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Clay-based Grouting Demonstration Project at the Mike Horse Mine in Lincoln, Montana

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ABSTRACT

The objective of this first clay-based grouting demonstration project in the United States, funded jointly by DOE and EPA, is to reduce the inflow of shallow groundwater and surface water through the Mike Horse fault system and into the abandoned underground workings of the Mike Horse Mine. Acid rock drainage from the portal of the mine should be reduced as result of grouting. The pH of the discharge varies from 3.5 to 5.5. The owners of the Mike Horse Mine, (ASARCO and ARCO), have permitted this clay-based grouting demonstration at the site under the Mine Waste Treatment Pilot Program.

To accomplish this purpose, clay-based grout is being injected into the underlying bedrock and alluvium through two rows of inclined holes drilled from the surface. Injection is being performed in two phases, the first of which was completed in the fall of 1994, and the second is planned to commence in July, 1995. This paper is based on preliminary and incomplete data obtained during the first phase and will be revised after completion of the project.

Four investigation angle holes were drilled, and packer tests were performed to determine pregrout conditions prior to commencement of actual work. The first phase consisted of drilling and grout injection through two rows of inclined grout holes. The angle of five grout holes was 35 degrees (from horizontal), and the angle of the remaining holes varied from 45 to 67 degrees (from horizontal). The length of the holes varied from 45 to 50 meters. The diameter of surface casings was 150 mm, and the diameter of boreholes was 112 mm. The grout was injected through a packer in order to control pressures and in stages to control grout dispersion.

During thirty working days, excluding packer testing, mobilization and demobilization, a total of 1195 cubic meters (1550 cubic yards) of clay-based grout was injected in the lower half of the grout holes. The average placement rate was 40 cubic meters (50 cubic yards) per day and was

done primarily during a single-shift operation. Immediate ramifications were observed when the water level rose in several monitoring wells. The largest increase was in MW-6 which rose from 63.45 meters to 38.00 meters (from 208.04 feet to 124.60 feet). The effects of grouting on streamflow, water levels in monitoring wells, and portal discharge are being monitored continuously.

INTRODUCTION

The Mike Horse Mine site, located approximately 15 miles east of the town of Lincoln, Montana, was selected for demonstration of the clay-based grouting technology. The Mike Horse Mine site is in the inactive Heddlestone Mining District and has been recognized as a contributor to the pollution problems associated with the upper Blackfoot River ecosystem which includes Mike Horse Creek.

The Mike Horse Creek is the major drainage feature in the project area. A relatively small, intermittent seep and the 300-level portal discharge both converge with the Mike Horse Creek and contribute to the overall flow regime. Historic data indicate that acid rock drainage and heavy metal-laden sediment from the portal discharge are being released into Mike Horse Creek. However, water quality analyses performed on surface water and groundwater in the project area showed non-elevated levels of metals and neutral pH water; therefore, metal loading occurs as groundwater flows through the mine workings before discharging from the portal.

The upper reach of Mike Horse Creek loses flow into the subsurface strata in the area where the stream crosses the Mike Horse vein/fault system. The mine workings generally follow the vein/fault system, which was a lead-zinc producing ore body. This area was designated for demonstration of the clay-based grouting technology. Grouting in the vein/fault system should inhibit groundwater from entering the mine workings and reduce the volume of acid rock drainage from the 300-level portal.

GEOLOGY AND HYDROGEOLOGY OF MIKE HORSE MINE SITE

Bedrock in the project area consists mainly of argillite with some porphyry. Unconsolidated alluvium overlies the bedrock along the valley bottom. The main intrusive/structural geologic feature in the project area is the mineralized Mike Horse vein/fault structure. Fractures are more prevalent in the porphyry than the argillite, with fracture intensity strongly related to proximity to the Mike Horse vein/fault structure.

Groundwater occurs at two levels: 1) a shallow aquifer in the unconsolidated alluvium and 2) a deeper fractured bedrock system. Groundwater movement in the alluvial aquifer is controlled by topography and the Mike Horse Creek drainage system. Orientation of the fractures associated with the Mike Horse vein/fault system exert a strong influence of groundwater flow in the bedrock aquifer. Flow paths are toward the 300-level mine workings.

The location of the vein/fault structure in relation to the losing reach of the Mike Horse Creek indicates that infiltration of surface water is through the fractures associated with the fault. In

addition, the direction of bedrock flow toward the mine workings supports the proposition of a hydraulic connection between groundwater in the fracture system of the Mike Horse vein/fault structure and the 300-level portal discharge.

AQUIFER TESTING AT THE MIKE HORSE MINE

The objective of the aquifer testing was to provide hydraulic parameters, to determine the degree of interconnectedness, and to define the hydrogeologic system at the Mike Horse Mine in order to plan grout emplacement. Aquifer testing was performed in six monitoring wells (MW-1 through MW-6) (Figure 1) and consisted of slug tests and pumping/recovery tests. Slug test results are representative of the aquifer opposite the screened section of the wells and are presented in Table 1.

MONITORING WELL	DEPTH OF WELL M	HYDRAULIC CONDUCTIVITY CM/SECOND	WATER TABLE LEVEL BEFORE GROUTING M (FT)
MW-1	38.10	$9.18X10^{-7}$	29.95 (85.10)
MW-2	12.19	$3.24X10^{-5}$	6.90 (22.63)
MW-3	42.67	$6.11X10^{-6}$	8.30 (27.22)
MW-4	21.34	$4.13X10^{-6}$	18.58 (60.94)
MW-5	36.58	$5.29X10^{-5}$	32.75 (107.40)
MW-6	126.57	$7.6x10^{-6}$ - $4.27x10^{-4}$	63.45 (208.04)
MW-7	15.43	(no data)	12.18 (39.04)

Table 1. Mike Horse Mine Slug Test Results and Associated Water Table Levels

In addition to testing in the monitoring wells, four angled investigation holes were cored to provide lithologic detail including fracture orientation and intensity. These holes, ADH-5 to ADH-9 (Figure 1), were later used for grouting of the Mike Horse vein/fault system.

GROUT FORMULATION

A complex array of laboratory studies, with regard to geochemical and geotechnical conditions and the characteristics of the chosen clay source, were undertaken in STG's Ukrainian laboratory. These tests resulted in the development of the clay-based grout formula used at the Mike Horse Mine.

Clays encountered in the Troy deposit found in northern Idaho were tested and subsequently used as the basic grout constituent. Two grout formulations were developed. The first was for low-acidic environments with a pH of 5.5, and the second was for acid mine water with a pH of 3.5.

During implementation of the first phase of the demonstration project, the grout used was for low-acidic environments (pH of 5.5). This grout composition consisted of 30 -35% Troy kaolinite clay, 6 - 7% sulfate resistant cement (Class V), 1 - 1.5% sodium silicate, and the remainder was water with other additives as required. The density of the grout composition was 1350 - 1400 kg/m^3, with a dynamic shear strength of 85 - 90 Pa, a structural viscosity of 37 - $40x10^{-3}$ Pa•second, and a compressive strength of 0.1 -0.15 MPa.

For the second phase of the project, STG has studied the Blossburg clay deposit found near Helena, Montana. A new clay-based grout formulation with approximately the same parameters has been developed. The Blossburg clay deposit is nearer to the Mike Horse Mine site than the Troy deposit, and therefore, should result in lower transportation and grouting costs.

GROUT PRODUCTION AND PLACEMENT

Clay-based grout will be injected into the underlying bedrock and alluvium in two phases through two rows of inclined holes drilled from the drill pad area as presented in Figure 2. The first phase of the demonstration project at the Mike Horse Mine began in September of 1994 and was completed November of 1994. The grout was injected through a packer in the lower half of the angled drilled holes. A low hydraulic conductivity zone was encountered, and injection was limited by the pump capacity of 4.1 MPa (600 psi). Results of grout injection into angled holes (35 degrees from horizontal) of the first row during the first phase are presented in Table 2.

GROUTING INTERVALS ALONG HOLES, M	TOTAL VOLUME OF GROUT PUMPED IN HOLES, M^3				
	HOLES				
	ADH-6	ADH-9	ADH-10	ADH-11	ADH-17
40 - 45	4	72	--	9	28
35 - 40	2	6	--	8	32
30 - 35	--	11	--	99	12

Table 2. Results of Grout Injection Through Angled Holes (35 Degrees from Horizontal) During First Phase

Results of grout injection during the first phase into angled holes (45 degrees from horizontal) of the second row are presented in Table 3. Grouting of the remaining stage of ADH-14 and the remaining stages in other holes will proceed during the second phase of the project.

GROUTING INTERVALS ALONG HOLES, M	TOTAL VOLUME OF GROUT PUMPED IN HOLES, M^3				
	HOLES				
	ADH-8	ADH-14	ADH-15	ADH-15'	ADH-16
45 - 50	43	193	10	39	11
40 - 45	51	80	--	53	5
35 - 40	42	18	--	--	16
30 - 35	3	--	--	--	--

Table 3. Results of Grout Injection into Angled Holes (45 Degrees from Horizontal) During First Phase

Results of grout injection into angled holes (57 to 67 degrees from the horizontal) during the first phase are presented in Table 4. Grouting of holes ADH-12 and ADH-13 in non-grouted intervals will be done during the second phase of the project.

GROUTING INTERVALS ALONG HOLES, M	TOTAL VOLUME OF GROUT PUMPED IN HOLES, M^3		
	HOLES		
	ADH-7	ADH-12	ADH-13
40 - 50	143	15	58
30 - 40	26	--	21
20 - 30	25	--	36
15 - 20	25	--	4
5 - 15	92	--	--

Table 4. Results of Grout Injection Through Angled Holes (57 to 67 Degrees from Horizontal) During First Phase

During thirty working days (excludes testing, mobilization and demobilization), a total of cubic meters of clay-based grout was injected in the boreholes. The average placement rate was 40 cubic meters per day, primarily on a one-shift basis.

The preliminary calculated coefficient of anisotropy is 0.6. The radius of grout dispersion in the direction of the main fracture system, computed by the permeability of water bearing rock and the pressure of injection, ranged from 2 - 3 meters to 9 - 10 meters, as presented in Table 5. Figure 3 presents an approximate schematic showing the grout curtain at a depth of 35 to 50 meters in the water bearing rock underlying the Mike Horse Creek losing reach.

RADIUS OF GROUT DISPERSION DURING FIRST PHASE, M	GROUT HOLES										
	ADH-7	ADH-8	ADH-9	ADH-11	ADH-12	ADH-13	ADH-14	ADH-15	ADH-15'	ADH-16	ADH-17
	9 - 10	5 - 6	7 - 8	2 - 3	2 - 3	4 - 5	9 - 10	2 - 3	4 - 5	3 - 4	4 - 5

Table 5. Radius of Grout Dispersion in the Direction of the Main Fracture System

WATER LEVEL MEASUREMENTS IN MONITORING WELLS AFTER THE FIRST PHASE

Table 6 shows monitoring well data from selected wells at the Mike Horse Mine site. Measurements were made using a portable water level meter. Immediate ramifications were observed when the water level in several monitoring wells increased. The most significant increase occurred in MW-6 which showed a change in level from 63.45 meters to 38.00 meters (208.04 feet to 126.60 feet) below this measuring point.

MONITORING WELL	DEPTH FROM TOP OF CASING TO WATER, M(FT)		VALUE OF UP(+)/DOWN(-) WATER TABLE IN MONITORING WELL, M(FT)
	11/07/94	02/01/95	
MW - 1	25.95 (85.10)	26.38 (86.51)	- 0.43 (1,41)
MW - 2	6.90 (22.63)	7.23 (23.72)	- 0.33 (1.09)
MW - 3	8.30 (27.22)	5.39 (17.70)	+ 2.91 (9.52)
MW - 6	63.45 (208.04)	38.00 (124.60)	+ 25.45 (83.44)
MW - 7	12.18 (39.94)	12.29 (40.32)	- 0.11 (0.38)

Table 6. Monitoring Well Data from the Mike Horse Mine

SECOND PHASE OF CLAY-BASED GROUTING DEMONSTRATION PROJECT

The second phase of the demonstration project is scheduled to begin in the field in July of 1995. The remaining stages of existing angle boreholes will be grouted during the second phase. MK/STG has calculated that approximately an additional 1400 cubic meters of clay-based grout will be injected for a total anticipated placement of 2600 cubic meters. After completion of grouting, evaluation and monitoring will be performed for approximately one year by both the Mine Waste Treatment Pilot Program and the EPA's Superfund Innovative Technology Evaluation program.

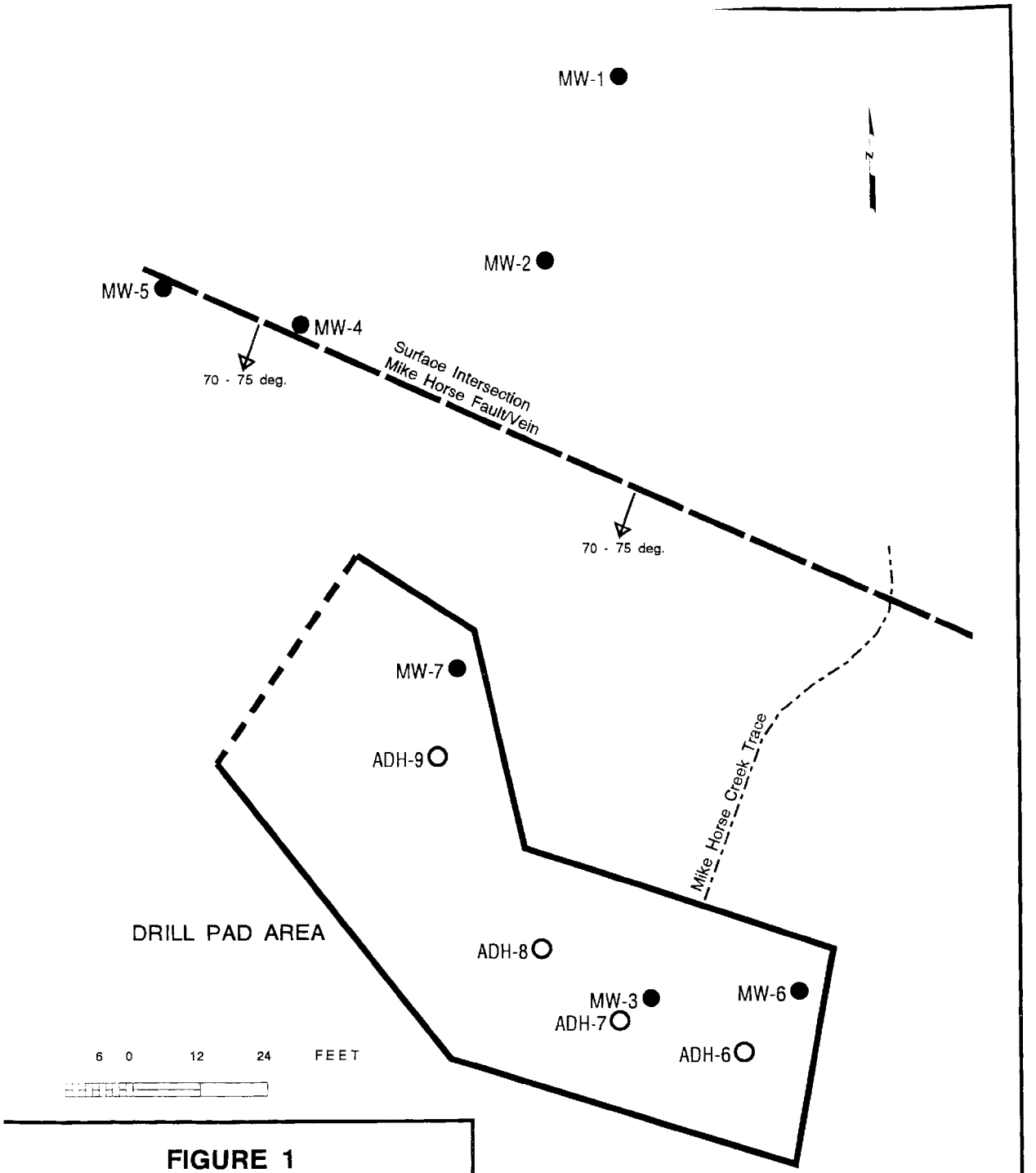

FIGURE 1

Monitoring Wells and Angled Drill Hole Locations on Drill Pad Area Prior to Grouting.

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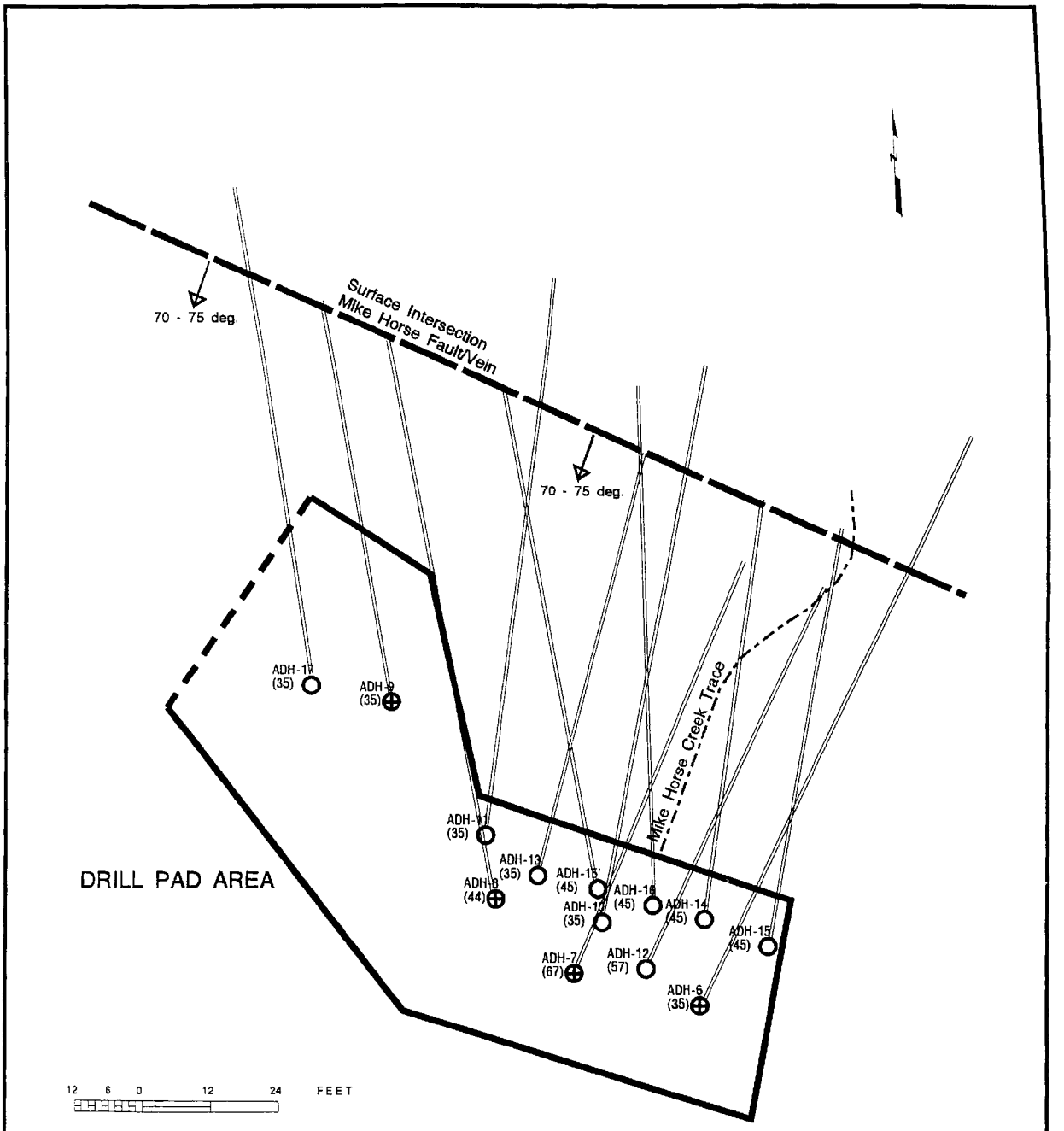

FIGURE 2

Grout Hole Locations

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LEGEND

⊕ (30) Pre-grout Drill Holes with inclination from horizontal in degrees

○ (45) Phase I and II Grout Holes with inclination from horizontal in degrees

↓ Dip of Fault/Vein

IMWA-155

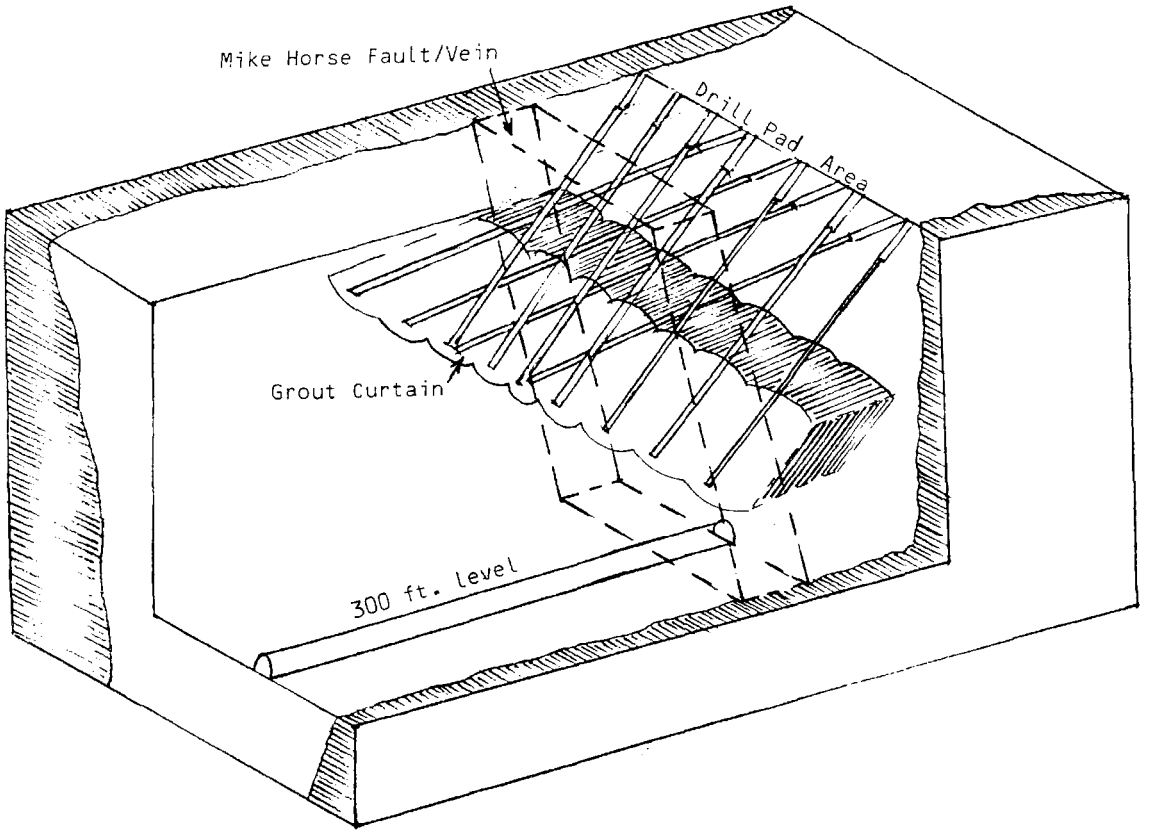

FIGURE 3

Schematic Showing the Creation of the Grout Curtain Through Angled Grout Holes

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