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SLOPE STABILISATION USING ADVANCE DEWATERING TECHNIQUES IN A LARGE OPENCAST MINE IN NORTH-WESTERN SPAIN

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ABSTRACT

The paper describes the geological and geotechnical behaviour of a side wall slope of an open cast excavation in a large lignite mine in North-Western Spain. The details of an hydrogeological investigation are given in order to establish the relationship between the structural and lithological behaviours of the rock mass, of Tertiary and Paleozoic ages, and the ground water conditions in the host rock. The largest geological structures occuring in the area are related to a complex systems of folds and faults. It was obvious, from the very onset of the investigation, that the side wall slope would be unstable without reducing the water pressure in the host rock by application of advanced dewatering techniques.

The study shows preliminary hydrogeological information developed in order to select the advanced dewatering techniques together with the monitoring programme adopted. Dewatering techniques such as surface open drains and gravel trenches, horizontal borehole drains and borehole pumping wells, were tested, as well as monitoring controls such as piezometric observations in boreholes, measurements of flow rates in surface drains, horizontal drains and pumping wells, together with hydrochemical control, and water temperature and rainfall records. This study enabled a comparison to be made among the techniques for dewatering the side wall slope in order to stabilize the area under investigation.

INTRODUCTION

The slope stability in an open cast mine is a basic requirement for safety and economic mining operation. Along with other factors, the presence of ground water on the face of mining slopes often creates serious stability problems. This is caused by an increase in fissure water pressure which reduces the effective shear strength and increases unit weight and, as a consequence, the shear stress. In recent years, various techniques of advanced dewatering of surface mining slopes have been developed in order to stabilize excavated slopes. The most frequently use techniques include surface drains, horizontal drains, backfilled toe drain trenches, pumping wells within or outside the mine and drainage adits or tunnels.

The most appropiate dewatering method feasible for a surface mining project depends upon the geology and hydrogeology of the mine site, scope of dewatering, mining method and the cost effectiveness.

SITE DESCRIPTION AND MINING ENVIRONMENT

The Puentes open cast lignite mine is located at North-Western Spain (figure 1) in the basin of Eume River and occupies an area of 14 km^2. The lignite deposits here were known in the last century and exploited on a limited scale until 1972. The lignite field can be

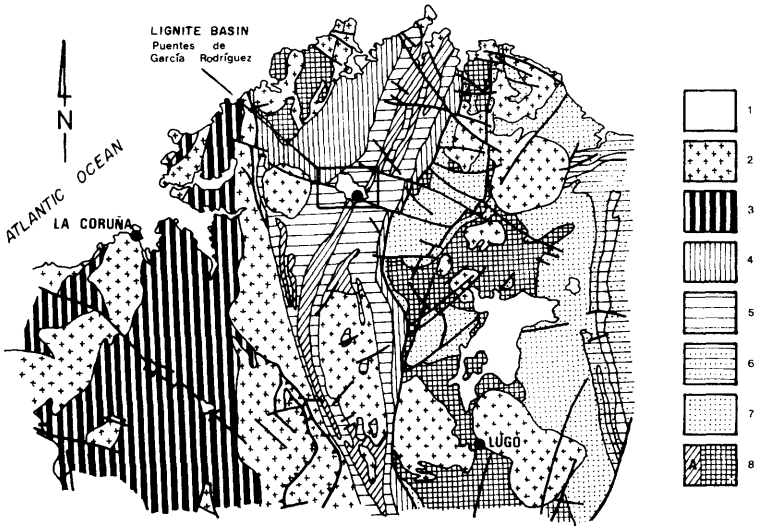

Figure 1. North-Western Spain geological map. 1, Tertiary deposits. Hercinian plutonic rocks. 3, Precambrian-Paleozoic (indifferent). Silurian. 5, Ordovician. 6, Cambrian-Ordovician. 7, Cambrian. Precambrian.

divided into two basins, joined by a strait in the centre. Nowadays mining activities are concentrated in the Western lignite basin. Total reserves of lignite are estimated as 420 Mt, out of which 320 Mt can be economically exploited. The average characteristics of lignite are given in table 1.

Table 1

Average characteristics of lignite at Puentes Mine

Minimum calorific value	1800 kcal/kg
Moisture content	45.00 %
Volatile content	18.53 %
Ash	21.80 %
Sulphur	2.54 %
Ratio overburden /lignite	2.33 m^3/t

The entire lignite production at Puentes Mine is used to generate electricity in a thermal power station which has a total capacity of 1400 MW. The life of the mine is estimated at 20-25 years. Figure 2 shows the general layout of the mining site, indicating the locations of mine, power house, coal terminal, and waste disposal area.

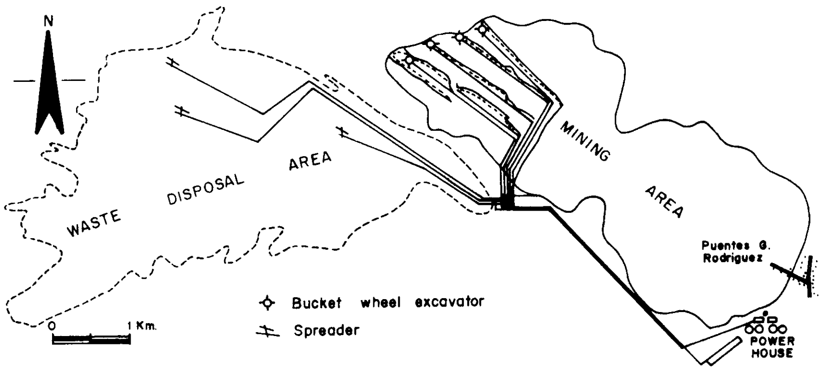

Figure 2. Location map of mine and facilities.

The production is obtained by five bucket wheel excavators, which have a theoretical production capacity of 3400 m^3/h, weight 2050 t, maximum cutting height 42 m, largest dimension 120 m and which utilize a maximum electrical power of 2600 kW.

The coal transport is carried out by several 1.6 m wide belt conveyors with total length of 18,205 m and an average speed of 5.2 m/s. The transport of overburden from the mine and ash from the power plant is carried out by 24,150 m long and 1.8 m wide belt conveyors.

Waste disposal in this mine is a very important subject because the total amount of overburden to be disposed of in tips is in the order of 700 Mm^3. At the present three spreaders are used to dispose this residual material with a machine capacity of 1500 m^3/h, weight 1356 tonnes, maximum height 32.5 m, length 102 m and maximum power of 2977 kW.

The production of Puentes Mine for the last years is given in table 2.

Table 2

Output Statistics of Puentes Lignite Mine

Year	Production Mt/y	Overburden ratio m^3/t lignite	Total manpower
1976	1.13	0.81	593
1977	2.96	1.32	741
1978	5.22	0.86	946
1979	7.31	0.84	1114
1980	11.09	1.24	-
1981	11.75	1.98	-
1982	13.39	1.83	-
1983	12.80	1.00	1510

The mine is highly mechanised and all the bucket wheel excavators are remotely operated from a computer centre located at the mine office. All the bucket wheel excavators work continuously for 24 hours a day, for 365 days a year, with an effective utilization time of 55-60 % and an effective cutting capacity of 1200-1300 m^3/h. The manpower required for each bucket wheel excavator can be appreciated in table 3. In addition, fifteen attendents per shift are required to maintain fifteen belt conveyors for the transport of coal and ash. Operations in this mine are very efficient as the overall O.M.S. is 35.0 tonnes.

Table 3

Manpower

Drivers	2
Electricians	1
Mechanics	1
Helpers	2
Foremen	1
TOTAL	7

GEOLOGICAL ENVIRONMENT

The lignite deposit at Puentes Mine, of Miocene age, is located in a tectonic depression closed by Paleozoic sediments (figure 1). Paleozoic rocks are characterized by crystalline mono-metamorphic and polymetamorphic formations, affected by several deformation phases of the Hercinian Orogeny. This tectonic activity folded and faulted the sediments, giving a very complex structure, which has an important role in the instability of the open cast slope. Some of these faults were reactivated during the Miocene, causing a depression of more than 300 m at the Northern border, in which were deposited the Tertiary sediments, mainly composed of lignite, carbonaceous clay, clay, marly sand and basal conglomerate. The thickness of the lignite seams is relatively uniform, but variable between 0.5 to 25.0 m. The thickness of interbedded layers is even more variable, having a maximum in the Northern half of the basin, where the overburden is more than 120 m. The dip of the lignite beds is aproximately 10º NE. Near the North tectonic border the lignite seams have been folded and affected by inverse faults (figure 3).

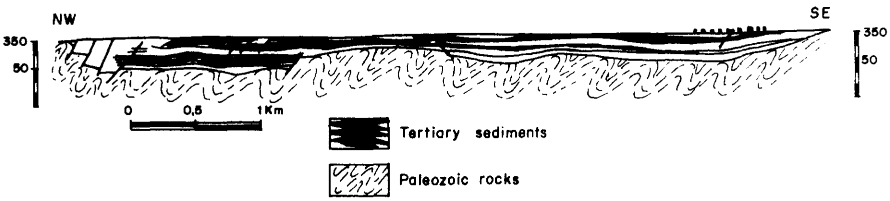

Figure 3. Geological cross section through the lignite deposit.

The host rock surrounding the lignite deposit is mainly quartzitic schist (with a variable proportion of quartz) together with phylite.

The rocks were affected by weathering before the deposition of the Tertiary sediments, and also by shear before and during the deposition of the Tertiary causing mylonite zones. The weathering and mylonite are responsible for the plastic behaviour of the rock mass.

STABILITY PROBLEMS AND RESEARCH OBJECTIVES

The rock mass in this area is characterised by the following factors:

- The Paleozoic formation is affected by faulting (resulting in mylonites), folding and weathering which is responsible for a low rock mass strength.

- The unconsolidated Tertiary deposits include clay, marly clay, and other plastic formations.

- Paleozoic and Tertiary sediments are saturated with water, giving rise to a high pore and fracture pressures and effective shear strength.

The objective of the present studies was to evaluate various techniques of dewatering of the host rock, in order to increase the effective shear strength and, consequently, the stability of the open cast slope.

ANALYSIS OF VARIOUS DEWATERING TECHNIQUES

1. Need for Research

The main objective for the drainage design was to intercept the superficial and underground water flow arriving at the mining excavation, saturating the open cast slopes and making them less stable. The main dewatering techniques considered for the present studies were as follows:

- Surface drains.
- Vertical pumping wells.
- Horizontal drains.

In order to evaluate the performance of the above dewatering techniques an experimental site was selected on the side wall slope of the open cast mine with the following criteria:

- The area affected by the excavation with a known stability problem was easily accessible and undisturbed by mining operations during these investigations.

- The stratigraphy, tectonics and hydrogeology of this area were complex and amenable to a detailed study.

2. Research Approach

The research study comprised the following distinct steps:

- The study in details of rainfall for the past twenty five years.
- The study of surface water flow pattern.
- The study of the performance of ground watering diversion techniques.

2.1 Rainfall

The rainfall in the area is fairly high and, due to lithological conditions, it is characterized by high degree of runoff and by low infiltration (table 4).

Table 4

Rainfall, runoff and infiltrantion for the last twenty five years

Year	Rainfall	Precipitation mm	Infiltration + Runoff	
			mm	% of precipitation
1950-51	Maximum	2604	1965	75
1975-76	Minimum	1021	548	54
1947-82	Average	1649	1037	63

2.2 Surface Water Flow Pattern

In order to design the maximum capacity for a dewatering technique the preliminary step was to estimate the quantity of water flowing towards the excavation. The parameters studied were: intensity and distribution of rainfall, morphology of the basins, drainage pattern, vegetation, soil permeability and its moisture content. For this hydrological study four techniques were used: statistical, rational, unit hydrogram and empirical methods. The above studies indicate that, for the twenty five years of projected life of the mine, the maximum rainfall in a period of 24 hours would be 113 mm and the corresponding maximum rainfall for one hour would be 18 mm.

A similar analysis also indicated that the maximum run-off, in the experimental area, during 24 hours period, would be 15.8 m /s, and the corresponding estimation for the total mining area would be 260.0 m /s. Based on the above estimations the size of the peripheral surface canal, surrounding the mine, was designed. The maximum run-off recorded during the life of the mine is 1 $m^3/s/km^2$.

2.3 Performance of Dewatering Techniques

Figure 4 shows the location of peripheral canal, surface drain and

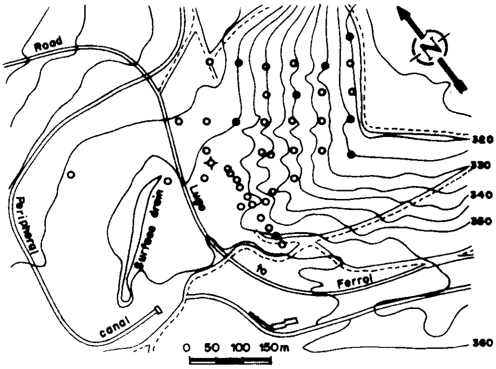

Figure 4. Experimental site for dewatering techniques, with location of peripheral canal, surface drain, pumping well and observation piezometers.

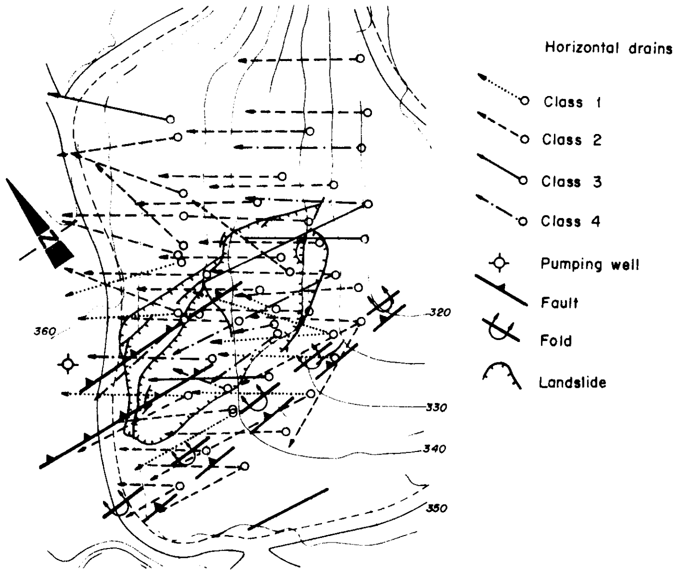

Figure 5. Horizontal drains (boreholes), classified by categories according with their water yield.

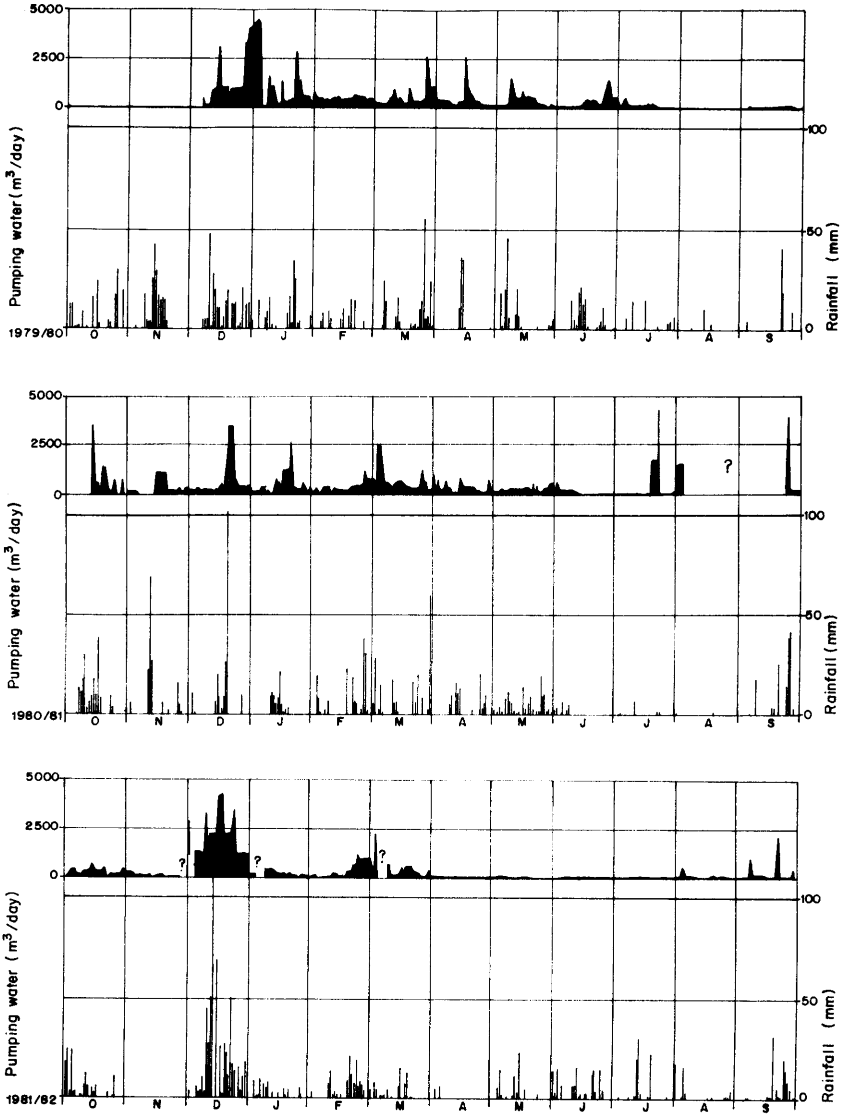

Figure 6. Evolution of pumping water from surface drain against rainfall.

vertical pumping well, together with the observation piezometers. Figure 5 shows the position of some 56 horizontal drains in the experimental area together with the position of the main geological structural discontinuities. The main objectives of the piezometric levels record were to investigate the effect of rainfall on infiltration and to observe the efficiency of the different dewatering techniques employed.

(i) Surface Drain

The purpose of the surface drain (figure 4) was to intercept the superficial and sub-surface water flow not collected by the peripheral canal. It was dug by a retro-excavator in the alluvial sediments to the depth of the geological contact between Tertiary and Paleozoic formations. The water collected in the surface drain was taken to a sump from where it was pumped to the peripheral canal. At a later stage, in order to save manpower, the water from the surface drain was conveyed by gravity to the main sump. Figure 6 shows the pumping performance of the surface drain against the rainfall. It can be cbserved that the water yield, rises rapidly to a maximum, corresponding to the rainy season (winter/spring), followed by a rapid fall. The maximum recorded yield was 4000 m^3/d, with an average yield of 500-1000 m^3/d in the rainy season. The relationship between monthly rainfall and the discharge from the surface drain is shown in figure 7 which gives a good idea of the effectiveness of this dewatering technique

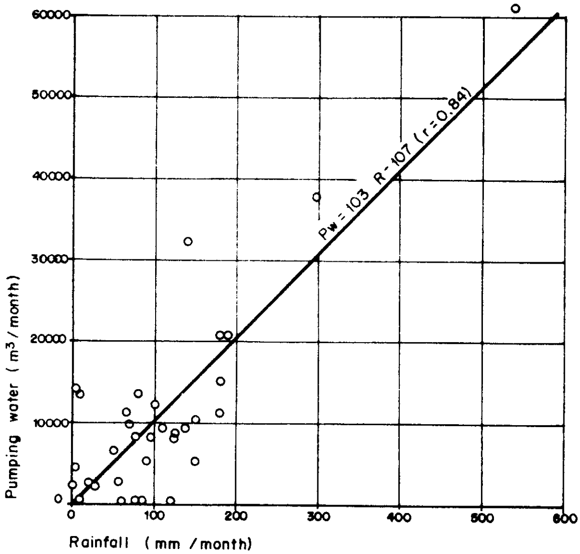

Figure 7. Relation between monthly rainfall and pumping water from the drainage well.

(ii) Pumping Well

The object of the pumping well was to investigate the possibility of advance dewatering of the Paleozoic rocks, reducing the water pressure on the Tertiary sediments. According to several pumping tests carried out in this well the hydrogeological parameters of the Paleozoic rocks at this point were:

- Transmissivity 3×10^{-2} to 7×10^{-2} m^2/d
- Permeability 4×10^{-4} to 9×10^{-4} m/d

These data indicate that there are possibilities of dewatering the Paleozoic formations by pumping wells. The pumping record, over a period of four years, showed that the rate of dewatering is independent of short-term rainfall (figure 8). The pumping yield of this operating well was low (0.2 l/s), but a regular drawdown in the Paleozoic piezometers was observed. This experience proved that the system of dewatering by wells is effective in Paleozoic formations.

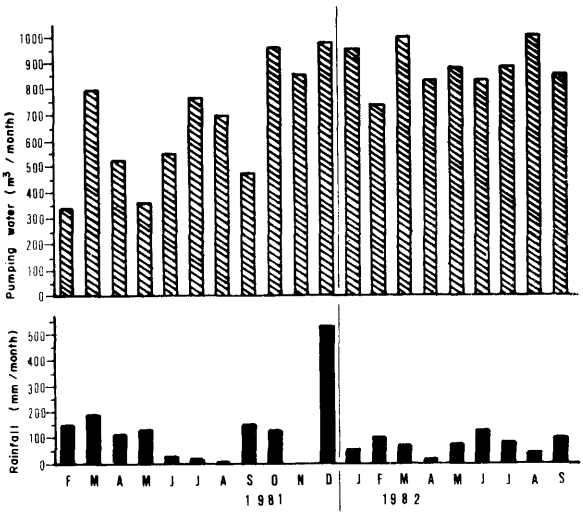

Figure 8. Relationship between monthly rainfall and pumping water from the drainage well.

(iii) Horizontal Drains

The main purpose of the horizontal drains was to lower the piezometric surface near the mining excavation thus stabilizing the pit slope.

Altogether 56 horizontal drains (figure 5) were drilled with a minimum diameter of 76 mm between 50-150 m length, and rising at an angle of 2º. From some locations three boreholes were drilled in a fan-fashion to intersect the potential water flow through fault planes. The boreholes were lined with 38 mm diameter uPVC pipes perforated with 3 mm diameter holes. The spacing of the horizontal drains was determined by trial and error method and was between 20-50 m. Four distinct groups of drains can be identified according to their performance:

- Boreholes which are virtually dry with discharge unaffected by the rainfall.
- Boreholes with very little discharge but giving a slight increase in discharge following a rainy period.
- Dry boreholes which can yield an appreciable amount of water after a rainy period with a relatively slow reduction in the yield.
- Boreholes with a high rate of discharge during the rainy season which can suddenly dry up in the dry period.

The first group of drains corresponds to the rock mass having very low permeability and no structural discontinuity. The second and third groups of drains intercepted some transient water flow and penetrated through a rock mass with a low hydraulic conductivity. Alternatively, the corresponding holes intercepted a variable water table near the surface. The last group correspond to drains intercepting geological structures or materials favorable for water flow such as faults, fractures and pervious rocks. The instantaneous reduction of flow in a horizontal drain is often indicative of ground failure damaging the pipe.

From the analysis of the flow pattern in the horizontal drains the following conclusions can be made:

- There is no relation between the direction and length of horizontal drains and their rate of discharge.
- The most permeable rocks in the area are lignite, Paleozoic formations, lignite and alluvial sediments.
- The boreholes giving maximum discharge are placed in the faulted area or in the areas of slope instability.
- Tertiary deposits, other than lignite, have very low permeability.

Figure 9 shows the total discharge from the horizontal drains together with the rainfall for a period of two years. It can be seen that there is correlation between the rainfall and the horizontal drain's discharge.

3. Pumping By Air Lift

The objectives of this study were as follows:

- To clean the piezometers eliminating the accumulation of clay, bentonite and fine sand particles.
- To obtain ground water samples for hydro-chemical analysis.
- To determine the tranmissivity and permeability of different strata.

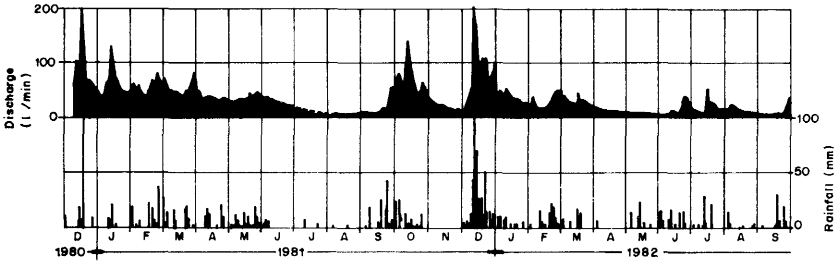

Figure 9. Total daily discharge from the horizontal drain against rainfall.

The equipment used for this test was a portable air compressor operated by a diesel motor and producing an air pressure of 0.8 MPa. Normally water was ejected from a depth of 60-70 m for a period of an hour from each piezometer. During this period the rate of discharge and the water temperature were measured and water samples were also collected for the hydro-chemical analysis. For the following one hour period the recovery of ground water table was recorded with time. The permeability of the rock mass was estimated using the Theis recovery formula:

$$T = 0.183 \frac{Q \log t/t'}{s'}$$

where:

T - transmissivity (m^2/d),
Q - well discharge (m /d),
t - time from the begining of the pumping,
t' - time required for the recovery of the piezometric surface since stopping of the pump and
s' - observed drawdown at the piezometer.

The transmissivity and permeability in this area (table 5) were estimated from the above tests.

According to this data it can be concluded that the general aquifer conductivity in Tertiary sediments is variable and low, but there are some indications of the presence of layers having comparatively high permeability. According to the Casagrande classification the sediments tested in 3 piezometers are fully drained,

Table 5

Hydrodinamics parameters

	Transmissivity (m^2/d)	Permeability (m/d)
Maximum	7.0×10^{0}	5.5×10^{-1}
Minimum	2.3×10^{-3}	1.3×10^{-4}
Average	8.3×10^{-1}	4.6×10^{-2}

in 15 they are poorly drained, while in 3 they are practically impervious. Other piezometers presented some operational problems. Three of the above well-drained piezometers were located in the faulty zone and in the area of slope instability. Figure 10 shows the relative permeability conditions obtained from the air-lift test together with the isotherm of the pumped water. It can be seen that high temperatures occur in the areas of faulting and slope failure.

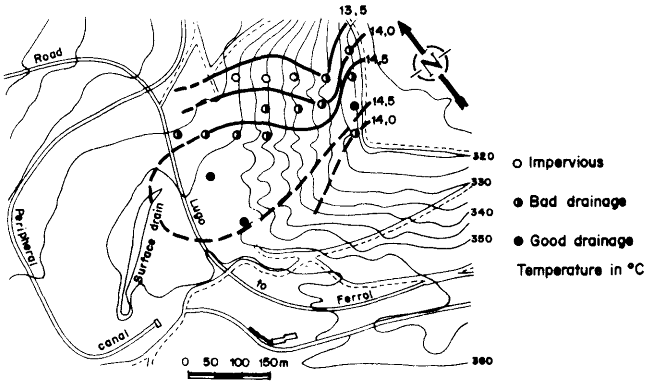

Figure 10. Drainage capabilities in the different piezometers according with the air-lift tests, and isothermic lines of "pumped" water.

In this area it can be proved that the ground water from the Paleozoic rock comes to the Tertiary through faults and this water is the major factor causing the open cast instability.

STUDY OF THE PIEZOMETRIC SURFACE

A total of 47 piezometers were installed in the area for the purpose of observing the performance of various rock mass dewatering techniques. During the rainy season the behaviour of various piezometers can be classified into two categories (figure 11):

. Where the change in the piezometric surface was between 3 to 15 m.

. Where the maximum change in the piezometric level was only 1 m.

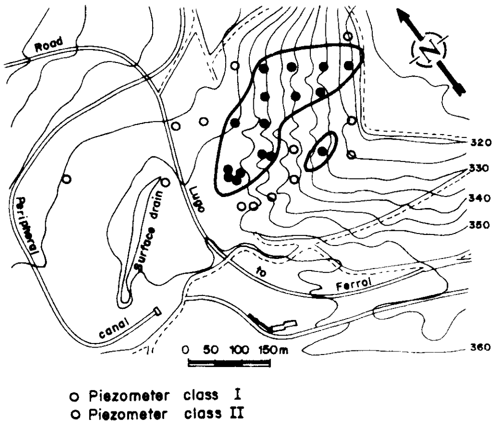

Figure 11. Classification of piezometers according with the water table variation during dry-rainy season.

The first group can be related to the area of high permeability and faults which provides an area for recharge. The second group forms an hydraulic barrier and is, therefore, a potential site for a slope failure. The ground water flow diagrams of the side wall slope are given in figure 12 showing a simple flow pattern characterized by the following features:

. The piezometric surface and the morphology of the area are practically parallel.

. The surface and ground water flows converge towards the area of the slope failure.

CONCLUSIONS

The trial application of this different rock mass dewatering

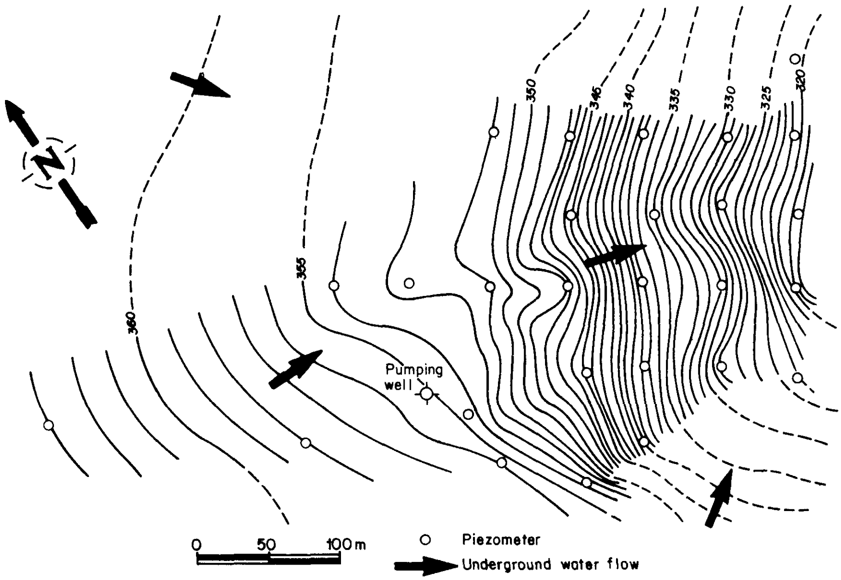

Figure 12. Piezometric map of the investigation site.

techniques for the side wall drainage of open cast slope give the following conclusions:

. Surface drains are efficient devices to intercept the surface water entering in the open cast mine through alluvial sediments.

. Pumping wells are effective devices for dewatering Paleozoic rock masses.

. Horizontal drains are an effective method for dewatering lignite and faulted rock masses, but present a danger of being cut-off by a slip in the failure zone, thus making them ineffective and potentially dangerous.

The general conclusion is that the surface drains should be used to dewater Tertiary and alluvial sediments, while pumping wells should be employed to dewater the Paleozoic rocks.

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