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Drainage Control at a Central Florida Open Pit Phosphate Mine

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INTRODUCTION

The application of gravity connector wells as a method of mine drainage control has been effective in improving the efficiency of ore yardage recovery and productivity at Watson Mine in Polk County, Florida. Open pit mining to depths greater than 50 feet deep without prior dewatering resulted in ore recovery from 40 to 60 percent. The affect of dewatering deep pit areas improved recovery to a range of 70 to 80 percent and increased production tonnage 20 percent.

GEOLOGY

The Bone Valley deposit lies east of Tampa Bay and underlies some 2,000 square miles of the coastal plain. Phosphate rock production from 11 companies in the field is approximately 35 million short tons annually.

The deposit is a deltaic shaped, shallow marine and estuarine sediment of pebble, sand and clay called matrix. It lies on the southwest flank of the Ocala Arch, which was significant to the occurrence and structural control of phosphate deposition during Miocene and Pliocene ages. (1) The ridge areas from Lakeland and Bartow to the eastern boundary are linear uplifts of the Central Highlands Flexure. (2) This region has a typical karst topography with chains of sinkhole lakes along the alignment of the ridges. Jointing and fault systems developed concurrently with the post-Miocene uplift activity. The surface features of sinkhole depressions and lakes are associated with subsurface patterns of structural adjustments on the Flexure. Swift Agricultural Chemicals Corporation operates two mines south of Bartow. Silver City Mine lies west of the karst region, but some of the Watson Mine property lies within the influences of the ridge-sinkhole region, see Figure No. 1.

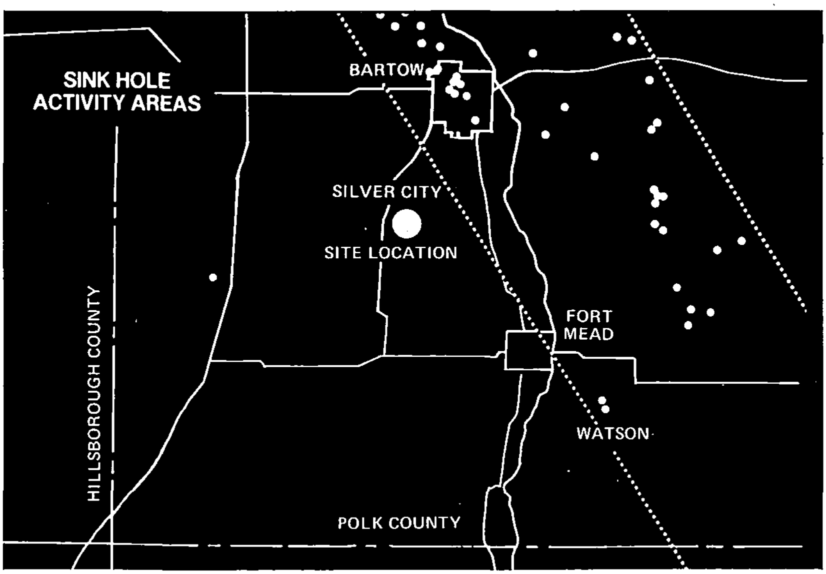

Figure No. 1
Sinkhole Activity

Mining Methods

Conventional mining practice in the phosphate field utilizes electric powered walking draglines with various boom lengths and bucket capacities to simultaneously strip overburden and mine matrix. The mining cut widths vary from 150 to 350 feet and range up to three quarters of a mile in length. In usual pit depths of 30 feet, dewatering is accomplished by waterjacks. The overburden is cast as a spoil into the adjacent mined out cut, see Figure No. 2. The matrix is stacked in a sump on the highwall where hydraulic monitors produce a slurry of 20 to 40 percent solids. The slurry is pumped to a processing plant where the gangue of sand and clay is separated from the phosphate particles. Mine planning for pit conditions in the karst terrain with thick overburden and deep pits is more complicated than planning layout in the shallow mining areas. The main concerns affecting productivity are pit slope stability, groundwater control and the influence of spoil volume on matrix recovery, see Figure No. 3.

Figure No. 2
Shallow Pit

Pit Slope Stability

The most important factor in the stability of the pit wall is the shear strength of the soil strata beneath the slopes. Soft clay layers, especially when inclined toward the pit face, are usually critical. Groundwater is also a very important factor. It not only reduces the weight of the soil through bouyancy, thus decreasing the frictional resistance of the soil, but seepage forces add to the gravity forces increasing the potential

Figure No. 3
Deep Pit

Figure No. 4
Slope Failure

for sliding. In cohesionless soil, below the groundwater level, the slopes tend to "flow" into the pit. In Figure No. 4, a series of circular slope failures, occurring as incremental slices into the pit wall, are a clear danger to the dragline operating near the edge of the pit.

Groundwater Control

Groundwater control is essential for the dragline operator to see the matrix and effectively recover all the matrix yardage in the cut. When water levels are high enough to cover the matrix, spotting the bucket for efficient matrix recovery is impossible. Also, the effective loading in the bucket is difficult as wet matrix falls from the bucket during hoisting from the pit.

Spoil Volume

When wet overburden is cast as a spoil in the adjacent mined out cut, the volume swells. In deep overburden areas the cut widths are changed from 350 down to 250 feet to reduce the spoil volume. This adjustment considers; 1) the effective reach of the dragline, 2) overburden and matrix slope ratios from engineering studies, and 3) an estimate of spoil slope. The amount of matrix yardage lost due to the respective slopes is calculated.

WATSON MINE STATISTICS

Table I relates the variable nature of overburden and matrix thickness, total depth, and the response of mining efficency as a percentage of tonnage recovery over a period of time. Shallow pit areas with 15 feet or less overburden and pit depths of 30 feet or less have the best mining recovery. The fiscal year 1973 illustrates the influence of deeper overburden and pits on recovery efficiency and production. Details are lost in year average data presented in this fashion. During 1973, a small dragline with a 14 cubic yard bucket mined the initial 5 months in a shallow pit deposit with 10 feet of overburden and 9 feet of matrix with a tonnage recovery of 89 percent. The large dragline with a 30 cubic yard bucket commenced mining during April, 1973 in a karst area that averaged 27 feet of overburden and 10 feet of matrix. However, as it included a few small sinkholes to 90 feet deep, the resulting average recovery was 53 percent.

Table No. I

Mining Statistics
Watson Mine, Swift Agricultural Chemicals Corporation

Fiscal Year	Over-Burden	Matrix	Total	% Tonnage Recovery
1970	15	15	30	75
1971	19	14	33	69
1972	14	13	27	78
1973	19	11	30	64
1974	26	15	41	58
1975	18	11	29	71
1976	21	14	35	64
1977	17	12	29	69
1978	22	11	33	65
1979	25	11	36	71

HYDROLOGY

Vertical turbine and submersible pump waterjacks are conventional methods of controlling groundwater seepage in the mine pits. However, at Watson Mine, the draglines have advanced into the karst terrain. In this locale, the pit bottom limestone, Hawthorne Formation, is the artesian Upper Floridan aquifer. Transmissivity through the aquifer averages some 2,200 square feet per day, but solution cavity development in the limestone causes wide fluctuations from that value. The altitude of the potentiometric surface from the limestone is sufficient to influence the surficial aquifer level in the overburden, particularily in the surface depressions underlain by sinkholes. Productivity is adversely affected as mining proceeds into sinkholes filled with thick, wet overburden and subject to the influx of artesian groundwater from the pit bottom limestone.

Through the efforts of the Swift operating personnel, the potentiometric surface of the Upper Floridan aquifer is being reduced in selected mining areas by gravity connector wells. The result has been dewatering of the surficial aquifer in the overburden and partial dewatering of the pit bottom limestone. In this case, the dewatered overburden was prestripped by scraper pans to a designed depth in preparation for mining.

KARST MINING TERRAIN

An aerial view of the mining area in the karst terrain of Sections 31 and 32, T31S, R26E is shown in Figure No. 5. Route U.S. 98 Highway is the east/west line along the north section line. The road turns south along the east section line of Section 32. Mining cut layout lines are superimposed as overlays on the aerial for mine planning purposes.

Mining in Section 32 commenced with the 30 cubic yard bucket dragline in April, 1973, but terminated in March, 1974 as the result of poor pit conditions and declining productivity. The dragline moved to a shallow pit area in Section 31. This photograph was made in 1976, the dragline is located in the left middle ground.

Connector Well Construction

Gravity connector dewatering wells are identified as dots on the aerial view. The three wells are located in Section

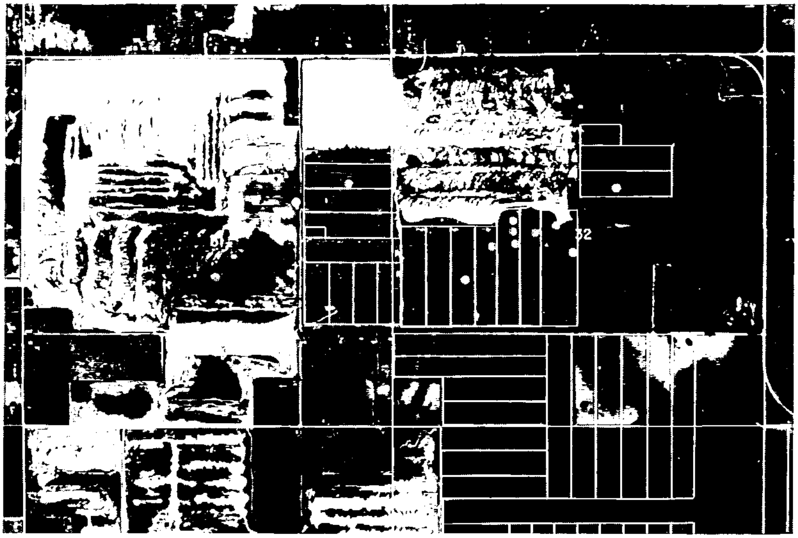

Figure No. 5
Aerial View Karst Terrain

31 in a line of sinkholes dewatered during the first experimental phase. The well in the center of the three was the initial test well, December, 1975, identified as Site 93 in the hydrologic studies by Hutchinson. (3) The construction of all the wells is by cable tool drilling. Casing used was standard black steel pipe, Api-5L, threaded, coupled and welded. As an example, at Site 93 an 8 inch hole is drilled and cased from the surface to 86 feet through the overburden and matrix, then seated in limestone. The 8 inch hole continued as an uncased hole through 30 feet of Hawthorne limestone intersecting several solution cavities. Underlying the Hawthorne is the Tampa Formation, a blue-green clay aquiclude 105 feet thick, which is cased off with a 6 inch pipe. The hole is continued as a 6 inch, uncased hole through the Suwannee and Ocala Group limestones into the dolomitic, cavernous Avon Park limestone. The hole bottomed at 855 feet. In January, 1976 the artesian water level in the Hawthorne stood at 33 feet below the surface, the artesian level of the Avon Park Limestone was 66 feet. Therefore, the artesian water of the Hawthorne limestone adjusts to the differential of 33 feet and flows by gravity into the Avon Park Limestone. By February 11, 1976, a monitor well into Hawthorne limestone

located 700 feet west of the connector well had dewatered 8 feet in 14 days.

Hydraulic Data

Before the initial well was drilled through the base of the Hawthorne, a pump test was conducted. Hydraulic data on a 200 gallon per minute test is as follows: Transmissivity at 8,800 square feet per day, hydraulic conductivity of 83 feet per day with a storage factor of 0.18×10^3. (3) A geophysics logging survey on the well in March, 1977 reported a gravity flow rate of 528 gallons per minute into the solution cavities of the Avon Park limestone.

FIELD PROBLEM

Based on the success of the principle of gravity dewatering in Section 31, a second site in Section 32 was selected. It is a sinkhole area of 28 acres located in the center of the section and the point where the large dragline terminated production in March, 1974.

On the surface, a depression of some 20 feet drop in elevation from the surrounding terrain is underlain by the sinkhole. It is of sufficiently low relief to have contained a 5 acre lake as recent as 1957. Underlying the depression was an average overburden of 33 feet and matrix thickness of 15 feet. Due to changes in pit bottom elevation in sinks, the overburden actually varied from 24 to 68 feet and matrix varied from 9 to 23 feet thick. Prospect tonnage and grade evalution identified 300,000 short tons of 73 percent BPL, calcium phosphate content. On Figure No. 5, the area is identified by the cluster of connector wells in the center of the section.

Surface Water Problem

The mined out cuts were flooded with rainfall and groundwater seepage since March, 1974. The water depth was estimated at 20 to 25 feet deep and high enough to cause a recharge into the overburden sands and matrix exposed along the highwall of the old pit.

Soil Engineering Test and Mine Cut Geometry

An engineering test conducted by Ardaman and Associates, Orlando Florida, of the soil in the overburden and matrix indicated a pit slope failure could occur due to the high watertable near the ground surface. The failure would occur behind the dragline as it stripped 68 feet of overburden and mined to an estimated depth of 100 feet.

Matrix Recovery

A graphic pit design shown in Figure No. 6, Exhibit I, indicated matrix yardage recovery would decline to 65 percent as slope angles would require 130 feet of horizontal distance under the highwall. Spoil stacking volume from excessive overburden depth would fill the mining cut and cause matrix loss along the base of the highwall. In Figure No. 6, Exhibit II, the above situation could be improved by dewatering and removing 20 feet of overburden which would reduce spoil volume and the horizontal distance of the pit slope. Prestripping was then planned by the use of scraper pans which would be available between dam building assignments.

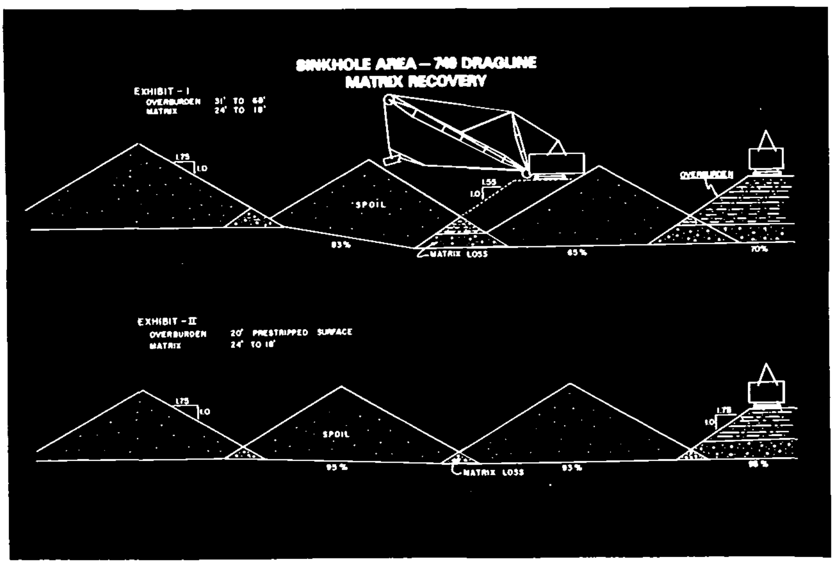

Figure No. 6
Graphic Pit Design

OPERATING PLAN

The surface water problem was the first to be eliminated. A 22 B Dragline was placed on a bench along the north side of the highwall. A ditch was dug combining the stored water of the east and west 1974 pits, which was pumped away with water-jacks.

Subsurface dewatering commenced in July, 1976 and by April, 1977, 8 connector wells had been drilled on the flanks and within the sinkhole. A 4 inch monitor well into the pit bottom limestone recorded a change in artesian head of the Hawthorne limestone from 34.4 feet in September, 1976 to 58.7 feet by May, 1977. Some 24 feet of water had been removed from the limestone under 14 acres in the center of the surface depression.

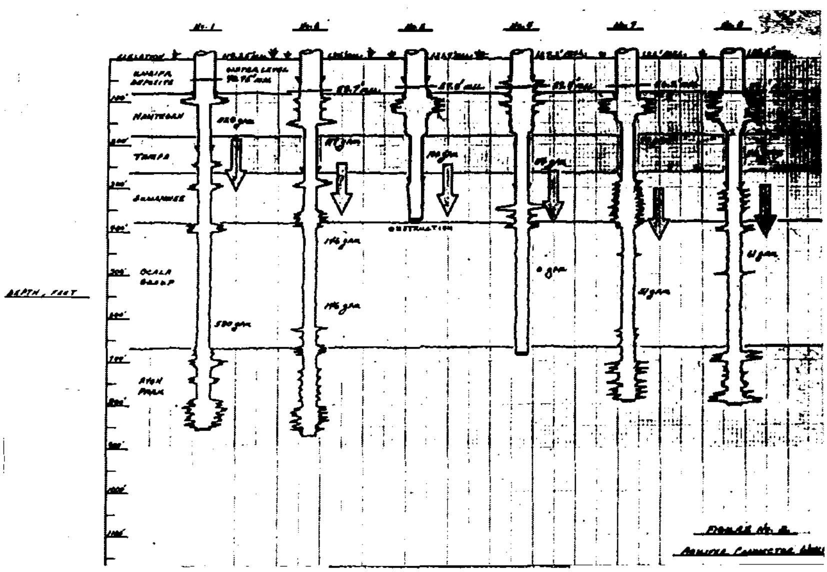

Figure No. 7
Geophysics Profile

Geophysics

The geophysics well surveys were conducted by CH2M Hill Inc. The well logs were run on 5 of the connector wells during the drilling project. The survey included electric, gamma ray, caliper, temperature, fluid conductance, and fluid velocity by the spinner flow meter. Water samples were collected at selected depths using a motorized depth sampler. The survey was designed to determine the hydrologic units penetrated by the wells, identify the dewatering and recharged zones, and determine the quantity and quality of the water flowing down the connector well from the Hawthorne limestone. Figure No. 7 shows the solution cavities in the Hawthorne limestone, a minor solution cavity development in the Suwannee limestone, and the solution cavities in the Avon Park limestone. The dewatering rates in this sinkhole ranged from 40 to 117 gallons per minute. Well No. 1, the initial well, was drilled in December, 1975.

Plugging Procedures

The connector wells were plugged within a week prior to the dragline advance through the well location. For example, the plugging record of well No. 6 as shown on Figure No. 7 is as follows: 20 feet of neat cement plugs were placed at intervals from 80 to 100 feet, at the contact of the matrix and pit bottom limestone, from 140 to 160 feet at the base of the Hawthorne, from 280 to 300 feet at the top of the Suwannee limestone, and 810 to 830 feet in the upper part of the Avon Park limestone. A clean limestone gravel backfill is placed between the cement plug sections and from 830 to 872 at the bottom of the hole.

Table II
Water Analysis (in ppm.)

pH	5.9	-	8.3	
P	1.8	-	0.25	
F	0.8	-	0.40	
SO_4	14.0	-	4.0	
NH_3	4.3	-	0.03	
Fe	0.06	-	2.0	(unfiltered)
Mg	8.6	-	6.5	
Ca	10.4	-	13.5	
K	0.9	-	0.2	
Na	2.3	-	2.5	
Cl	5.6	-	14.3	
Alkalinity as $CaCO_3$	20.0	-	70.0	

Water Quality

Table II represents the range of water quality analyses during the period March, 1976 to April, 1979 in 23 wells drilled to date.

These chemical analyses are reported monthly to the Southwest Florida Water Management District which permits the drilling, recording, and plugging of connector wells in the district.

Influence of Dewatering

The results of dewatering is shown in the profile on Figure No. 8. The change in artesian head from the Hawthorne limestone between October, 1976 to June, 1977 with respect to the elevation of the overburden, matrix and pit bottom limestone. Figure No. 9 is the sinkhole profile showing the change in the elevation of the watertable in the overburden. In order to speed up this natural dewatering rate, screened wells were installed in the overburden. Their influence is shown as cusps on the watertable surface. The screen sections were set at 35 to 55 feet below the surface specifically to dewater the overburden sands. Screen openings were in the range of 10 to 24 thousandths of an inch and reinforced with perforated PVC to permit cable tool drilling through the section into the Avon Park Limestone.

By March, 1977, the watertable had declined sufficiently to commence overburden stripping by scraper pans. In six weeks, 340,000 yards of dewatered overburden had been removed to an average depth of 15 feet.

MINING EXPERIENCE

When the dragline entered the west flank of the sinkhole in July, 1977, it walked and operated on the prestripped surface as easily as a natural ground surface. The watertable in the overburden had declined 38 feet below the original ground surface which was 23 feet below the prestripped surface.

Mining progressed through the sinkhole on plan as shown in Figure No. 5 from July through November, 1977. The matrix yardage recovered was 570,000 cubic yards at an 82 percent recovery. Directly over the deepest portion of the sinkhole,

GEOLOGIC CROSS SECTION OF AREA TO BE MINED

Section 32, Township 31 South, Range 26 East

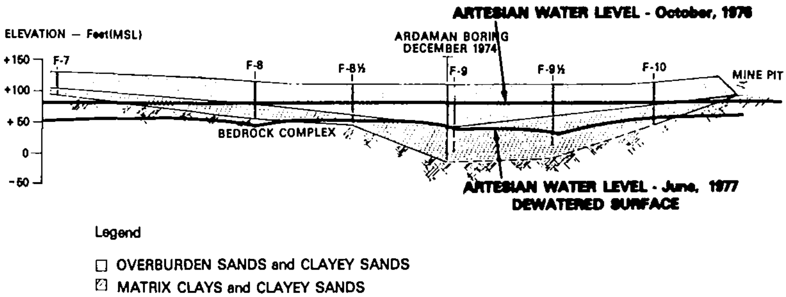

Figure No. 8
Reduction of Artesian Head

GEOLOGIC CROSS SECTION OF AREA TO BE MINED

Section 32, Township 31 South, Range 26 East

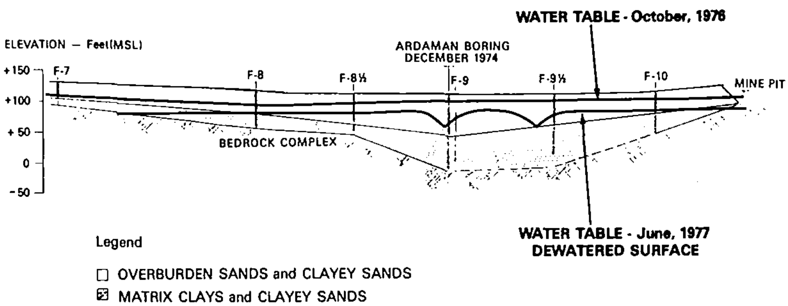

Figure No. 9
Reduction of Watertable

a 14 acre area, overburden after prestripping averaged 28 feet and matrix averaged 20 feet. In this specific area, matrix yardage recovered was 300,000 cubic yards at a 71 percent recovery.

During March, 1974, the pit condition entering the sinkhole caused mine production to decline from 17,000 to 10,000 short tons per week as tonnage recovery reduced from 48 percent to 32 percent. In July, 1977 at approximately the same location in the sinkhole, mine production was 19,500 short tons per week as tonnage recovery averaged 65 percent. The pit condition had improved significantly, note Figure No. 10. During the month the dragline operated on the prestripped surface, it stripped an additional 28 feet of overburden and mined 20 feet of matrix. Water in the pit was minimal from overburden groundwater seepage. Artesian springs did not occur from the pit when the Hawthorne limestone was exposed after matrix extraction. The spoil stacks were dry, but some excessive volume covered 10 to 15 percent of the matrix yardage in the pit.

In order to achieve ground stability for scraper pan work and mining, 8 gravity connector wells were drilled over 800 feet into the Avon Park limestone. Dewatering rates ranged from 40 to 117 gallons per minute. The wells operated an average of 192 days for a total time of 1,540 days to remove 185 million gallons of groundwater. The groundwater level within the sediments overlying the pit bottom limestone declined 42 feet below the original ground surface which in turn was lowered to greater than 50 feet by pit waterjack.

The effects of dewatering on pit geometry and matrix yardage recovery are shown on Figure No. 11. During 1974, the high watertable in the overburden caused a 3:1 pit slope and precludes efficient mining recovery. A dashed line shows the actual pit geometry after dewatering effort in July of 1977.

Pit Wall Failure

Mining in deep pit areas is a constant hazard. Early in the morning of September 13, 1977, a pit wall failure occurred up to the tub of the dragline. It appeared that pit wall failure occurred when the weak layers of matrix were mined as found in the test hole drilling of 1974 at depths of 88 to 94 feet. This test found varied types of loose to dense clayey sands in 70 feet of overburden and two weak zones within the 54 feet of matrix at the 88 to 94 foot and the 118 to 122 foot

Figure No. 10
Improved Deep Pit Condition

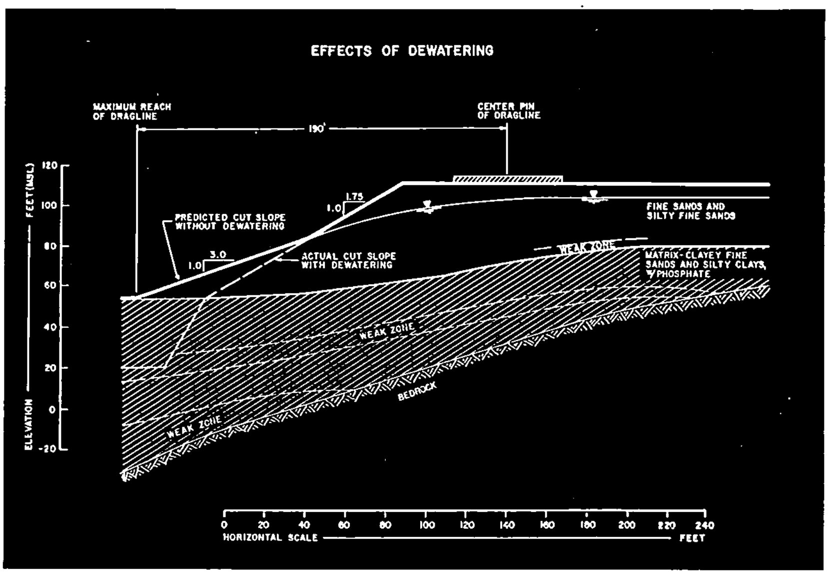

Figure No. 11
Effects of Dewatering

intervals. A dewatering well drilled 100 feet west of this test location, designed to relieve the artesian groundwater pressure in the bedrock limestone, found 80 feet of overburden and 115 feet of matrix to the top of the Tampa Clay Formation. The Hawthorne limestone bedrock was not found in 195 feet of drilling from the surface. The soils test of 9/15/77 was drilled two days after the pit slope failure. The overburden was 40 feet deep with a matrix thickness of 30 feet. Two weak zones were located at 30 to 40 feet and at 55 to 60 feet, see Figure No. 12.

The weak layers of 88 to 94 foot interval of test 12/74 and 55 to 60 foot interval of the test 9/77 are considered continuous and sloping parallel to the bedrock. The predicted failure by sliding wedge and bishop circular analysis resemble the failure surface. As mining removed the overburden and matrix to the depths of 80-85 feet, the soil mass above this weak zone slid down slope along the plane of failure.

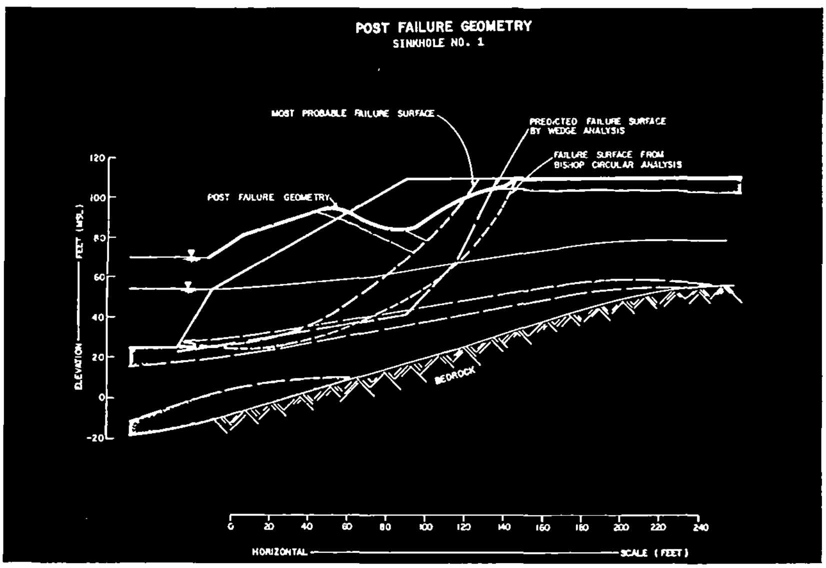

Figure No. 12
Pit Wall Failure

Immediately following the pit wall failure, the dragline retreated about 100 feet to firm ground along the cut line. Mining continued after the engineering test drilling to a depth of 70 feet. This incident confirmed earlier test results that dewatering and prestripping would prevent ground failure from occurring behind the dragline causing it to slide into the pit.

SUMMARY

In summary, the application of subsurface and surface dewatering is essential to open pit mine drainage control in the deep sinkhole areas at Watson Mine. Gravity connector wells have dewatered the surficial aquifer in the overburden and reduced the artesian head in the pit bottom limestone. The effect has been improved matrix yardage recovery, productivity, and dragline safety.

Prior to the dewatering and prestripping application in mine planning, the production rate in the sinkhole mining area was 1,700 short tons per acre mined, after preparation in 1977, the production rate was 4,700 short tons per acre mined. Based on the success of two field experiments, current mining areas are being dewatered with connector wells at a rate of 3 million gallons per day and prestripping at designed depths in the overburden is a continuous operation.

ACKNOWLEDGEMENTS

The author wishes to thank the management of Swift Agricultural Chemicals Corporation for their support and permission to publish this paper. A special thanks is extended to Mr. David H. Barnett, Mining Manager, for support and supervision during the project. The author gratefully acknowledges Mr. David R. Spedden, metallurgist, for his many suggestions and critical review of this paper.

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