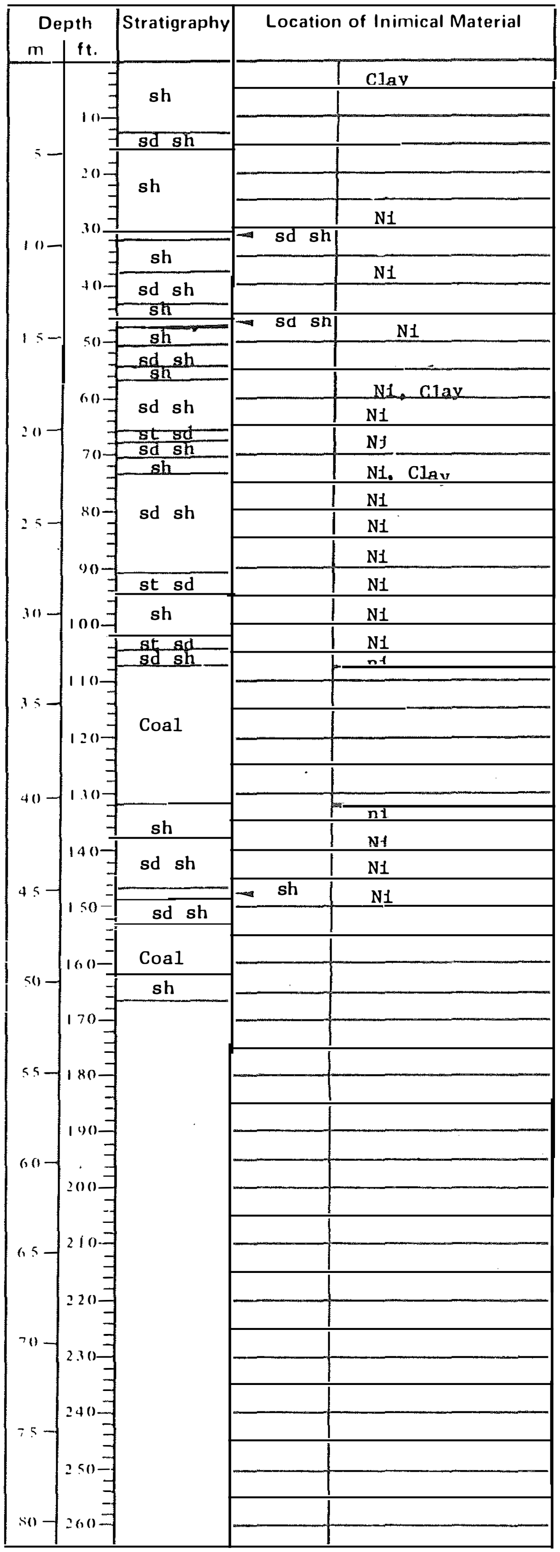
STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	8.67 ± 0.66	7.50 – 9.60
Saturation	%	38.73 ± 5.45	27.90 – 45.70
Cond.	mmhos/cm	3.65 ± 1.18	2.16 – 5.94
Ca	meq/L	25.14 ± 10.01	11.30 – 40.20
Mg	meq/L	16.19 ± 11.58	1.02 – 43.30
Na	meq/L	10.00 ± 5.66	5.25 – 24.30
SAR	---	2.14 ± 0.71	1.53 – 3.91
Zn	ppm	24.40 ± 32.86	2.40 – 117.00
Fe	ppm	60.75 ± 28.72	17.00 – 104.00
Cu	ppm	1.81 ± 0.82	0.80 – 3.40
Mn	ppm	7.83 ± 5.10	2.30 – 22.00
Ni	ppm	1.38 ± 0.90	0.02 – 3.30
Cd	ppm	0.05 ± 0.00	0.05 – 0.05
Pb	ppm	4.43 ± 2.14	1.00 – 8.50
Hg	ppm	0.007 ± 0.003	0.003 0.01
Se	ppm	0.04 ± 0.03	0.005 0.11
Mo	ppm	0.30 ± 0.09	0.12 0.50
B	ppm	2.06 ± 0.76	1.27 – 3.95
PO_4-P	ppm	±	
NO_3-N	ppm	0.51 ± 0.24	0.29 – 0.86
NH_4-N	ppm	22.08 ± 13.55	5.00 – 46.00
Clay	%	±	
Silt	%	±	
Sand	%	±	

Depth m	Depth ft.	Stratigraphy	Location of Inimical Material
			Cond, Zn
	10		Cond, Zn
			Cond
5	20		Cond
			Cond, Zn
			Cond, Zn
10	30		Cond, Ni
	40		Cond, Ni
			Ni
15	50		Ni
			Ni
	60		Ni
20			Zn, Ni
	70		Zn, Ni
			Ni
25	80		Ni
			Ni
	90		Ni
30	100		
	110		
35			Ni
	120		Ni
			Ni
40	130		Ni
	140		
45	150		
50	160		
	170		
55	180		
	190		
60	200		
65	210		
	220		
70	230		
	240		
75	250		
80	260		



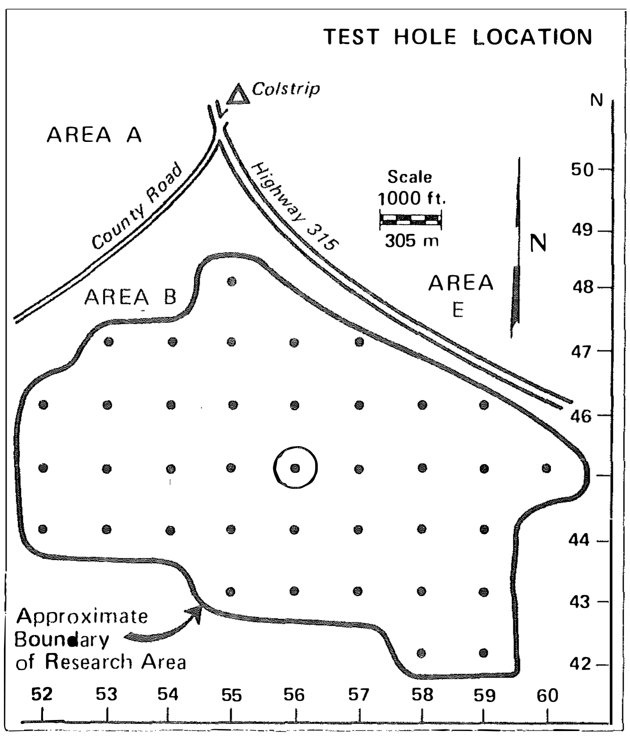
Appendix A-19. Chemical data for test hole N45-E55.



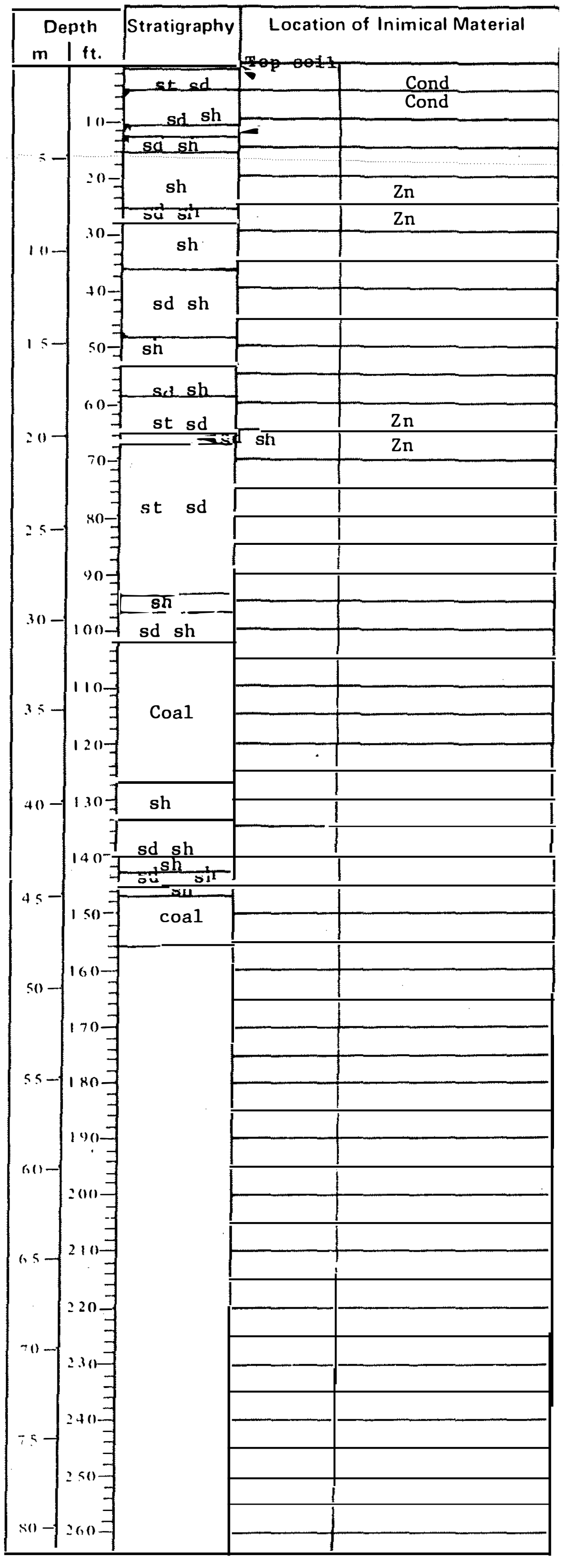
TEST HOLE DESIGNATION N45-E56

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	8.1 ± 2.3	7.3 - 8.6
Saturation	%	38.4 ±11.8	30.2 - 48.3
Cond.	mmhos/cm	1.49 ± 0.74	0.63 - 3.59
Ca	meq/L	5.01 ± 3.84	1.72 - 20.16
Mg	meq/L	9.39 ± 6.39	3.70 - 31.25
Na	meq/L	3.26 ± 1.93	1.09 - 7.91
SAR	---	1.26 ± 0.75	0.58 - 3.52
Zn	ppm	3.16 ± 3.06	0.64 - 14.40
Fe	ppm	24.9 ±11.8	2.0 - 43.5
Cu	ppm	1.97 ± 0.98	0.50 - 4.40
Mn	ppm	3.4 ± 1.3	1.2 - 6.2
Ni	ppm	1.18 ± 0.69	0.12 - 2.42
Cd	ppm	0.25 ± 0.63	0.06 - 3.45
Pb	ppm	3.00 ± 1.70	0.12 - 6.74
Hg	ppm	0.010 ± 0.011	0.001 - 0.044
Se	ppm	0.01 ± 0.002	0.01 - 0.02
Mo	ppm	0.98 ± 0.49	0.36 - 2.32
B	ppm	0.65 ± 0.65	0.10 - 2.23
PO4-P	ppm	2.06 ± 2.19	0.10 - 11.00
NO3-N	ppm	1.35 ± 0.51	0.15 - 2.20
NH4-N	ppm	11.44 ± 5.76	3.38 - 20.26
Clay	%	27.6 ± 8.5	13.2 - 51.2
Silt	%	34.5 ±10.9	6.0 - 52.8
Sand	%	38.0 ±15.0	12.4 - 80.8



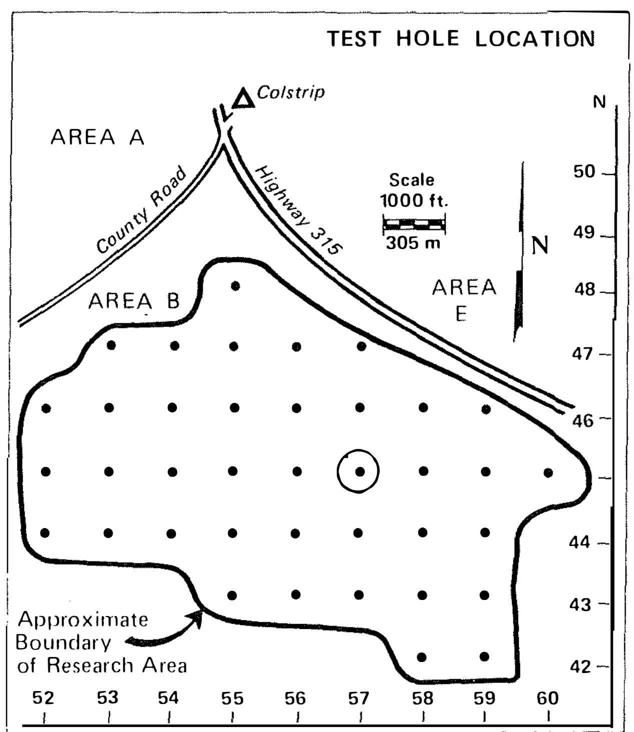
Appendix A-20. Stratigraphic and chemical data for test hole N45-E56. (st sd=silty sand, sd sh=sandy shale, sh=shale).



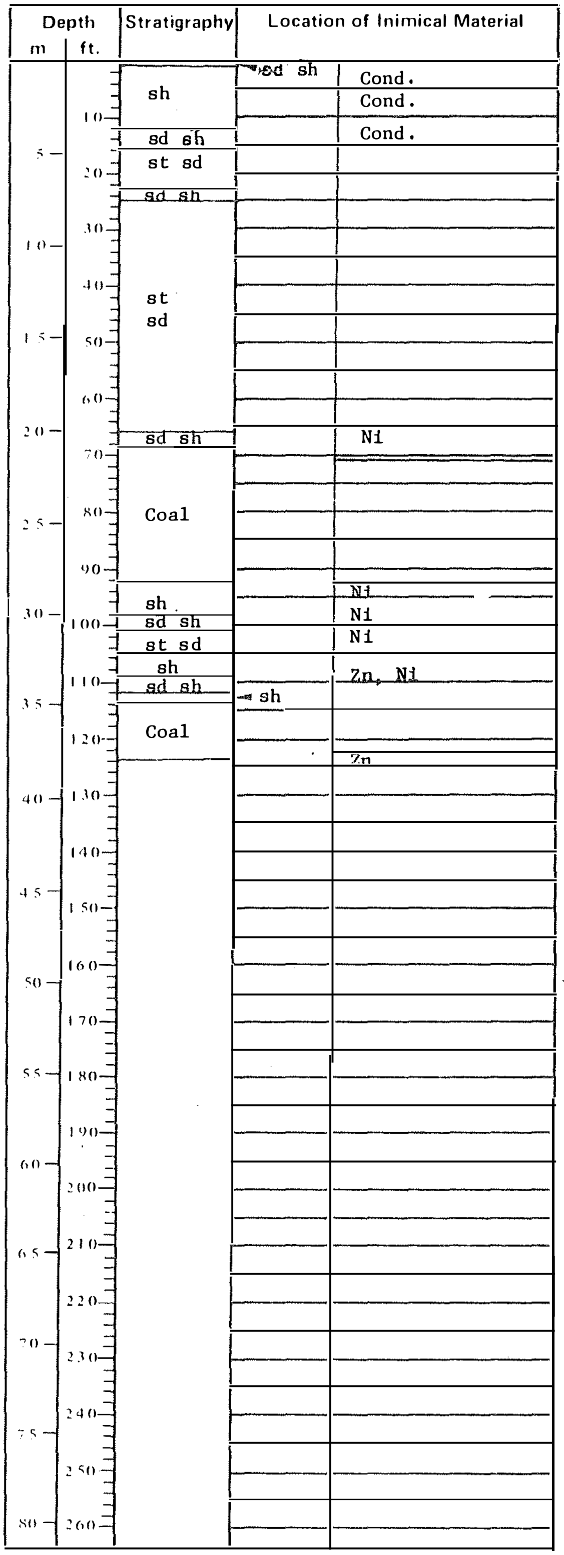
TEST HOLE DESIGNATION N45-E57

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	8.14 ± .17	8.0 - 8.50
Saturation	%	35.92 ± 10.38	23.3 - 58.00
Cond.	mmhos/cm	1.39 ± 1.40	0.54 - 4.86
Ca	meq/L	6.66 ± 8.65	1.58 - 28.90
Mg	meq/L	9.73 ± 10.88	3.39 - 37.80
Na	meq/L	3.96 ± 4.52	1.48 - 15.63
SAR	---	1.29 ± 0.60	0.78 - 2.71
Zn	ppm	13.23 ± 15.73	1.00 - 44.3
Fe	ppm	35.56 ± 24.82	17.00 - 89.00
Cu	ppm	1.42 ± 0.85	0.20 - 2.80
Mn	ppm	8.41 ± 2.76	4.80 - 11.90
Ni	ppm	0.36 ± 0.27	0.10 - 0.80
Cd	ppm	0.05 ± 0.00	0.05 - 0.05
Pb	ppm	1.76 ± .83	.90 - 3.3
Hg	ppm	0.010 ± .001	0.008 - 0.011
Se	ppm	0.015 ± 0.005	0.005 - 0.02
Mo	ppm	0.22 ± 0.082	0.13 - 0.42
B	ppm	1.15 ± 0.36	0.67 - 1.68
PO_4-P	ppm	- ± -	- -
NO_3-N	ppm	0.64 ± 0.136	0.58 - 0.92
NH_4-N	ppm	15.56 ± 11.26	4.00 - 32.00
Clay	%	- ± -	- -
Silt	%	- ± -	- -
Sand	%	- ± -	- -



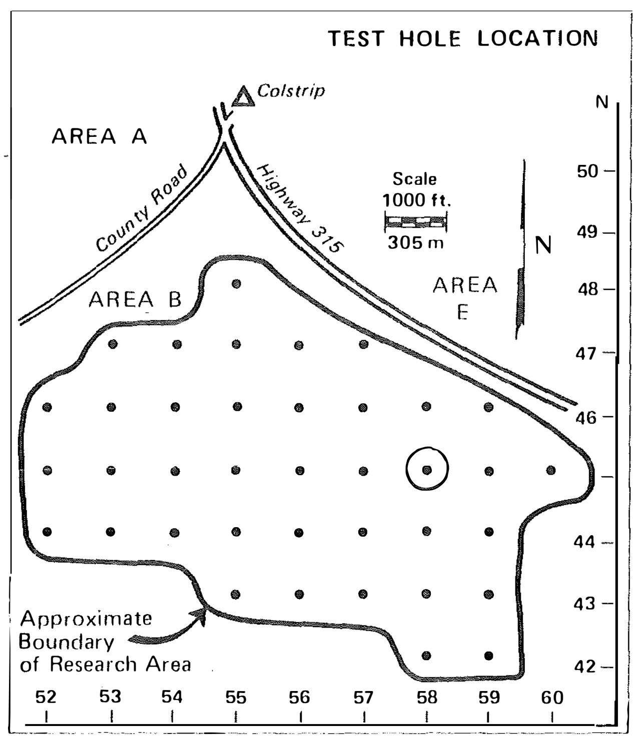
Appendix A-21. Stratigraphic and chemical data for test hole N45-E57. (st sd=silty sand, sd sh=sandy shale, sh=shale).



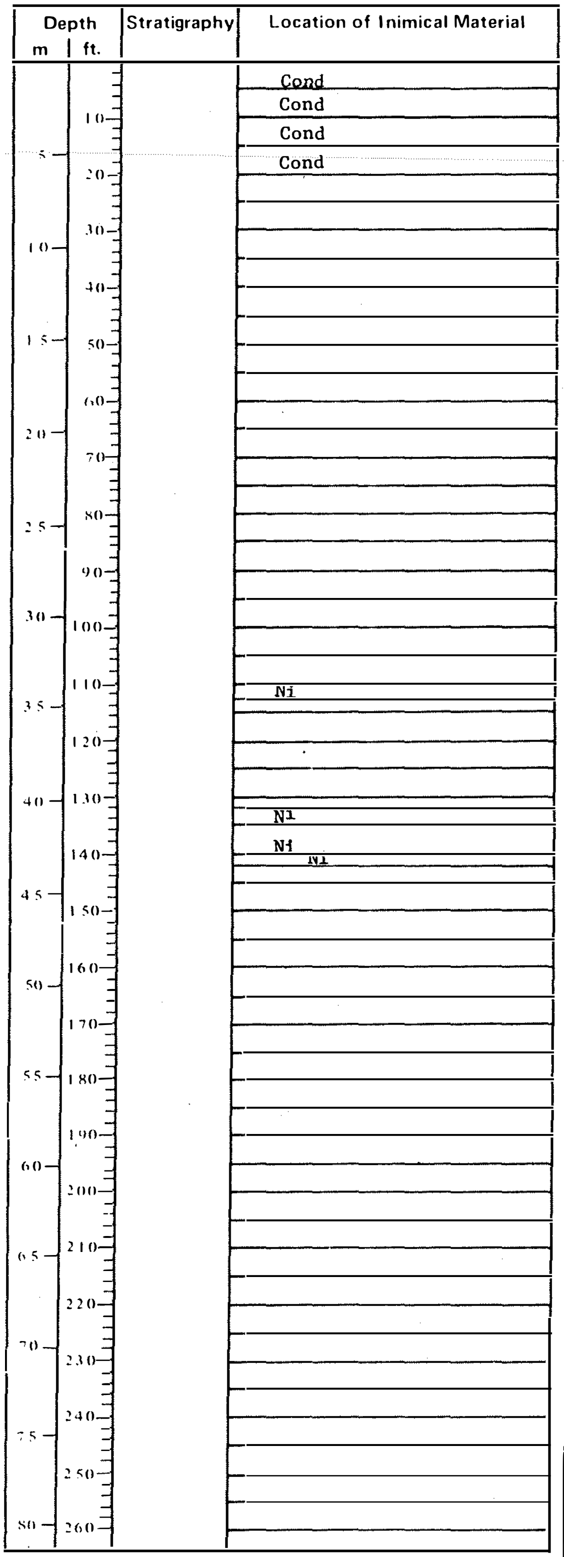
TEST HOLE DESIGNATION N45-E58

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	7.90 ±.44	7.20 -8.50
Saturation	%	31.68 ±5.75	23.30 -46.90
Cond.	mmhos/cm	1.94 ±2.46	0.41 -10.00
Ca	meq/L	7.32 ±7.18	1.47 -24.85
Mg	meq/L	16.04 ±28.44	1.97 -118.42
Na	meq/L	3.54 ±5.61	0.59 -22.96
SAR	---	.86 ±.64	0.16 -2.71
Zn	ppm	7.40 ±13.37	0.08 -53.60
Fe	ppm	17.64 ±16.23	4.00 -60.00
Cu	ppm	.86 ±1.04	0.05 -4.20
Mn	ppm	3.26 ±3.05	0.40 -10.80
Ni	ppm	.63 ±.88	0.05 -3.29
Cd	ppm	.08 ±.05	0.05 -0.23
Pb	ppm	1.96 ±1.94	0.23 -5.12
Hg	ppm	.02 ±.02	0.001 -0.06
Se	ppm	.02 ±.01	0.01 -0.03
Mo	ppm	.50 ±.34	0.12 -1.63
B	ppm	.36 ±.37	0.01 -1.51
PO_4-P	ppm	2.45 ±1.77	1.10 -6.80
NO_3-N	ppm	.51 ±.91	0.15 -3.50
NH_4-N	ppm	12.84 ±9.10	0.50 -33.96
Clay	%	16.14 ±8.01	2.00 -32.00
Silt	%	25.63 ±17.49	6.70 -74.00
Sand	%	55.23 ±23.39	13.40 -82.30



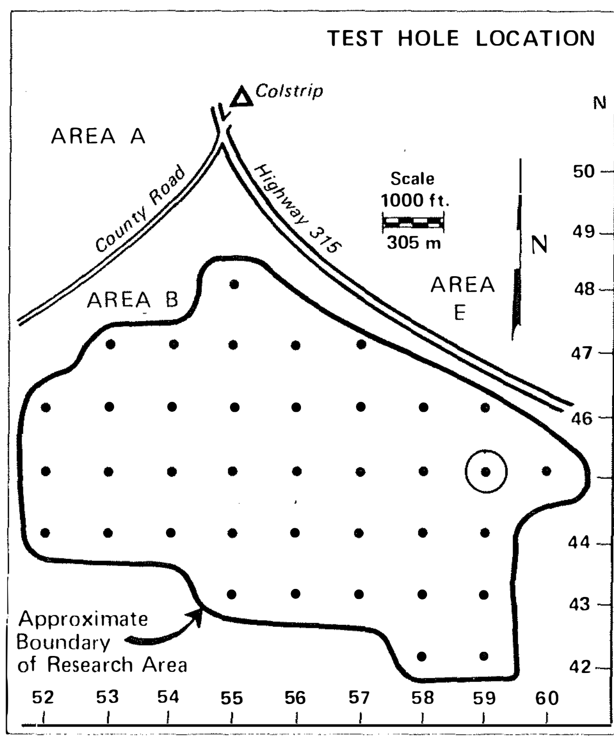
Appendix A-22. Stratigraphic and chemical data for test hole N45-E58. (st sd= silty sand, sd sh=sandy shale, sh=shale).



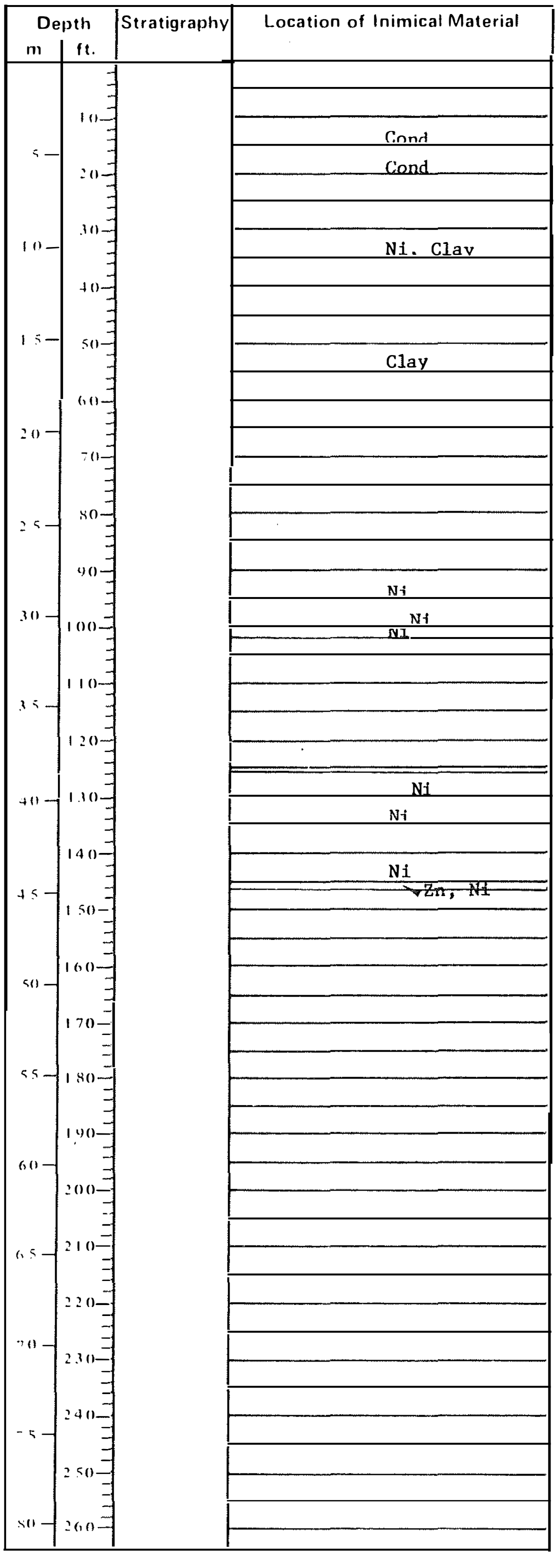
TEST HOLE DESIGNATION N45 E59

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	8.01 ± 0.32	7.20 - 8.70
Saturation	%	33.95 ± 8.26	20.80 - 57.70
Cond.	mmhos/cm	1.60 ± 1.23	0.34 - 6.20
Ca	meq/L	5.87 ± 5.58	0.90 - 23.05
Mg	meq/L	12.29 ± 14.29	1.89 - 71.96
Na	meq/L	4.23 ± 3.93	0.78 - 20.52
SAR	---	1.43 ± 0.71	0.55 - 3.69
Zn	ppm	5.50 ± 8.22	0.36 - 40.40
Fe	ppm	20.02 ± 13.71	3.20 - 49.00
Cu	ppm	0.75 ± 0.75	0.10 - 2.90
Mn	ppm	2.10 ± 0.99	1.00 - 4.40
Ni	ppm	0.61 ± 0.78	0.05 - 3.14
Cd	ppm	0.07 ± 0.04	0.06 - 0.23
Pb	ppm	1.72 ± 1.41	0.23 - 4.85
Hg	ppm	0.02 ± 0.02	0.003 - 0.11
Se	ppm	0.02 ± 0.008	0.01 - 0.03
Mo	ppm	0.54 ± 0.36	0.05 - 1.35
B	ppm	0.24 ± 0.30	0.005 - 1.36
PO_4-P	ppm	1.59 ± 0.72	0.80 - 3.50
NO_3-N	ppm	0.24 ± 0.22	0.15 - 0.95
NH_4-N	ppm	12.22 ± 8.90	0.50 - 30.28
Clay	%	23.30 ± 11.33	7.30 - 53.20
Silt	%	30.49 ± 14.14	3.40 - 52.60
Sand	%	46.20 ± 21.74	17.40 - 89.30



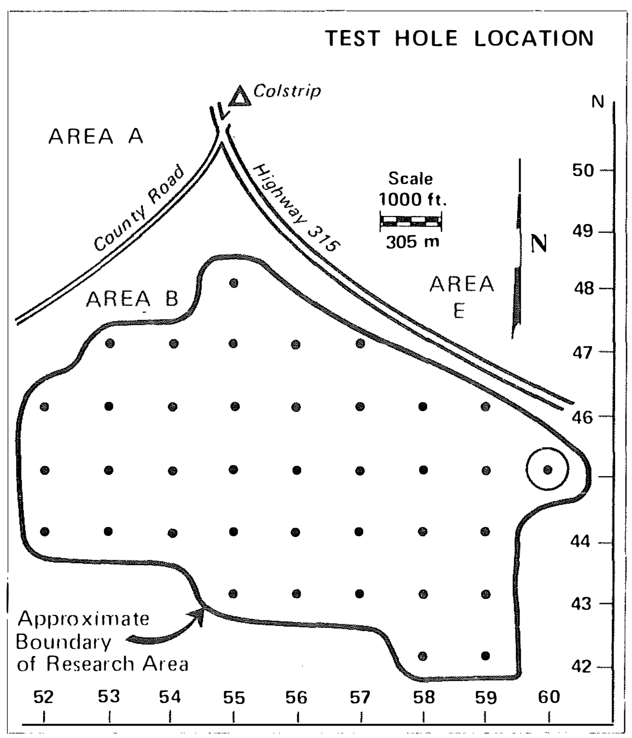
Appendix A-23. Chemical data for test hole N45-E59.



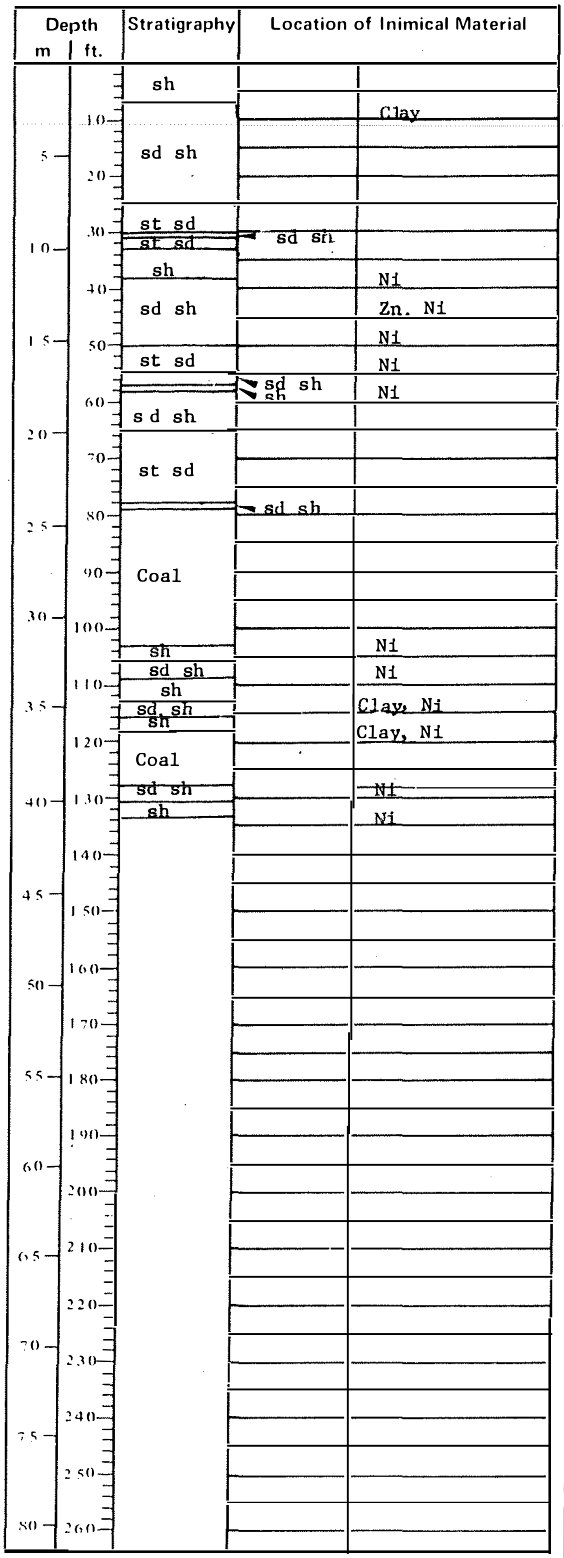
TEST HOLE DESIGNATION N45E60

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min--Max
pH	---	8.01 ± 0.32	7.20 - 8.70
Saturation	%	33.95 ± 8.26	20.80 - 57.70
Cond.	mmhos/cm	1.60 ± 1.23	0.34 - 6.20
Ca	meq/L	5.87 ± 5.58	0.90 - 23.05
Mg	meq/L	12.29 ± 14.29	1.89 - 71.96
Na	meq/L	4.23 ± 3.93	0.78 - 20.52
SAR	---	1.43 ± 0.71	0.55 - 3.69
Zn	ppm	5.50 ± 8.22	0.36 - 40.40
Fe	ppm	20.02 ± 13.71	3.20 - 49.00
Cu	ppm	0.75 ± 0.75	0.10 - 2.90
Mn	ppm	2.09 ± 1.00	1.00 - 4.40
Ni	ppm	0.61 ± 6.78	0.05 - 3.14
Cd	ppm	0.07 ± 0.04	0.06 - 0.23
Pb	ppm	1.72 ± 1.41	0.23 - 4.85
Hg	ppm	0.024 ± 0.023	0.003 - 0.11
Se	ppm	0.018 ± 0.008	0.01 - 0.03
Mo	ppm	0.54 ± 0.36	0.05 - 1.35
B	ppm	0.25 ± 0.30	0.005 - 1.36
PO_4-P	ppm	1.59 ± 0.72	0.80 - 3.50
NO_3-N	ppm	0.24 ± 0.22	0.15 - 0.95
NH_4-N	ppm	12.62 ± 8.72	0.50 - 30.28
Clay	%	23.17 ± 11.30	7.30 - 53.20
Silt	%	30.50 ± 14.14	3.40 - 52.60
Sand	%	46.20 ± 21.74	17.40 - 89.30



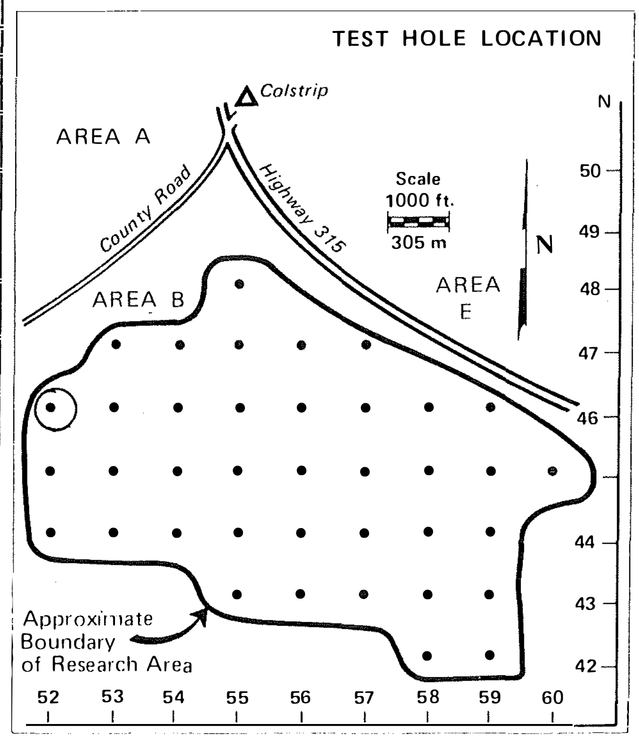
Appendix A-24. Chemical data for test hole N45-E60.



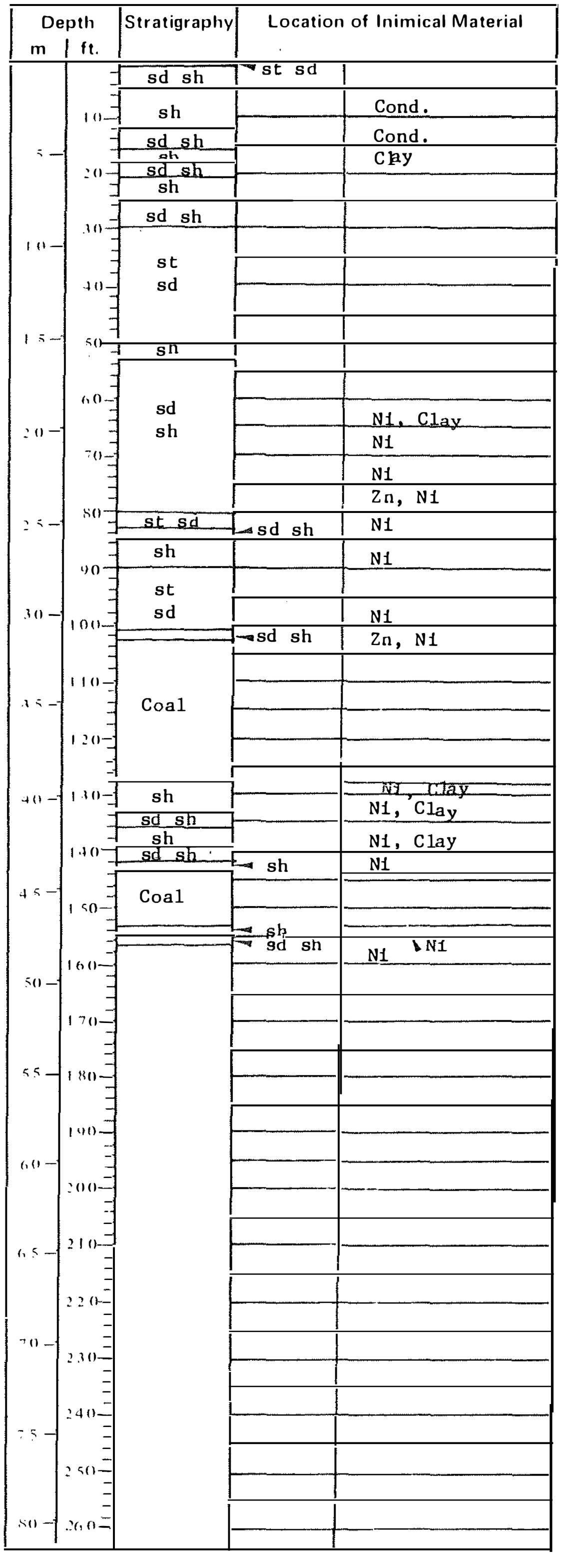
TEST HOLE DESIGNATION N46-E52

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min--Max
pH	---	8.2 ± 0.4	7.4 - 8.8
Saturation	%	35.4 ± 8.3	24.5 -49.9
Cond.	mmhos/cm	1.19 ± 0.61	0.49 - 3.30
Ca	meq/L	3.08 ± 1.67	1.07 - 6.59
Mg	meq/L	5.38 ± 3.74	0.82 -19.74
Na	meq/L	3.94 ± 2.66	1.61 -12.17
SAR	---	1.84 ± 1.01	0.84 - 3.97
Zn	ppm	7.42 ±17.66	0.34 -78.00
Fe	ppm	16.7 ±13.01	4.4 -40.0
Cu	ppm	0.57 ± 0.43	0.05 - 1.40
Mn	ppm	2.5 ± 1.71	1.0 - 7.4
Ni	ppm	0.86 ± 0.89	0.06 - 4.17
Cd	ppm	0.17 ± 0.11	0.06 - 0.35
Pb	ppm	3.45 ± 2.46	0.78 - 9.73
Hg	ppm	0.029 ± 0.042	0.001 - 0.148
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	0.42 ± 0.19	0.06 - 0.71
B	ppm	0.32 ± 0.15	0.10 - 0.71
PO_4-P	ppm	4.44 ± 8.78	0.50 -31.60
NO_3-N	ppm	0.68 ± 0.78	0.15 - 2.85
NH_4-N	ppm	12.61 ±13.21	3.64 -65.47
Clay	%	20.0 ±13.02	5.2 -45.2
Silt	%	36.1 ±17.21	12.8 -74.0
Sand	%	43.9 ±25.82	7.8 -79.6



Appendix A-25. Stratigraphic and chemical data for test hole N46-E52. (st sd=silty sand, sd sh=sandy shale, sh=shale).

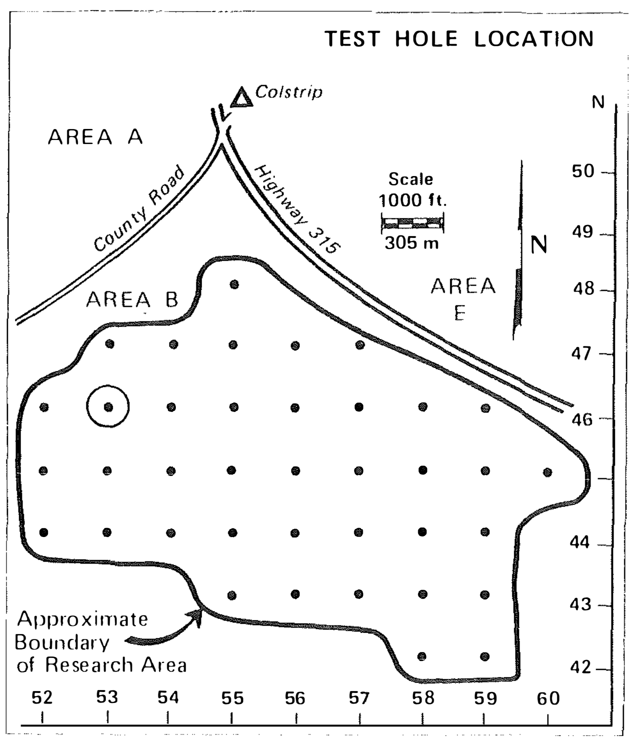


TEST HOLE DESIGNATION N46-E53

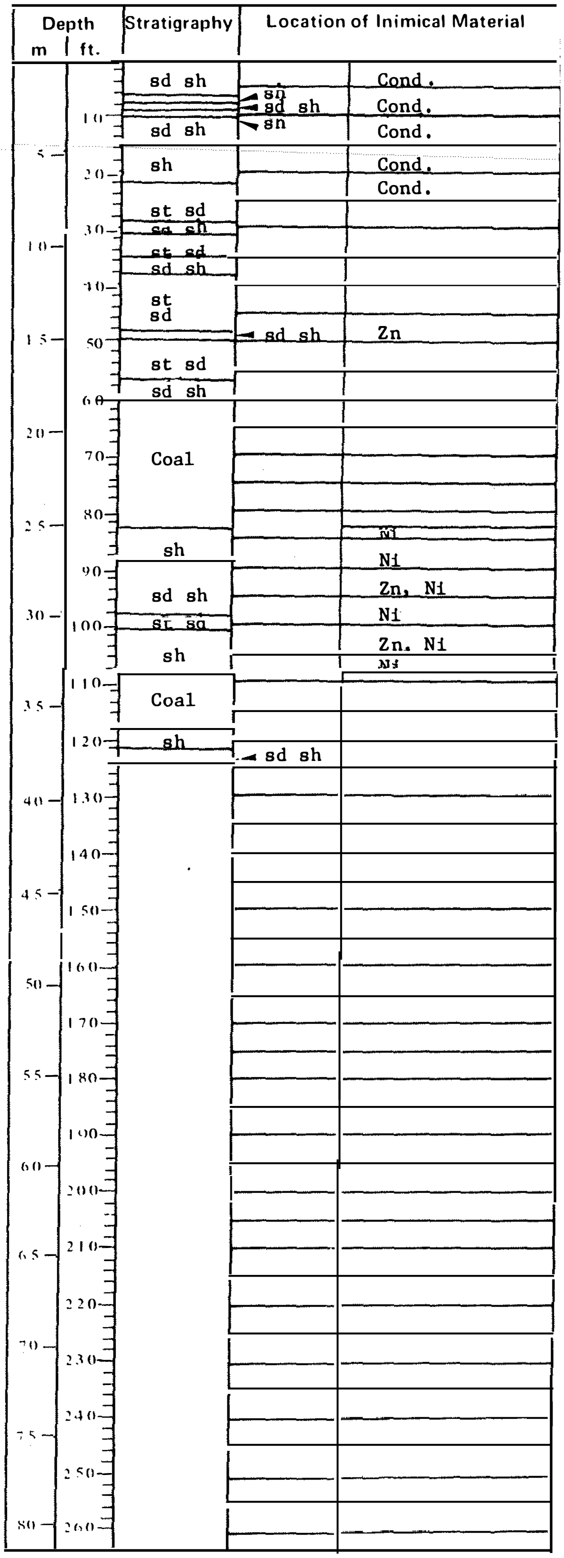
STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min--Max
pH	---	8.1 ± 0.3	7.4 - 8.4
Saturation	%	37.3 ± 6.7	27.0 - 49.7
Cond.	mmhos/cm	1.84 ± 1.43	0.89 - 7.4
Ca	meq/L	4.33 ± 3.75	1.82 - 21.36
Mg	meq/L	12.18 ±15.20	2.26 - 76.48
Na	meq/L	4.42 ± 3.88	1.91 - 18.26
SAR	---	1.84 ± 1.50	0.78 - 6.79
Zn	ppm	12.83 ±25.68	0.50 - 100.00
Fe	ppm	30.0 ±18.91	4.4 - 70.0
Cu	ppm	1.25 ± 0.60	0.40 - 2.80
Mn	ppm	3.4 ± 1.4	1.8 - 7.0
Ni	ppm	0.96 ± 0.74	0.06 - 2.28
Cd	ppm	0.06 ± 0.015	0.05 - 0.11
Pb	ppm	3.03 ± 2.00	4.4 - 6.47
Hg	ppm	0.026 ± 0.04	0.001 - 0.170
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	0.63 ± 0.28	0.05 - 1.02
B	ppm	0.53 ± 0.45	0.02 - 1.88
PO_4-P	ppm	1.24 ± 1.05	0.10 - 4.80
NO_3N	ppm	1.17 ± 1.05	0.15 - 3.50
NH_4-N	ppm	17.21 ± 9.84	2.42 - 33.78
Clay	%	27.9 ± 13.11	8.0 - 52.4
Silt	%	36.6 ± 16.57	6.8 - 61.0
Sand	%	35.5 ± 22.4	10.0 - 84.6

TEST HOLE LOCATION



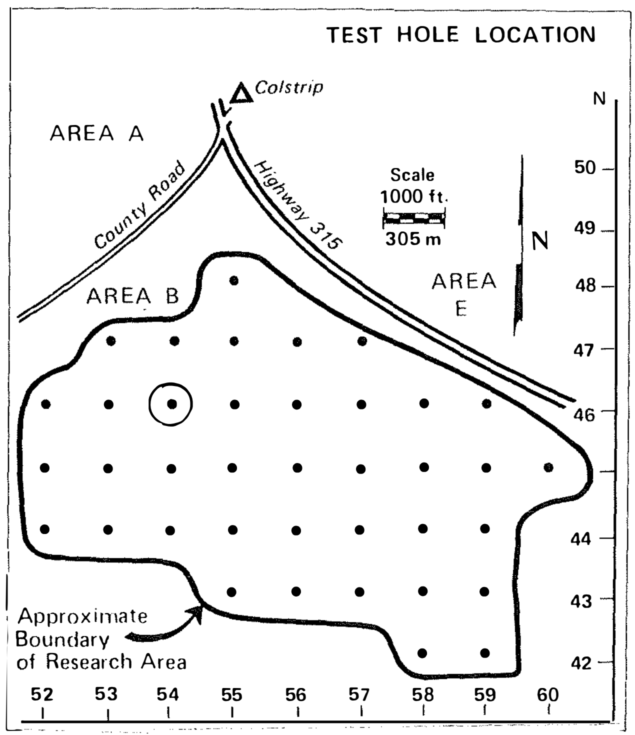
Appendix A-26. Stratigraphic and chemical data for test hole N46-E53. (st sd=silty sand, sd sh=sandy shale, sh=shale).



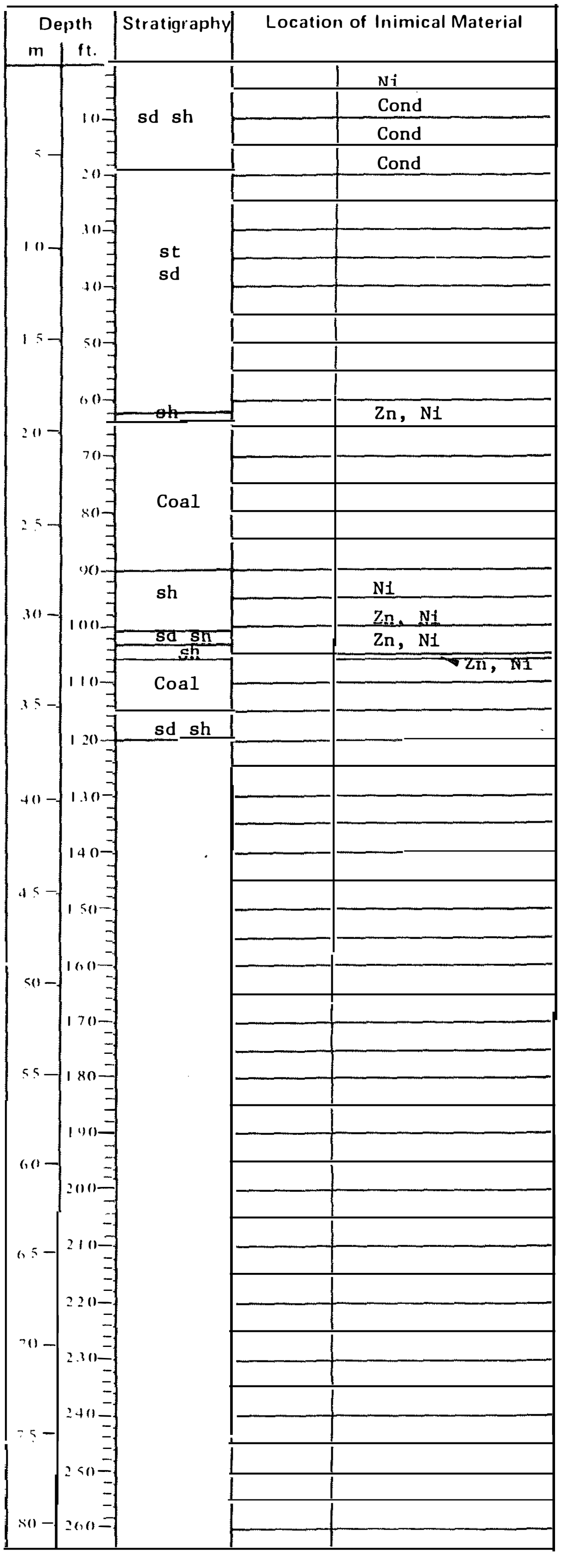
TEST HOLE DESIGNATION N46-E54

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min--Max
pH	---	8.0 ± 0.5	7.2 - 8.6
Saturation	%	34.4 ± 6.3	28.1 - 50.4
Cond.	mmhos/cm	3.32 ± 2.91	0.78 - 9.11
Ca	meq/L	11.70 ± 7.91	2.00 - 25.75
Mg	meq/L	21.93 ± 24.13	3.50 - 78.95
Na	meq/L	10.17 ± 11.06	1.78 - 32.35
SAR	---	2.14 ± 1.38	0.95 - 4.84
Zn	ppm	10.61 ± 15.84	0.20 - 55.00
Fe	ppm	23.4 ± 26.33	4.4 - 84.0
Cu	ppm	1.18 ± 0.82	0.10 - 2.9
Mn	ppm	2.7 ± 1.64	1.0 - 7.0
Ni	ppm	0.64 ± 0.70	0.06 - 2.00
Cd	ppm	0.06 ± 0.02	0.06 - 0.11
Pb	ppm	2.48 ± 2.36	0.50 - 8.37
Hg	ppm	0.02 ± 0.019	0.003 - 0.08
Se	ppm	0.01 ± 0.01	0.01 - 0.03
Mo	ppm	0.83 ± 0.21	0.57 - 1.4
B	ppm	0.24 ± 0.26	0.02 - 1.03
PO_4-P	ppm	3.77 ± 4.97	0.80 - 22.60
NO_3-N	ppm	0.25 ± 0.26	0.15 - 0.95
NH_4-N	ppm	10.25 ± 8.28	0.50 - 25.46
Clay	%	16.7 ± 9.45	3.6 - 33.0
Silt	%	34.1 ± 20.4	9.0 - 54.2
Sand	%	49.2 ± 29-1	15.6 - 82.0



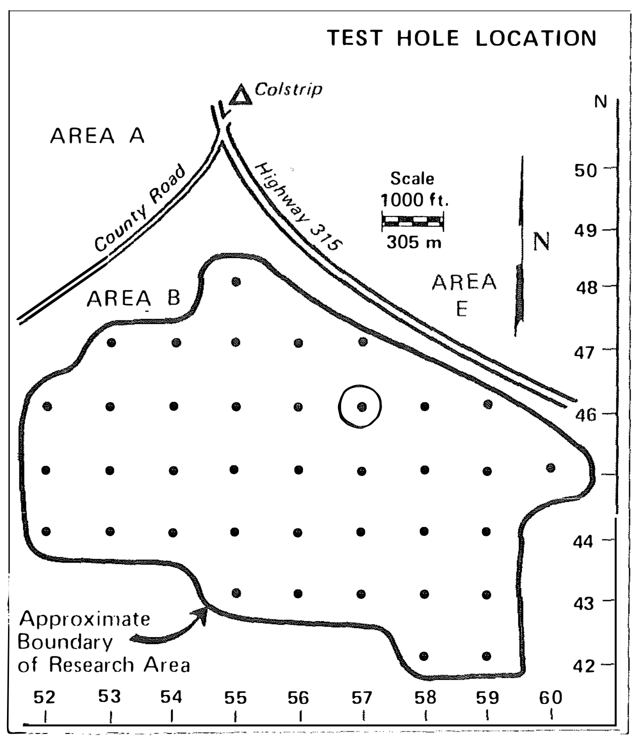
Appendix A-27. Stratigraphic and chemical data for test hole N46-E54. (st sd=silty sand, sd sh=sandy shale, sh=shale).



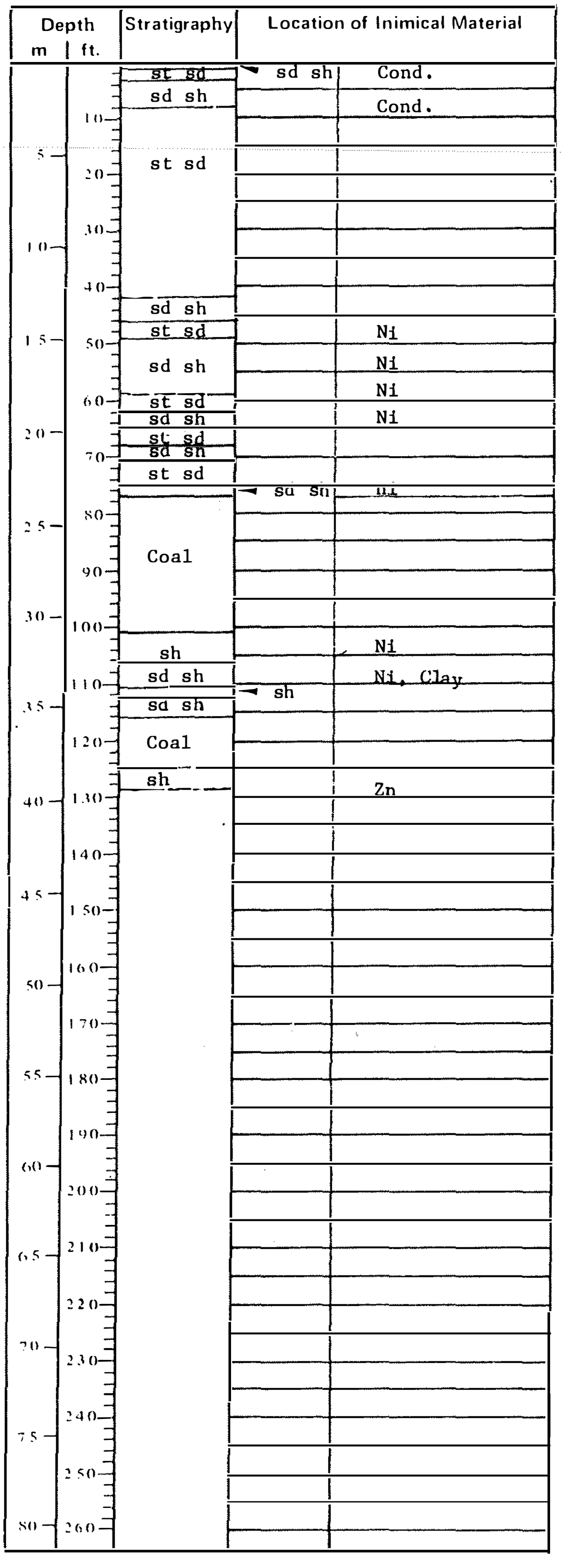
TEST HOLE DESIGNATION N46-E57

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min--Max
pH	---	8.15 ± 0.43	7.30 -8.70
Saturation	%	31.92 ± 3.43	26.90 -38.40
Cond.	mmhos/cm	2.54 ± 3.01	0.64 -10.90
Ca	meq/L	8.05 ± 7.71	1.82 -24.25
Mg	meq/L	13.43 ± 19.59	2.67 -74.84
Na	meq/L	11.11 ± 16.96	1.70 -60.87
SAR	---	2.69 ± 2.30	1.06 -8.68
Zn	ppm	30.31 ± 58.73	0.28 -208.00
Fe	ppm	12.29 ± 10.95	4.60 -39.00
Cu	ppm	0.70 ± 0.58	0.10 -1.60
Mn	ppm	2.78 ± 1.88	1.00 -7.40
Ni	ppm	0.70 ± 0.60	0.06 -1.86
Cd	ppm	0.13 ± 0.09	0.06 -0.35
Pb	ppm	2.47 ± 1.55	0.50 -6.20
Hg	ppm	0.02 ± 0.02	0.001 -0.05
Se	ppm	0.02 ± 0.01	0.01 -0.03
Mo	ppm	0.51 ± 0.21	0.07 -0.94
B	ppm	0.30 ± 0.32	0.01 -1.14
PO_4-P	ppm	1.56 ± 0.82	0.80 -3.50
NO_3-N	ppm	1.84 ± 2.86	0.15 -10.00
NH_4-N	ppm	6.47 ± 3.26	3.40 -13.58
Clay	%	14.52 ± 10.20	1.80 -30.80
Silt	%	32.22 ± 13.81	11.00 -65.00
Sand	%	53.26 ± 15.03	30.60 -78.60



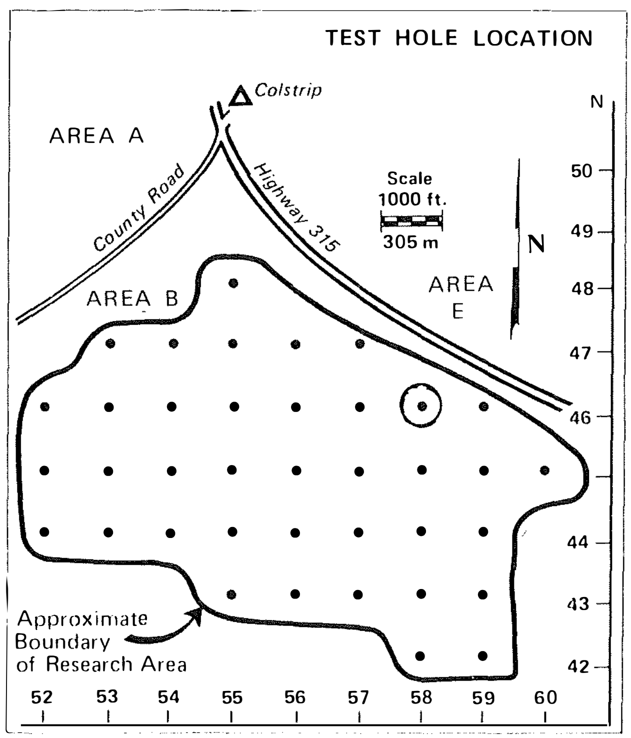
Appendix A-30. Stratigraphic and chemical data for test hole N46-E57. (st sd=silty sand, sd sh=sandy shale, sh=shale).



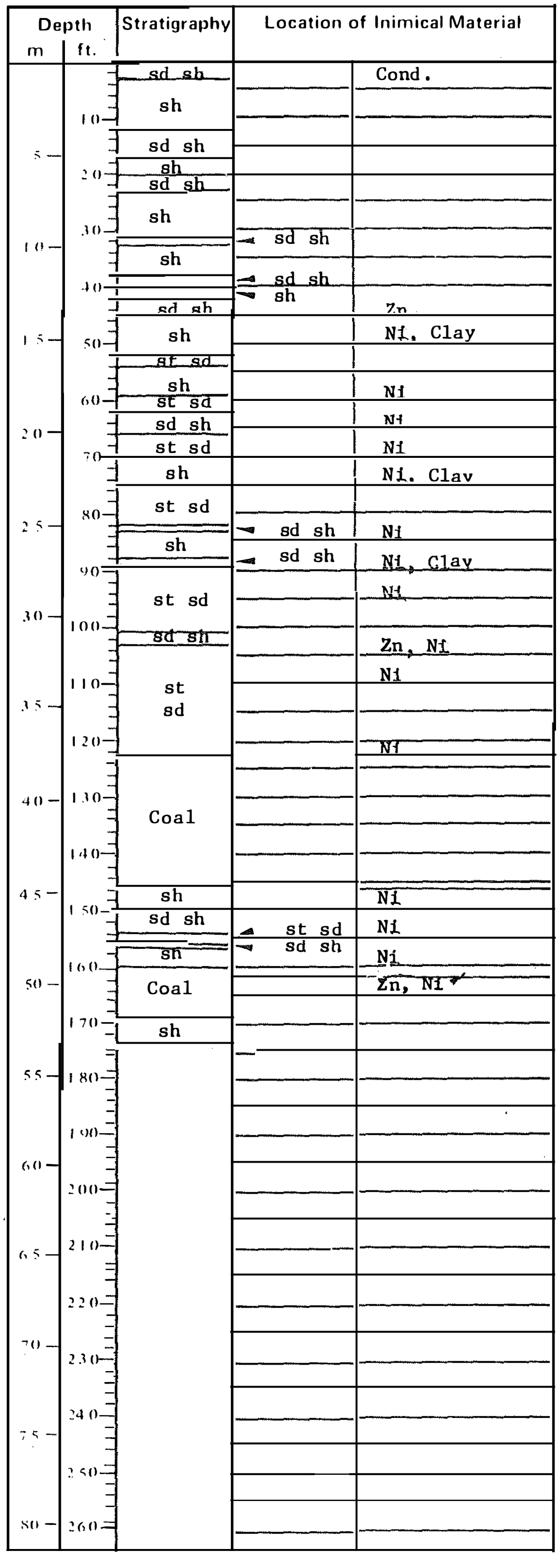
TEST HOLE DESIGNATION N46-E58

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min-Max
pH	---	8.0 ± 0.4	7.1 - 8.6
Saturation	%	34.0 ± 7.1	26.2 - 57.3
Cond.	mmhos/cm	1.48 ± 1.13	0.50 - 4.90
Ca	meq/L	5.06 ± 4.20	1.30 - 19.76
Mg	meq/L	8.52 ± 6.01	3.04 - 26.64
Na	meq/L	5.72 ± 6.64	1.48 - 31.30
SAR	---	2.00 ± 1.37	0.73 - 7.28
Zn	ppm	7.41 ± 9.50	0.08 - 32.20
Fe	ppm	23.0 ±16.56	0.1 - 60.
Cu	ppm	0.85 ± 0.83	0.05 - 2.70
Mn	ppm	2.4 ± 1.82	0.1 - 8.0
Ni	ppm	0.86 ± 1.03	0.05 - 4.32
Cd	ppm	0.07 ± 0.07	0.06 - 0.35
Pb	ppm	2.05 ± 1.70	0.12 - 5.39
Hg	ppm	0.024 ± 0.03	0.003 - 0.103
Se	ppm	0.02 ± 0.01	0.01 - 0.03
Mo	ppm	0.82 ± 0.28	0.22 - 1.29
B	ppm	0.28 ± 0.48	0.01 - 2.16
PO_4-P	ppm	1.26 ± 0.60	0.50 - 3.50
NO_3-N	ppm	0.80 ± 1.73	0.15 - 8.15
NH_4-N	ppm	12.03 ± 6.36	1.70 - 20.38
Clay	%	19.4 ± 9.85	7.9 - 42.2
Silt	%	20.8 ±13.88	4.5 - 54.0
Sand	%	59.8 ±21.8	23.2 - 87.5



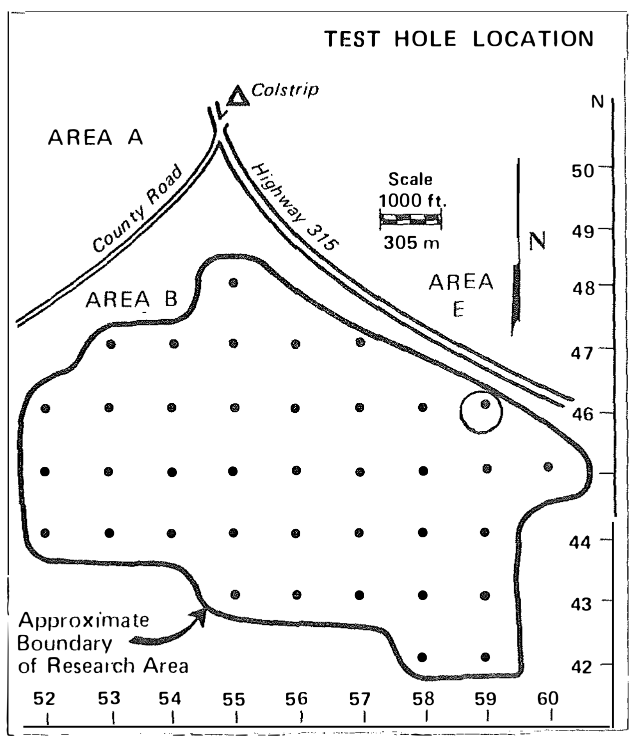
Appendix A-31. Stratigraphic and chemical data for test hole N46-E58. (st sd=silty sand, sd sh=sandy shale, sh=shale).



TEST HOLE DESIGNATION N46-E59

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min--Max
pH	---	8.0 ± 0.4	6.8 - 8.6
Saturation	%	36.9 ± 7.1	27.8 - 55.8
Cond.	mmhos/cm	1.44 ± 0.81	0.39 - 4.20
Ca	meq/L	3.85 ± 1.77	1.30 - 8.28
Mg	meq/L	7.35 ± 6.77	1.64 - 35.36
Na	meq/L	3.88 ± 2.67	0.74 - 9.83
SAR	---	1.70 ± 1.32	0.54 - 6.31
Zn	ppm	9.94 ±14.84	0.36 - 58.60
Fe	ppm	38.9 ±23.7	5.5 - 84.0
Cu	ppm	1.40 ± 0.79	0.40 - 3.0
Mn	ppm	4.2 ± 2.3	1.4 - 11.7
Ni	ppm	1.10 ± 0.81	0.06 - 2.85
Cd	ppm	0.07 ± 0.03	0.06 - 0.11
Pb	ppm	3.44 ± 2.59	0.50 - 10.00
Hg	ppm	0.040± 0.02	0.001 - 0.120
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	0.66 ± 0.23	0.14 - 1.32
B	ppm	0.42 ± 0.37	0.06 - 1.83
PO_4-P	ppm	1.80 ± 1.66	0.50 - 7.80
NO_3-N	ppm	0.20 ± 0.26	0.15 - 1.55
NH_4-N	ppm	24.79 ±10.19	0.50 - 43.66
Clay	%	24.7 ±10.3	12.4 - 50.0
Silt	%	45.2 ±13.4	15.0 - 62.8
Sand	%	30.0 ±17.5	8.4 - 64.6



Appendix A-32. Stratigraphic and chemical data for test hole N46-E59. (st sd=silty sand, sd sh=sandy shale, sh=shale).

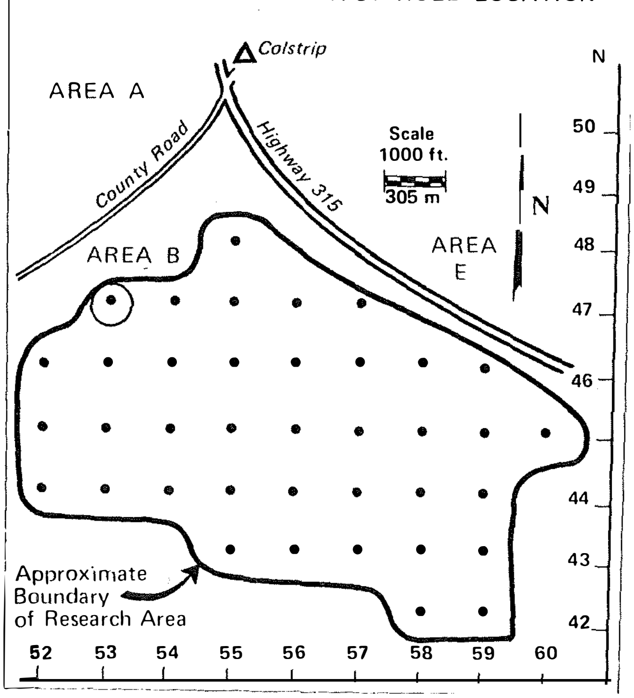
Depth m	Depth ft.	Stratigraphy	Location of Inimical Material
			Cond
			Zn

TEST HOLE DESIGNATION N47 E53

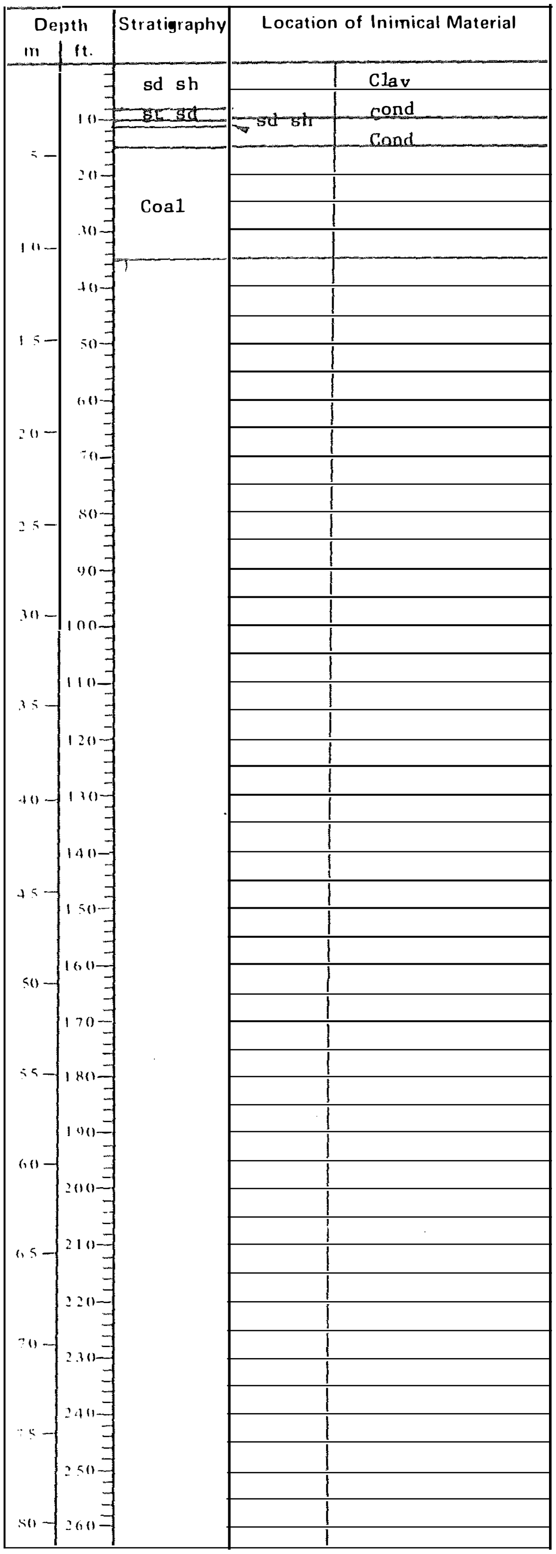
STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	7.73 ± 0.30	7.10 - 8.00
Saturation	%	36.26 ± 5.70	29.70 - 45.90
Cond.	mmhos/cm	2.34 ± 1.26	1.31 - 4.82
Ca	meq/L	10.79 ± 7.67	4.29 - 23.35
Mg	meq/L	12.64 ± 10.16	6.06 - 34.95
Na	meq/L	4.82 ± 1.85	3.04 - 7.87
SAR	---	1.46 ± 0.20	1.24 - 1.82
Zn	ppm	9.76 ± 18.36	1.08 - 55.00
Fe	ppm	32.14 ± 7.56	21.50 - 40.00
Cu	ppm	1.74 ± 0.36	1.10 - 2.30
Mn	ppm	9.38 ± 7.07	1.00 - 20.60
Ni	ppm	0.56 ± 0.22	0.25 - 0.90
Cd	ppm	0.10 ± 0.03	0.06 - 0.11
Pb	ppm	2.08 ± 0.88	1.32 - 3.76
Hg	ppm	0.03 ± 0.02	0.008 - 0.05
Se	ppm	0.01 ± 0.00	0.01 - 0.01
Mo	ppm	0.50 ± 0.12	0.38 - 0.72
B	ppm	0.37 ± 0.09	0.28 - 0.55
PO_4 P	ppm	4.00 ± 0.55	3.50 - 5.10
NO3 N	ppm	1.99 ± 3.36	0.15 - 10.00
NH4 N	ppm	18.21 ± 7.13	7.27 - 30.39
Clay	%	27.76 ± 7.95	19.60 - 36.20
Silt	%	39.24 ± 11.58	27.00 - 53.80
Sand	%	33.00 ± 15.60	10.00 - 47.00

TEST HOLE LOCATION



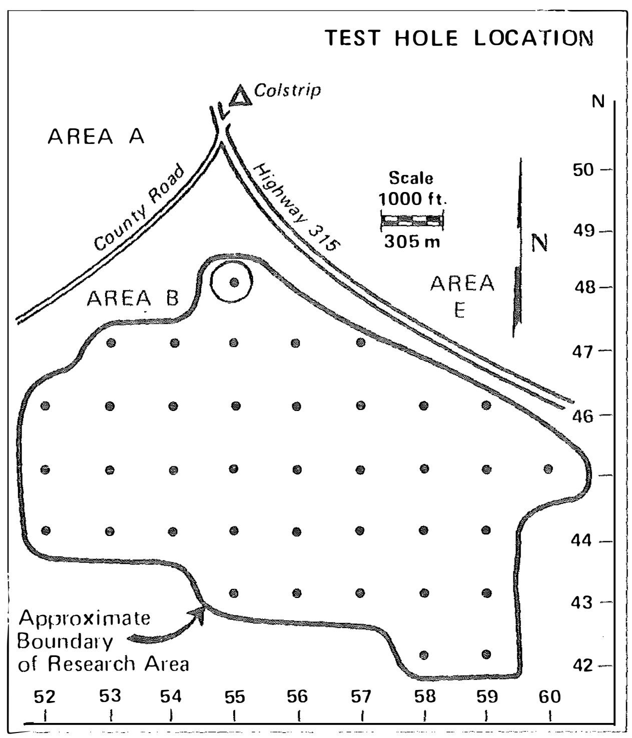
Appendix A-33. Chemical data for test hole N47-E53.



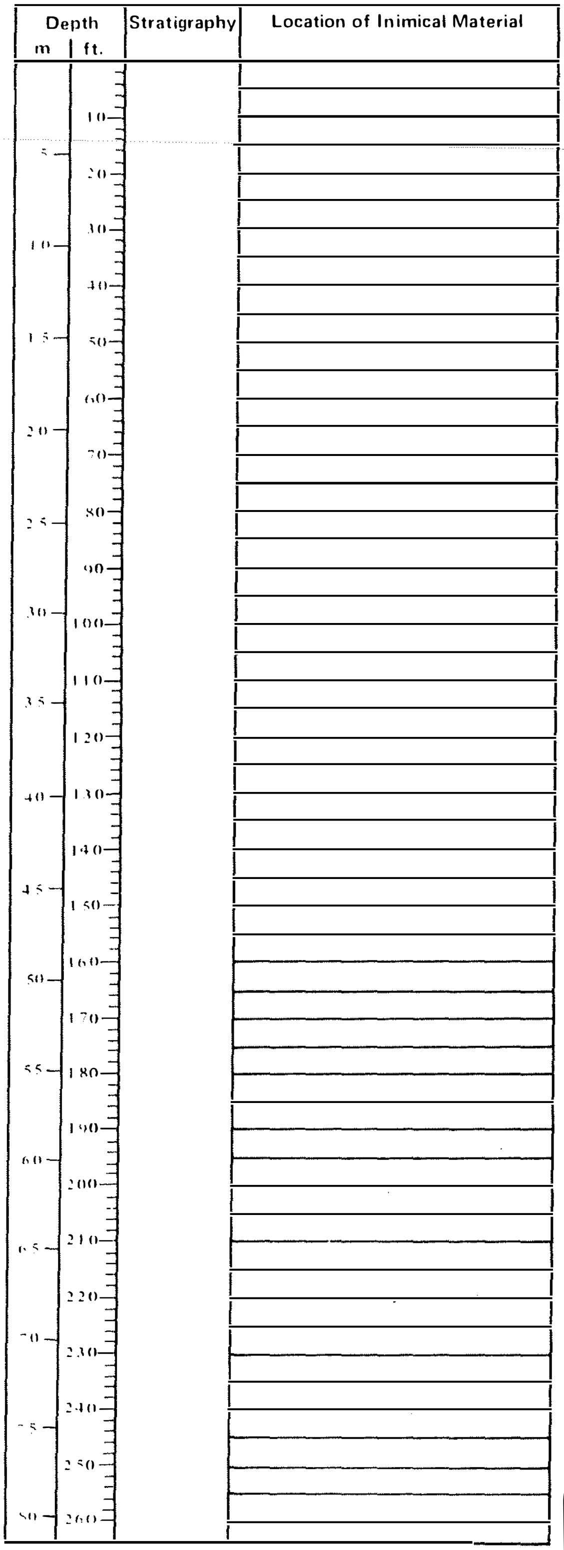
TEST HOLE DESIGNATION N48-E55

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min--Max
pH	---	8.10 ± 0.10	8.00 - 8.20
Saturation	%	43.03± 9.36	32.40 - 50.00
Cond.	mmhos/cm	4.40 ± 3.75	0.70 - 8.20
Ca	meq/L	16.20± 10.8	3.69 - 22.95
Mg	meq/L	39.10± 38.2	3.80 - 79.77
Na	meq/L	8.38 ± 6.96	1.78 - 15.65
SAR	---	1.35 ± 0.90	0.40 - 2.19
Zn	ppm	5.37 ± 5.47	0.72 - 11.40
Fe	ppm	9.07 ± 1.21	7.80 - 10.20
Cu	ppm	1.20 ± 0.20	1.00 - 1.40
Mn	ppm	1.47 ± 0.31	1.20 - 1.80
Ni	ppm	0.27 ± 0.23	0.06 - 0.51
Cd	ppm	0.09 ± 0.03	0.05 - 0.11
Pb	ppm	1.14 ± 0.62	0.78 - 1.86
Hg	ppm	0.05 ±0.000	0.04 - 0.05
Se	ppm	0.03 ± 0.01	0.02 - 0.03
Mo	ppm	0.33 ± 0.14	0.19 - 0.46
B	ppm	0.52 ± 0.24	0.29 - 0.76
PO_4-P	ppm	8.97 ± 0.81	8.50 - 9.90
NO_3-N	ppm	3.23 ± 3.52	0.35 - 7.15
NH_4-N	ppm	17.69± 6.60	10.18 - 22.58
Clay	%	33.13± 20.7	13.20 - 54.60
Silt	%	42.43± 10.0	34.70 - 53.80
Sand	%	24.43± 24.2	6.60 - 52.10



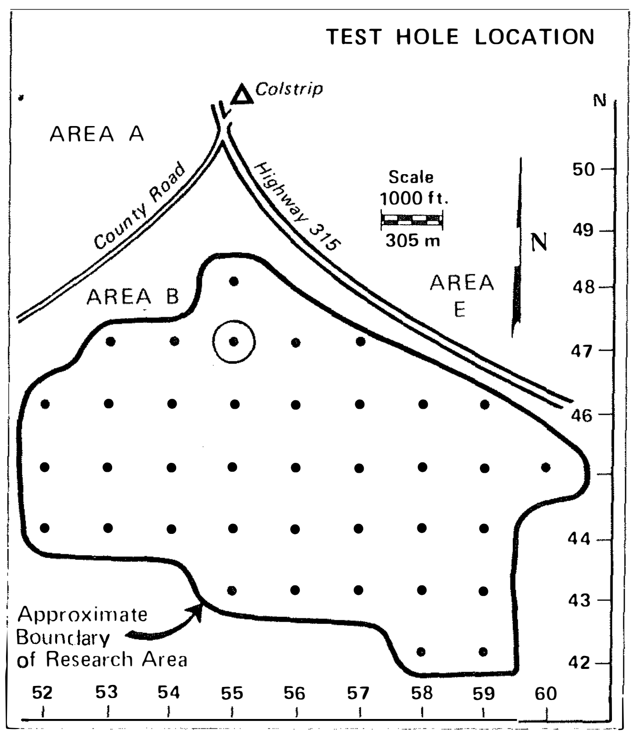
Appendix A-36. Stratigraphic and chemical data for test hole N48-E55. (st sd=silty sand, sd sh=sandy shale, sh=shale).



TEST HOLE DESIGNATION N47 E55

STATISTICAL ANALYSIS FOR TOTAL THICKNESS

Parameter	Units	Mean ± Std. Dev.	Range Min–Max
pH	---	8.08 ± 0.38	7.50 - 8.50
Saturation	%	29.82 ± 6.10	22.30 - 36.50
Cond.	mmhos/cm	1.34 ± 0.72	0.41 - 2.16
Ca	meq/L	5.53 ± 3.33	1.54 - 10.27
Mg	meq/L	7.12 ± 3.90	2.27 - 12.94
Na	meq/L	2.22 ± 1.44	0.74 - 3.77
SAR	---	0.85 ± 0.40	0.42 - 1.36
Zn	ppm	2.95 ± 1.38	1.20 - 5.00
Fe	ppm	31.33 ± 13.02	18.00 - 50.00
Cu	ppm	1.72 ± 1.11	0.40 - 3.10
Mn	ppm	7.73 ± 1.48	5.70 - 10.10
Ni	ppm	0.55 ± 0.31	0.20 - 1.00
Cd	ppm	0.05 ± 0.00	0.05 - 0.05
Pb	ppm	2.62 ± 1.58	1.00 - 5.20
Hg	ppm	0.001 ± 0.002	0.006 - 0.011
Se	ppm	0.04 ± 0.018	0.02 - 0.06
Mo	ppm	0.42 ± 0.21	0.23 - 0.81
B	ppm	0.34 ± 0.00	0.34 - 0.34
PO_4-P	ppm	±	
NO_3-N	ppm	0.67 ± 0.12	0.58 - 0.75
NH_4-N	ppm	8.33 ± 3.14	5.00 - 13.00
Clay	%	±	
Silt	%	±	
Sand	%	±	



Appendix A-37. Chemical data for test hole N47-E55.

Laurenroth, W.K., J.L. Dodd, R.K. Heitchmidt and R.G. Woodmansee. 1976. Biomass dynamics and primary production in mixed prairie grasslands in southeastern Montana: baseline data for air pollution studies. Appendix A in the bioenvironmental impact of a coal-fired power plant, second interim report, Colstrip, Montana, June 1975 (ed. Lewis, R.A., N.R. Glass, and A.S. Lefohn), EPA-600/3-76-013, Corvallis, Ore. 314 p.

Lewis, R.A., N.R. Glass and A.S. Lefohn (eds.). 1976. The bioenvironmental impact of a coal-fired power plant. Second interim report, Colstrip, Montana, June, 1975. EPA-600/3-76-013, Corvallis, Oregon. 314 p.

Lewis, R.A. and A.S. Lefohn (eds.). 1976. The bioenvironmental impact of a coal fired power plant. First interim report, Colstrip, Montana, December, 1974. EPA-600/3-76-002, Corvallis, Oregon. 109 p.

Lewis, B.D. and R.S. Roberts. 1977. Geology and water-yielding characteristics of the Northern Powder River Basin, Southeastern Montana. U.S. Geological survey Open-file Report.

Meyn, R.L., E.S. Sunberg and R.P. Young. 1976. Research on reclamation of surface mined lands at Colstrip, Montana. Mt. Agr. Exp. Sta. Res. Rep. 101, Mt. State University, Bozeman. 84 p.

Mogen, C.A., et al. 1959. Chesnut, chernozem, and associated soils of western North Dakota. Soil Sci. Soc. Amer. Proc. 23:56-60.

Montana St. Dept. of Nat. Resources and Cons. 1974. Draft ElS on Colstrip electric generating units 3 and 4, 500 KV transmission lines and associated facilities. Vol. 3A-Power plant. Energy Planning Div., Helena, Mt.

Morris, M.S. 1946. An ecological basis for the classification of Montana grasslands. Proc. Mt. Acad. Sci. 6:41.

Munshower, F.F. and E.J. DePuit. 1976. The effects of stack emissions on the range resource in the vicinity of Colstrip, Montana: Progress Rep. 1975. Mt. Agr. Exp. Sta. Res. Rep. (in press), Mt. State University, Bozeman.

Northern Great Plains Resource Program. 1975. Regional Profile. Surface Resource Work Group, N.G.P.R.P., Denver, CO. 758 p.

Packer, Paul E. 1974. Rehabilitation potentials and limitations of surface-mined land in the northern Great Plains. USDA For. Serv. Gen. Tech. Rept. INT-14. Intermountain Forest and Range Exp. Sta., Ogden, UT.

Parker, F.S. and D.A. Andrews. 1939. The Mizpah coal field, Carter County, Montana. U.S. Geol. Survey Bull. 906-C.

Payne, G.F. 1973. Vegetative rangeland types in Montana. Mt. Agr. Exp. Sta. Bull. 671, Mt. State University, Bozeman. 15 p.

Redmond, C.E. and H.W. Omodt. 1967. Some till-derived chernozem soils in eastern North Dakota. I Morphology, Genesis and Classification. Soil Sci. Soc. Amer. Proc. 31:89-99.

Renick, B.C. 1929. Geology and groundwater resource of central and southern Rosebud Co., Mt. USGS water supp. pap. 600. U.S. Govt. Print. Off., Washington, D.C.

Robinson, C.S., Mapel, W.J., and Bergendahl, M.H., 1964. Stratigraphy and structure of northern and western flanks of the Black Hills uplift, Wyoming, Montana, and South Dakota: U.S. Geol. Survey Prof. Paper 404, 134 p.

Ross, R.L., E.P. Murray and J.G. Haigh. 1973. Soil and vegetation inventory of near-pristine sites in Montana. USDA, SCS, Bozeman, MT 55 p.

Sindelar, B.W. 1972. Range types and productivity of two study areas in southeastern Montana. Rep. prepared for Western Energy Co., Butte, MT. 21 p.

Sindelar, B.W., R. Atkinson, M.E. Majerus and K. Proctor. 1974. Surface mined land reclamation research at Colstrip, Montana. Mt. Agr. Exp. Sta. Res. Rep. 69, Mt. State University, Bozeman. 98 p.

Sindelar, B.W., R.L. Hodder and M.E. Majerus. 1973. Surface mined land reclamation research in Montana. Mt. Agr. Exp. Sta. Res. Rep. 40, Mt. State University, Bozeman. 122 p.

U.S.D.A. Soil Conservation Service. 1971. Technicians guide to range sites, condition classes and recommended stocking rates in SCS districts of the sedimentary plains of Montana, 15-19 inches precipitation zone. 2 p.

U.S. Dept. of Commerce, NOAA. Climatological summary for Colstrip, Montana. 1941-1970.

U.S. Dept. of the Interior. 1977. Resource and potential reclamation evaluation Bear Creek Study area- West Moorhead Coalfield. EMRIA REPORT #8.

Van Voast, W.A. and R.B. Hedges. 1974. Hydrology of Western Energy Company's probable mine areas near Colstrip, southeastern Montana. Preliminary report. Montana Bureau of Mines and Geology.

Van Voast, W.A. and R.B. Hedges. 1976. Hydrogeologic conditions and projections related to mining near Colstrip, southeastern Montana. Mont. Bur. of Mines and Geology open-file report, June, 1976.

Westinghouse Environmental Systems Dept. 1973a. Colstrip generation and transmission project. Applicants environmental analysis.

Westinghouse Environmental Systems Dept. 1973b. Montana strip mining permit application. Pittsburgh, Penn. 293 p.

Wright, J.W. and E.A. Wright. 1948. Grassland types of southcentral Montana. Ecology 29:448-460.