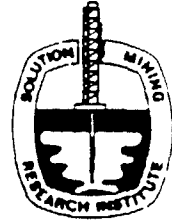


SOLUTION MINING RESEARCH INSTITUTE

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**MEETING
PAPER**



FALL MEETING 1990 - PARIS OCT. 14-19

Solution Mining Development with Single Wells in a Salt Deposit with a High Content of Insolubles

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IN A SALT DEPOSIT WITH A HIGH CONTENT OF
INSOLUBLES**

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1. THE DEPOSIT

The Timpa del Salto rock salt deposit is found at the western limits of the Crotonese Neogenic Basin, beside the Ionian Sea in Calabria (Italy). The brinefield is near to Belvedere Spinello town in the Province of Catanzaro (Figure 1).

These evaporite sediments belong to the Messinian period (Upper Miocene) and can be divided into two successive phases separated by an intra-Messinian tectonic episode (Figure 2). The lower phase comprises marls, limestones, anhydrites and a thick stratum of gypsum, whereas the upper phase, which is discordant with respect to the lower one, consists of a detrital salt-bearing formation and an overlying evaporite formation.

The detrital salt-bearing formation is made up of a base layer of well-stratified gypsums and anhydrites overlain by alternating lenses of dark marly clays, sandstones, gypsum-sandstones, gypsum-rudites, gypsums and rock salt, and by brecciated zones containing anhydrite, gypsum, gypsum-sandstone and clayey materials cemented with rock salt. These deposits seem generally to have been formed during repeated, often discordant cycles, with brecciated rocks tending to predominate at the base and rock salt at the top of each single cycle. In the upper parts, however, the border is gradual and characterised by a diminishing both of grain size and of the percentage of gypsum; the stratification becomes less well defined.

This formation represents a phase of erosion and resedimentation of recently deposited material between the basins. The detrital salt-bearing formation of Timpa del Salto deposit is not in stratigraphic contact with the overlying formation, but is transgressive: in certain places, it is directly linked with the Middle Pliocene and bears evidence of erosions from other formations. This is attributed to the concomitance of the erosion phases, particularly during the Middle Pliocene, and to compressive tectonic phases that displaced parts of the overlying formations.

Within the areas of this formation concerned by the mine, a distinction has been made between the main upper bed with an average thickness of about 220 m, and several thinner underlying beds. Clayey sandy and sandstone sediments belonging to the Plio-Pleistocene period are found above the Messinian evaporite deposits.

The deposit dips mainly towards the southeast, within a graben oriented NE-SW.

2. THE BRINEFIELD

Salt extraction by solution mining was initiated in December 1970, using a multiple-well method that was based on several hydraulically interconnected boreholes. An average of 12 - 14 wells were always operating, producing about 400 m³/h of brine containing 300 g/l of NaCl. Annual salt output was about 1 million tonnes (Figure 3).

The multiple-well method created large, irregularly shaped and interlinked voids whose size and connections remained unknown.

A large area of subsidence eventually formed on the surface with a maximum depression of about 1 meter (as of 1989), and three sinkholes appeared in 1983, 1984 and 1985.

The sinkhole that appeared on the surface on 25 April 1984, at a distance of about 400 m from the active boreholes, lies at the foot of a hill just above the large Timpa del Salto fault. The latter is oriented N-S and represents the western border of the rock salt deposit. A large mass of overlying rock and earth slid into the sinkhole causing a considerable quantity of brine to spill out, flooding the land downhill. After a long period of suspension, mining activity was gradually resumed at significantly lower production rates. The practice of hydrofracturing at high pressures was progressively abandoned. Trials were started involving the use of single boreholes whose adoption had already been planned before the event of 1984.

At present, all mining activity is by means of single boreholes and involves the southeastern area of the deposit.

The average output averages is about 0.6 million tonnes of salt per year, from 16-17 active wells (Figure 4).

In order to maximise the security of operations in the new brinefield, a series of control systems, including computer-aided continuous monitoring, has been set up to monitor micro-seismic activity, evolution of subsidence, stability of hill slopes, and variations both of water table levels and the characteristics of surface and subsurface water.

In the areas where the mining activity has modified the environment, significant land reclamation works have been carried out involving levelling, transport of top soil and seeding of indigenous species.

3. THE INSOLUBLES

Saltbed 1, which is the one currently being mined, has a high content of insolubles. Figures 5 to 8 showing the salt logs of the 17 existing single boreholes reveal an average solubles content of 31.2%.

However, not all of the saltbed is exploited because of the need to leave a substantial slab of rock salt in place in order to support the overlying clayey structures and thereby guarantee the stability of the void.

The design thicknesses both of the slab and supporting pillars and the design diameter of the voids were determined by K.B.B. of Hannover by applying the finite elements method and using the findings of laboratory tests aimed at determining the mechanical characteristics of this rock salt formation.

When account is taken of the slab to be left in place, the average content of insolubles of the minable area of saltbed 1 is 28.2%.

4. THE MINING ACTIVITIES

The high percentage of insolubles (28.2% on average) in saltbed 1 and the related coefficient of increase of volume raise a number of problems with regard to the initial phase of void formation.

In fact, when a void is first started, the insolubles must have sufficient sump space to settle or they will plug the borehole.

Several methods for starting a new void have been tested, involving both direct and indirect injection, modifying the rate of injection and modifying the diameters of the casings and tubings.

The results suggest that the best technique for starting a new borehole is the direct method (injection through the tubing), using 5" tubing and 9 7/8" casing and flow rates of 50-60 m³/h (Figure 9).

Because of the grades characteristics of the deposit and in order to obtain a brine with a sufficiently high content of salt, it was necessary to use two boreholes in series. The brine from the first borehole, which has an average content of 200-220 g/l of salt, is injected into the second borehole, from which it emerges with a salt content of 295-300 g/l.

The direct method is used in the first borehole to make sure that the water does not come into contact with the roof of the void as this would provoke a rapid rise of the solution process. The indirect method is used in the second borehole to obtain a more saturated brine.

The use of a blanket is also being tested and some of the boreholes are still operating with this method. It is perhaps premature to draw final conclusions regarding the validity of this method in the Belvedere Spinello brinefield. At this time, it can only be said that the boreholes without a blanket but with a casing that is cemented up to the hanging wall of the underground void seem to be giving better results because the cementing seems to stabilise the rock salt around the casing as well. In the boreholes with a blanket, where fuel oil replaces the cementing around the casing, rock salt has frequently broken off within the borehole. This has occurred because the geomechanical characteristics of this detrital salt-bearing formation, which is made up of breccia and alternations of clays, are poor.

The presence in the salt-bearing formation of clayey alternations seems to create a sort of natural blanket. The void thus tends to develop in a uniform manner without the preference for evolving upwards that would occur in the case of a pure NaCl deposit.

5. CONTROL OF VOID FORMATION

Mining activity in a given borehole involves several successive steps. A step is defined as representing the period during which the points of injection and outflow of liquid (water or brine) remain unchanged. A step generally ends either when production from the borehole becomes difficult due to plugging of the tubing as a result of the accumulation of insolubles in the sump of the void, or when the weight of extracted salt reaches a pre-determined quantity. Measurements within the borehole are then carried out by means of logs that allow to identify, in the area around the casing, the maximum elevation attained by the solution process (hanging wall of solution). All the required data are then inputted into the PC and the Cavita model is run to draw the section of the void. Analysis of the section then allows to decide whether or not to cut the casing and/or raise the tubing.

The parameters that characterise each production step are:

- the elevation at which the fluid is injected,
- the elevation at which the fluid is pumped out,
- the weight of NaCl extracted during the step,
- the elevation of the solution hanging wall when the step ended,
- the salt grade of the part of the saltbed that was exploited during the step. This grade is calculated automatically by the model on the basis of the salt logs. The content of insolubles along the length of the borehole is also calculated.

The salt log is calculated by a computer programme that correlates the results of the chemical analyses carried out on cores taken when the borehole was drilled with the findings of the logs prepared afterwards: formation density, gamma ray, neutron and sonic logs.

The shape and the size of the voids that are created are systematically controlled using the special Cavita mathematical model. The latter has been installed on the mine's PC and uses only the data collected during the solution mining activity (Figures 10-13).

Once a year, a sonar survey by echo-log is carried out to measure the shape and dimensions of the voids.

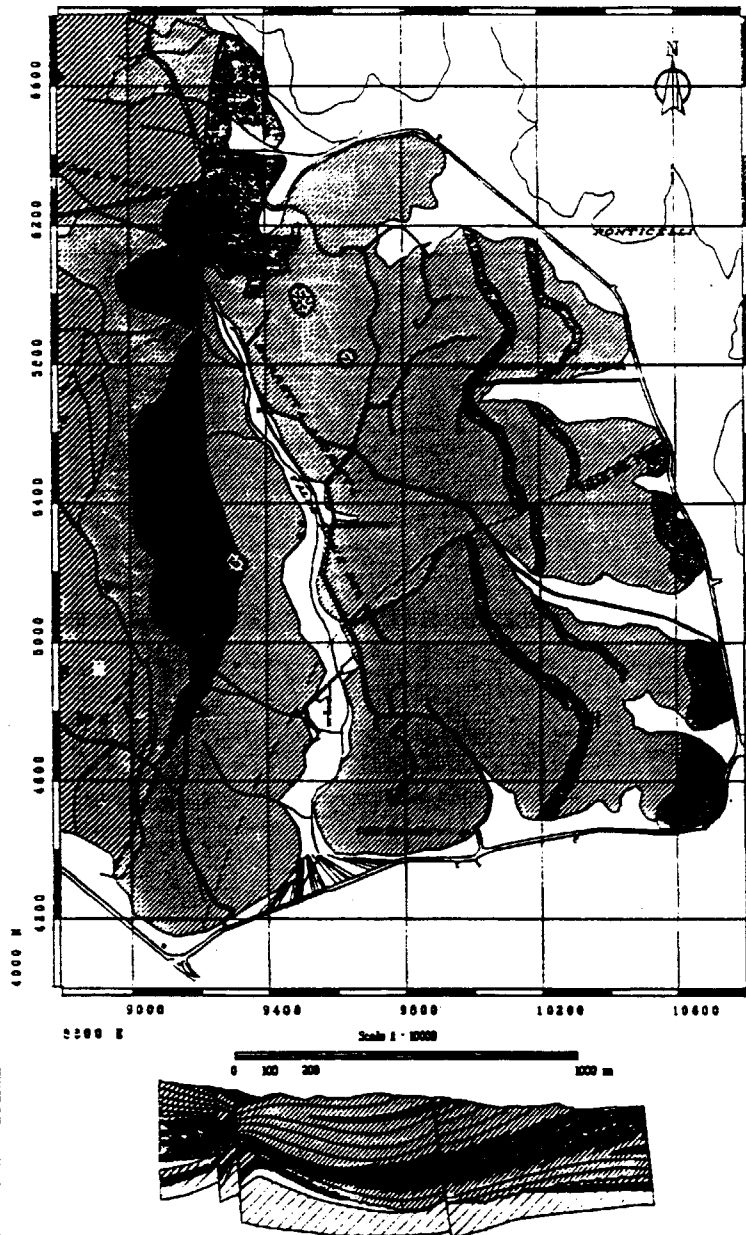
Comparisons of the drawings of the void that have been "calculated" with those that have been "measured" (Figure 14) reveal an excellent level of correspondence. This allows to conclude that the day-to-day control of void formation by means of the Cavita model can provide a reasonably close approximation of how the voids created by solution mining are developing. This makes it possible to manage the mining activity and make any

interventions that are necessary to ensure that the voids develop in the desired shape and size as determined by the design.



CARTA GEOLOGICA BELVEDERE SPINELLO

MINING ITALIANA S.p.A.



- ALLUVIONI RECENTI TERRAZZATE
- ARENARIA DI S.MAURO
Alternanza di sabbie calcaree e sabbie a deboli
contenimenti di colore dal giallo al rosso
- ARGILLA MARNOSA DI CUTRO
Potente successione costituita da argilla, argilla marnosa
con interstratificazioni sabbiose
- ARENARIA DI SCANDALE
Formazione prevalentemente arenacea con sabbie e
argille quarzose distinguibile dai sandstones
di Faidutti e quella di Scandale
- ARGILLA MARNOSA DI SPARTIZZO
Alternanza di argille marnose scure e arenarie quarzose
chiate con un membro inferiore arenoso quarzoso bianco
ricco in Carboni e Pteridofiti
- ARENARIE DI ZINGA
Alternanza di arenarie e sabbie, spesso quarzose
interstratificate di livelli limoniosi
- MARNA ARGILLOSA DEI CAVALIERI
Argille grigio scure alla base e bruno alla sommità
- CONGLOMERATO DELLE CARVANE
Conglomerato poligeno con clasti di elementi
sub-circolari, sferici, ovali di granito
gesso e marciante
- FORMAZIONE EVAPORITICA SUPERIORE
Alternanza di argille marnose giallo verdastre, argille
giallastre, gesso, gesso e argille con carboni
e pteridofiti
- FORMAZIONE DETRITICO SALINA
Alternanza di galestri, argille marnose scure,
arenarie quarzose, gesso e argille con carboni
e pteridofiti

Faglia probabile

Camini di collasso

Faglia

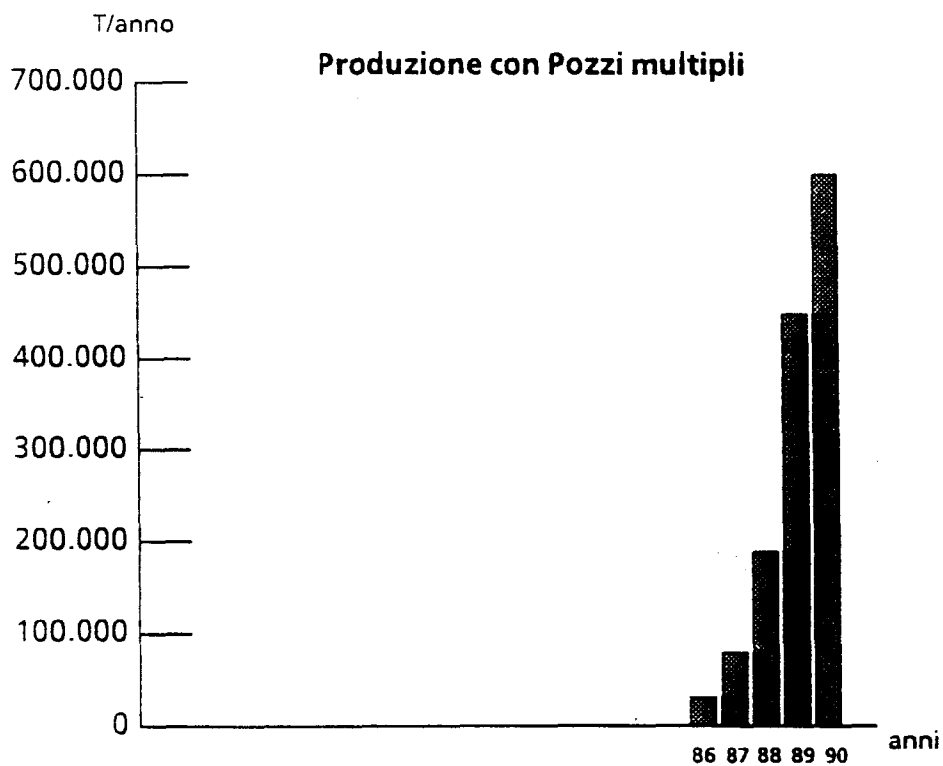
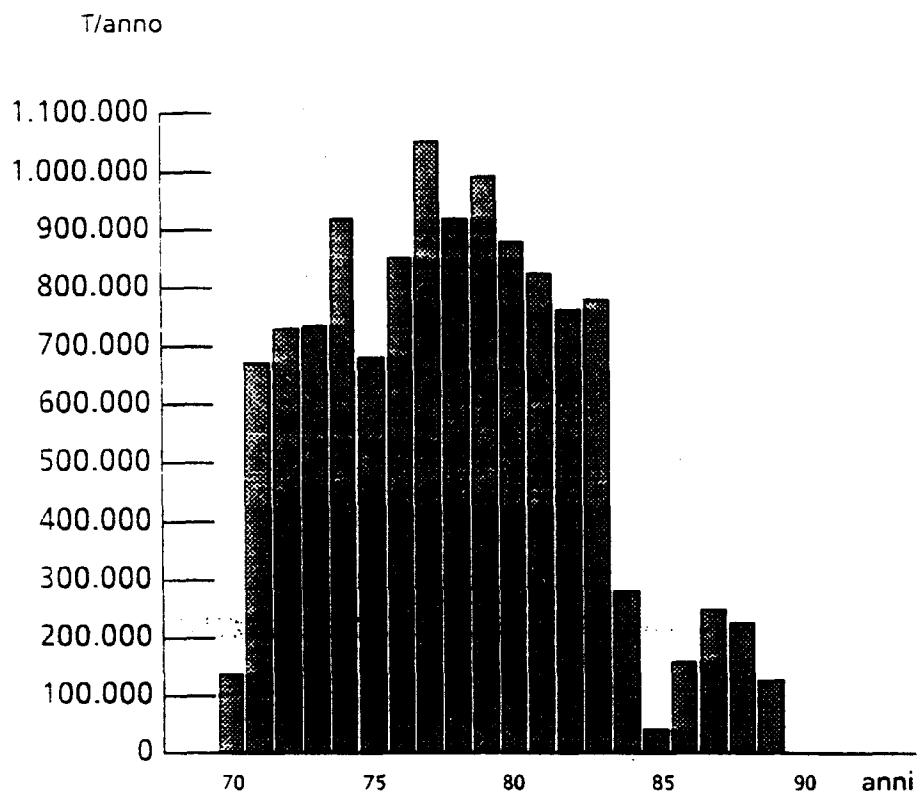
Conoide di deiezione

→ 15 - 30 gradi

→ 30 - 45 gradi

Figure 2

PRODUZIONE DI SALE



Produzione con Pozzi Singoli

Figure 3

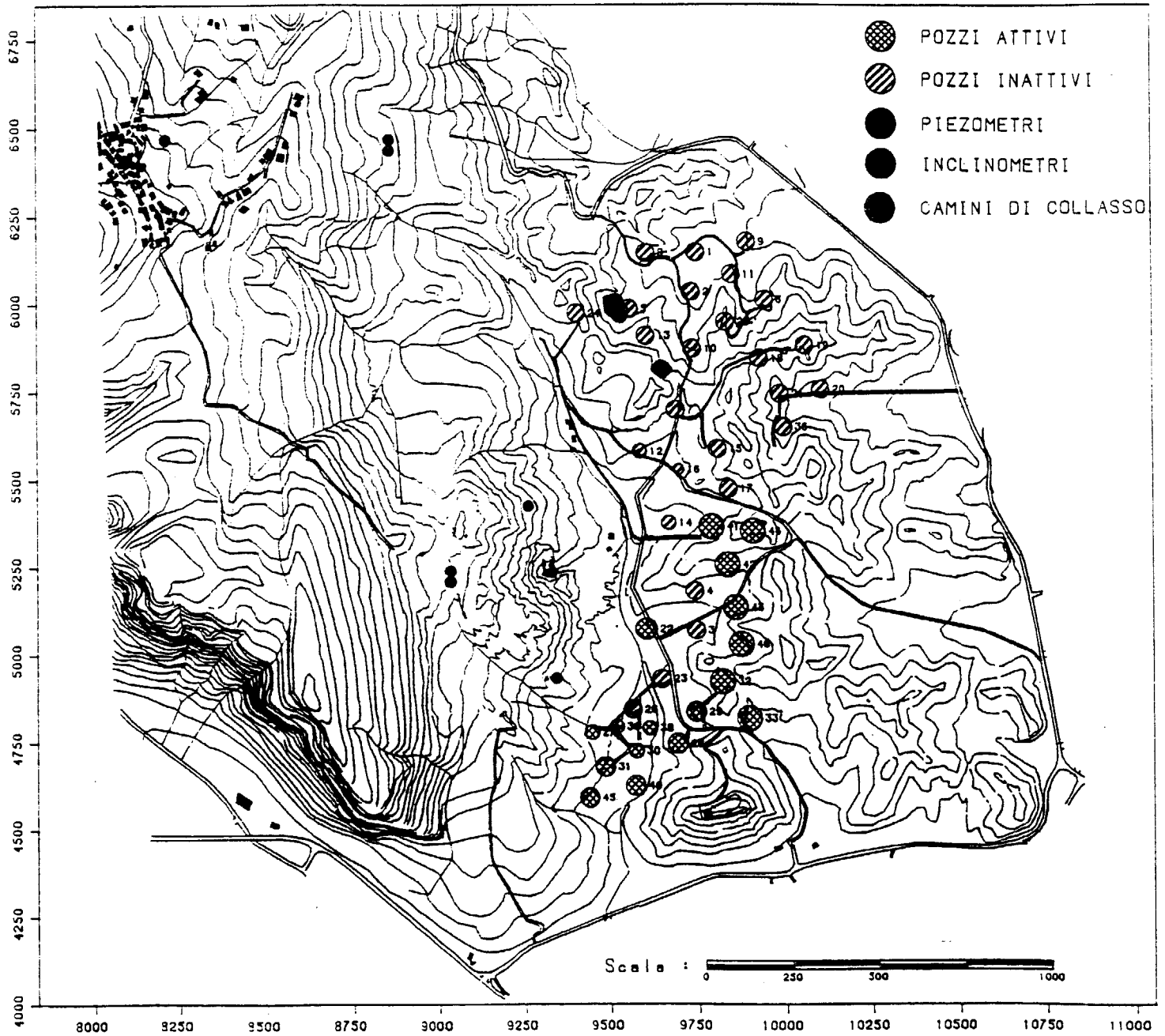


Figure 4

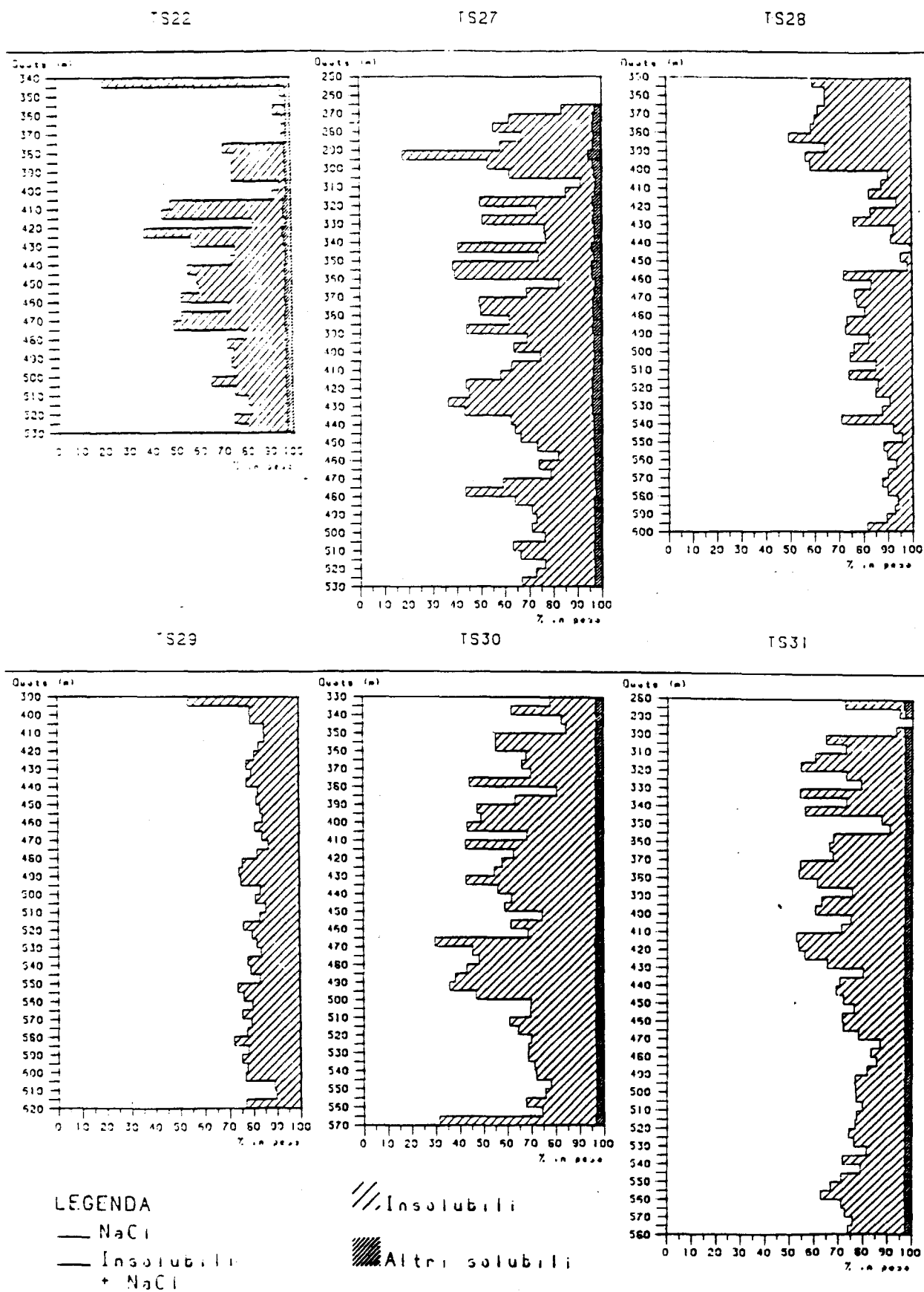


Figure 5

TS44

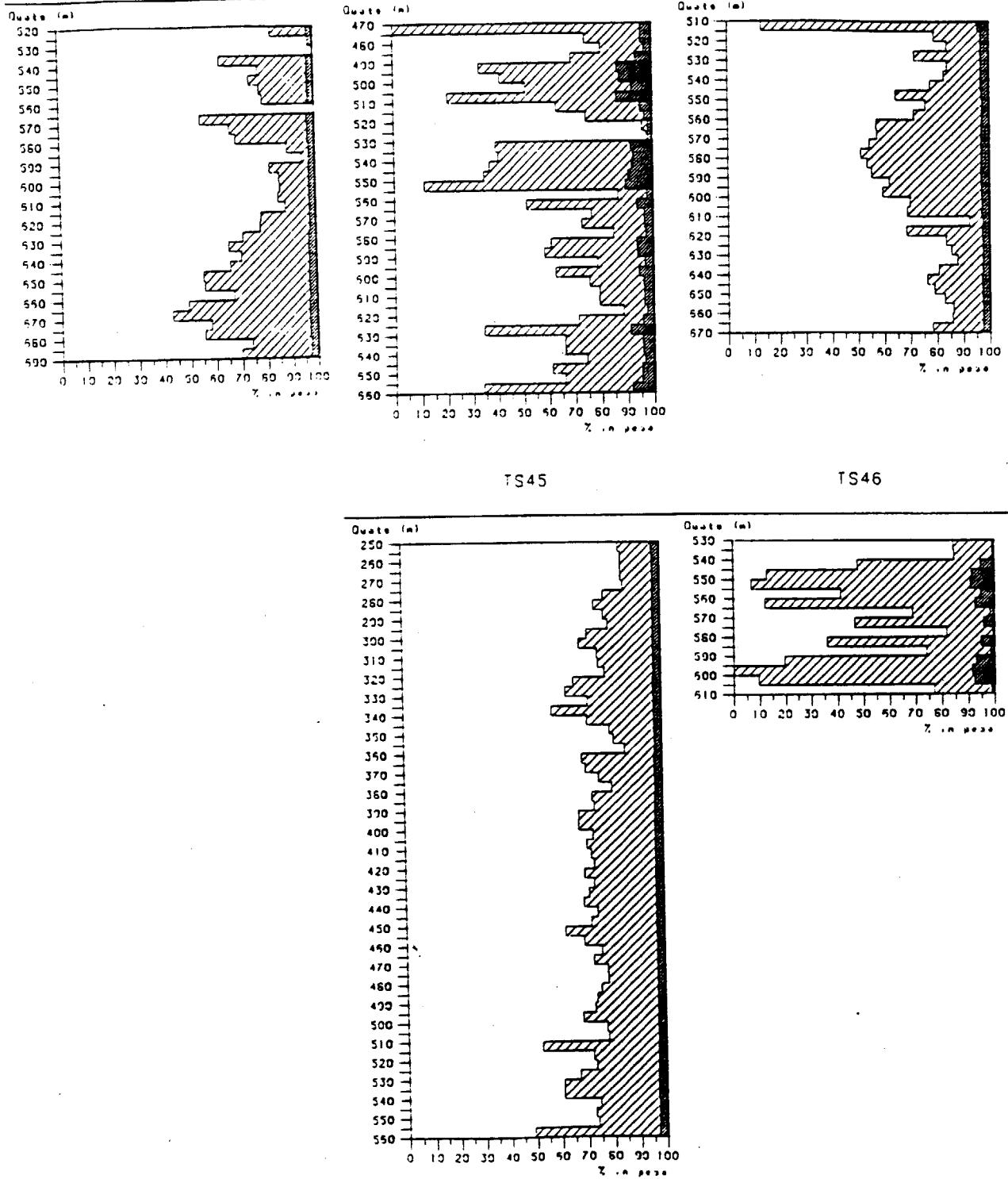
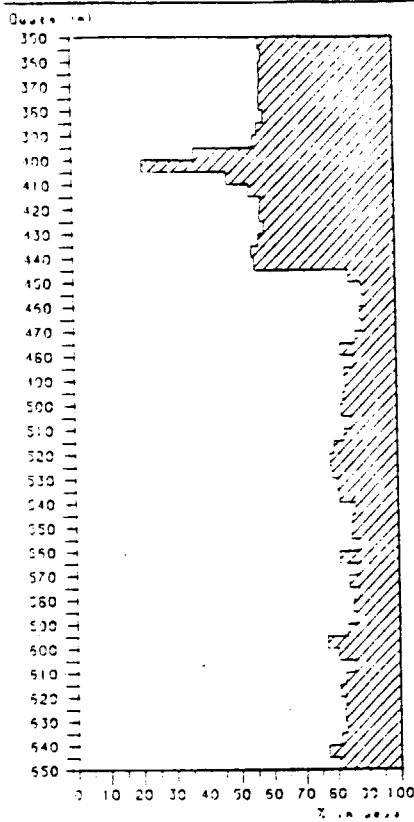


Figure 6

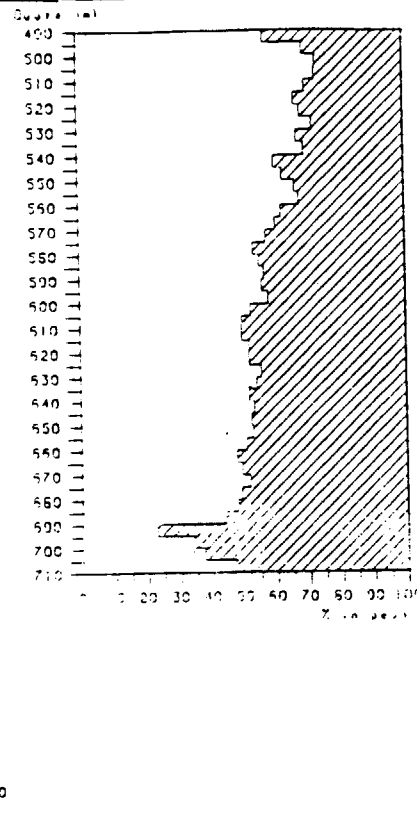
TS32

TS33

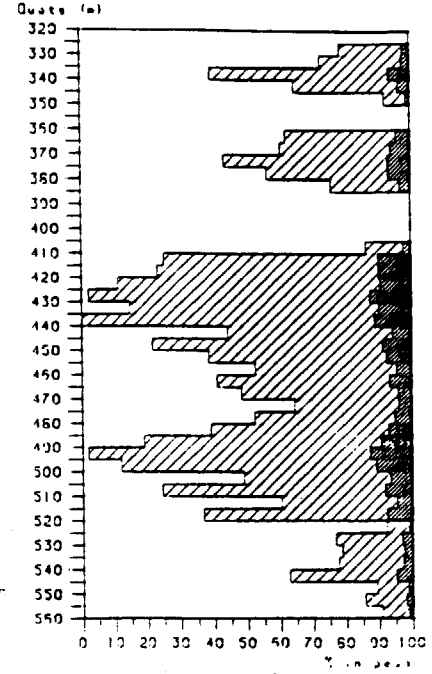
TS38



TS39



TS40



TS41

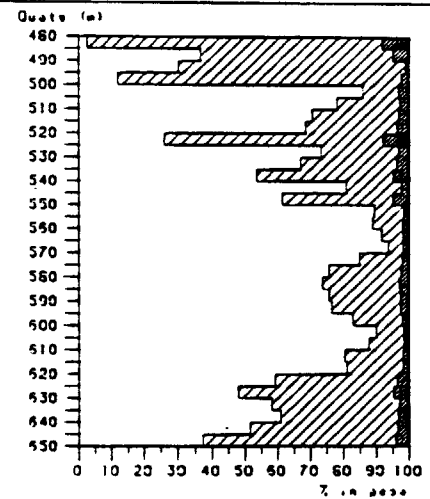
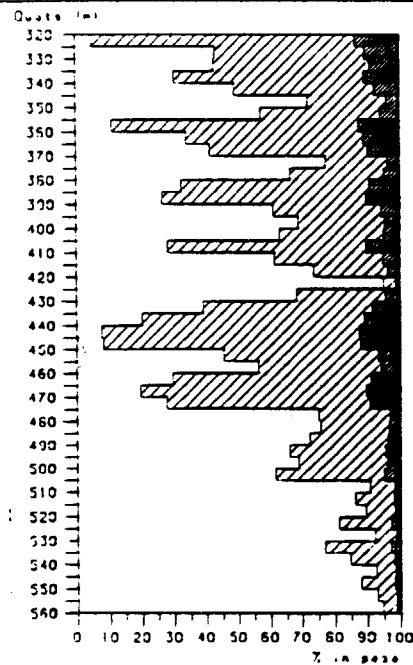
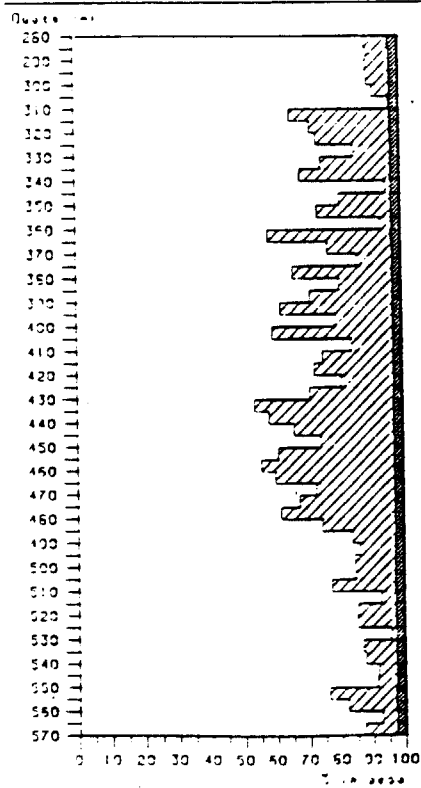


Figure 7

Figure 8

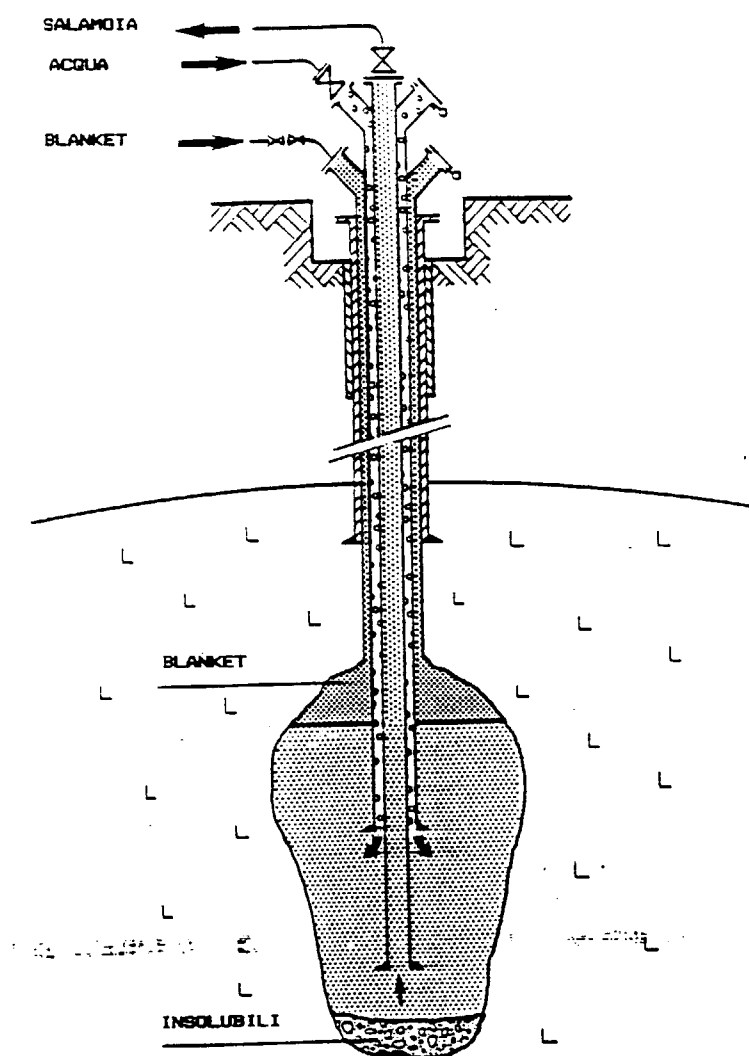


Figure 9

POZZO : TS29

Fatt. aumento volume sterile : 1.30
 Letto iniziale (m) : -619.0

N.P.	Data	Q. iniezione fluido (m)	Q. estrazione fluido (m)	Temperatura in peso (°C)	Peso NaCl estratto (t)	Vol. NaCl estratto (mc)	Vol. Tot. scavato (mc)	Tetto dissoluz. (m)	Volume cavita' (mc)	Quota sterile (m)	Raggio cavita' (m)	Superficie cavita' (mq)	Velocita' scavo NaCl (kg/mq/gg)	
1	23-04-82	-618.5	-605.4	80.4	5177	2397	2913	-605.0	0.78	1984	-615.7	9.8	911.3	0.00
2	28-05-85	-618.0	-605.4	82.6	14138	6545	7834	-596.0	0.35	5515	-611.1	13.9	1398.8	7.26
3	22-10-85	-618.0	-605.4	82.4	29114	13479	16672	-590.0	1.09	11404	-605.7	19.8	2144.7	57.50
4	12-04-86	-618.0	-605.4	80.5	38740	17935	21479	-588.5	3.12	15100	-603.6	24.2	2543.8	17.62
5	17-07-86	-592.0	-600.0	78.8	42893	19858	23857	-586.5	0.94	16658	-602.9	25.2	2864.6	43.88
6	06-05-87	-600.0	-592.0	78.1	48230	22329	26939	-584.0	0.47	18640	-602.0	26.1	2978.1	6.24
7	13-09-87	-600.0	-592.0	77.6	54075	25035	30334	-582.0	0.62	20795	-600.8	26.9	3167.7	14.63
8	17-03-88	-600.0	-592.0	75.9	89334	41358	51221	-573.0	0.35	33468	-597.3	31.8	4900.4	46.99
9	11-05-88	-600.0	-592.0	75.6	94209	43615	54121	-571.0	0.31	35211	-596.4	29.4	4199.2	19.48
10	26-08-88	-574.5	-587.3	75.6	100345	44456	57770	-570.5	2.50	37405	-595.2	29.6	4347.6	13.42
11	12-12-88	-587.3	-574.5	76.1	120377	55730	69610	-565.5	0.62	44626	-593.1	31.5	5402.4	38.05
12	03-04-89	-574.5	-586.6	75.9	158309	73291	92075	-560.0	1.09	58264	-589.9	34.5	6963.8	55.27
13	10-07-89	-562.0	-574.0	76.1	181371	83968	105704	-557.0	1.56	66579	-588.0	35.8	6863.7	34.04
14	22-08-89	-562.0	-574.0	76.4	184611	85468	107614	-554.0	0.62	67751	-586.9	36.1	6790.9	11.04
15	20-09-89	-562.0	-571.8	76.4	185931	86079	106392	-553.0	1.25	68229	-586.6	36.5	6622.3	6.79
16	12-02-90	-562.0	-571.8	76.3	206144	95437	120305	-549.8	0.94	73542	-585.1	38.0	7544.1	19.68
17	03-05-90	-551.0	-571.8	76.2	214497	99304	125240	-547.0	1.25	78556	-583.8	37.7	7637.9	13.75
18	31-05-90	-551.0	-571.0	76.0	216761	100352	126580	-546.0	1.25	79370	-583.5	37.4	7355.7	10.79
19	20-07-90	-551.0	-571.0	76.1	220521	102093	128802	-544.0	0.62	80726	-582.6	37.7	7540.9	10.10

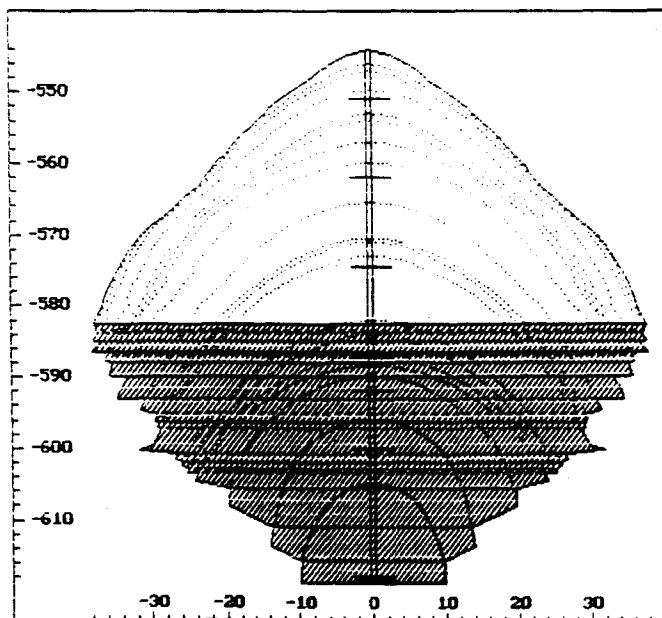


Figure 10

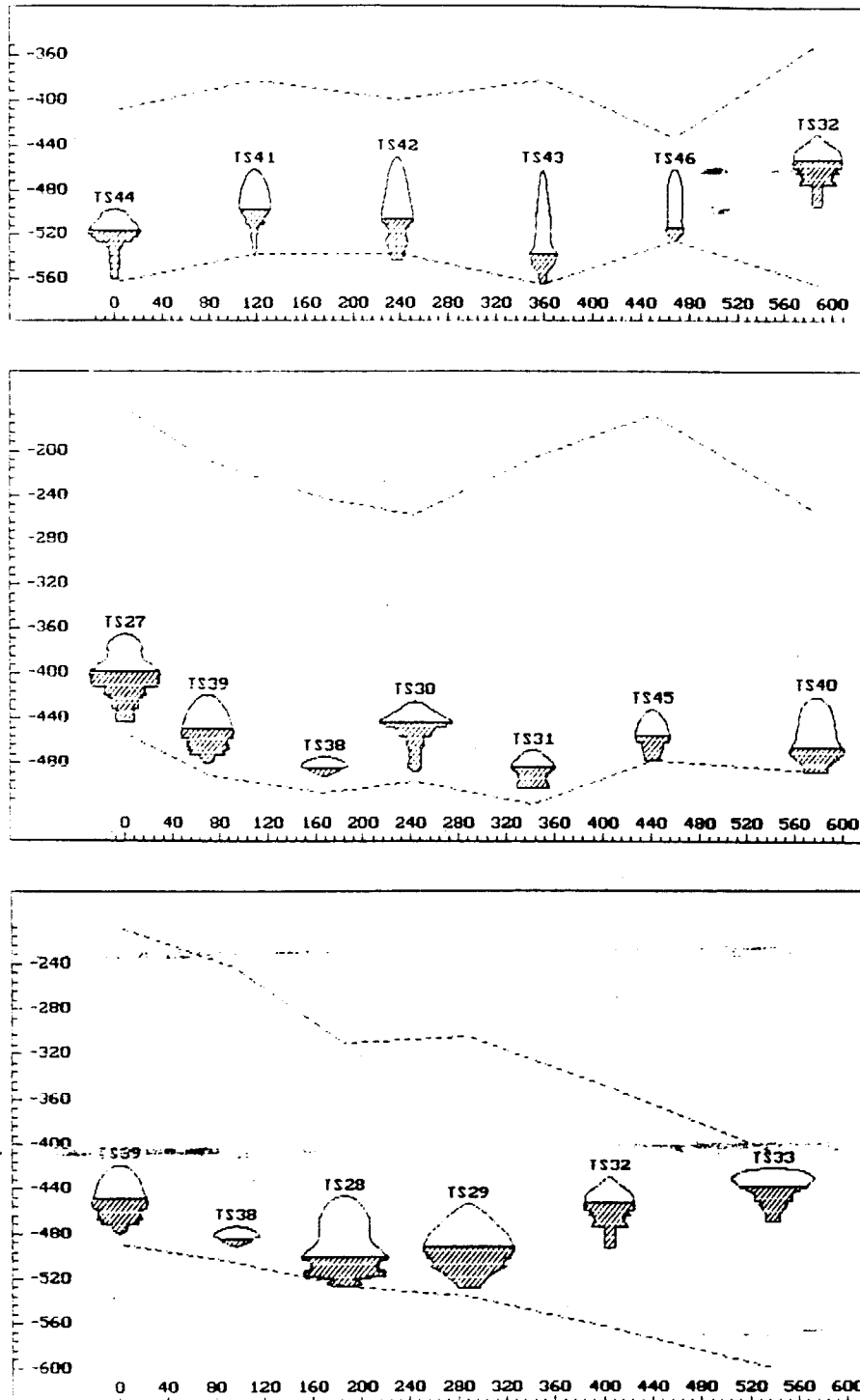


Figure 11

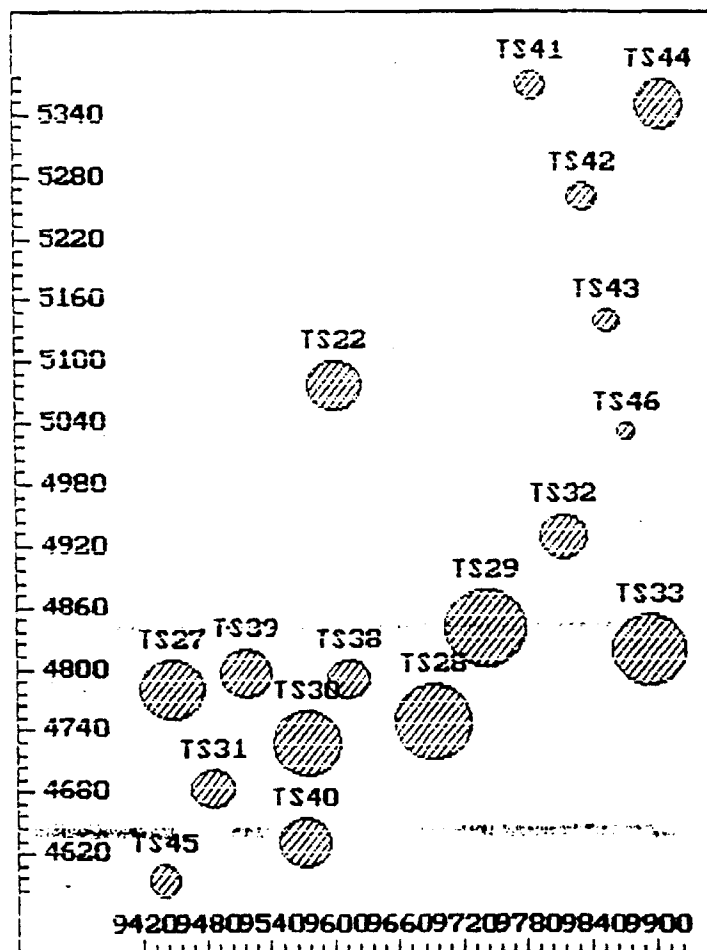


Figure 12

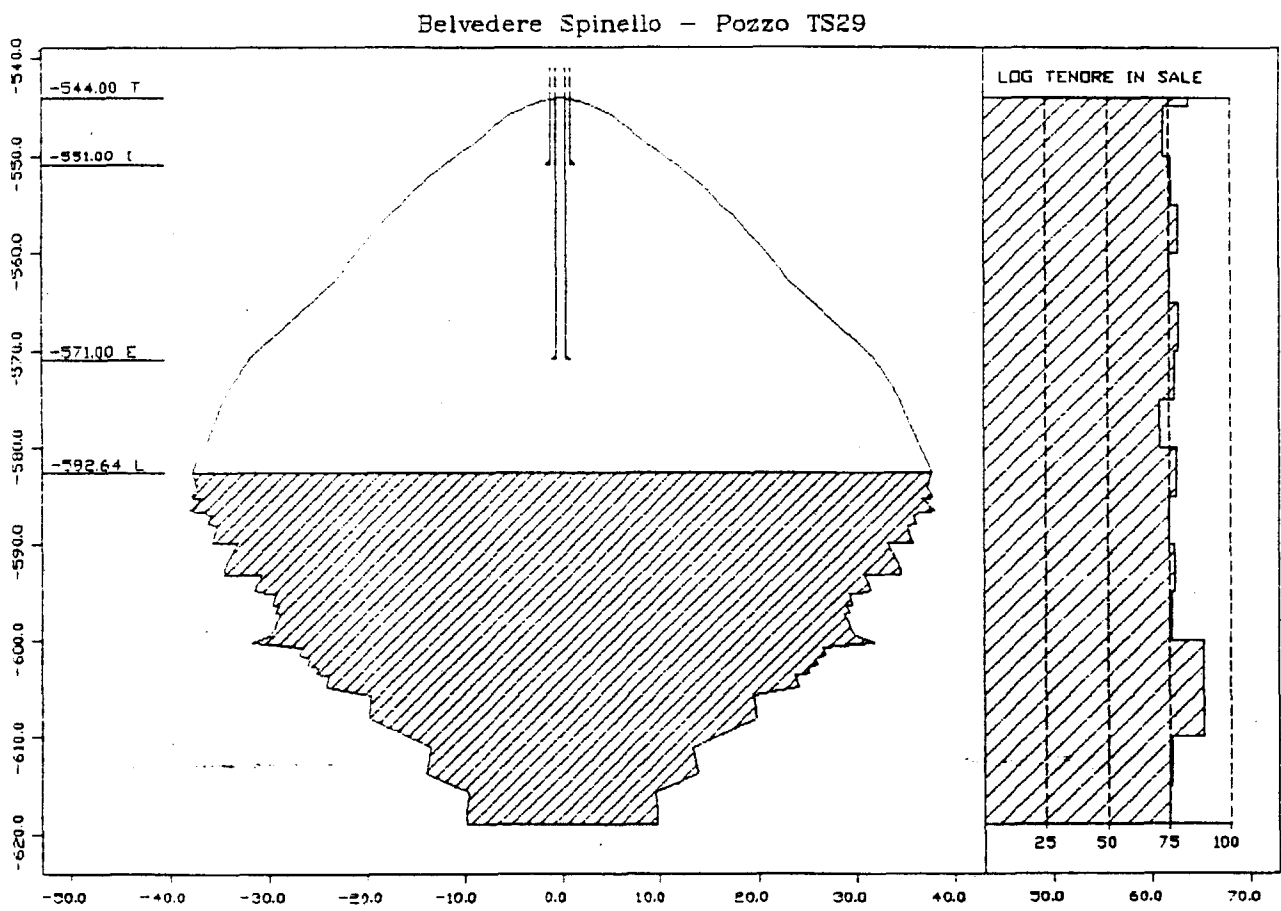


Figure 13