Pore Pressure Development within Low Permeability Soils and its Incidence on Slope Configuration at the Puentes Mine - LaCoruña, Spain

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ABSTRACT

The EMPRESA NACIONAL DE ELECTRICIDAD, S.A. (ENDESA) owns a lignite open pit in the province of La Coruña, NW of Spain. The deposit is within a Tertiary sedimentary basin of a tectonic origin. Its stratigraphic series consists of an alternancy of soils, mainly impervious clays and lignite.

Open pit operations demand a slope design which includes a mole drainage system. The main problem faced here is how to drain very low permeable soils. Monitoring and study of piezometric development of this kind of materials have allowed us to understand those motions which favour pressure dissipation, thus enhancing a positive slope design according to convenient periods of time and to payable demands.

Results covering the works undertaken over several years of investigations are presented in the paper, together with their practical applications.

INTRODUCTION

The Puentes mine is situated nearby the Village of As Pontes within the Province of La Coruña, NW of Spain. Figure 1 shows a general layout together with the information about the main Tertiary basins within the area.

As it may be seen from Figure 1, on this area there are a set of fairly big basins striking NNE-SSW, whereas on the other hand, on a section more to the north, there is another group of basins very different from the previous ones, since they are smaller and they strike NW-SE and at the same time they are linked to two complex structure faults (Bacelar et. all., 1988). Belonging to this group we may find the As Pontes lignite deposit.

The lignite deposit is being mined by the EMPRESA NACIONAL DE ELECTRICIDAD, S.A. (ENDESA), having an approximate output of 12 MT_m lignite/year to feed (with T_m denoting metric tons) a 1,400 MW Power Plant belonging to the same company and located nearby the mining area. The mining ratio (waste/m^3/lignite T_m) ranges between 3 and 4, meaning that the waste amounts to 40 Mm^3 which is conveyed to an outside dump. The deposit area covers about 15 km^2 and the overall mineable reserves were about 300 MT_m half of which have already being mined.

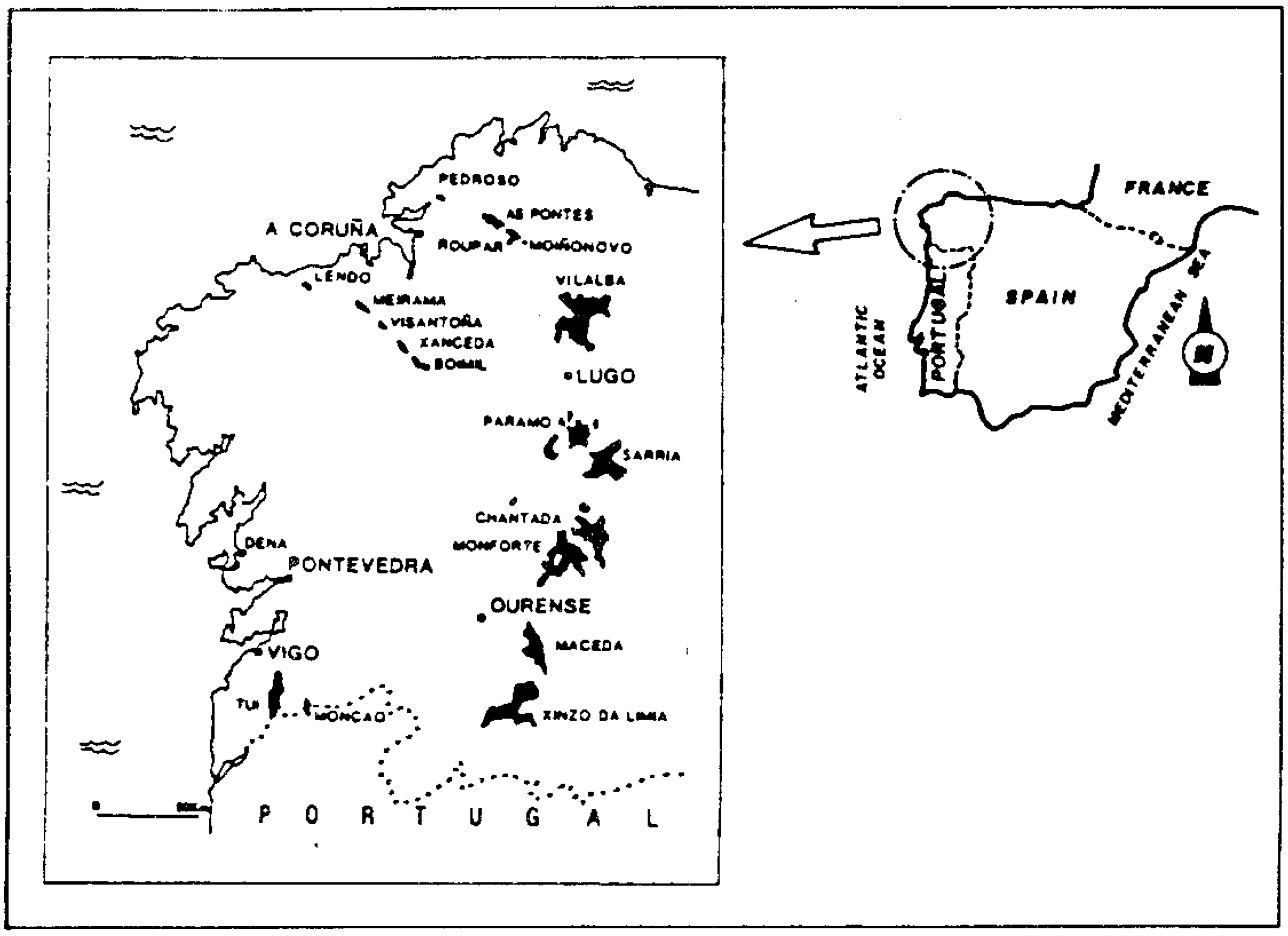


Figure 1: Geographical location and main Tertiary basins on the NW of Spain.

GEOLOGICAL, GEOTECHNICAL AND HYDROGEOLOGICAL SUMMARY

Geology

The Puentes deposit is a Tertiary sedimentary basin of a tectonic origin, formed by a series of clays, marls, sands and different kinds of lignites (brown lignite, xiloid lignite and pyropisite) having frequent lateral changes of facies. It is of an elongated shape and on its northern border it reaches its maximum depth, up to 600 m, because the border was very active, whereas its southern border is of an erosional discordance nature.

The maximum thickness of a lignite layer is 30 m and the total mineable lignite depth is 100 m.

Tertiary deposits dip north, ranging from 5° to 15°, due to their northern border sinking. Towards the series wall it is where we find the higher part of clayey materials such as kaolinite, illite and montmorillonite.

On the Eastern Field there accumulate alluvial detritus from the Eume River. At the same time, on nearby areas to the active border where the sedimentary process is stronger, there appear also fine sand to medium sand deposits.

All of the series mentioned are placed upon a Precambrian-Ordovician basement made of porphyritic schists and gneiss (Precambrian), as well as phyllites, quartzites and grauwackes (Lower primary and middle one).

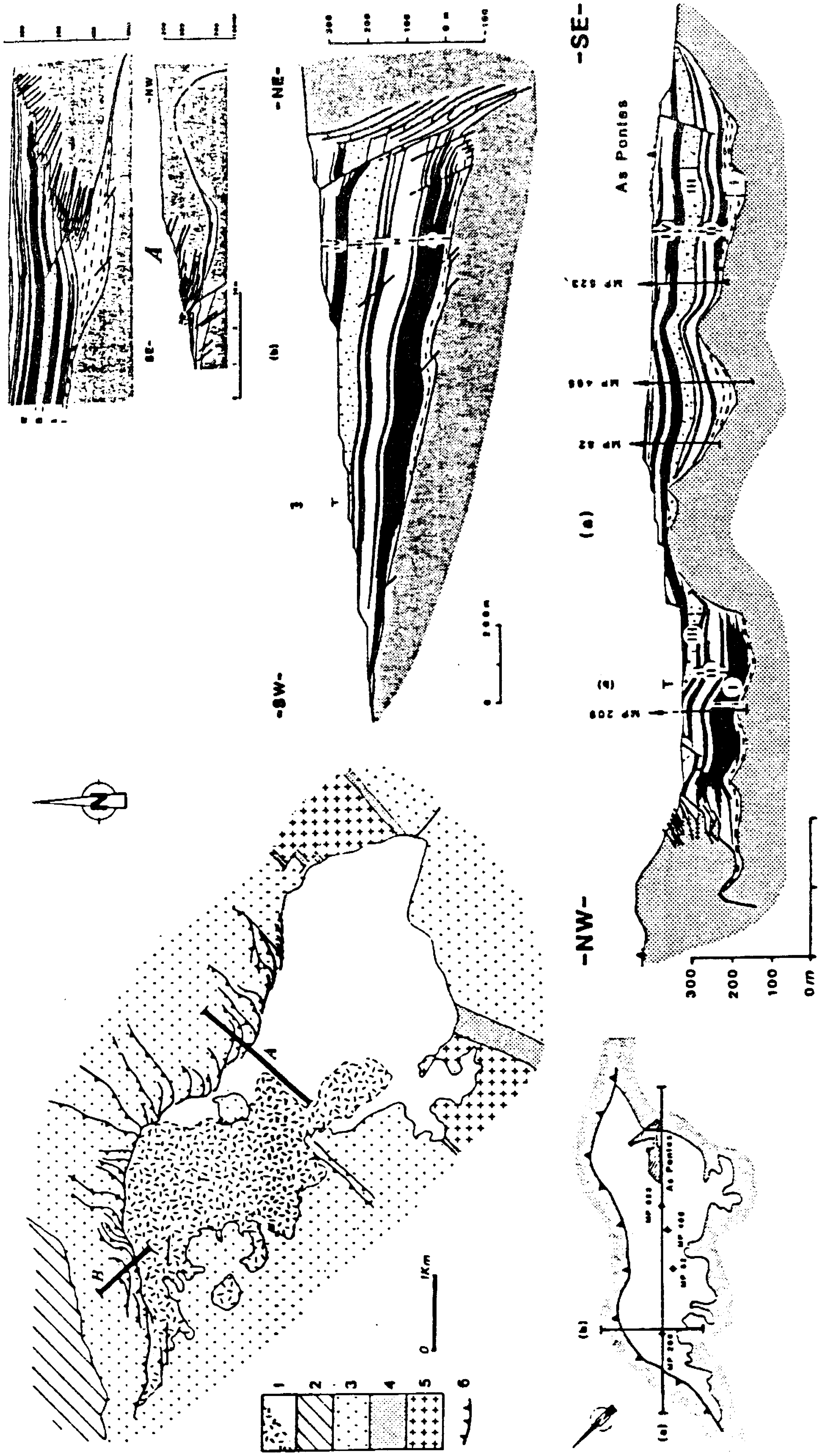


Figure 2: Showing a geological layout of the deposit as well as some representative profiles of the basin and some details of the active borders.

Geotechnics

From a geomechanical point of view, the most representative materials are the following ones:

- Tertiary materials: clays, lignites, sands and middle lithological materials.
- Primary materials: basically phyllites with quartzitic bands. Rock behaviour depends on the tectonizing and weathering degree they have suffered. Based on the aforesaid, three groups can be identified under the name of: "weathered", "tectonized" and "sound" rocks.

The main discontinuities which appear on the rock are the following:

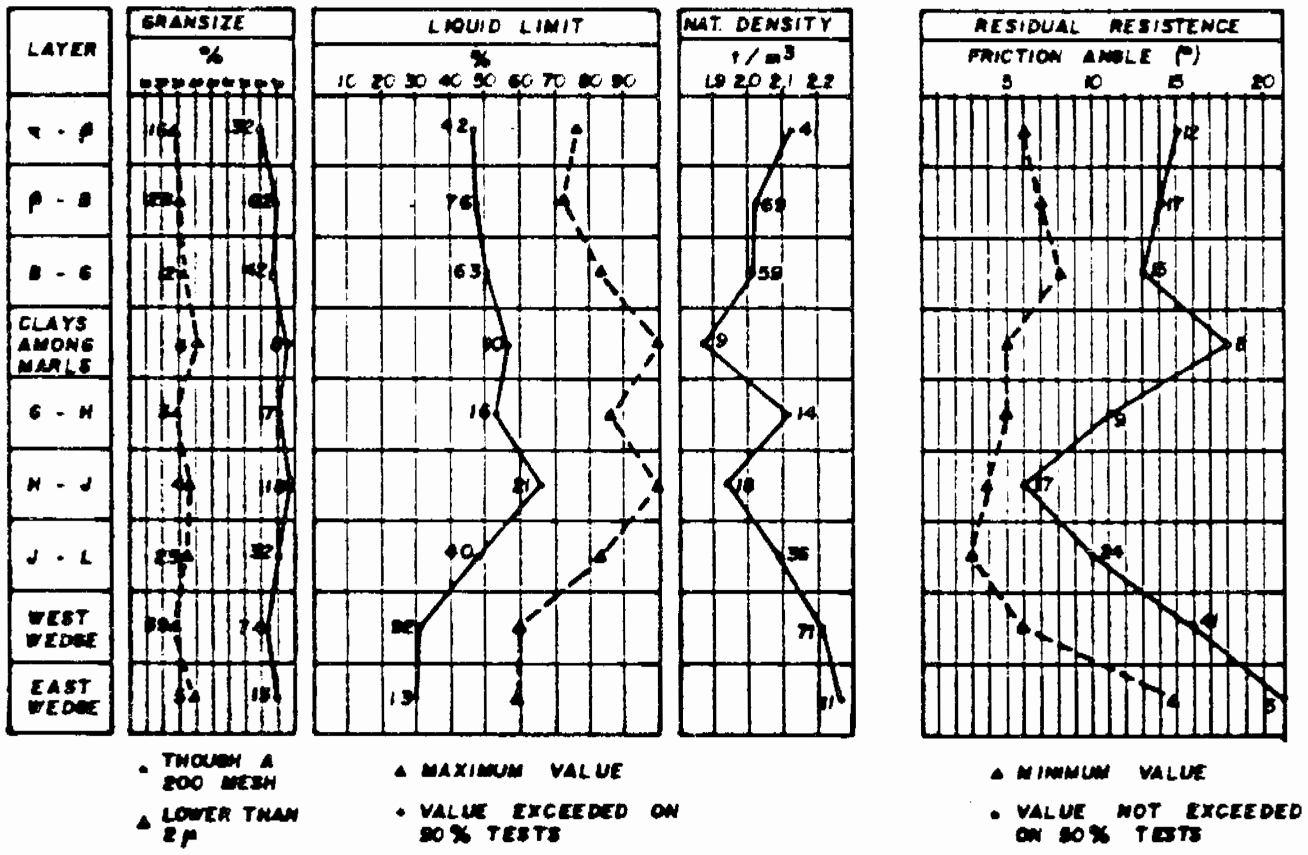
- Tertiary material layering
- Primary material cleavaging
- Direct, reverse or overthrusting faults, affecting Tertiary and Primary materials.

We have tried unsuccessfully to group materials based on primary lithologies since a fractured and altered state prevails over the petrographic diversity of those materials.

Based on laboratory tests, there follows a summary of geomechanical parameters of soil and rock:

	PEAK RESISTANCE		RESIDUAL RESISTANCE		DENSITY
	ϕ (°)	C' (T/m²)	ϕ (°)	C' (T/m²)	(T/m³)
PRIMARY:					
SOUND ROCK	50	0	35	-	2,6
TECTONIZED ROCK	33	0	22	-	2,3
WEATHERED ROCK	23	0	16	-	2,25
SCHIST	-	-	18	-	-
TERTIARY:					
MATERIAL	30	0	-	-	2,16 - CLAY 1,30 - LIGNITE
FAULTS	-	-	15 (16-20)	-	
LAYERING	-	-	8 (10-12)	-	

GEOMECANICAL PARAMETERS



TERTIARY CLAY PARAMETERS

It seems that the deficient quality of these materials bear low resistance values. It calls our attention the very low values of the angle of friction of some clays (between 3° and 8°) which have played an important role on the presence of some slidings, that occurred in the mine.

When it came to set up the criteria to design the final slopes, apart from taking into account the geomechanical parameters before mentioned, we tried to obtain a piezometric level going from the slope toe to half its height and all this related as it should to the pressure level of t he faulty areas we consider most probable (because they are most unfavourable), faulty areas which may extend through different lithologies or structures (see figure 3), so the need to plan an underground draining operation on those areas as a previous step to achieve safe coefficients, ranging from 1 to 1.2 never lower for obvious reasons and, in some cases, a bit higher.

Hydrogeology

As regards hydrogeology it has to be said that it is limited by three main subjects:

- High pluviometry (1,700 l/m^2 per year average precipitation) which causes a constant aquifer seepage.
- Low permeability and transmissivity values, both of primary rocks and Tertiary materials.
- High hydraulic anisotropy of the geological environment with flows through faults and important hydrostatic loads, even above soil surface.

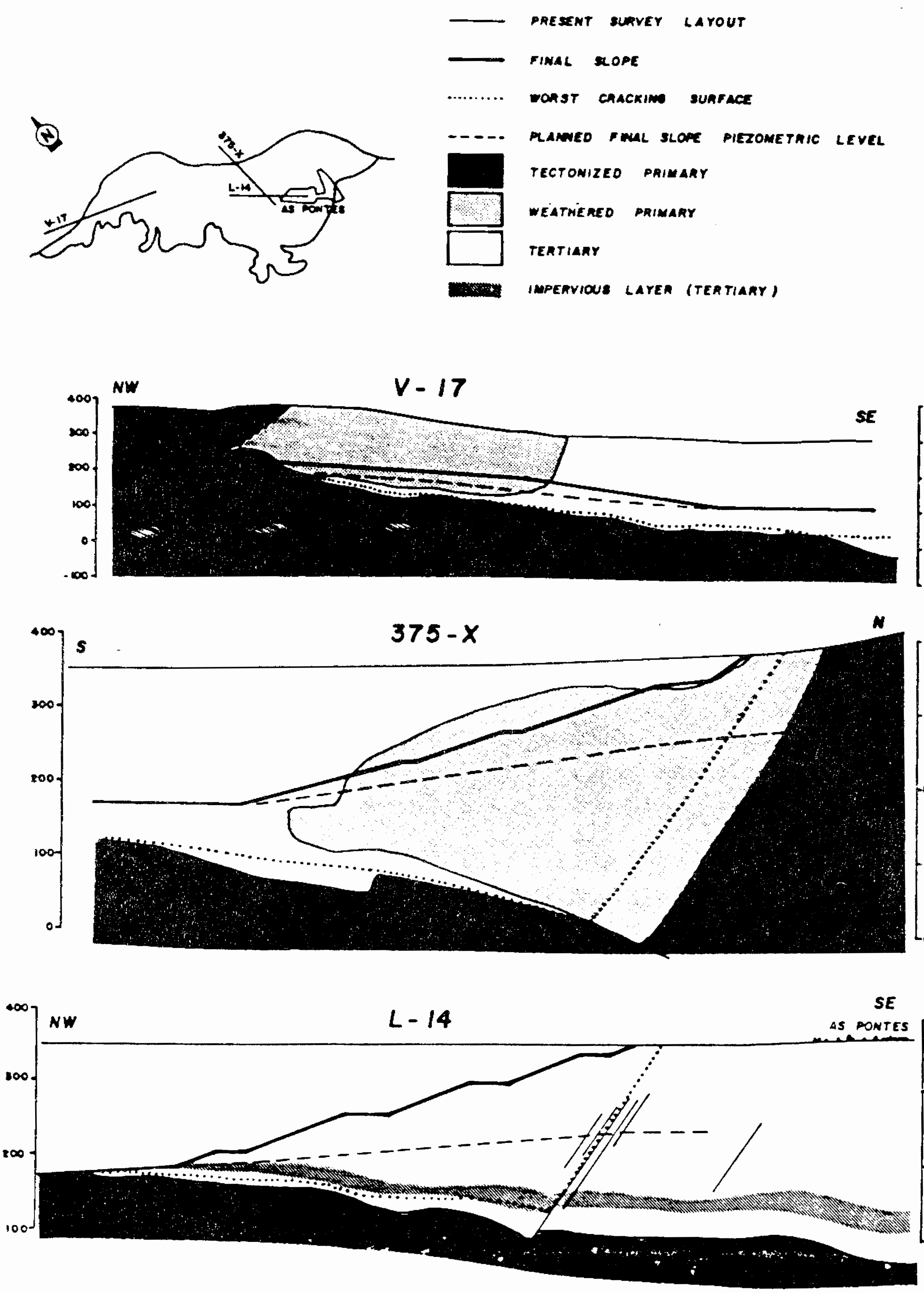


Figure 3. Slope shape on different geological sections of the deposit

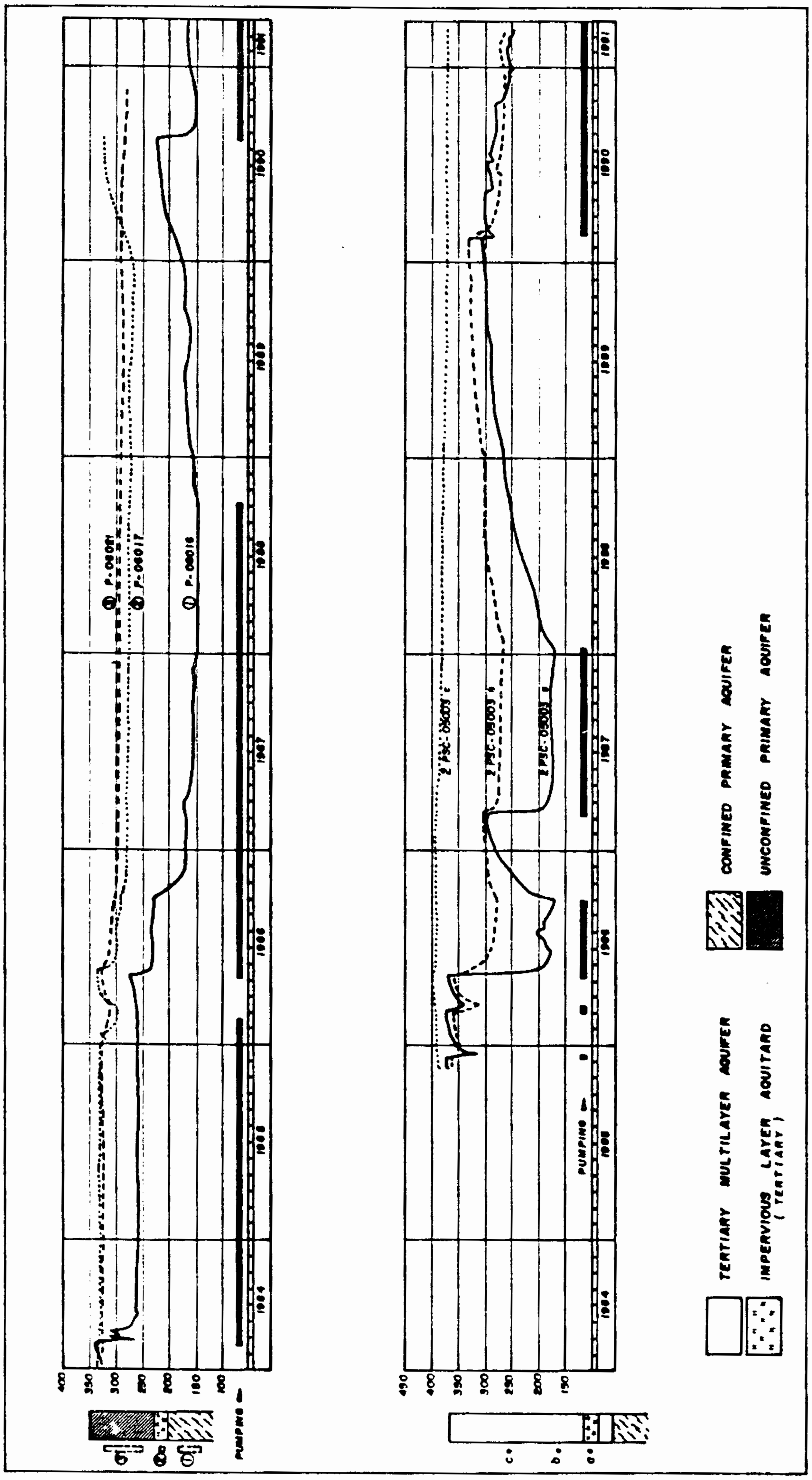


Figure 4: Piezometric development on impervious materiales related with limit aquifers drainage

Pumping tests were performed to define the hydraulic parameters of the aquifers as well as to identify the presence of aquitards. Main aquifers are (Rodrigo et. all., 1988):

- Unconfined aquifer: - formed of fissured primary materials. Their parameters are:
  $T = 1 - 20\ m^2/d$, $S = 10^{-2} - 10^{-3}$; $k = 39 . 10^{-8}$-$7.7 . 10^{-5}$ cm/s
- Confined aquifer: - formed by primary materials underlaying the Tertiary deposit strata. It is also a fissured aquifer bearing the following parameters:
  $T = 1$-$5\ m^2/d$; $S = 10^{-3}$-10^{-5}; $k = 3.9x10^{-6}$-$1.9x10^{-5}$ cm/s
- Multilayer aquifer: - it is formed by a series of Tertiary materials having a very fractured arrangement and different permeability degrees. Its parameters are:
  $T = 15$-$20\ m^2/d$; $S = 5x10^{-3}$; $k = 5.8x10^{-5}$-$7.7x10^{-5}$ cm/s.

HYDRAULIC BEHAVIOUR OF IMPERVIOUS MATERIALS

Figures 4A and B show the piezometric development of the different sensors installed on impervious materials and its relationship with other piezometers installed on nearby aquifers. It may be seen that once pumped, those aquifers drain, whereas on the other aquifers it does not occur with the same intensity.

These figures represent an example of this behaviour on West and East field areas; nevertheless there are many piezometers behaving the same way.

Once an statistical analysis based on those piezometric developments was accomplished, it was proved that there exists a close relationship between depth of sensors and their hydraulic charge they have to stand. This relationship is shown on Figures 5A and 5B where reversed values following piezometric points were observed in several last years. It may be proved that even though clay drainage is difficult, nevertheless it is resulting on lowering of a pore pressure level.

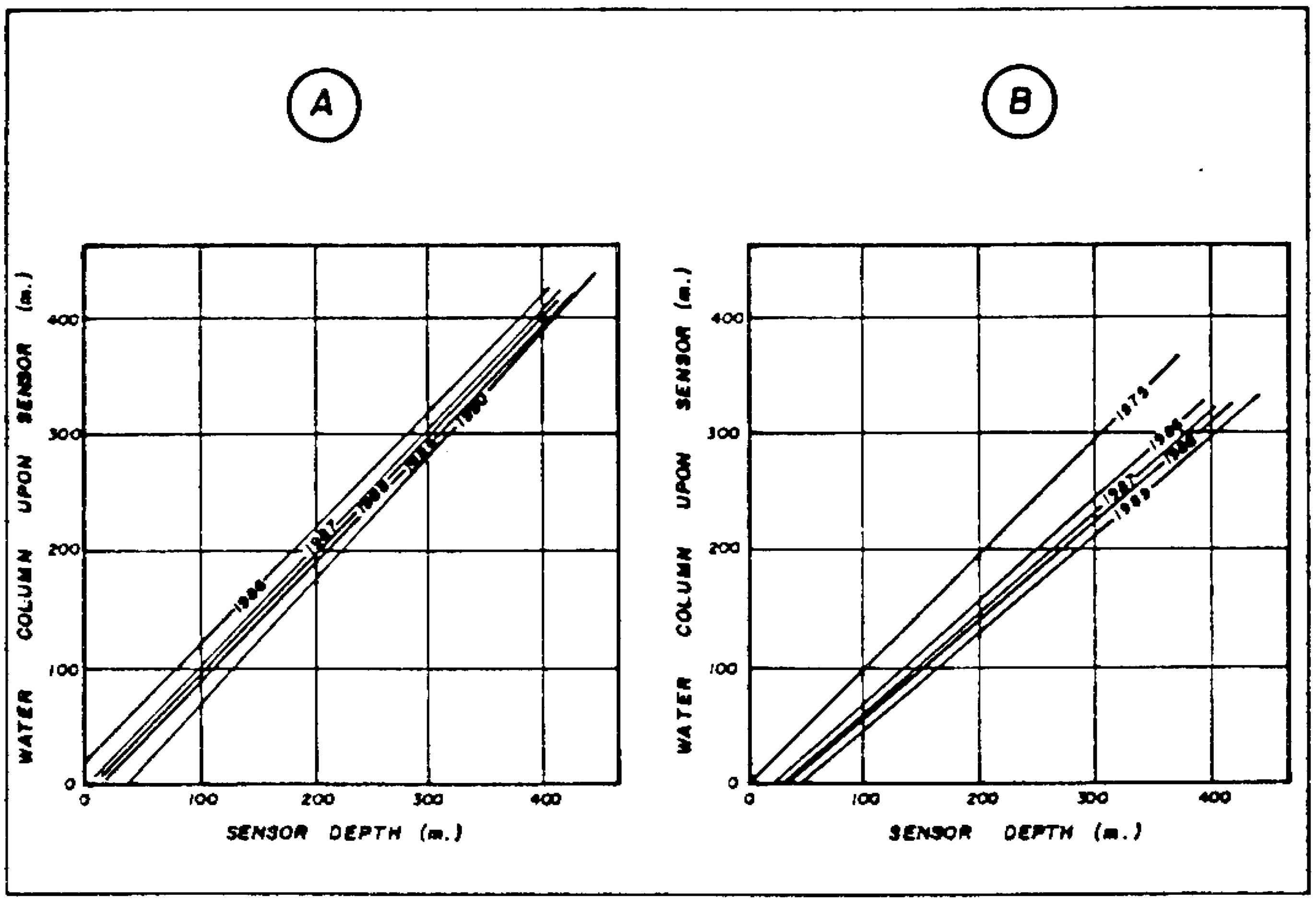


Figure 5: Hydraulic pressure law development of clayey materials. (A - East Field, B - West Field). Lines derived from grouping several piezometric points for every specific year.

The explanation to the aforesaid is presented as a hypothesis once the information given from the two figures above is summed up on two more representative ones (Figures 6A and 6B), which show the development of the piezometric level along time, related to different depth levels. A discontinuity is observed on these curves, happening around 1985 on the West Field which coincides in time with the starting up of underground draining, showing increasing pressure dissipation on that time. Once draining reaches its highest efficiency, curves gradients again decrease, however the steady piezometric level lowering before and after draining operations shows the probable existence of another process taking place which would help drainage.

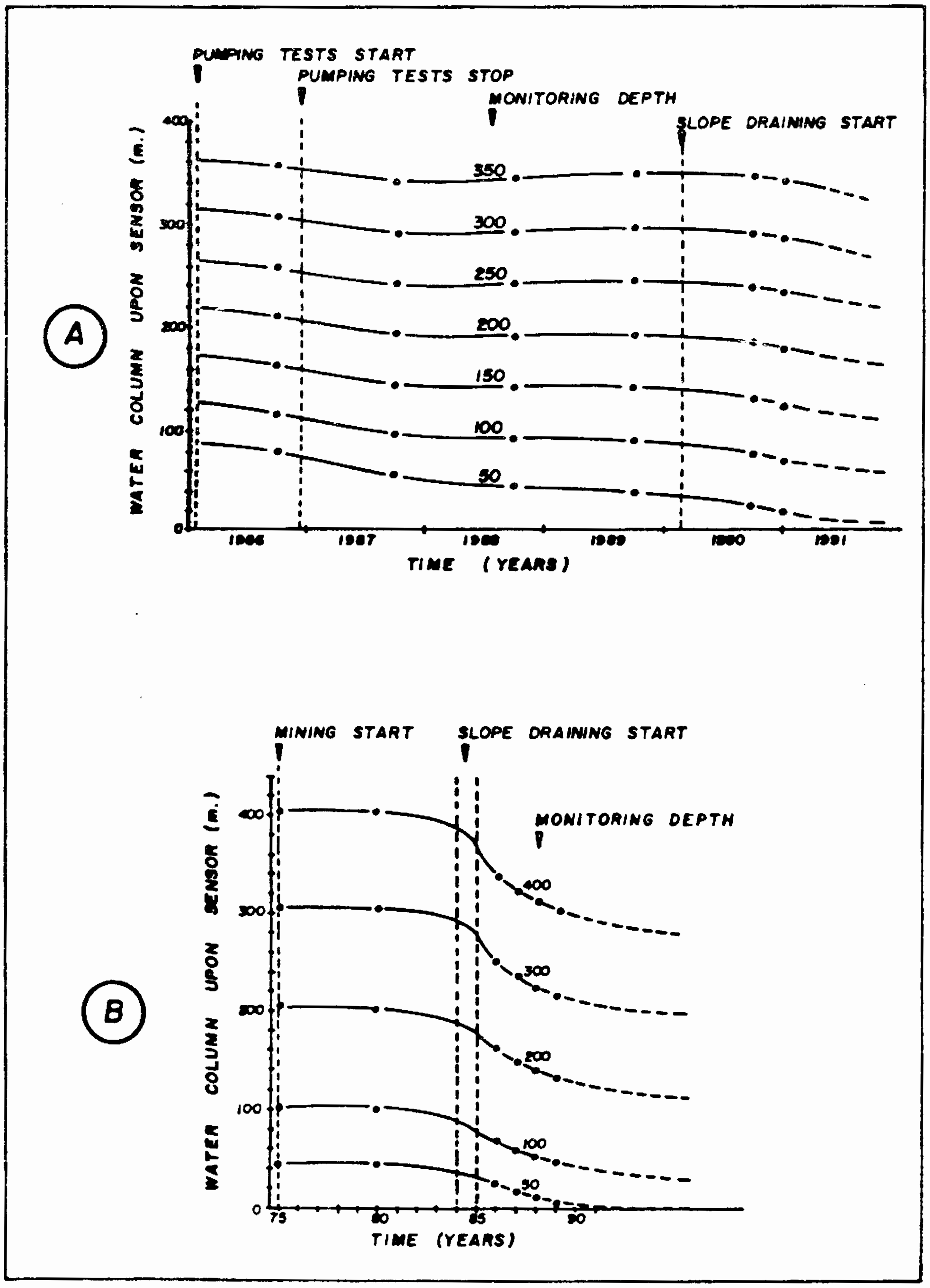


Figure 6: Hydraulic pressure dissipation related with draining and mining of clayey minerals. (A - East Field; B - West Field).

It was thought that the second process should bear a relationship with lithostatic discharge resulting from mining. Following this hypothesis a test was accomplished on an area with no draining, to see the effect it would have the nearness of the mining cut on piezometric levels. The results are shown on Figure 7, where it can be seen how different piezometric sensors respond to draining when the mining front is getting near.

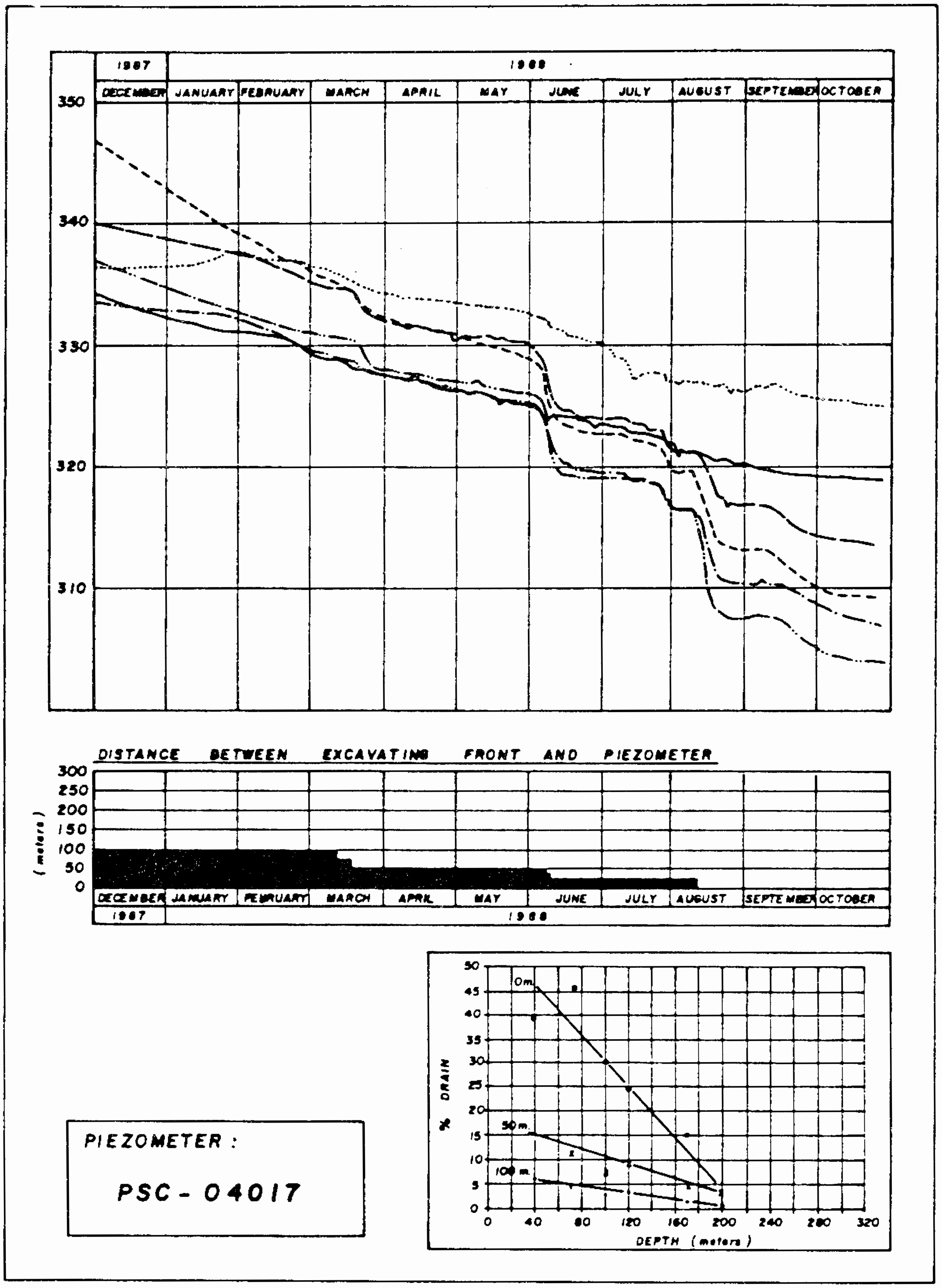


Figure 7: Hydraulic pressure dissipation due to mining operation.

This process is reversible, that is, when material is dumped, pore pressure levels increase proportionally. Figure 8 shows a piezometric level increase when material is dumped on that point and pressure dissipation taking place along the years.

Therefore, the remaining drainage, observed on Figure 6B before and after pumping must be due to this second cause.

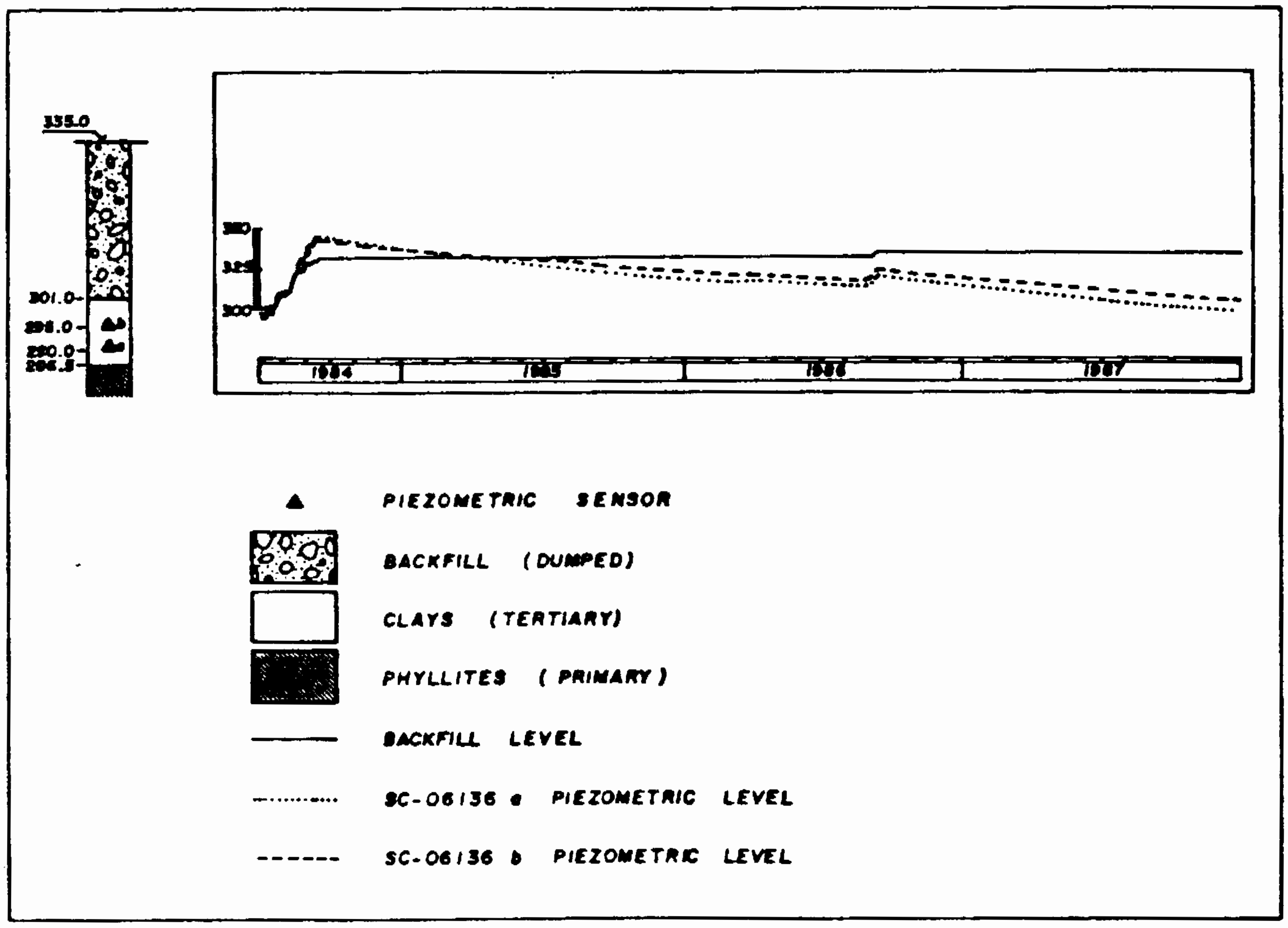


Figure 8: Hydraulic pressure increase related with dumping load and their dissipation with time.

If we pay attention to those tables representing East Field, Figs. 5A and 6A, it is observed that its gradients are not as high since underground drainage layer has not been completely accomplished and because the few existing wells have been pumping for a short time, from 1990. In this case the most important process, regarding dissipation is due to mining.

Both Figures 6A and 6B allow us to make an estimation of what pressure dissipation will be on every depth level (stroke lines) and so it will help us to foresee the stress state, according to different levels as well as on the final one.

UNDERGROUND DRAINAGE CRITERIA

Based on the previous data analysis we may conclude the following:

- The Paleozoic confined aquifer as well as the unconfined one, are partially drainable through wells, nonetheless the first one will demand a lower number of wells since its confining allows us to reach a wider drainage range. The scheduled mesh to drain the unconfined aquifer is

150 m between subsequent wells and of 400 m for the confined aquifer.

To pump both aquifers is most important because it results on an extended drainage effect through dripping on the overthrusting Tertiary area and on the impervious and deep layers of the Tertiary series where cracking surfaces follow.

- The Tertiary multilayer aquifer, having more fragmented layers (East Field area) seems to be more easily drainable through wells since the layers are confined. The mesh to accomplish good drainage system includes wells every 300 m. As regards clay layers they develop well when pressure dissipate through contact surfaces as well as by the lithosthatic discharge from the excavating front.

- When Teriary section bears high clay thickness (West field area) the very mining operation drainage performance.

- Following the above stated measures, it is planned to reach those piezometric levels needed to grant stability on scheduled slopes.

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