PROBLEMS ASSOCIATED WITH THE RAPID DEWATERING OF A MULTILAYERED AQUIFER AND MINING OF A TRIAL COAL PIT AT BOWMANS, SOUTH AUSTRALIA

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ABSTRACT

The Electricity Trust of South Australia excavated a circular pit, 250 m in diameter and 60 m deep to the top of a 20 m thick coal seam in order to obtain a bulk sample for trial burning. Excavation commenced in Sept 1979 and the target date for completion was the end of April 1980. 45 m of sands and silty sands above the coal required to be dewatered and an aquifer beneath the coal needed to be depressurised to prevent heave in the pit floor. Design based on inadequate sub-surface informatio led to the poor performance of the original dewatering system of 10 wells. Subsequent installation of 11 wells inside the pit also failed to produce the desired dewatering effect. Final depth was achieved at the end of Oct 1980 with the aid of multiple overlapping vacuum well point systems and a great deal of repair and failure prevention work on the poorly drained slopes. Pumps and other equipment were withdrawn from the pit on 8th Nov 1980 after 5000 tonnes of coal had been mined. Within two days the lower slopes had failed completely. The unexpected occurrence of strongly developed horizontal layering in materials with relatively poor drainage properties (high silt content) resulted in the project taking twice the anticipated time and costing far in excess of the original budget.

INTRODUCTION

The Bowmans Trial Pit is located 100 km north of Adelaide near the village of Bowmans/see Figure 1/. Considerable reserves of low grade lignite occur in the Wakefield Coalfield in the North St. Vincent Tertiary sedimentary basin. The Electricity Trust of South Australia (ETSA) are investigating the possibility of using the low grade lignites in a thermal power station to be built in the next decade and required bulk samples of the lignite for test burning in West Germany and the USA. Of the several options for obtaining the bulk sample, an open pit was selected in order to obtain experience in the dewatering and excavation of overburden to assist in the future design of a full scale mine. The open pit also allowed a surplus of lignite to be collected should further testing be required.

The Bowmans area has an average annual rainfall of 400 mm concentrated mostly in the winter (June to Sept) and an evaporation rate of 2 000 mm/annum, most of which occurs in the summer (Nov to March). Ground surface at the site was approximately 20 to 21 m above Australian Height Datum (A.H.D.) and the static level of the groundwater was approximately 6 m A.H.D.

THE DESIGN STAGE

No drilling to obtain specific hydrogeological information had been done at the pit site at the time of the original design in 1978. Information from rotary drilled coal exploration holes and one geotechnical percussion hole located at the pit centre was used to construct the simple hydrogeological model/See Figure 2/ on which the initial design of the dewatering system and pit slopes was based. Limited discharge testing had been carried out in 1975 and 1976 at two sites more than 5 km south of the pit where lithologies appeared to be different from those at the pit site. In these tests the assumption had been made that the overburden consisted of several thin aquifers separated by confining beds. Interpretation of these early pump tests led to the belief that dewatering would present no problems and this concept was transferred from the pump test sites to the actual pit site where a less complex hydrogeological model was proposed.

Pit Slope Design

Grain size analysis was carried out on selected tube samples from the percussion hole and slope stability analysis determined that the shape of the pit should be as follows:

Overall Shape - conical with spiral haul road
Benches 10 m wide at 15 m vertical intervals
Slopes between benches of 45°
Overall slope approximately 31°
Diameter at top of coal of 25 m
Diameter at surface of 250 m.

These slopes were designed on the assumption that the overburden materials would be completely dewatered at the time of excavation.

It was estimated that the 1.2 x 10^6 m^3 of overburden could be excavated in 200 to 230 days including preliminary earth works, therefore a work schedule was programmed commencing in Sept 1979 with a target completion date of the end of April 1980 thus avoiding the winter rains.

Design and Construction of Outer Wells

The original pit design incorporated a ring of 5 dewatering wells with screens located above the coal. The first of these wells, W1, was drilled in August 1979 together with 14 piezometers. Geological and Geophysical logging of the rotary mud drilled hole indicated well developed horizontal layering. Two well screens were set at depths of 45-48 m and 51-57 m and the well was pumped for 3 days at 10 1/sec/see Figure 3a/ producing drawdowns of 8 m in a piezometer completed at the same depth as the pumping well screened interval and only 0.5 m in a piezometer at a similar radius from the pumping well but completed in the top part of the overburden aquifer. The horizontal layering was clearly restricting vertical drainage.

The hydrogeological model was revised to include three layers above the coal, a sand split within the coal and carbonaceous sands and silts beneath the coal.

Aquifer A from 6 m AHD to - 12 m AHD
Aquitard from - 12 m AHD to - 19 m AHD
Aquifer B from - 19 m AHD to - 40 m AHD
Aquiclude (coal) from - 40 m AHD to - 50 m AHD
Aquifer C (sand) from - 50 m AHD to - 51 m AHD
Aquiclude (coal) from - 51 m AHD to - 60 m AHD
Aquifer D from - 60 m AHD to - 90 m AHD

It was apparent that the production wells would have to produce water from both Aquifers A and B if significant dewatering effects were to be produced in a short time so well W2 was drilled on the opposite side of the pit to W1 and screens were set in both the A and B aquifers. W2 was tested at 29.5l/sec for 1.5 days/see Figure 3b)/ and produced drawdowns of 3.2 m in Aquifer B and 1.7 m in Aquifer A. The threefold increase in discharge compared to W1, and the smaller drawdown obtained in aquifer B suggested significant variation in the hydraulic properties of the aquifer materials in the area of the pit.

At the time of the W2 discharge test, excavation of the pit had already commenced (the top 15 m of excavation were in dry clay) and it was important to commission the dewatering system as soon as possible. The original 5 wells were increased to 10 and all but W1 were screened in aquifers A and B. The 10 wells were completed in December 1979. Each well was tested to determine its specific capacity (ie discharge per metre of drawdown) which was found to vary systematically around the pit with a minimum value of 0.45 l/sec/m at W1 and a maximum of 1.44 l/sec/m at W6/see Figure 4/. 5 wells were equiped with line shaft driven turbine pumps and 5 with electric submersible pumps with fibreglass column. All 10 wells were operating by mid Jan 1980 with a total pumping capacity of 2201/sec.

Analytical models were applied to determine the probable dewatering effects of the 10 wells and the results indicated that dewatering could not be achieved in the time available without the addition of some additional discharge capacity within the pit. In-pit wells could be constructed from the second bench at -9 m AHD provided sufficient drawdown had occurred to allow excavation to the -9 m level.

It was necessary to depressurise aquifers C and D, whose piezometric levels were similar to Aquifers A and B, in order to prevent uplift of the floor of the pit. This was achieved by constructing 5 wells which were pumped at a combined discharge of 10 l/sec and satisfactorily controlled pressures to the required levels/see Figure 7, piezometer D/.

Pipe Line Design

Water produced during the pump testing programme was highly saline (20,000 to 30,000 mg/l TDS) and the Department of Environment required that this water be discharged into the St Vincent Gulf. Water from the wells was collected in a ring main, fed to a 250 kl header tank and discharged via 8 km of 375 mm asbestos-cement pipe into a salt water section of the Wakefield River. The pipeline was designed and installed before all the wells were drilled and had the capacity to transmit 115l/sec under gravity. Two booster pumps were added when it was found that the combined discharge capacity of the wells was almost twice the pipeline capacity.

An emergency storage dam was also constructed close to the pit to enable dewatering to continue in the event of failure of the pipeline or booster pumps.

THE CONSTRUCTION STAGE

The initial excavation of top soil and dry stiff clay was carried out by scraper after some ripping by a bulldozer. Rubber tyred frontend loaders and trucks were intended to be the major equipment used for the majority of the pit. This method was satisfactory down to -7m AHD excavating approximately 1 x 10^6 m^3 of overburden by the end of March 1980 when wet conditions in the floor of the pit created trafficability problems. From -7m AHD to top of coal at -40m AHD, hydraulic excavators were employed to dig up to 3m below the level of their own catapillar tracks. Progress was relatively slow due to the necessity to import material to make a working surface, the frequent inconvenience of installation of well point systems and the restricted working space as the pit became deeper. A single hydraulic excavator was used to mine the coal sample to a final depth of 69 m below surface (-48m AHD). Approximately 5 000 tonnes of coal were recovered.

Progress in Dewatering and Depressurisation

From Jan 1980, when all 10 outer well pumps were operating, daily observations were made in 25 piezometers located around the periphery of the pit. 10 piezometers were screened in aquifer B, 9 in Aquifer A, 1 in the aquitard, 1 in the sand split within the coal seam and 4 beneath the coal.

2 piezometers were also located 650 m east and 1000 m west of the pit with screens in the B zone to monitor regional effects. The depth to water beneath the floor of the pit was monitored by drilling auger holes which were allowed to collapse once a water level had been determined.

Less than half the anticipated drawdown had occured by the end of January 1980/see Figure 6/ and the floor of the pit was rapidly approaching the saturated zone. In order to establish a bench at -9m AHD it was necessary to install 2 complete rings of vacuum well points at -5m AHD and -7m AHD. These well points were emplaced by jetting where possible but many required predrilling due to the presence of indurated sands at the base of aquifer A and the top of the aquitard. A combined discharge of approx. 50 l/sec was obtained from the well points/see Figure 6/ and the rate of drawdown was increased sufficiently for the -9m bench to be established in April 1980.

The marked deviation of the actual water levels from the predicted water levels was interpreted as being due to the presence of the aquitard which was restricting vertical drainage. At this stage it was still felt that the B aquifer would behave as a single hydraulic unit which could be dewatered allowing drainage of the aquitard. 11 wells were installed from the -9m bench to top of coal with screens over the bottom 12 m (from -28m to -40m AHD) and electric submersible pumps were suspended on flexible hose supported by nylon ropes. Total discharge capacity of the 11 in pit well pumps was 148 l/sec however in practice the wells yielded a maximum of 90 l/sec shortly after commissioning. This additional withdrawal of water from aquifer B within the area of maximum drawdown of the

10 outer wells resulted in a drop in production of the outer wells from 160 l/sec to 110 l/sec /See Figure 6/.

Once again actual drawdown failed to match predicted drawdown therefore the hydrogeological model needed revision and more drastic dewatering measures were required to ensure success of the project. Six percussion drilled piezometers were installed from the -9 m bench with careful sampling. These holes revealed the presence of a second aquitard from -29m AHD to -31m AHD, composed of highly carbonaceous sand with extremely small hydraulic conductivity. The six inpit piezometers, three at the north side and three at the south side of the pit, measured piezometric levels immediately above the coal, below the carbonaceous sand aquitard and in the upper B zone aquifer. The piezometric level above the coal was found to be seven metres lower than in the upper B zone aquifer indicating that the 11 inpit wells were depressurising the lower B zone aquifer but were having only a very limited effect on the upper B zone aquifer. It was clear that further progress in dewatering required a concentrated effort within the pit. Vacuum well points were selected as the best way of achieving dewatering and pit wall stability. Each ring of well points, though having the theoretical capacity to lower the water level by up to 6 metres, was found in practice to achieve 2 to 3 metres of drawdown within 7 days of commissioning and 5 m of drawdown approximately 3 to 4 weeks later.

Average spacing between well points was 2 metres and the screened interval was from 6 metres to 7 metres below surface. Each well point had a maximum capacity of 0.5 l/sec but average production from each well point was approximately 0.3 l/sec.

In early June 1980 when the major vacuum well pointing began, there were still 23 metres of saturated materials between the pit floor and the top of coal. Careful planning was required to select the most suitable level from which to install each ring of well points so that optimum dewatering effects could be obtained with a minimum of interuption to excavation during the installation of the well points. It should be noted that the well point system removed some of the pumping load from the outer 10 wells and the 11 in pit wells/See Figure 6/ resulting in problems with the control of water levels in the pumping wells. The final stage of excavation of overburden was achieved with 6 overlapping systems of well points/see Figure 5/ at EL -15, EL - 19, EL - 22.5, EL - 26, EL - 32 and EL - 36 m AHD. An additional system of short well points was installed at EL - 26 in an attempt to control seepage at the base of Aquifer B (upper). Combined discharge from well points reached a maximum of 100 l/sec in August 1980 and declined to between 50 and 60 l/sec during September and October.

Problems with well pumps

Pumps installed in the 10 outer wells suffered numerous problems. The original 5 line shaft pumps suffered problems of corrosion of the drive shaft couplings resulting in frequent breakages. The pumps themselves were subject to severe corrosion due to the chemistry of the water, and mechanical wear due to aeration of the water which was caused by flow from the Aquifer A screens cascading down the well to the pumping level. Similar problems occurred when the level in the wells fell below the Aquifer B (upper) screens. As the line shaft pumps failed they were replaced by electric submersible pumps.

The original 5 electric submersible pumps suffered only minor corrosion problems. Many of the pumps required modification in the form of removal of impeller stages as the pumping water levels in the wells fell. This was necessary in order to control discharge so that a minimum of aeration occurred.

Precaution against pump breakdown and power failure

The outer 10 wells and 11 in-pit wells were all electrically driven. Spare pumps were held in stock and a standby diesel generator capacity of 560 kilowatts was available on site. In addition the 1100 volt mains electricity supply lines were duplicated. The well point systems were operated by diesel driven vacuum/centrifugal pumps. Each system had a standby pump as did the high lift pumps used to lift the water out of the pit from well points and a sump.

Slope failure mechanisms in the pit and repair methods

Three major modes of failure were observed in the walls and floor of the pit. All were due to poor drainage or the development of high pressures associated with the horizontal layering in the materials.

Horizontal piping occurred at the toes of slopes where slightly more permeable material was subjected to a hydraulic gradient of more than five percent. /see Figure 8a)/. Collapse of horizontal pipes in several cases resulted in bench failures which were repaired by inserting a P.V.C. pipe into the natural opening and back filling with sand or gravel. The restored slope was then supported by drainage fabric (either filter cloth or hessian) and sand bags.

Vertical piping /see Figure 8b)/ was occasionally associated with horizontal piping where auger holes, drilled to determine water level beneath the pit floor, had disturbed the horizontal layering permitting the flow from a lower aquifer to feed a horizontal pipe.

Slumping of newly cut faces occured when drainage was incomplete, again governed by the horizontal layering. Filter cloth was layed over the lower part of the slope, held in position by metal pegs driven into the upper part of the slope. Sand bags were then placed on top of the filter cloth at the toe of the slope to prevent excessive movement of sand and to allow gravity drainage to occur. (see Figure 8 c) & d)/. The most concentrated repair work was associated with the seepage problem at the base of Aquifer B (upper) where the carbonaceous sand aquitard effectively prevented vertical drainage.

Erosion of benches and slopes by wind caused minor problems of burial of well points in drift sand. Heavy winter rains caused considerable erosion of benches and faces and burial of well point systems. Sand was washed by stormwater into one of the in-pit wells wedging the pump so that it could not be withdrawn from the hole.

Face sampling and the revised hydrogeological model

During the final stages of mining the pit was mapped geologically by ETSA personnel [1] and a continuous series of 147 samples of all pit wall materials was collected. These samples were subjected to grain size analysis. The percentage silt size material(<0.06 mm) was compared with the natural gamma radiation logs from drillholes located close to the sample sites/ see Figure 9/. Hydraulic conductivities based on the median grain size (MD_{50}) were also calculated/see Figure 9/ using the method of Masch and Denny [2] . Where silt content exceeds ten percent it is likely that the hydraulic conductivity of the material is controlled by the silt fraction, regardless of the median grain size eg in the aquitard separating Aquifer A and Aquifer B (upper). The gamma log is generally a good indication of silt content and is thus a good indicator of horizontal layering. The right hand column of figure 9 shows intervals in which hydraulic conductivity (K) is not proportional to MD_{50} together with an indication of the reason for the reduction in K. The carbonaceous sand aquitard separating aquifer B (upper) and B (lower) shows a very high gamma log response which is not related to silt content but is probably due to uranium associated with the carbonaceous material. A zone of reduced K which has no gamma response is the 2 metre thick zone of indurated sand between EL - 5 and -7 metres AHD. Carbonaceous fines immediately above the coal appear as a zone of greater than ten percent silt which has no gamma response.

In general terms the face sampling programme has shown that the gamma log is a good indicator of horizontal layering which, coupled with careful sampling of percussion holes should permit the construction of a more valid hydrogeological model. The suggested model for Bowmans overburden materials is:

Aquifer A from 6 m to -4 m AHD; K 6m /day
Aquitard from -4 to -19m AHD; K vertical = 0.01m/day
Aquifer B (upper) from -19 m to -28 m AHD; K = 5m/day
Aquitard from -28 m to -30 m AHD; K vertical = 0.001m/day
Aquifer B (lower) from -30 m to -42 m AHD; K = 8m/day

DECOMMISSIONING

On 8th November 1980 the well point systems were progressively closed down and all pumps and pipework removed from the pit. The five wells depressurising the subcoal aquifer were closed down at the same time.
On 9th November the 11 in-pit wells were closed down and pumps and pipework recovered together with many of the well points. The 10 outer wells were then decommissioned and observations of the recovery of water level in the pit and piezometers was commenced. A photographic record of the collapse of the lower part of the pit was also made/ see Figure 10 a) and b)/.

SUMMARY

The main problems associated with the project were:-

a) Inadequate data at the design stage.
b) Short term nature of the project requiring rapid dewatering.
c) Corrosive groundwater.
d) Multilayered aquifer with some poorly draining intervals.

The effects that the above problems had on the project were:-

1) Failure of 10 outer and 11 inpit wells to achieve anticipated drawdown.
2) Complication of mining operation due to wet conditions.
3) Extension of project into winter rain season with run-off generated erosion.
4) Need for much repair and failure prevention work on poorly drained slopes.
5) Serious rise in costs due to necessity for multiple well point systems.

6) Frequent deepwell pump failure as a result of corrosion and aeration.
7) Factor of Safety close to 1.0 at the pit bottom with total dependance on well point pumps for wall stability in lower 20 metres of overburden.

Geotechnical and hydrogeological consultants for the Bowmans project were Coffey and Partners Pty. Ltd. and the in-pit dewatering contractor was Hanson Sykes Pumps Pty. Ltd.

References

(1) Springbett, G.M. Geological Investigations of the Bowmans Trial Pit. ETSA unpublished report/ 1981/
(2) Masch, F.D. and Denny, J.J. Grain Size Distribution and its Effect on the Permeability of Unconsolidated Sands. Water Resources Research Vol 2 No. 4 pp665-677/1966/

List of Figures

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Figure 2: Original Hydrogeological Model
1/Clay : 2/Coal : 3/Basement
A,B,C/Sand aquifers.

Figure 3a: Discharge Test Results for W1.
X Piezometer in Aquifer B at r = 20 m
⊙ " " " at r = 70 m
A " " Aquifer A at r = 20 m
+ " " " at r = 70 m
1/ Average drawdown in aquifer B
2/ Average drawdown in aquifer A

Figures 3b: Discharge Test Results for W2.
X Piezometer in Aquifer B at r = 30 m
⊙ " " " at r = 80 m
+ " " Aquifer A at r = 10 m
A " " " at r = 20 m
1/ Average drawdown in aquifer B
2/ Average drawdown in aquifer A

Figure 4: Specific Capacity of 10 Outer Wells.

Figure 5: Wells and Well Points Operating During Final Stages of Mining
A/ Outer Wells
B/ In-pit Wells
C/ Well Points
1/ Water level Aquifer A
2/ Water level Aquifer B (upper)
3/ Water level Aquifer B (lower)
4/ Clay
5/ Aquifer A
6/ Aquitard
7/ Aquifer B (upper)
8/ Carbonaceous Sand Aquitard
9/ Aquifer B (lower)
10/ Coal

Figure 6: Synopsis of Water Level, Pit Floor Level and discharge during Project
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2/ Fine sand, 40% of interval indurated
3/ Very fine sand with gravel bands
4/ Fine sand
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6/ Fine sand with 2 silty bands
7a/ Carbonaceous sand aquitard
7b/ Slightly carbonaceous sand, medium grain size
8/ Clay
9/ Coal

Figure 10a: Bowmans Pit in final stage of mining
Figure 10b: Bowmans Pit, 2 days after removal of pumps

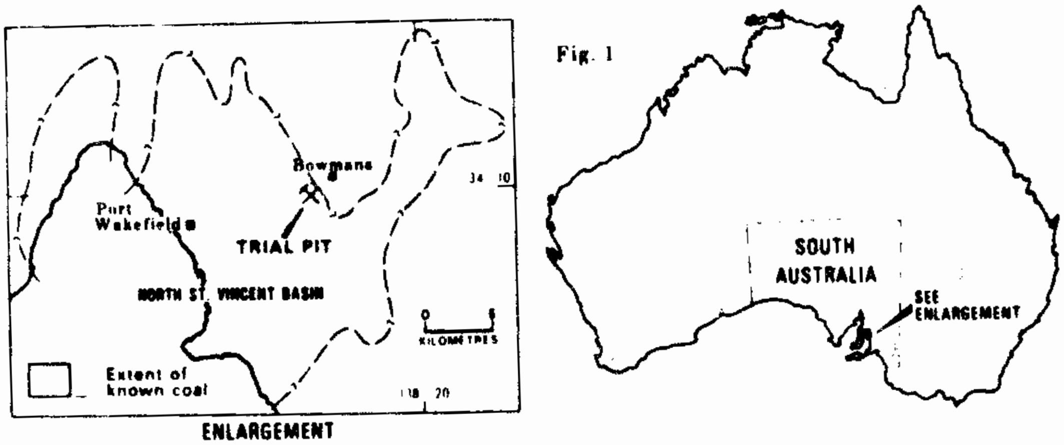

Fig. 1

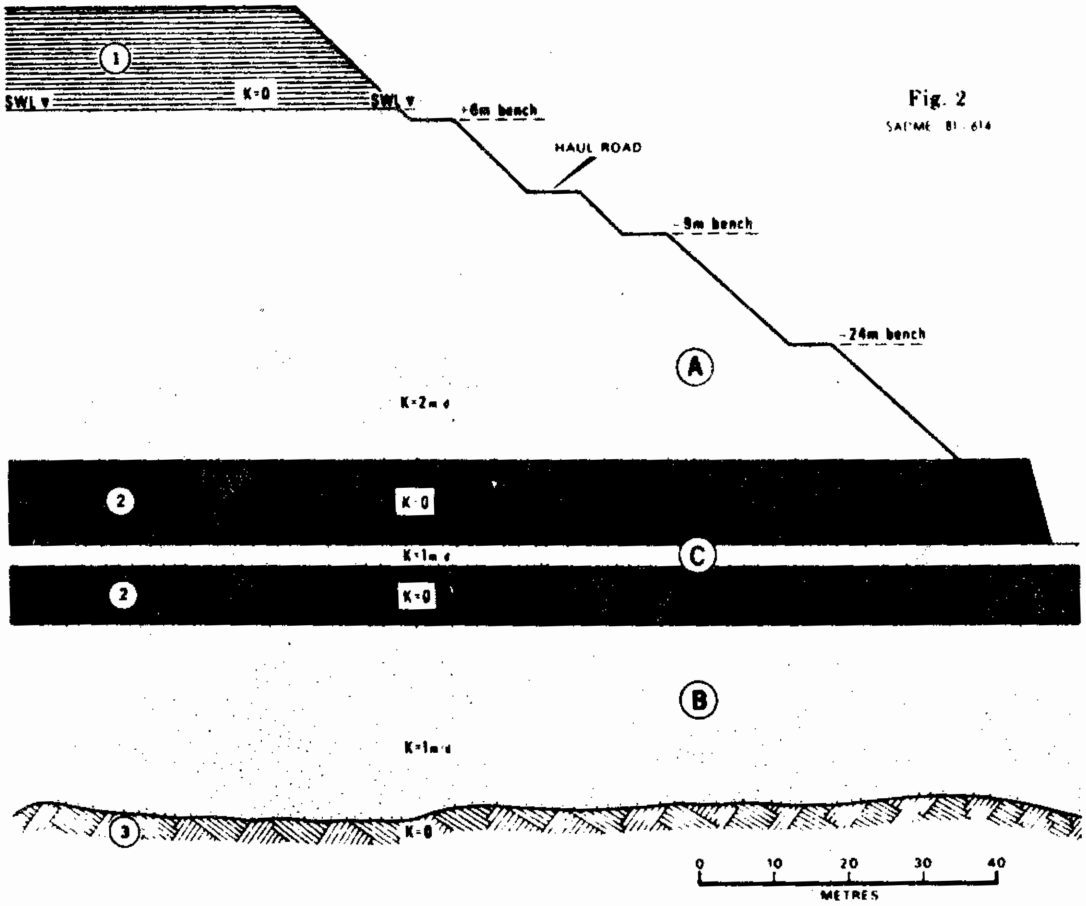

Fig. 2
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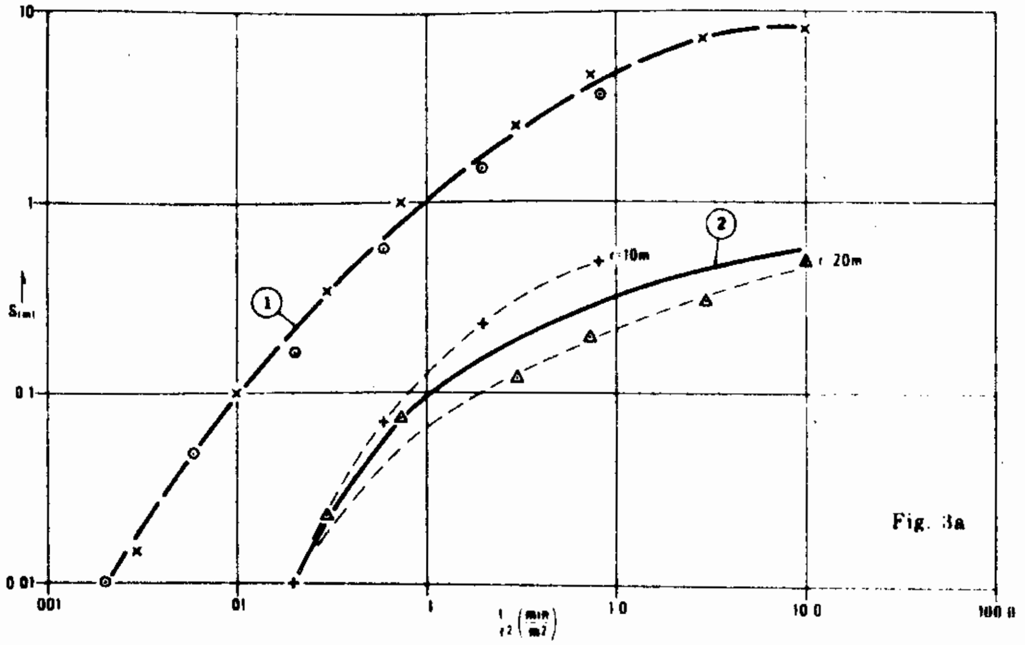
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Fig. 3a

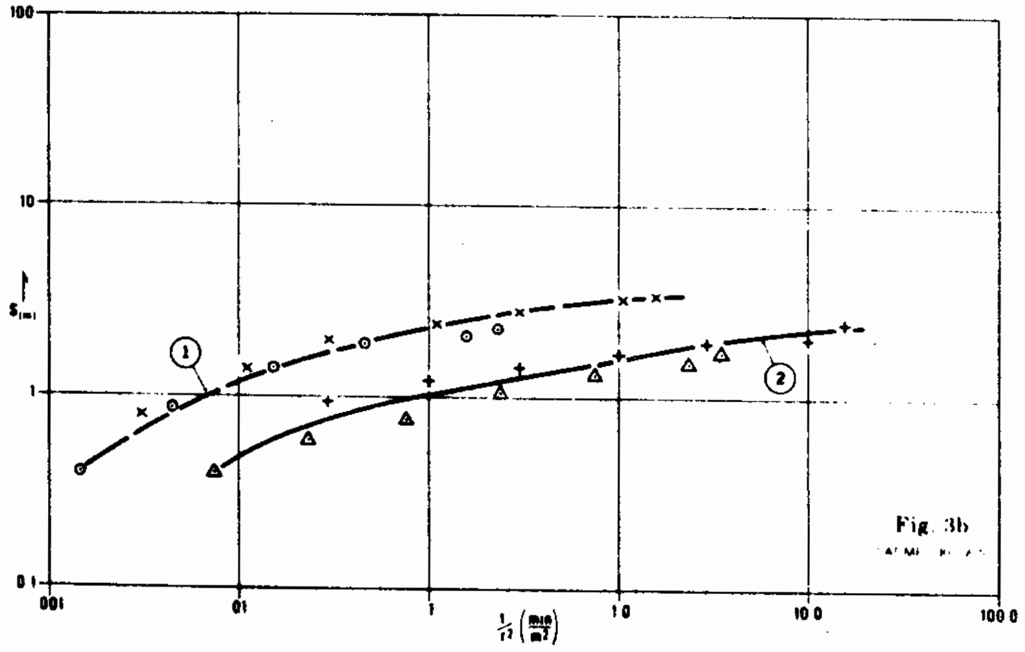
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Fig. 3b

Fig. 4

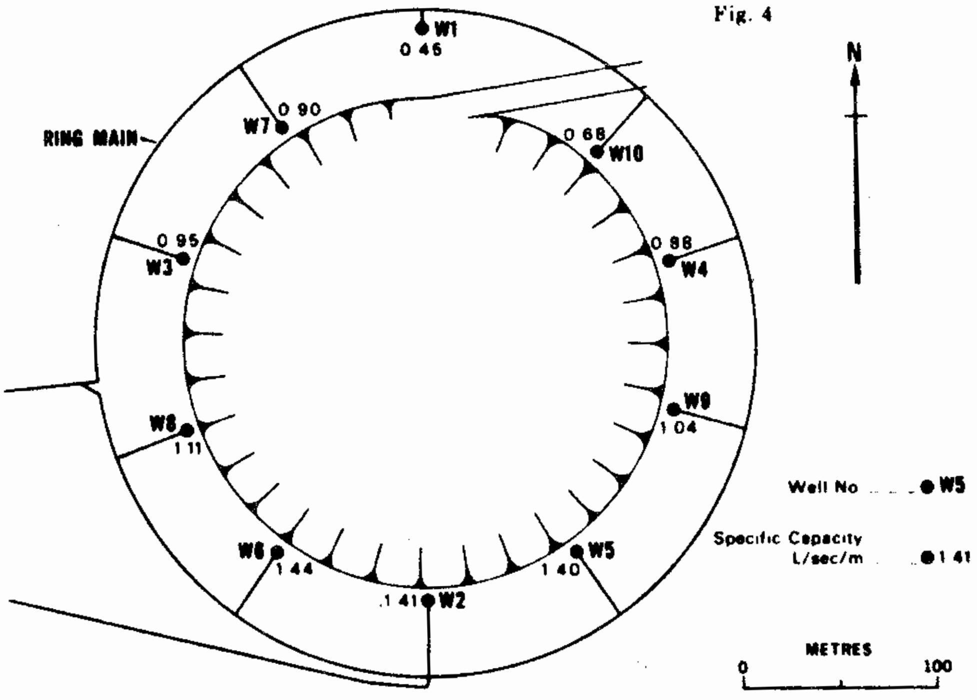

Fig. 5

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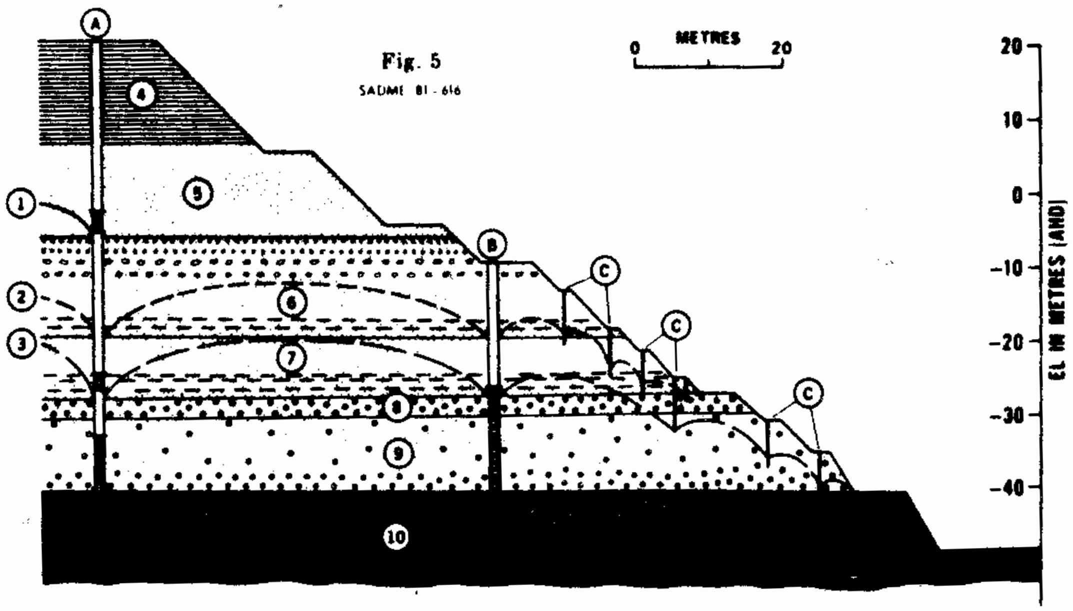

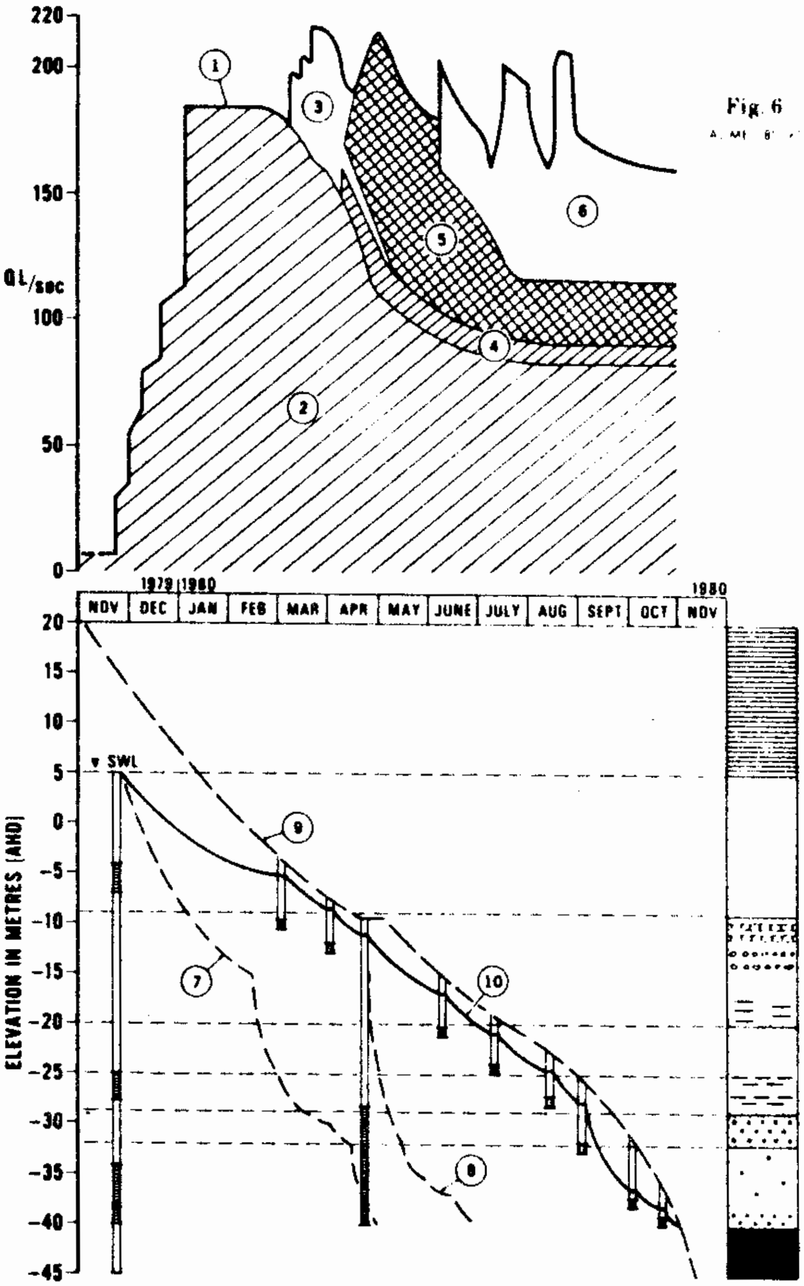
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ELEVATION IN METRES (AHD)
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Fig. 6

[illegible]

Fig. 7

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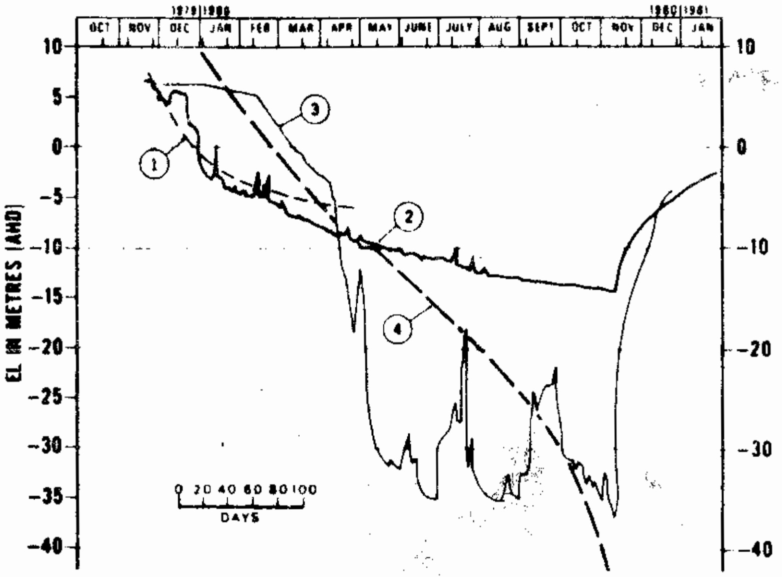

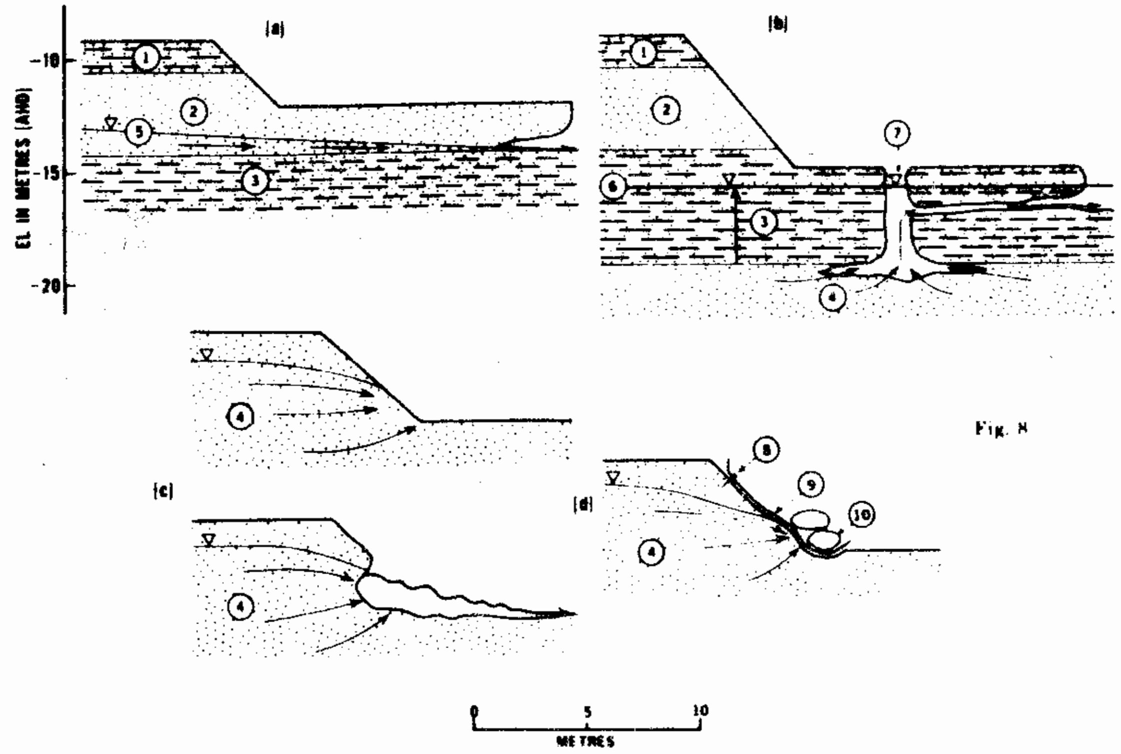
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Fig. 8

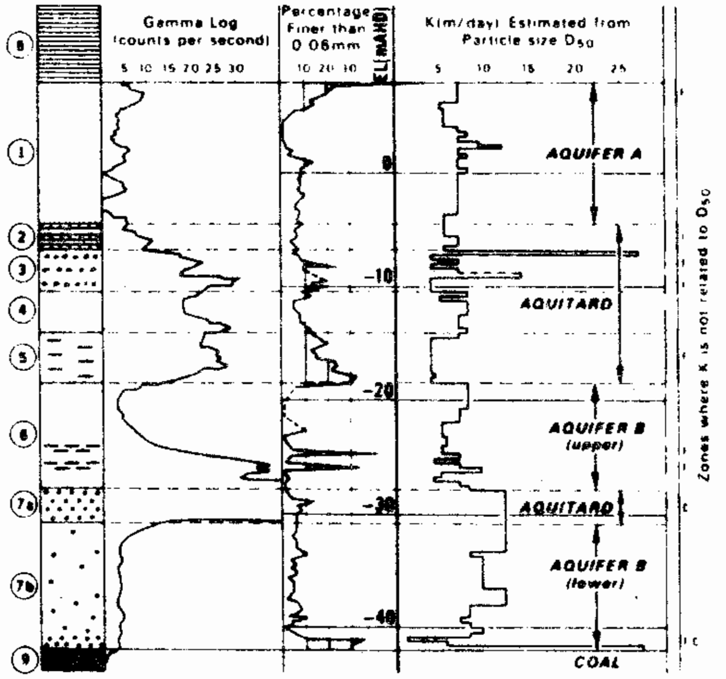
Gamma Log (counts per second)
5 10 15 20 25 30
Percentage Finer than 0 06mm
10 20 30
EL (AHD)
0
-10
-20
-30
-40
K(m/day) Estimated from Particle size D50
5 10 15 20 25
AQUIFER A
AQUITARD
AQUIFER B (upper)
AQUITARD
AQUIFER B (lower)
COAL
Zones where K is not related to D50
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Fig. 9

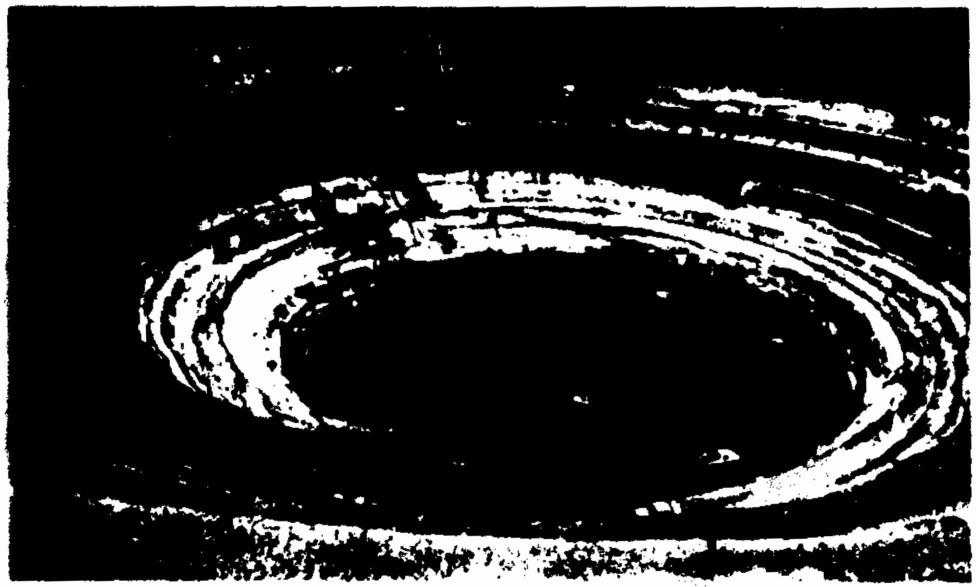

Figure 10a

Figure 10b