# VACUUM DRAINAGE TO STABILIZE ROCK SLOPES ON MINING PROJECTS

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## ABSTRACT

Horizontal drains were installed under vacuum in a mine slope. The benefit arises from an increased hydraulic gradient due to exhausting to a negative atmospheric pressure. The prototype was based on the well known civil engineering dewatering practice, well pointing. Results showed that a vacuum of 457 mm of mercury was obtainable in a fractured moderately permeable rock slope. Immediate drawdown of the water table occurred resulting in a total of 1.1 m of drop occurring after 59 minutes of operation. Flow increased from 0 l/s to 0.2 l/s discharging from the horizontal drains when the vacuum was applied. It was found that drawdown continued to occur with the water level dropping below the drain elevation. The system developed may be employed as a depressurization tool for slope stabilization projects.

## INTRODUCTION

The presence of groundwater in surface mining operations often creates serious problems. The most important is generally a reduction in stability of the pit slopes. This is caused by pore water pressures and hydrodynamic shock due to blasting reducing the shear strength; seepage pressures, water in tension cracks and increased unit weight which increase the shear stress.[1]

Groundwater and seepage also increase the cost of pit drainage, shipping, drilling and blasting, tire wear and equipment maintenance. Surface erosion may also be increased and, in northern climates, ice flows on the slopes may occur.

Based on experience, pit slope angles can be steepened by an average of about 7° when a high pit slope water table can be lowered below the potential failure surface. In addition, blasting costs can be significantly reduced if expensive slurry explosives can be replaced by ANFO.

Procedures have been developed in the field of soil mechanics and engineering of dams to obtain quantitative data on pore water pressures and rock permeability [2], to evaluate the influence of pore water and seepage pressures on stability and to estimate the magnitude of groundwater flow. [3]

Based on field investigations, a design can be prepared for the control of groundwater in the slope and in the pit. Methods of control include the use of horizontal drains, blasted toe drains, construction of adits or drainage tunnels and pumping from wells in or outside of the pit. [4] [5] Recent research indicates that subsurface drainage can be augmented by applying a vacuum. The first application of this potential technique was proposed by Brawner in 1977.[4]

The application of a vacuum to horizontal drains or drainage adits will increase the hydraulic gradient and increase the rate of drainage. If the drainage is below the failure surface the direction of seepage is changed from generally parallel to the movement which reduces stability to a direction approximately perpendicular to the failure surface which increases the normal pressure on the failure surfaces.

The purpose of the research program was to determine the practicability of developing a vacuum horizontal drain, to assess the change in rate of drawdown and to determine the potential practical application of the vacuum drainage to open pit mine slope stability.

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## SITE DESCRIPTION AND GEOLOGY

### Location, Access and Climate

The Gibraltar Mine is located in the south-central portion of the province of British Columbia, Canada approximately 370 kilometres northeast of Vancouver, Canada on the westerly slope of Granite Mountain near the town of McLeese Lake. (Fig 1)

Access to the mine is provided by a 15 kilometre paved highway that connects with the main north-south Highway 97 at McLeese Lake. The area in and around the mine site is of moderate topographic relief, with elevations ranging between 1070 and 1250 metres. The mine processes about 40,640 tonnes per day of copper and molybdenum ore.

Air temperatures range from a winter minimum of -35°C to a summer maximum of 35°C. Annual precipitation at the minesite is approximately 500 mm, of which 165 mm falls as snow.

### Geology of the Gibraltar Deposits

Although it is generally accepted by most geologists who are familiar with Gibraltar that the ore bodies are "porphyry deposits with a difference", the present geologic staff at the mine are not entirely sure that it is that simple. It is entirely possible that this is a stratiform deposit within the Cache Creek Group which has undergone extensive metamorphism and now could be classified as a gneiss. [6]

The most important geological features with respect to the ground water problems at Gibraltar are fracture systems, joint sets, shear zones and gouge-filled faults. The first three provide the open spaces necessary for the storage and movement of groundwater whereas the gouge-filled faults usually act as damming structures. This can cause significant problems with the periphal vertical deep well dewatering program. Most of the faults on the property dip quite steeply ($75^o$-$80^o$) and if a deep well is positioned on the hanging wall side of a gouge-filled fault, it will probably have little or no effort on the groundwater regime on the footwall side.

In general, the rock at Gibraltar is a highly fractured and jointed, altered quartz diorite. (Fig 2) The main ore minerals are chalcopyrite and molybdenite.

The main fracture systems or joint sets associated with the ore bodies are related to the structures which control the attitude of the ore itself. There are two main structures which have been identified as obviously controlling the grade and attitude of the ore. These are the Sunset and Granite Creek structures. The Sunset zones strike roughly northwest-southeast and dip approximately $35^o$ S.W. The Granite Creek zones strike roughly east-west and dip shallowly to the south. The fracture intensity within the Sunset zones is somewhat greater than within the Granite Creek, and the greatest intensity is to be found where the two intersect.

## HYDROLOGY AND PIT DEWATERING

Mining at Gibraltar began in 1971 with the development of the Gibraltar East Stage I pit. By mid-1973 groundwater began to cause significant problems with higher mining, maintenance and blasting costs and concerns about the effects on pit wall stability. Studies were conducted, and a report [7] indicated that a test program of peripheral deep wells should be carried out in the Pollyanna-Granite Lake pit area. Conclusions of the studies were:

1. Peripheral wells could be used to dewater the pit areas.
2. Regional groundwater flow was from northeast to southwest.
3. The southwesterly dipping Sunset ore structures provide a secondary transmissibility in a northwesterly-southeasterly direction.
4. Gouge-filled faults can act as "dams" to the regional flow.

The rock mass hydraulic parameters are highly variable and reflect the variation in degree of fracturing, oxidation and alteration between and within the deposits. Mass permeabilities range between $10^{-6}$ and $10^{-8}$ m/sec, transmissibilities from $3.2 \times 10^{-5}$ to $7.9 \times 10^{-4}$ m /s and the storage factor from 0 to .014.

To date 32 in-pit and periphal wells have been drilled by Gibraltar Mines. Basically, the dewatering program has been a success, and mining is proceeding under relatively dry conditions with concommitantly lower costs than otherwise would have been the case. The cost of this program is high and the present program was to determine if a less expensive procedure could be developed.

## LOCATION AND PROGRAM LAYOUT

vacuum system has been developed by the authors that can be installed : operating open pit mines. The prototype was installed on the east ıll of Granite Lake pit of Gibraltar Mines Ltd. and tested for a period ꞉ two weeks under field conditions during May 1981. The purpose of the ꞉st was to determine:

. Whether a vacuum can be developed in a fractured medium.
What effect vacuum has on the groundwater regime.

ıe area selected (Fig 3) has an average hydraulic conductivity of )$^{-7}$ m/sec which correlated well with values obtained in an earlier ·oundwater study.[6] The study area was limited to a 13.7 m bench as ıdicated in Fig 4.

"Napco" (Fig 5 ) precussion drill was employed to drill three 15.2 m-7.6 mm ameter vertical holes spaced approximately 15.2 m apart for the instal- ıtion of piezometers. The Napco was employed due to its availability . the property. Three horizontal drainholes were inclined at +2% and ·illed from the bench below to be located midway between the previously ·illed peizometers. The piezometers were subsequently monitored to de- ꞉rmine the effect of the horizontal drains. The second stage required ıe system to be placed under vacuum with simultaneous monitoring being ınducted.

### ezometer Installation

ıitially it was proposed to drill three vertical and three inclined pie- meters positioned so as to obtain a 3-dimensional representation of ıe water table. This plan was abandoned due to extreme difficulties ·ising from inadequate flushing of the drill cuttings.

ıree holes were eventually drilled to 1.5 m below the top of the subse- ıent bench. A 19 mm diameter PVC pipe was inserted in each drill hole serve as an open standpipe piezometer. Bentonite seal was installed two of the cases resulting in a 3 m test region compared to a 15.2 m ·st section in the central piezometer. (Fig 6)

### ·rizontal Drain Installation

ıe "Napco" was employed to drill the horizontal holes which were spaced a 12.2 m pattern to be located between the previously drilled piezo- ters. The drainholes were of 76 mm diameter inclined at + 2% to allow ·r gravity drainage and flushing. Two holes were drilled (Fig 7) to .3 m and one to 18.3 m. The limitation was governed by the drill pabilities. A packer/grout arrangement was employed to ensure that sufficiently closed medium would be developed in order for the vacuum stem to be fully enclosed (Fig 8). The outer 6.1 m of slope face s determined to be highly fractured.

### cker and Grout Installation

hedule 80 4.8 mm O.D perforated pipe 38 mm I.D. with 0.2 mm ots was employed within the vacuum zone. The packer was an expandable bber membrane enveloping a blank PVC pipe whose dimensions are 1 5 m x mm O.D. (Fig 9) The remaining 4.6 m within the fractured zone was composed of a blank section of PVC pipe which was enveloped by a cement grout. It is desirable that an expansive cement be employed, ie 10% enderblast-N. The packer was inflated by means of a nitrogen canister which requires approximately 3 l/hole of gas. The entire drain, including perforation, packer and grout sections were inserted pre-fabricated into the drainhole. It was found that a bentonite surface pack aided the development of a more complete seal. (Fig 10) The grout unit consisted of a grout pump and mix tank as shown in Fig 11. Cement was pumped into the collar of the drainhole and air was exhausted from a tube terminating at the junction between the packer and grout section.

Vacuum System

A well point dewatering system, Figure 12, was employed with the well points horizontal instead of vertical. The vacuum pump was capable of exhausting 12 l/sec of air and producing 0.7 m (mercury) of vacuum at mean sea level. A header system was employed whereby the three drains were attached to the vacuum pump through valves enabling a vacuum to be applied individually or in combination with each other. The exhausted water flow can be measured since flow to the pump is exited through a port. (Figure 12) The vacuum is monitored through the reading of a gauge attached to the pump. The pump was a diesel driven self-contained unit capable of exhausting a constant volume.

## RESULTS

Preliminary Preparation

It was soon realized that upon installation of the peizometers that the water table was well behind the slope. The south peizometer indicated the phreatic surface was 15.2 m below the surface. This was not expected since seepage was present along the 1149 m level in the vicinity of the test area, with an artesian drill hole present on the 1387 m level behind the test slope. The three drainholes did not exhibit any water flow. The slope was then recharged by employing a siphon and redirecting flow from a conduit 3 benches above the crest of the test area. Five days of recharge were required totaling about 5000 litres with a maximum discharge of 0.76 l/s being diverted from the conduit. This resulted in raising the water table to levels indicated in Fig 13.

The horizontal drains did not exhibit a continuous flow. However, upon flooding in the vicinity of the north piezometer, water did periodically flow through the north drain (Figure 14) with a greater discharge emited from a fracture between piezometers north and central. This fracture has a dip direction of 248$^{o}$ and a dip of 60$^{o}$ and resulted in it bisecting the test area. Because of this the water table could not be raised substantially in the vicinity of the northern piezometer.

It was questioned whether a vacuum could be developed since the test area was not fully saturated prior to recharging as is normally the case in conventional well point dewatering. The test area was moderate to highly fractured with about 40 to 60% infill with the dominant structure as indicated above.

Vacuum Test 1

The pump was tested upon installation to ensure that it was trouble free since it was to be left at the mine site for a two week period. Initially the north drain was placed under vacuum resulting in 0 mm of mercury being recorded on the vacuum gauge. It was evident that the packer had become deflated since it recorded zero air pressure. The central and southern drain individually recorded a vacuum of 380 mm of mercury.

Prior to engaging the vacuum pump the water table relative to the south drain was as follows: (Figure 13)

1. North piezo-water table 1.7 m below south drain.
2. Centre piezo-water table 0.49 m below south drain.
3. South piezo-water table 2.3 m below south drain.

The result of applying vacuum to the southern drainhole where initially no water flowed was as follows:

1. 381 mm of vacuum obtained.
2. Flow increased from 0 l/s to 0.2 l/s which was constant for 15 minutes whereafter no flow occurred.
3. Affect on piezometers:
   a. P south - water table dropped 0.15 m
   b. P centre - water table dropped 0.15 m
   c. P north - no effect

It must be noted that four hours prior to the test 5400 litres of water had been placed in the vicinity of the central piezometer. This had resulted in ponding to occur with a rising trend in the water table. (Figure 15). The northern piezometer was not affected since it was separated from the south drain by the southwest dipping structure.

Test Methodology

Further testing comprised the following procedures:

1. The water level was raised above the drain holes.
2. The test was run in stages:
   a. Vacuum on south drain
   b. Vacuum on south and central
   c. Vacuum on south, central and north drains
3. Continuous monitoring of piezometers during the test.
4. The test was conducted until:
   a. No effect on the water table was noticed
   b. No water was pumped through the vacuum pump
5. Continuous monitoring of the vacuum guage and exit flow from vacuum pump.

A problem with the above procedure was that it required five days to replenish the supply of water to the test area in order to raise the water level above the drains.

Test 2

i. Stage: South Drain Engaged

The initial test was conducted when the water levels were as indicated in Figure 13:

a. South piezometer water level 0.6 m below south drain.
b. Centre piezometer water level 2.8 m above the south drain.
c. North piezometer water level 0.18 m above the south drain.

The south drain could maintain a vacuum of 178 mm, the centre 165 mm, and the north 381 mm of vacuum. The north drain was re-inflated which resulted in the increased vacuum. The lower values for the central and southern drains were possibly due to the flushing action during the first trial. The packers were fully inflated in both the centre and south drain. The higher water levels did not result in a continuous water flow under gravity drainage with no vacuum applied.

Figure 16 shows the immediate effect resulting from applying the vacuum and the results are summarized below:

1. 178 mm of vacuum created on the south drain.
2. 0.3 l/s initially flowed then reduced to 0 l/s 32 minutes later.
3. Affect on piezometers:
    a. P south water table dropped 0.9 m in 70 minutes whereafter inflow was greater than outflow
    b. P centre - water table dropped 1.1 m in 59 minutes whereafter inflow was greater than outflow
    c. P north - no effect, influence of discontinuity

ii. South and Centre Drain Engaged

Vacuum was applied in addition to the central drain upon determining that further drainage was not possible. At this point the water table was as follows:

a. P south water level 1.7 m below D-centre, 1.4 m below D-south.
b. P centre water level 2.0 m above D-centre, 2.3 m above D-south.

The following was observed:

1. An 89 mm vacuum resulted from the combined drainage.
2. 0.02 l/s flowed initially to 0 l/s after five minutes.
3. Recharge was greater than discharge in P central with result in rising water table.
4. P north was unaffected due to discontinuity.
5. P south indicated a drop of 0.05 m in the water table, after 41 minutes the water table began to rise.

ii. North, Centre and South Drain Engaged

The water table continued to rise, indicating recharge greater than discharge (ie, greater than 0.6 l/s) with the three drains engaged. The combined vacuum was 63 mm with 0.03 l/s flowing initially to 0 l/s fifteen minutes later. The conclusion was that the vacuum was too low to obtain drawdown.

## COST OF INSTALLATION

This prototype can be applied to an expanded pit scale with unit costs lower than that estimated, however, an indication is given in Table 1.

## PRACTICAL IMPLICATIONS

It is evident from the field observations that vacuum drainage is technically feasible and can be employed in a fractured or jointed medium. It operates on the basis of an increased hydraulic gradient and mass permeability which would result in a wider zone of influence for an individual drain. Consequently this would enable an increased drain spacing to exist and as a result a lower drain frequency. It was also shown that vacuum effects are very rapid and that a direct relationship exists between the degree of vacuum and the amount of drawdown.

The prototype is applicable to a pit depressurization system since it is a self-contained unit that has been technically proven in well point dewatering through the past thirty (30) years. This system tends to accelerate the rate of drawdown which is an important factor in order to stabilize active slides. The reasons being that with increased deformation due to slide movement, shear strength parameters are reduced. Vacuum drainage would thus stabilize slides much more rapidly. The area of influence of the vacuum drain extends below the level of the drains itself. This was shown in Test 1 whereby drawdown occurred when the drain was located 2.3 m above the water table. Conventional well pointing is capable of normally lifting 4.5 m of water column. Vacuum may be applied to drainage adits underneath slides resulting in stabilization.

## CONCLUSIONS

It has been shown that vacuum drainage resulted in water flow and drawdown in the water table where initially the drains were ineffective. Figure 17 shows one instance where water did not flow freely when the water table was 2.7 m above the horizontal drains. This may have resulted because of tight fractures in the vicinity of the drain. It was generally the case that the slope face is fractured. It was not evident that flow was occurring since seepage was not channelled into the drain unless exhausted under vacuum. It is believed that flow was re-directed upon vacuum engagement.

The drilling of the drainholes intercepted a large number of fractures with drilling perpendicular to the major principal joint set. The vacuum pressure increased the hydraulic gradient and resulted in the flow of water and rate of drainage in excess of that which occurred soley due to gravity.

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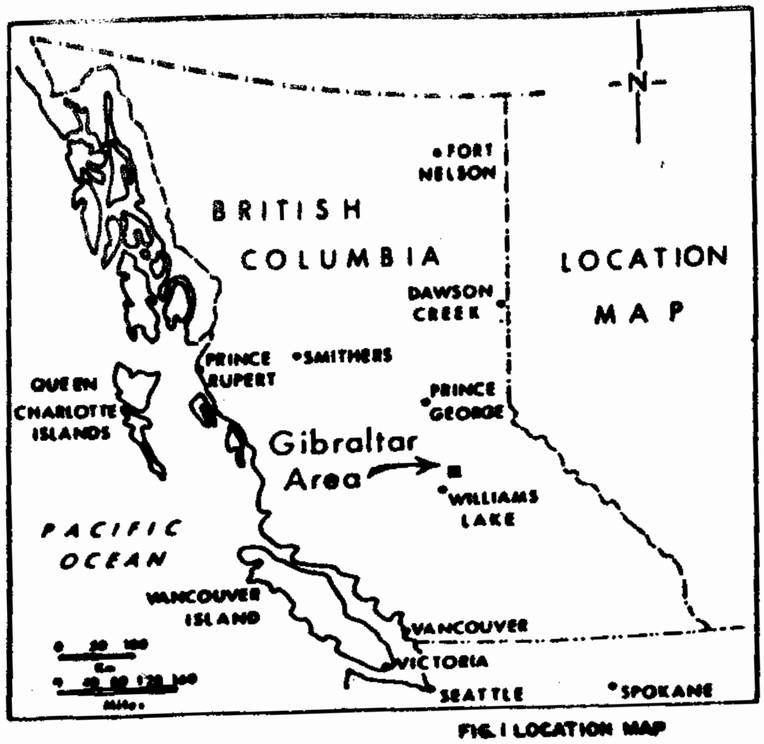
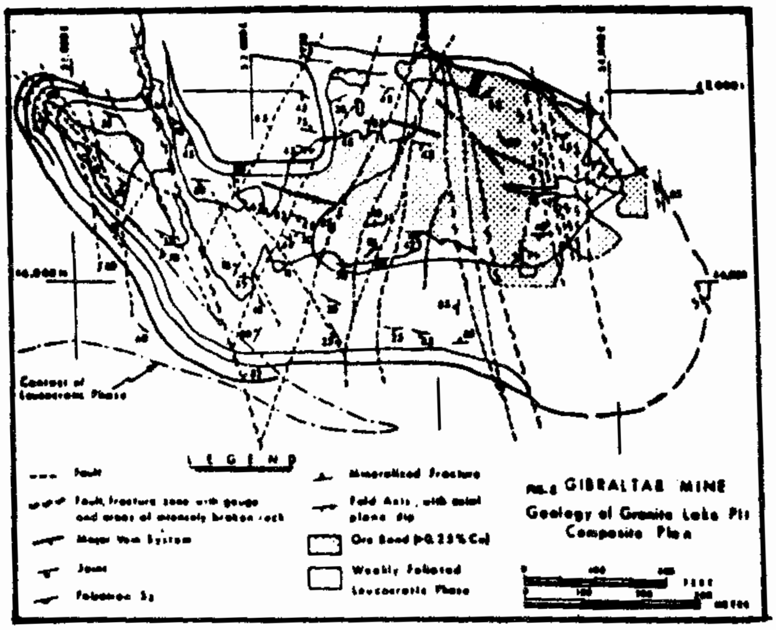



FIG. I LOCATION MAP




GIBRALTAR MINE
Geology of Granite Lake Pit
Composite Plan

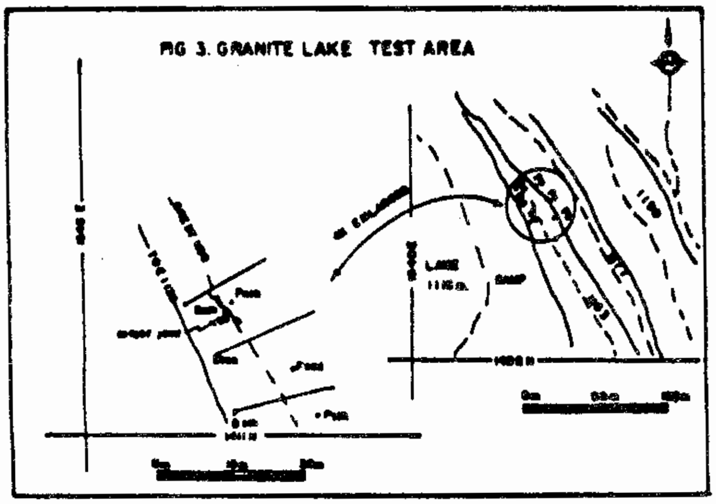
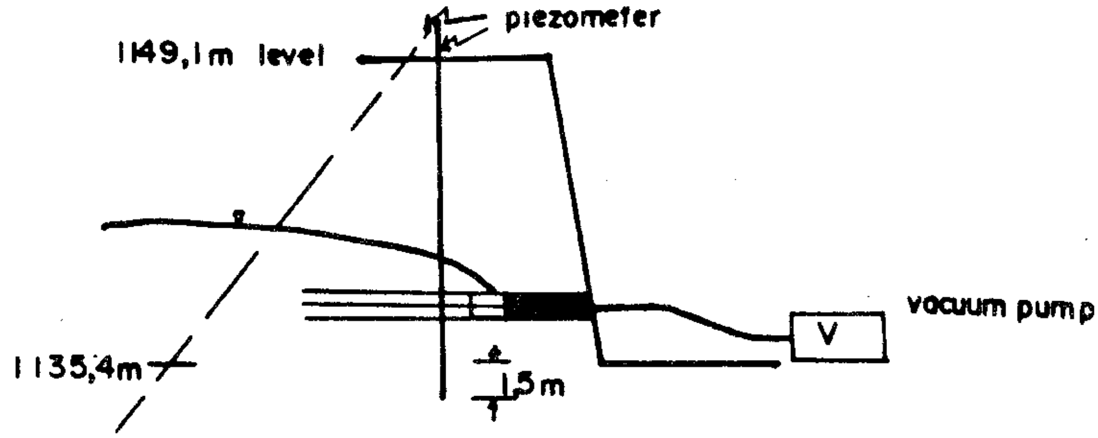


FIG 3. GRANITE LAKE TEST AREA

Fig.3 Photograph of Test Area

FIG.4 SCHEMATIC REPRESENTATION OF VACUUM SYSTEM



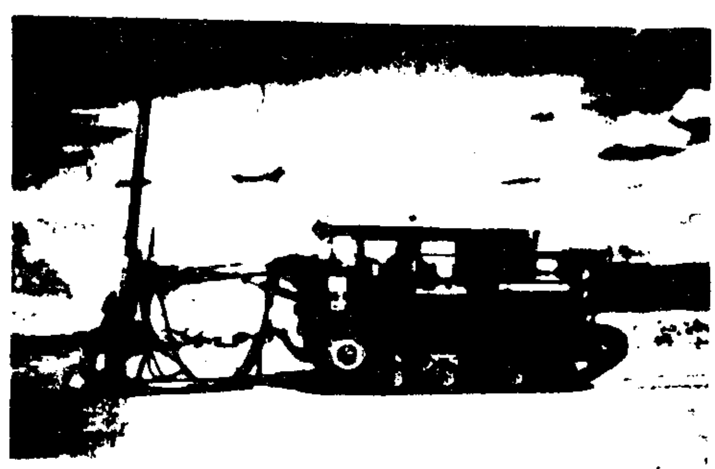



Fig.5 Photograph of Napco Drill

FIG. 6 PIEZOMETER CONSTRUCTION

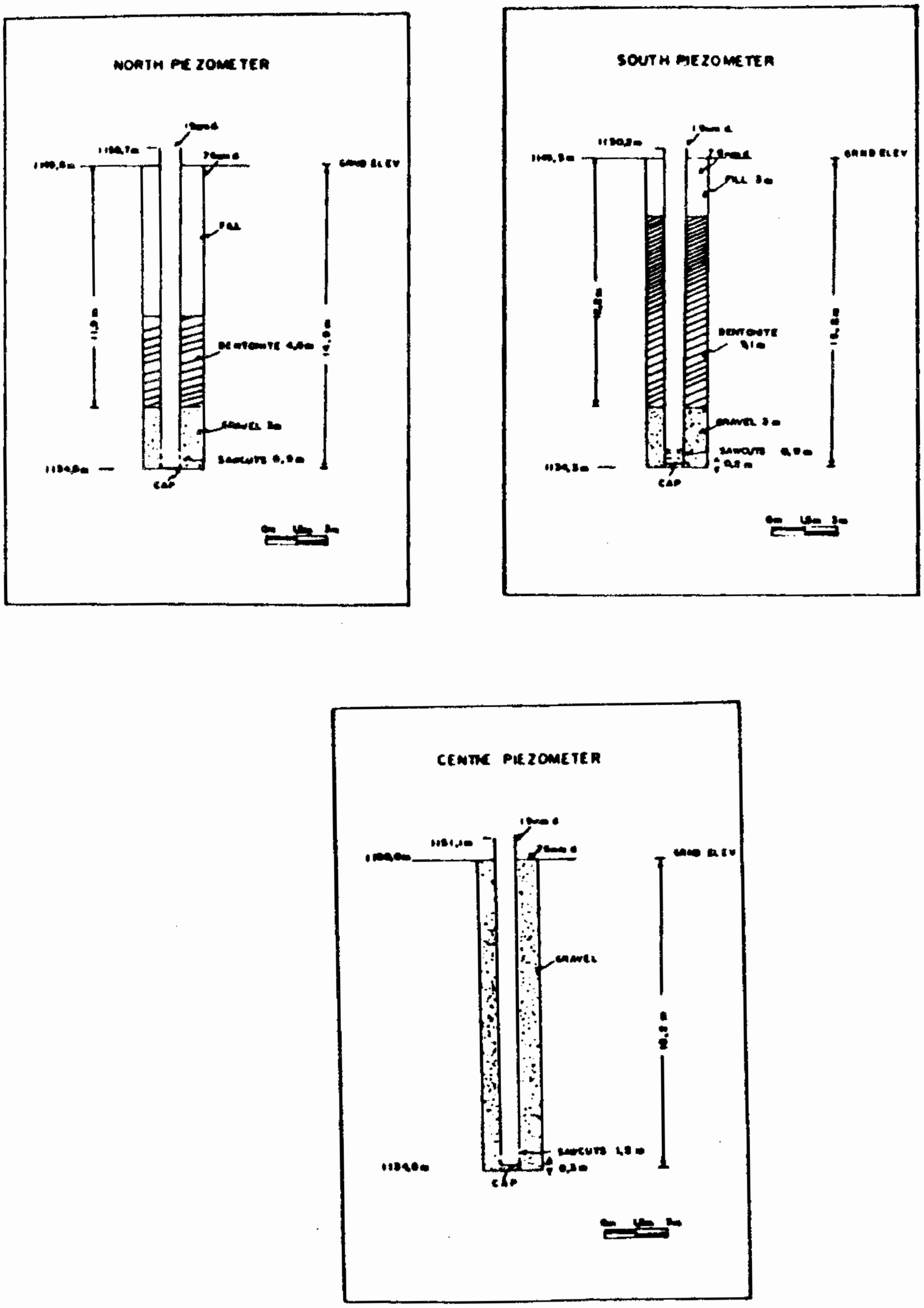


FIG.7 HORIZONTAL DRAIN CONSTRUCTION

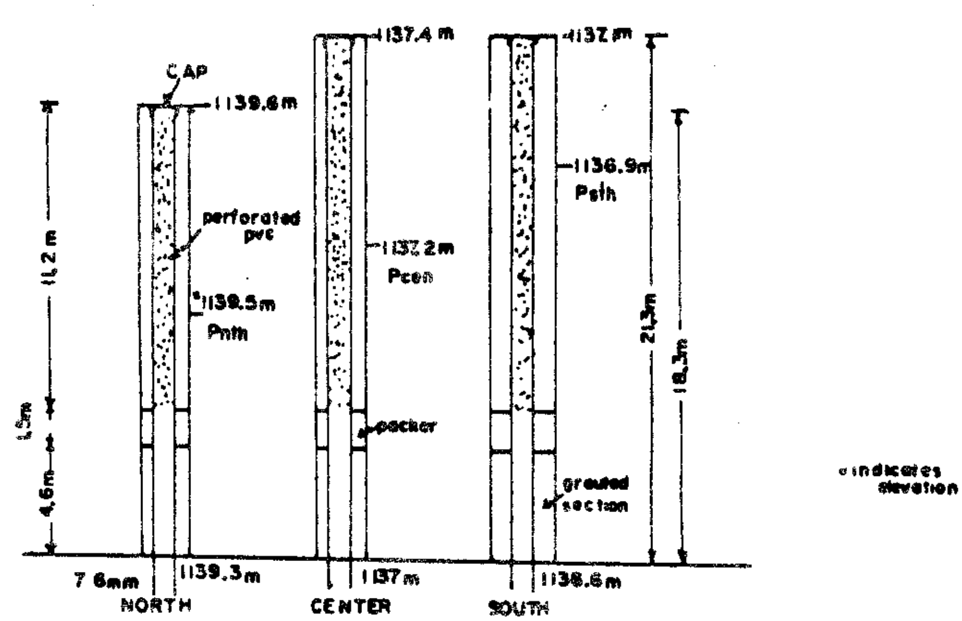



FIG. 7 DRAIN CONSTRUCTION

FIG.8 PACKER SYSTEM

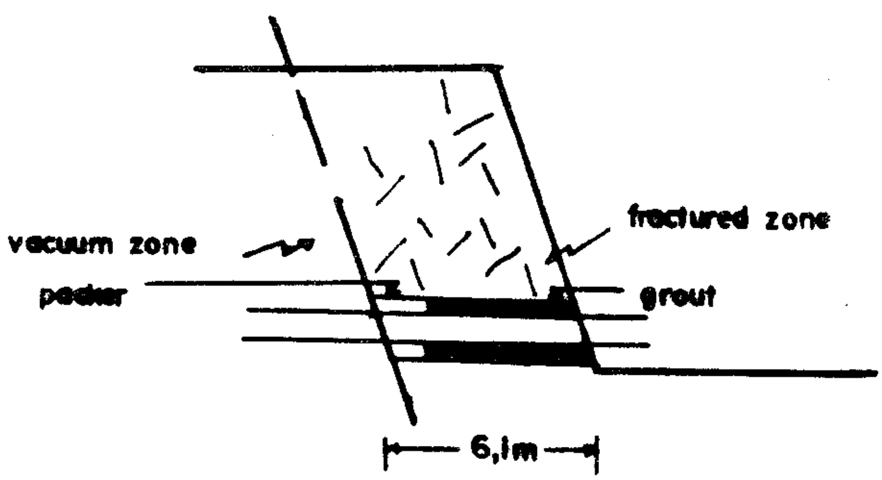


Fig.9 Photograph of Packer

Fig.10 Photograph of Bentonite Seal

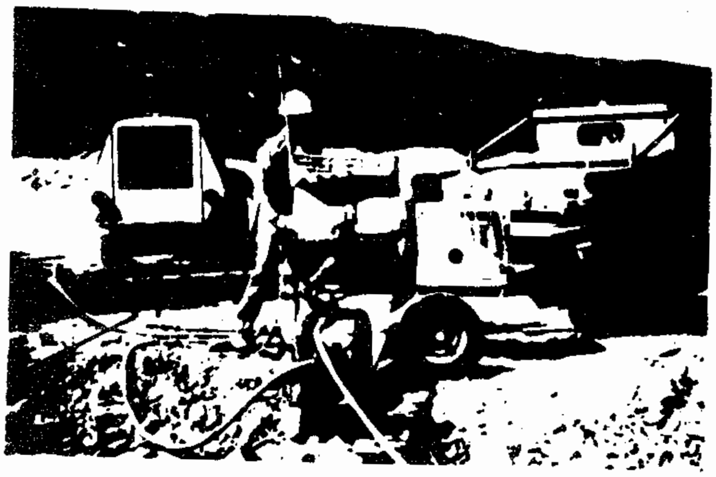


Fig.11 Photograph of Grout Unit

Fig.12 Photograph of Well Point Unit

FIG 13 PIEZOMETER NEST

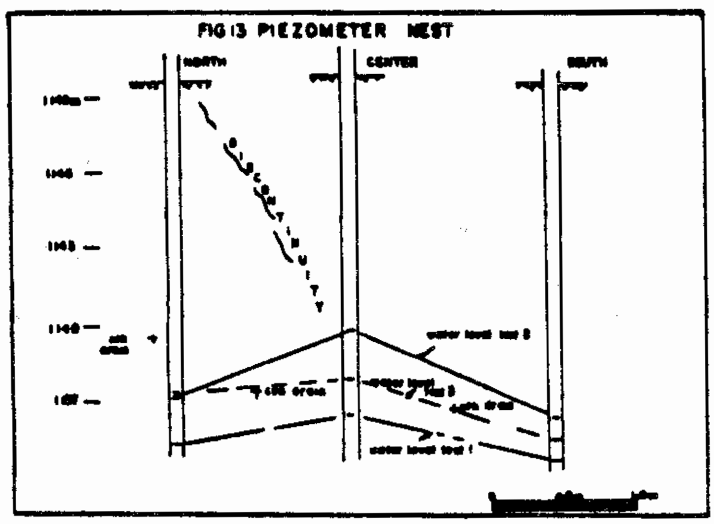



Fig.14 Photograph of Flow Through Drain

FIG.15 WATER LEVEL VS. TIME
TEST-1

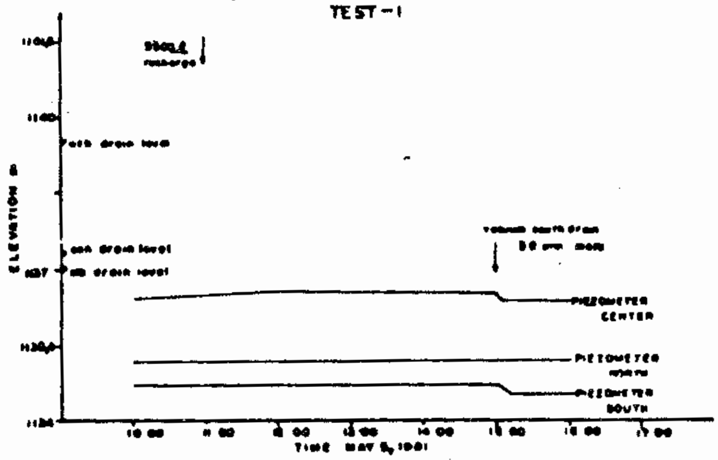



FIG.16 WATER LEVEL VS. TIME
TEST-2

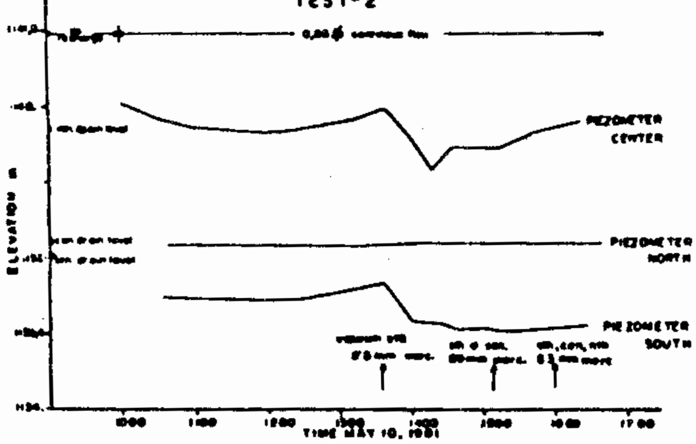



FIG.17 WATER LEVEL VS. TIME
VACUUM TEST- GIBRALTAR MINES

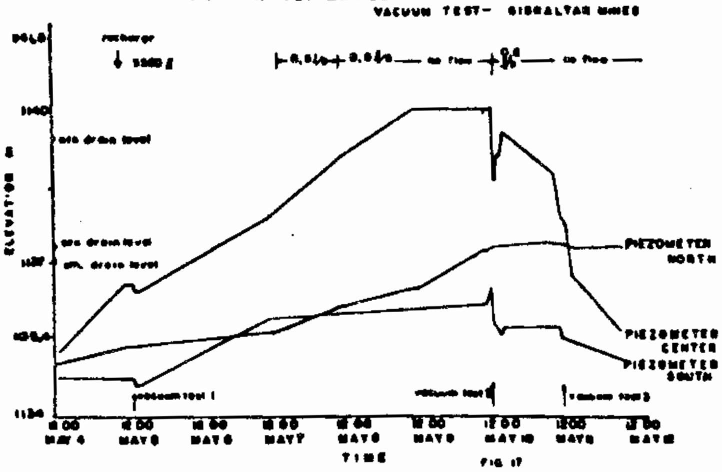


Table 1.0: Cost Summary

| Item | Cost/Unit | Amount |
|---|---|---|
| Perforated PVC Pipe | $ 9.60/m | $ 518.00 |
| Blank PVC Pipe | 7.33/m | 198.00 |
| Packers & Misc. | 282.00/unit | 846.00 |
| Grout Equipment | | |
| - Rental & operation | 298.00/unit | |
| - Materials | 50.00/hole | 1045.00 |
| Vacuum Pump | | |
| - Rental | 525.00/wk | |
| - Installation | 133.00/hole | |
| - Materials, ie, pipe | 67.00/hole | 1920.00 |
| Piezometers & Miscellaneous | 3.44/m | 557.00 |
| TOTAL: | | $ 5084.00 |