GEOLOGICAL SURVEY OF WYOMING

BEARING CAPACITY OF RECLAIMED SPOIL, ROSEBUD MINE, COLSTRIP, MONTANA

by

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BEARING CAPACITY OF RECLAIMED SPOIL, ROSEBUD MINE, COLSTRIP, MONTANA

Jon M. White[1] and Donald E. Clark[2]

INTRODUCTION

Strip mining of coal, as well as iron, bentonite, uranium, and other minerals has affected portions of the Great Plains and Rocky Mountains. Most approved mine plans in the west call for the reclamation of the mined areas to farmland, rangeland, or wildlife habitat.

Other post-mining uses are possible. The land may be used for schools, industrial, or residential use. Recreational parks, airports, open-air theatres, and commodity stockpiles are possible additional uses. Bearing capacity, foundation settlement, and surface subsidence of strip-mined areas are thus of practical concern. Considerable knowledge of these matters has been gained from experience in England (Arguile, 1971; Charles, et al, 1977; Kilkenny, 1968), the Applachian coal fields (Earl, 1976) and Texas (Schneider, 1977; Clary and Mathewson, 1975). This paper extends that knowledge by describing results of recent research on the geotechnical properties of strip coal mine spoils in the Northern Great Plains.

Geologic Setting

The Colstrip area of Montana lies in the north-central portion of the Powder River Basin, a structural and topographic basin containing a sequence of Phanerozoic sedimentary rocks. The Montana portion of the basin is bounded

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on three sides by structural uplifts which include the Black Hills to the southeast, the Bighorn Mountains in the west, the Porcupine Dome on the north, and the Miles City Arch on the northeast. The Powder River Basin extends southward into Wyoming where it widens and the sedimentary sequence thickens. In the Colstrip area, the sediments dip west or southwest toward the basin axis at a dip of about one degree.

LOCAL GEOLOGY

Most geologic studies of the Colstrip area concentrated on groundwater and coal resources. Dobbin (1930) and Pierce (1936) mapped and described the coal at Forsyth and Colstrip. Kepferle (1934) and Ayler, Smith and Deufman (1969) outlined the surface mineable coal. Matson and Blumer (1973) described the quality and reserves of coal at Colstrip. Renick (1929) and Perry (1935) investigated the groundwater resources of the area. VanVoast, Hedges and McDermott (1977) considered the effects of mining on the aquifers of the area.

The Colstrip coal deposit of Matson and Blumer (1973) lies within the Forsyth Field as described by Dobbin (1930). In ascending order, sedimentary rocks exposed in the Forsyth Field include the Upper Cretaceous Judith River, Bearpaw, and Hell Creek formations; the Paleocene Fort Union Formation; Pleistocene terrace gravel; and Holocene alluvium. The Fort Union contains economically mineable coal and is subdivided into the Tullock, Lebo, and Tongue River members. All members contain coal, but the thickest and most laterally persistent coals occur in the Tongue River Member. In the Colstrip area, ten coals, which range from 3 to 30 feet thick, have been mapped in a stratigraphic sequence of 600 feet of Tongue River rocks. The coal beds are the Burley, Robinson, Stocker Creek, McKay, Rosebud, Lee, Popham, Sawyer, Proctor, and Richard. Where it is overlain by 250 or less feet of overburden, the Rosebud coal bed is the economically mineable coal in the Colstrip area. Western Energy Company presently mines the Rosebud near Colstrip. A few miles south of Colstrip, Peabody Coal Company mines both the McKay and the Rosebud coals. The noncoaly material between the McKay and Rosebud coals locally is 4 to 160 feet thick.

The Rosebud coal bed is strippable along the divide separating Rosebud and Arnnells creeks. These streams have eroded Tongue River rocks to a gently rolling terrain. Locally, the streams have formed dominant bluffs of sandstone or clinker.

In this area, the rock above the Rosebud coal consists of about 90 feet of massive, poorly indurated, fine-grained yellowish-gray sandstone (Figures 1 and 2). Overlying the sandstone is a friable sandstone interbedded with silty clay, shale, and several yellow-brown fresh-water limestone beds. The high divides in the area are commonly capped by gray to yellow-brown shale and sandstone (Kepferle, 1954). In places where the coal has burned, the overburden is baked into "clinker". The floor rock is a dense, light gray clayey to silty sandstone. A typical gray underclay locally underlies the coal.

The sediments of the Colstrip area were probably deposited in a low- to high-energy fluvial environment, associated with significant paludal and fresh-water lacustrine environments. The lithologic units are strongly interbedded, thereby indicating depositional environments, shifting with time (Robinson, 1972; McDonald, 1972).

METHOD OF INVESTIGATION

The area investigated was a portion of Area "A" of Western Energy Company's

Rosebud Mine near Colstrip, Montana, in Sec. 33, T.2 N., R.41 E., Montana Principal Meridian (Figure 3). Beginning in 1975, the area was mined in generally east-west strips about 200 feet wide, and of various lengths up to about one mile. Shale and sandstone overburden was removed to a depth of 30 to 100 feet by conventional excavation equipment, prior to coal removal. Heterogeneous overburden from each pit was placed in an adjacent pit created by prior mining in an uncontrolled manner with no special treatment or compaction. During reclamation, the overburden was regraded to approximate the original contours of the land, the site was revegetated with natural grasses.

In 1977, Western Energy Company investigated the feasibility of developing typical residential and light commercial facilities on backfilled areas. They drilled five test borings (Figure 3). Standard penetration resistance tests were made and disturbed and undisturbed samples obtained. In the laboratory, grain size distribution, Atterberg limits and natural moisture, and density were determined for a number of samples. Consolidation and direct shear tests were performed. The results of this testing are presented in Appendix A.

RESULTS

The mine backfill material was reworked bedrock shale and sandstone, intermixed with sand, clay, and coal. Blow count values are from 7 to more than 100 blows per foot. The test data suggest that a field unit weight of 100 lb/ft^3 is conservative and may be used in bearing capacity and settlement computations.

Two series of direct shear tests were performed: three tests were performed on sandstone and three on shale. All tests indicate no cohesion; for sandstone $\emptyset = 51°$ and for shale $\emptyset = 45°$. We believe these values are indicative of the tested samples and not the overall mass of mine backfill. Of the 55 standard penetration tests driven one foot, the blow counts ranged from 7 to 63. Distribution appears random. Seven is a reasonable value for design and corresponds to a loose sand or a medium stiff clay (Terzaghi and Peck, 1967, p.341). These values are used in subsequent computations of bearing capacity and settlement.

CONCLUSIONS

Bearing Capacity

Bearing capacity formulae are based on soil strength and are intended to prevent failure due to overstressing of the soil. Presumptive bearing capacities such as those in the Uniform Building Code (p. 478) are implicitly a function of strength. Design by either formula or presumptive bearing capacity is intended to provide a conservative design. Foundation failure of modern buildings is therefore almost always a result of differential settlement. Terzaghi and Peck (1967, p.481) quote the presumptive bearing values of 32 foundation materials in 10 building codes. Fill is considered in none of the codes and building on uncompacted fill is considered a poor practice. However, uncompacted surface mine backfill has for decades supported structures in Britain and Germany,and the practice is becoming more common in the eastern United States.

To determine the bearing capacity for this western site, we use the familiar relation

$$q = \frac{2}{5} CN_c + \gamma D_f N_q + \frac{1}{2} \gamma B N_\gamma$$

for a long footing on loose sand, one foot wide and one foot deep, where $C = 0$, $q \simeq 900$ psf. At four feet below grade $q \simeq 3{,}000$ psf.

For the same footing in clay, we use,

$$q = 5c(1 + 0.2 \frac{Df}{B}) (1 + 0.2 \frac{B}{L})$$

and let C - 900 psf, L = ∞. Then q = 5,400 psf and at four feet depth q = 8,100 psf.

The required bearing capacity for a mat foundation would be very small relative to the above determined values and the available bearing capacity is considered adequate by inspection.

The bearing capacities computed above should be reduced by a factor of three for dead loads and frequently applied live loads (Terzaghi and Peck, 1967, p.510). Thus allowable bearing values for a one foot wide footing would be about 300, and 100 psf on sand at depths of one and four feet, respectively, and 1,800 and 2,700 psf on clay, respectively. To reduce uncertainties from the uncontrolled placement typical of surface mining, a valuable building should not be built until spoil is removed and soil is replaced in an engineered surface pad. This pad would achieve uniformity. For support of typical light-weight buildings, the minimum footing widths of building codes would take precedence over bearing capacities computed from soil strengths.

Settlement

Available data suggest that there exists considerable potential for settlement at the site investigated, and this agrees with prior experience (Charles, et al., 1977, p.229). We estimated 0.3 feet to 1.0 feet of settlement due to compaction of the mine backfill in the next four to ten years. Based on relations given by Lambe and Whitman (1969, p.221), we further estimate up to 0.5 feet of settlement due to loading from building foundations.

DISCUSSION

There would be no advantage to piers or piles set in the mine backfill material because the piers or piles would settle with the fill. And deep piles, set on strata beneath the backfill must be designed to resist large downdrag loads as the backfill settles around them. Deep piles would certainly be uneconomical for the light structures herein envisioned. This leaves shallow, rigid foundations as the only practical support for light building at the site. Given 30 to 100 feet of backfill, overall settlements would probably be 1/16 - 3/16 inch per year for 50 years after equilibrium is attained.

Several foundation options exist. A compacted fill pad is certainly an attractive solution. At a depth of twice the footing width, the vertical pressure on the soil is only about 20% of the footing contact pressure. That depth is therefore usually considered sufficient. If footings are placed at a depth of four feet because of frost considerations, and if a typical footing is 2 feet wide, then eight feet of backfill would need to be removed and replaced by an engineered pad.

A specially reinforced basement could work also. Properly reinforced to resist deformation and to transmit load to the slab, a wall could be used without special treatment of the backfill. If a basement is not needed, and if rock fragments do not preclude trenching, then a trench footing may be used. For these, a trench some four feet deep and 2 feet wide is dug. Racks of reinforcing steel are placed and the concrete poured. The resulting footings derive much of their supporting capacity from skin friction. Little bearing capacity is required.

The Building Research Advisory Board (1967?) has proposed a special slab. It consists of cross-trenches about two feet deep, each containing racks of reinforcing steel. The trenches are cast integrally with the overlying slab.

The foundation resists load by a combination of skin friction along the trenches and footing pressure against the slab and trench bottoms.

The bearing capacities determined by this investigation are apparently typical of the site and of other similar sites and are sufficient to support residential or light industrial and commercial structures. If slabs or special footings are used, the site is appropriate for a trailer court, residential subdivision, and shopping center. Foundations for heavy structures would be extraordinarily expensive as they would require piles set below the backfill. Water and sewer utilities and drainage facilities should be designed to accommodate up to 1.5 feet of settlement.

These results agree with those of other researchers. The bearing capacities and potential settlements are of the same order as those reported by Kilkenney (1968) and Arguile (1971). Thus, construction of light structures on strip mine backfill at the Rosebud site presents no difficulties that have not been overcome in Appalachia, Germany, and England.

ACKNOWLEDGEMENTS

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APPENDIX A

Summary of field and laboratory test results, residential development in Section 33, Colstrip, Montana.

OFR 83-2

NORTHERN TESTING LABORATORIES, INC.
CONSULTING GEOTECHNICAL ENGINEERS
Great Falls, Billings, Montana - Boise, Idaho - Gillette, Wyoming

SUMMARY OF FIELD AND LABORATORY TEST RESULTS
RESIDENTIAL DEVELOPMENT IN SECTION 33
COLSTRIP, MONTANA

Sheet 1 of 2
Job No. 77-150

Core No.	Depth in Feet	Classification	Penetration Test Blows Per Foot	Moisture Content Percent	Atterberg Limits Liquid Limit,%	Atterberg Limits Plastic Limit,%	Atterberg Limits Plasticity Index	Gradation Percent Retained Gravel	Sand	Silt	Clay
H 1	3.0 - 4.5	FILL, Sandstone	33	10							
	8.0 - 8.5	FILL, Sandstone, Sand	--	11	In-place Dry Density = 98 pcf						
	8.5 - 9.2	FILL, Sandstone	--	10	In-place Dry Density = 97 pcf						

Direct Shear Test Results:

Moisture Condition	Normal Stress, psf	Maximum Shear Stress, psf
Field Moisture	1000	820
Saturated	2000	1360
Field Moisture	3000	3400

Core No.	Depth in Feet	Classification	Penetration Test Blows Per Foot	Moisture Content Percent	Atterberg Limits Liquid Limit,%	Atterberg Limits Plastic Limit,%	Atterberg Limits Plasticity Index	Gradation Percent Retained Gravel	Sand	Silt	Clay
	9.5 - 11.0	FILL, Shale, Claystone	10	10	25	13	12	0	18	57	25
	13.0 - 14.5	FILL, Shale Claystone	20	10							
	18.0 - 18.7	FILL, Shale, Claystone	50/0.2	9							
	23.0 - 24.5	FILL, Sandstone	13	6							
	28.0 - 29.5	FILL, Sandstone	15	9							
	33.0 - 34.5	FILL, Sandstone	20	8							
	38.0 - 39.5	FILL, Sandstone	33	9							
	43.0 - 44.5	FILL, Sandstone	17	8							
	48.0 - 49.5	FILL, Sandstone	16	10							
	53.5 - 54.5	SAND, Gravelly	26	10							
	58.0 - 59.5	SAND, Gravelly	26	9							
	63.0 - 63.1	COAL	30/0.1	--							
	68.0 - 68.3	COAL	100/0.3	--							
H 2	2.7 - 34	FILL, Shale, Claystone	--	12	In-place Dry Density = 92 pcf.						

Direct Shear Test Results

Moisture Condition	Normal Stress, psf	Maximum Shear Stress, psf
Field Moisture	1000	930
Saturated	2000	2150
Field Moisture	3000	2970

Core No.	Depth in Feet	Classification	Penetration Test Blows Per Foot	Moisture Content Percent	Atterberg Limits Liquid Limit,%	Atterberg Limits Plastic Limit,%	Atterberg Limits Plasticity Index	Gradation Percent Retained Gravel	Sand	Silt	Clay
	3.4 - 4.2	FILL, Shale, Claystone	--	13	In-place Dry Density = 98 pcf						
	4.2 - 5.7	FILL, Sandstone	12	9							
	7.7 - 9.2	FILL, Sandstone	14	14							
	17.7 - 19.2	FILL, Sandstone	14	13	In-place Dry Density = 108 pcf.						
	22.7 - 24.2	FILL, Sandstone	22	9	Granular	Non - Plastic		0	72	16	12
	27.7 - 29.2	FILL, Sandstone	12	9							
	32.7 - 34.2	FILL, Shale, Claystone	17	15							
	37.7 - 39.2	FILL, Shale, Claystone	60	10							
	42.7 - 44.2	FILL, Shale, Claystone	17	13							
	47.7 - 49.2	FILL, Shale, Claystone	36	13							
	52.7 - 53.9	FILL, Sandstone	--	13	In-place Dry Density = 105 pcf						
	57.7 - 59.2	FILL, Sandstone	17	11							
	62.7 - 64.2	FILL, Sandstone	20	18							
	67.7 - 67.8	SHALE, Claystone	50/0.1	--							
H 3	2.8 - 4.3	FILL, Shale, Claystone	18	11	29	15	14	0	14	35	51
	7.8 - 9.3	FILL, Shale, Claystone	16	12							
	12.8 - 14.3	FILL, Shale, Sandy	34	12							
	17.8 - 19.3	FILL, Shale, Sandy	17	14							
	22.8 - 24.3	FILL, Shale, Sandy	15	14							
	27.8 - 29.3	FILL, Shale, Sandy	12	12							
	32.8 - 34.3	FILL, Shale, Sandy	20	12							
	37.8 - 39.3	FILL, Shale, Sandy	15	13							
	42.8 - 44.3	FILL, Shale, Sandy	19	10							
	47.8 - 49.3	FILL, Shale, Sandy	--	13	In-place Dry Density = 107 pcf.						
	52.8 - 54.3	FILL, Sandstone	22	11							
	57.8 - 59.3	FILL, Sandstone	15	11							
	62.8 - 64.3	FILL, Sandstone	17	14							
	67.8 - 67.9	SHALE, Claystone	50/0.1	--							
	72.8 - 73.2	SHALE, Claystone	100/0.4	11							

OFR 83-2

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SUMMARY OF FIELD AND LABORATORY TEST RESULTS
RESIDENTIAL DEVELOPMENT IN SECTION 33
COLSTRIP, MONTANA

Sheet 2 of 2
Job No. 77-150

Core No.	Depth in Feet	Classification	Penetration Test Blows Per Foot	Moisture Content Percent	Atterberg Limits			Gradation Percent Retained			
					Liquid Limit,%	Plastic Limit,%	Plasticity Index	Gravel	Sand	Silt	Clay
H 4	0.0 - 8.0	FILL, Shale Sandy (Sulfate Content = .078%)	--	5	22	12	10	0	34	35	31
	3.0 - 4.5	FILL, Shale Sandy	--	15	In-place Dry Density = 113 pcf						
	8.0 - 9.5	FILL, Shale, Sandy	15	10							
	13.0 - 14.5	FILL, Shale, Sandy	7	17							
	18.0 - 19.5	FILL, Shale, Sandy	8	16							
	23.0 - 24.5	FILL, Shale, Sandy	--	18	In-place Dry Density = 108 pcf						
	28.0 - 29.5	FILL, Shale, Claystone	15	15							
	33.0 - 34.5	FILL, Shale, Claystone	19	16							
	38.0 - 39.5	FILL, Sandstone	17	10							
	43.0 - 44.5	FILL, Sandstone	11	9							
	48.0 - 49.5	FILL, Sandstone	38	8							
	53.0 - 54.5	FILL, Sandstone	46	6							
	58.0 - 59.5	FILL, Sandstone	14	11							
	63.0 - 64.5	FILL, Shale, Claystone	19	14							
	68.0 - 68.5	SHALE, Claystone	100/0.5	10	32	16	16	0	0	55	45
H 5	2.9 - 4.4	FILL, Sandstone	13	10							
	7.9 - 9.4	FILL, Shale, Siltstone	21	10	21	18	3	0	26	60	14
	12.9 - 14.4	FILL, Sandstone	17	11							
	17.0 - 19.4	FILL, Sandstone	18	7							
	22.9 - 24.4	FILL, Sandstone	41	11							
	27.9 - 29.4	FILL, Sandstone	13	6							
	32.9 - 34.4	FILL, Sandstone	19	13							
	37.9 - 39.4	FILL, Sandstone	--	11	In-place Dry Density = 105 pcf.						
	42.9 - 44.4	FILL, Sandstone	63	9							
	47.9 - 49.4	FILL, Sandstone	30	9							
	52.9 - 54.4	FILL, Sandstone	27	11							
	57.0 - 59.4	FILL, Sandstone	27	7							
	62.9 - 64.5	FILL, Sandstone	36	5							
	67.9 - 68.4	FILL, Sandstone	100/0.5	9							

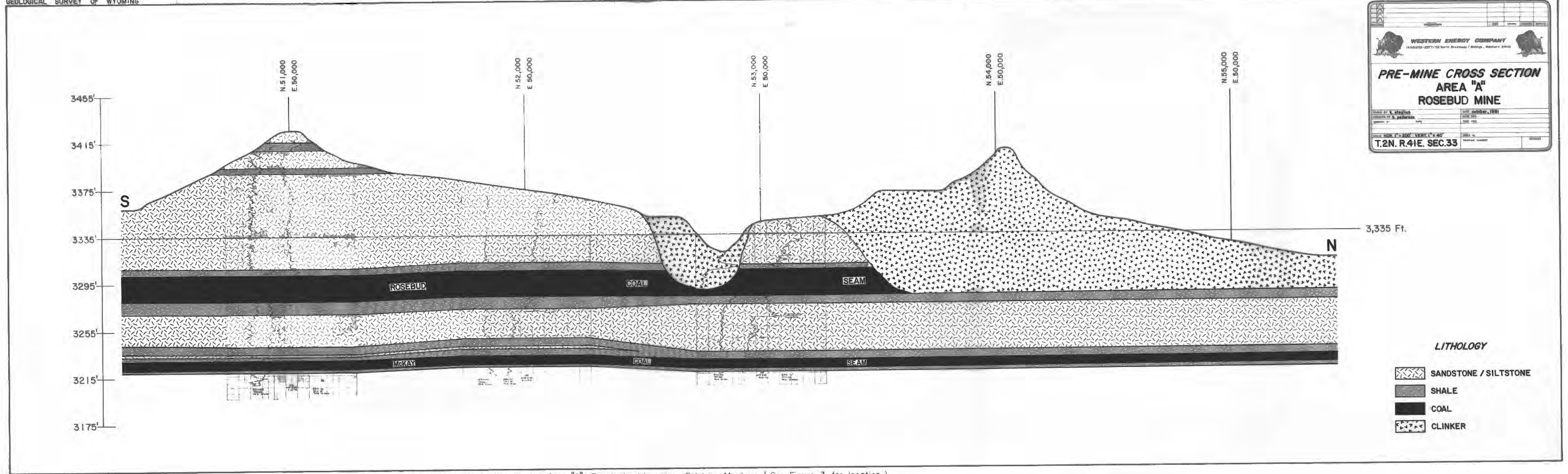

Figure 1. Pre-mine cross section S-N, Area "A", Rosebud strip mine, Colstrip, Montana (See Figure 3 for location)

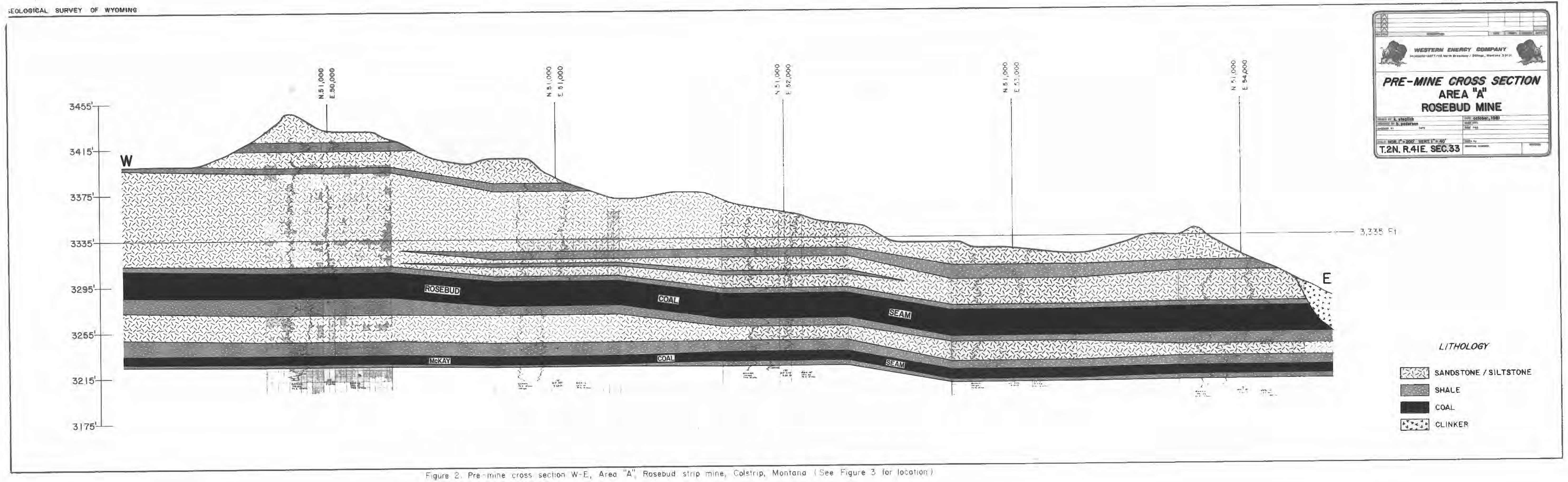

Figure 2. Pre-mine cross section W-E, Area "A", Rosebud strip mine, Colstrip, Montana (See Figure 3 for location)

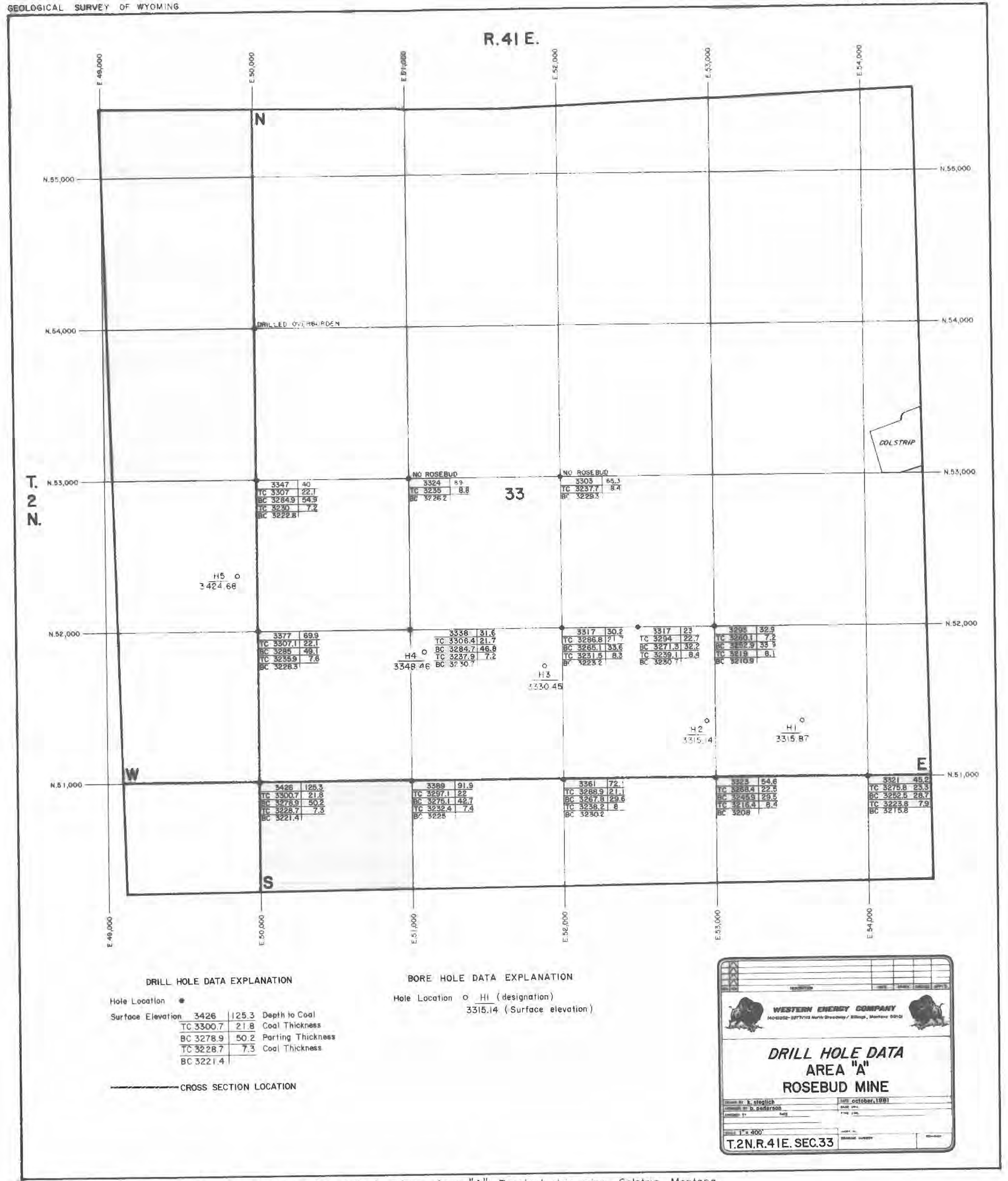

Figure 3. Pre-mining drill hole and post-mining bore hole locations, Area "A", Rosebud strip mine, Colstrip, Montana