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BOREHOLE MINING: AN ENVIRONMENTALLY COMPATIBLE METHOD FOR MINING OIL SANDS

Prepared for:
UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by
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16. Abstract (Limit: 200 words)

This report presents the results of a demonstration of the technical, economic, and environmental feasibility of hydraulic borehole mining of shallow oil sands. Borehole mining offers a method for extracting the oil sands with minimal disturbance to environmental quality. This project consisted of two concurrent tasks: mining operations and environmental monitoring. To generate the environmental impact, nearly 1,000 tons of oil sands were mined from two boreholes. Water quality and ground subsidence were monitored. No significant changes occurred in the chemical composition of the process water, indicating that the borehole mining process does not dissolve the mined material. The average subsidence in the immediate vicinity of the boreholes was about 1/2 inch, although some points were slightly elevated. In general, the amount of subsidence increased with time and decreased with distance from the borehole. A mining cost analysis was used to project an estimated cost for production mining of about $38 per barrel of oil.

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Foreword

This report was prepared by Flow Technology Company, a Division of Flow Industries, Inc., Kent, Washington, under USBM Contract Number J0295064. The contract was initiated under the Mining Environmental Research Program. It was administered under the technical direction of Twin Cities Mining Research Center, United States Bureau of Mines, with Dr. George A. Savanick acting as the Technical Project Officer. Mr. B. G. Horton was the contracting officer for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period from June 1979 to September 1979. This report was submitted by the authors on February 29, 1980.

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The authors are particularly indebted to Dr. George Savanick, who aided substantially in the project's success, and to Barry Pardus for providing the illustrations presented as Figures 11 and 12 in this report.

There were no inventions developed or patents applied for as a result of the project.

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1. Introduction

The hydraulic borehole mining method allows the removal of underground deposits of oil sands with much less capital cost and increased safety compared to conventional underground mining and without the extensive surface disruption associated with strip mining. The support mining equipment (pumps, engines, derrick, etc.) is operated from the surface and only the mining tool is underground, yet the selectivity of this system allows the removal of small or discontinuous mineral deposits and minimizes the removal of host rock.

The hydraulic borehole mining method includes site selection, site preparation, drilling of boreholes, setting up of borehole mining equipment, mining operations, and backfilling operations. Site selection is based on exploration drilling and consequent analyses. Site preparation includes constructing access roads, clearing the site, and forming a slurry settling pond. Boreholes are drilled below the bottom of the ore zone and cased to the top of the ore zone. A schematic of the borehole mining system, showing two borehole mining units, can be seen in Figure 1. Each of the mining tools includes a cutting jet system, a swivel, tool sections, and a jet pump section. Each mining trailer carries a mining tool, a derrick, hoists, controls, and a diesel-powered hydraulic pump. The pump trailer carries three diesel-powered high-pressure pumps, with electrically powered charge (suction) and slurry pumps. (Note that the Bureau of Mines borehole mining tool, described in Appendix A, was used for the oil sands tests.)

Mining operations begin by lowering the borehole mining tool into the borehole. Ore production begins immediately. The mining tool simultaneously cuts the ore with a high-pressure waterjet (at 500 to 5000 psi) and transports the resulting ore slurry (at 800 to 1200 gpm) to the surface with a water jet pump. Potentially, the ore could be transported directly to a processing plant by slurry pipeline. Backfilling of the waste sand into the borehole cavities should help prevent surface subsidence and the accumulation of waste material (see Marvin, Knoke, and Archibald, 1979).

Hydraulic borehole mining systems have been developed and field tested by Flow Technology Company, a Division of Flow Industries, Inc., under the Bureau of Mines Advancing Coal Mining Technology Program and

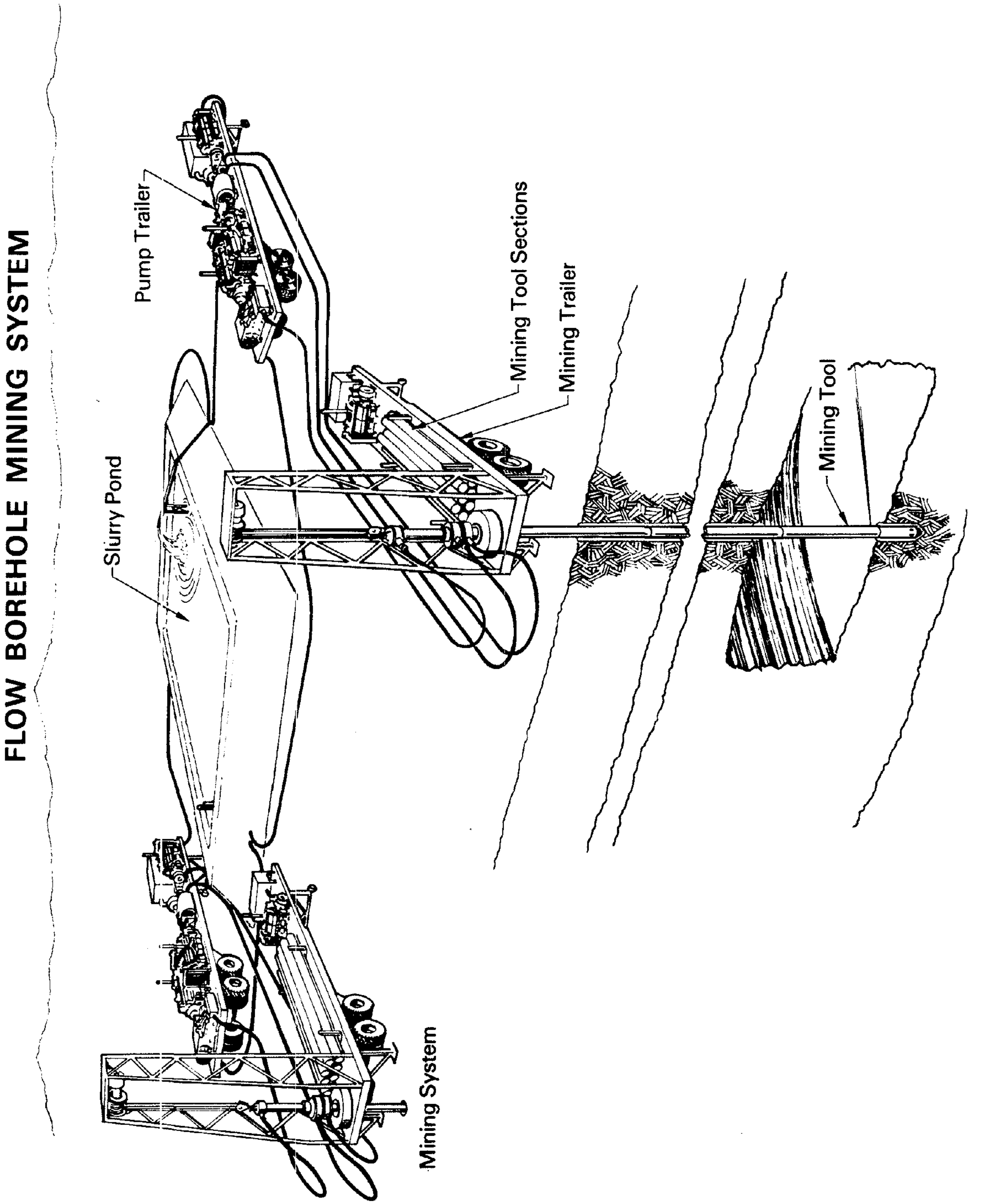

Figure 1. Borehole Mining System.

the Advancing Metal and Nonmetal Technology Program for mining coal and uranium, respectively. The application of a hydraulic borehole mining apparatus to the remote extraction of coal was initiated in 1974. The development of the first borehole coal mining tool was reported by Cheung et al. (1975) and Murman, Yu, and Cheung (1975). The results of the first coal field test were presented in Cheung et al. (1976). A review of the economics of hydraulic borehole coal mining was performed by Cheung (1977). The addition of a coal crusher to the mining tool has been started (see Cheung et al., 1978). The application of the hydraulic borehole mining method to uranium sands was reported by Archibald (1978). Backfilling of uranium cavities has also been tested (see Marvin, Knoke, and Archibald, 1979).

Hydraulic borehole mining promises to be an environmentally attractive method for extracting oil sands and other underground ore deposits. It has the advantages of minimizing surface disruptions, waste rock piles, damage to ground water quality and hydrology, and surface water pollution. Surface disruptions are minimal because no overburden is removed. Waste rock piles are not needed because a negligible amount of host rock is removed. Impact on ground water is incidental because only ground water is used for the mining process. No surface streams need be polluted because a closed-loop water system can be employed.

Flow Technology Company, under contract to the U. S. Bureau of Mines, has completed a research and development project to investigate the economic and environmental aspects of mining shallow oil sands using a hydraulic borehole mining apparatus. The objectives were to demonstrate that oil sands can be mined economically and in an environmentally compatible manner with a hydraulic borehole mining system. Specific objectives included mining 1100 tons of sand within 45 calendar days, monitoring the environmental impact in terms of ground subsidence and ground water quality, and obtaining sufficient technical data to refine predictions of the mining and economic performance of a production mining system for oil sands.

The project consisted of five tasks. Under the first task, the equipment required to perform the mining operation was prepared and transported to the test site outside of Taft, California. Under the second task, the baseline conditions for ground subsidence and ground water quality were determined. Under the third task, the hydraulic borehole mining equipment was set up and used to mine oil sands. Under the fourth task, the degree of ground subsidence and the changes in process water quality as a result of mining operations were determined. Under the fifth task, the technical and economic data were analyzed, and an economic analysis of hydraulic borehole mining of oil sands was prepared.

The results of these tasks are presented in the next three sections, followed by the conclusions and recommendations.

2. Mining Operation

The objective of the hydraulic borehole mining operation was to mine a typical borehole cavity in the oil sands to provide technical and economic data and to simulate the environmental impact of production mining. Nearly 1000 tons of oil sands were removed from two adjacent 150-foot boreholes in Section 26, Township 32S, Range 23E, Kern County, California (Midway-Sunset Oil Field). A site location map and a brief description of the geology and lithology of the area are given in Appendix B. Appendix C is a property analysis report on core samples taken from the borehole side walls.

The side benefits gained from the mining operation were experience in production mining of oil sands and technical data concerning tool refinements and component lifetimes.

2.1 Equipment Setup

The general arrangement of the borehole mining site is shown in Figure 2. Site preparation included grading of the site and adding an access road, a plastic-lined slurry pond, the boreholes and water wells, a water supply, and electrical power (see Figure 3). The hydraulic borehole mining equipment included the borehole mining tool (a three-passage swivel, a 22-foot Kelly section, eight 20-foot standard sections, and the mining section) and a gasoline-engine-driven turntable unit (see Figure 4), a de-airing tank, the slurry discharge tanks, the high-pressure pumping units, an optional water holding tank, and a charge pump (see Figure 5) which fed water to the tank from the pond. The miscellaneous equipment moved to the site included a crane to support the mining tool in the borehole (see Figure 6), a forklift for equipment loading, a backhoe to handle the ore, an office trailer, and hand tools for setup, maintenance, and repair work. All of the mining equipment, in operation, is shown in Figure 7. The Bureau of Mines hydraulic borehole mining tool and the turntable unit are described more fully in Appendix A.

As shown in Figure 2, two boreholes were drilled at the test site in early July. They were created in the following manner. A 36-inch-diameter hole was drilled to 110 feet (the top of the ore zone). A 20-inch-diameter casing was welded, lowered into the hole, and cemented

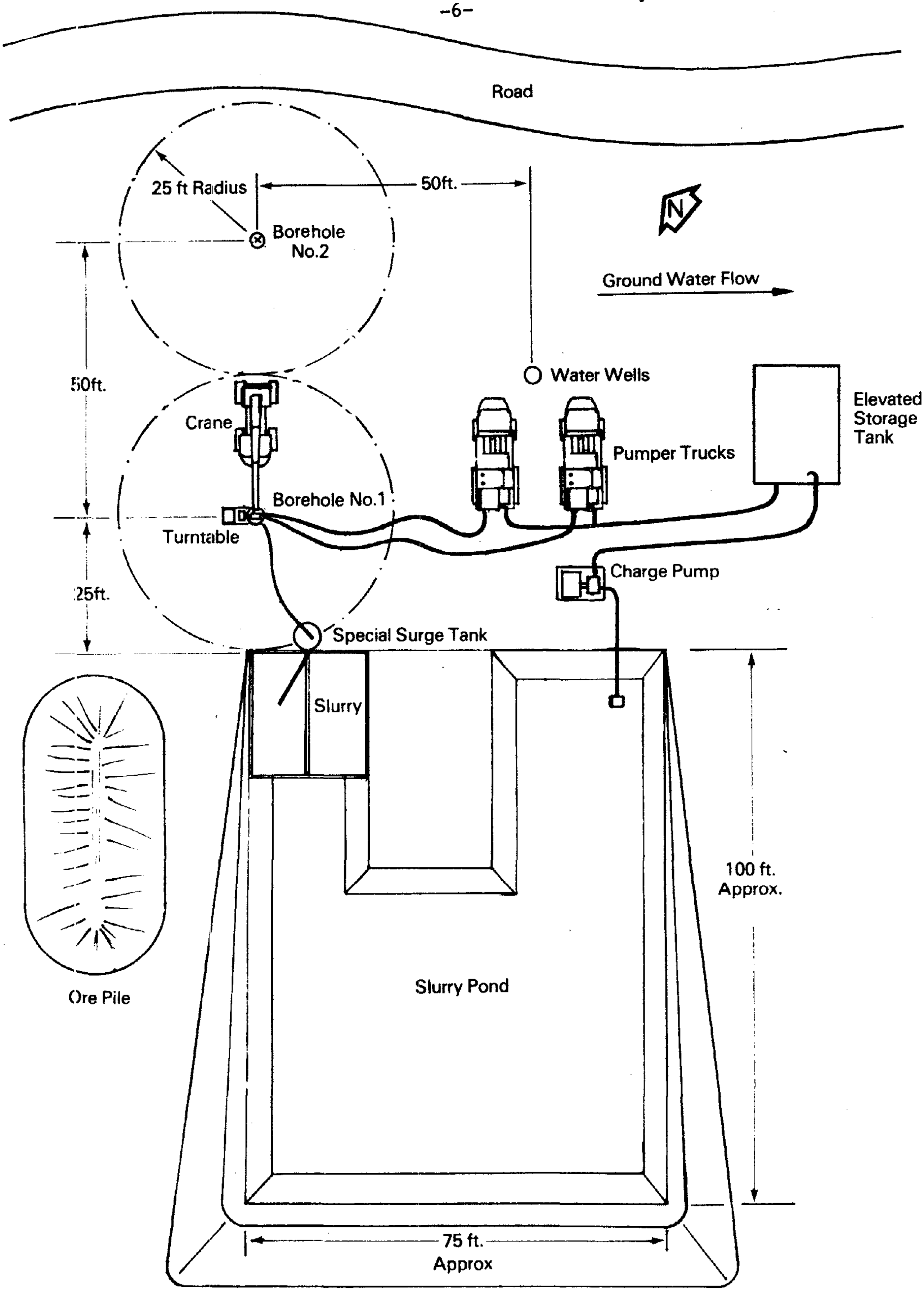

Figure 2. Borehole Oil Sands Field Test Equipment Arrangement.

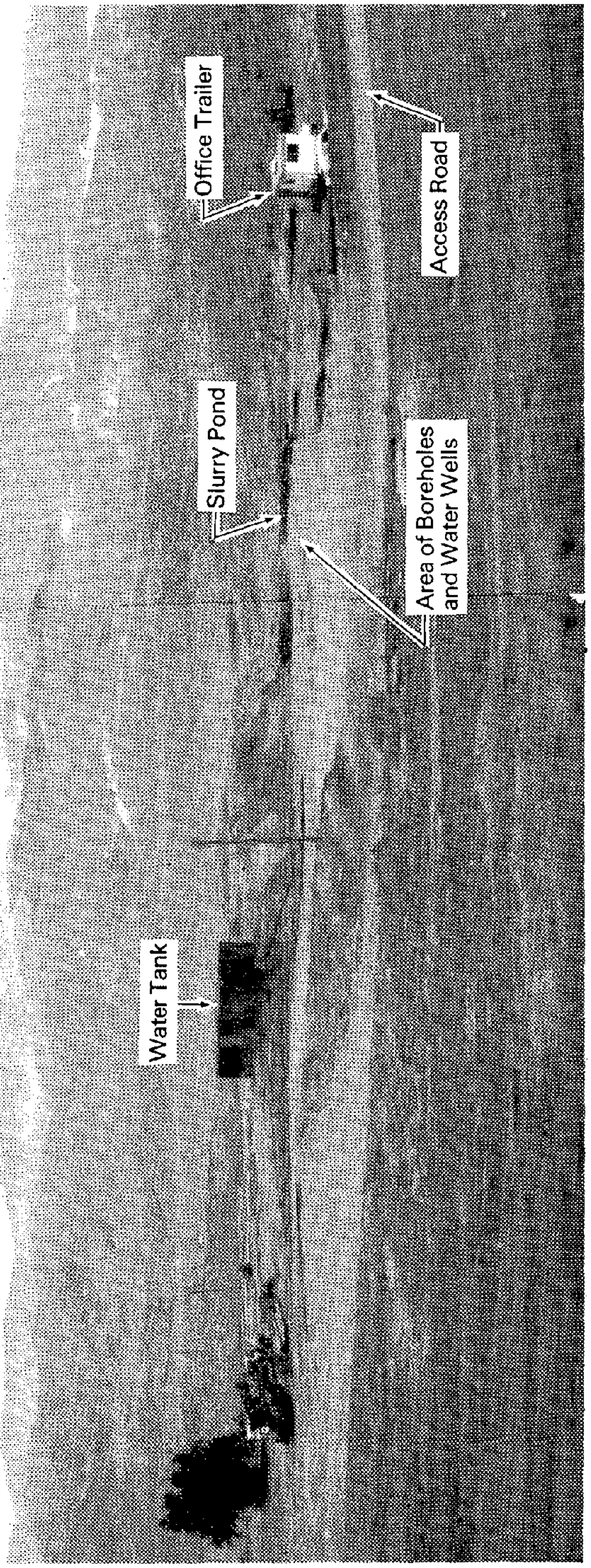

Figure 3. Site Preparation Prior to Equipment Setup.

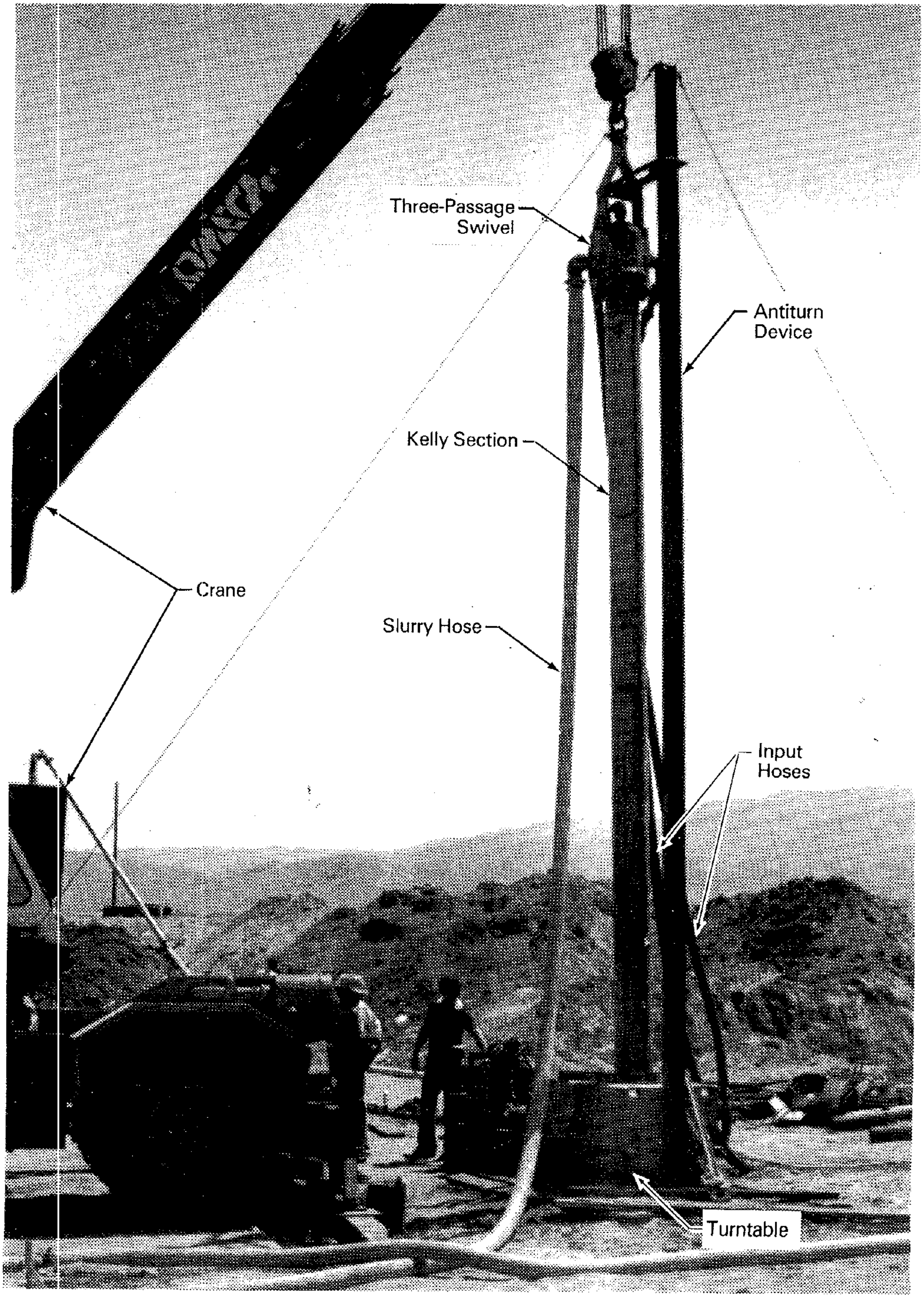

Figure 4. Hydraulic Borehole Mining Tool Being Lowered Through Turntable.

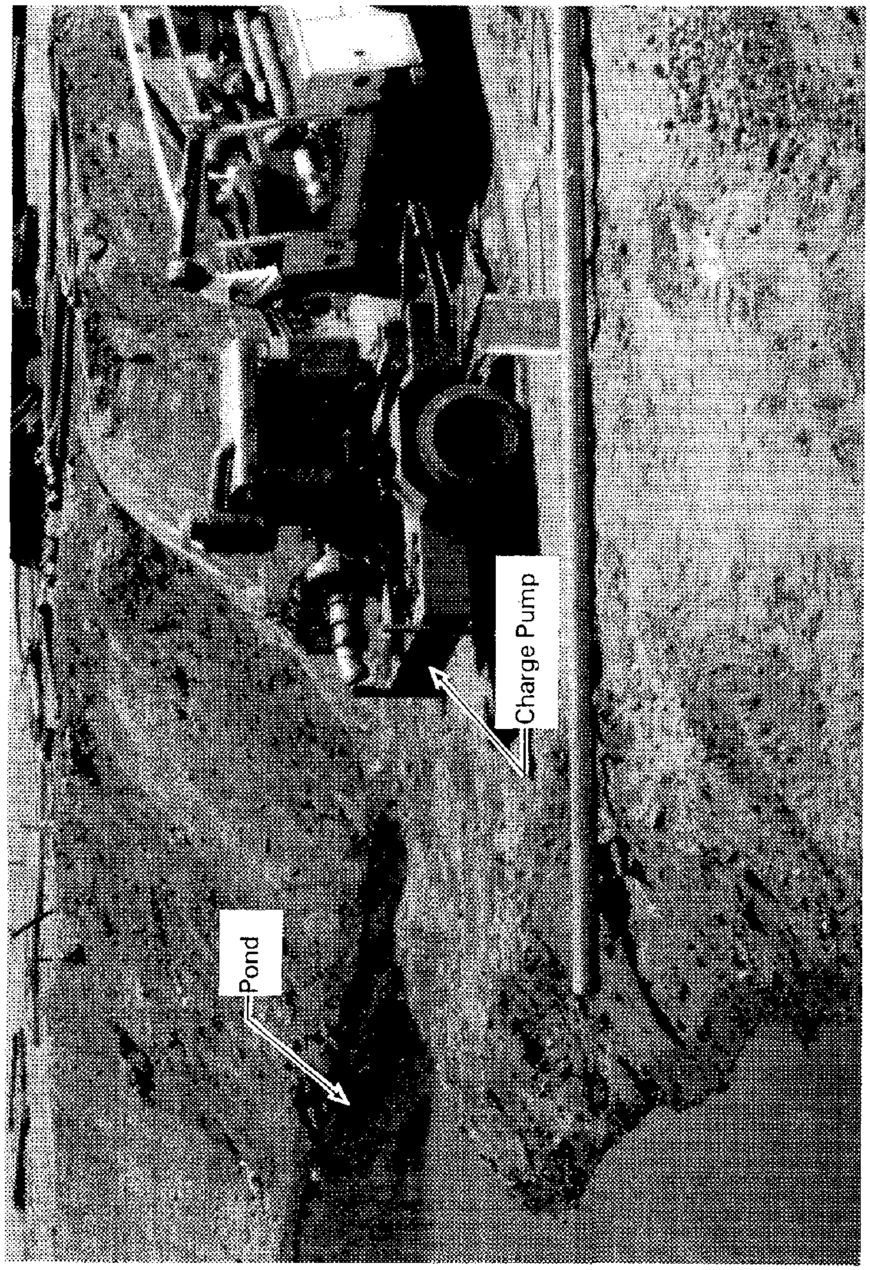

Figure 5. Charge Pump.

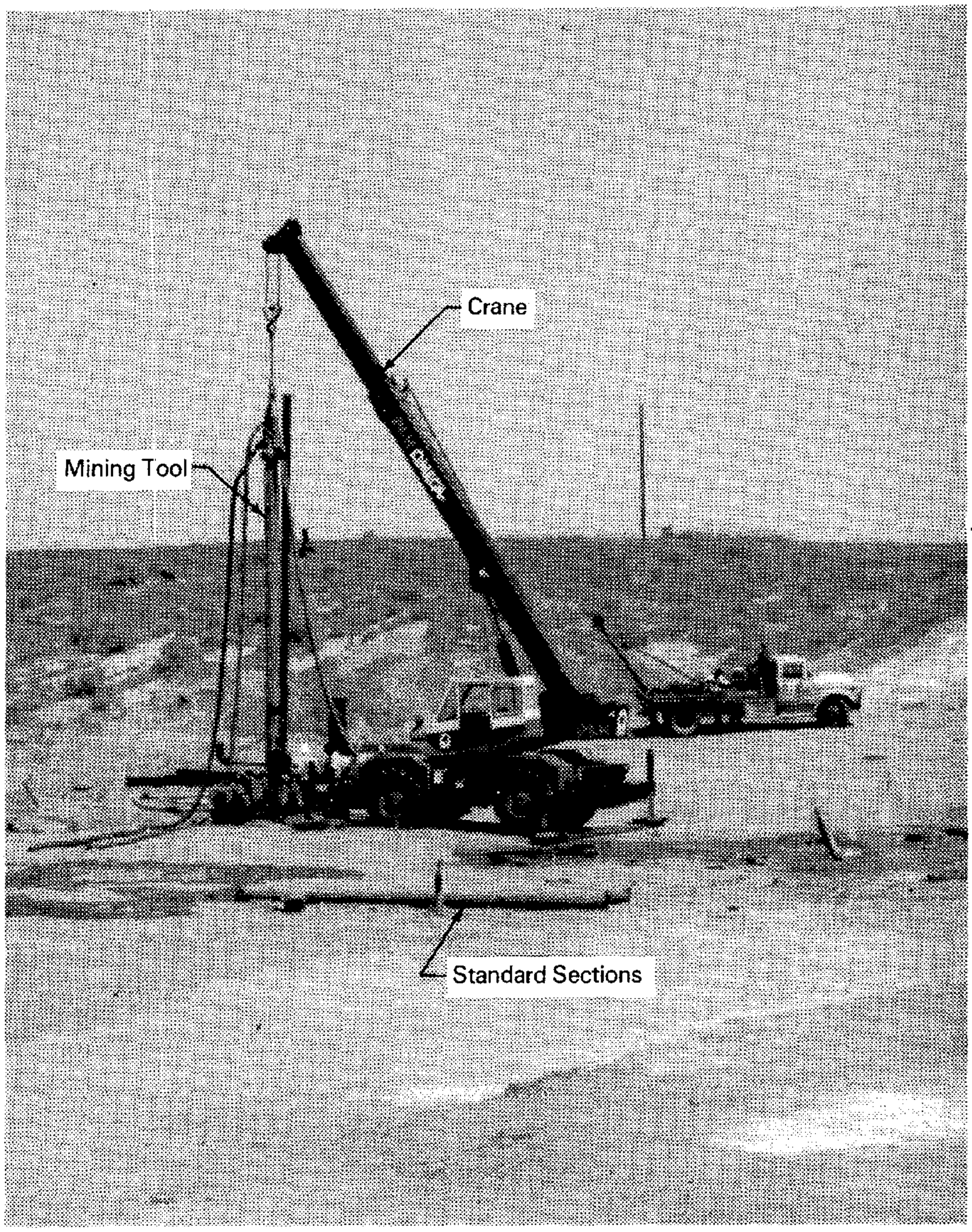

Figure 6. Crane Supporting Mining Tool in Borehole.

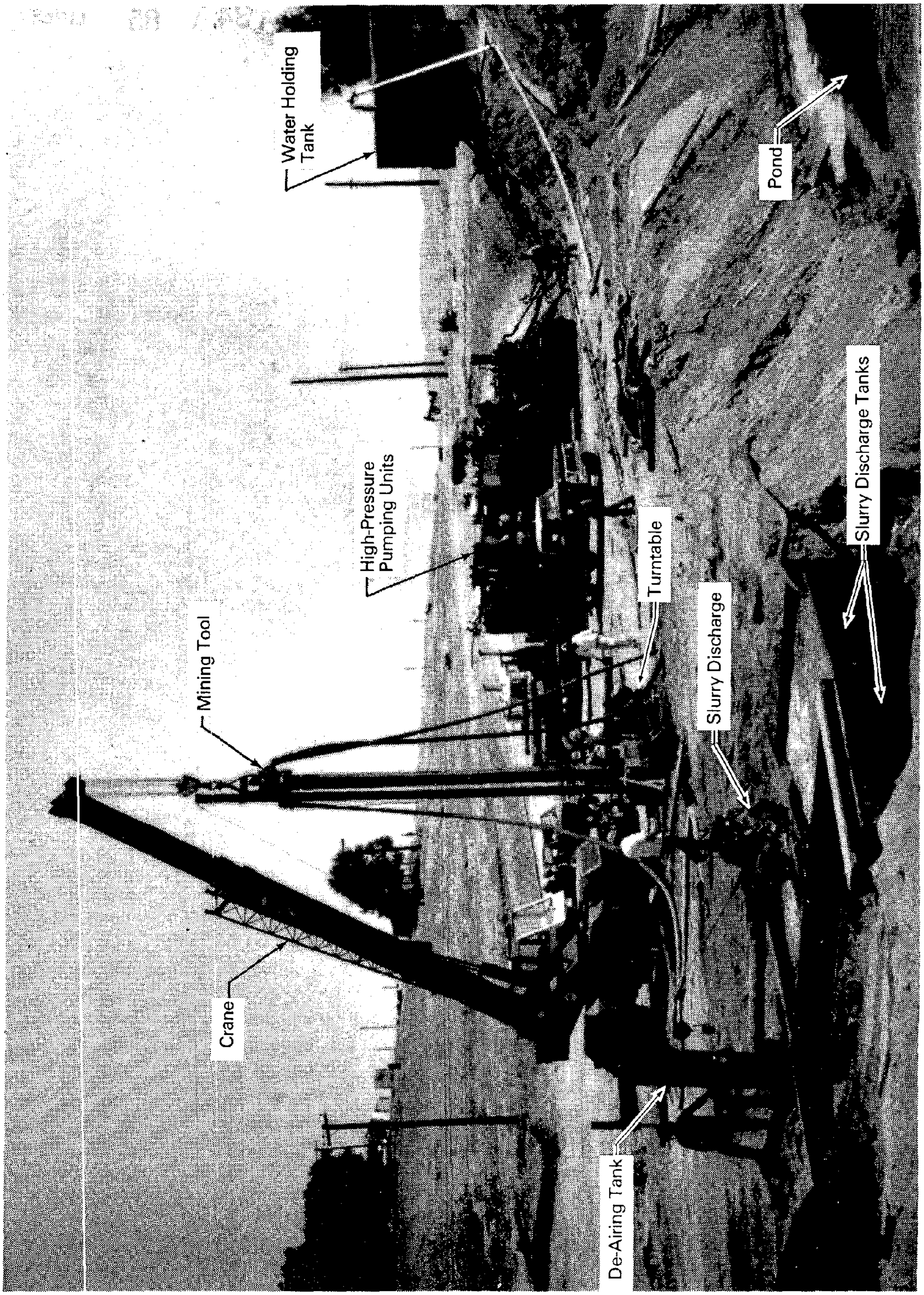

Figure 7. Mining Equipment in Operation.

in place--20 yards of cement were required for each borehole. A 17-5/8-inch-diameter hole was then drilled from 110 feet to 160 feet (the bottom of the ore zone).

Two Halliburton* HT-400 pumping units were employed, one for the cutting jet water and the other for the jet pump water. The cutting jet water was supplied to the top of the three-passage swivel through 50 feet of 2-1/2-inch hose. The jet pump water was supplied to the side of the swivel through 50 feet of 3-inch hose. The ore slurry emerged from the side of the swivel and was transported through 50 feet of 4-inch hose to the backflush valve, the surge tank, the slurry discharge tanks, and the slurry pond.

2.2 Mining Procedure

The mining procedure consisted of moving the mining tool with the crane and the turntable while pumping water around two circuits: the jet cutting circuit and the jet pump circuit. In the jet cutting circuit, the water (1) was drawn from the pond with the charge pump, (2) was stored in the elevated tank, (3) was pressurized up to 2500 psi by a high-pressure pumping unit, and (4) was channeled through the swivel to the mining tool and out the jet cutting nozzle. The cutting jet water (300 gpm) eroded the ore and formed a slurry which flowed to the slurry inlet on the tool. The orientation of the cutting jet was controlled by moving the tool up and down with the crane and turning the tool with the turntable. In the jet pump circuit, the water (1) was again drawn from the pond with the charge pump, (2) was stored in the same elevated tank as before, (3) was pressurized to 1500 psi by the other high-pressure pumping unit, and (4) was channeled through the swivel to the mining tool and out the jet pump nozzle. The jet pump water (500 gpm) entrained the ore slurry formed by the cutting jet water and forced it up to the surface and out the swivel. The slurry then flowed through the backflush valve (used to occasionally clear the slurry inlet), into the surge tank (which removed flow surges caused by air sucked into the slurry inlet), and into the slurry discharge tanks. An upward-pointing

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*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

slurry discharge (Figure 8) allowed an estimate of the slurry flow rate by measuring the plume height. The oil sands which settled in the tanks (98.5 percent of the sand) was measured and removed with the backhoe to the ore pile. The slurry flowing into the pond was thus relatively clear.

The typical operating parameters are listed in Table 1. A range of values is given if the parameter varied significantly.

2.3 Mining Operations

Hydraulic borehole mining of oil sands was conducted from July 25 to August 24, 1979. About 467 tons of ore (about 8000 cubic feet) were removed from Borehole 1 and about 527 tons (about 9000 cubic feet) were removed from Borehole 2 during that month.

The mining operation is summarized in Table 2 and reported in detail in the mining test log (Appendix D). Table 2 lists the date on which the mining occurred, the amount of time that the jet pump operated (the cutting time is slightly less), the number of tons of ore removed from the slurry discharge tanks, the tank number, the borehole number, the mining rate averaged over a tankful, and the cutting jet depth from which the ore was mined (the slurry inlet is 4.2 feet lower). The operating time is broken down by tankful and by date. The total operating time, the total number of tons mined, and the average mining rate are noted at the bottom of Table 2. The amount of ore in the pond was measured on September 5 when the pond was drained.

Only one major complication was encountered during the mining operation. As the mining in Borehole 1 proceeded, it became apparent that the borehole was being slowly filled with a material through which the tool could not auger. It was believed that this material was rocks carried to the borehole by the sand and not pumped to the surface because of their size. The rocks accumulated around and below the mining tool until the cutting jet could not be lowered below the bottom of the casing (110 feet). On July 30, mining in Borehole 1 was halted for this reason.

A hydraulic motor with higher torque was installed on the turntable to allow the tool to work down faster and farther into the rocky material. Then mining was continued in Borehole 2 while Borehole 1 was

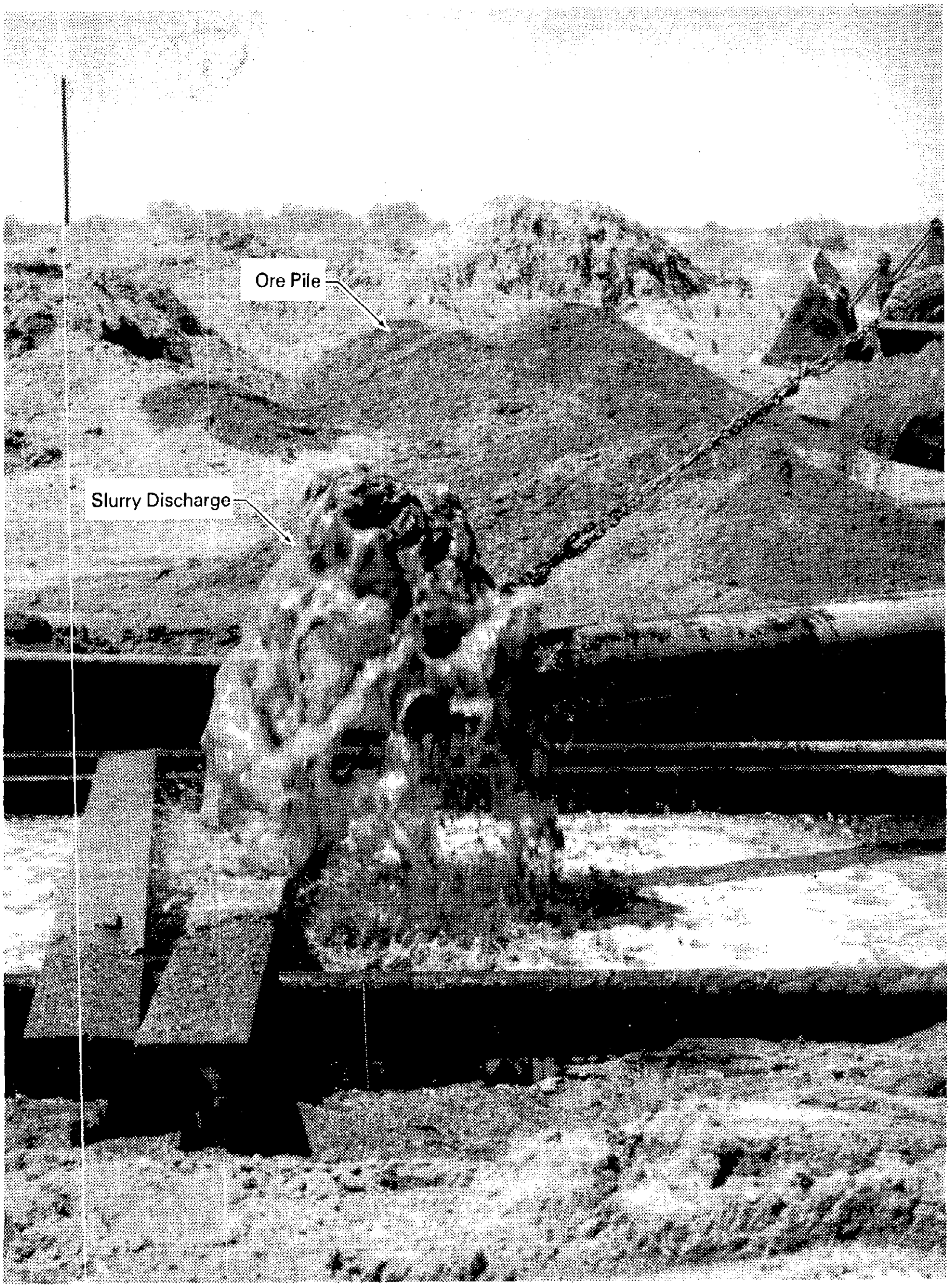

Figure 8. Slurry Discharge.

Table 1. Operating Parameters

Cutting Jet	Typical Value	Range
Pressure (psi)	400	100-2500
Flow rate (gpm)	300	100-500
Hydraulic power (hp)	50	10-700
Nozzle diameter (in.)	0.62	0.62-0.75
Line diameter (in.)	1.70	
Rotation rate (rpm)	10	4-15
Traverse rate (ips)	60	2-120
Vertical cutting increment (in.)	2	
Angle of cutting arc (degrees)	180	0-360
Depth (ft)	130	110-150
Jet Pump		
Pressure (psi)	1000	450-1500
Flow rate (gpm)	500	350-650
Agitation jet flow rate (gpm)	90	60-110
Hydraulic power (hp)	300	100-600
Nozzle diameter (in.)	0.70	
Agitation jet diameter (in.)	0.188	
Throat diameter (in.)	2.50	2.5-2.9
Nozzle line diameter, effective (in.)	2.5	
Secondary Flow		
Flow rate (gpm)	400	300-600
Solids (percent by weight)	15	0-35
Specific gravity	1.1	1.0-1.3
Slurry Flow		
Flow rate (gpm)	800	600-1100
Line diameter (in.)	3.75	
Solids (percent by weight)	7	0-18
Specific gravity	1.05	1.0-1.15
Mining rate (tph)	15	0-45

Table 2. Oil Sands Mining Summary

Date	Time (hrs)	Sand in Tank (tons)	Tank No.	Borehole No.	Mining Rate (tph)	Depth (ft)
7-24	3	0		1	0	-
7-25	1.25	26.24	1	1	21.0	150
7-26	2.35	40.95	2	1	17.4	123-135
	2.75	34.97	3	1	12.7	121-122
7-27	2.5	40.58	4	1	16.2	118-121
	2.0	46.50	5	1	23.2	117-119
	1.25			1		118
7-30	1.5	44.00	6	1	16.0	114
	1.5			1		113
8-13	2.1	34.37	7	2	9.5	110-145
	2.2			2		126-145
8-14	3.0	39.90	8	2	7.7	130-140
	4.3	39.84	9	2	9.3	138-140
	2.2			2		122-132
8-15	6.75	42.16	10	2	4.7	108-140
	1.7			2		135-136
8-16	1.0	39.10	11	2	14.5	140
	2.75	42.00	12	2	15.3	135-140
	0.40			2		140
8-17	1.0	37.71	13	2	26.9	125-135
	1.25	36.00	14	2	28.8	135
	1.25	34.92	15	2	27.9	130
	1.25	32.76	16	2	26.2	130
	1.1	38.10	17	2	34.6	124
	1.2			2		132
8-18	0.75	41.83	18	2	21.5	126
	2.25	41.39	19	2	18.4	129
	2.25			2		124-126
8-22	3.5			2		106-120
8-23	1.0	42.85	20	1	6.3	105-112
	1.0	44.64	21	1	44.6	116
	1.25	44.54	22	1	35.6	110-115
	1.5	38.41	23	1	25.6	114
	1.0			1		112
8-24	1.5	40.35	24	1	16.1	112-113
	2.5	34.38	25	1	13.8	112-115
9-5	Pond	7		1	est.	
		8		2	est.	
	70.05	993.50			14.2	

partially cleaned out with a bailer. The new turntable motor did help the tool to work down but did not prevent rocks from again blocking the borehole. When Borehole 2 ceased to produce, the tool was returned to Borehole 1 for more mining (see Table 2). The addition of a rock crusher to the mining tool, such as the one being developed for borehole coal mining, should prevent rocks from filling the borehole and allow more sand to be mined from each borehole.

3. Environmental Assessment

Environmental monitoring was performed to quantify the environmental impact of borehole mining. This was accomplished through site surveys to determine the degree of ground subsidence and water samples taken from both monitoring wells and the slurry pond to analyze the effect of borehole mining on ground water quality. Testing was performed before, during, and after the mining operation. Ground subsidence was found to be negligible; water quality data, however, were inconclusive.

3.1 Ground Subsidence

In order to evaluate the ground subsidence potential, a series of site surveys was performed during the course of the mining operation to collect information on site ground elevations. The contour of the area around the two boreholes was surveyed with reference to an adjacent bench-mark having an assumed elevation of 100 feet. About 30 points surrounding each borehole were documented weekly between July 23, 1979 (before mining began) and September 24, 1979 (a month after mining ended).

Figure 9 shows the location of the Toups Bench Mark (TBM); Figure 10 shows the project site subdivided into grid sections covering the area overlying the borehole mining area and subsurface cavity. Table 3 summarizes survey results with the change in elevation assumed to be the difference from the initial survey to the final survey. It appears that minor ground subsidence occurred and that the amount of subsidence increased with time and decreased with distance from the boreholes. Grid selections associated with Borehole 1 (i.e., A through E) experienced more subsidence than those associated with Borehole 2.

The average change in elevation was between 1/4 and 1/2 inch of subsidence, although some points were found to be slightly elevated rather than depressed. This amount of subsidence is considered to be negligible since elevation changes of this order could be the result of soil compaction caused by heavy vehicles and mining equipment in the area. Contour maps of the site elevation changes based on Table 3 are shown in Figures 11 and 12.

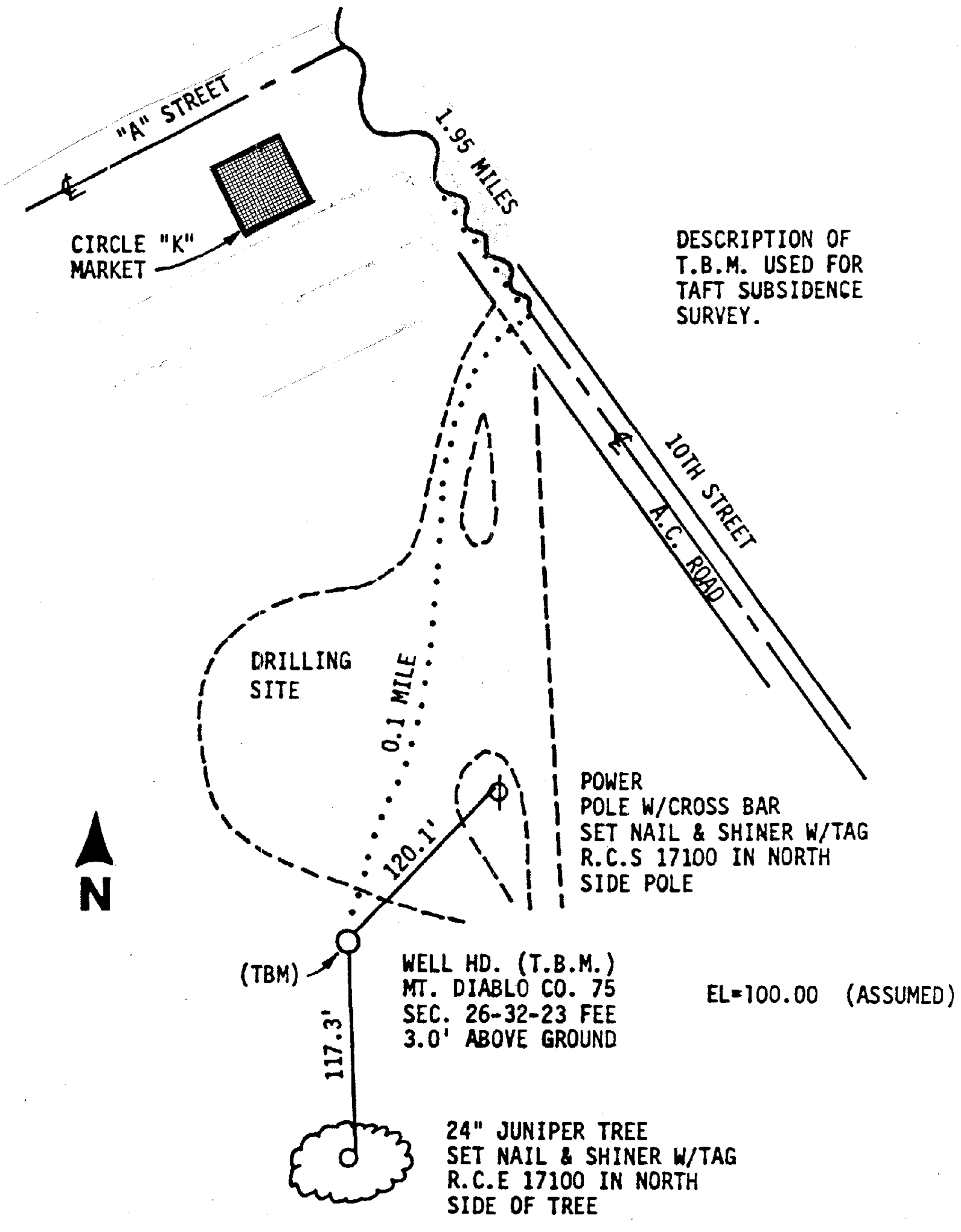

Figure 9. Toups Bench Mark.

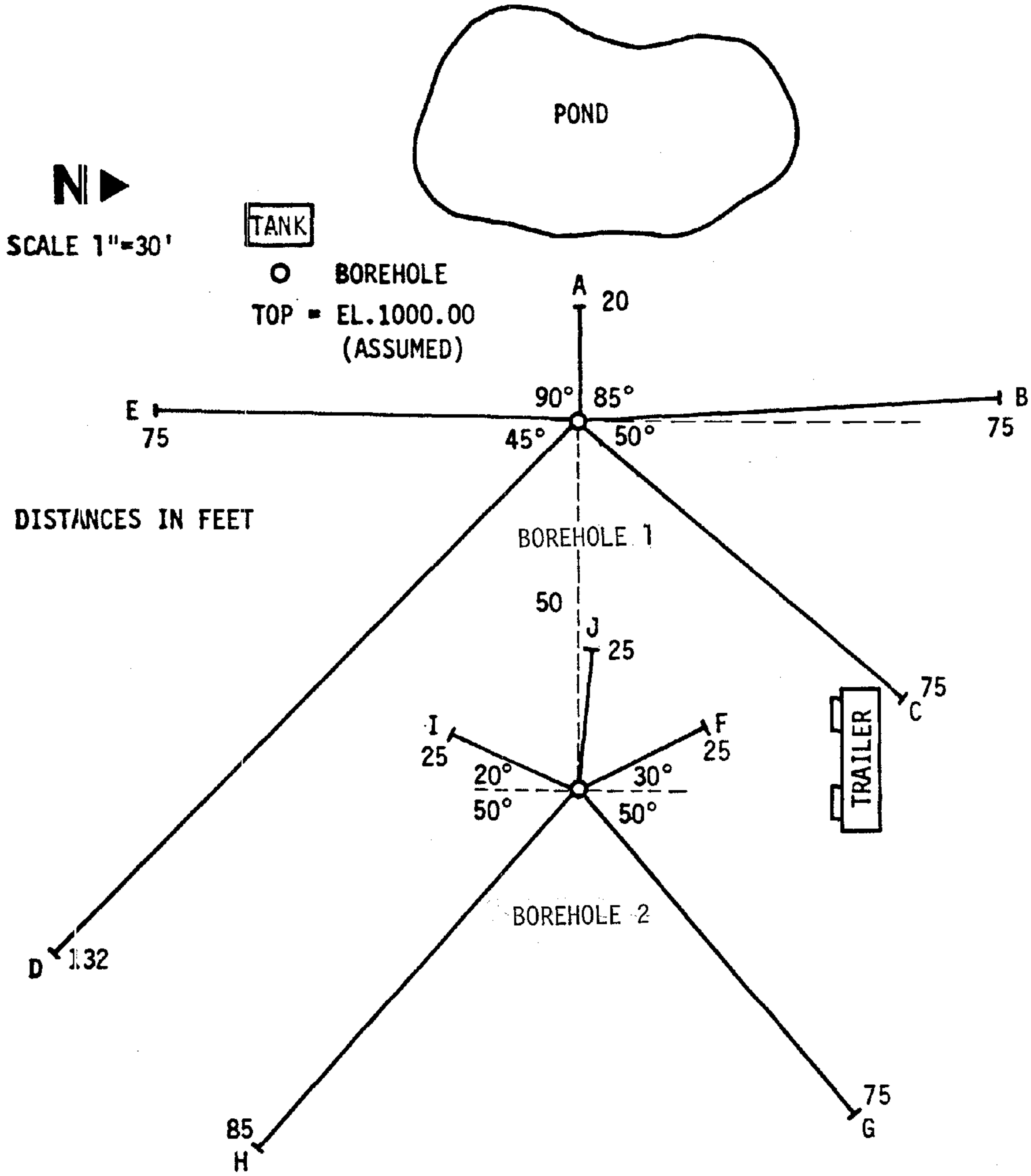

Figure 10. Survey Grid System.

Table 3. Borehole Mining Survey Results

	Relative Elevation, feet							
Location	7/23	7/30	8/6	8/13	8/20	8/26	9/24	Change in Elevation
Bench Mark	100.00	100.00	100.00	100.00	100.00	100.00		
A 5	86.22	86.18	86.18	86.19	86.19	86.17	86.14	0.08
A10	86.28	86.23	86.22	86.23	86.22	86.20	86.18	0.10
A15	86.38	86.35	86.35	86.35	86.37	86.35	86.32	0.06
A20	86.40	86.39	86.39	86.39	86.41	86.40	86.37	0.03
B 5	86.05	86.05	86.05	86.05	86.07	86.05	86.03	0.02
B10	86.14	86.14	86.14	86.14	86.15	86.13	86.10	0.04
B15	86.09	86.10	86.09	86.10	86.11	86.08	86.06	0.03
B20	86.13	86.14	86.15	86.16	85.94*	85.91	85.90	0.04
B25	85.88	86.15*	86.15	86.16	86.18	86.16	86.14	0.01
B50	85.73	85.70	-	86.11*	86.13	86.12	86.10	0.01
B75	87.25	-	-	87.50*	87.51	87.50	87.48	0.02
C 5	86.31	-	86.30	86.25	86.27	86.25	86.23	0.08
C10	86.27	86.26	86.27	86.28	86.30	86.27	86.25	0.02
C15	86.32	86.31	86.33	86.34	86.36	86.33	86.32	0.00
C20	86.30	86.30	86.32	86.32	86.34	86.32	86.30	0.00
C25	86.44	86.44	86.45	86.46	86.48	86.47	86.45	+0.01
C50	86.76	86.76	86.76	86.77	86.80	86.77	86.76	0.00
C75	88.18	88.18	88.19	86.20	88.22	88.20	88.19	+0.01
D 5	86.48	86.23	86.23	86.24	86.25	86.21	86.19	0.29
D10	86.50	-	86.49	86.49	86.51	86.49	86.47	0.03
D15	86.58	86.57	86.57	86.58	86.60	86.58	86.56	0.02
D20	86.54	86.54	86.54	86.55	86.57	86.55	86.53	0.01
D25	86.56	86.55	86.55	86.56	86.58	86.56	86.54	0.02
D50	86.63	86.62	86.62	86.63	86.66	-	86.62	0.01
D75	86.93	86.98	86.97	86.89*	86.92	86.91	86.89	0.00

* Denotes new hub set
\+ Denotes stations which resulted in net gain in elevation

Table 3. Borehole Mining Survey Results (Continued)

	Relative Elevation, feet							
Location	7/23	7/30	8/6	8/13	8/20	8/26	9/24	Change in Elevation
E 5	-	-	-	86.41*	86.39	-	86.34	0.07
E10	-	-	-	86.59*	86.59	-	86.55	0.04
E15	86.50	86.50	86.50	86.51	86.52	86.50	86.47	0.03
E20	86.53	86.48	86.53	86.54	86.54	86.52	86.50	0.03
E25	86.61	86.60	86.61	86.62	86.63	86.61	86.58	0.03
E50	86.75	86.72	86.71	86.76	86.78	86.76	86.74	0.01
E75	87.03	87.02	87.03	87.05	87.06	87.04	87.07	+0.04
F 5	86.27	86.28	86.29	86.30	85.73*	85.70	85.69	0.04
F10	86.15	86.17	86.17	86.18	86.20	86.18	85.17	+0.02
F15	86.21	86.22	86.23	86.24	86.26	86.23	86.27	+0.06
F20	86.57	86.58	86.58	86.61	86.63	86.59	86.57	0.00
F25	86.69	86.49*	86.48	86.49	86.51	86.49	86.48	0.01
G 5	-	86.16	86.17	86.18	85.97*	85.95	85.94	0.03
G10	86.32	86.32	86.34	86.35	86.36	86.35	86.33	+0.01
G15	86.59	86.59	86.60	86.66	86.63	86.60	86.59	0.00
G20	86.64	86.64	86.65	87.12	86.68	86.65	86.64	0.00
G25	87.09	87.10	88.10	88.73	87.14	87.10	87.11	+0.02
G50	88.69	88.70	88.71	88.73	88.75	88.72	88.71	+0.02
G75	91.99	92.00	92.01	92.02	92.05	92.06	92.01	+0.02
H 5	-	86.20*	86.20	86.20	86.24	86.21	86.20	0.00
H10	86.26	86.24*	86.23	86.24	86.27	86.24	86.23	0.01
H15	86.49	86.50	86.52	86.53	86.55	86.52	86.51	+0.02
H20	86.63	86.64	86.66	86.67	86.69	86.66	86.05	0.58
H25	86.68	86.69	86.71	86.72	86.74	86.71	86.70	+0.02
H50	88.40	88.40	88.41	88.43	88.45	88.42	88.41	+0.01
H85	90.15	90.15	90.16	90.17	90.19	90.17	90.15	0.00

* Denotes new hub set
\+ Denotes stations which resulted in net gain in elevation

Table 3. Borehole Mining Survey Results (Continued)

	Relative Elevation, feet							
Location	7/23	7/30	8/6	8/13	8/20	8/26	9/24	Change in Elevation
I 5	-	86.04*	86.04	86.05	86.07	86.04	86.03	0.01
I10	-	85.89*	85.09	85.89	85.92	85.88	85.88	0.01
I15	86.34	86.30	86.29	86.30	86.32	86.30	86.28	0.06
I20	86.35	86.36	86.36	86.36	86.39	86.36	86.35	0.00
I25	86.40	86.41	86.41	86.41	86.44	86.41	86.40	0.00
J 5	86.11	86.14	86.15	86.16	86.19	86.15	86.10	0.01
J10	86.07	86.08	86.09	86.16	86.19	86.09	86.06	0.01
J15	86.18	86.11*	86.13	86.16	86.19	86.11	86.10	0.01
J20	86.20	86.23	86.23	86.16	86.19	-	86.22	+0.02
J25	86.21	86.20	86.21	86.16	86.19	86.21	86.19	0.02

* Denotes new hub set
\+ Denotes stations which resulted in net gain in elevation

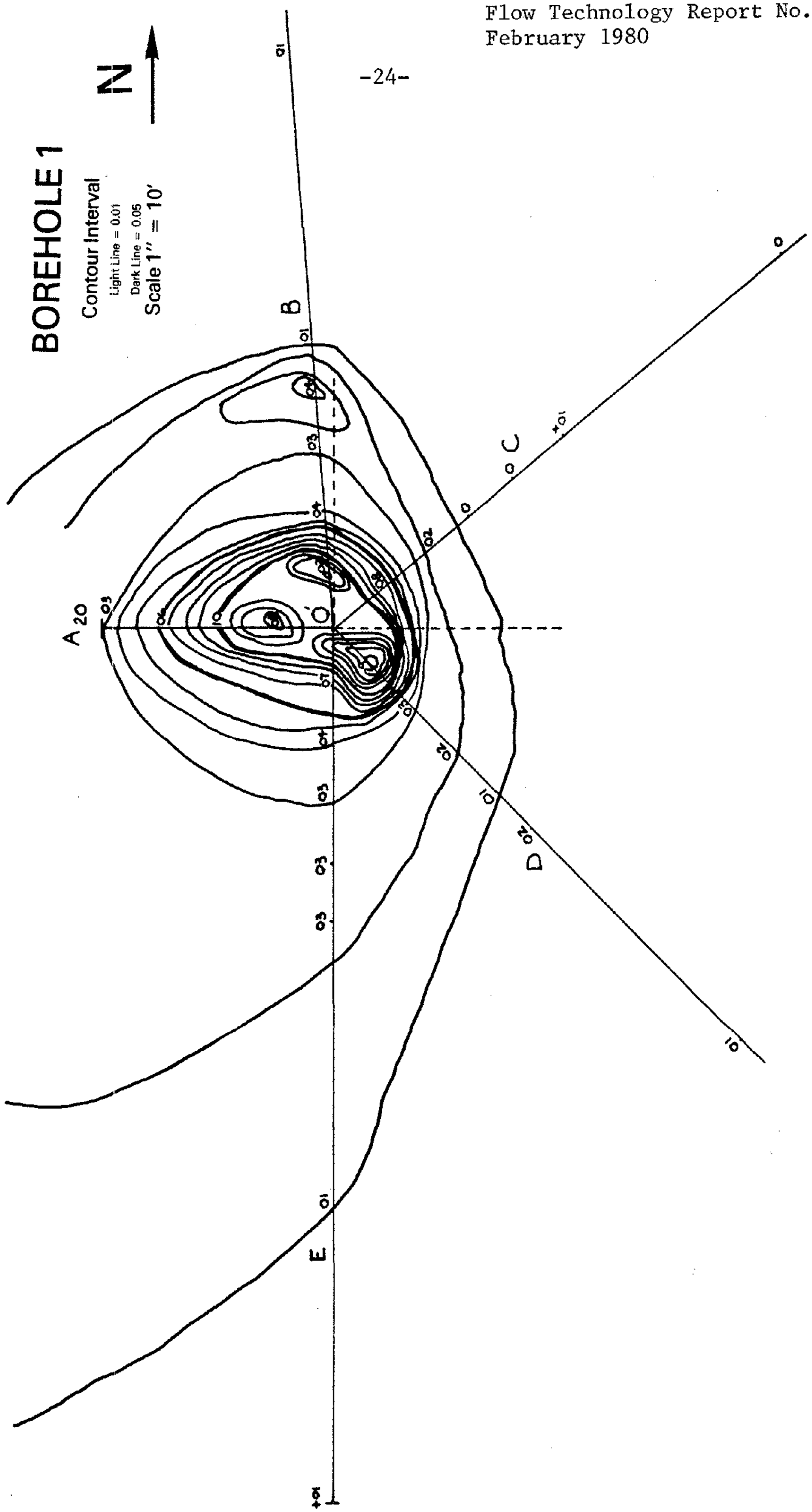

Figure 11. Borehole 1 Site Contour Map.

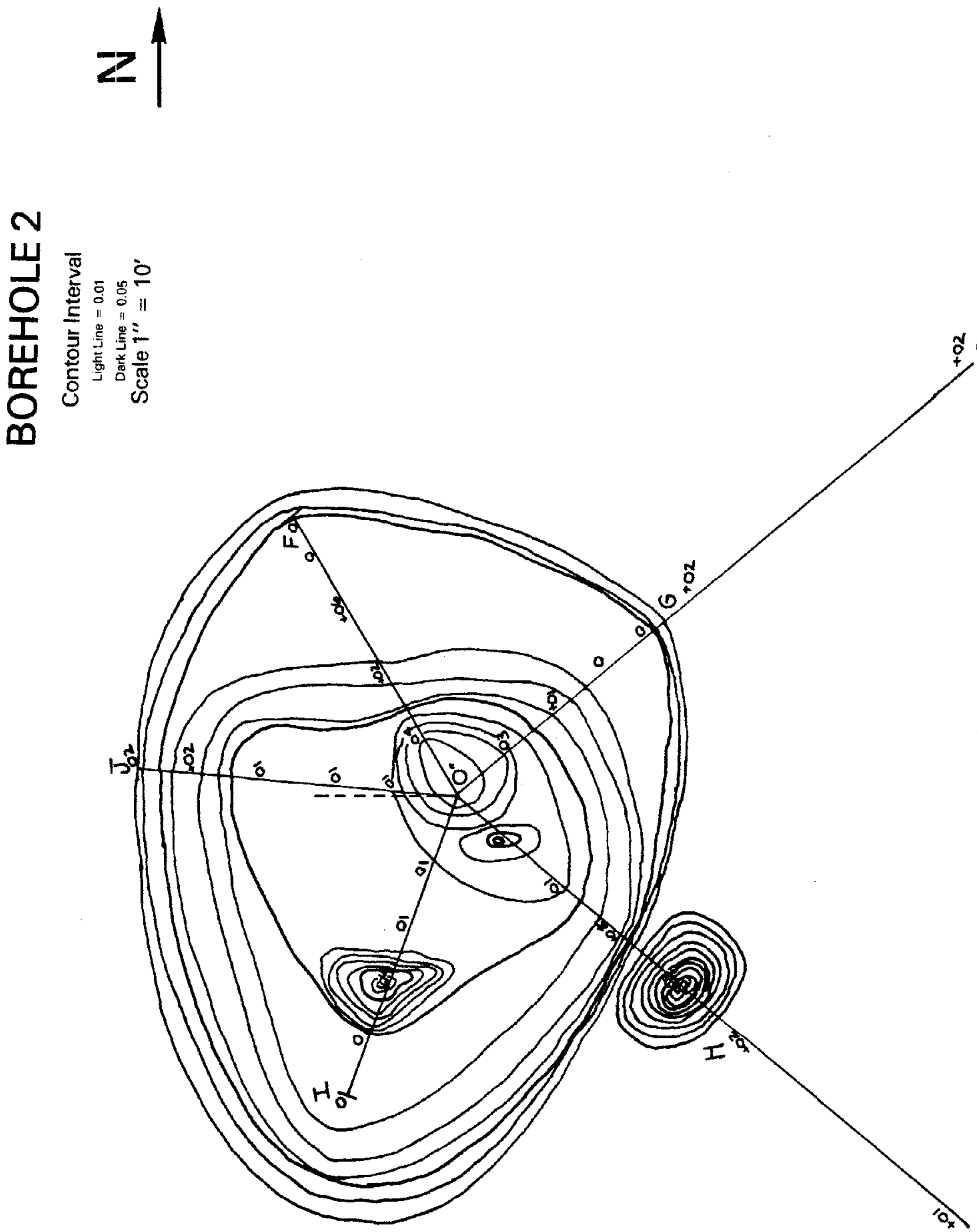

Figure 12. Borehole 2 Site Contour Map.

The small but measureable ground-level subsidence that occurred over these 500-ton borehole cavities indicates that there would be significant subsidence over a 5000-ton cavity. Therefore, in a commercial oil sands mining operation, backfilling the cavities would provide a satisfactory method both to reduce ground-level subsidence and dispose of tailings.

3.2 Water Quality

An investigation was performed to determine the location and flow direction of ground water underlying the project site. Based on this investigation and information from 80-year-old drilling logs, it was decided to locate the monitoring well approximately centered between the two boreholes and 50 feet distant from them in a roughly southerly direction (see Figure 2). The well was accordingly drilled to a depth of 760 feet but failed to encounter water. It was then decided to perforate the well in a potential aquifer (sand) at 550 feet. The well was bailed dry of process water and a ground water sample was taken the next day. The results of an analysis performed on this sample are summarized in Table 4, which also summarizes the results of an analysis performed on a sample of the process water.

The test plan called for collecting water samples from the well every other day. However, no samples other than the initial sample could be obtained from the well. In fact, it is speculated that the initial sample was process water forced into the pore spaces of the soil surrounding the well during drilling. Even though standing process water left by drilling was removed from the well, it is possible that some drained back to become the initial sample.

A second monitoring well was drilled in early August to provide water samples from the horizontal migration of the mining process water. This second well was cased, cemented, and shot at the depth of the oil sands (150 feet).

Water quality samples were collected from the slurry clarifier (Figure 13) on July 26 and August 7, 13, 17, 18, 20, 22, and 24. Table 5 is a summary of the analytical results obtained. An evaluation of these samples could provide some insight into the potential changes in water quality composition that could be expected from any downstream

Table 4. Initial Water Quality Sampling Results - July 16, 1979

Constituent	Monitoring Well	Water Used In Mining Process
Calcium	13	42
Magnesium	1.2	18
Sodium	1,930	1,590
Potassium	87	55
Carbonate	86.9	0
Bicarbonate	412.3	1,088
Chloride	220.7	1,879.7
Sulfate	225	145
Nitrate	708.8	10.6
Fluoride	1.0	2.6
Iron	1.8	0.06
Manganese	0.04	0.03
Arsenic	<0.01	<0.01
Copper	0.03	0.01
Zinc	0.11	0.02
MBAS	0.3	0.5
Hardness	37.5	179.2
Total Dissolved Solids	5,420	4,315
pH	8.6	7.3
Electrical Conductivity	8,280	6,820
Color	40	200
Odor	5	1
Turbidity	4.0	4.3
Barium	<1.0	<1.0
Cadmium	0.01	<0.01
Chromium	0.01	0.06
Lead	0.14	<0.01
Mercury	0.0002	<0.002
Selenium	0.02	<0.01
Silver	<0.01	<0.01
Total Organic Carbon	15.6	17.5
Phosphate	6.0	30.0
Chromium [hexavalent]	<0.01	<0.01

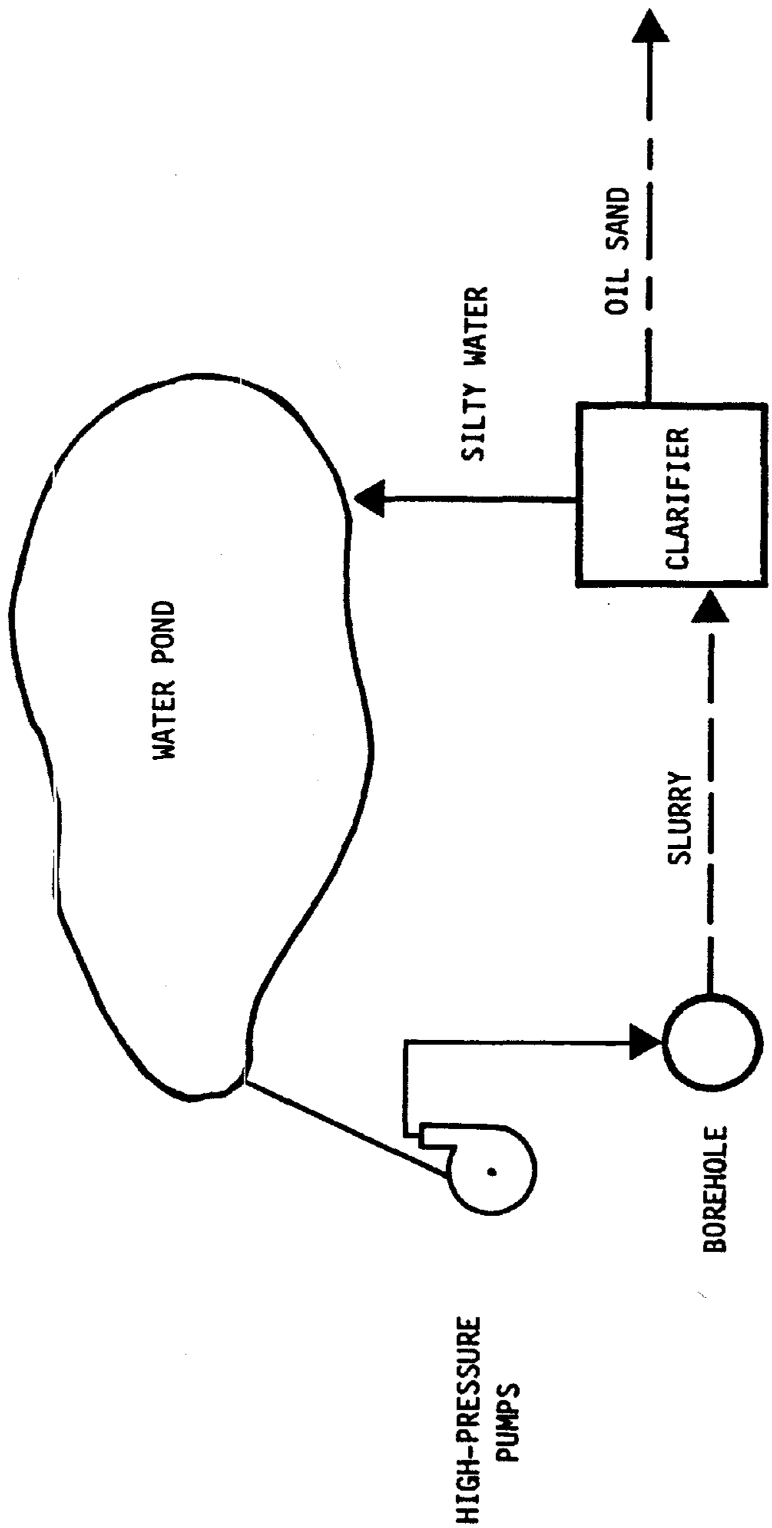

Figure 13. Borehole Oil Sands Mining Flow Diagram.

Table 5. Sample Analysis Results Summary

Constituent [a]	Sampling Date 7/26	8/7	8/13	8/17	8/18	8/20	8/22	8/24
Calcium	42	2.8	1,740	35	35	39	57	56
Magnesium	18	2.4	0.03	22	22	25	42	73
Sodium	1,590	3,250	350	1,750	1,750	1,790	1,750	1,685
Potassium	55	147	101	62	62	66	64	62
Carbonate	0	644.1	54.5	139.7	124.4	0	0	0
Bicarbonate	1,088	925.1	0	876.6	913	1,124.3	1,008.3	984
Chloride	1,879.7	3,600.2	3,168.3	2,028.4	2,067.4	2,124.0	2,109.8	2,102.8
Sulfate	145	330	59	153	163	190	390	380
Nitrate	10.6	4.4	1.8	0.9	0.9	0.9	<0.5	0.9
Fluoride	2.6	1.0	0.2	1.9	2.0	1.9	1.8	1.8
Iron	0.06	0.58	0.27	0.16	0.16	0.12	0.15	0.16
Manganese	0.01	0.01	0.03	0.03	0.03	0.05	0.21	0.06
Arsenic	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Copper	0.01	0.18	0.06	0.01	0.02	0.01	0.02	<0.01
Zinc	0.02	0.06	0.04	0.04	0.03	0.03	0.05	0.02
MBAS	0.5	IS[g]	IS[g]	0.7	0.7	0.6	0.6	0.7
Hardness	179.2	16.9	<4,353.6	178.1	178.1	200.5	315.5	440.5
Total Dissolved Solids	4,315	8,449	5,534	4,711	4,683	4,851	4,906	4,861
pH [b]	8.0	9.4	11.6	8.3	8.2	8.1	8.1	8.1
Electrical [c] Conductivity	6,820	11,780	9,890	6,590	5,650	7,540	7,772	7,540
Color [d]	250	300	2	200	250	200	150	150
Odor [e]	1	5	2	5	5	5	4	4
Turbidity [f]	8.4	1,000	3,000	700	770	600	2,400	2,100
Barium	<1.0	<1.0	3.6	<1.0	<1.0	<1.0	<1.0	<1.0
Cadmium	<0.01	0.02	IS[g]	0.01	0.01	0.01	0.01	0.01
Chromium	0.05	<0.01	0.05	0.01	0.01	0.01	<0.01	<0.01
Lead	<0.01	<0.01	IS[g]	<0.01	<0.01	<0.01	<0.01	<0.01
Mercury	0.0002	IS[g]	IS[g]	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Selenium	<0.01	IS[g]	IS[g]	<0.01	<0.01	<0.01	<0.01	<0.01
Silver	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01
Total Organic Carbon	13.8	IS[g]	IS[g]	123.2	145.2	189.2	167.2	171.6
Phosphate	30.0	IS[g]	IS[g]	1.2	1.5	1.7	0.8	0.9
Chromium [hexavalent]	<0.01	IS[g]	IS[g]	<0.01	<0.01	<0.01	<0.01	<0.01

[a] Results expressed in mg/l unless otherwise noted
[b] pH units
[c] Micromhos/cm
[d] Color units
[e] Odor threshold
[f] Nephelometric turbidity units [NTU]
[g] Insufficient sample to conduct analysis

migration of mining water. A review of these results showed that the chemical composition of the water varied throughout the study. The samples collected on August 7 through 13 were noted to have the largest variation from the other samples. A check was performed on the validity of the laboratory analysis by the electroneutrality balance. All samples were found to be acceptable except the one collected on August 13, 1979; thus, it is not considered to be valid.

The samples collected on August 17 through 24 are considered to provide the most meaningful data. First, the process water is directly related to the incoming source water. The incoming source water, in this instance, was waste brine from the neighboring oil recovery operations and could be expected to vary with time due to the amount and type of oil recovery operations taking place. For example, it is highly probable that the higher concentrations of constituents noted in the August 7 analysis was the result of a high concentration of make-up water to the recirculation pond. Second, the time frame over which these samples were collected was relatively short and provides a means of observing any trends in the chemical composition of the water used in the borehole mining. Figure 14 through 20 are graphic representations of the various constituents listed in Table 5. As can be seen, the plots tend to fluctuate without any definite trend. However, if just the data from August 17 through 24 is studied, the plots provide a more meaningful picture of what could be happening. It appears that the total mineral content of the water increases slightly with time after its contact with the oil sand material during the mining process. The total dissolved solids and chloride levels both followed the basic pattern. During August 17 through 24, the total dissolved solids and chlorine concentrations increased approximately 5 percent while the electrical conductivity increased approximately 15 percent. Some of the increased concentrations of salts are directly attributable to the evaporative losses of the pond.* This is borne out by the fact that the ratio of sodium to

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*It is necessary to add an average of 12,000 gallons per day to the slurry pond to make up its approximately 200,000-gallon capacity. It is believed that 2,000 to 6,000 gallons per day were lost through evaporation and 2,000 to 14,000 gallons per day through seepage from the borehole cavity.

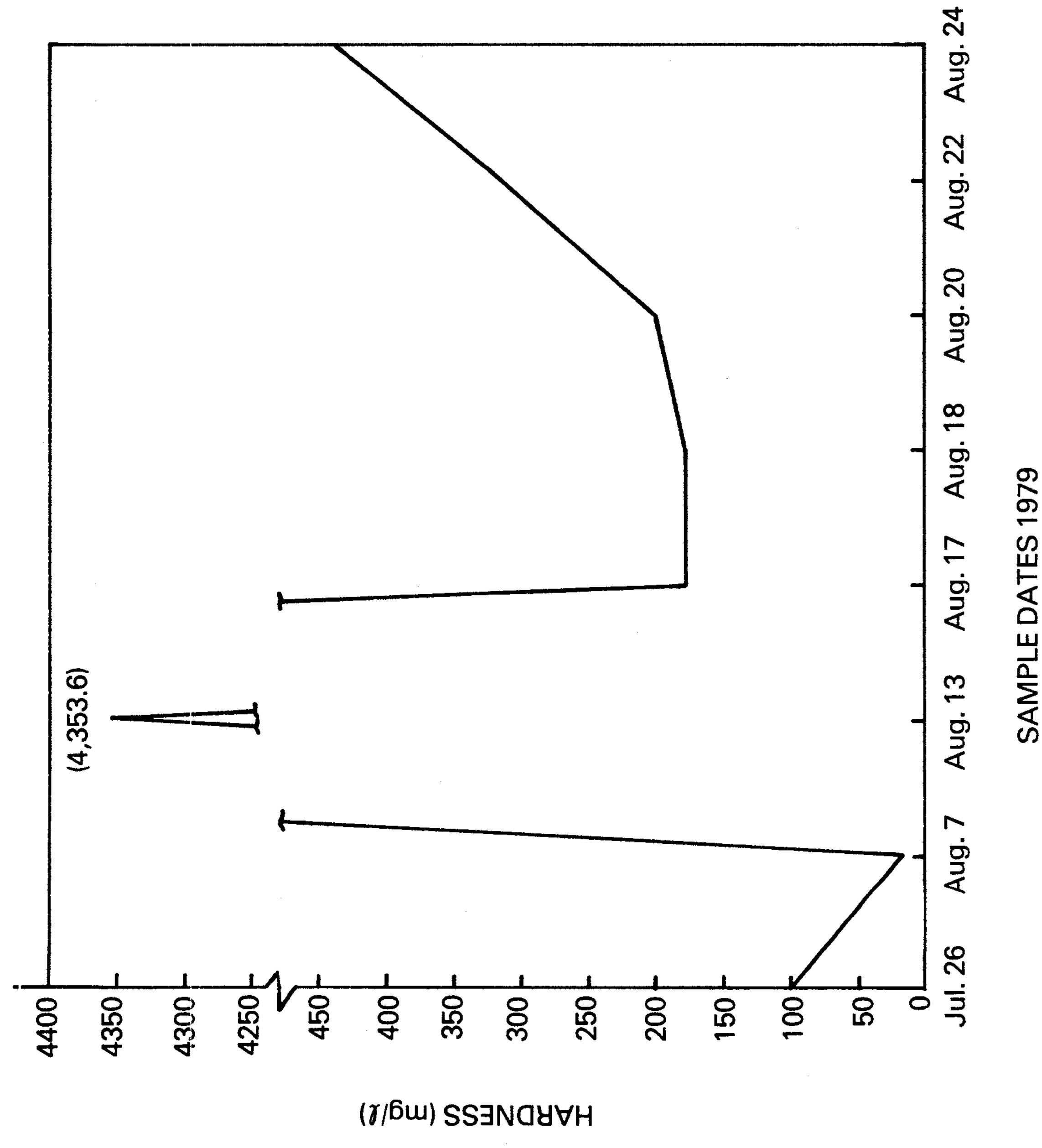


Figure 14. Variation in Water Hardness.

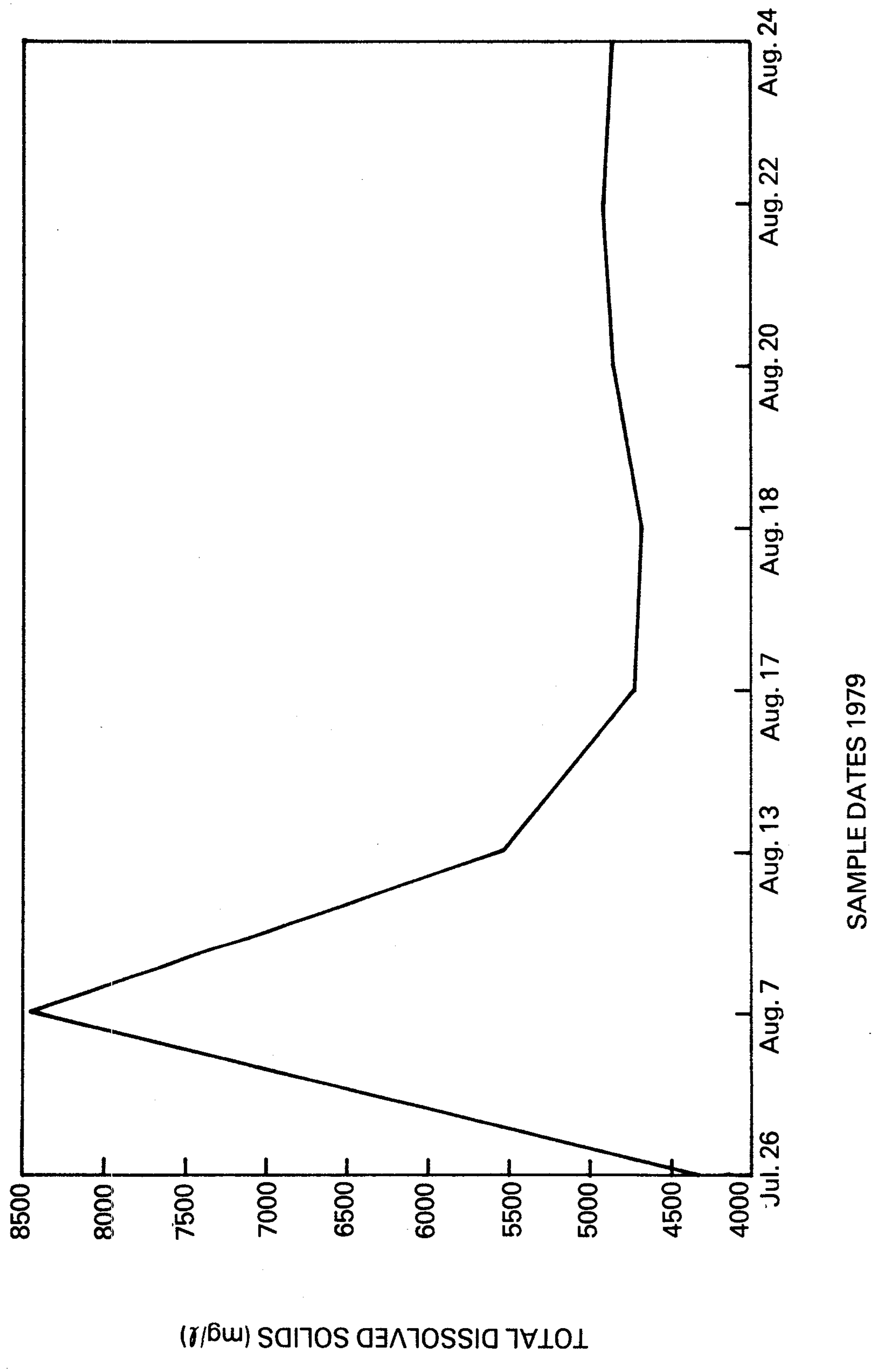


Figure 15. Variation in Total Dissolved Solids.

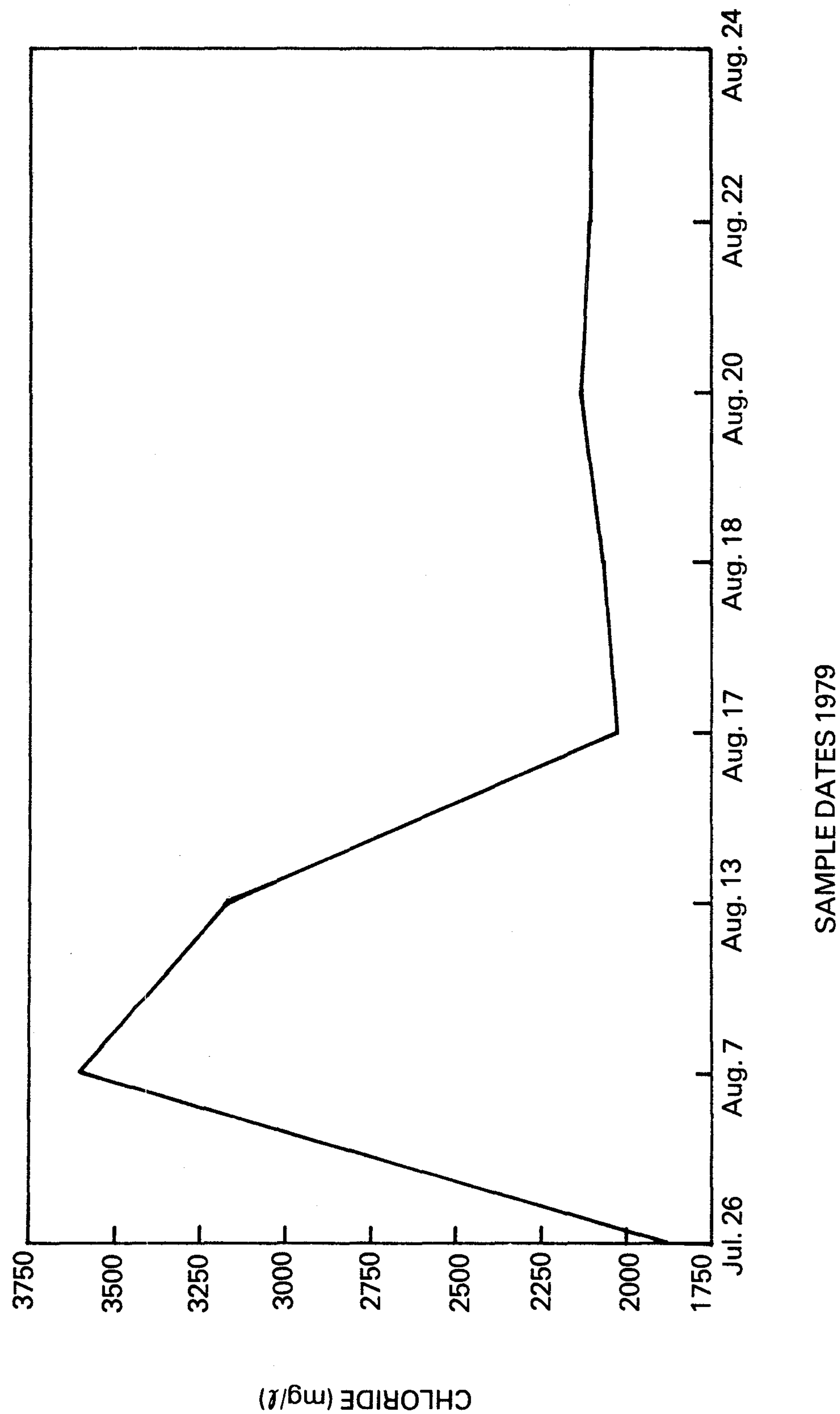
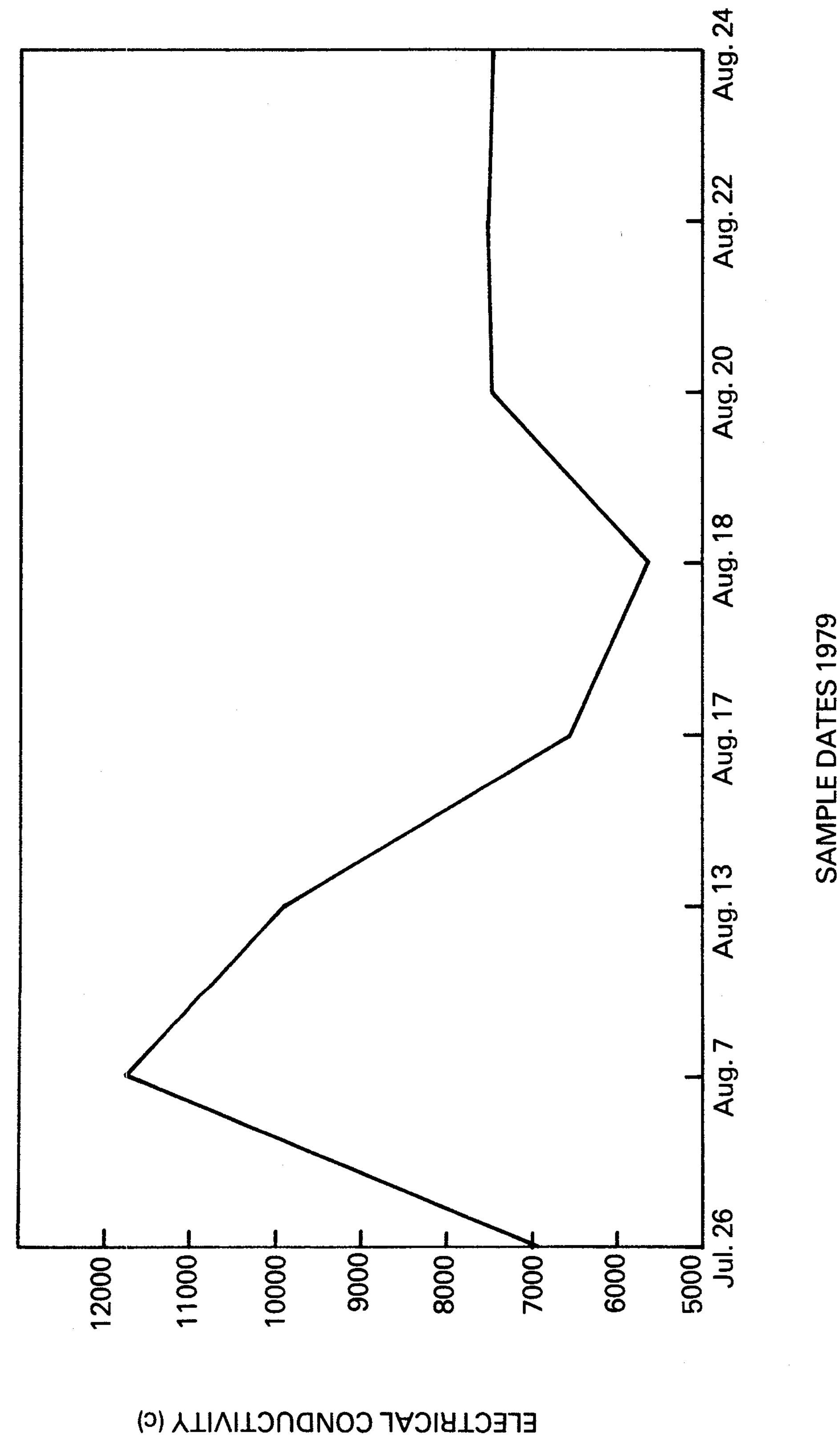


Figure 16. Variation in Chloride Level.



(c) MICROMHOS/cm

Figure 17. Variation in Electrical Conductivity.

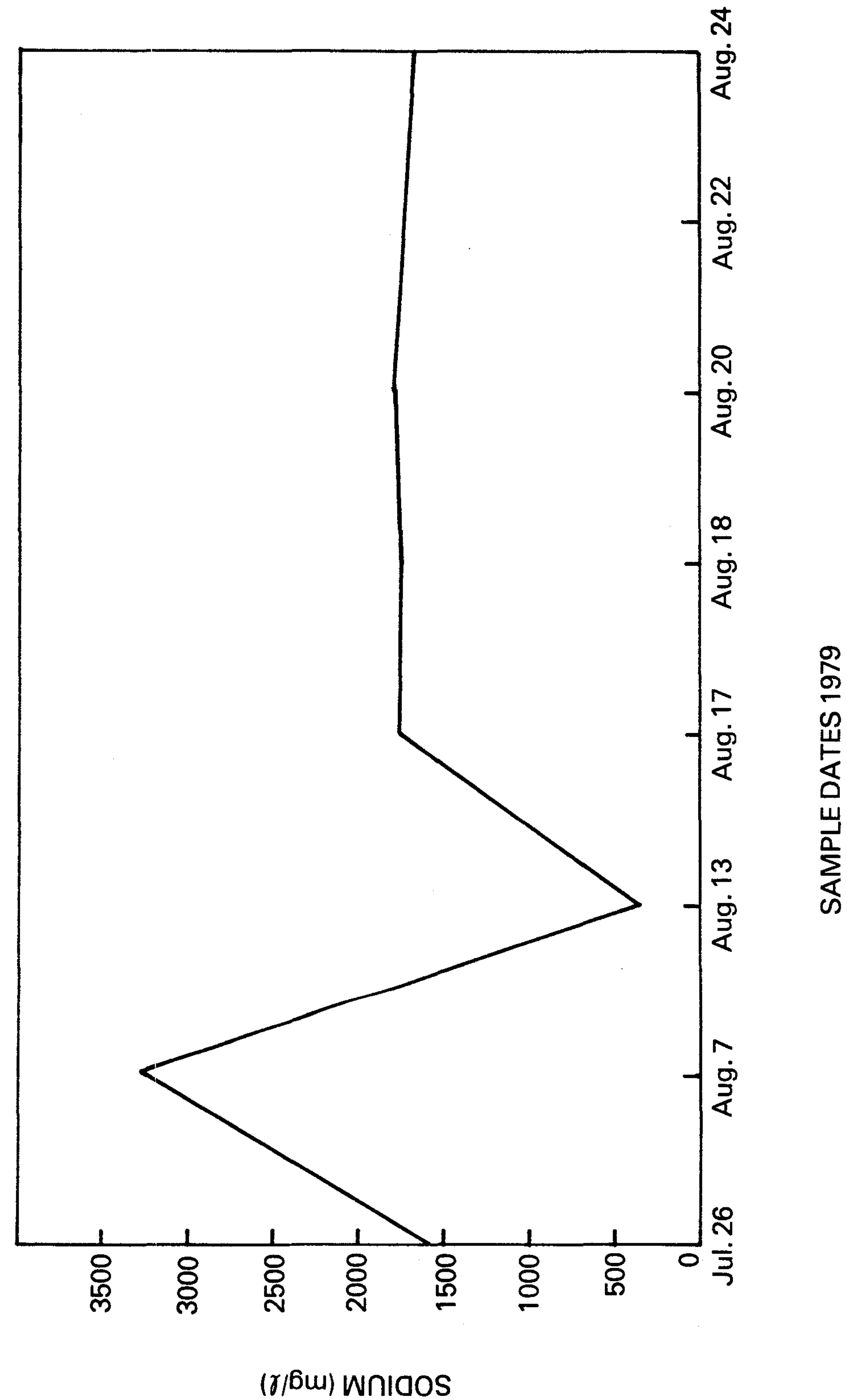


Figure 18. Variation in Sodium Level.

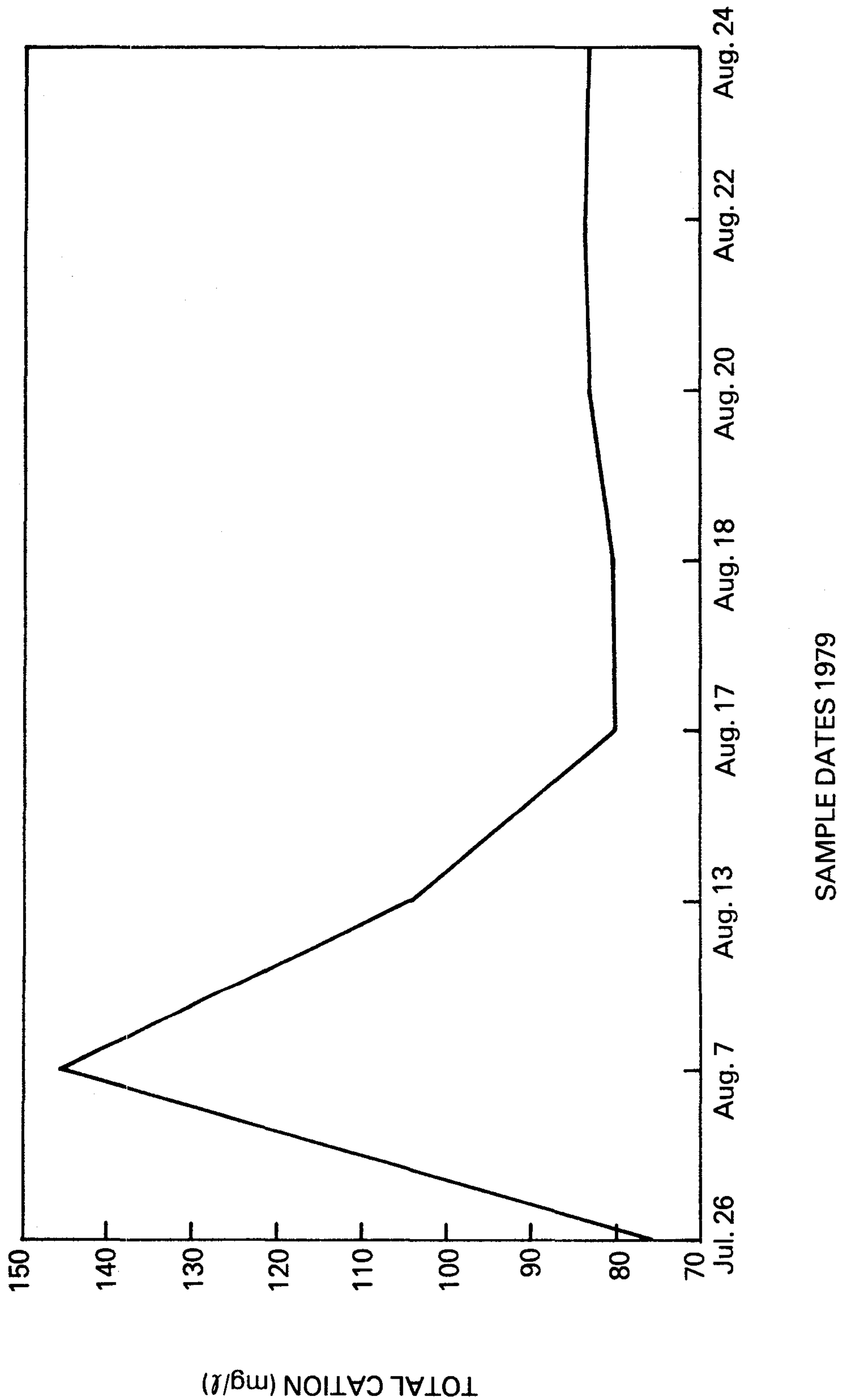


Figure 19. Variation in Total Cations.

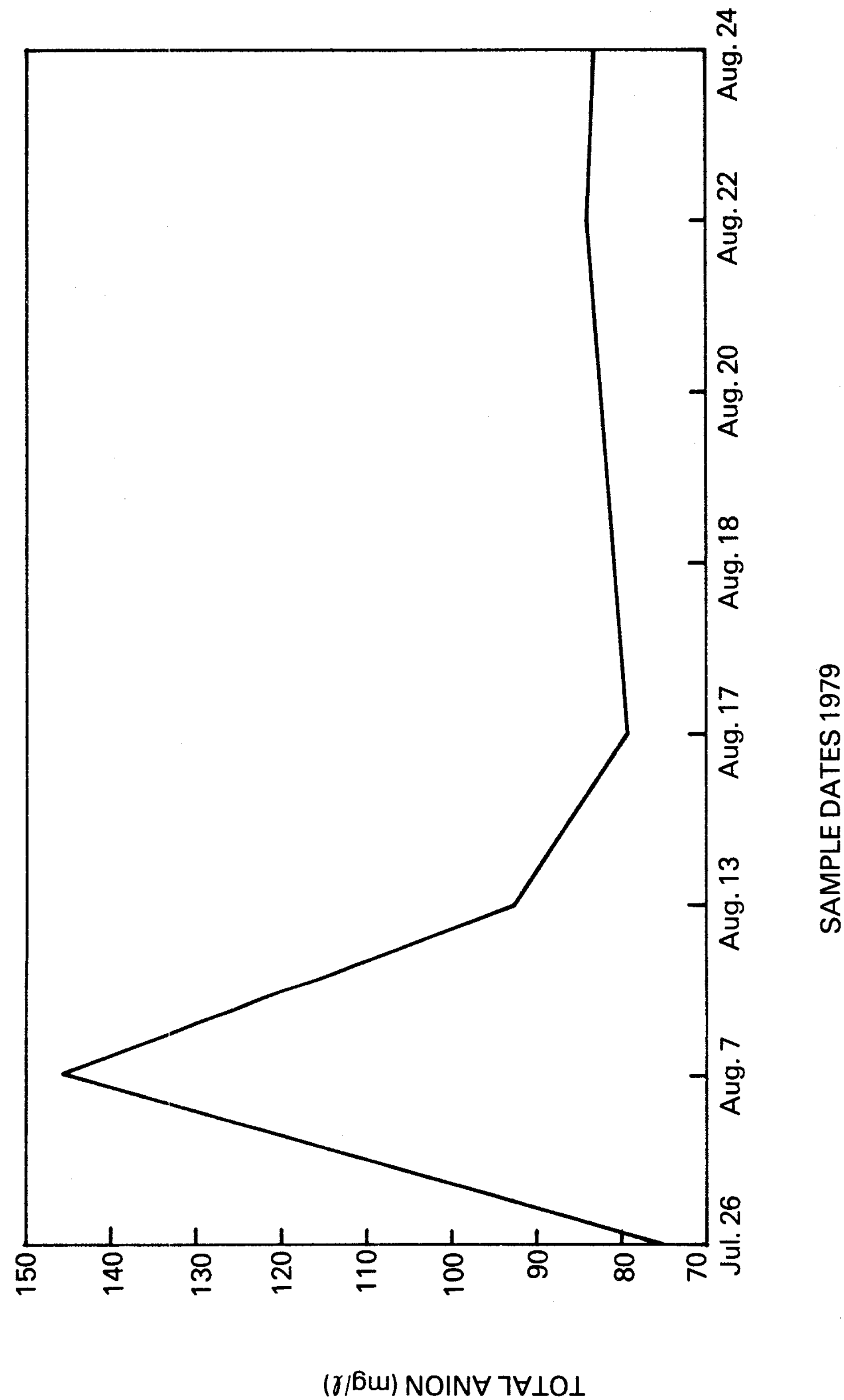


Figure 20. Variation in Total Anions.

chloride ions (expressed in terms of equivalent weights) remained essentially the same. A slight decrease in percent sodium to total cations was noted in the August 24 sample analysis, but the percent chlorides to total anions remained essentially the same. This small change in percentages may be attributable to available laboratory error. The results are summaried in Table 6.

Based upon the data available, it is impossible to draw any firm conclusions with regards to water quality. It appears that no significant changes occur in the chemical composition of the process water. This leads to the speculation that the borehole mining process does not actually dissolve the mined material, but the data is inclusive. Lack of a water mass balance over the entire system precludes the possibility of obtaining an accurate estimate of the quantity of water lost during mining. Also, because the monitoring well did not penetrate the ground water table, no information about the possible migration of process water or its effects on ground water is available.

Table 6. Comparison of Sodium and Chloride Equivalents*

Sample Date	Sodium:Chloride	% Sodium to Total Cations	% Chloride to Total Anions
7/26	1:30	93	72
8/07	1:39	97	70
8/13	-	-	-
8/17	1:33	94	72
8/18	1:30	94	72
8/20	1:30	93	73
8/22	1:28	91	71
8/24	1:24	88	71

*Sodium and chloride expressed in milliequivalents per liter.

4. Mining Cost Analysis

The hydraulic borehole mining of oil sands provided sufficient information to project an estimated cost of production based on a Bureau of Mines tool used at this test site. Certain assumptions were made concerning the cost of building and operating an oil-sand separation plant and other miscellaneous costs. In addition, a cost analysis was performed based upon a hypothetical hydraulic borehole mining tool (Figure 1) with a higher mining rate and used at a more favorable site.

4.1 Basis of Analysis

The borehole mining cost analysis is based on the following projected operation plan. First, drilling crews will drill, log, case, and complete boreholes in an area before the mining operation begins. Support crews will then prepare reservoirs, water supplies, slurry ponds, and slurry and water lines to transport the ore to the separation plant. These crews will also assist the operating crew in moving and setting up the borehole mining equipment. The operating crew will mine with the borehole mining equipment, moving it to new boreholes as necessary. A maintenance crew will perform all maintenance and repair work and keep a stock of spare parts and supplies on hand. Mining operation managers will supervise the mining, plan the moves, monitor the progress, and keep the operation fully manned. A 10,000-ton-per-day separation plant will be sited within two miles of the mining area. The sand tailings will be backfilled into the borehole cavities. The entire operation will run three shifts per day, 330 days per year.

The equipment required for the Bureau of Mines tool system is described in Appendix A, i.e., the equipment used for this test. The percentage of ore recovery, the ore body requirements, the number of mining units, the number and depth of boreholes, and the corresponding costs depend on the type of mining tool used and ore body being mined. A detailed list of parameters used in the mining cost analysis are listed in Table 7. Those parameters characterizing this tool at the test site used for this project are the ore thickness (25 ft), overburdening thickness (125 ft), and the average mining rate (14 tph).

Table 7. Basis for Mining Cost Analysis

Item	Bureau of Mines Tool	Hypothetical Tool	
Ore Body			
Cavity radius	25	25	ft
Cavity separation	10	10	ft
Ore thickness	25	200	ft
Overburden thickness	125	200	ft
Ore grade	0.50	0.50	bbl/ton
Ore body width	2,000	2,000	ft
Ore density	118	118	lb/cu ft
Mining arc	360	360	deg
Drilling cost	25	25	$/ft
Capital Cost			
Exploration cost	2,000,000	2,000,000	$
Capital depreciation period	10	10	yr
Working capital	25	25	%
Mining system cost	1,500,000	1,500,000	$/unit
Slurry and water lines	15,000	15,000	$/unit
Plant cost	30,000,000	30,000,000	$
Miscellaneous capital costs	5,000,000	5,000,000	$
Operating			
Mine capacity	10,000	10,000	ton/day
Average mining rate	14	20,40 or 100	ton/unit/hr
Utilization level	24	24	hr/day
	330	330	day/yr
Mining unit availability	60	60	%
Reservoirs and water supply	400,000	400,000	$/yr
Maintenance supplies	150,000	150,000	$/unit/yr
Miscellaneous operating supplies	1,200,000	1,200,000	$/yr
Fuel	100,000	100,000	$/unit/yr
Ore transportation	0.40	0.40	$/ton
Plant operating	3.50	3.50	$/ton
Tailings disposal	1.50	1.50	$/ton
Labor for Mining (not plant or drilling)			
Operating labor (1.5 man-level per unit)	18.00	18.00	$/unit/hr
Support labor	25	25	% oper. labor
Maintenance labor	25	25	% oper. labor
Supervisory labor	20	20	% direct labor
Payroll benefits	30	30	% total labor
Payroll overhead	40	40	% total labor
Finance			
Local taxes and insurance	2	2	% cap. cost
Royalty payments	7	7	% gross rev.
Income tax	46	46	% taxable income
Depletion allowance	None	None	

The equipment required for the hypothetical borehole mining operation will be the system described in the introduction and illustrated on Figure 1 (the auxiliary equipment for rock crushing is not shown). This system will have a faster average mining rate (20, 40, or 100 tph) than the Bureau of Mines system (14 tph) and will be used at a site having an ore thickness of 200 ft and an overburden thickness of 200 ft, as listed in Table 7. Borehole cavities in oil sands deposits may not be as well-formed as that shown in Figure 1. Oil sands deposits comprise unconsolidated sedimentary material and cavities in such material may slough and experience a slow surface subsidence. Backfilling the cavities, however, should minimize such subsidence.

To assist in evaluating hydraulic borehole mining of oil sands, the discounted cash flow rate of return (DCFROR) on investment has been calculated as a function of value per ton for the two ore body types following the procedure described in Section 3 of Appendix E. The following definitions and assumptions were made in addition to those shown in Table 7:

(1) A straight-line depreciation schedule.
(2) The operating income is the gross revenue less royalty payments and operating expenses.
(3) The taxable income is the operating income less depreciation.
(4) The net cash flow is the operating income less income tax, working capital (first year only), and capital investment (first year only).
(5) The rate of return on investment is based on the net cash flow over the ten-year depreciation period.

4.2 Cost and Ore Body Summary

The initial capital investment and the operating costs of the two borehole mining systems are summarized in Table 8. These figures have been calculated from the detailed assumptions listed above (Section 4.1) and in Table 7 following the procedure detailed in Appendix E.

The second column is the borehole economics code results for the Bureau's tool (14 tph) with the product value (selling price) adjusted to give a DCFROR of 20 percent. The next three columns are results for

Table 8. Borehole Mining of Oil Sands - Cost Summary

		Hypothetical Tool		
Initial Capital Cost Items ($K)	Bureau of Mines Tool	Low Mining Rate	Most Likely	High Mining Rate
Separation plant	30,000	30,000	30,000	30,000
Borehole mining units (number)	75,000(50)	52,500(35)	27,000(18)	10,500(7)
Working capital	27,638	21,450	15,676	11,963
Exploration	2,000	2,000	2,000	2,000
Slurry and water lines	750	525	270	105
Miscellaneous	5,000	5,000	5,000	5,000
Total Capital Cost	140,388	111,475	79,945	59,568
Operating Cost Items ($/bbl)				
Reservoirs and site preparation	0.24	0.24	0.24	0.24
Drilling	2.93	0.91	0.91	0.91
Mining: Payroll	7.78	5.44	2.80	1.09
Payroll benefits	2.33	1.63	0.84	0.33
Payroll overhead	3.11	2.18	1.12	0.43
Fuel	3.03	2.12	1.09	0.42
Maintenance supplies	4.55	3.18	1.64	0.64
Misc. operating supplies	0.73	0.73	0.73	0.73
Ore transportation	0.80	0.80	0.80	0.80
Separation plant	7.00	7.00	7.00	7.00
Tailings disposal	3.00	3.00	3.00	3.00
Total Direct	35.50	27.23	20.17	15.59
Indirect Cost Items ($/bbl)				
Local taxes and insurance	1.37	1.09	0.78	0.58
Royalty payments	4.69	3.64	2.66	2.03
Federal income tax	8.56	6.71	4.83	3.64
Depreciation	8.51	6.76	4.84	3.61
Total Indirect	23.13	18.20	13.11	9.86
Profit After Taxes ($/bbl)				
(for DCFROR of 20%)	8.37	6.57	4.72	3.55
Total (Selling Price)	67.00	52.00	38.00	29.00

Note: ($K/year) = 3300 x ($/ton)

the hypothetical tool at three mining rates (20, 40, and 100 tph) with the product value again adjusted to give a DCFROR of 20 percent. As discussed, some other parameters differ between the Bureau and hypothetical tool cases. Note that the total capital cost includes the working capital and that the depreciation includes the depreciation on the working capital. Also, all operating costs are consistent units ($/bbl).

The number of mining units (indicated on Table 8) is an important parameter impacting the total capital cost and the labor operating cost. Also, the number of boreholes drilled per year and other ore body parameters (Table 9) have an effect on the operating costs.

4.3 Sensitivity Study

A study of the sensitivity of DCFROR on investment has been prepared based on the most-likely hypothetical case with a product value set at $25/bbl. The figures for the baseline case are included as the sample case in Appendix E. Five figures summarize the sensitivity to cavity radius, ore thickness, overburden thickness, ore grade, and average mining rate (Figures 21 through 25).

Each figure includes curves for two ore grades. This shows that the sensitivity results do not vary with grade and that good rate of return values are possible with moderate improvements in ore grade. A circle on the 0.50-bbl/ton curve shows the baseline data point. There is insensitivity to cavity radius over 30 feet (Figure 21), ore thickness over 100 feet (Figure 22), and overburden thickness under 400 feet (Figure 23). Ore grade (Figure 24) has a large effect on the economics (note the scale change) as does the mining rate (Figure 25). If an ore body exists with fairly high grade (>0.75 bbl/ton), it could be mined very profitably at 40 or more tons per hour.

Table 9. Borehole Mining of Oil Sands - Ore Body Summary

Item	Bureau of Mines Tool	Hypothetical Tool (All Mining Rates)
Recovery (% of ore in place)	55	55
Ore body requirements (kilotons/yr)	6,050	6,050
Ore body length required (ft/yr)	2,051	256
Ore per borehole (tons)	2,896	23,169
Borehole required per year	1,139	142
Annual production (bbl/yr)	1,650,000	1,650,000

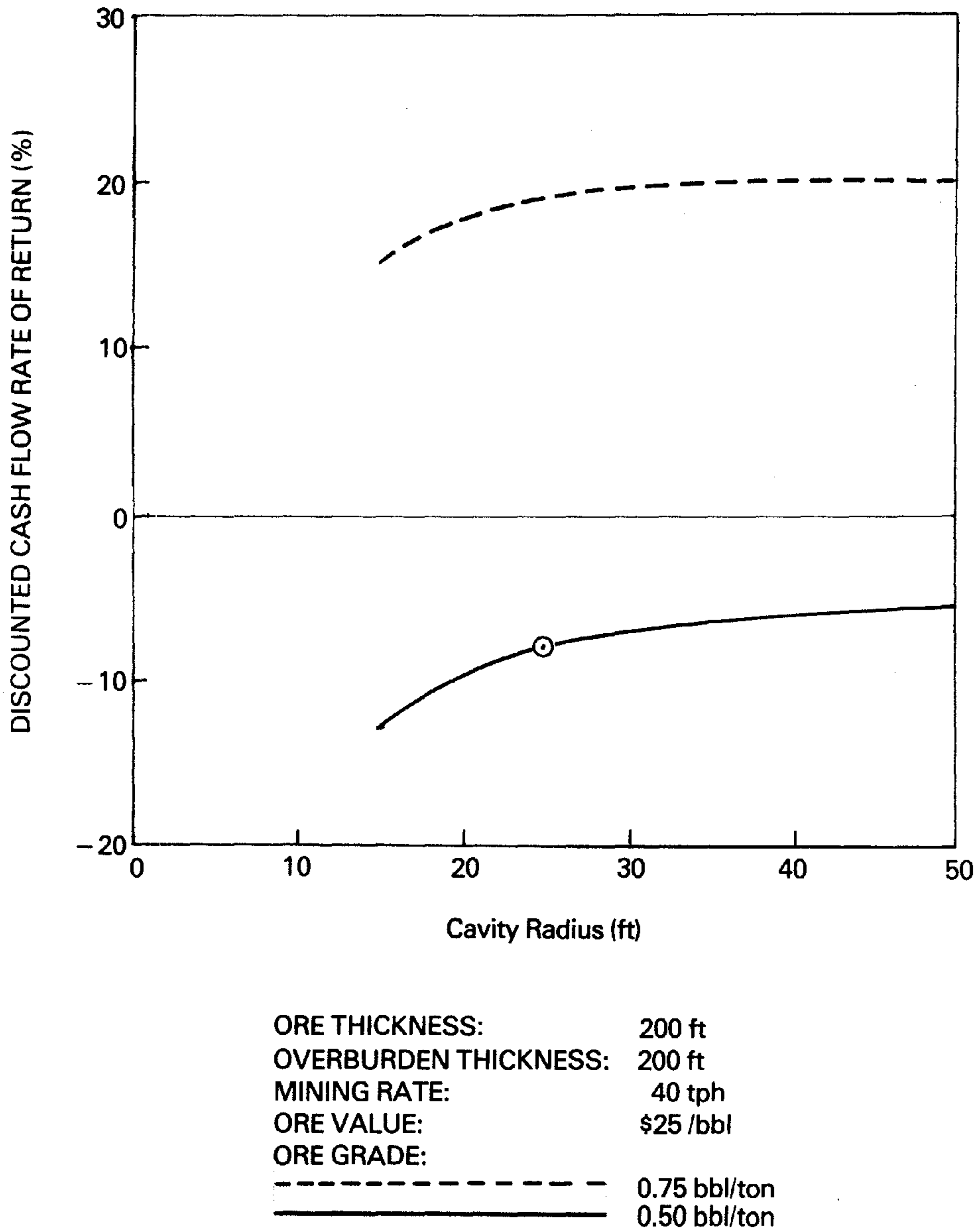
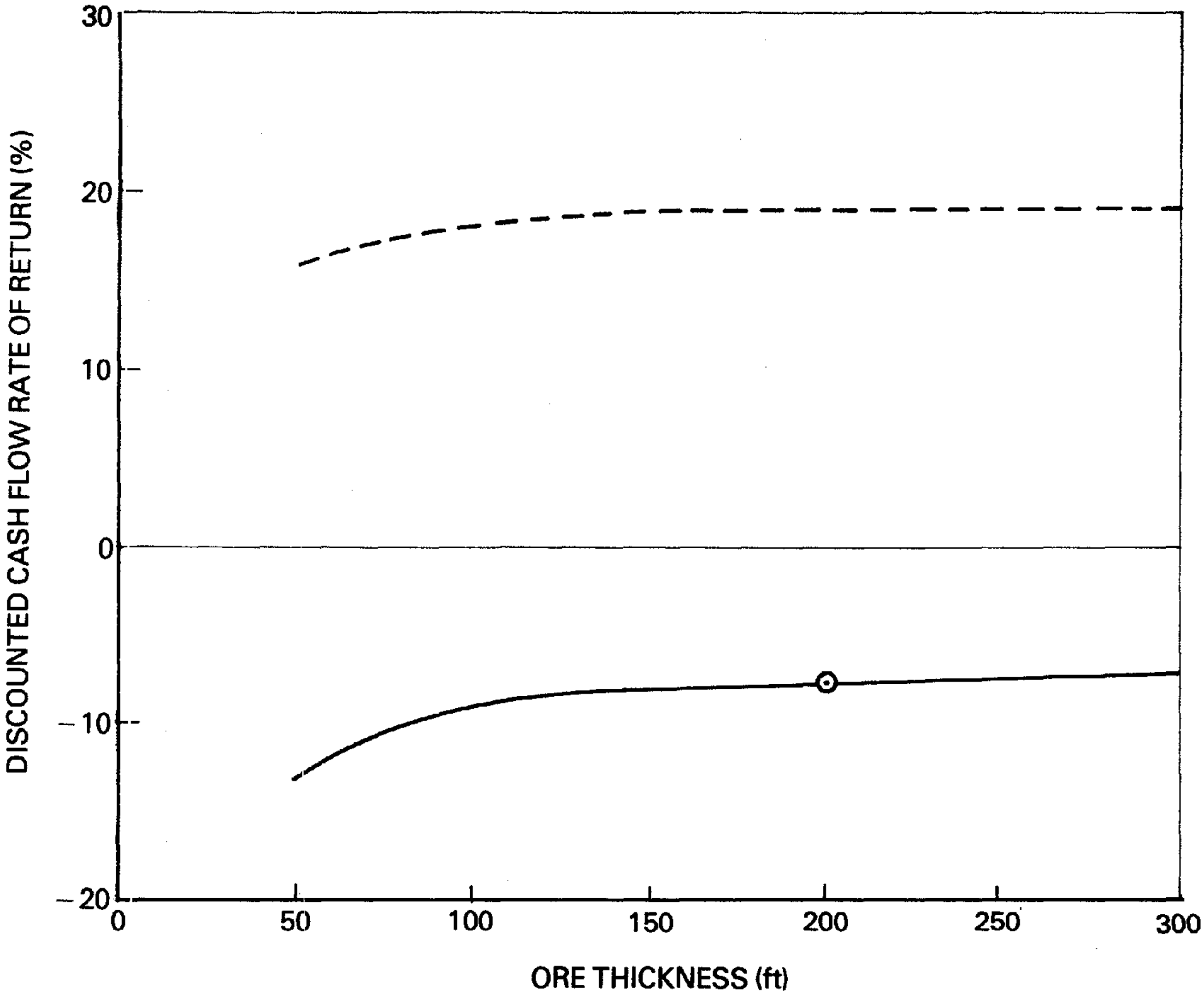
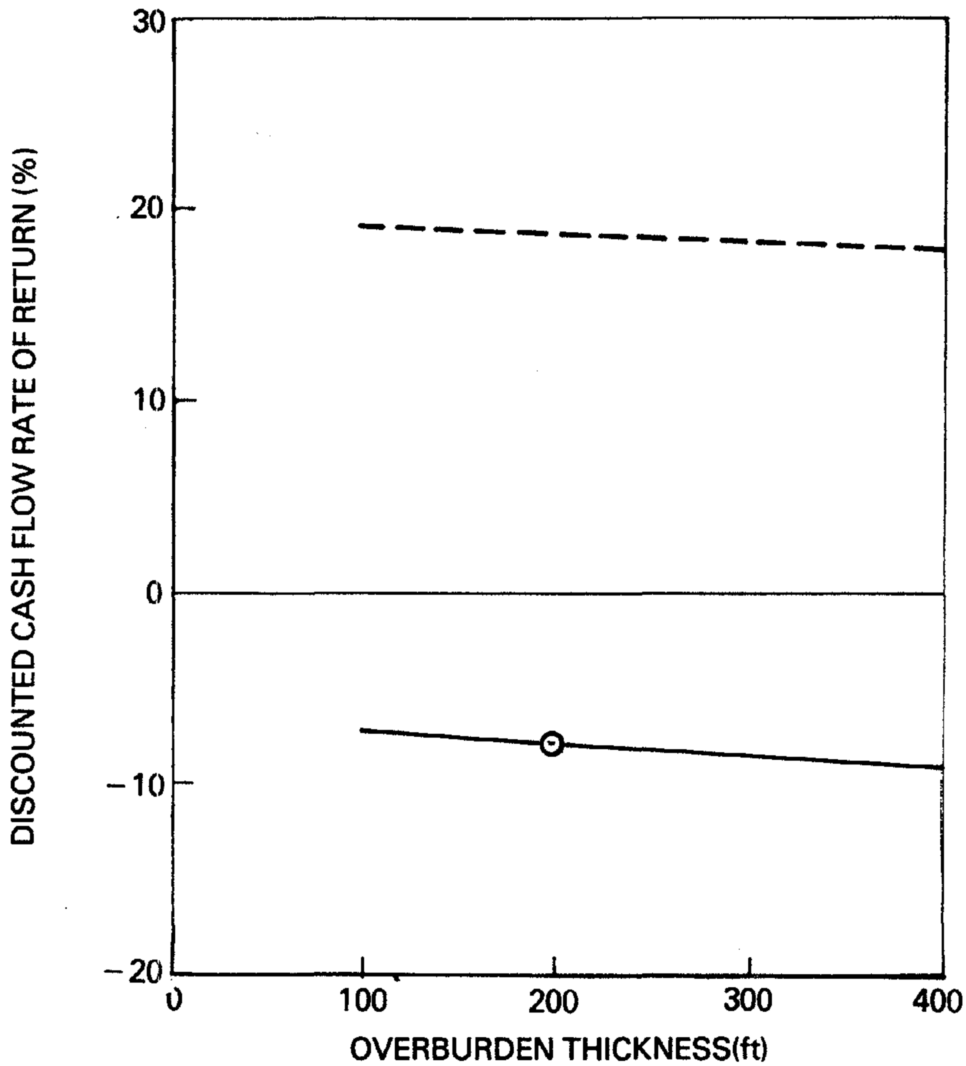


Figure 21. Sensitivity to Cavity Radius.



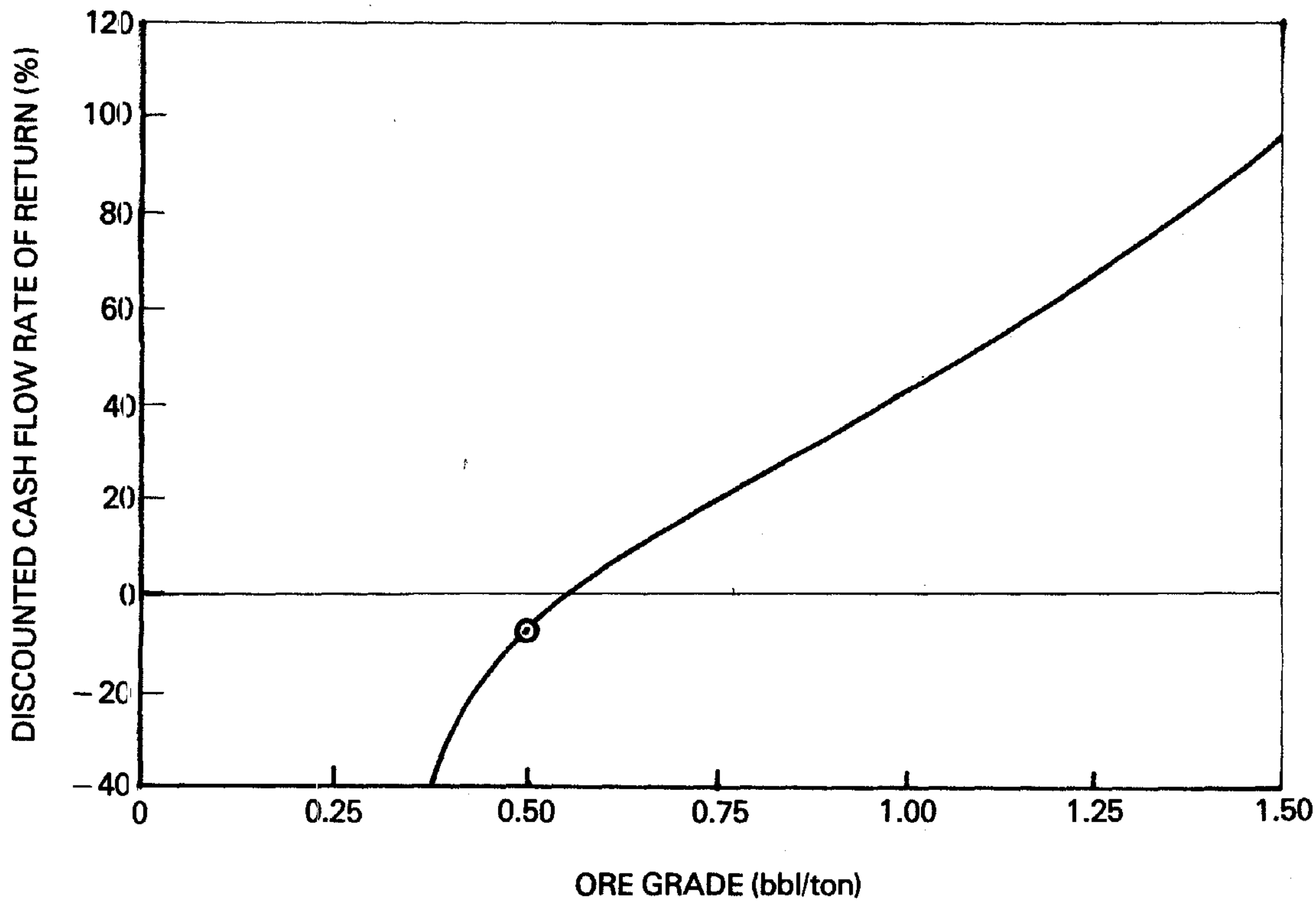
CAVITY RADIUS: 25 ft
OVERBURDEN THICKNESS: 200 ft
MINING RATE: 40 tph
ORE VALUE: $25/bbl
ORE GRADE:
- - - - - - - - 0.75 bbl/ton
———————— 0.50 bbl/ton

Figure 22. Sensitivity to Ore Thickness.



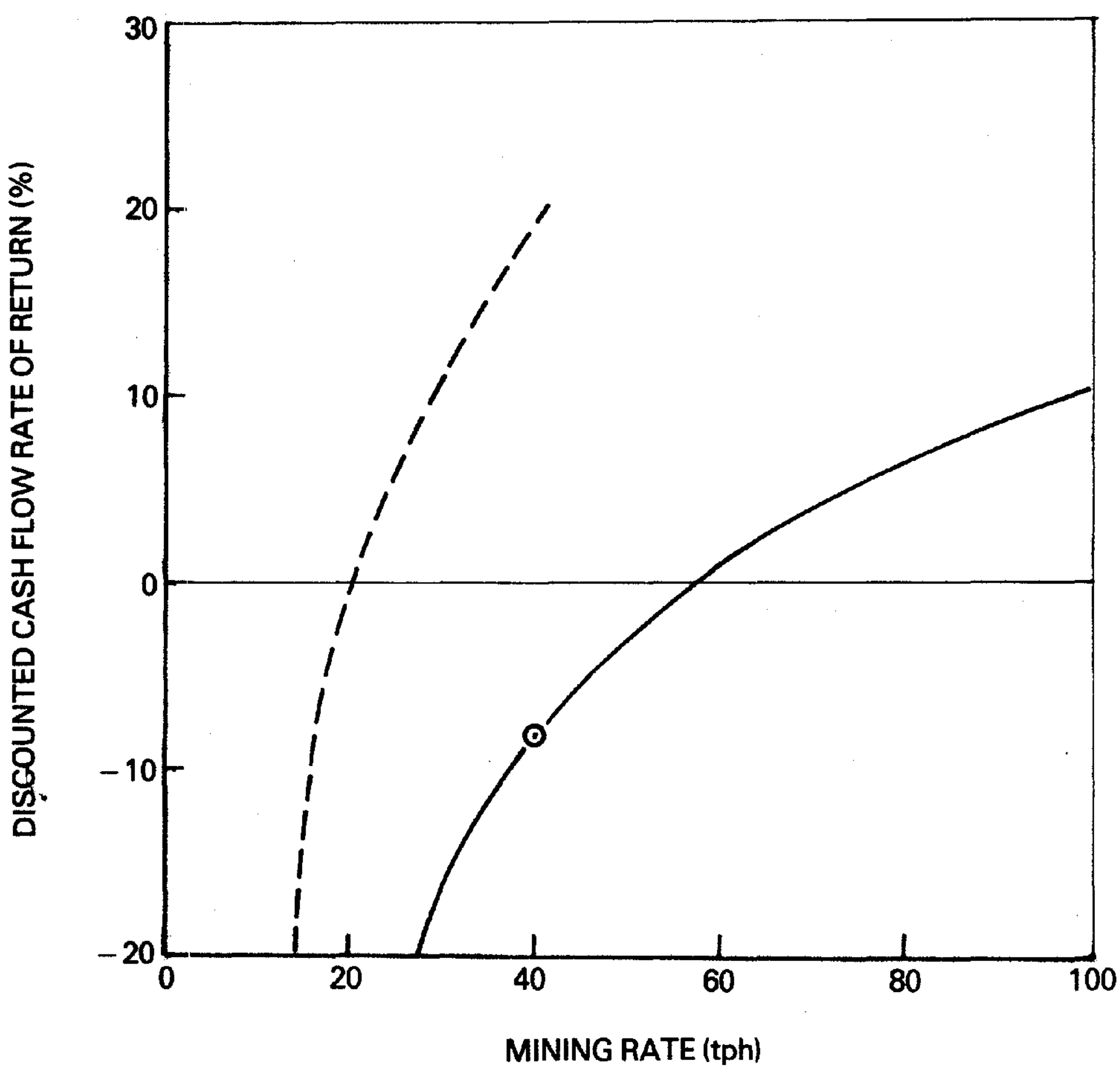
CAVITY RADIUS: 25 ft
ORE THICKNESS: 200 ft
MINING RATE: 40 tph
ORE VALUE: $25 /bbl
ORE GRADE:
– – – – – – 0.75 bbl/ton
———— 0.50 bbl/ton

Figure 23. Sensitivity to Overburden Thickness.



CAVITY RADIUS:	25 ft
ORE THICKNESS:	200 ft
OVERBURDEN THICKNESS:	200 ft
MINING RATE:	40 tph
ORE VALUE:	$25 /bbl

Figure 24. Sensitivity to Ore Grade.



CAVITY RADIUS: 25 ft
ORE THICKNESS: 200 ft
OVERBURDEN THICKNESS: 200 ft
ORE VALUE: $25 /bbl
ORE GRADE:
– – – – – – – – 0.75 bbl/ton
———————— 0.50 bbl/ton

Figure 25. Sensitivity to Mining Rate.

5. Conclusions

Hydraulic borehole oil sands mining has been shown to be technically feasible with minimal environmental impact. A high-pressure water cutting jet was used to produce an oil-sand slurry that was pumped to the surface by a slurry jet pump. Mining rates as high as 45 tons per hour were demonstrated while nearly 1000 tons of oil sands were mined during 70 hours of operation.

A slight amount of ground subsidence occurred over the two-month period during and following mining operations. This subsidence is concluded to be negligible in terms of environmental impact. However, ground subsidence may become significant when larger underground cavities are developed.

It is tentatively concluded that the mining process does not dissolve the mined material and that a small percentage of the process water is lost underground.

A mining cost analysis projects an estimated cost of production mining at about $38.00 per barrel of oil. This cost includes drilling, borehole mining, fuel, ore transportation, tailings disposal, royalty payments, taxes, separation costs, and a reasonable rate of return on the mining and support equipment investment.

6. Recommendations

It is recommended that a rock crusher be added to the slurry jet pump inlet on the mining tool. This recommendation is based on the only major problem encountered during this project, i.e., rocks blocking the downward progress of the mining tool.

It is recommended that the underground borehole cavities be back-filled both to dispose of tailings and to reduce ground subsidence.

It is recommended that further testing and operations be performed to refine the results of the mining cost analysis.

References

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APPENDIX A: MINING TOOL

A.1 Hydraulic Borehole Mining Tool

The mining tool is the heart of the hydraulic borehole mining system. It carries the high-pressure water down to the cutting jet and supports the jet pump that lifts the slurry, generated by the cutting jet stream, to the surface. Basically, the tool consists of a three-passage swivel, a Kelly section, standard sections, and a mining section. Three conductors are provided in the sections; two to carry water down to the cutting jet and the jet pump, and the other to carry slurry up. The sections are bolted together. Detailed descriptions of the mining tool components are given as follows.

The three-passage swivel is shown in Figure A-1. The outer housing is stationary and is used to support the mining tool, which is suspended from a crane and moved up and down during operation. The inner part of the swivel rotates with the mining tool. Passages are provided to carry water into the mining tool and to carry slurry out. The swivel can be connected to the Kelly section, the standard section or the mining section.

Figure A-2 illustrates the Kelly section. The torque required to rotate the mining tool is transmitted from the rotary table to the mining tool through this section. The Kelly section is 22 feet long, with a 12-inch diameter. The section contains three conductors, the same as the standard sections. It has two keys along its length at 180 degrees for drive. Driving keys are on one of the standard sections to increase the vertical travel capability of the mining tool.

A standard section is shown in Figure A-3. Standard sections are installed as the mining section is lowered down the borehole until the desired mining level is reached. The standard section is 20 feet long, 12-inches in diameter and contains three conductors to transport water down to the mining section and to transport the slurry up. One water passage, for the high-pressure cutting jet, is a 2-inch pipe. The slurry line is a 4-inch pipe. The space around the 2- and 4-inch pipes and inside the 12-inch housing carries the jet pump driving water. A groove is provided at the top of each standard and Kelly section for support during section connection and disconnection.

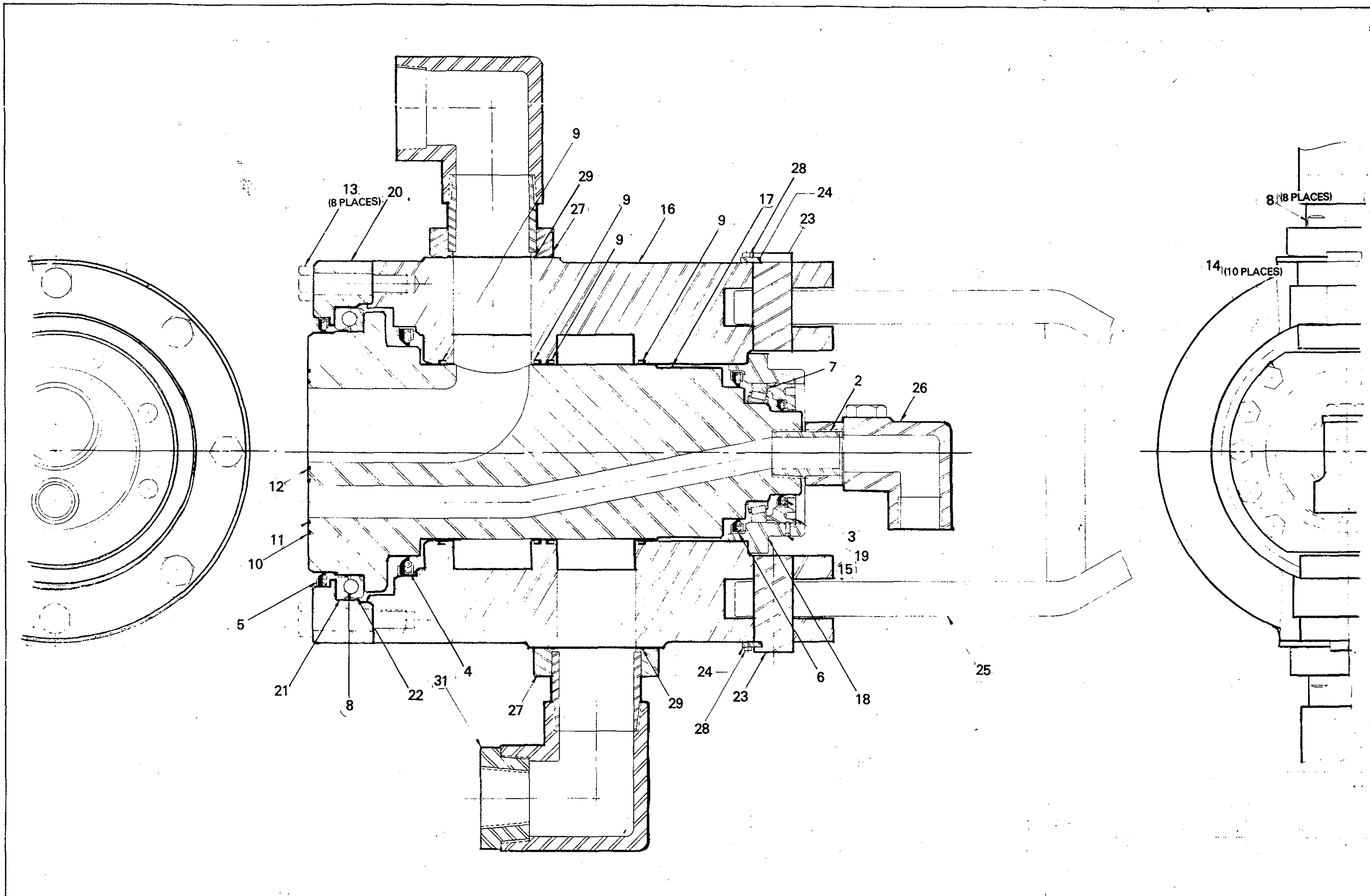

Figure A-1. Swivel Assembly.

PARTS LIST			
QTY.	ITEM NO.	DESCRIPTION	SPECIFICATION
	1	SWIVEL ASSY	
1	2	PIPE FTG	2 FF-S
1	3	SEAL, CHICAGO RAWHIDE	C/R 43051
1	4	SEAL, CHIGAGO RAWHIDE	C/R 107551
	5		
1	6	SEAL, CHICAGO RAWHIDE	C/R 68745
1	7	BRG TIMKEN	CUP L225818, CONE L225849
5	8	O-RING, PARKER	2-268, BUNA N
3	9	BOLT, SHOULDER-MOD	B3084-1
1	10	SEAL, NATIONAL	417608, TYPE 41
5	11	SEAL, PARKER POLYPAK	37509500 9 1/2 x 10 1/4 x 3/8
	12		
8	13	BOLT 1 x 4 1/2	1 x 4 1/4 GRADE 8
10	14	BOLT 5/8 x 2 1/2	5/8 x 2 1/2 GRADE 8
1	15	SET SCREW	1/4 x 3/4
1	16	SWIVEL-OUTER	D1063-1
1	17	SWIVEL-INNER	D1062-1
1	18	SEAL RETAINER	C1077-1
1	19	BRG RETAINER	C1078-1
1	20	THRUST RING	C1079-1
1	21	BEARING, TIMKEN	CUP L357010, CONE L357049
	22		
2	23	PIN, SWIVEL	B1158-1
2	24	RETAINER PIN	B1157-1
1	25	HANGER FTG	D1068-1
1	26	CHICKSAN FTG	3207750
2	27	FLANGE ASSY	B1160-1
2	28	BOLTS	5/16 x 1 GRADE 3
2	29	O-RING PARKER	2-245
8	30	BOLTS	5/8 x 2 3/4 GRADE 8
1	31	BUSHING	4 x 2 1/2 STEEL

Figure A-1. Swivel Assembly (Cont.).

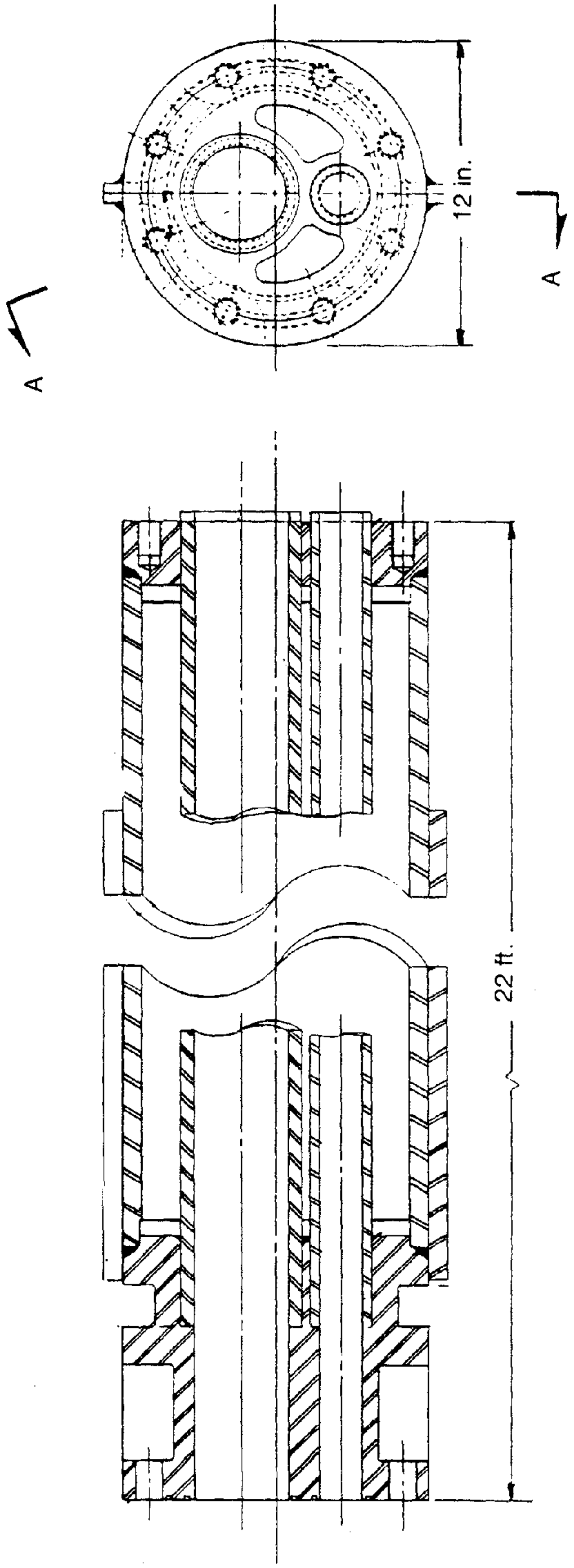

Figure A-2. Kelly Section.

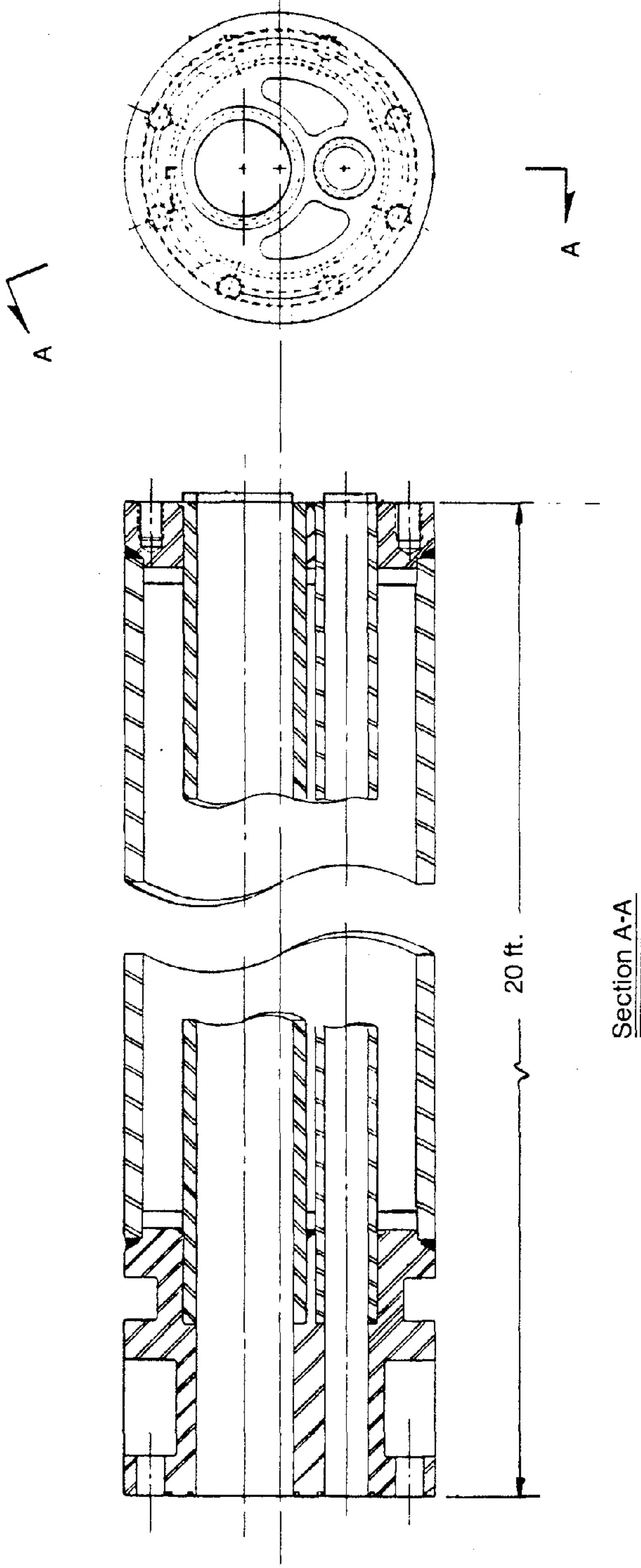

Figure A-3. Standard Section.

The mining section is the bottom section of the mining tool. It is 6 feet long with a 12-inch diameter and it consists of two sections. The top section is the nozzle section, shown in Figure A-4, which contains the high-pressure cutting jet nozzle. This section bolts to a standard section. The lower portion is the pump section, shown in Figure A-5. This section contains the slurry jet pump, with screened intake ports to allow slurry entry into the pump while preventing entry of large material that would block the pump. Should the oversize material block the intake ports, an aboveground valve is used to stop the slurry flow, thereby back-flushing the intake with the jet pump driving water. The bottom of the mining section is equipped with a conical auger. When lowering the mining tool, this auger assists in moving any material that has filled the void left when the tool was raised. The auger is also used to help remove drilling chips at the bottom of the borehole when the tool is initially installed. A small water jet is located near the center of the auger to agitate the material at the bottom of the borehole.

A.2 Rotary Turntable

The rotary turntable is a Hacker* Model A-15-T Rotary Table, a commercially available item used on conventional drilling rigs. Figure A-6 shows the rotary table separate from the driving mechanism. The design requirement for the turntable involved a gasoline engine driving an oil hydraulic pump which supplied hydraulic power to a hydraulic motor. The motor, in turn, rotated the rotary table. This hydraulic drive system along with hydraulic controls, solenoid valves and electrical limit switches provided rotational speed control of the turntable from 0 to 20 rpm. Additionally, this control provided an automatic reversing for an oscillating turntable motion, adjustable from 0 to 360 degrees. All of these components were mounted on a steel frame, forming an integral rotary turntable assembly. Figure A-7 shows a hydraulic circuit diagram of the turntable.

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*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

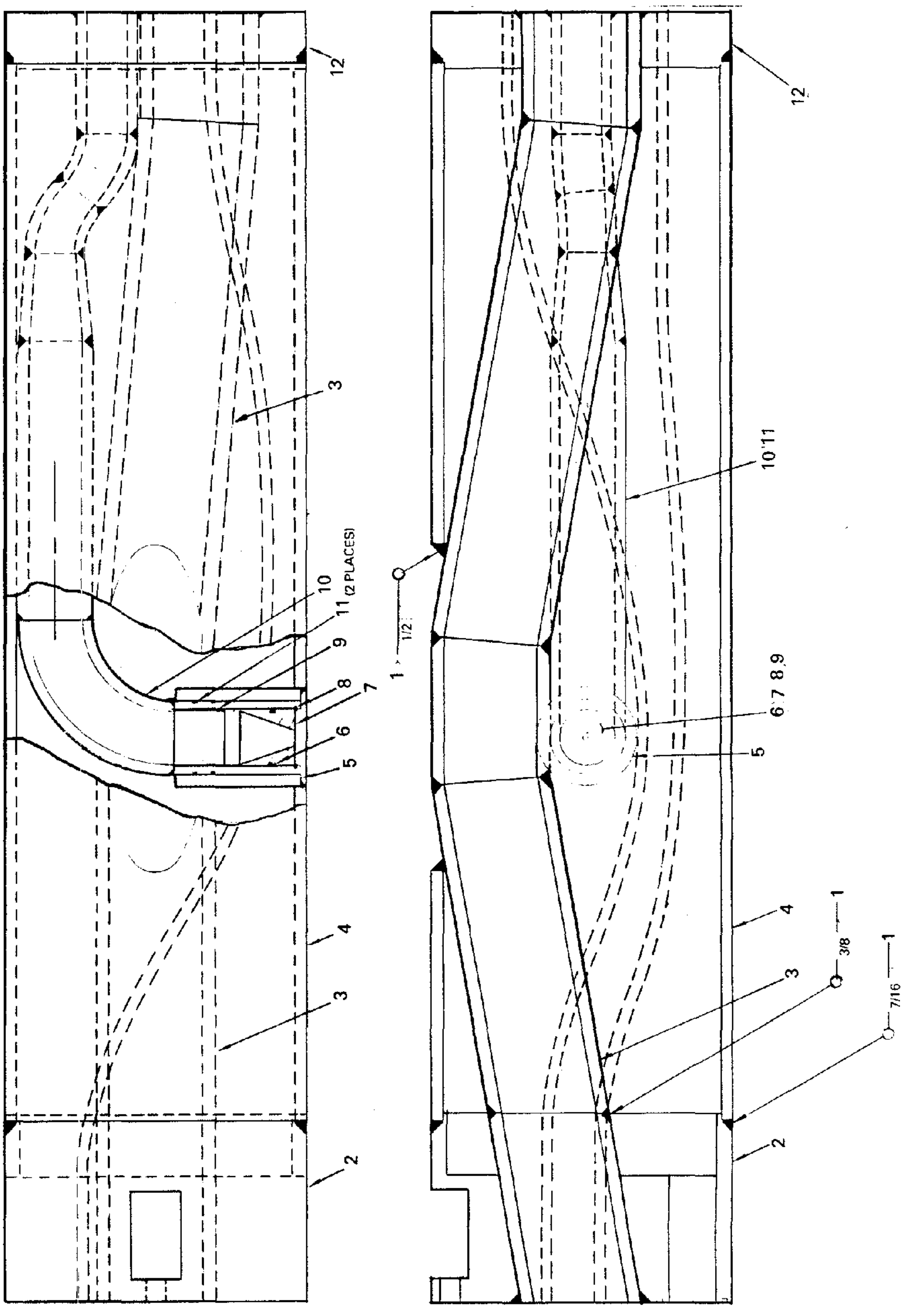


Figure A-4. Nozzle Section.

PARTS LIST			
QTY.	ITEM NO.	DESCRIPTION	SPECIFICATION
	1	NOZZLE ASSY	D1320
1	2	TRANSITION SECTION	D1076
1	3	SLURRY TUBE WELDMENT	D1314
1	4	HOUSING, MINING SECTION	D1315
1	5	SUPPORT, NOZZLE	C1314
1	6	O-RING & BACK-UP RING	PARKER OR EQUIV.
1	7	NOZZLE	C311
1	8	SNAP RING	TRUARC N5000-225
1	9	HONEYCOMB ASSY	B1456
1	10	NOZZLE TUBE WELDMENT	
2	11	O-RING	PARKER OR EQUIV.
1	12	PLATE, CONNECTOR	D1316

Figure A-4. Nozzle Section (Cont.).

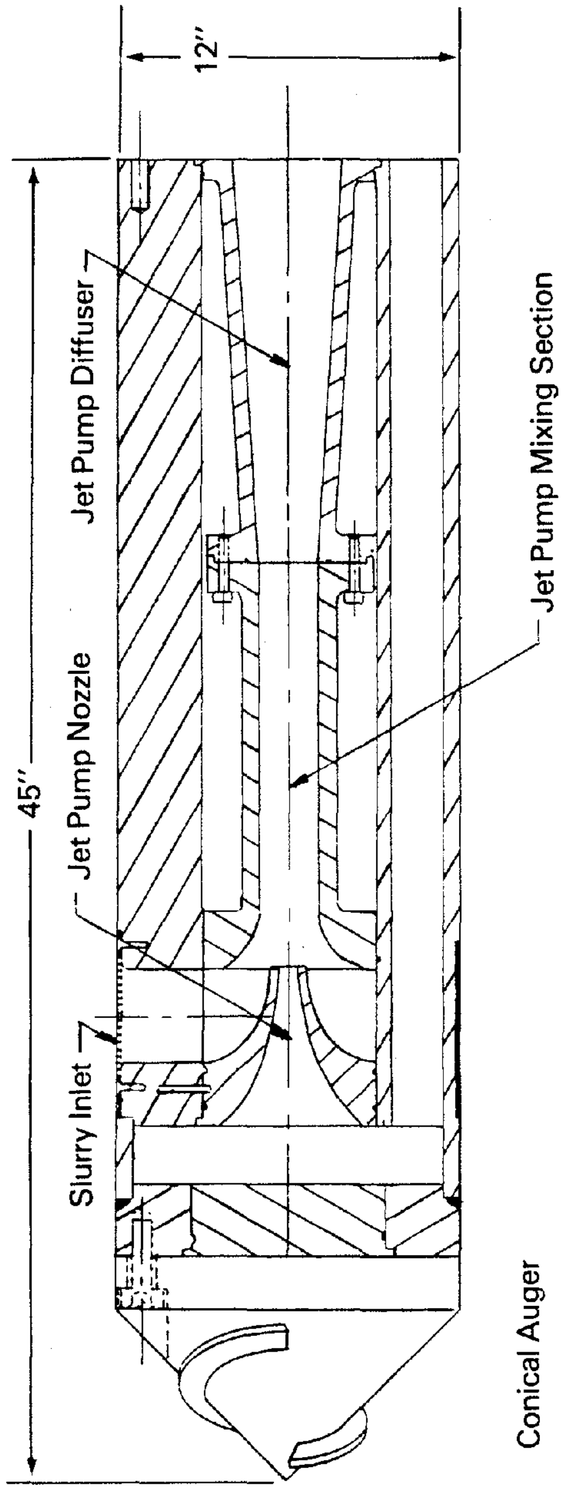
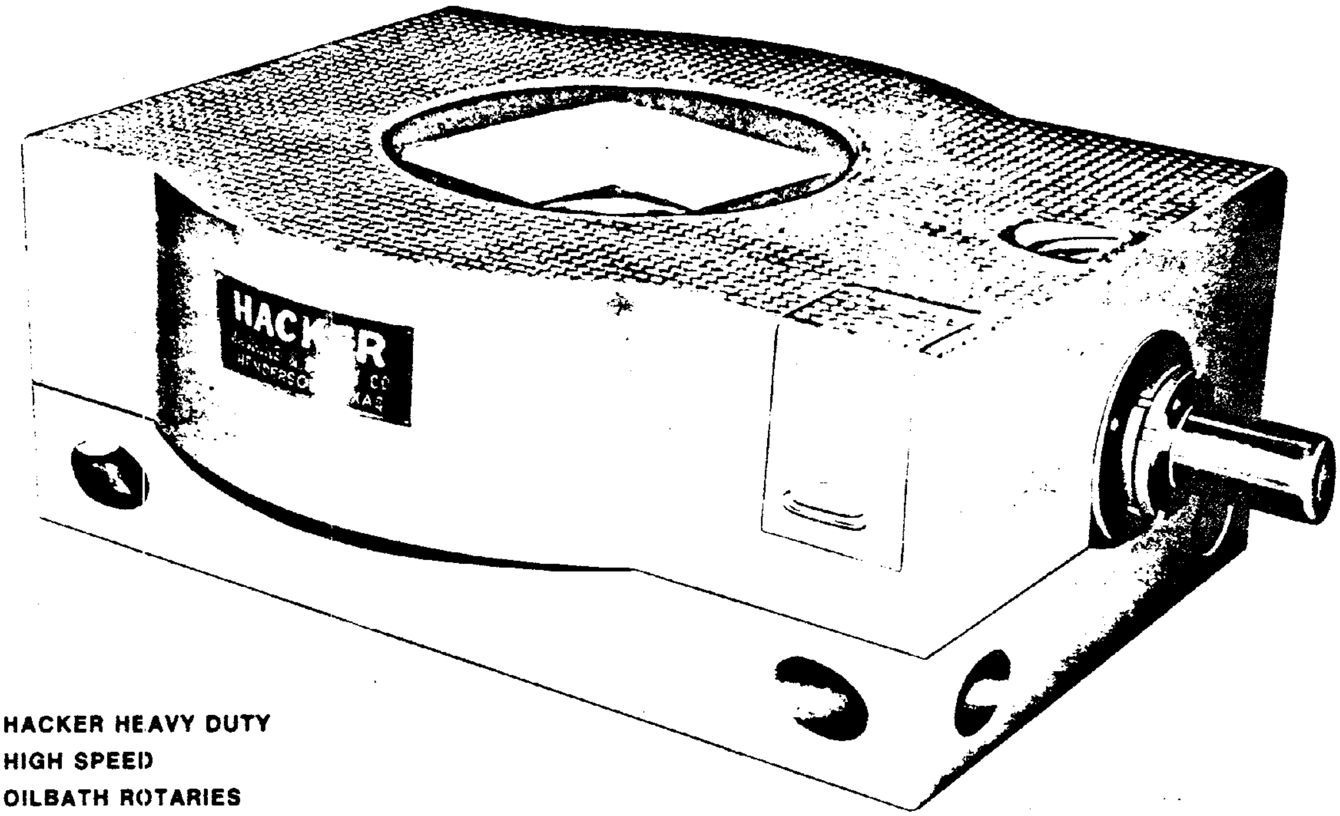


Figure A-5. Mining Section.



HACKER HEAVY DUTY
HIGH SPEED
OILBATH ROTARIES
MODELS B-10, A-12, A-15 Standard and A-15-T
10", 12" and 15¼" Table Openings

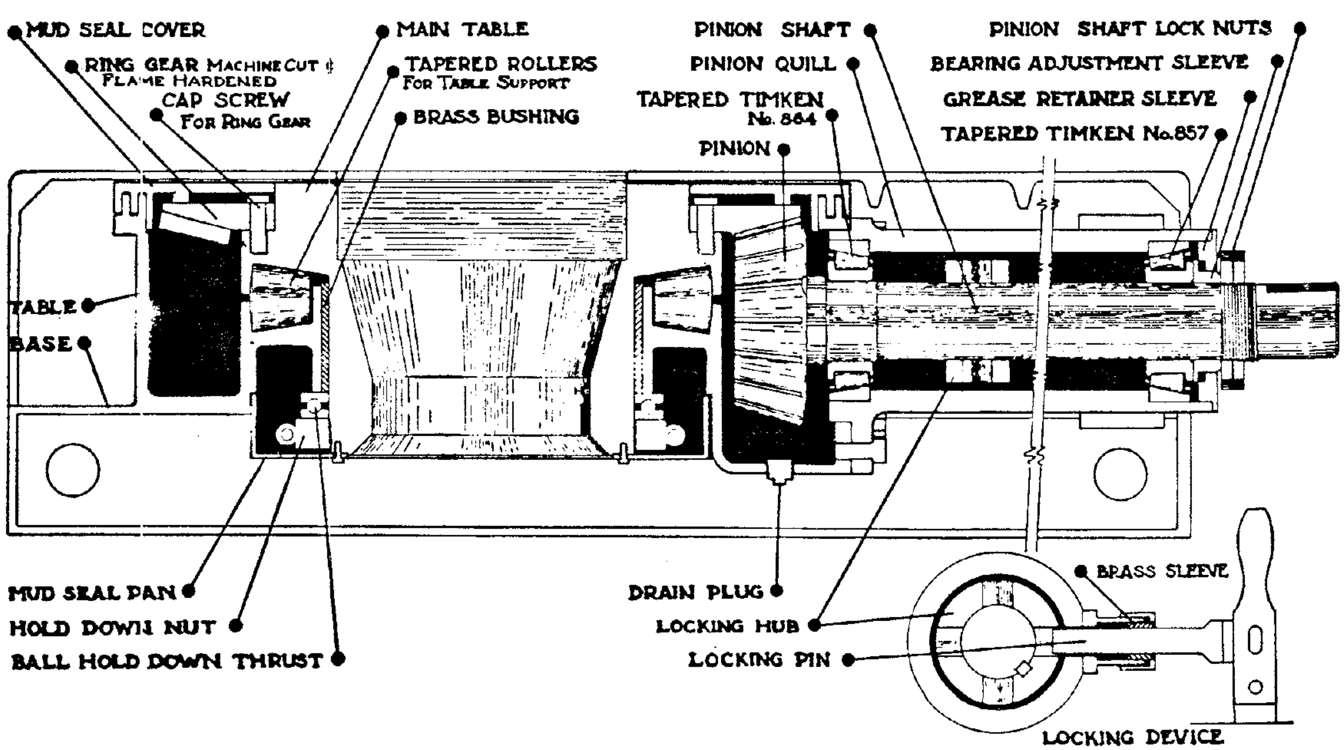
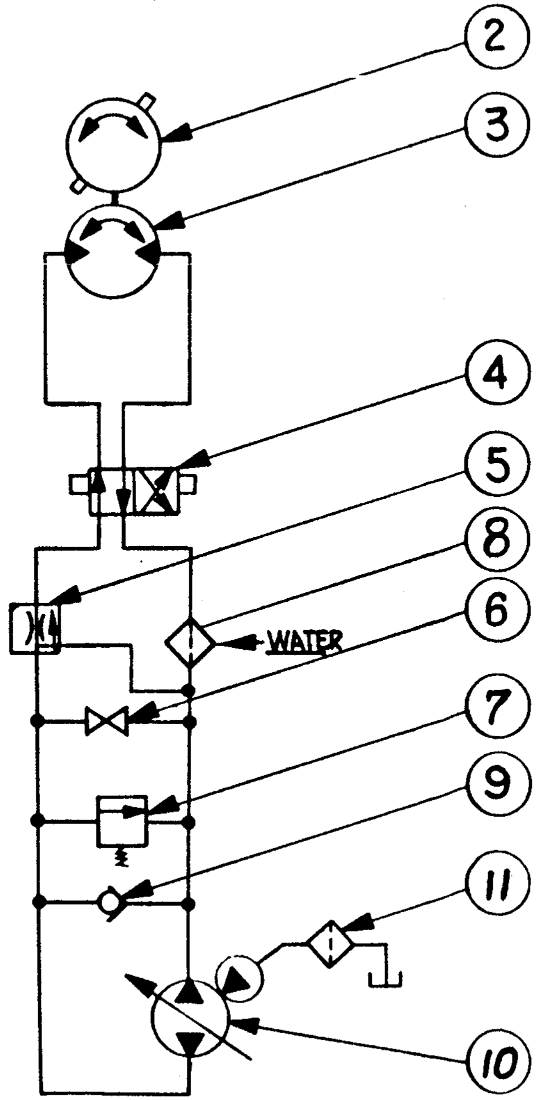


Figure A-6. Rotary Table.



PARTS LIST

QTY	QTY -1	ITEM NO	DESCRIPTION	SPECIFICATION
	—	1	TURNTABLE HYD. SCHEM.	
		2	ROTARY TABLE	HACKER' MODEL AIS. STD. STL
		3	HYDRAULIC MOTOR	KAYABA
		4	4-WAY VALVE	PARKER # D3-WIDK, 12 VDC
		5	VALVE	FLUID CONTROLS-2F84-R-3-3-3-8S
		6	BALANCE VALVE	APOLLO, 3/4 NPT
		7	RELIEF VALVE	PARKER # RA600-S-3-10
		8	OIL COOLER	YOUNG # F-302-HR-1P
		9	CHECK VALVE	PARKER # VCL-8P-05
		10	PUMP	SUNDSTRAND. MODEL 15
		11	FILTER	MICHIGAN # SAF5860, ELEMENT # S58

PART NO.	USED ON	QTY	REV.	DATE	DESCRIPTION	BY	CK
USAGE			REVISION				

TOLERANCES EXCEPT AS NOTED
DECIMAL: ± —
FRACTIONAL: ± —
ANGULAR: ± —

FINISH ALL MACHINED SURFACES EXCEPT AS NOTED
BREAK ALL SHARP EDGES

DATE OCT 26, 1978
DRAWN BY L. ROWE
ENGINEER
CHECKED
APPROVED
SCALE —

FLOW INDUSTRIES INC
PO BOX 5040
KENT, WASHINGTON 98031

TITLE TURNTABLE HYD. SCHEM.
-BOREHOLE-

APP'D. FOR MFG.
DRAWING NUMBER B3021
SH —

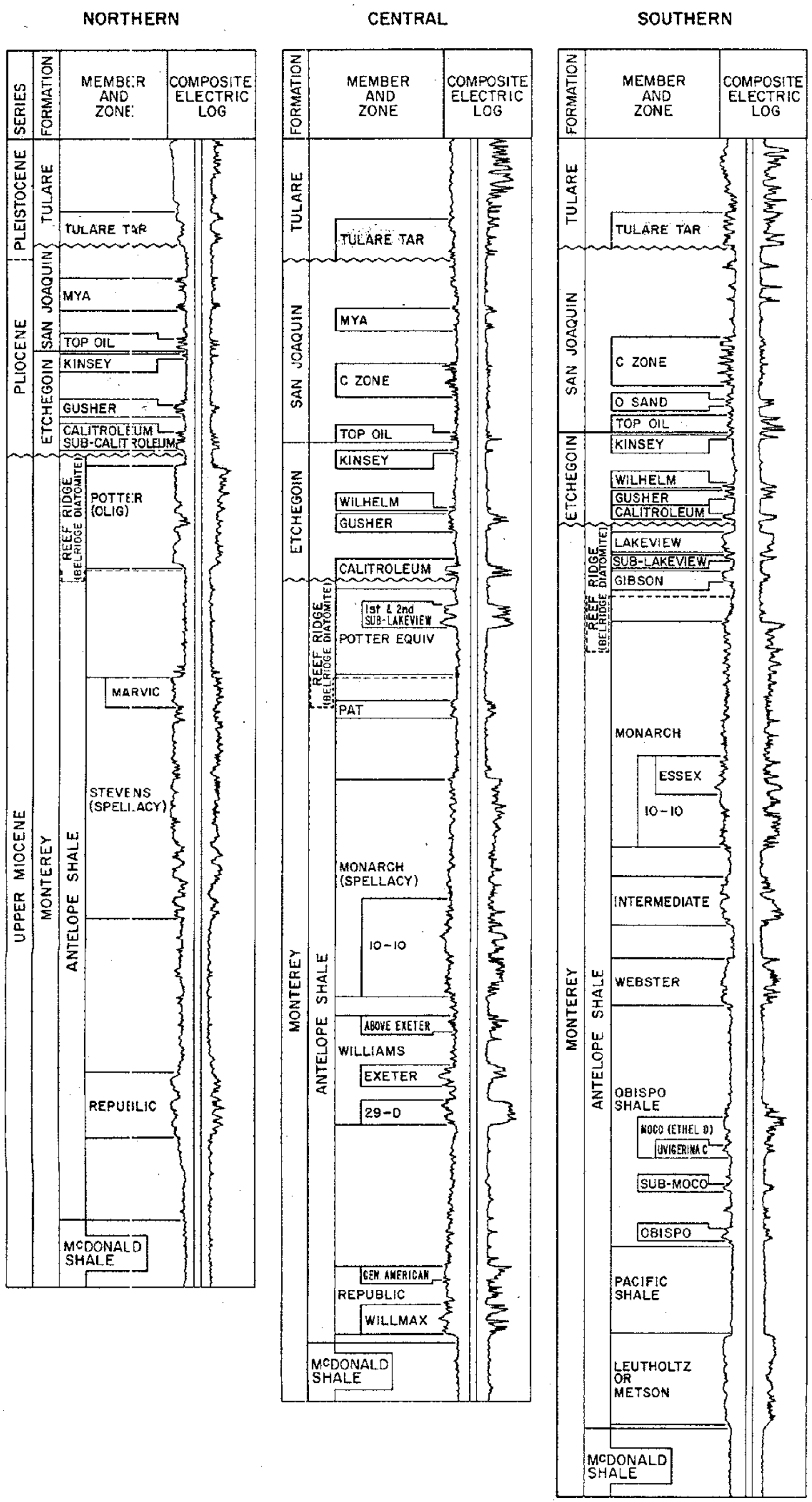
BRUNING 40-105 37397

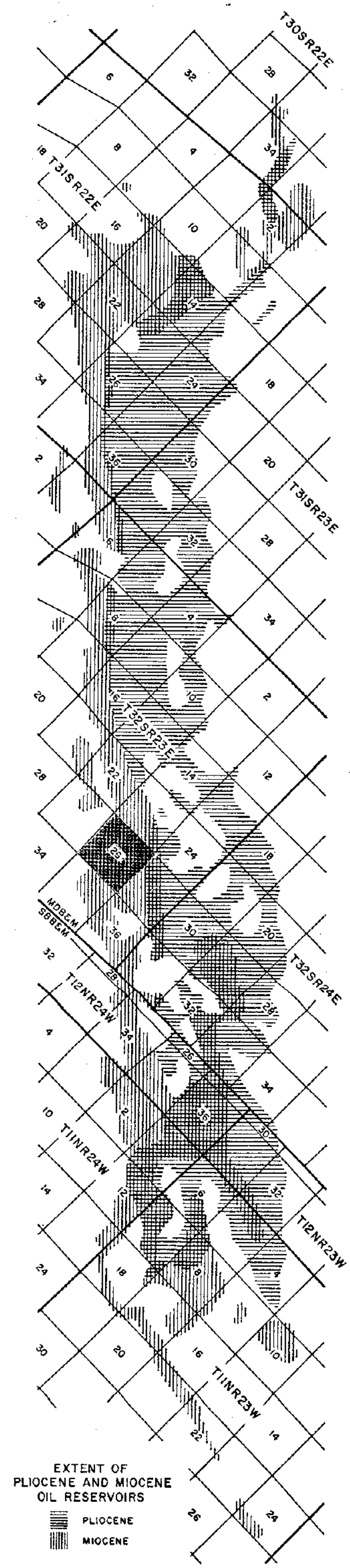
Figure A-7. Turntable Hydraulic Circuit.

The turntable is mounted over the borehole in a mining operation, where it provides rotational and oscillating movement to the mining tool which passes through the rotary table down to the high-pressure cutting jet. The turntable also allows vertical movement of the mining tool while continuously rotating the tool.

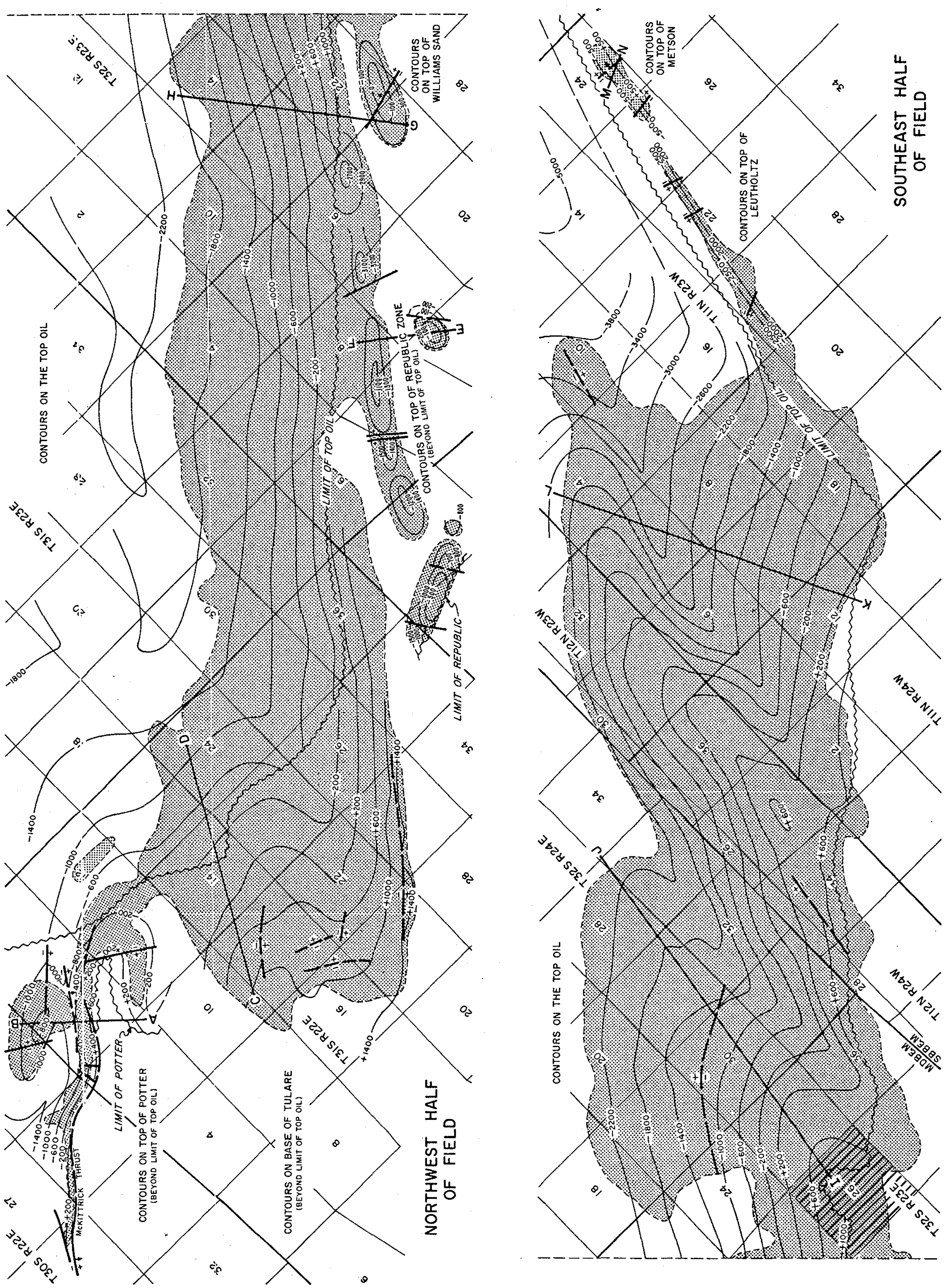
APPENDIX B: SITE LOCATION MAP

MIDWAY-SUNSET OIL FIELD





MIDWAY-SUNSET OIL FIELD



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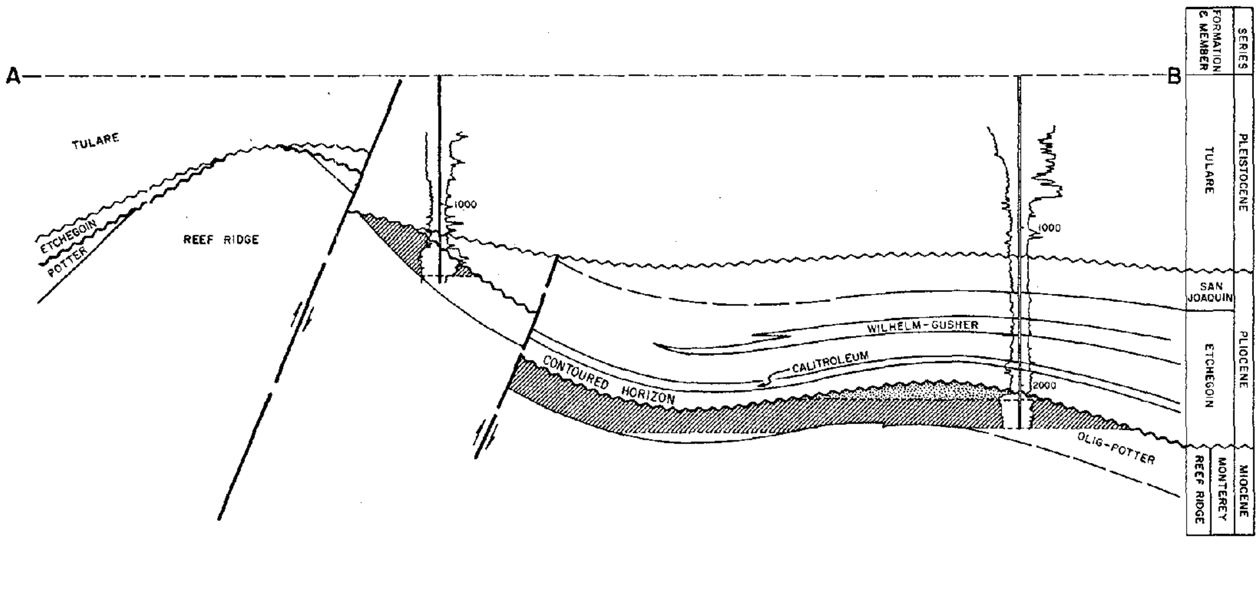
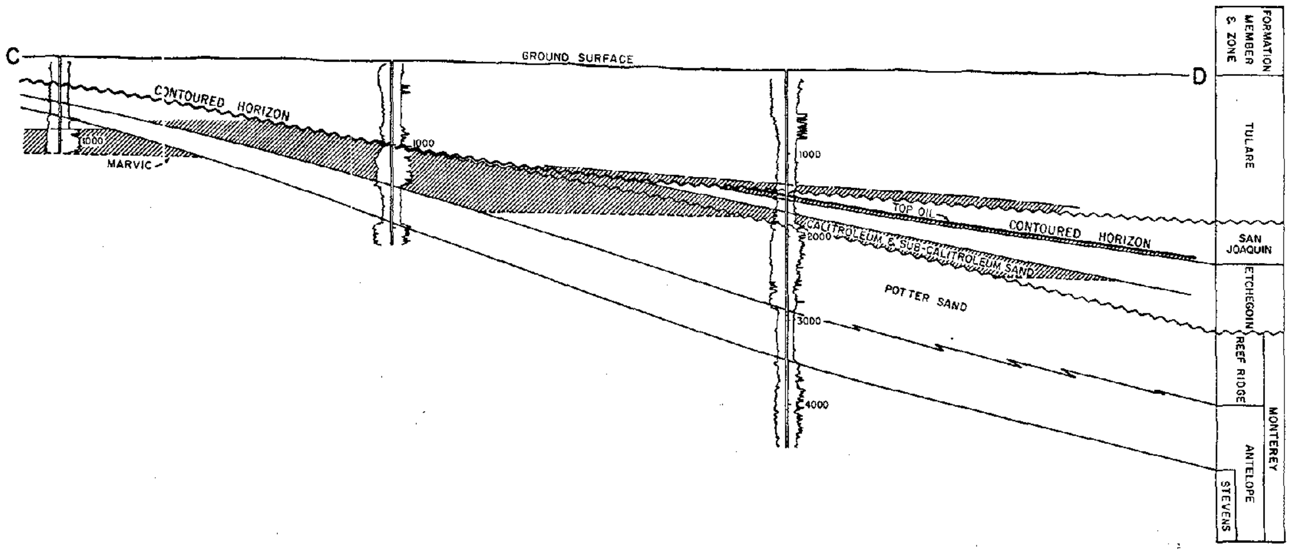
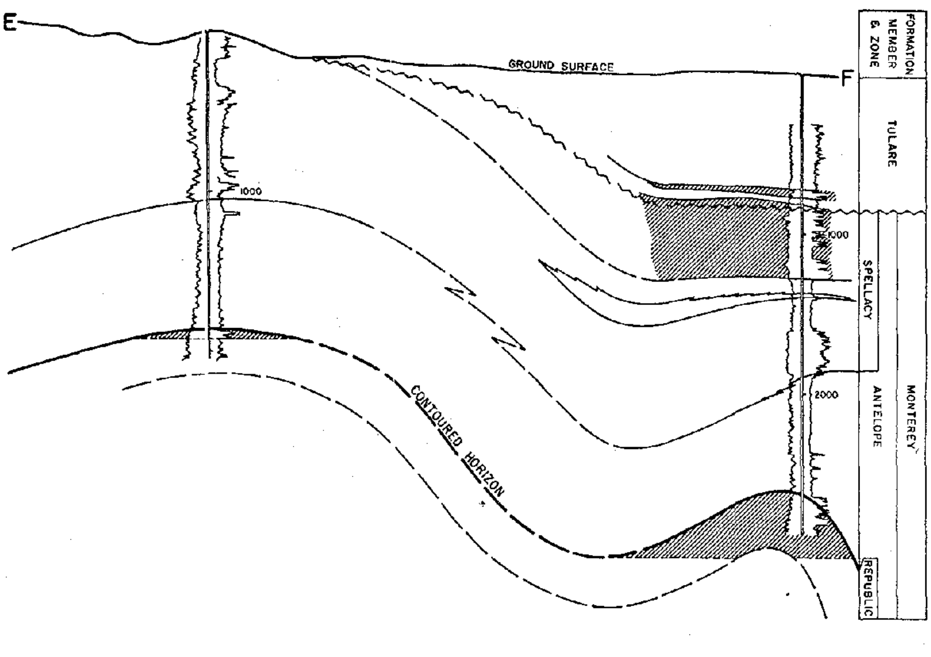
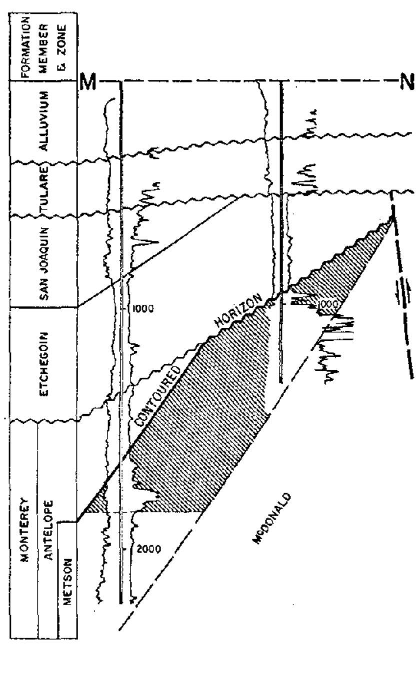
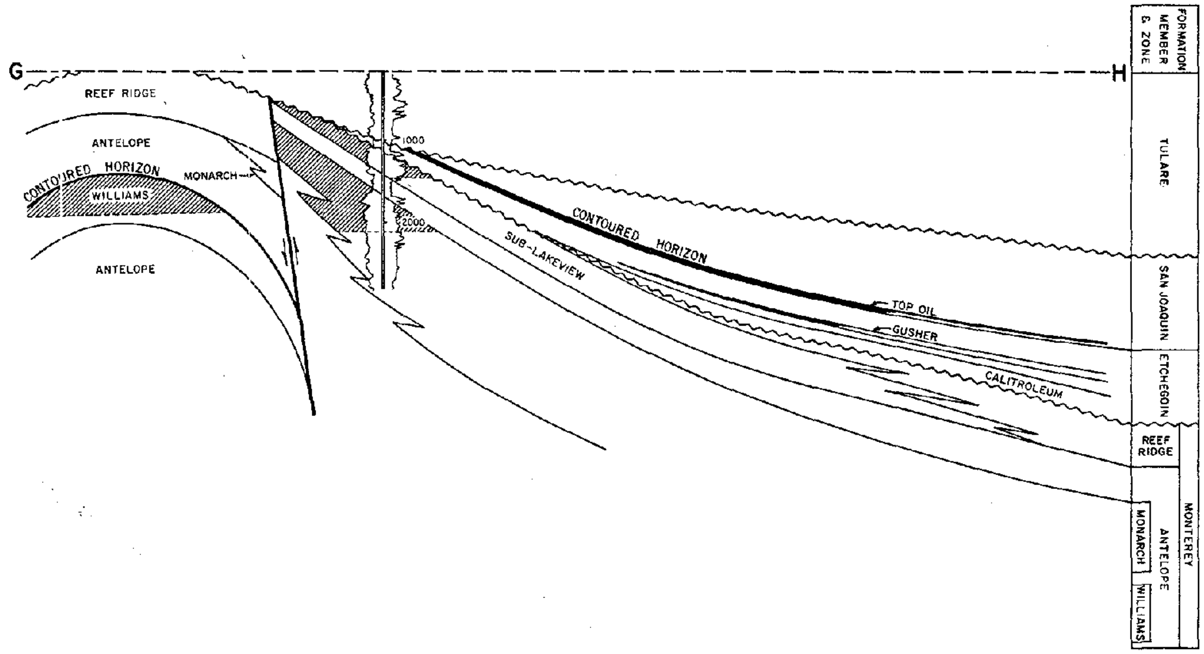


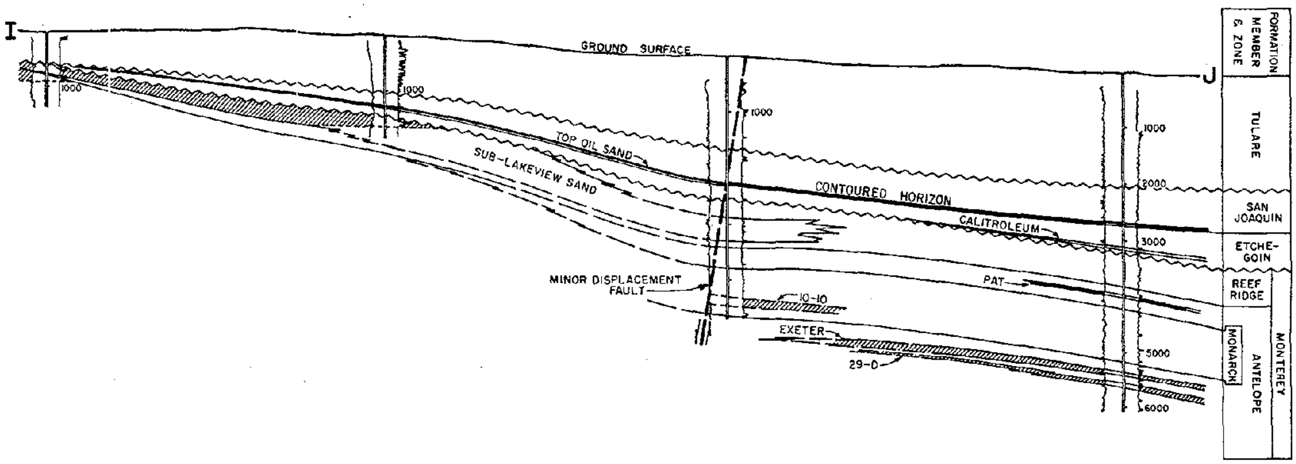


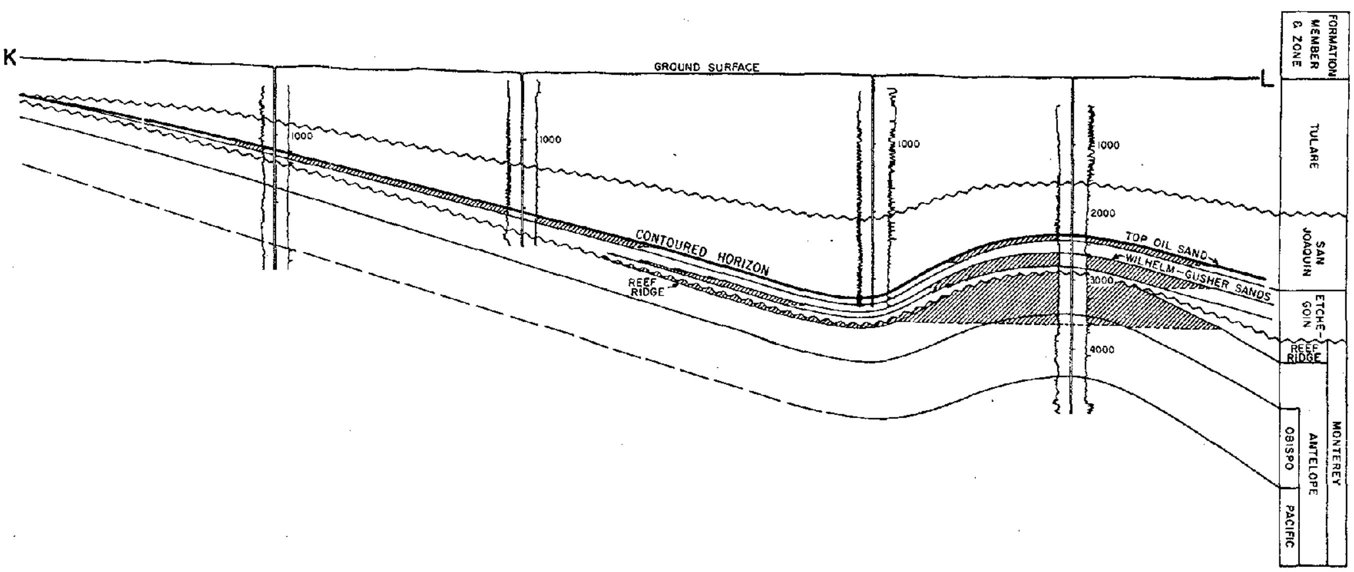




MIDWAY-SUNSET OIL FIELD







CALIFORNIA DIVISION OF OIL AND GAS

MIDWAY-SUNSET OIL FIELD

LOCATION: Vicinity of Taft, about 28 miles southwest of Bakersfield

Kern and San Luis Obispo Counties

TYPE OF TRAP: Regional homocline modified by: anticlines; anticlinal noses; lithofacies variations; angular unconformities; lenticular sands; fractured shales

ELEVATION: 600 - 1,750

DISCOVERY DATA

Zone	Present operator and well name	Original operator and well name	Sec. T. & R.	B & M	Initial daily production Oil (bbl)	Initial daily production Gas (Mcf)	Date of completion
Tulare	Operator name and well number unknown	Same as present	N.A.	MD	N.A.	N.A.	prior to 1894
Mya Tar	Getty Oil Co. No. 101	Associated Oil Co. No. 101	2 31S 22E	MD	10	N.A.	Jan 1920
Top Oil	Operator name and well number unknown	Operator name and well number unknown	N.A.	MD	N.A.	N.A.	N.A.
Kinsey	Same as above	Same as above	N.A.	MD	N.A.	N.A.	N.A.
Wilhelm	Same as above	Same as above	N.A.	MD	N.A.	N.A.	N.A.
Gusher	Chanslor-Western Oil & Dev. Co. No. 2	Chanslor-Canfield Midway Oil Co. No. 2 [A]	6 32S 23E	MD	3,000	N.A.	Nov 1909
Calitroleum	Operator name and well number unknown	Same as present	N.A.	MD	N.A.	N.A.	N.A.
Lakeview and Sub-Lakeview	Mobil Oil Corp. "Lakeview" 1	Lake View Oil Co. [B] No. 1	25 12N 24W	SB	68,000	N.A.	Mar 1910
Potter	Exeter Oil Co. Ltd. "Exeter-BAOC" 101-15	Dominion Oil Co. No. 1	15 31S 22E	MD	100	N.A.	Jan 1910
Marvic	Mobil Oil Corp. "Marvic" 1	Marvic Associates Ltd. No. 1	16 31S 22E	MD	72	N.A.	May 1941
Monarch	Standard Oil Co. of Calif. "Monarch" 28	Sunset-Monarch Oil Co. No. 1	2 11N 24W	SB	N.A.	N.A.	about 1902
Webster	Directors Oil Co. No. 7	Ruby Oil Co. No. 7	2 11N 24W	SB	35	N.A.	Dec 1913
Moco	Mobil Oil Corp. "Moco 35" WT 504	General Petroleum Corp. "Moco 35" 204	35 12N 24W	SB	188	20	Jul 1957
Obispo	Union Oil Co. of Calif. "Obispo" 6	Obispo Oil Co. No. 6	32 12N 23W	SB	6,000	N.A.	Sep 1925
Pacific	Mobil Oil Corp. "Pacific" 4	General Petroleum Corp. "Pacific" 4	32 12N 23W	SB	1,078	N.A.	Jun 1947
Metson	Tenneco Oil Co. "Metson" 47-24	Bankline Oil Co. "Metson" 47-24	24 11N 23W	SB	27	0	Mar 1953
Leutholtz	Gulf Oil Corp. No. 2 - "I.M. Woodward USL"	Western Gulf Oil Co. No. 2 - "I.M. Woodward USL"	21 11N 23W	SB	1,021	120	Aug 1945
Republic	Shell Oil Co. "Sec. 8" 25	Republic Petroleum Co. No. 25	8 32S 23E	MD	1,114	350	Mar 1928

Remarks: [A] First of over 100 gushers in field and is the first significant production from the Gusher zone.
[B] "America's Most Spectacular Gusher" blew out and flowed uncontrolled for 18 months after which the flow stopped probably because the bottom of the hole caved in. It was estimated that the early flow rate was about 68,000 b/d and that production amounted to 8-1/4 million barrels oil of which 3-1/2 million barrels was lost by evaporation and seepage.

DEEPEST WELL DATA

Present operator and well name	Original operator and well name	Date started	Sec. T. & R.	B & M	Depth (feet)	At total depth Strata	At total depth Age
The Superior Oil Co. "C.W.O.D." 58-21	Same	Nov 1957	21 32S 23E	MD	14,504	lower Santos	early Mio

PRODUCING ZONES

Zone	Average depth (feet)	Average net thickness (feet)	Geologic Age	Geologic Formation	Oil gravity (°API) or Gas (btu)	Salinity of zone water gr/gal	Class BOPE required
Tulare	200-1,400	50-200	Pleistocene	Tulare	13	200-1,000	None
Mya Tar	1,100	150	Pliocene	San Joaquin	12	260	None
Top Oil	500 - 2,500	20 - 50	Pliocene	San Joaquin	15 - 23	1,490 - 2,160	None
Kinsey	2,000 - 3,600	15 - 175	Pliocene	Etchegoin	14 - 26	1,500 - 1,860	None
Wilhelm	2,000 - 3,000	100	Pliocene	Etchegoin	14 - 26	1,700 - 2,100	None
Gusher	2,000 - 3,000	75	Pliocene	Etchegoin	14 - 26	1,440 - 1,580	None
Calitroleum	1,500 - 4,500	80	Pliocene	Etchegoin	14 - 26	1,620 - 2,040	None
Lakeview	2,600 - 3,300	20 - 200	late Miocene	Monterey	21	1,670	None
Sub-Lakeview	400 - 3,100	10 - 300	late Miocene	Monterey	22	440	III
Potter	200 - 2,500	60 - 500	late Miocene	Monterey	14	5 - 400	None
Marvic	1,000	200	late Miocene	Monterey	13	40	None
Monarch	600 - 2,000	50 - 400	late Miocene	Monterey	13 - 17	50 - 1,300	None
Webster	1,500 - 1,800	50 - 250	late Miocene	Monterey	14	N.A.	None
Moco	2,150	70 - 450	late Miocene	Monterey	15	980	III
Obispo	3,600	50 - 1,500	late Miocene	Monterey	14 - 27	970	III
Pacific	3,700	50 - 300	late Miocene	Monterey	16	600	III
Metson	1,250	400	late Miocene	Monterey	8 - 12	790	None
Leutholtz	3,200	40 - 400	late Miocene	Monterey	15 - 24	550	III
Republic	1,300 - 4,900	150	late Miocene	Monterey	12 - 24	70	III

PRODUCTION DATA (Jan. 1, 1973)

1972 Production Oil (bbl)	1972 Production Net gas (Mcf)	1972 Production Water (bbl)	1972 Proved acreage	1972 Average number producing wells	Cumulative production Oil (bbl)	Cumulative production Gas (Mcf)	Peak oil production Barrels	Peak oil production Year	Total number of wells Drilled	Total number of wells Completed	Maximum proved acreage
34,579,424	5,810,674	66,810,031	24,370	5,549	1,157,831,025	500,583,802	34,579,424	1972	10,318	9,486	28,090

STIMULATION DATA (Jan. 1, 1973)

Type of project	Date started	Cumulative injection - Water, bbl; Gas, Mcf; Steam, bbl (water equivalent)	Maximum number of wells used for injection
Water flood	1954	20,838,718	15
Steam flood	1963	15,398,177	47
Cyclic-steam	1963	195,087,515	4,870
Air injection for a fire flood	1960	N.A.	24
Gas injection for pressure maintenance	1944	43,302,959	7

SPACING ACT: Does not apply except at extreme southeast end of field.

BASE OF FRESH WATER: None

CURRENT CASING PROGRAM: Various; depending on zone and location.

METHOD OF WASTE DISPOSAL: Percolation and evaporation sumps; during 1972, 6,222,115 bbl. of waste water was injected into 7 disposal wells.

REMARKS: In a report by W.L. Watts titled "Sunset Oil Claims" in the Calif. State Mining Bureau Bull. No. 3 (1894) mention is made of steam injection into a well in Sec. 21, T. 11N., R. 23W., S.B.B. & M to reduce the viscosity of the heavy oil so it can be pumped to the surface. Later application and refinement of this method of reservoir stimulation was a significant contributing factor toward attaining the peak oil production in 1972.

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APPENDIX C: CORE SAMPLE PROPERTY ANALYSIS REPORT

516 E. 18TH STREET BAKERSFIELD CALIFORNIA 93305 805/324-4915

RECEIVED
JUL 2? 1979
OFFICE OF
RICHARD C. RUSSELL, JR.

CORE LABORATORIES, INC.

July 17, 1979

Century Oil Management, Inc.
P. O. Box 5113
Oildale, CA 93308

Attention: Mr. Gerald Muth

Subject: Core-Analysis Data
Sec 26 #3W Well
Midway Sunset Field
Kern County, California

Gentlemen:

Percussion type sidewall core samples recovered from the subject well were submitted to our Bakersfield laboratory for analysis. The results of these analyses are presented in the accompanying report with a general lithological description of the samples. The sample weights are also reported in order that these data may be taken into statistical account in evaluating the sampled intervals.

We sincerely appreciate this opportunity to serve you and hope these data prove beneficial in the evaluation of your reservoir.

Very truly yours,

CORE LABORATORIES, INC.

James A. Cusator

James A. Cusator
District Manager
California Professional Engineer
P-1176

Enclosures
JAC:smc

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

CORE ANALYSIS REPORT

FOR

CENTURY OIL MANAGEMENT INC.

#26-3W
MIDWAY SUNSET
KERN,CALIFORNIA

CORE LABORATORIES, INC.
Petroleum Reservoir Engineering
DALLAS, TEXAS

PAGE 1

CENTURY OIL MANAGEMENT INC.
#26-3W
MIDWAY SUNSET
KERN,CALIFORNIA

DATE : 16-JUL-79
FORMATION :
DRLG. FLUID: WB
LOCATION : SEC. 26-T32S/R23E

FILE NO : BP-1-8364
LABORATORY: BAKERSFIELD
ANALYSTS : DK BB
ELEVAION : 700'MAT

SIDEWALL CORE ANALYSIS

REC IN	DEPTH	PERM MD	POR %	OIL% PORE	WTR% PORE	O/W RATIO	SAMPLE WEIGHT	API OIL	DESCRIPTION
1.8	70.0	1394.	19.8	16.3	53.2	0.31	15.55		SD;FT BRN,F-CGR,SLTY,LSTN,GLD FLU
1.8	75.0	43.	22.0	12.9	80.0	0.16	15.51		SD;GY-BRN,VFGR,SLTY,CLY LAM,LSTN,GLD Fl
1.7	80.0	268.	23.5	22.3	55.3	0.40	17.50		SD;BRN,VF-FGR,CLY,LSTN,GLD FLU
1.6	85.0	1496.	29.1	11.1	62.2	0.18	12.98		SD;GY-BRN,F-CGR,LSTN,DGLD FLU
1.7	90.0	1384.	28.9	8.3	68.1	0.12	15.63		SD;LT-BRN,F-CGR,SLTY,LSTN,GLD FLU
1.4	95.0	1875.	35.8	3.7	78.0	0.05	11.93		SD;BRN,F-CGR,LSTN,DGLD FLU
1.6	100.0	2064.	32.5	6.3	65.3	0.10	13.21		SAME
0.8	105.0	2135.	28.7	4.0	70.0	0.06	3.55		SAME
1.5	110.0	14.	37.8	0.0	95.2	0.00	12.71		CLY;GY/CGR,NO STN,NO FLU
1.6	115.0	16.	27.9	7.5	84.1	0.09	13.65		SAME
1.0	120.0	18.	40.0	12.7	60.8	0.21	9.63		SD;GY-TAN,VF-CGR,SLT NOD,LSP STN,GLD FL
1.1	125.0	236.	29.9	10.0	57.7	0.17	9.81		SD;GY-BRN,F-CGR,SHLY,LSTN,GLD FLU
2.0	130.0	1261.	29.1	16.3	61.7	0.26	14.78		SD;BRN,VF-MGR/GRAN,DSTN,GLD FLU
1.1	135.0	1184.	34.2	14.0	51.7	0.27	8.08		SAME
1.6	140.0	1065.	28.7	13.5	64.7	0.21	12.21		SD;BRN,F-CGR,DSTN,GLD FLU
0.4	145.0	1389.	21.3	11.1	55.6	0.20	2.81		SD;GY-LT BRN,F-CGR,LSTN,DGLD FLU
1.6	150.0	1268.	30.6	13.6	62.5	0.22	12.50		SD;BRN,F-MGR,SLTY,DSTN,GLD FLU
0.9	155.0	1343.	35.1	25.0	60.2	0.42	6.04		SAME/PBLE
1.1	160.0	1486.	29.0	11.9	62.9	0.19	10.90		SAME/PBLE
2.0	165.0	1561.	31.9	8.3	58.8	0.14	18.05		SD;BRN,F-CGR,DSTN,GLD FLU
1.7	170.0	2084.	28.4	26.8	44.6	0.60	15.74	11	SAME
1.6	175.0	1931.	31.9	13.3	69.1	0.19	12.01		SAME
1.0	180.0	2261.	28.3	15.5	59.2	0.26	5.13		SAME
1.4	185.0	1954.	26.1	34.0	37.4	0.91	11.61		SAME
1.8	190.0	1722.	27.1	16.3	47.4	0.34	14.44		SAME
1.6	195.0	1736.	35.9	13.4	59.3	0.23	13.81		SAME,SLTY,CLY,DSTN,DGLD FLU
1.7	200.0	2496.	34.1	24.2	47.9	0.50	13.62	10	SD;BRN,F-MGR,DSTN,GLD FLU
1.1	205.0	1893.	31.8	11.8	68.2	0.17	5.54		SD;GY-BRN,F-CGR,LSTN,DGLD FLU

CORE LABORATORIES, INC.

Petroleum Reservoir Engineering

DALLAS, TEXAS

PAGE 2

CENTURY OIL MANAGEMENT INC.
#26-3W

DATE : 16-JUL-79
FORMATION :

FILE NO : BP-1-8364
LABORATORY: BAKERSFIELD

SIDEWALL CORE ANALYSIS

REC IN	DEPTH	PERM MD	POR %	OIL% PORE	WTR% PORE	O/W RATIO	SAMPLE WEIGHT	API OIL	DESCRIPTION
1.5	210.0	1906.	30.4	12.8	65.2	0.20	12.80		SD;BRN,F-MGR,DSTN,GLD FLU
1.7	460.0	165.	52.2	8.9	76.8	0.12	9.53		SD;BRN,F-CGR,CLY PBLE,DSP STN,SP GLD FL
1.8	465.0	223.	47.7	11.5	65.9	0.17	10.42		SAME
0.7	470.0	206.	38.1	11.7	70.0	0.17	8.94		SD;GY-BRN,VF-CGR,SLTY,LSP STN,SP GLD FL
0.7	475.0	29.	35.0	12.0	64.0	0.19	5.70		CLY;GY/BRN SD,DSP STN,SP GLD FLU
1.5	480.0	163.	43.7	15.0	64.3	0.23	12.91		SD;TAN,F-CGR,CLY PBLE,DSP STN,SP GLD FL
1.5	485.0	269.	47.7	14.5	67.3	0.22	9.97		SAME
1.6	490.0	304.	46.8	19.5	64.0	0.30	12.93		SAME
1.7	495.0	21.	34.9	0.9	88.7	0.01	12.67		SLTSTN;GY-TAN,CGR,LSP STN,SP GLD FLU
2.0	500.0	18.	39.9	2.8	85.1	0.03	13.34		CLY;GY-TAN/SLSTN INCL,LSP STN,SPGLD FLI
1.7	505.0	869.	46.4	18.2	60.1	0.30	13.22		SD;BRN,F-VCGR,SLTY,DSTN,GLD FLU
2.0	510.0	349.	50.8	14.4	71.5	0.20	12.09		SAME/CLY PBLE
1.0	520.0	906.	32.1	32.3	36.5	0.89	12.13	13	SAME
1.1	525.0	231.	49.4	15.1	70.7	0.21	13.91		SAME/CLY PBLE
1.2	530.0	106.	46.2	13.4	73.6	0.18	11.44		SAME/CLY PBLE
1.7	535.0	27.	39.8	6.6	70.7	0.09	10.80		SLTSTN;GY-TAN/PBLE,LSTN,SP GLD FLU
2.0	540.0	42.	39.6	14.6	73.0	0.20	12.81		SD;LT-BRN,VFGR,CLY,DSTN,GLD FLU
1.8	545.0	36.	36.5	7.6	71.4	0.11	11.80		SLTSTN;TAN/VCGR,LSTN,GLD FLU
1.9	550.0	10.	36.5	0.4	74.2	0.01	12.61		CLY;GY/CGR,VLSP STN,VSP GLD FLU
1.0	555.0	364.	39.7	17.7	51.8	0.34	7.70		SD;GY-BRN,F-CGR/VHVY SH LAM,DSTN,GLD FL
1.5	560.0	293.	40.0	18.4	66.1	0.28	14.40		SD;GY-BRN,F-VCGR,SLTY,DSP STN,SP GLD FL
1.4	565.0	566.	47.2	22.6	46.5	0.49	7.95		SD;BRN,F-MGR,CLY INCLS,DSTN,GLD FLU
1.0	570.0	1269.	43.0	35.5	39.1	0.91	13.78	12	SD;BRN,F-MGR,CLY,DSTN,GLD FLU
1.8	575.0	8.3	32.9	0.0	91.5	0.00	12.66		SH;GY,NO STN,NO FLU
1.7	580.0	6.8	33.4	0.0	92.4	0.00	14.00		SAME
1.6	585.0	13.	53.3	7.4	83.5	0.09	6.44		SLTSTN;TAN,SHLY,DIAT,LSTN,GLD FLU
1.7	590.0	11.	55.1	6.8	87.1	0.08	7.76		SAME

APPENDIX D: MINING TEST LOG

D.1 Mining Test Log

Following is the log book of the field operations. The eleven columns of data are:

(1) The cutting jet nozzle pressure,

(2) The turntable rotational rate,

(3) The depth of the cutting jet,

(4) The vertical increment of the jet cutting pattern,

(5) The rotational arc of the cutting jet,

(6) The jet pump primary nozzle pressure,

(7) The slurry discharge flow rate,

(8) The solids concentration in the slurry discharge,

(9) The mass flow rate of solids in the slurry discharge,

(10) The tons of oil sands in each slurry discharge tank, and

(11) The slurry tankful number.

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
Site Surveyed on 7-23-79											
7-24-79 NOZZLE DIAMETER 0.747											
	Installed tool in Borehole 1. Halliburton on site, connected and ready to start-up at 3:00 p.m.										
3:00 p	Start-up for shake-down run. No pressure on jet pump. Looks like sections are misconnected. May be one bolt-hole off on section connection, allowing jet pump water into cutting jet passage.										
6:00 p	Shut down, pumped some solids, 5 to 10 percent, very low flow.										
7-25-79 NOZZLE DIAMETER 0.747											
8:00 a	Started up to check tool connection. With jet pump on, only water flowed out cutting jet pipe. Pressure on both sides equal, indicating a misconnection. Pulled tool and found one connection off one bolt-hole. Reinstalled tool.										
3:00 p	Start-up.										
3:00 p	400	8	150		360	750		15			
3:15 p	400	8	150		180	450		8			
3:30	Shut down for Halliburton to change hose.										
3:45	Off	8	150		360	750		30			
4:00	Off	8	150		360	750		35			
4:15 p	Off	8	150		360	750		38			
4:30 p	Off	8	150		360	750		35		26.24	#1

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
4:30 p	Shut down. Pumped very high solids for 45 minute run. Filled one tank. Halliburton cannot supply 750 psi continuous from one pump. Gearing not the same as Wyoming. Pumpers will bring out second pumper tomorrow.										
4:30 p	Swabbed out water well, water at 470 feet level, oil and water pulled out.										
	7-26-79 NOZZLE DIAMETER 0.747										
9:30 a	Halliburton connected second pumper.										
9:30	Start-up, water leak, shut down to tighten connection.										
10:15	250	12	125		360	750					Start-up
10:30	250	12	135		360	750		12			
10:40	Blew hydraulic hose on turntable. Shut down to repair. Very hard rotation, material, probably rocks, around tool.										
10:45	Could not pick up water in water well.										
10:55 a	Hydraulic hose repaired.										
	100	12	135		360	750		18			
11:05	100	12	128		360	750		9			
11:05	Trying to get tool on bottom, but turntable stops turning. Sand sloughing in. Must pull up to get turntable to turn. Losing hole at times.										
11:15	Cutting jet off, sand coming in, burying tool.										
11:15 a	0	12	126			750		18			

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
11:25 a	0	12	128			750		17			
11:25	Trying to mine down, backflushing.										
11:35	100		126		180	750		14			
11:35	Problem with antirotation beam. Stopped rotation to tighten cables.										
11:50 a	100	12	126		180	750		16			
	Trying to get to 140 feet. Will not mine down.										
12:00 n	100	12	123		360	750		13–19			
	Have to raise miner to keep rotation. When we raise miner, we can't get back down.										
12:15 p	100	12	123		360	750		17			
12:15	Trying to mine down to 135'. Using backflush valve to agitate sand.										
12:45	Switched tanks.									40.95	#2
1:00 p	100	12	122		360	800					
1:15 p	100	12	122		360	750	Still losing ground.				
1:30	100	12	121		360	750		8			
1:30	Still losing ground. Can't get tool to go down.										
2:05	100	12	121		360	750	Clearing out tank #2				
2:10 p								12			

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
2:15 p	100	12	121		360	750		16			
2:30	100	12	121		360	750		15			
	Rotating tool to the left. Do not lose as much hole if rotation is to the left.										
2:35	100	12	121		360	750		5			
2:40	100	12	121		360	750		17			
3:15	Lost hole up to end of Kelly. Got back down to 120'. Cable on crane blocks twisted.										
3:30 p	Shut down. Pulled Kelly and swivel.										
	7-27-79 NOZZLE DIAMETER 0.747										
7:00 a	Took out second Kelly section (20'). Will go in with 22' Kelly to try and clean out hole.										
9:00	Measured tank and switched to right tank.								13.99	34.97	#3
	Tighten nipples on swivel. In hole with 122 feet total.										
10:00	Start up. Mining at 118'. Try to get to 122'.										
10:15	100	15	118		360	750		10-15			
10:30	Rotating to the right.										
10:45	180	15	120-121		360	750		5-19			
11:00	500	8	120		180	1000		10			
11:30 a	500	8	120		180	1000					

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	
12:00 n	500	10	120		180	1000		5-15	Looking good.		
12:30 p	Switched slurry tanks.										
12:45	Measured tank.								16.23	40.58	#4
1:15	500	8	119		180	1000		8-16			
1:15	Rotation very hard. Still losing depth in hole.										
1:30	500	8	118	up	180	1000		9-18			
1:45	500	8	118		180	1000		6-13	Rotation hard at times.		
	Have to use backflush valve to help clear sand from bottom of miner.										
2:15	500	10	117		180	1000		5-12	Looking good		
2:35	Change tanks.										
3:00	Measured tank.									46.5	#5
	500	12	118		180	1000		6-16			
3:45 p	Shut down.										
7-30-79 NOZZLE DIAMETER 0.747											
8:00 a	Halliburton took one truck over weekend. Hooking up second truck. Battery on crane not charging. Welder from Hale to weld cap on conductor. Cut drain holes in tanks.										
8:30 a	Got down to approximate 110'. Bottom of casing is 108'. Has caved in to top of casing.										

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
8:30 a	Put 3-foot extension on de-airing tank.										
10:00	Start-up. Down to 114'. Can't get any deeper.										
10:30	400	10	114		180	1000		18			
10:45	600	10	114		180	1000		5-16			
11:00 a	Rotation very hard. Down to 114 feet, cannot get down any deeper.										
11:30	600	10	114		180	1000		5-15			
	Surveyor on location.										
11:35 a	Change slurry tanks.									44.0	#6
12:00 n	600	10	114		180	1000		5-12			
12:10 p								3-8			
12:30	600	10	113		180	1000		2-7	Solids very low.		
	Still losing hole.										
1:00	Shut down. Not getting any solids. Cutting jet in shoe of casing. Pull miner.										
3:00 p	Out of hole.										
	8-13-79 NOZZLE DIAMETER 0.747										
	Installed tool in Borehole 2.										
9:30 a	Start-up. No backhoe.										

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
9:45 a	100	0	120		0	500	Halliburton having trouble getting up to pressure.	0-22			
	Pumped down from 110' to 128'. Pulled up, shut down.										
9:50 a	Down. Must get another Halliburton truck from Bakersfield.										
1:20 p	Start up. Pump down to 145'.										
1:45	Down to 145'					800		0-30			
2:10	Start mining.										
2:15	500	8	145	0	180	800		17			
2:15 p	Solids very low. Pumping down.							0-3			
2:25	600	8	145	0	180	1300		17-23	Looking good.		
2:35	600	8	145	0	180	1000		4	Solids low.		
2:40	600	8	140	Raised up to 140'.				18	Solids		
2:45	Mine back down to 145'.							21			
	Mining at 360°. Try to mine out a sump.										
3:00	Down to 145'.										
3:00	500	12	145	2	360	1000		14			
3:00 p	Switched tanks. Measured tank.									34.37	#7

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
3:20 p	500	8	145	2" up	180	1000	Solids very low.				
3:40	500	8	135		180	1000		3-5			
3:50	Halliburton down to repair leak. Pulled up to 130'.							6			
3:55	Start up again.										
4:10 p	500	8	126	2" down	180	1000		3-8			
4:20	500	8	132	2	180	1000		5			
4:30	1000	8	135	2	180	1000		0			
4:32	0	0	135	0	0	1000		0			
	Pumped hole down, full of water.										
4:50	0	0	135	0	0	1000		0	Pumping down.		
5:05	Down. Can't pump hole down.										
5:30	Pumping down.										
6:15 p	Shut down.										
8-14-79 NOZZLE DIAMETER 0.747											
7:00 a	Pull tool out of hole.										
12:00 n	Back in hole.										

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
12:45 p	Start up.										
	100	12	130		360	1000		0			
	Mined up and down from 124' to 142'.										
1:00	600	12	135	3" per min.	360	1000		10-20			
1:15	Working tool up and down to clear out cavity in bottom of hole. Solids improving.										
1:30	600	10	131	2	360	1000		14			
1:45	500	10	133	2	360	800		14			
2:00	500	10	136	2	360	800		17			
2:15 p	500	12	138	Down	360	800		10-13			
2:30	500	12	139		360	800		12			
2:45	400	12	139	Up	360	1000		5-8	Pulling up and mining down.		
3:30	400	12	140	On Bottom	360	800		5-15			
3:40	100	12	140		360	800	Trying to pump water from hole.				
3:40	Switch tanks and measure.									39.90	#8
3:50	400	10	140	0	180	800		2			
4:15 p	400	10	138	2	180	800		7			

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
5:20 p	400	10	138		180	1100					
6:30 p	Union leaking on swivel. Dropped pump pressure and fixed.										
7:30	O-ring on bottom of swivel leaking. Tightened allen bolts. Seems to have quit.										
8:00	Start.										
8:15 p	The union bushing on jet line started leaking. Removed and retaped.										
9:10	Switched tanks and measured.									39.84	#9
9:45	500					800					
10:30 p	Pulled to 122' and mining down.							1-5			
10:30	200	8	132	2	180	900		3-7			
11:15	Take out 20' of tool. Will try to mine in the upper zone. Lower zone is producing very little sand.							2-3			
11:45 p	Kelly section on.										
12:00 m	Down to relevel rotary table.										
	8-15-79 NOZZLE DIAMETER 0.747										
1:00 a	Start up.										
	400	10	121		360	900		0			

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	
1:30 a	500	8	115		360	900					
	Mining up to 108' to 120'.										
2:00	Turntable motor quit, down to repair.										
3:15	Got turntable started.										
3:30 a	Start up.										
6:00 a	Shut down to position hoses.										
6:10	Start										
7:40	Down. Diesel engine refueling (ran out).										
8:15	Start. Down time on trucks was 25 minutes.										
8:58	Down. Pumping truck lost pressure due to supply pump not keeping up.										
11:30 a	Put on 20 foot section. Going back down to 140 feet.										
12:00 n	500	10	140		360	1300		15-20			
12:30 p	Switched tanks and measured.									42.16	#10
	Sand coming in much better.										
12:30	500	10	136		360	900		12-20	Looking better.		
1:00 p	Halliburton out of water. Shut down to fill tank.										

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	
1:20 p	Start up.										
1:30	200	10	135		360	1000		10-20			
2:30 p	Shut down. No water in 500-foot well. No water in 150-foot well. Samples taken from borehole. Pulling tool to change nozzle size to 0.620.										
8-16-79 NOZZLE DIAMETER 0.620											
	Found hole through slurry pipe into jet pump primary water supply in one 20-foot section. Original weld leaked and pipe eroded away. Jet pump primary water has been short circuiting. Probable reason for low solids. Installing 0.620" nozzle. Agitation jets (3) 0.188 @ 1000 psi = 97 Jet pump primary 0.700 @ 1000 psi = 449 Cutting jet 0.620 @ 1000 psi = 352 gpm 898 gpm										
7:00 a	Start putting tool back in hole.										
10:30	Running bailer in Borehole 1.										
11:00 a	Broke flapper door on bailer. Took to shop to repair.										
11:15 a	Ready for Halliburton.										
12:00 n	Start-up. Pumping down.										
12:30 p	900	12	140		360	1000	900	25			
12:30 p	Started bailer in Borehole 1.										
1:00 p	Changed tanks.									39.10	#11

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
1:15 p	800	12	140		360	1000		12			
1:45	800	12	140		360	1000		6-12			
2:00	800	12	140		360	1000		15-25			
2:10	100	12	138		360	1000	Try to pump down.				
2:10 p	Broke 3-inch pressure line on jet pump. Shut down to install new hose (2-inch high-pressure hose).										
3:15 p	Start-up. Pumping down.					1500					
	200	12	135	0	360	1500		0-2 No solids.			
4:05	Pump down.										
4:05	200	12			360	1500		15			
4:30	200	12			360	1500		15-20			
4:50	200	8			360	1500		10-15			
4:52	Changed tanks and measured.									42.00	#12
5:15	200	8	140		360	1500		12-18			
5:15 p	Shut down.										

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	
	8-17-79 NOZZLE DIAMETER 0.620										
7:30 a	Running bailer in Borehole 1. Rocks up to 3" in diameter. Down to 120'.										
8:00	200	12	125		360	1500		15-28			
8:20	200	8	130		180	1500		15-22			
	Trying to work down to 140'. Solids very high.										
8:30	When we work at 180^{o}, the sand and rock tend to fall in and we cannot keep the oscillation going. Back to 360^{o} to work our way down!										
8:30 a	200	12	133			1500		10-22			
9:00 a	200	12	135			1500		10-20			
	Changed tanks.									37.71	#13
10:15	Changed tanks.									36.00	#14
11:00 a	200	12		2	360	1500		10-20			
11:30 a	Changed tanks and measured.									34.92	#15
12:00 n	Halliburton down.										
12:10 p	Start up.										
12:30	200	12	130	Down	360	1300		10-15			
12:35 p	Halliburton down again.										

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
12:40 p	Start up.										
1:00 p	Shut down. Pump from pond to Bakertank will not supply enough water.										
	Change tanks.									32.76	#16
1:00	Tried to take water samples. No water in 700' or 150' water wells.										
1:30 p	Start up.										
1:40	Down to clean screen on water supply pump.										
2:10	Start up again.										
2:10	200	12	124	2	360	1300		10-20			
3:05 p	Changed tanks.									38.10	#17
4:00 p	200	12	132	2		1300		8-14		/	
4:15 p	Down. Halliburton. One engine overheating.										
	8-18-79 NOZZLE DIAMETER 0.620										
7:45 a	Start up.										
8:00	200	12	126	2	360	1500					
	Trying to pump down to 140'. Caved in to 126'.										
8:30 a	Switched tanks.									41.83	#18

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
8:30 a	500	12	129	2	360	1500		10-15			
10:45	Changed tanks. Swivel seal starting to leak. (52 hours of operation).									41.39	#19
11:00	200	12	124		360	1500		10-15			
11:30	The rock (or whatever) is caving in and starting to push us back out of the hole. Pumping water down and will try to get down further.										
11:45	200	12	126	Down	360	1500		3-5			
11:50 a	No solids. Jet off. Pumping down.										
12:30 p	Pumping down. No solids. Can't get down past 127 feet.										
12:50 p	Trying to pump down.										
1:00 p	Shut down to pull tool.										
	Pulled tool from hole. Found two sections with holes washed out.										
	8-19-79 NOZZLE DIAMETER 0.620										
	Day off.										
	8-20-79 NOZZLE DIAMETER 0.620										
7:00 a	Weld holes in typical sections. Change cutting nozzles. Run sections back in hole to 120'. No water in 750' or 150' water wells.										

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
8-21-79 NOZZLE DIAMETER 0.620											
7:00 a	Waiting on Halliburton.										
7:30	Start up. Blew high-pressure hose. Down. Took out one 25' section of hose and replaced with pipe from Halliburton. When hose broke, it destroyed controls on motor that drives turntable. Took controls off pump and replaced on turntable.										
7:40	Start up. Broke another hose. Down again.										
	Sent Halliburton home. Blew seals in swivel. Changed seals in swivel.										
8-22-79 NOZZLE DIAMETER 0.620											
7:00 a	Took photos of unit in operation for Century Oil.										
9:00 a	Started back in hole.										
12:30 p	Start up.										
12:30 p	700	8	120	0	180	1500		10-20			
12:45 p	700	8	120	0	180	1500		5-8			
1:00 p	300	10	120	0	360	1500		5-8			
	Raising up approximately 110' and down to 120'.										
1:15 p	300	10									
1:20 p	1000	10	110	2	360	1500		3-6			

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
2:00 p	500	10	115		360	1500		3-10			
2:30	500	10	120		360	1500		2-5			
3:00	2500	12	106-116	2	360	1500		2-5			
	Can't get down below 116'. Trying to get back to 120'. Working up and down with 2500 psi on jet.										
4:00 p	2500	8	106-118	2	360	1500		0-2			
	No solids. I do believe we have found some "rocks".										
	Shut down.										
8-23-79 NOZZLE DIAMETER 0.620											
7:00 a	Came out of Borehole 2. Change turntable back to Borehole 1. Went into Borehole 1 with miner.										
1:00 p	Waiting on Halliburton.										
1:30	Fill hole with water.										
1:45 p	Pumping out water. 9-10 inches of water height (1000 gpm).										
	500	0	105	0	0	1500		0			
2:15 p	500	10	110		360	1500		0			
2:25 p	200	8	112		360	1500		10-15			
2:35 p	Change tanks and measured (first time in days).									42.85	#20

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
2:45 p	200	8	116		360	1500		15-22	All right.		
3:00	200	8	116		360	1500		10-20			
3:15	200	8	116		360	1500		10-20			
3:35	Change tanks. One hour run on this tank.									44.64	#21
4:00	300		110	2	360	1500		6-12			
4:15	300	115	2	360	1500		10-20				
4:45	Change tanks and measure.									44.54	#22
5:15	Solids dropping off.										
5:30	200	8	114	2 (up & down)	360	1500		8-12			
6:15	Change tanks. Top seal leaking.									38.41	#23
6:20	Halliburton lost an engine. Shut down. Ran out of diesel.										
7:15 p	Start up										
7:15	200	10	112		360	1500		Low			
8:10 p	Shut down. Pump out hole for last 20 minutes.										
8-24-79 NOZZLE DIAMETER 0.620											
6:30 a	Start up.										
	1000	10	112		360	1500		2-5			

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
6:45 a	Trying to get down to 120 feet. Solids very low; seal leaking very bad; cannot pump down.										
7:00	0	12	112		360	1500		2-5			
7:15	0	12	113		360	1500		5-8	Cannot pump down.		
7:30	0	12	113		360	1500					
7:40	200	12	112		360	1500	Pump down.				
8:00	Change tanks.									40.35	#24
8:15	0	12	115		360	1500		0			
8:30	200	10	112		360	1500		3-8			
8:45	200	6	114		360	1500		3-8			
	No water in 750' or 150' water wells.										
9:15	We have mined up - we have mined down - we are getting no solids!										
10:15 a	1500	4	114		360	1500		0			
	We're getting no solids.										
10:30 a	Got tired. Shut down.										

MINING TEST LOG

TIME	CUTTING					PUMPING				OTHER	
	Nozzle Pressure (psi)	Turntable Speed (rpm)	Depth (ft)	Vertical Step (in)	Mining Arc (deg)	Nozzle Pressure (psi)	Discharge Flow Rate (gpm)	Percent Solids (%)	Mining Rate (tph)	Slurry Tank (tons)	Tank Number
9-4-79 NOZZLE DIAMETER 0.620											
12:30 p	On location. One man from Hale & Son. Took miner out of Borehole 1 and lay down.										
9-5-79 NOZZLE DIAMETER 0.620											
	Hale & Son, three men getting equipment ready to load on truck to ship to Kent.										
										34.38	#25
										15	Pond

Borehole 1: 467 tons

Borehole 2: 527 tons

Total: 994 tons

APPENDIX E: MINING COST ANALYSIS

E.1 Introduction

The following is a computation procedure for finding the capital costs, the operating costs, and the rate of return on investment for hydraulic borehole mining. Certain assumptions must be made to perform this analysis, and they are described in the main text. The computation procedure begins with ore body specifications and cost estimates for individual processes. After adding labor and other operating costs, the information for the rate of return calculation is generated. The rate of return is then found by the interval bisection method.

E.2 Cost Analysis

	Baseline Case
1. Recovery (% of ore in place) $\frac{\text{(mined area)}}{\text{(total area)}}$	55
2. Ore body requirements (kilotons/year) $\frac{\text{(tons per day)(days per year)}}{\text{(recovery)}}$	6,050
3. Ore body length required (ft./year) $\frac{\text{(ore body required)(ore density)}}{\text{(ore thickness)(ore width)}}$	256
4. Number of units required $\frac{\text{(mining capacity)}}{\text{(mining rate)(hours/day)(unit availability)}}$	18
5. Effective mining rate required (tons/unit/hr) $\frac{\text{(mining capacity)}}{\text{(number of units)(hours/day)(unit availability)}}$	38.6
6. Ore per borehole (tons) $\frac{\pi\ \text{(radius)}^2\text{(thickness)}}{\text{(ore density)}}$	23,169
7. Boreholes required (number/year) $\frac{\text{(annual milling capacity)}}{\text{(ore per borehole)}}$	142
8. Annual drilling cost ($K/year) (no. boreholes)(drilling cost)(depth + 20 ft.)	1,496
9. Capital cost of mining units ($K) (mining unit cost)(no. of units)	27,000
10. Cost of slurry and water lines ($K) (cost per unit)(no. of units)	270
11. Annual operating labor ($K/year) (labor/unit hr.)(no. units)(hr./year)	2,566
12. Annual support labor ($K/year) (annual operating labor)(ratio of support to operating)	642
13. Annual maintenance labor ($K/year) (operating labor)(ratio of maintenance to operating)	642
14. Annual supervisory labor ($K/year) (operating + support + maintenance)(ratio of supervisory to direct)	770
15. Total annual payroll ($K/year) (operating + support + maintenance + supervisory)	4,619

16.	Annual payroll benefits ($K/year) (percentage)(total annual payroll)	1,386
17.	Annual payroll overhead ($K/year) (percentage)(total annual payroll)	1,848
18.	Annual fuel cost ($K/year) (fuel cost/unit)(no. units)	1,800
19.	Total capital cost less working capital ($K) (plant + mining units + lines + exploration + miscellaneous)	64,270
20.	Annual taxes and insurance ($K/year) (percentage)(total capital cost)	1,285
21.	Annual maintenance supplies ($K/year	2,700
22.	Annual operating cost ($K/year) (payroll + benefits + overhead + ore transportation + tailings + plant + fuel + maintenance supplies + drilling + reservoir + insurance + miscellaneous supplies)	34,553
23.	Gross revenue ($K/year) (annual mine capacity)(value/unit of product) (units/ton of ore)	41,250 (at $25/bbl)
24.	Royalties ($K/year) (percentage)(gross revenue)	2,888
25.	Depletion base ($K/year) (gross revenue) - (royalties)	38,363
26.	Operating income ($K/year) (depletion base) - (annual operating cost)	3,809
27.	Depreciation of capital investment less working capital ($K/year) (capital investment) / (depreciation period)	6,427
28.	Taxable income before depletion allowance ($K/year) (operating income) - (depreciation)	-2,618
29.	Depletion allowance, lesser of: ($K/year)	0
	a) (percentage)(depletion base)	0
	b) (50%)(taxable income before depletion allowance) (must be greater than zero)	0
30.	Taxable income after depletion allowance ($K/year) (taxable income before) - (depeltion allowance)	-2,618

31.	Income tax ($K/year) (46%)(taxable income after depletion allowance)	-1,204
32.	Working capital (first year only)($K) (percentage)(gross revenue)	10,313
33.	Net cash flow, first year ($K/year) (operating income) - (income tax) - (working capital) - (capital investment)	-69,569
34.	Net cash flow, remaining years ($K/year) (operating income) - (income tax)	5,013

E.3 Rate of Return on Investment

The rate of return on investment to the end of the depreciation period is computed from the net present value (1). The rate of return is based on the net cash flow for each year. The net cash flow, R, is defined as the gross revenue less royalties, operating costs, taxes, and capital costs. The rate of return, i, over the depreciation period, n, is adjusted to make the net present value (PV) equal to zero:

$$PV = R_1(1 + i)^{-1} + R_2(1 + i)^{-2} + \ldots + R_n(1 + i)^{-n} = 0$$

For the mining cost analysis, all capital costs are assumed to occur during the first year. Hence,

$$R_1 = \text{net cash flow, first year}$$

$$R_2, R_3, \ldots, R_n = \text{net cash flow, remaining years} \quad .$$

The zero present value is found by the interval bisection method. Upper and lower values of rate of return are chosen such that the upper gives a positive present value and the lower gives a negative present value, thus surrounding the zero present value. The present value is then calculated at a rate of return equal to the average of the upper and lower rates of return, bisecting the interval. The new rate becomes either a new upper or lower value, depending upon whether the present value is positive or negative. The interval containing the zero present value is reduced in this manner until the rate of return is known to the desired accuracy.

1. Curtis, A. B. and Cooper, J. H. "Mathematics of Accounting," 4th Edition, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1961.