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SALT MUSHROOMS IN THE ARAB POTASH COMPANY'S SOLAR EVAPORATION SYSTEM

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RESUME

Le but de cet exposé est de mettre en lumière le phénomène extraordinaire de "concrétion de sels" et ses conséquences dans les bacs solaires d'Arab Potash Company.

Les concrétions de sel ont pour effet de réduire la surface disponible pour l'évaporation de l'eau de la saumure et ainsi limiter l'écoulement entre les bacs lorsqu'ils sont reliés les uns aux autres ; spécialement dans les bacs de sel. La densité de formation dépend de la porosité de la structure du sol au fond des bacs ; plus la structure du sol est poreuse, plus la densité de concrétion de sels est importante. Dans ces conditions, le premier bac de sel (SP-1) est le plus affecté au point de gêner le bon fonctionnement du système.

Ces formations anormales résultent de l'alimentation en saumure subissant une pression artésienne au fond des bacs. Cette saumure a une composition différente de celle du bac et entraîne la précipitation de chlorure de sodium par effet d'ions commun lorsque les deux saumures se mélangent l'une à l'autre.

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INTRODUCTION

The Arab Potash Company is situated 178 kilometers to the south from the Jordanian capital of Amman, and approximately 200 kilometers north of the port of Aqaba. This project utilizes two of Jordan's most abundant natural resources; solar energy, and the mineral rich brine of the Dead Sea.

The salts in the Dead Sea are concentrated by evaporation utilizing the high intensity solar insolation and the low humid environment during the summer that takes place in a system of solar ponds. An enclosure of approximately 85 kilometers of earth dikes have been constructed to enclose a total of 100 km^2 of evaporation area and is divided into two parts; 70 km^2 are concentration ponds (3 salt ponds) and 27 km^2 of production ponds (6 carnallite ponds) with a small and narrow pond in between for control purposes (3 km^2, pre-carnallite pond) **[Figure # 1 in the Appendices]**.

Formations of sodium chloride salt are experienced in all areas of the solar evaporation system. These formations are usually referred to as "reefs" or "mushrooms" depending on their appearance. In some areas, the salt forms in an irregular but continuous line, while in other areas it forms a circular shape at the surface of the brine which is supported by a smaller stem protruding from the bottom of the pond, resembling the shape of a mushroom.

Salt formations grow throughout the solar evaporation system, the severity and size of these formations vary widely. The formation severity depends on the porosity of the ground structure below the bottom of the pond. Only pond SP-1 has the severity of these formations become sufficient to interfere with the operation of the system as yet.

It is necessary to cope with the reefs and mushrooms problem in this area every year since 1984 when this area of the salt ponds was first filled with brine. The problem is becoming more formidable each year as the mushrooms accumulate more and more. Methods of coping with this problem have included manual labor and Jack hammers, excavators, a drag line equipped with a 1 - ton drop hammer, and blasting, but as the salt mushrooms and reefs growth proceeded - horizontally covering more area, these methods have become more difficult and less effective.

Cutter suction type dredger has been in operation since 1989 to clear and extend the flow channel at the end of the first salt pond (SP-1) that has been established in a place to the north of dike 12 through an area of heavy growth of reefs and mushrooms which, although not restricting brine flow at present, will restrict flow through the pond in the near future if left unattended to. Establishing and maintaining this flow channel unobstructed has utilized the total capacity of the dredger.

At the end of this year (1994), a bucket wheel type dredger will be utilized in the first salt pond (SP-1) with a more capacity than the old cutter suction type dredger in order to accelerate the process of removing the existing mushrooms and reefs formations.

In parallel with the above mechanical solutions, a research procedure had been conducted since 1990 to find out the causes of these abnormal formations.

RESULTS

Since 1990, a research procedure had been conducted in three steps:

a) Drilling boreholes in the mushroom locations
b) Samples taking and mixing experiments on brines
c) Setting up models

All of which are aiming at proving that the cause behind the formation of salt mushrooms is attributed to the mixing of an artesian brine coming up from underneath the pond with the brine existing in the pond at the locations where the mixing occur, by the common ion effect theory.

a) Drilling boreholes in the mushroom locations:

Investigating the presence of artesian ground waters at the site of the highly populated mushroom at salt pond (SP-1) was the primary purpose of the study. Five boreholes had been drilled (BH1, BH2 ..... BH5); 2 nos. of these boreholes (offshore boreholes) were bored to determine soil stratigraphy and to obtain soil and water samples (BH1 and BH2) and 3 nos. were drilled through certain mushrooms to explore their nature.

The sample borings were drilled with a Bomag B-100 rotary drilling rig mounted on a pontoon. The depth of the brine is 2 m to 4 m. The borings were drilled to depths of 40 m and 54.5 m.

Additional boreholes were drilled through the mushroom to depths of 0.5 m to 6 m below the top of the mushroom to explore their nature and thickness. Detailed descriptions of the materials encountered in the boring (BH2) is presented on individual log in the appendices **(Appendix A).**

Observations made in the open boreholes subsequent to the drilling and sampling operations indicated the presence of artesian ground water in borehole BH2, where a standpipe pizometer was installed.

A representative core samples were taken from three boreholes drilled in the center of three mushroom structures, BH3, BH4 and BH5 to depth 0.5 m, 3.0 m and 6.0 m respectively. Coring was carried out from top to bottom of the three mushroom structures located in different parts of SP-1 in order to study the nature of these structures. In case of BH3, the mushroom was broken so no core samples obtained. BH4 of 3 m depth, showed whitish, fine and medium crystalline salt. Furthermore, a suit of 10 samples collected from different depth intervals of BH5 were chemically analyzed. The following table **(Table #1)** shows the results:

Table # 1: Chemical analysis of the Mushrooms

Depth	ANALYTICAL RESULTS (weight%)							
	K^+	Na^+	Mg^{++}	Ca^{++}	Cl^-	CO_3^{--}	SiO_2^{--}	H_2O
0.0 - 0.2	0.17	35.23	0.73	0.30	55.40	0.011	0.006	6.39
0.2 - 0.4	0.16	34.84	0.82	0.32	56.49	0.014	0.007	6.99
0.4 - 0.63	0.15	35.52	0.69	0.26	55.69	0.028	0.007	5.97
0.63 - 0.85	0.15	35.19	0.72	0.27	58.39	0.026	0.006	6.66
0.85 - 1.0	0.15	35.02	0.80	0.30	54.70	0.019	0.004	6.73
1.0 - 1.20	0.14	35.57	0.63	0.22	55.80	0.029	0.007	6.22
1.20 - 1.46	0.11	35.97	0.53	0.20	57.84	0.017	0.007	5.70
1.46 - 1.66	0.14	35.02	0.72	0.24	56.29	0.006	0.008	7.19
5.90 - 5.93	0.72	31.74	1.17	0.49	42.76	0.049	0.010	11.07
5.93 - 6.0	0.15	36.08	0.46	0.38	60.60	0.032	0.008	5.01
Average	0.14	35.38	0.67	0.27	56.80	0.020	0.006	6.31

b) Samples taking and mixing experiments on brines:

8 Nos. of brine samples had been taken from BH2 borehole and the chemical analysis were as follows (**Table # 2**):

Table # 2: BH2 Borehole Samples

Date	Temp. °C	Act-Den g/cm^3	Den-36°C g/cm^3	Mg^{++} %	Ca^{++} %	K^+ %	Na^+ %	Cl^- %	H_2O %
21/03/92	25.0	1.2097	1.2053	1.60	0.74	0.27	6.74	16.62	74.035
08/03/93	27.0	1.2077	1.2041	1.73	0.68	0.31	6.60	16.71	73.971
20/04/93	28.0	1.2087	1.2055	1.72	0.71	0.28	6.70	16.86	73.730
27/04/93	28.5	1.2095	1.2065	1.75	0.64	0.30	6.84	17.06	73.412
20/07/93	38.0	1.2100	1.2108	2.00	0.88	0.36	6.03	17.02	73.713
08/09/93	32.0	1.2061	1.2045	1.70	0.66	0.30	6.14	15.87	75.332
26/10/93	30.0	1.2063	1.2039	1.82	0.66	0.29	6.62	16.95	73.661
30/04/94	30.0	1.2070	1.2046	1.81	0.75	0.22	6.33	16.57	73.982
Average	29.8	1.2081	1.2057	1.77	0.72	0.29	6.50	16.71	73.980
St. Dev.	3.6737	0.00146	0.00210	0.109	0.072	0.037	0.278	0.359	0.5465

* Act-Den ==> Actual Density (g/cm^3) .* Den-36 ==> Density at 36°C (g/cm^3).

Mixing experiments of two brines have been carried out; BH2 brine and SP-1 pond brine, in order to prove that the common ion effect theory applies to this situation. Brine from BH2 borehole was mixed with the brine above that borehole (SP-1 Pond Brine) with different ratios. The mixing procedure was carried out at constant temperature for all the ratios (30°C): **Table # 3** shows the chemical analysis of the two brines used in the mixing experiments:

Table # 3: BH2, SP-1 Samples

Location	Temp. °C	Act-Den g/cm³	Den-36°C g/cm³	Mg^{++} %	Ca^{++} %	K^{+} %	Na^{+} %	Cl^{-} %	H_2O %
BH2	33.0	1.2066	1.2054	2.00	0.37	0.29	6.33	16.51	74.496
SP-1	33.5	1.2540	1.2530	4.50	1.67	0.77	1.84	19.62	71.602

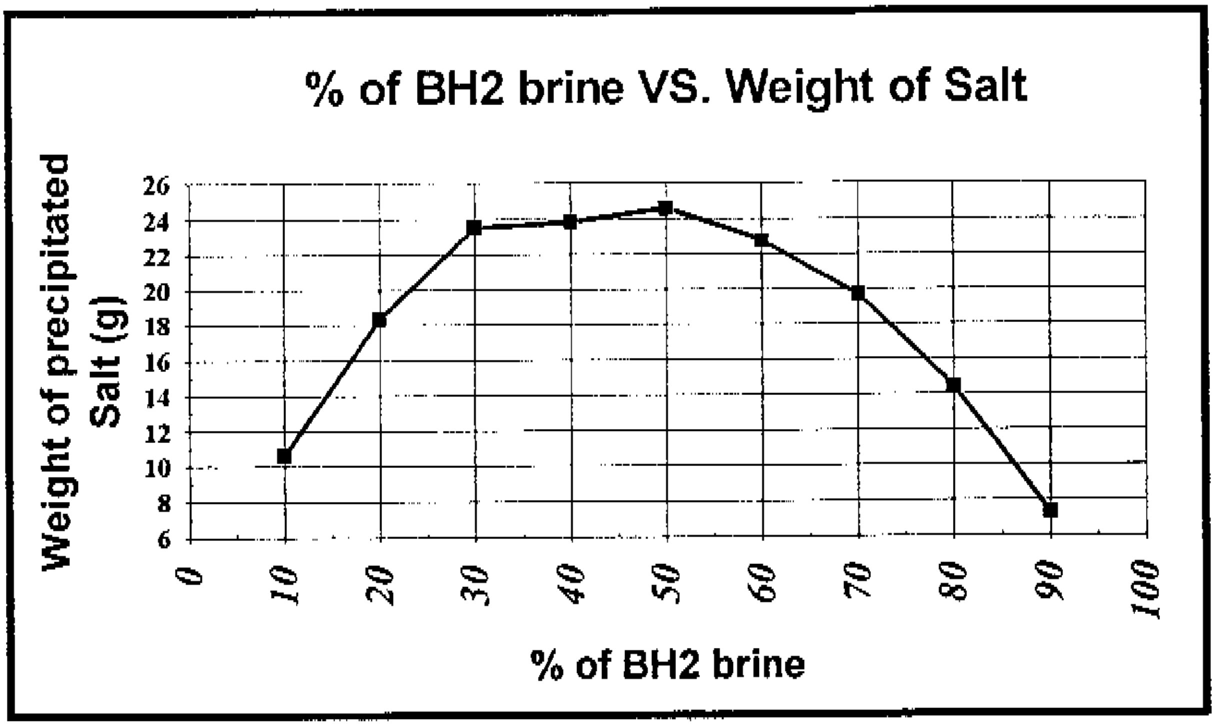
* Act-Den ==> Actual Density (g/cm³) .* Den-36 ==> Density at 36°C (g/cm³)

After mixing of the previous two brines, NaCl salt has precipitated immediately, **Table # 4** below shows the amount of precipitated NaCl salt at different mixing ratios:

Table # 4: Mixing Experiment Results

Volume of SP-1 brine (ml)	Volume of BH2 brine (ml)	Weight of Solid (g)
1800	200	10.6
1600	400	18.3
1400	600	23.5
1200	800	23.8
1000	1000	24.6
800	1200	22.8
600	1400	19.7
400	1600	14.5
200	1800	7.3

A curve shows the relation between the mixing percentage of BH2 brine related to the amount of solid precipitated is shown below. The percentage of NaCl salt precipitate in the solid is about 98.5%.

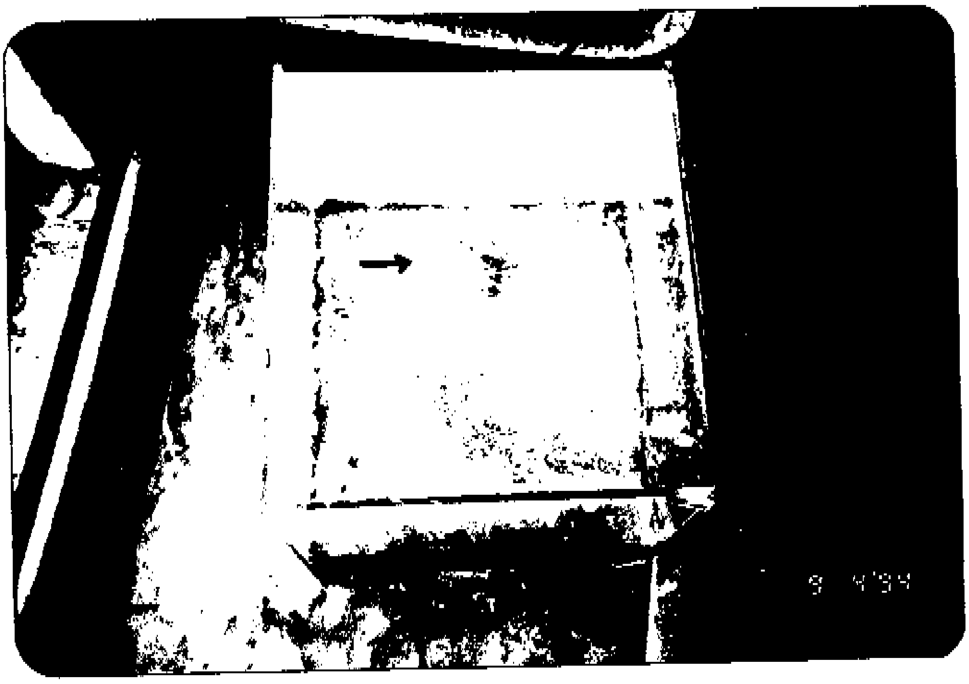


c) Setting up models:

Three types of models were executed during the study, the third one is the improved model, photo below shows the improved one:

The above model was constructed from a gelatin material with a dimension of (35, 31.5, 23 cm) and divided into two parts; the lower part for storing the artesian brine (Brine from BH2 borehole) and the upper part filled by pond brine (SP-1 pond brine). A small hole was drilled in the intermediate layer between the two parts, this layer represent the bed of the pond

After filling up the model with the two brines, a 6 cm salt mushroom has appeared after less than 18 hours of operation of this model above the small hole, which was drilled in the intermediate layer between the two brines. Photographs below shows the salt mushroom after draining the brine from the model:



The above experiment is a laboratory bench experiment started at 2.00 PM on 08/04/94 and in the morning of 09/04/94 the result has been discovered.

A crystallization of a needle shape crystal has appeared in the upper part, chemical analysis shows that this needle shape is NaCl salt crystals.

DISCUSSION OF RESULTS

1) From the borehole logs in Appendix (A1), it is clear that the bed underneath the pond is consisting of three major parts; a small bed of NaCl salt which has precipitated during the solar ponds operation, intermediate zone of mud and a large bed of NaCl below these two parts.

2) The chemical analysis of the mushrooms (Table #1), shows that the composition of the mushroom structure is mainly NaCl salt.

3) From the chemical analysis of BH2 brine, it is clear that this brine is NaCl brine with low percentage of other salts, which means that the source of this brine is a fresh water layer under the bed of the pond that seeps up through the NaCl salt bed to the pond surface. During the movement of this fresh water, NaCl dissolves, with other salts, in the medium of this fresh water.

4) From the mixing experiments, it is shown that the maximum NaCl precipitation was at the ratio of 50% mixing.

5) The needle shape NaCl crystal which has appeared in the upper part of the model was due to the sudden cooling effect in the laboratory environment during the night.

CONCLUSIONS

1) The cause of the salt mushroom structure in the Arab Potash Company's Solar Evaporation System, is due to the mixing of the artesian brine under the pond bed with the pond brine by the common ion effect theory.

2) To stop the growth of the salt in the shape of a mushroom, a series of bore holes must be drilled throughout the cavity of the artesian water in order to reduce the artesian pressure by pumping the water through the drilled boreholes and, thus, reducing the artesian pressure.

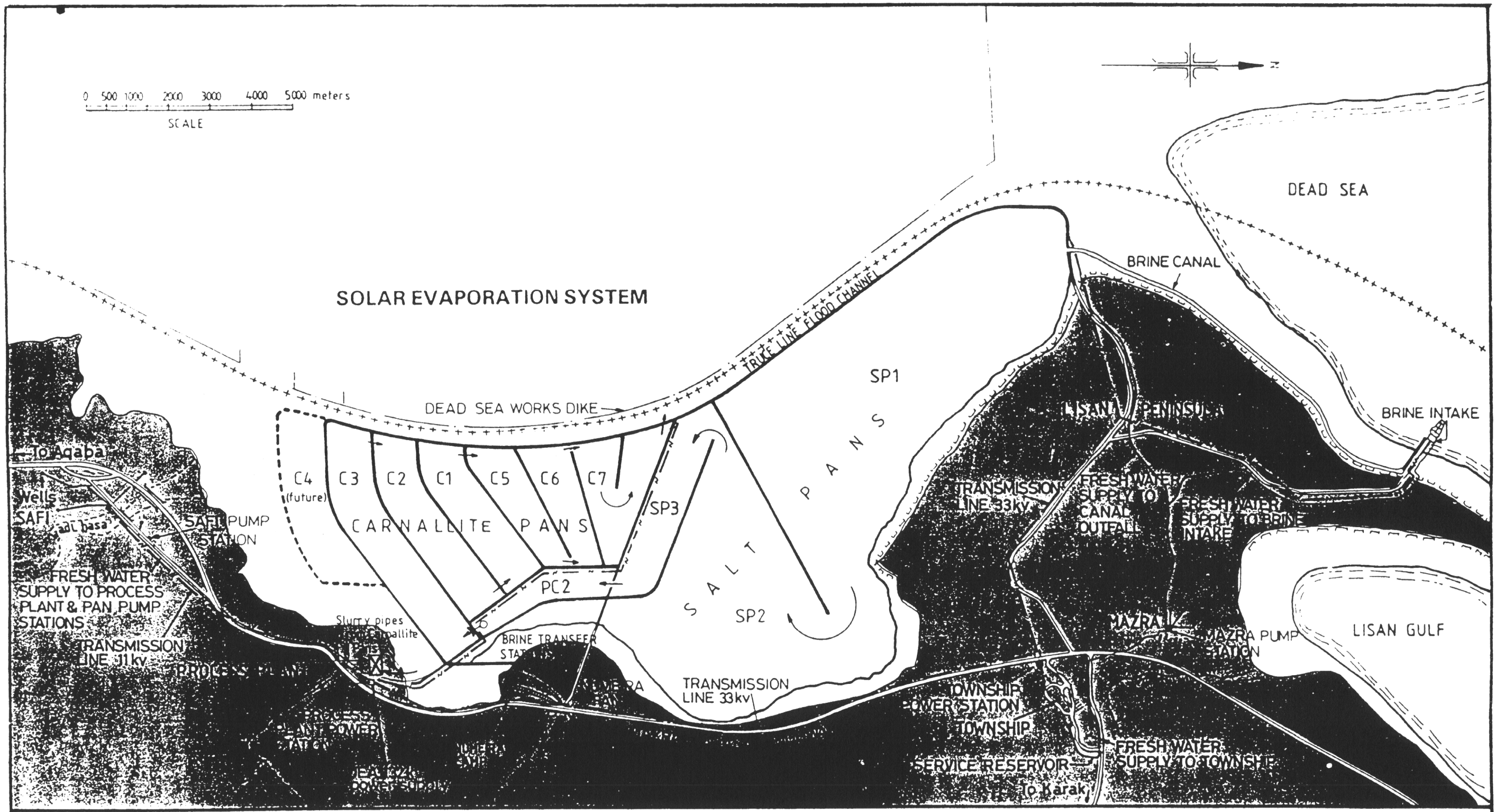
RECOMMENDATIONS

1) Further model runs should be made in the laboratory for further and detailed study.

2) A large scale model should be constructed and operated under the normal condition (Outside the laboratory).

3) More investigating boreholes drillings are needed in order to determine the volume of the artesian brine storage cavity under the pond bed, and measuring the artesian pressure.

4) Local or outside financing firms needed to continue this study.



THE ARAB POTASH COMPANY LTD.

THE HASHEMITE KINGDOM OF JORDAN

LOG OF BORING No B.H.2/SP.1

EXPLORATORY HOLES - SALT PAN 1
MESSRS ARAB POTASH COMPANY LTD.
GHOR AL SAFI - JORDAN

TYPE:
5" Triple-tube core barrel
4" Split barrel sampler
412 Double-tube core barrel

LOCATION: See Plate 1

DEPTH, m	DESCRIPTION OF MATERIAL ELEVATION: Pan Surface: -394.804 Pan Bed : -396.604	RECOVERY %	R.Q.D. %	BLOWS / ft	UNCONFINED COMPRESSION, Kg/cm² 5 10 15 20 25 30 PLASTIC LIMIT — WATER CONTENT, % — LIQUID LIMIT 10 20 30 40 50 60	DENSITY, gr/cm³
1	Whitish soft salt					
2	Greyish to tan laminated SILTY CLAY, soft intercalated with thin bands or seams of SILT, firm	100 100 100 100				
3–4		100 100 100 100				
5–7		100 100 100 100				
8	-soft thin bands at 3.5m to 4m, 8m to 8.5m and 15m to 15.5m	100 100 100				
9–12		100 100 100 100 100 100 100 100				
13–15	-stiff below 13m	100 100 100 100				

TYPE 4" Split-barrel sampler
412 double-tube core barrel

DEPTH, m	DESCRIPTION OF MATERIAL ELEVATION	RECOVERY %	R.Q.D. %	BLOWS / ft	UNCONFINED COMPRESSION, Kg/cm² 5 10 15 20 25 30 PLASTIC LIMIT — WATER CONTENT, % — LIQUID LIMIT 10 20 30 40 50 60	DENSITY, gr/cm³
16–21		100 100 100 100 100 100 100 100 100				
22	Whitish fine to coarse crystalline SALT, hard with thin bands of greyish clay at different depths	100	25			
23		100	0			
24		100	25			
25		100	33			
26		100	0			
27		100	0			
28		100	0			
29		100	0			
30		100	60			

TYPE 412 double-tube core barrel

DEPTH, m	DESCRIPTION OF MATERIAL ELEVATION	RECOVERY %	R.Q.D. %	BLOWS / ft	UNCONFINED COMPRESSION, Kg/cm² 5 10 15 20 25 30 PLASTIC LIMIT — WATER CONTENT, % — LIQUID LIMIT 10 20 30 40 50 60	DENSITY, gr/cm³
31		100	0			
32		100	0			
33		100	30			
34		100	0			
35		100	0			
36		100	10			
37		100	70			
38		100	46			
39		100	20			
40		100	0			

Notes :

Casing was installed to 19.3m below pan bed level

COMPLETION DEPTH 40m

DATE Started: October 15, 1991 Completed: October 26, 1991