PROBLEMS OF SILICA SCALING AT CERRO PRIETO GEOTHERMAL POWER STATION

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Abstract

In the Cerro Prieto Geothermal field, where the predominant fluid in the reservoir is water, we have had problems with silica and other deposits in the first exploration wells as well as in production wells. Scaling problems have also been encountered in silencers, cyclone separators, drains, water pipes, etc. Some scale problems have also been encountered in the turbine blades of the geothermal electric plant. Most of these problems have been solved by corrective procedures which, in some cases, have turned into routine. Scale deposition is a problem that certainly diminishes the useful capacity of geothermal fluids with water predominance, but it does not actually endanger the installations, since this problem is under control.

Description of the Geothermal Field of Cerro Prieto

The "Cerro Prieto" geothermal field presents hydrothermal surface manifestations in an area of about 30 square kilometers, where the production zone is located (Fig. 1). Thirty deep wells have been drilled in this field to a depth ranging from 700 m. to 2,000 m. Flow is obtained through pre-slotted casing or through gun perforated casing, after cementing the production casing, except 150 m. to 300 m. of the bottom part, where the hot strats are located. High enthalpy water flows through these perforations and is conducted to the surface through the 7-5/8" production casing.

As the water ascends through the production casing, the hydrostatic pressure diminishes and it partially flashes into steam. The flow through the valve tree is a water-steam mixture containing from 20 to 40% of steam. This mixture is admitted to a centrifugal Webre type centrifugal separator, 54" in diameter. The steam is sent to the power plant and the separated water to an evaporating pond.

From 20 to 80 tons per hour of steam are obtained from each well at a pressure of 100 psig. To date, 13 wells are used to supply the necessary steam to maintain at full load two units of 37.5 MW each, at a steam rate of 9.4 Kg/KWh.

Composition of the Brine and its Relationship to Silica and Other Scaling Salts

A typical analysis of the brine extracted by the wells is shown in Table I. As it can be seen, the following relationship can be established:

Cations:

$Na^{+} > K^{+} > Ca^{++} > Mg^{++}$

Anions:

$Cl^{-} > HCO_3^{-} > SO_4^{=}$

According to the classification of Chebotarey (1956) the brine is of subterranean origin and formed under restricted circulation or stagnation. By means of isotopic analysis of the geothermal fluid it has been established that the water from the geothermal reservoir is of meteoric origin and proceeds mainly from the Colorado River.

The high concentration of dissolved solids is the result of the solubility action of the hot water on the sedimentary rocks (see the sandstone analysis in Table II) acting for thousands of years, and reaching an equilibrium state or saturation with respect to some elements such as silicon, sodium and potassium.

The geothermal fluids also contain substantial amounts of dissolved gases, mainly CO_2 and H_2S and in minor amounts NH_3, H_2, and CH_4.

The high content of dissolved silica in the well brine is the result of dissolution of rock at temperature, a fact experimentally verified by different investigators. Results of tests conducted in our Laboratory with a sandstone core sample obtained from a well at a depth of 1,090 m. and using brine of the wells are shown in Fig. 2. Prior to the test, silica in the brine was precipitated and separated from the brine. As expected, the concentration of silica in solution increases with the temperature.

Silica concentrations determined in these tests are shown in Fig. 2 by (+). As can be seen, they follow the solubility curve obtained by Kennedy (1950) and Morey and Fournier (1962).

It has been possible to establish that the fluid discharge by the Cerro Prieto wells is saturated with respect to silica at the temperature at which the brine is found. This fact has been utilized to determine the temperature and enthalpy of the hydrothermal brines with acceptable accuracy. This method has been employed by Fournier and Rowe (1966) and Mahon (1966) for the same purpose.

Table I

Chemical Analysis of the Separated Water of Well M-5 After Being Exposed to Atmospheric Pressure

Element	ppm
Na	9062
K	2287
Li	38
Ca	520
Mg	1
B	14
SiO_2	1250
Cl	16045
Br	31
F	2
SO_4	6
CO_3	2
HCO_3	74
NaCl (Cl)	26442
As	0.5
Fe	0.3
pH	7.7
Cond. (mmhos)	32200

Table II

Chemical Composition of Sandstone Obtained from A Depth of 1090 M. at "Cerro Prieto"

Element	ppm
Na	4875
K	11200
Li	72
Ca	28000
Mg	8505
B	244
Cl	2100
Fe	520
Br	65
SiO_2	266000

In a similar manner, the brine is saturated with respect to carbonates at the temperature of the brine.

Due to the saturation condition of some of its components, deposition of scale occurs on the inside of the well casing as the geothermal fluid undergoes physical changes on its way to the surface. The scaling occurs physically when the high enthalpy water ascends through the production casing and the pressure at which it is subjected is reduced causing partial flashing of the water into steam. The zone of the casing where this change of phase occurs depends on the original enthalpy of the fluids. Fig. 3 shows the relation between the enthalpy measured in each well and the depth at which the deposits are found.

Chemically, deposition occurs when the brine (originally saturated with respect to silica and carbonates at the initial temperature) becomes supersaturated as a portion of the water flashes into steam and the temperature of the brine is reduced by this change of phase.

CO_2 originally present in the brine is transferred to the steam when boiling is initiated. The initial equilibrium is disturbed and bicarbonates are precipitated as carbonates according to the following reaction:

$$Ca(HCO_3)_2 \rightarrow CaCO_3 + H_2O + CO_2\uparrow.$$

Scaling problems of the production casing are more or less severe, depending on the zone where scale is produced and the depth of this zone. If, for instance, the deposit is formed in the production casing, rimming of the well recovers the well output. If, however, the deposit is formed in the slotted portion of the casing, fluid flow is restricted and the slots cannot be cleaned by rimming. Scale may also occur in the surrounding ground seals and diminishing permeability with no means of cleaning it.

Deposits similar to those formed in the production casing keep on forming in the separators, water piping, silencers and drains. Silica and other insoluble deposits are formed because water containing these salts is carried over the steam. This carryover is responsible for scales formed in condensate traps and on turbine blades.

Conclusions

Scaling in the production pipes from wells and in other installations has caused problems and restricted the integral use of the geothermal fluids. However, it has been possible to solve scaling problems as they occurred and operation of the wells and the geothermoelectric plant has been continuous since its inauguration in April, 1973. In the future, we hope to use preventive systems that will make the use of geothermal energy from water-predominant reservoirs much easier.

Table III

Chemical Composition of Scale in Production Pipe of Wells: 1A, M7, M9, M10, M11, M29 and M39

<u>Well 1A</u>:

$CaCO_3$	94.6 %
$MgCO_3$	4.2 %
NaCl	1.1 %

<u>Well M7</u>:

Ca	29 %
Mg	6.1 %
Cl	1.28%
Fe_2O_3	1.23%
SiO_2	6.0 %
SO_4	0 %

<u>Well M9: (750731) at 147-170 m.</u>

$CaCO_3$	75.56%
SiO_2	12.51%
NaCl	0.82%
FeS	9.46%

<u>Well M10</u>:

$CaCO_3$	75.67%
$MgCO_3$	3.19%
SiO_2	19.52%
FeS	1.62%

Well M11:

A.

		% (w)
SiO_2		25.1
Fe	(FeO)	3.7
Cu	(CuO)	0.1
Ca	(CaO)	24.4
Mg	(MgO)	12.0
Na	(Na_2O)	0.4
K	(K_2O)	0.3
Zn	(ZnO)	0.2
Mn	(MnO)	0.9
Cl		1.4
Au		0.0001
Ag		0.0061
CO_3		14.2
C.L at 400°C		1.4
C.L at 800°C		22.9

B.

Depth m	% (w) $CaCO_3$	SiO_2	FeS	NaCl
27	30.53	61.10	5.73	0.71
74	35.0	60.05	4.31	0.64
121	48.92	44.34	4.59	0.43
167	43.9	51.6	3.67	0.46
214	35.93	56.96	4.36	0.54
260	44.44	49.54	4.03	0.59
307	54.7	39.5	5.08	0.64
344	52.00	42.28	5.08	0.64
399	33.89	59.46	5.81	0.84
482	38.85	54.10	6.08	0.97
585	38.55	53.91	6.52	1.02
600	39.31	52.52	3.74	1.63
659	55.54	37.44	1.64	0.49
715	79.74	12.87	1.25	0.28

Well M29: (Nov.-Dec. 1975)

Depth m	% (w) $CaCO_3$	SiO_2	NaCl	FeS	
500	78.00	8.02	0.81	12.59	
507	90.18	2.31	0.33	0.69	
554	91.55	0.59	0.07	0.59	
601	92.3	1.34	0.07	2.16	
648	92.95	1.18	0.07	0.80	
694	94.07	0.52	0.08	0.71	
750	93.59	1.54	0.12	1.21	
797	93.72	1.55	0.1	0.5	
867	87.69	5.27	0.12	2.16	
890	85.47	8.37	0.26	1.54	
1030	18.00	25.63	0.27	9.78	(1)

(1) $MgCO_3$ 41.53%

Well M39 (Aug.-Sept. 75)

Depth m	% (w) $CaCO_3$	SiO_2	NaCl	FeS
250	84.43	6.09	0.11	3.18
928	61.24	23.34	0.27	1.86
964	87.78	2.89	0.03	0.082
992	71.11	15.10	0.28	1.46
1015	70.26	15.98	0.17	4.64
1057	73.25	17.95	0.26	0.94
1076	90.56	5.18	0.14	0.98
1085	71.28	17.08	0.20	2.27
1095	73.30	17.60	0.25	3.07
1116	78.94	9.10	0.19	3.97
1140	76.55	18.43	0.15	1.37

Chemical Analysis of Scale in Water Discharge Pipes in Wells M3 and M34

	% (w)	
	Well M3 (white)	Well M34 (white, gray and brown)
$CaCO_3$	9.52	6.5
SiO_2	3.6	85.1
Fe_2O_3	0	4.29
MuO	0	0.04
Co	0.005	0.003
Ni	0.0015	0
Cu	0.013	0.003
Au	0.00002	0.00013
Ag	0.0020	0.002

Chemical Analysis of Scale Inside of Cyclone Separator - of Well M34. Color of Sample: Black

	% (w)
SiO_2	31.4
Fe_2O_3	0
MnO	0.2
Co	0.05
Ni	0.013
Cu	0.049
Au	0.0005
Ag	0.0043

Chemical Analysis of Scale in Silencer of Well M5 and Well M8

	% (w)	
	Well M5 (gray)	Well M8 (white)
SiO_2	91.7	93.2
Fe_2O_3	1.4	0.86
MnO	0.06	0.05
Co	0.0069	0.0245
Cu	0.015	0.0086
Au	0.00002	0.001
Ag	0.0021	0.0021

Chemical Composition of Scale in Turbine Rotor Blades and Fixed Blades

Phases detected in X-ray analysis:

Magnetite
Pyrite
Pyrrhotite
Calcite
Halite
KCl

A. 2nd Maintenance Unit No. 1, Nov. 1975

	Fixed Blades				Rotor Blades
	1	4	5	6	1
SiO_2	55.4	1.0	0.8	2.0	0.5
FeO	1.3	35.2	26.6	29.7	34.9
CaO	24.6	0.3	0.3	0.1	0.1
CrO_4	0.1	0.2	0.1	0.1	0.1
MgO	0.1	0.1	0.1	0.1	0.1
MnO	0.7	0.3	0.3	0.5	0.5
S	T	37.6	37.6	51.7	T
SO_4	3.6	0.0	37.2	0.0	67.2
Cl	1.3	0.2	0	0	0

B. 3rd Maintenance Unit No. 2, March, 1976

	Fixed Blades					Rotor Blades			
	1	3	4	5	6	1	4	5	6
SiO_2	14.1	0.5	0.5	0.7	1.1	0.4	0.4	0.5	1.6
CaO	24.0	0	0	0	0	0	0	0	0
FeO	25.7	44.3	56.6	28.8	21.9	50.3	33.5	38.7	17.3
S	-	9.6	5.2	0.4	0.2	0.5	3.1	2.4	0.3
CO_3	14.5	0	0	0	0	0	0	0	0
K_2O	0.2	-	0	0	0	0	0	0	0
Na_2O	9.4	0	0	0	0	0	0	0	0

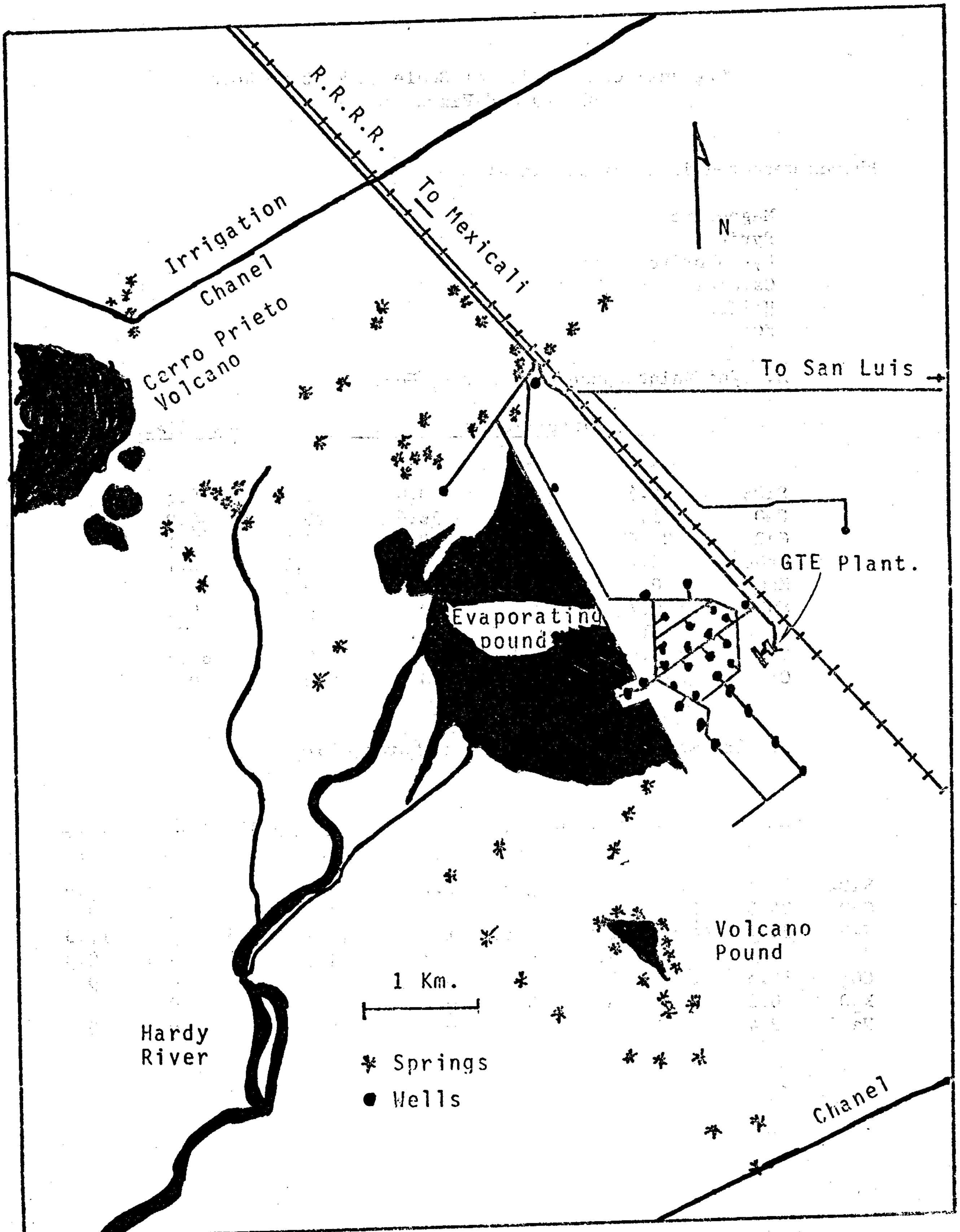
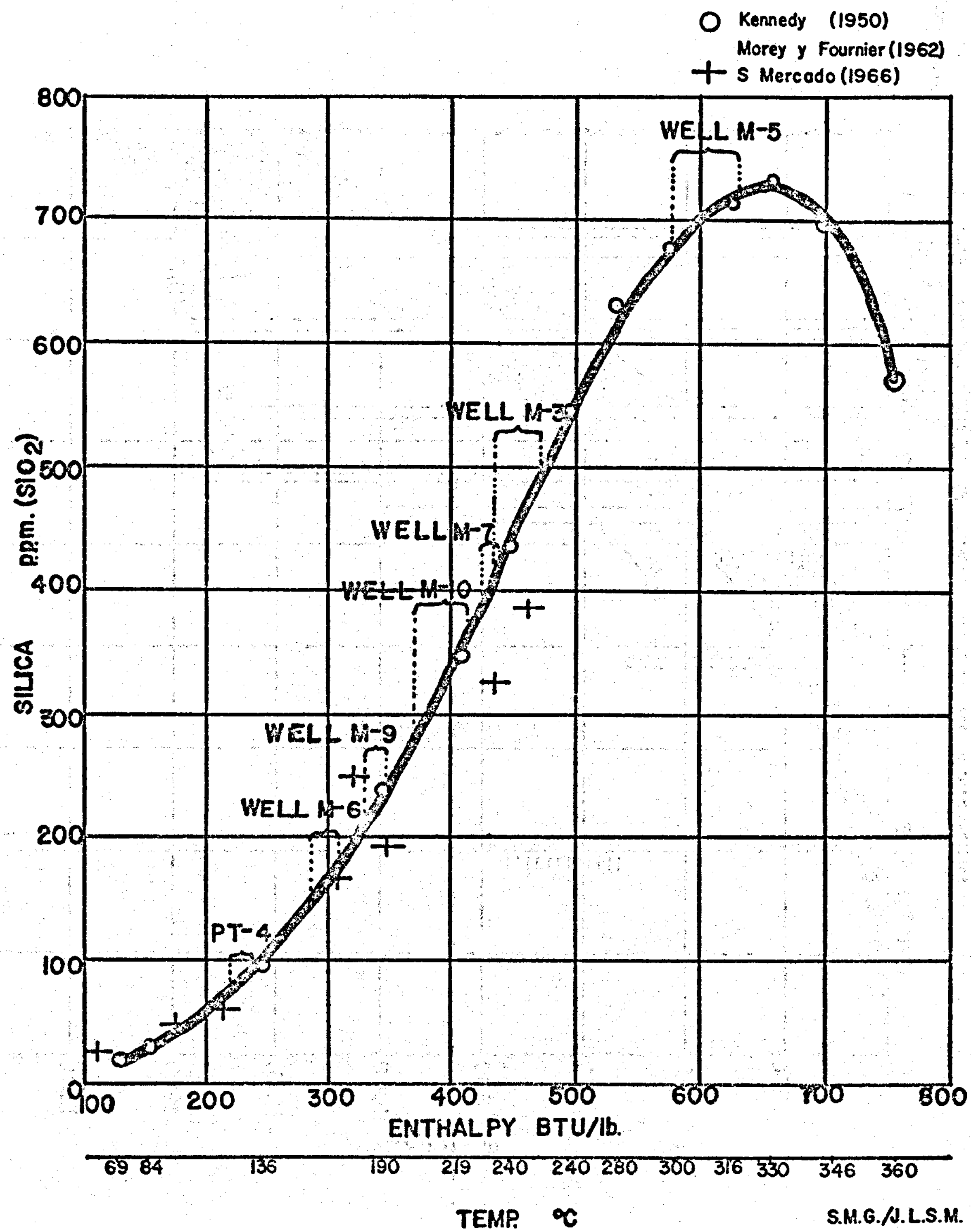


FIG. 1. - CERRO PRIETO GEOTHERMAL FIELD

FIG.2. QUARTZ SOLUBILITY VS TEMPERATURE



DEPOSITS IN CERRO PRIETO GEOTHERMAL WELLS

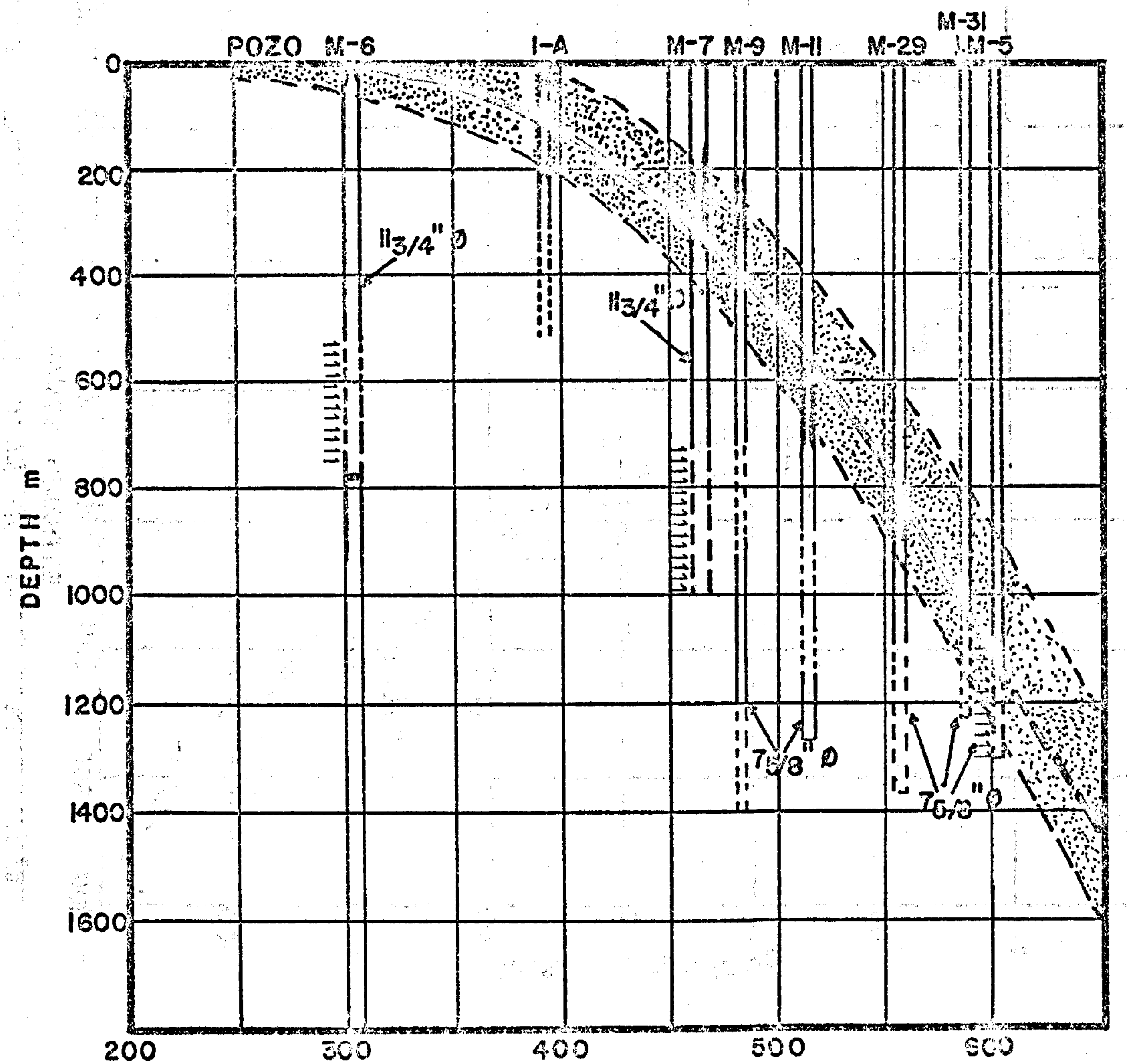
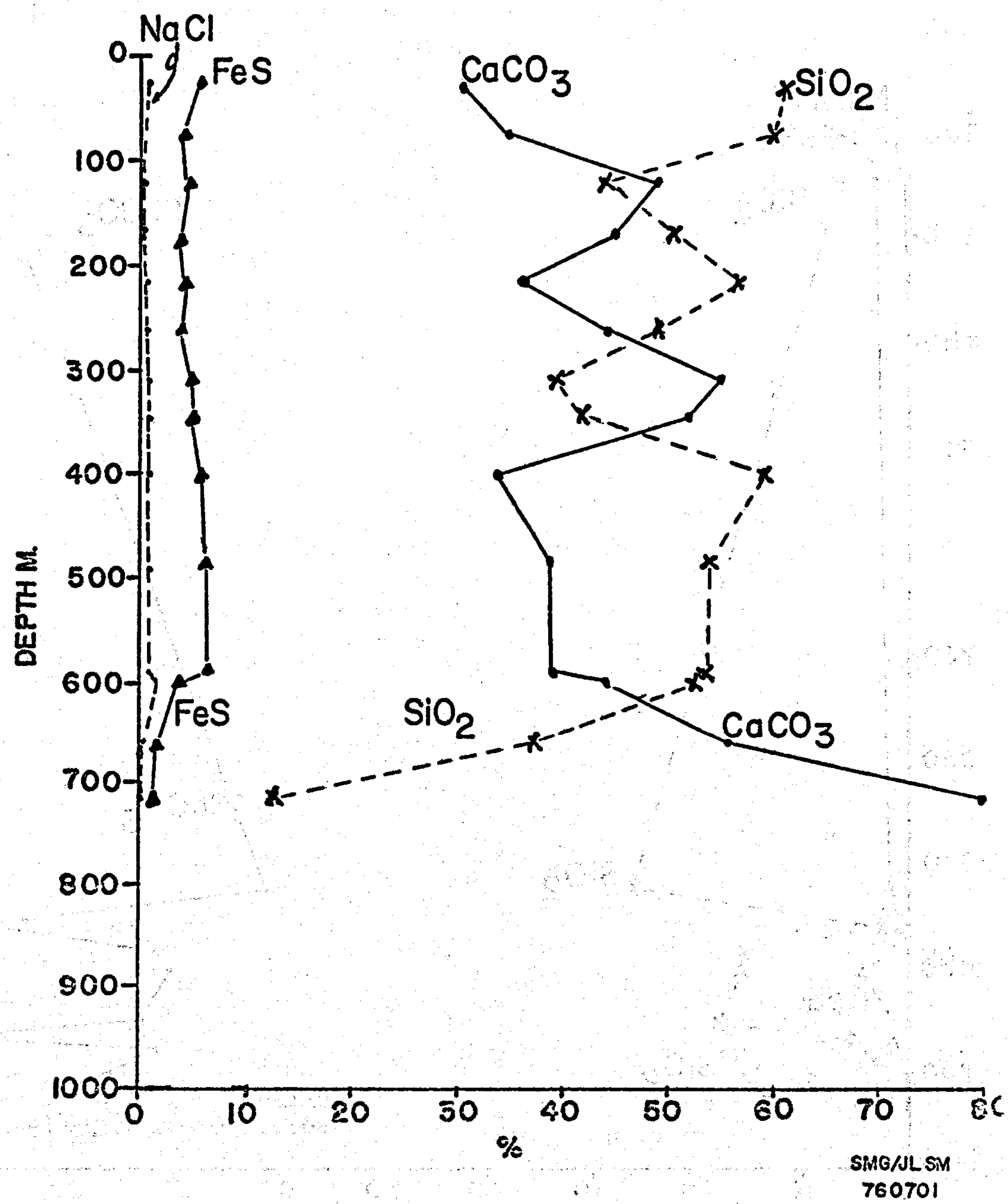


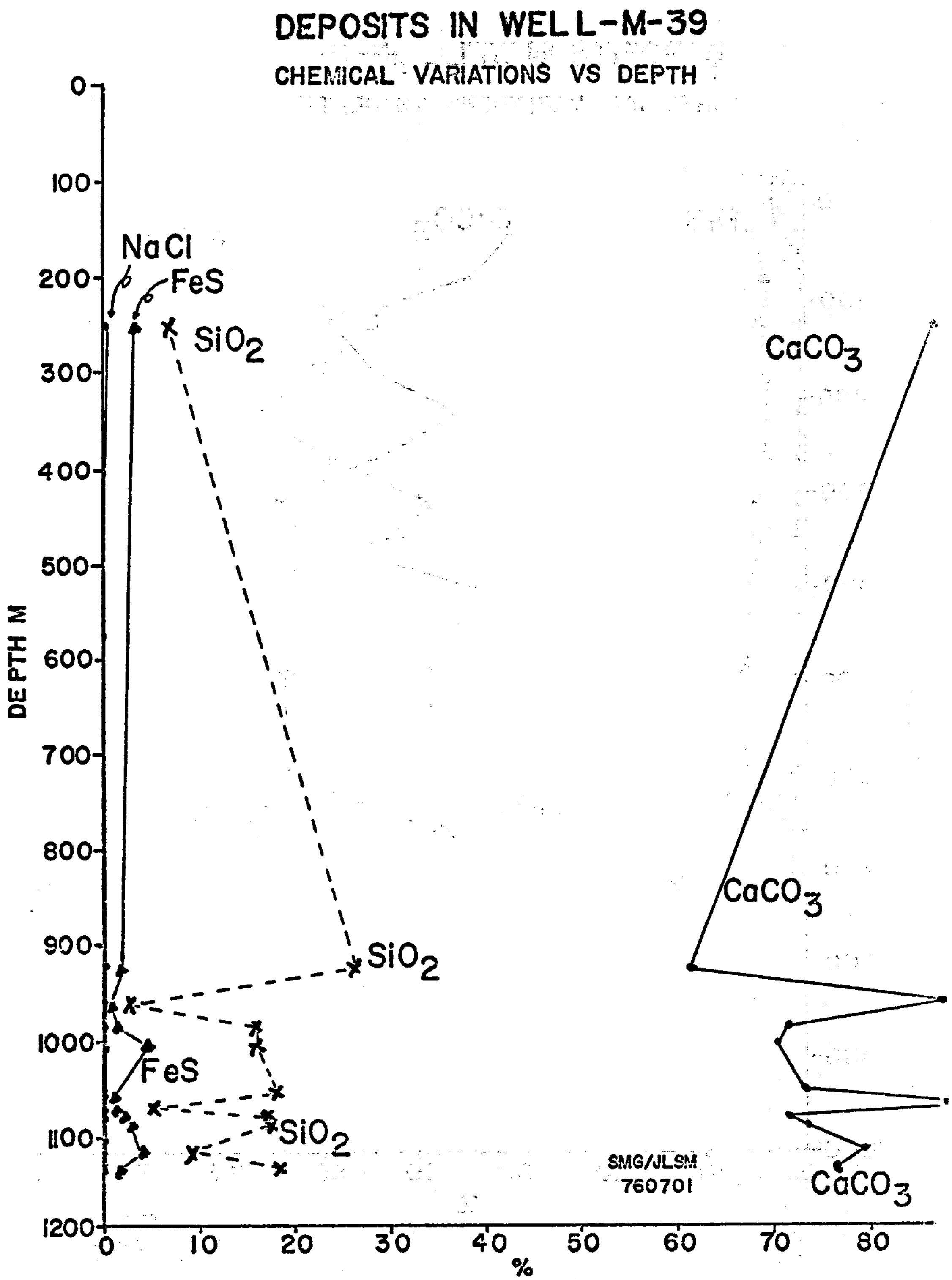
FIG. 3 ENTHALPY BTU/lb

S.M.G./JL.S.M.

DEPOSITS IN WELL M-11

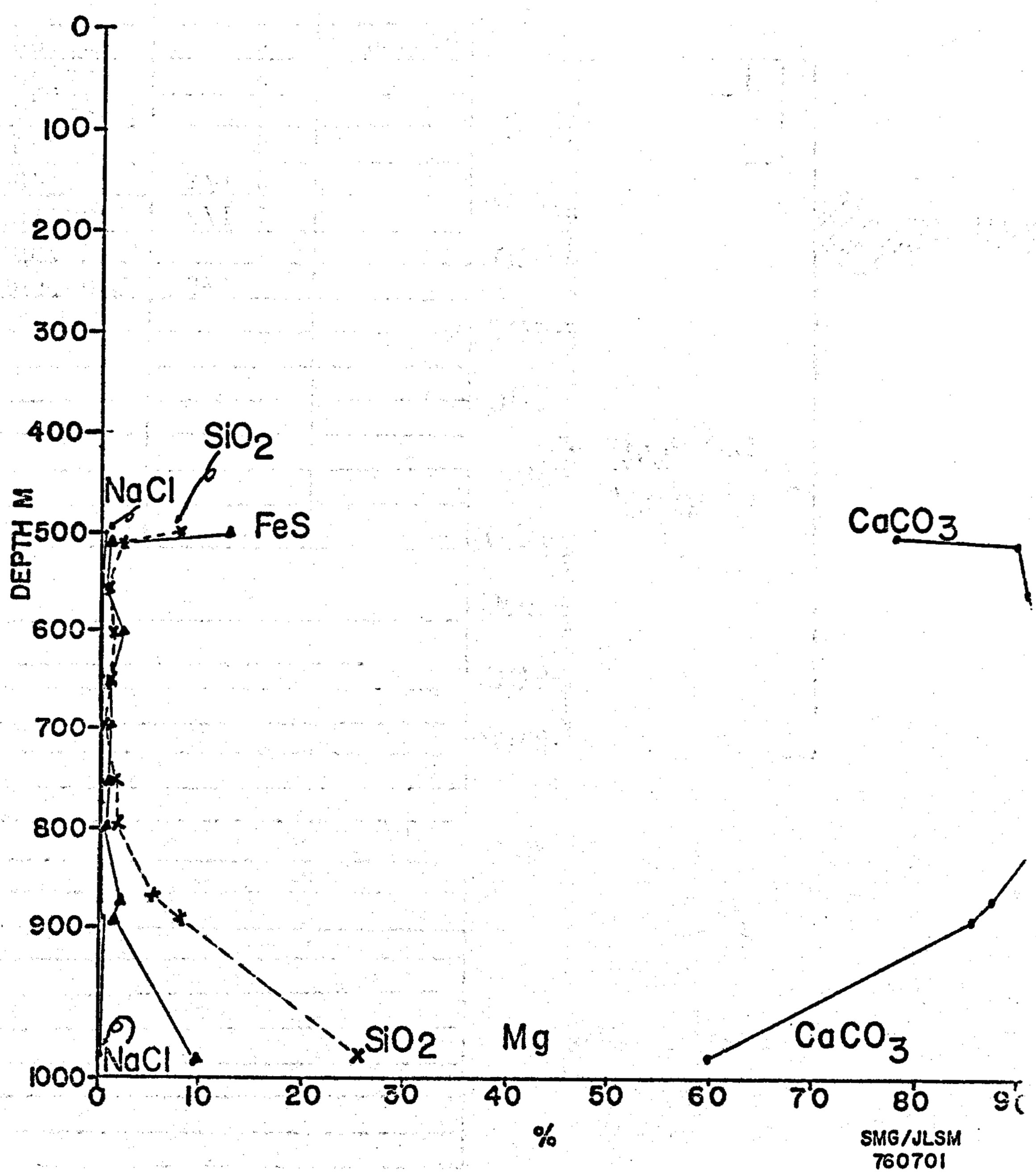
CHEMICAL VARIATIONS VS DEPTH

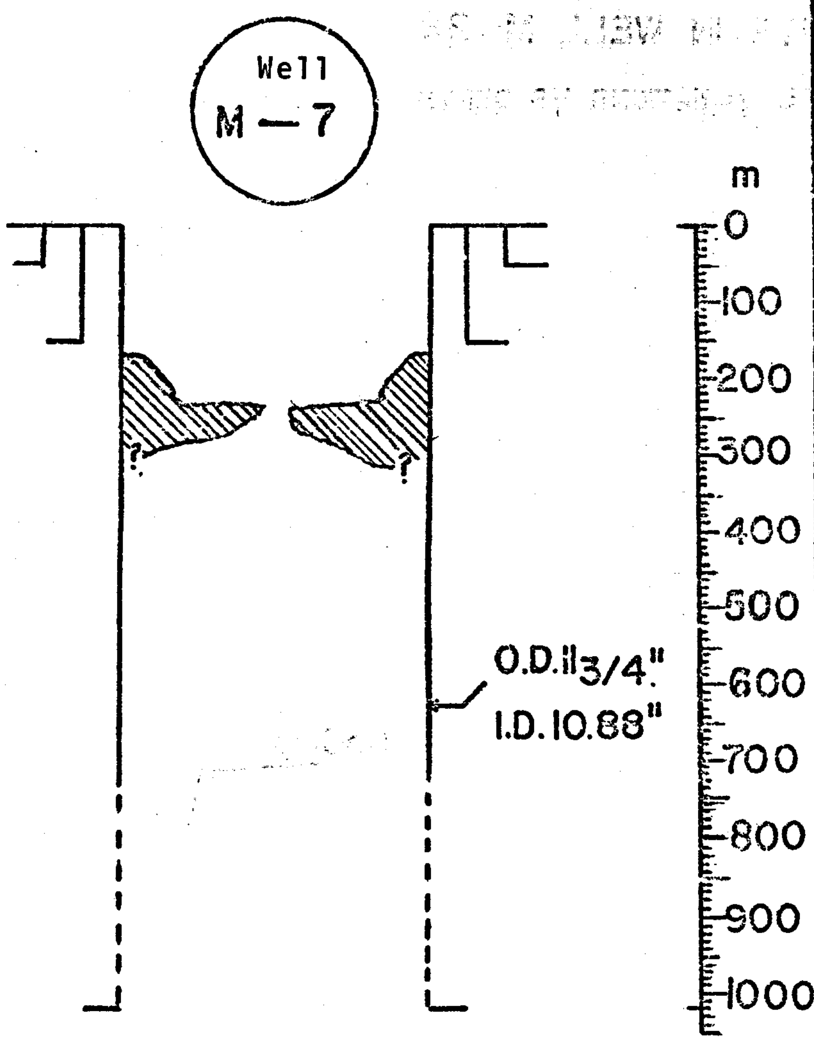



DEPOSITS IN WELL-M-39
CHEMICAL VARIATIONS VS DEPTH
DEPTH M
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
NaCl
FeS
SiO2
CaCO3
CaCO3
SiO2
FeS
SiO2
CaCO3
SMG/JLSM
760701
0
10
20
30
40
50
60
70
80
%

DEPOSITS IN WELL M-29

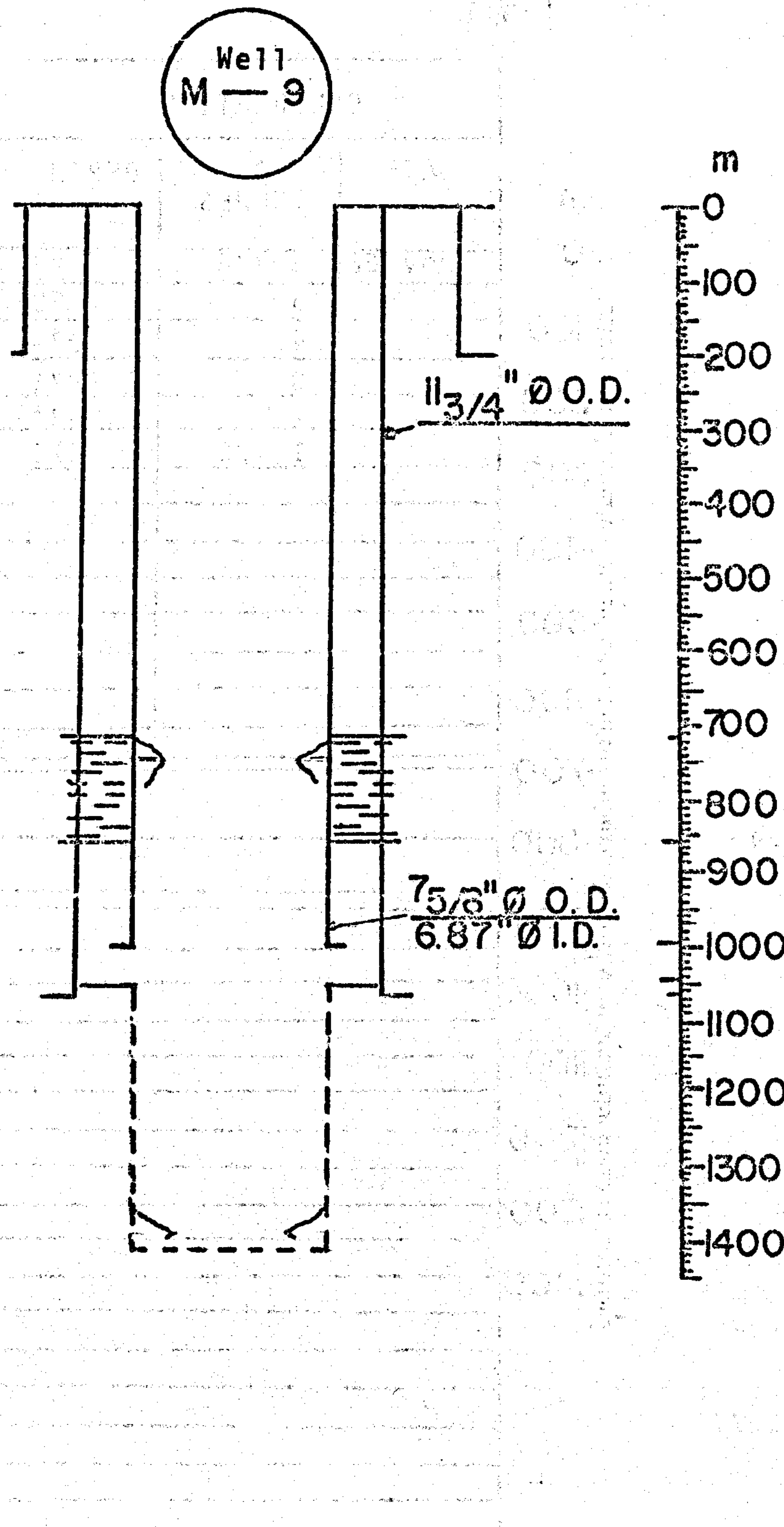
CHEMICAL VARIATIONS VS DEPTH





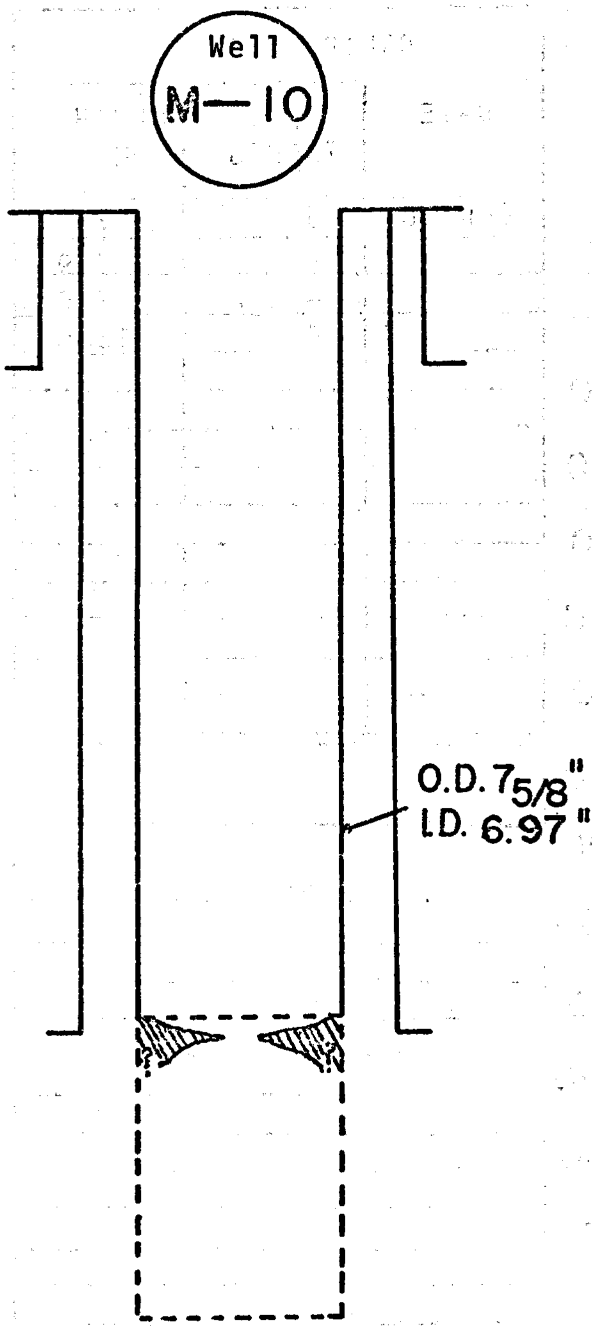
CALIBRATION		
DATE	Ø INCHES	DEPTH M
Jul/68	10	168.00
	8	211.90
	7	228.20
	6	228.20
	3 1/2	231'40
	1 1/2	229.50
	1	231.80
	1/2	1000.00

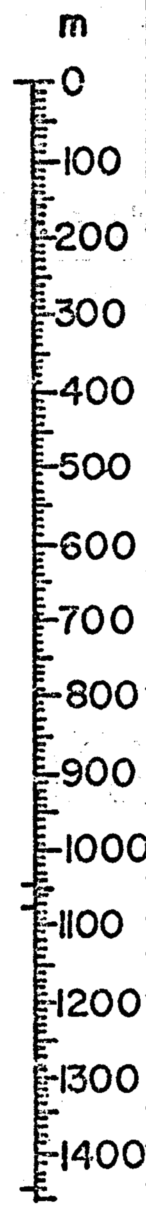
SMG/JLSM
760706



CALIBRATION		
DATE	Ø INCHES	DEPTH M
Jun/68	6	744
	5	749
	4 1/2	750
	4	1380

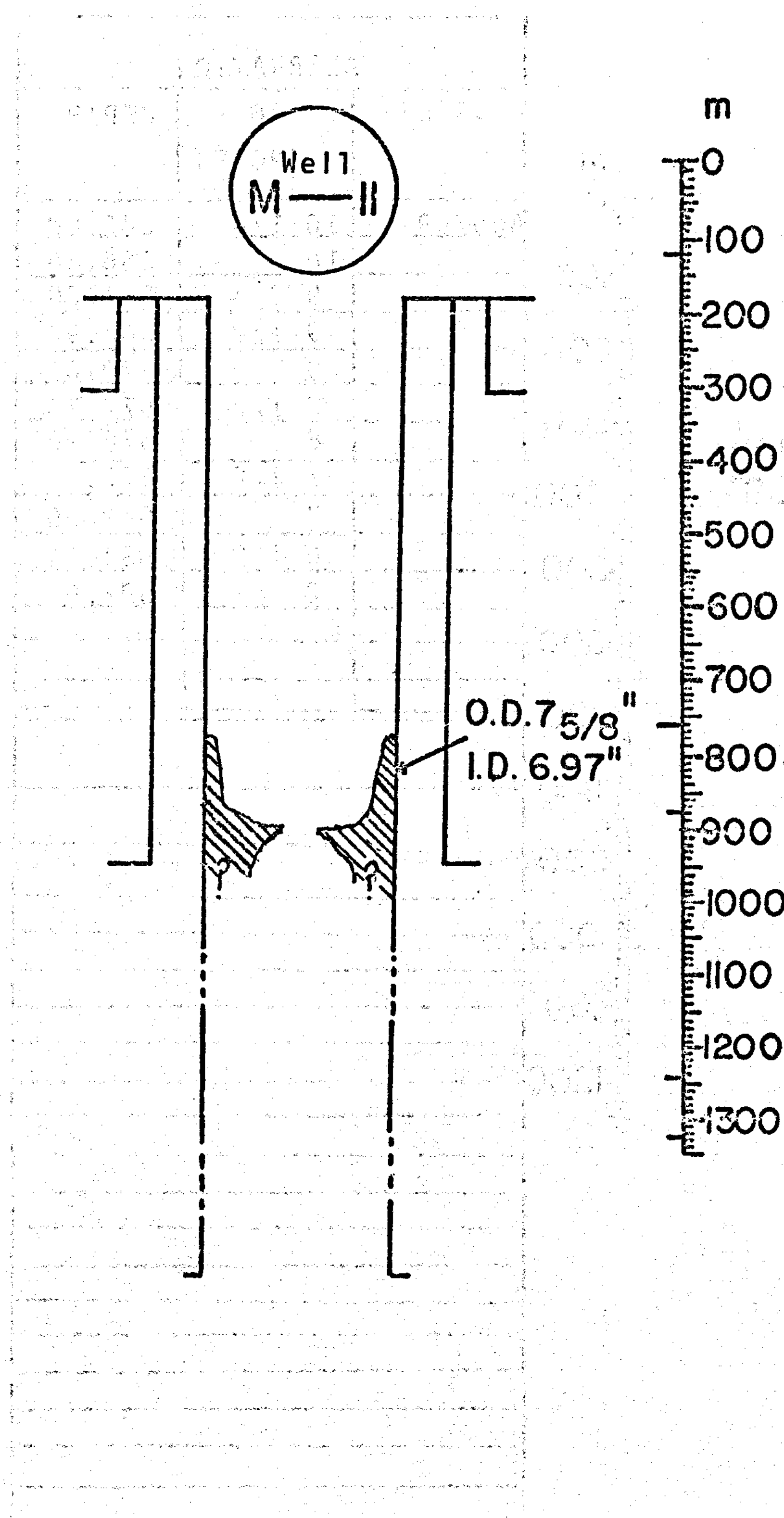
SMG/JLSM
760706





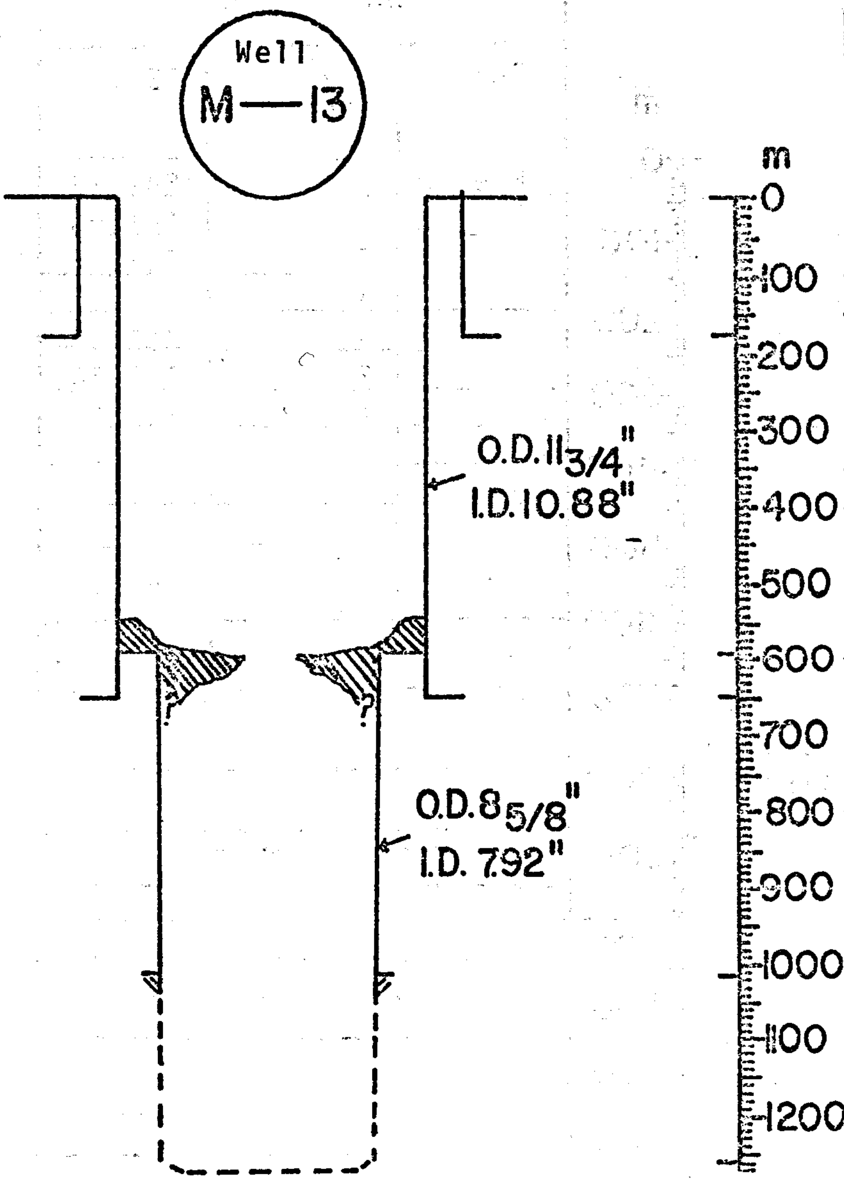
CALIBRATION		
DATE	Ø INCHES	DEPTH
Nov/68	5 7/8	29
	5	98
	4	1070
	3	1071
	2	1074
	1 1/2	1076

SMG/JLSM
760707



CALIBRATION		
DATE	Ø INCHES	DEPTH
Ene/68	7	582.17
	6	691.89
	5	707.14
	4	710.18
	3	710.79
	2	711.70
	1 1/2	713.23

SMG/JLSM
760708



CALIBRATION		
DATE	Ø INCHES	DEPTH
Ago/69	10 1/4	545.00
	10	556.30
	9 3/4	561.20
	9 1/2	563.90
	9	570.00
	8 1/2	573.70
	8	576.10
	7 1/2	577.90
	7	582.50
	6 1/2	584.30
	2	592.0

SMG/JLSM
760709

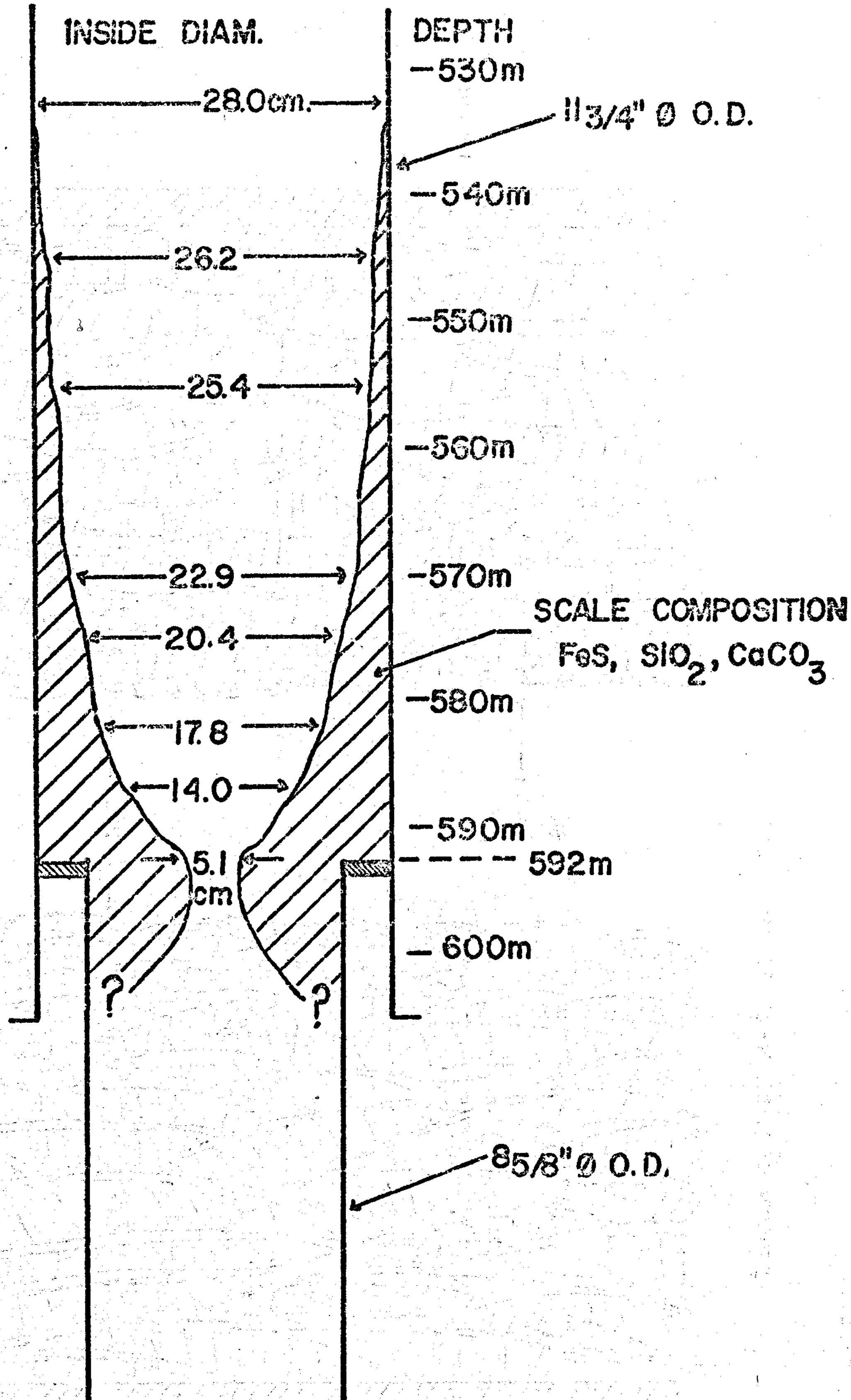
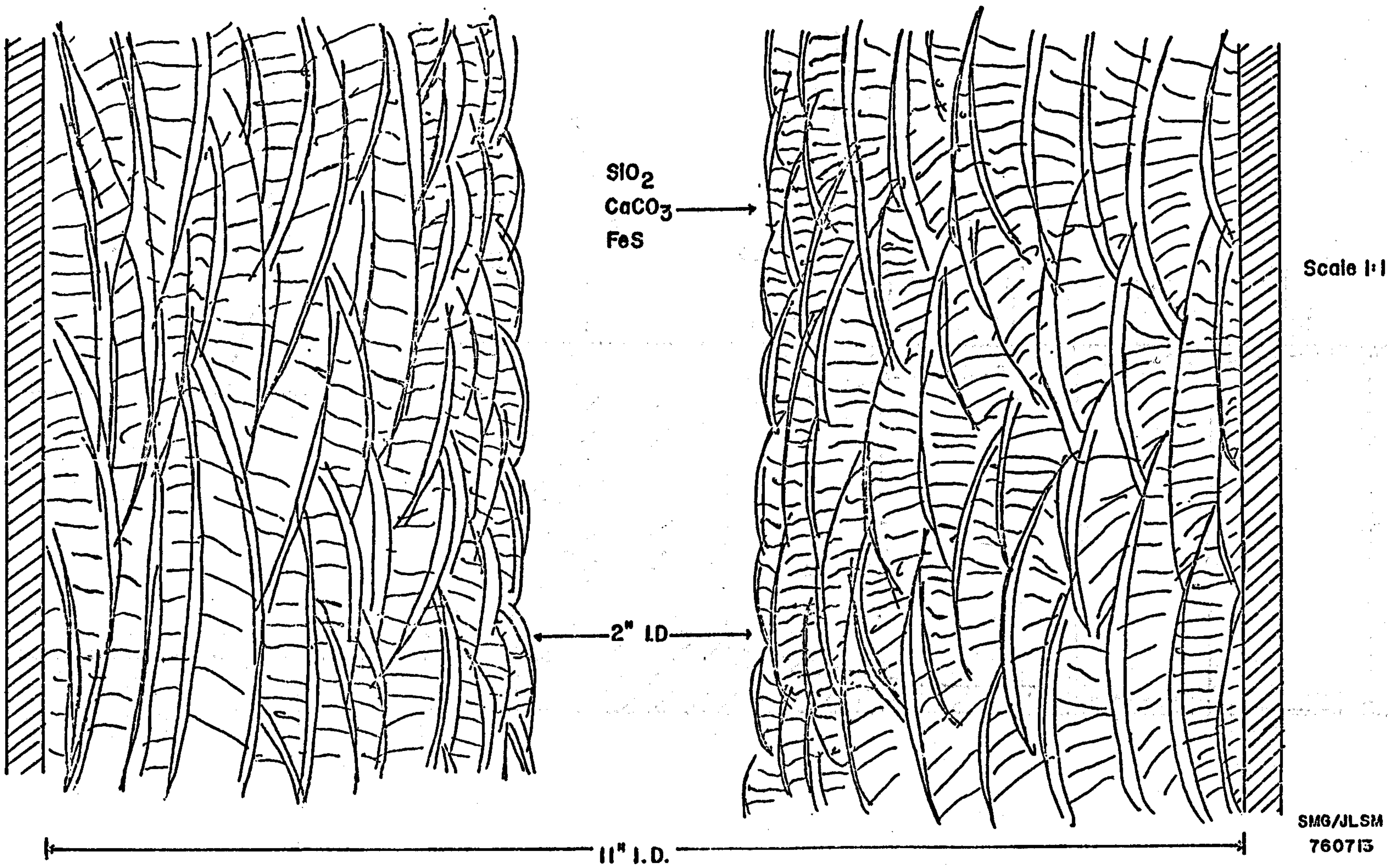
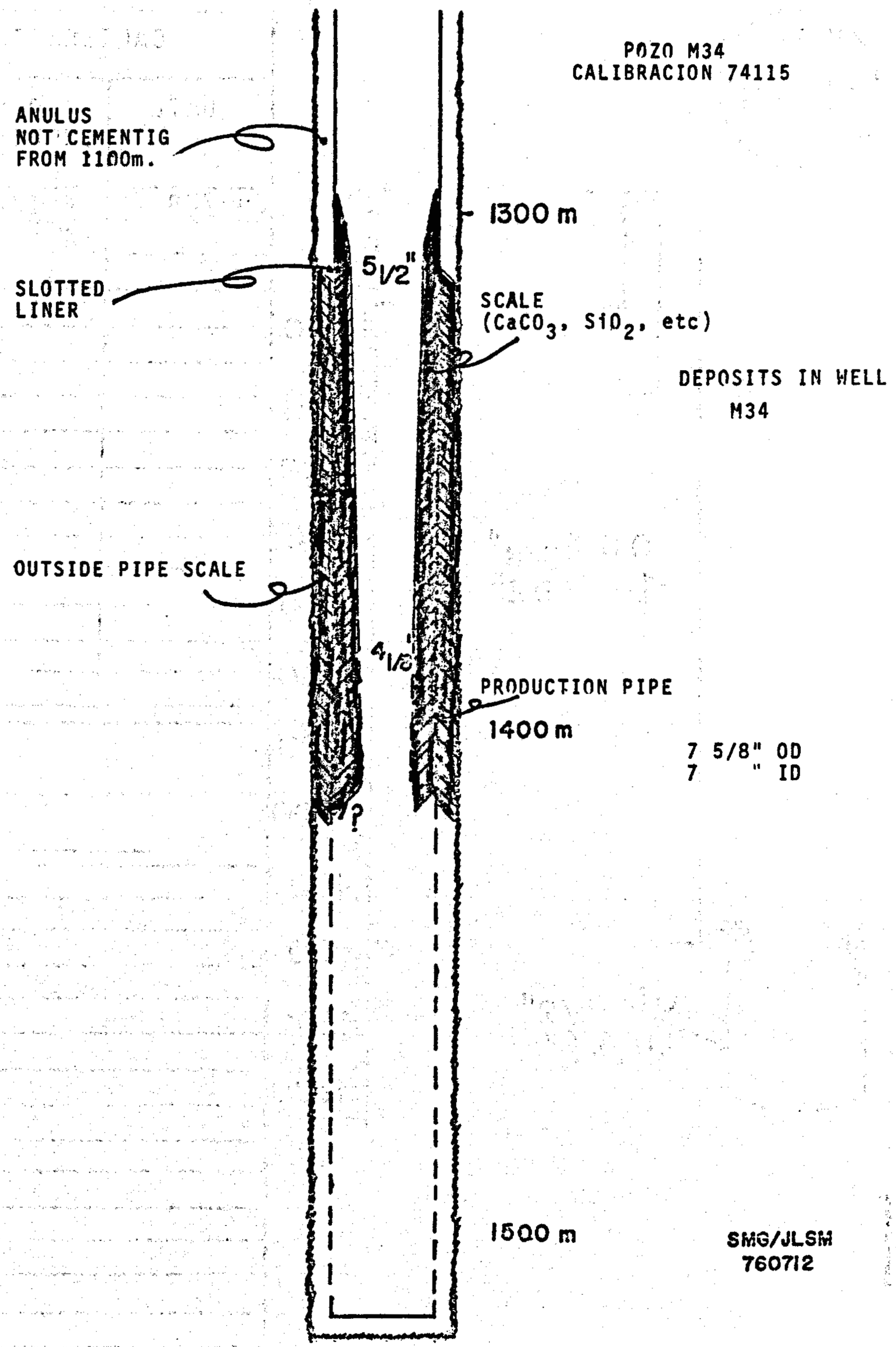


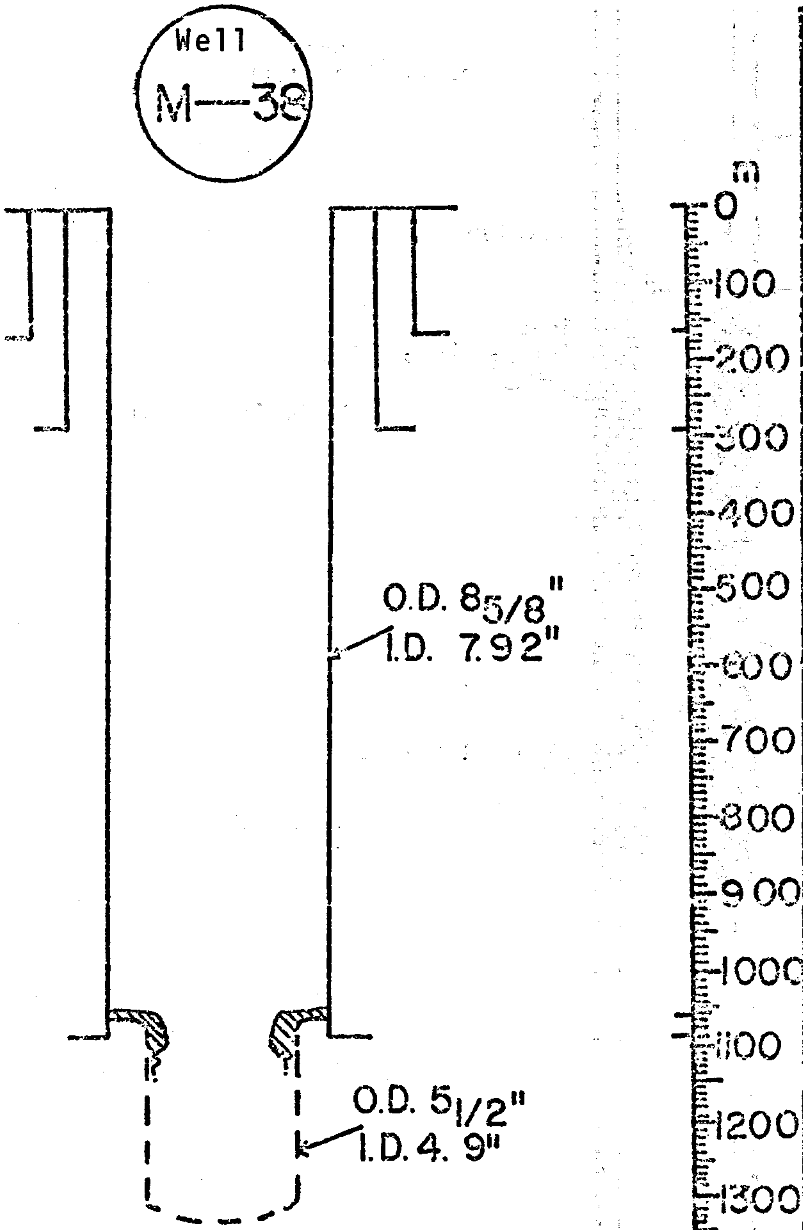
Fig. ——— PROFILE OF SCALE IN WELL M-13

SMG/JLSM
760705

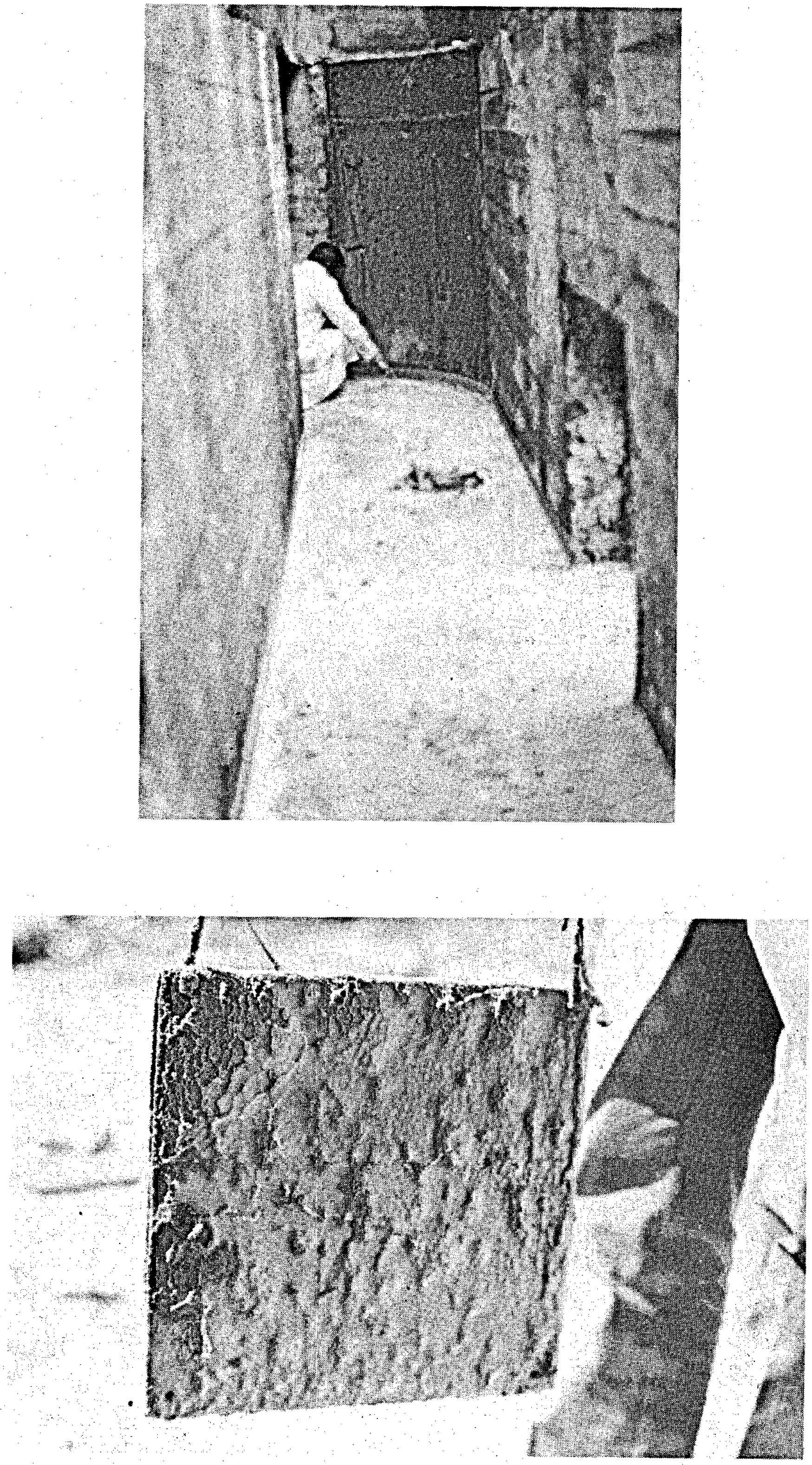
DEPOSITS OF WELL M-13 AT 591 m DEPTH



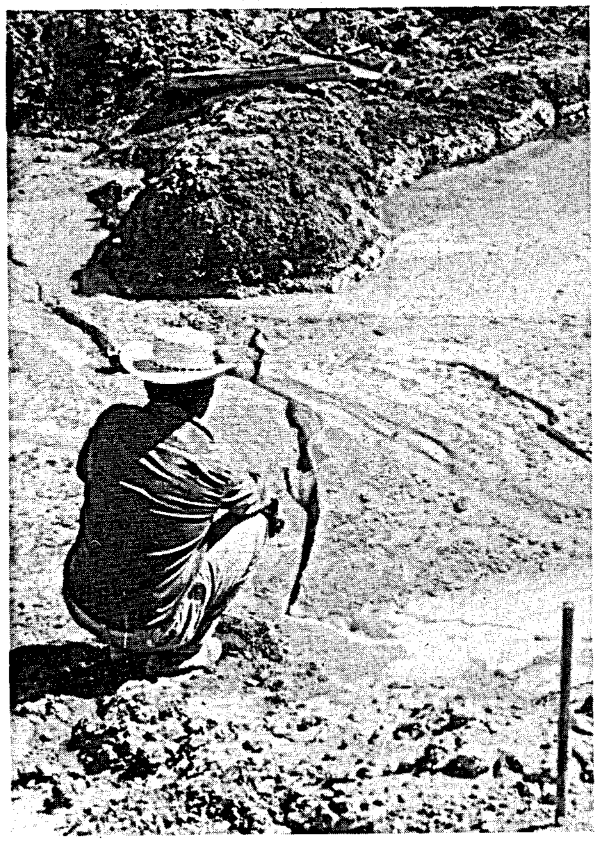

POZO M34
CALIBRACION 74115
ANULUS
NOT CEMENTIG
FROM 1100m.
1300 m
5 1/2"
SLOTTED
LINER
SCALE
($CaCO_3$, SiO_2, etc)
DEPOSITS IN WELL
M34
OUTSIDE PIPE SCALE
4 1/2"
PRODUCTION PIPE
1400 m
7 5/8" OD
7 " ID
?
1500 m
SMG/JLSM
760712



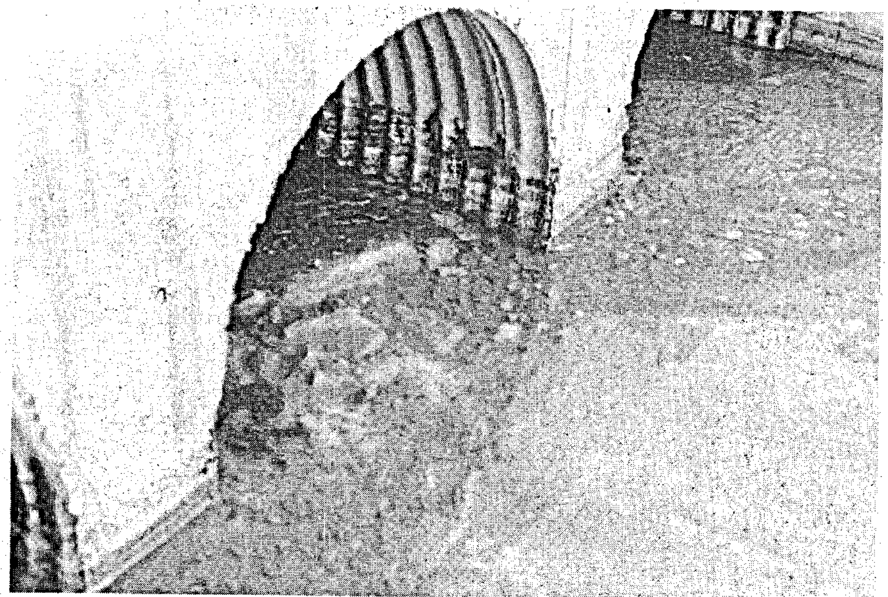
CALIBRATION		
DATE	Ø INCHES	DEPTH
Jun/68	4 1/2	1064
	4	1093



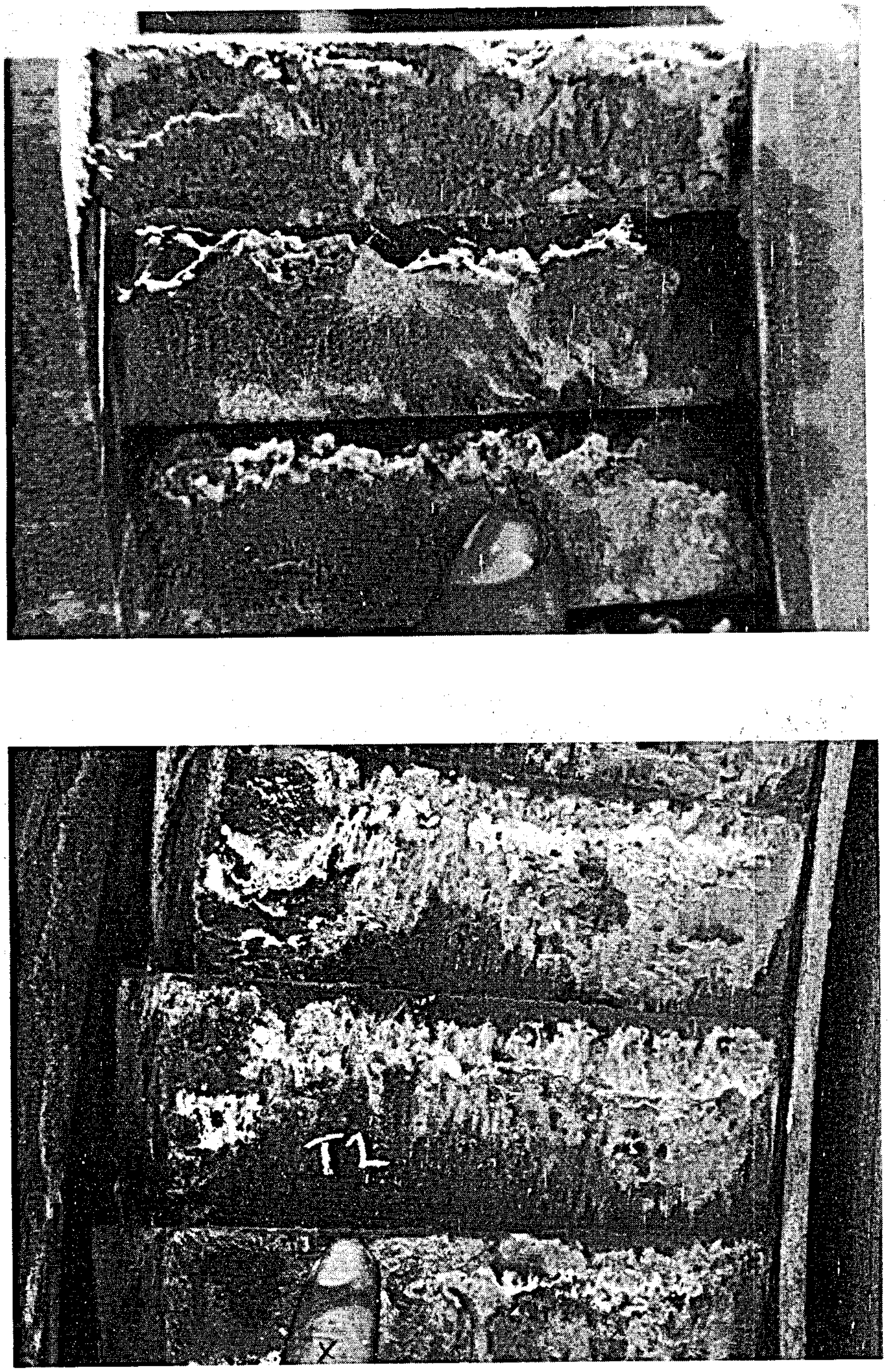
3.4.- Deposits inside of silencer: a) Bottom; and b) Test Plate.



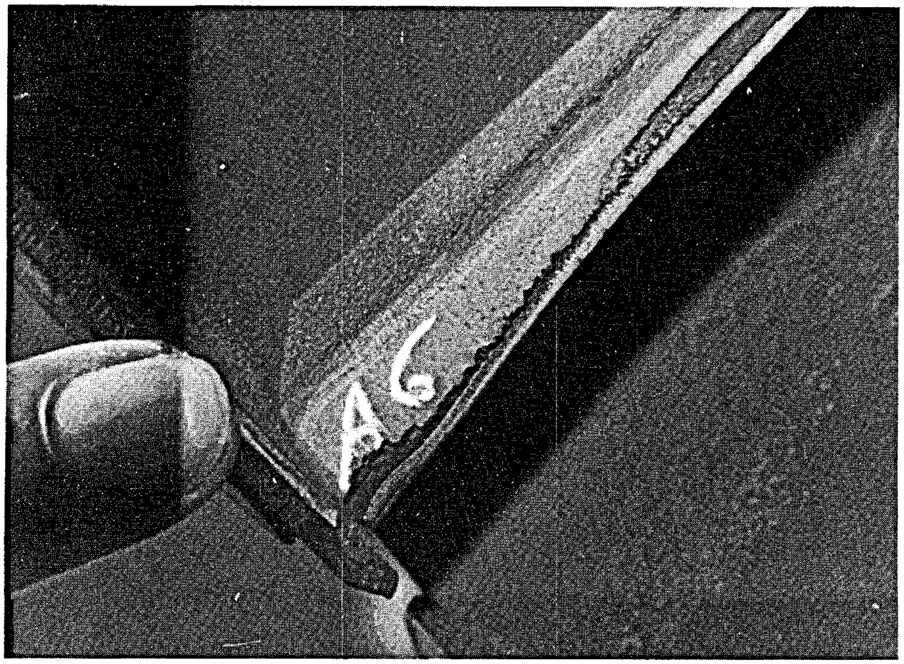
3.5.- Silica deposit (99% SiO_2) in drainage.

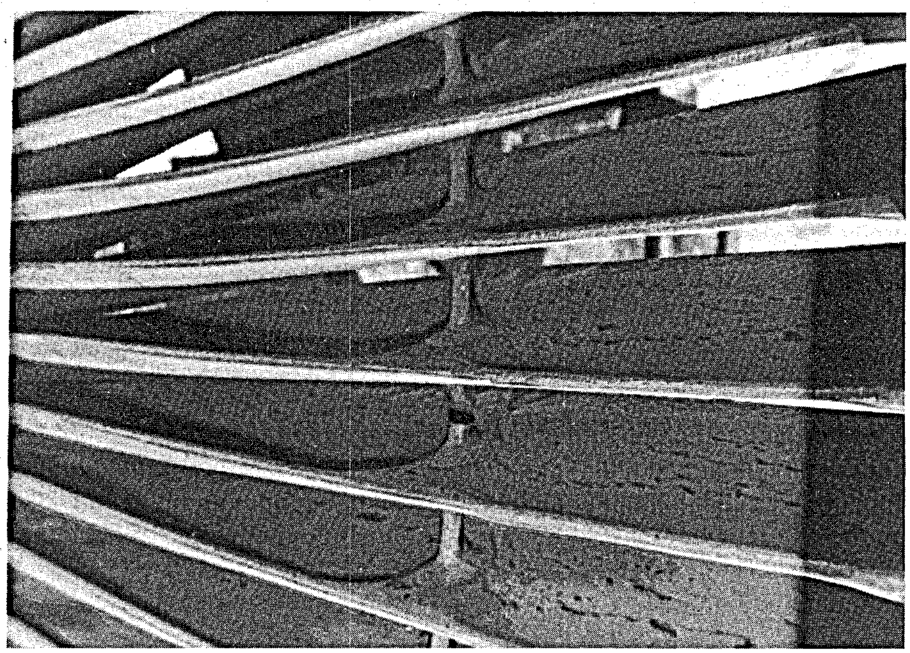


3.5.- Silica deposit (99% SiO_2) in drainage.



3.6.- Scale in turbine fixed blades. First and second steps.





3.6.- Scale in turbine blades of 6th step.