DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

REPT.BK.NO. 86/83
BRUKUNGA MINE, INVESTIGATION OF ACID DRAINAGE

GEOLOGICAL SURVEY

by

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GROUNDWATER AND ENGINEERING

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DME.250/79

CONTENTS

TABLES

FIGURES

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

Rept.Bk.No. 86/83
D.M.E. No. 250/79
Disk No. 140

BRUKUNGA MINE, INVESTIGATION OF ACID DRAINAGE

ABSTRACT

The abandoned Brukunga Pyrite Mine is a source of acid drainage which pollutes nearby creeks.

Six holes were drilled in the quarry benches to investigate the production of acid drainage. Comparison of chemical analyses of drillhole samples with analyses of uncontaminated groundwater and water in the outflow drains shows that acid drainage is produced in two ways:

- Rainwater is infiltrating the quarry benches and oxidizing pyrite.
- Groundwater from outside the quarry area is emerging in the lowest quarry floor and oxidizing pyrite.

Remedial work is proposed as follows:

- The benches should be sealed in the 'recharge areas'.
- Work should be carried out in the lowest cuts so that groundwater is discharged without coming into contact with air in the presence of pyritic material.

It is important that no work is done to cover up the quarry faces until it can be seen that the sealing of the quarry floor has been effective.

INTRODUCTION

The Brukunga Mine lies about 30 km ESE of Adelaide and 4 km N of Nairne (Fig. 1).

Between 1952 and 1972, pyrite was mined for manufacturing sulphuric acid for superphosphate production.

Since abandonment acid drainage from the mine has been polluting the adjacent Dawesly Creek, causing low pH values in the summer and unsightly deposits of iron and manganese oxides.

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INTRODUCTION

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Since abandonment acid drainage from the mine has been polluting the adjacent Dawesly Creek, causing low pH values in the summer and unsightly deposits of iron and manganese oxides.

Most of the problem has stemmed from the tailings dam on the eastern side of Dawesly Creek. However a significant amount of acid drainage is being produced by seepage from the mullock heaps and mine faces on the western side of Dawesly Creek.

The object of this program was to investigate the nature of the seepages in the quarry face.

GEOLOGY & HYDROGEOLOGY

The orebody was beds of the Nairne Pyrite Member which occur in pyritic phyllites of the Talisker Calc-Siltstone (Belperio, 1985). Like most Kanmantoo Group rocks of Cambrian age these are generally of low permeability and well-yields are small.

Groundwater salinities are typically about 2 000 mg/L, reflecting poor circulation and low recharge rates.

Groundwater circulation is on a local scale in fissure aquifers of limited extent, which discharge into creeks, such as Dawesly Creek.

DRILLING

In November 1985, a total of eight holes were drilled at locations shown in Figure 2. Results are summarized in Table 1 and drillhole logs are shown in Appendix A. Water analyses are in Table 2.

TABLE 1
Wells Drilled - 1985

Unit No.*	Depth (m)	Water Cut(m)	Yield L/s	pH
7454	20.6	12	very small	4.7
7455	25	9	0.25	4.9
7456	20.6	15 and 19	Very small	
7457	25	7 and 18	Very small	4.3
7458	7	2	0.2	3.4
		7	0.5	3.7
7459	25	3 and 11	Very small	-

*Add prefix 6627WW

TABLE 2
Chemical Analyses

Unit No.*	Depth (m)	Date	TDS	pH	Acidity to pH8.3	Fe^{2+}	Mn^{2+}	Al^{3+}	Zn^{2+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-
W5908	6	18/ 1/56	1796	-	-	292	-	103	-	49	39	14	-	Nil	1155	145	Ni
W5917		1972	953	7.4	-	1.4	-	-	-	40	39	263	10	165	00	440	<
W5918		18/ 1/52	2104	-	-	Nil	-	-	-	83	97	586	-	150	127	1062	Ni
W5920	34	25/ 5/50	1947	-	-	-	-	-	-	51	71	593	-	131	176	926	Ni
W5944		18/ 1/56	2427	-	-	-	-	-	-	125	113	630	-	147	257	1154	Ni
P5945		5/ 1/73	11207	2.5	-	848	-	-	-	548	720	660	4	Nil	790	530	
P5948		1976	1458	3.8	-	67	-	47	-	59	55	220	9	Nil	830	350	<
W7454	10	13/11/85	9800	3.4	3430	1350	24	89	21	600	315	175	20	Nil	7060	129	<
W7455	9	14/11/85	16700	3.3	9050	3520	41	45	22	380	225	36	10	Nil	12400	33	<
W7456	20	27/11/85	17200	3.5	12000	5250	73	83	55	360	315	150	18	Nil	16100	227	<0.
W7456		8/ 5/86	14000	2.9		4380	72	49	45	240	250	125	10	Nil	12900	450	<0.
W7456		9/ 5/86	12500	2.9		4050	68	45	37	240	240	150	13	Nil	11600	250	<0.
W7457	7	15/11/85	16700	3.2	9800	3020	42	380	24	350	195	53	10	Nil	13800	90	<
W7458	2	16/11/85	15600	3.0	9080	2750	51	285	29	320	190	30	18	Nil	11900	45	<
W7458	7	16/11/85	15100	3.0	9230	2670	49	285	32	255	190	32	11	Nil	11600	50	<
W7459		27/11/85	14800	3.3	9500	4430	95	75	50	450	375	205	22	Nil	13500	187	<0.
W7459		8/ 5/86	27600	3.1		8900	110	430	80	340	400	48	8	Nil	26700	140	<0.
W7459		9/ 5/86	27200	2.8		8100	113	470	83	350	420	53	8	Nil	26300	150	<0.
P7469		13/11/85	18700	2.7	9560	2130	37	425	8	430	380	200	6	Nil	14800	311	2
P7468		13/11/85	21600	2.7	11750	2600	47	570	35	370	350	185	7	Nil	17100	372	1

* Add prefix 6627W

(Note: WW are water wells
WP are water points)

SEEPAGES

Numerous minor seepages can be seen in the faces of the upper benches as high as 405 m AHD.

Water from these does not flow any distance before being lost to evaporation. These seepages are believed to be intermittent, operating for a limited time after rainfall.

The significant seepages are those occurring in the two lowest cuts and are described below.

Northern Cut

This area is the major source of acid drainage, the total outflow being gauged at 0.22 L/s on 18/11/85. A water analysis is shown in Table 2 and pollutant outputs in Table 3 (6627WP7468).

TABLE 3
Estimated pollutant loads as at 13/11/85

	Northern Cut WP7468	Southern Cut WP7469	Total
Outflow, m^3/day	20	3.3	23
Dissolved solids, kg/day	432	62	490
Acidity as $CaCO_3$ kg/day	230	32	260
Iron, kg/day	52	7	60

Three groups of springs can be seen on the upper part of the west face of the cut. An attempt to gauge the flow from one of these was unsuccessful because of its small size and the permeable nature of the quarry floor.

The visible springs are too small to account for the total outflow and other inflows must be occurring either under the rockpiles at the southern end of the cut or upwards through the floor. This is confirmed by the water chemistry (see Discussion).

Southern Cut

There are three groups of visible seepages all in the upper half of the face:

One at the northern end of the western wall.
One at the southwestern corner.
One near the southern end of the western wall.

On the quarry floor at the southern end, there is also a small area of less acid (pH about 4.3) water which has been colonized by a clump of reeds. Presumably this marks the emergence of more deeply circulating groundwater.

The visible seepages appear to be large enough to account for the small outflow of this cut.

A water analysis of the outflow from this cut is shown in Table 2 (6627 WP 7469) and pollutant output in Table 3.

PRODUCTION OF ACID DRAINAGE

Acid seepage is generated by the oxidation of pyrite, as represented by the equation:

$$FeS_2 + 7/2O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4{}^{2-} + 2H^+$$

The reaction is catalyzed by Thiobaccillus bacteria and probably proceeds through a number of intermediate steps.

Water emerging from seeps in the quarry face has been observed to decrease from a pH of about 3.5 to 3.1. A decrease in pH was also observed in a sample of water taken from the rock face. Apparently this decrease is due to oxidation of the ferrous to ferric ion and subsequent hydrolysis of the ferric ion:

$$2Fe^{2+} + 2H^+ + \frac{1}{2} O_2 \rightarrow 2Fe^{3+} + H_2O$$

$$Fe^{3+} + H_2O \rightleftharpoons Fe\ (OH)^{2+} + H^+\ (pK_a = 2.2)$$

It can be seen from Figure 3 that much of the iron produced in the quarry area is not reaching the outflow drains.

Precipitated brown iron oxides are evident on the rock faces and in the pools on the pit floor, especially on the filamentous green algae which grow in the water.

The solubility of oxygen in water at 20°C is 0.04 g/L (Aylward and Findlay, 1966), sufficient to raise the sulphate concentration by 69 mg/L by oxidizing pyrite.

Since observed sulphate concentrations are many times higher than this, it is obvious that pyrite is being oxidized in contact with air, not merely by contact with water carrying dissolved oxygen. Therefore acid is being produced either close to the water table or by descending waters above the water table.

The quarry bench is a bare vegetation-free surface with crushed rock overlying fractured rock. It is therefore an ideal surface for infiltration of rainfall.

Water level measurements are available for the time of drilling (late spring) when no rain had fallen for a few months and after a wet winter (Table 4).

TABLE 4

Water levels in observation wells

Unit No.*	Water levels, m below surface	
	27/4/85	16/9/86
7454	1.41	0.16
7455	2.52	0.42
7456	10.40	9.83
7457	1.68	0.51
7458	1.60	1.21
7459	9.75**	0.95

* Add prefix 6627WW

**Not recovered at time of measurement.

It can be seen that the water table rises almost to the surface after rain. Most of the problem seems to be due to oxidation within three metres of the surface at the bench.

Elemental sulphur can be seen on the lower quarry floor, a result of partial oxidation of pyrite under acidic conditons (Krauskopf 1967, p. 276).

$$FeS_2 + \frac{1}{2} O_2 + 2H^+ + Fe^{2+} + H_2O + 2S$$

WATER CHEMISTRY

Waters in and around the mine fall into three broad groups each with distinct chemistry:

- uncontaminated groundwater,
- water below the quarry bench,
- water in the outflow drains.

Uncontaminated Groundwaters

No wells nearby are now available for sampling.

However old analyses are available for a well near the mine, one downstream and a diamond drillhole into the orebody which flowed.

These are shown in Table 5.

TABLE 5
Uncontaminated Groundwaters

Unit No.*	Date	Ca^{2+}	Mg^{2+}	Na^+	HCO_3	SO_4^{2-}	Cl^-	Comments
WW5918	18/1/52	83	97	586	150	127	1062	Diamond drillhole in Pyrite Beds
WW5920	25/5/50	51	71	593	131	176	926	Well at mine site
WW5944	18/1/50	125	113	630	147	257	1154	Private well, south of mine

* Add prefix 6627

The important features of these waters are the relatively high sodium and chloride contents and the moderate sulphate levels. pH was not measured but the presence of bicarbonate shows that the waters were not acid.

It should be noted that although these analyses are all over 30 years old this does not mean that uncontaminated groundwater no longer exists in the area, merely that no suitable wells for sampling still exist.

Waters below the quarry bench

These are the waters intersected during the 1985 drilling program and shown in Table 6.

TABLE 6
Water from holes in the mine area, 1985

Unit No.*	Fe^{2+}	Al^{2+}	Ca^{2+}	Mg^{2+}	Na^+	HCO_3^-	SO_4^{2-}	Cl^-	pH	Acidity to pH6 as $CaCO_3$
WW7454	1350	89	600	315	175	0	7060	129	3.4	3430
WW7455	3520	45	380	225	36	0	12400	33	3.3	9050
WW7456	5250	83	360	315	150	0	16100	227	3.5	12000
WW7456	4380	49	240	250	125	0	12900	450	2.9	-
WW7456	4050	45	240	240	150	0	11600	250	2.9	-
WW7457	3020	380	350	195	53	0	13800	36	3.2	13400
WW7458 (2m)	2750	285	320	150	30	0	11900	45	3.0	9080
WW7458 (7m)	2670	425	255	190	32	0	11600	50	3.0	9230
WW7459	4430	75	450	375	205	0	13500	187	3.3	9500
WW7459**	8900	430	340	400	48	0	26700	140	3.1	-
WW7459**	8100	470	350	420	53	0	26300	150	2.8	-

* Add prefix 6627

** This water had been sitting in the well for months and these analyses should be disregarded.

These waters have the following characteristics:

- Very high levels of sulphate, iron and acidity resulting from the oxidation of pyrite.
- Zero bicarbonate, because of the high acid content.
- High levels of calcium and magnesium resulting from reaction between the acidic water and the rock.
- Sodium and chloride levels are much lower than in natural groundwaters of this area (Table 4). Chloride contents tend to increase with depth (Fig. 4).

The samples fall into two groups: WW7454, WW7456 and WW7459 with sodium and chloride levels over 120 mg/L and the remainder with sodium and chloride below 55 mg/L.

The latter represent waters infiltrated directly through the bench.

The analysis for WW7454 is consistent with mixing of uncontaminated groundwater with directly infiltrated contaminated water. The significance of analyses from WW7456 and WW7459 is not clear.

Originally it was suspected that the high level of contamination in these wells was a result of bailer sampling a day or more after drilling.

The wells were pumped and sampled to check this. When pumped, WW7459 yielded only the volume in storage and showed no recovery overnight. The samples obtained had the highest levels of sulphate recorded in this area. It is concluded that the samples represent water which had been in the well for months reacting with the pyritic rock.

WW7456 produced some water from the aquifer when pumped and showed significant recovery overnight.

Sulphate was significantly lower than in the original bailed sample showing that this had been affected by reaction between air, water and the rock.

The variation in chloride content between samples taken on consecutive days is probably due to analytical error.

The results from this well can be interpreted in two ways:

- The high level of sulphate results from the oxidation of pyrite in the well wall, and the samples can be disregarded.
- Native groundwater is in fact oxidizing pyrite at the water table.

The former seems the more likely, but, the possibility that oxidation is occurring at the water table cannot be eliminated.

The Outflow Drains

Analyses of water from the outflow drains are shown in Table 7.

TABLE 7
Water from the quarry drains 13/11/85

Unit No.*	Fe^{2+}	Al^{3+}	Ca^{2+}	Mg^{2+}	Na^+	HCO_3^-	SO_4^{2-}	Cl^-	pH	Acidity to pH= as $CaCO_3$
WP7469	2130	425	430	380	200	0	14800	311	2.7	9560
WP7468	2600	570	370	350	185	0	17100	372	2.7	11750

* Add prefix 6627

These samples have similar levels of contamination from oxidizing pyrite to those in the test holes shown in Table 5.

However sodium and chloride concentrations are much higher. It is concluded that the acid water flowing out of the open cut is a mixture of waters formed in two ways.

Firstly, acidic waters of the type found in the test holes (Tab. 5) are formed within the quarry benches and seep into the open cut.

Secondly, some local groundwater (high sodium and chloride) is emerging in the floor of the cut and reacting with pyritic material on the quarry floor.

The following supporting evidence is offered:

- In the northern cut, the seepages visible in the sides of the cut are clearly less than what is flowing out of the drain.
- In the southern cut is a small area, where the water in the broken material of the quarry floor is less acid (pH about 4), and which has been colonized by a clump of reeds. Presumably slightly contaminated groundwater is emerging into the quarry floor.
- In the floor of the cut boulders of pyritic rock are crumbling under chemical attack and native sulphur is abundant, clear evidence that pyrite is oxidizing.

Chloride and sulphate contents are shown in Figure 5.

The proportion of sulphates produced by the two processes can be estimated as follows.

Estimated average sodium & chloride concentrations are:

	Na^+(mg/L)	Cl^-(mg/L)
Groundwater	590	1000
Water under bench	37	40
Water in outflow drain	185	311

Assuming that evaporation can be neglected, the groundwater contribution to outflow is calculated as 0.27 and 0.28 respectively.

From this it is estimated that at the time of measurement, 40% of sulphate in the outflow had been produced in the pit floor.

Calcium and magnesium concentrations are higher in the outflow drain than in either uncontaminated groundwater or the contaminated groundwaters under the quarry bench. This shows that the acid waters are dissolving calcium and magnesium from rock on the pit floor.

PRESENT SITUATION

At present the following remedial measures have been taken (Fig. 6).

- Dams, drains and pipes have been constructed to divert surface runoff from the pit area.
- Acid drainage is collected and pumped to the dam below the tailings pond to be treated by the lime neutralization plant.

The effectiveness of these measures has been reduced by broken pipes and partly blocked drains resulting from inadequate maintenance.

POSSIBLE SOLUTIONS

The treatment of acid drainage in the lime neutralization plant cannot be considered to be a long term solution, and ways must be found to reduce acid production.

At the time of measurement about 60% of sulphates originated within the quarry bench and 40% were produced by emerging groundwater within the quarry floor.

These proportions will vary through the year because of different responses to rainfall, but clearly both processes are important and need to be controlled.

- <u>Prevention of Infiltration.</u>

  The quarry benches, being free of vegetation and natural soil cover allow ready infiltration of rainfall. To prevent this the following measures are needed.

  - The existing system of drains to prevent surface runoff entering the pit area should be maintained and upgraded where necessary.
  - The bench floors should be sealed with clay, bitumen or plastic.
  - The sealed areas must be drained without water coming into contact with pyritic material.

- Control of groundwater entering the quarry.
  It is not feasible to prevent natural groundwater from entering the quarry at the lowest level.

Acid production could be stopped by preventing water and air coming into contact with pyrite simultaneously. This could be achieved by levelling out the broken rock in the floor of the cut and covering with a layer of clay. By keeping a water table within the clay layer, oxygen would be prevented from coming into contact with the pyrite, and groundwater could be discharged with only slight contamination.

Because of the uncertainties surrounding mechanisms of acid production and their control, remedial work should be carried out in stages.

It is most important that the bench near the Pistol Club should be sealed first so that the effectiveness or otherwise of sealing can be evaluated before any measures are taken to cover the seepage faces.

CONCLUSIONS

1. Acid drainage is being produced in two ways:
   - Rainfall infiltrates into the quarry benches, oxidizes pyrite and re-emerges in the lowest cut.
   - Natural groundwater from outside the mine area seeps into the lowest cut and oxidizes pyrite in contact with the air.
2. The first mechanism of acid production could be controlled by sealing the quarry benches to prevent rainwater from infiltrating.

3. The second mechanism of acid production could be controlled by levelling the floor of the lowest cut and covering with clay to allow groundwater to drain out without coming into contact with air.
4. The northern end of the quarry occupied by the Pistol Club is the major source of acid drainage.

RECOMMENDATIONS

1. The quarry bench in the area of the Pistol Club should be sealed with clay, covered with soil and grassed to prevent water from infiltrating.
2. Drains should be constructed to conduct surface runoff away from the sealed area without coming into contact with pyritic material.
3. No work should be done to cover the quarry faces until sealing of the benches has proved to be effective. This will mean leaving it for at least one winter.
4. When acid production from infiltrating rainwater has been effectively controlled remedial work should be carried out on the lower cut as follows:

   - The broken pyritic rock should be levelled across the base of the cut.
   - The above should be covered with about a metre of clay.
   - A bund and outflow drains should be constructed to maintain an artificial water table within the clay.
   - The clay could then be covered with rock from the mullock heaps to produce the desired contours. This in turn should be covered with clay and soil and vegetated.

R E Read

RER:ZV

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SENIOR GEOLOGIST

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APPENDIX A

GEOLOGICAL LOGS

WELL	PAGE
6627WW7455	A-1
7456	A-2
7457	A-3
7458	A-4

MINES DEPARTMENT OF SOUTH AUSTRALIA
ENGINEERING DIVISION

WATER WELL LOG

PROJECT: BRUKUNGA, HOLE 1

LOCATION OR COORD:

SEC. HD.

El. Surface m
El. Ref. Point m Datum

HOLE NO: PN 17323

UNIT / STATE NO 6627WW7454

OBS

AQUIFER SUMMARY:	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL TESTED From:	INTERVAL TESTED To:	SUPPLY kilolitres/day*	SUPPLY Test Length (hrs)	SUPPLY Method	TOTAL DISSOLVED SOLIDS milligrams/litre	TOTAL DISSOLVED SOLIDS Analysis No:
									W—

DEPTH (m) From	DEPTH (m) To	GRAPHIC LOG	ROCK / SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION / AGE	OPEN CORE SAMPLE	CASING Dia(mm)	CASING From(m)	CASING To(m)
0	3			No sample					
3	9		Schist	Grey pyritic schist, 20% pyrite.					
9	15		Schist	Grey Schist, 5% pyrite.					

REMARKS:

*NOTE 10 kl / day = [illegible] / hr.

DRILL TYPE: Rotary/Hammer

CIRCULATION: AIR

SHEET 1 OF 1

COMPLETED: 12/11/85

LOGGED BY: R. READ

DATE: 12/11/85

PROJECT: BRUKUNGA, HOLE 3

MINES DEPARTMENT — SOUTH AUSTRALIA
ENGINEERING DIVISION

WATER WELL LOG

HOLE NO: PN17325

UNIT / SERIAL NO
6627WW7456

DH

LOCATION OF COORDS:

SEC. HD. KANNAMTOO

El. Surface m

El. Ref. Point m Datum

AQUIFER SUMMARY:	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL TESTED From:	INTERVAL TESTED To:	SUPPLY kilolitres/day*	SUPPLY Test Length (hrs)	SUPPLY Method	TOTAL DISSOLVED SOLIDS milligrams/litre	TOTAL DISSOLVED SOLIDS Analysis No:
									W —

DEPTH (m) From	DEPTH (m) To	GRAPHIC LOG	ROCK / SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION / AGE	DEPTH CORE SAMPLE	CASING Dia (mm)	CASING From (m)	CASING To (m)
0	20		Schist	Pyritic Schist ('ore-bed') 10-20% pyrite					

REMARKS:

* NOTE: 110 kl / day = 1000gals / hr.

DRILL TYPE:

COMPLETED:

GEOLOGIST: LJP

LOGGED BY: R. READ

SHEET ... 1 OF ... 1 ...

DATE:

No 7

MINES DEPARTMENT — SOUTH AUSTRALIA
[illegible] DIVISION

WATER WELL LOG

PROJECT: BRUKUNGA, HOLE 4

LOCATION OR COORDS:

SEC. HD. KANMANTOO

RL Surface m

RL Ref. Point m Datum

BORE NO:

UNIT / STATE NO 6627WW7457

DH

AQUIFER SUMMARY:	DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL TESTED From:	INTERVAL TESTED To:	SUPPLY kilolitres/day*	SUPPLY Test Length (hrs)	SUPPLY Method	TOTAL DISSOLVED SOLIDS milligrammes/litre	TOTAL DISSOLVED SOLIDS Analysis No:
									W—

DEPTH (m) From	DEPTH (m) To	GRAPHIC LOG	ROCK / SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION / AGE	DEPTH CORE SAMPLE	CASING I.D.(mm)	CASING From(m)	CASING To(m)
0	6		Pyritic Schist	About 5% pyrite					
6	9		Pyritic Schist	As above, slightly weathered					

REMARKS:

*NOTE: 110 kl / day ≈ 1000gph / hr.

DRILL TYPE: ROTARY HAMMER

CIRCULATION: AIR

SHEET 1 OF 1

COMPLETED:

LOGGED BY: R. READ

DATE:

PROJECT: BRUKUNGA, HOLE 5

MINES DEPARTMENT — SOUTH AUSTRALIA
ENGINEERING DIVISION

WATER WELL LOG

HOLE NO: PN 17327

UNIT / STATE NO 6627WW7458

LOCATION OR COORDS.

SEC. HD. KANMANTOO ft. Surface ft. Ref. Point m m Datum

DH

AQUIFER SUMMARY:

DEPTH TO WATER CUT (m)	DEPTH TO STANDING WATER (m)	INTERVAL TESTED From:	INTERVAL TESTED To:	SUPPLY kilolitres/day*	SUPPLY Test Length (hrs)	SUPPLY Method	TOTAL DISSOLVED SOLIDS milligrammes/litre	Analysis No: W—

DEPTH (m) From	DEPTH (m) To	GRAPHIC LOG	ROCK / SEDIMENT NAME	GEOLOGICAL DESCRIPTION	FORMATION / AGE	DEPTH CORE SAMPLE	CASING Dia(mm)	CASING From(m)	CASING To(m)
0	2		Schist						
2	2.5		Fracture Zone	Very broken near vertical fracture, quartz and fine-grained chloritic pyritic fault gourge? Ferruginous staining.					
2.5	?		Schist						

REMARKS:

*NOTE: [illegible]

DRILL RIG:

CIRCULATION:

SHEET......... OF.........

COMPLETED:

LOGGED BY:

DATE:

A-4

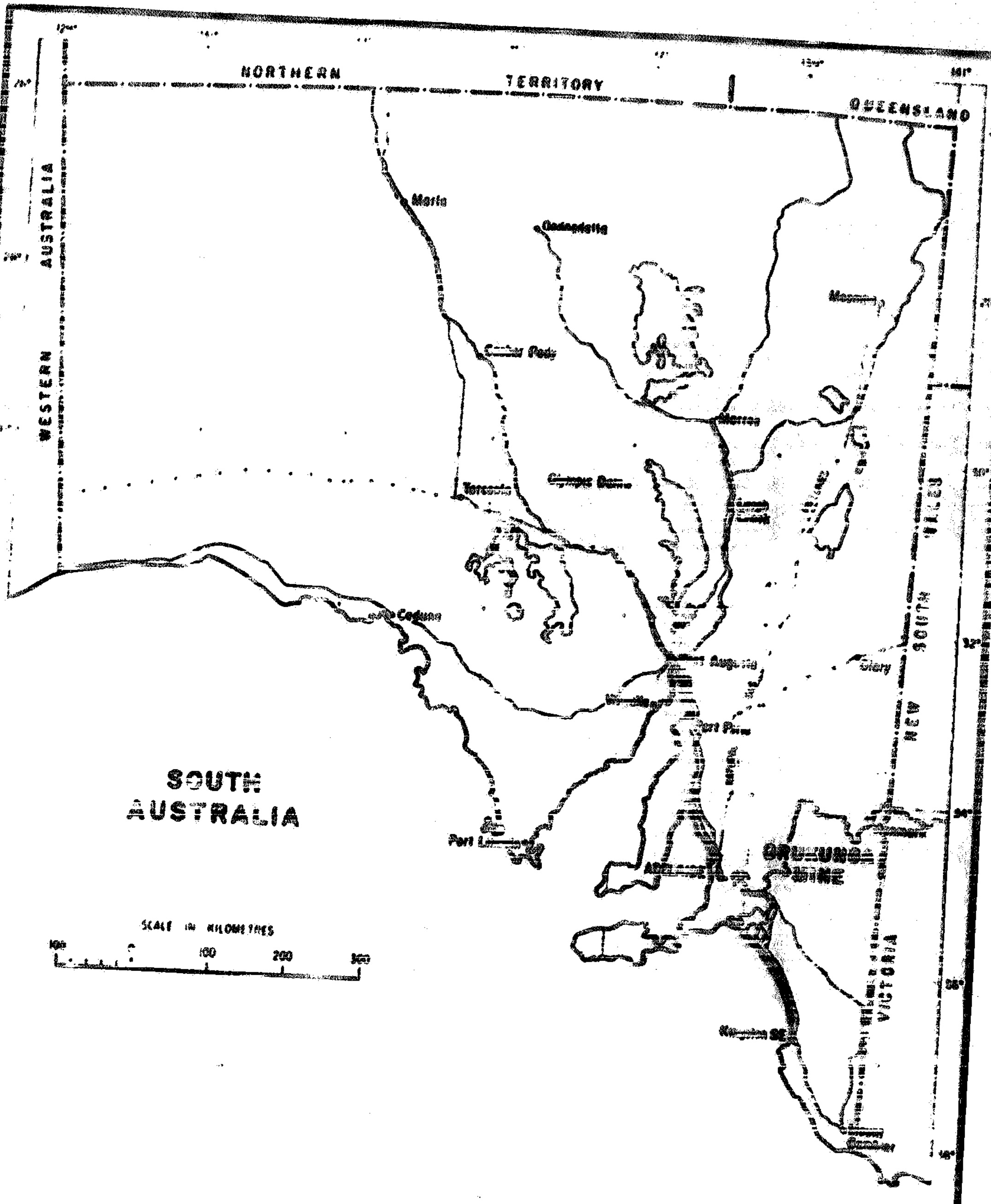


Fig........1

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BRUKUNGA MINE
INVESTIGATION OF ACID DRAINAGE

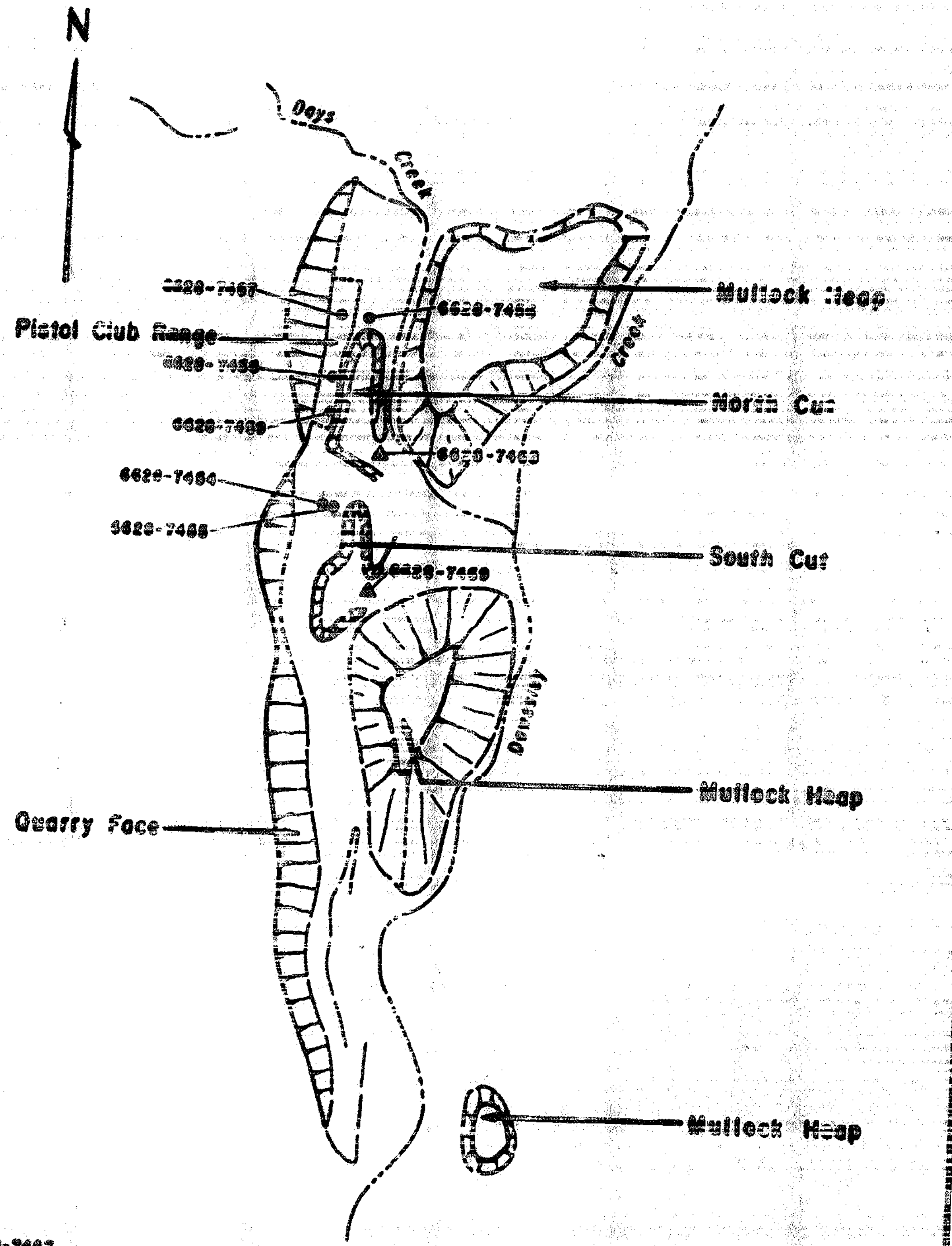
LOCALITY PLAN

COMPILED R.E.R.
DRAWN R.H.
DATE Aug [illegible]
CHECKED

CDO [illegible]·11·84 DATE

SCALE As shown

PLAN NUMBER S18844



6628-7457 ● Test Well with Unit Number (abbrev.)

6628-7463 ▲ Surface Water Sample Point with Unit Number (abbrev.)

SCALE
0 100 200 300 400 500
METRES

Fig. 2

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BRUKUNGA MINE
INVESTIGATION OF ACID DRAINAGE

WELL LOCATION PLAN

COMPILED R.E.R.	C.G.O. 24-11-86 DATE
DRAWN R.H.	SCALE
DATE Aug 1986	PLAN NUMBER
CHECKED	S18845

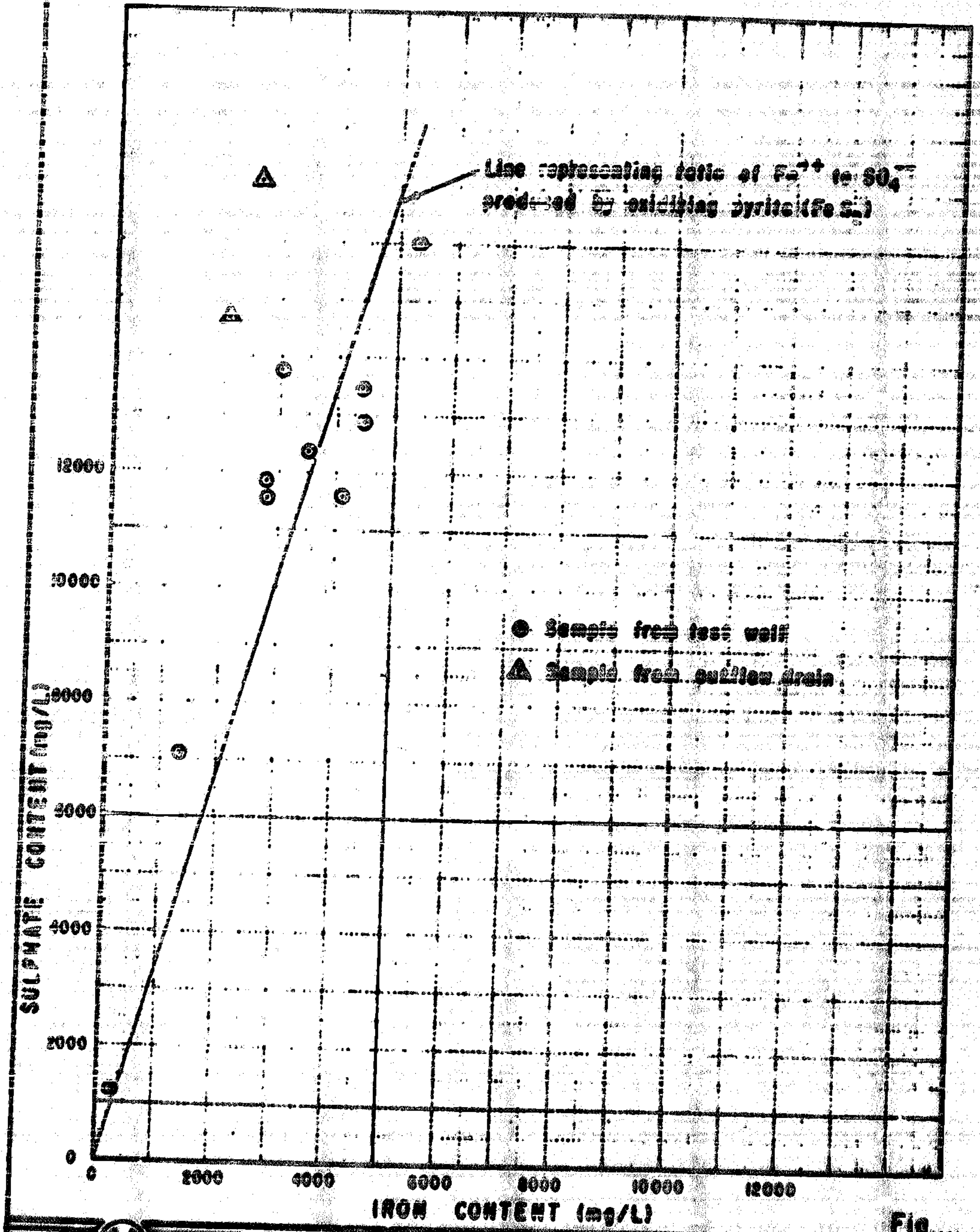


Fig......3

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BRUKUNGA MINE
INVESTIGATION OF ACID DRAINAGE

RELATION BETWEEN IRON AND SULPHATE CONCENTRATIONS IN TEST WELLS AND DRAINS

COMPILED R.E.R.	24-11-86 DATE
DRAWN R.H.	SCALE
DATE Aug 1986	PLAN NUMBER
CHECKED	S18846

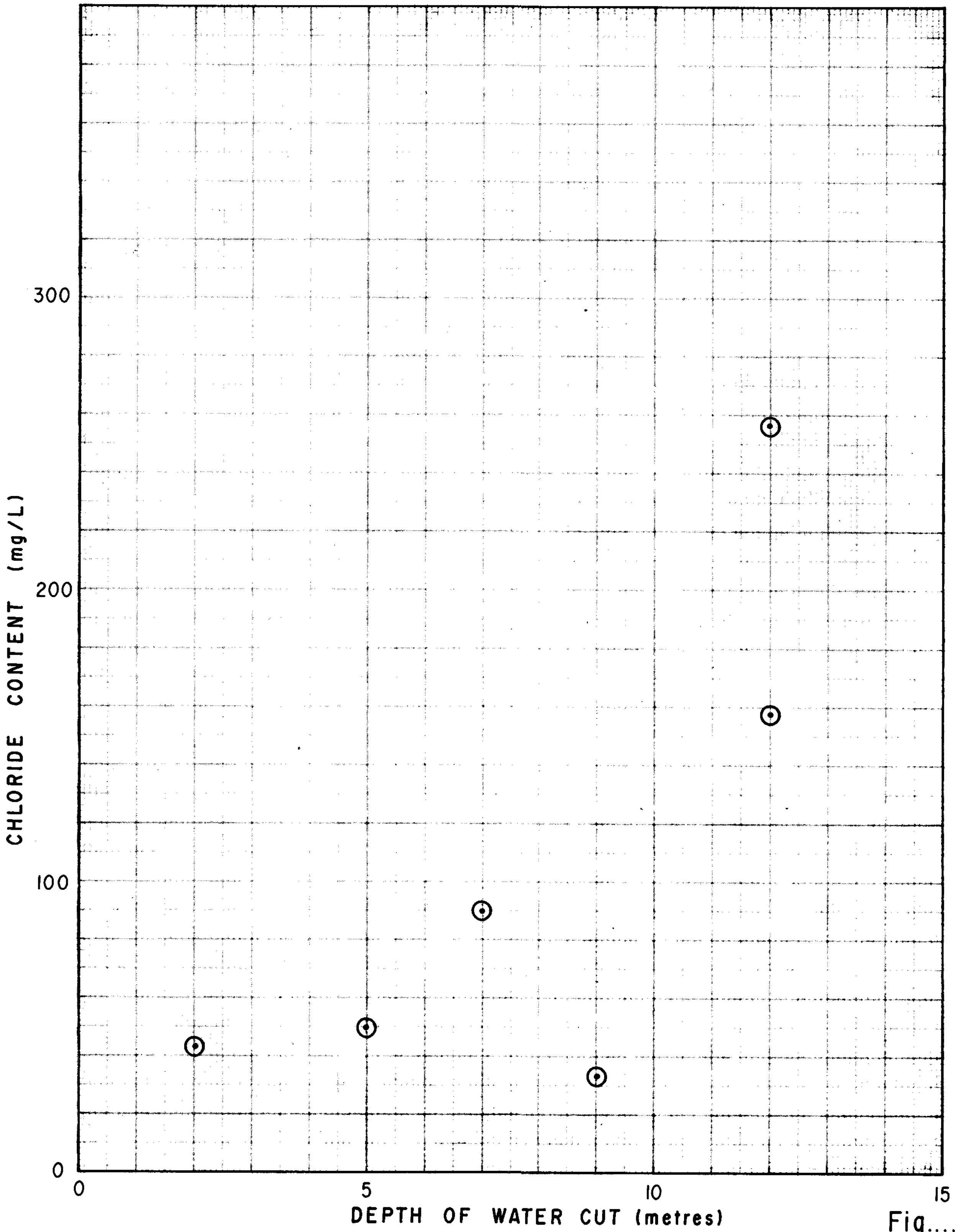


Fig...... 4

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BRUKUNGA MINE
INVESTIGATION OF ACID DRAINAGE

CHLORIDE CONTENT OF WATER v. DEPTH BELOW QUARRY BENCH

COMPILED R.E.R.	LLR 24·11·86 C.D.O. DATE
DRAWN R.H.	SCALE
DATE Aug 1986	PLAN NUMBER
CHECKED	S18847

1205

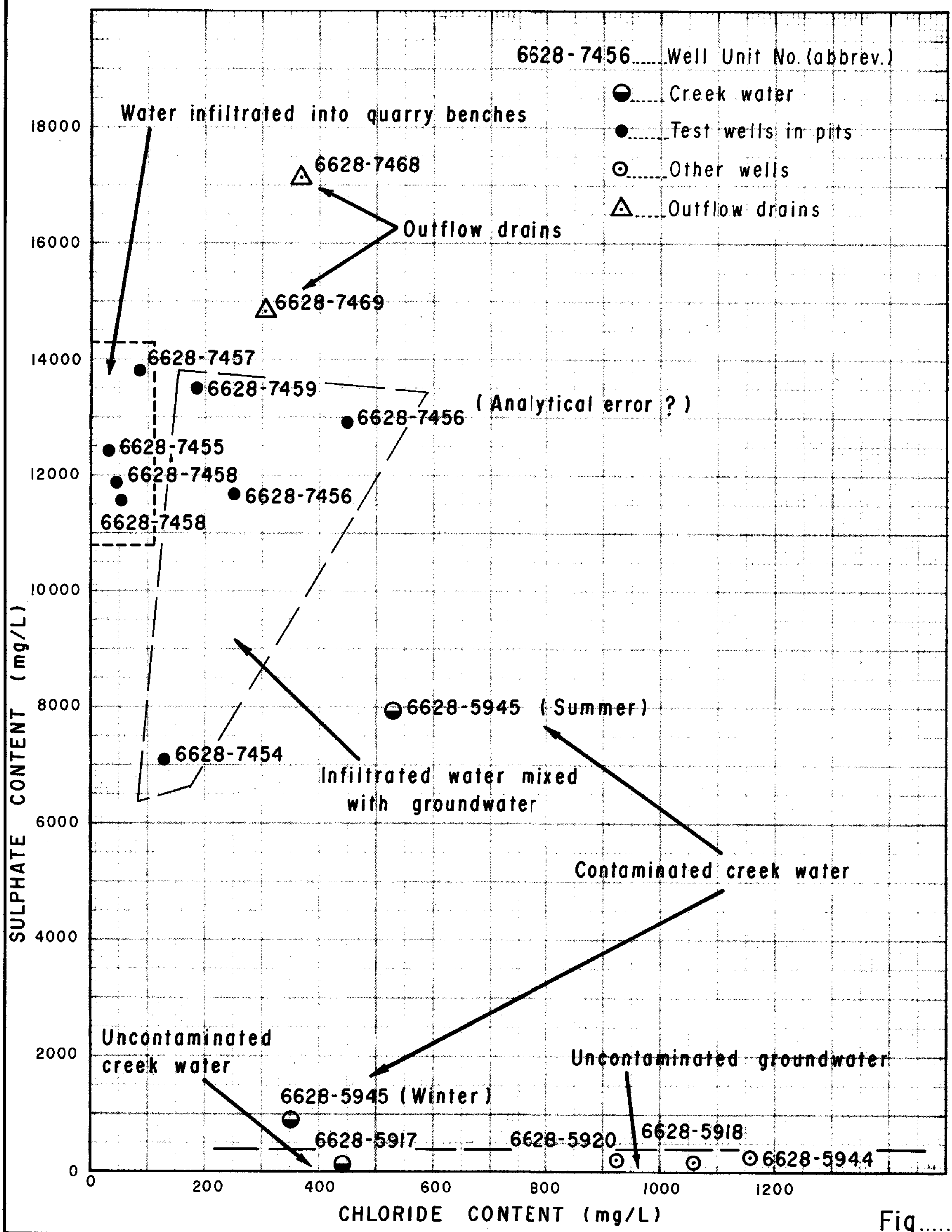


Fig....... 5

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BRUKUNGA MINE
INVESTIGATION OF ACID DRAINAGE

RELATION BETWEEN CHLORIDE AND SULPHATE CONCENTRATIONS IN CREEK, WELLS AND DRAINS

COMPILED R.E.R.	UR C.D.O.	24·11·86 DATE	
DRAWN R.H.	SCALE		
DATE Aug 1986	PLAN NUMBER		
CHECKED	S18848		

4205

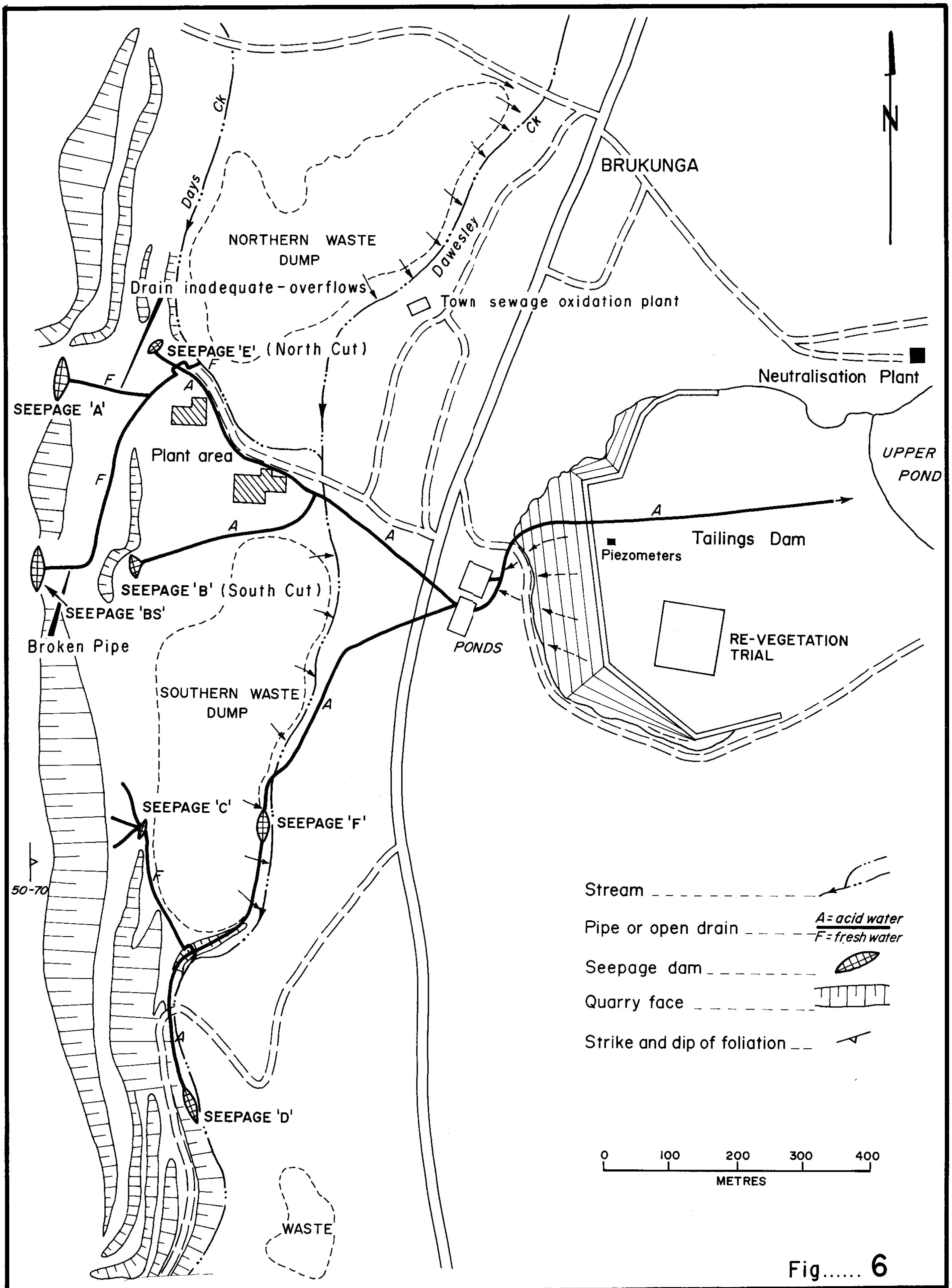


Fig...... 6

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

BRUKUNGA MINE
INVESTIGATION OF ACID DRAINAGE

LAYOUT OF REMEDIAL WORKS NOVEMBER 1985

COMPILED R.E.R.

WR 24·11·86
C.D.O. DATE

DRAWN R.H.

SCALE As shown

DATE Aug 1985

CHECKED

PLAN NUMBER S18849

4205

APPENDIX

NAIRNE PYRITE MEMBER

LOGS OF DIAMOND DRILL HOLES 108 AND 109

(REPRINTED FROM RB 66/119)

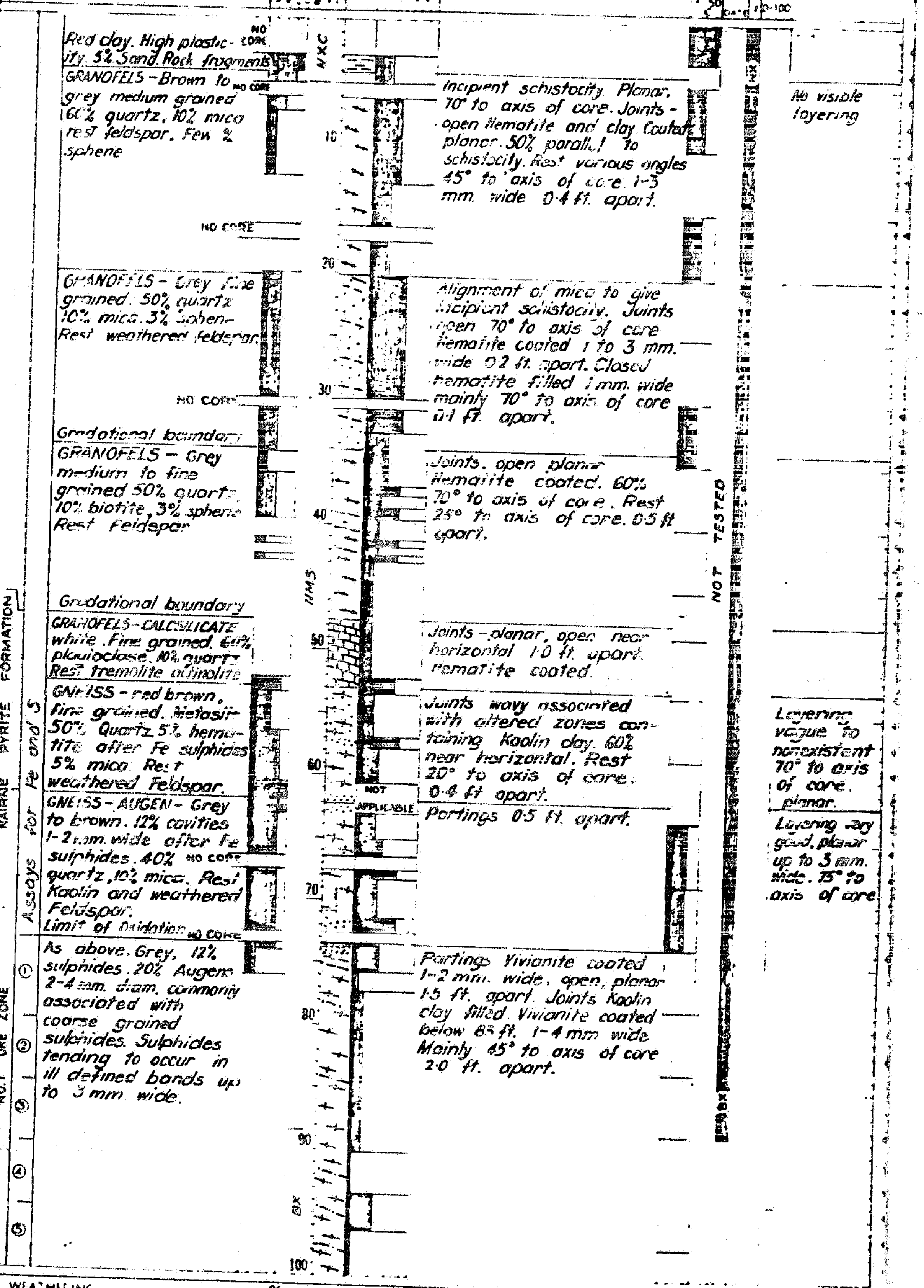
[illegible] LOG OF DIAMOND DRILL HOLE

830/67

FEATURE SOUTH END HILL
LOCATION BRUKUNGA

SECTION 4410
HUNDRED KANMANTOO
COORDINATES 4250 S 588 E
ANGLE FROM HORIZONTAL 30° at surface
DIRECTION 270° GRID 260° TRUE

[illegible] 1112·0
[illegible] 1112·4
Datum Pt. Adelaide M.S.L.



Red clay. High plasticity. 5% Sand. Rock fragments

GRANOFELS – Brown to grey medium grained 60% quartz, 10% mica rest feldspar. Few % sphene

GRANOFELS – Grey fine grained. 50% quartz 10% mica. 3% Sphene. Rest weathered feldspar.

Gradational boundary

GRANOFELS – Grey medium to fine grained 50% quartz, 10% biotite, 3% sphene Rest Feldspar

Gradational boundary

GRANOFELS – CALCSILICATE white. Fine grained. 60% plagioclase. 10% quartz Rest tremolite actinolite

GNEISS – red brown. fine grained. Metasilt 50% Quartz 5% hematite after Fe sulphides 5% mica. Rest weathered Feldspar.

GNEISS – AUGEN – Grey to brown. 12% cavities 1-2 mm. wide after Fe sulphides. 40% quartz, 10% mica. Rest Kaolin and weathered Feldspar. Limit of Oxidation

As above. Grey. 12% sulphides. 20% Augen 2-4 mm. diam. commonly associated with coarse grained sulphides. Sulphides tending to occur in ill defined bands up to 3 mm wide.

Incipient schistocity. Planar, 70° to axis of core. Joints – open Hematite and clay Coated planar. 50% parallel to schistocity. Rest various angles 45° to axis of core. 1-3 mm. wide 0·4 ft. apart.

Alignment of mica to give incipient schistocity. Joints open 70° to axis of core Hematite coated 1 to 3 mm. wide 0·2 ft. apart. Closed hematite filled 1 mm. wide mainly 70° to axis of core 0·1 ft. apart.

Joints. open planar Hematite coated. 60% 70° to axis of core. Rest 25° to axis of core. 0·5 ft apart.

Joints – planar, open near horizontal 1·0 ft. apart. Hematite coated.

Joints wavy associated with altered zones containing Kaolin clay. 60% near horizontal. Rest 20° to axis of core. 0·4 ft apart.

Partings 0·5 ft. apart.

Partings Vivianite coated 1-2 mm. wide, open, planar 1·5 ft. apart. Joints Kaolin clay filled. Vivianite coated below 83 ft. 1-4 mm wide Mainly 45° to axis of core 2·0 ft. apart.

No visible layering

Layering vague to nonexistent 70° to axis of core. planar.

Layering very good, planar up to 3 mm. wide. 75° to axis of core

WEATHERING
FR Fresh
SW Slightly weathered
MW Moderately "
HW Highly "
CW Completely "

FRACTURE LOG
[illegible]

CAMBRIAN
KANMANTOO GROUP
NAIRNE PYRITE MEMBER

LEGEND
⇄ Quartz, biotite Granofels
§ SCHIST
⟋ GNEISS. METASILT
▨ GRANOFELS CALCSILICATE
Breccia Zone
Major Joint
Bedding Trend
Altered Zone

METALLIC MINERALS SECTION

[illegible]	15	[illegible]	M MASON
[illegible]	1 1000	[illegible]	24TH JULY '67
[illegible]	ASCHMONEIT	[illegible]	RAJ
[illegible]	30TH JUNE '67	[illegible]	LVW
[illegible]	11TH JULY '67		

1 . 3

[illegible]76

PROJECT NAIRNE PYRITES PTY LTD

LOG OF DIAMOND DRILL HOLE

HOLE No. 108

830/67

SECTION 4410 HUNDRED KANMANTOO

FEATURE SOUTH END HILL

COORDINATES 4250 S 588 E

LOCATION BRUKUNGA

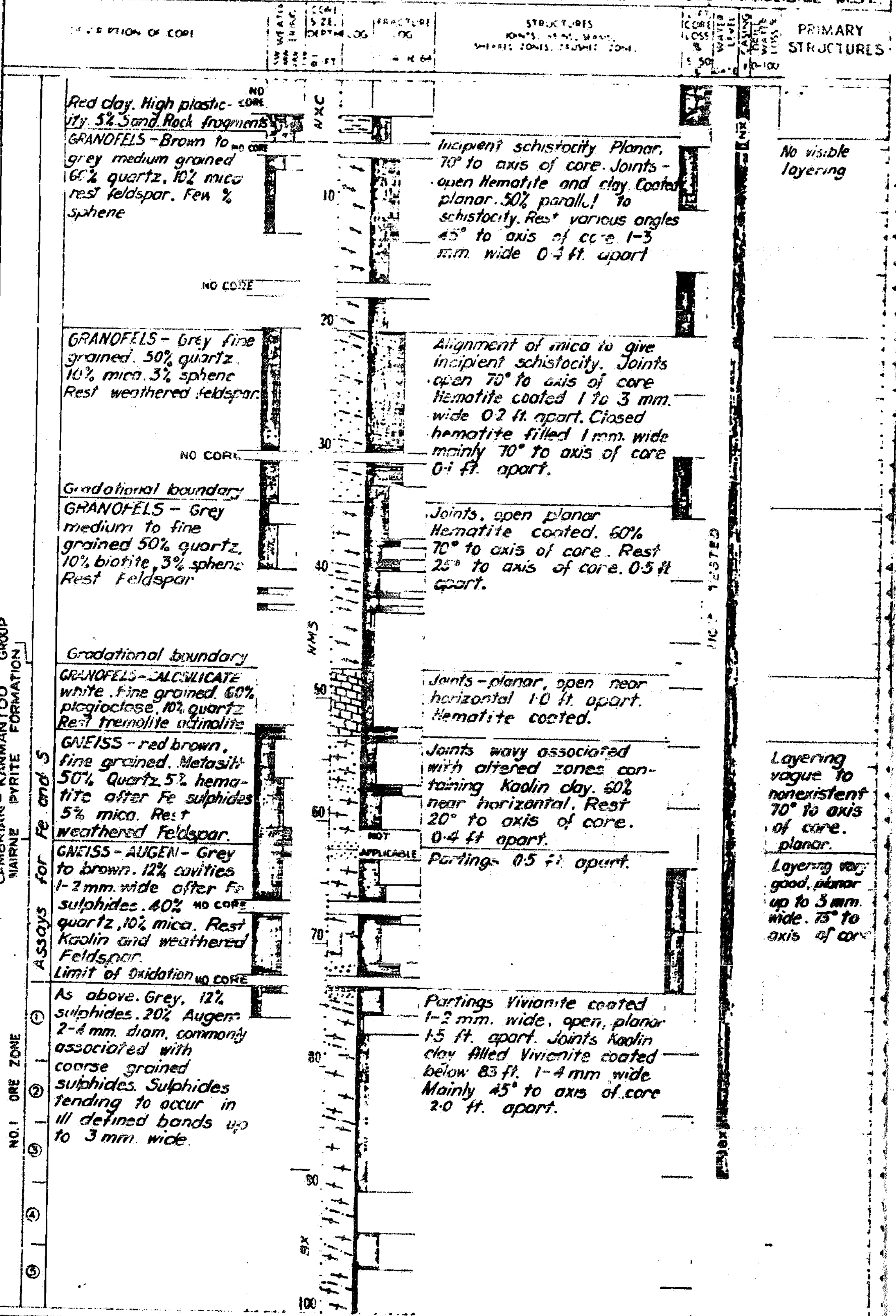
ANGLE FROM HORIZONTAL 30° at surface

DIRECTION 270° GRID 260° TRUE

R.L. Surface 1112·0 ft

R.L. Collar 1112·4 ft

Datum Pt. Adelaide M.S.L.



Red clay. High plasticity. 5% Sand. Rock fragments

NO CORE

GRANOFELS - Brown to grey medium grained. 60% quartz, 10% mica rest feldspar. Few % sphene

NO CORE

GRANOFELS - Grey fine grained. 50% quartz. 10% mica. 3% sphene. Rest weathered feldspar

NO CORE

Gradational boundary

GRANOFELS - Grey medium to fine grained 50% quartz. 10% biotite, 3% sphene. Rest Feldspar

Gradational boundary

GRANOFELS - CALCSILICATE white. Fine grained. 60% plagioclase. 10% quartz. Rest tremolite actinolite

GNEISS - red brown, fine grained. Metasilt 50% Quartz 5% hematite after Fe sulphides 5% mica. Rest weathered Feldspar.

GNEISS - AUGEN - Grey to brown. 12% cavities 1-2 mm. wide after Fe sulphides. 40% quartz, 10% mica. Rest Kaolin and weathered Feldspar.

NO CORE

Limit of Oxidation

NO CORE

As above. Grey, 12% sulphides. 20% Augen 2-4 mm. diam. commonly associated with coarse grained sulphides. Sulphides tending to occur in ill defined bands up to 3 mm. wide.

Incipient schistocity. Planar, 70° to axis of core. Joints - open Hematite and clay. Coated planar. 50% parallel to schistocity. Rest various angles 45° to axis of core. 1-3 mm. wide 0·4 ft. apart

Alignment of mica to give incipient schistocity. Joints open 70° to axis of core Hematite coated 1 to 3 mm. wide 0·2 ft. apart. Closed hematite filled 1 mm. wide mainly 70° to axis of core 0·1 ft. apart.

Joints, open planar Hematite coated. 60% 70° to axis of core. Rest 25° to axis of core. 0·5 ft apart.

Joints - planar, open near horizontal 1·0 ft apart. Hematite coated.

Joints wavy associated with altered zones containing Kaolin clay. 60% near horizontal. Rest 20° to axis of core. 0·4 ft apart.

Partings 0·5 ft apart.

Partings Vivianite coated 1-2 mm. wide, open, planar 1·5 ft. apart. Joints Kaolin clay filled Vivianite coated below 83 ft. 1-4 mm wide Mainly 45° to axis of core 2·0 ft. apart.

No visible layering

Layering vague to nonexistent 70° to axis of core. planar.

Layering very good, planar up to 3 mm. wide. 75° to axis of core

WEATHERING

FR Fresh
SW Slightly weathered
MW Moderately "
HW Highly "
CW Completely "

FRACTURE LOG

4 8 64

1/2 3 1/2 1/64

CAMBRIAN
KANMANTOO GROUP
NAIRNE PYRITE MEMBER

LEGEND

⇄	Quartz, biotite Granofels
∫∫∫	SCHIST
⤡	GNEISS METASILT
▨	GRANOFELS CALCSILICATE

- - - Breccia Zone

╲ Major Joint

╲ Bedding trend

⋯ Altered Zone

METALLIC MINERALS SECTION

	15	Logged by	M MASON
	F 1000		
	ASCHMONEIT	Date	24TH JULY '67
Started	30TH JUNE '67	Traced	RAJ
Finished	11TH JULY '67	Checked	LWW

1 . 3 . 00076

NAIRNE PYRITES PTY LTD

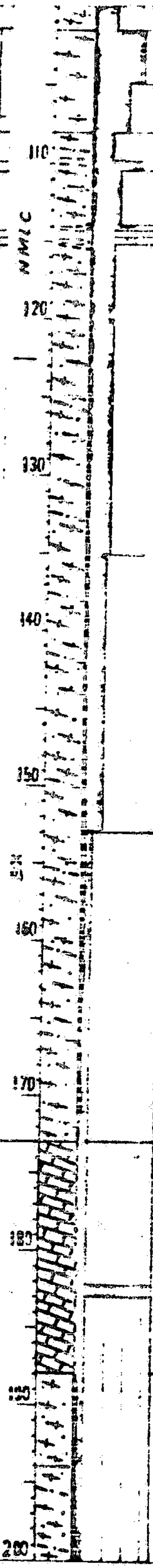
LOG OF DIAMOND DRILL HOLE

103
S.D/68

SECTION 4414
KANMANTOO
FEATURE IRONSTONE RIDGE
LOCATION BRUKUNGA (4 MILES SOUTH)
COORDINATES 4000S 45E (67-513 Plan)
ANGLE FROM HOR ZONTAL 31° at [illegible]
DIRECTION 254° True
R.L. Surface 977.6
R.L. Collar 978.0
Datum Arbitrary (67-513)

DESCRIPTION OF CORE	STRUCTURES	PRIMARY STRUCTURES
As below		
GNEISS - brown fine grained 20% mica 40% quartz. 3% hematite after sulphides Rest weathered feldspar Limit of oxidation	Layering good Partings 0.05 ft apart Hematite coated Incipient schistocity 80° to axis of core Relaxation joints.	
GNEISS - METASILT - light grey fine grained 14% coarse grained Fe sulphides and as fine grains within the mass 70% of Fe sulphides in bands parallel to layering 0.5 to 5 mm wide 3 to 20 mm apart. 65% quartz 3% phlogopite Rest feldspar. Few coarse grains galena and sphalerite in pyrite bands. Below 122 ft. sulphide bands thicker (5 mm.) and further apart. (40 to 60 mm) Average 15% Fe sulphides. Below 135 ft. 11% Fe sulphides. Bands 0.2 to 0.3 ft. apart - Decreases to 10% at 152 ft.	Layering - very distinct Average 80 to 85° to axis of core, planar, up to 3mm wide - discontinuous pyrite lenses. Movement along the coarse pyrite bands is shown by faulted joints. Movement is only of a few mm. and is variable in direction. Compare with deformation in lower sulphide bed. Partings - along sulphide lenses. Vivianite coated 1 to 1 mm wide. 0.5 ft. apart. Cuspate closely spaced at 110, 114 and 115 ft. Kaolin coated near limit of oxidation. Joints - closed 5 to 15° to axis of core. Vivianite filled. Mainly less 0.5 mm. wide and from 5 mm. to 2.0 ft. in length. Often 2 to 10 mm. apart. Less common and mainly of at least 1.0 ft length below 135 ft.	136 S3
GRANOFELS - CALCSILICATE white fine grained. 3% fine grained Fe sulphides randomly scattered. 3% brown phlogopite. 60% plagioclase. 10% quartz. Rest tremolite, actinolite Gradational boundary	Vague layering due to alignment of mica 80° to axis of core. Partings 1.0 ft. apart planar. Vivianite coated. Open. Joints closed 0.5 to 1 mm. wide planar Vivianite. Filled 5 to 18° to axis of core. 2.0 ft apart. Faulted to minor extent 1 mm movement.	
GNEISS - METASILT - light grey fine grained. 7% Fe sulphides 10% below 194 ft Mainly as coarse grained bands 2 to 5 mm wide 1.0 ft apart. 0.2 ft apart below 194 ft 60% quartz 3% phlogopite Rest plagioclase. 10% of coarse sulphides is phyrrotite	Layering very good planar. 80 to 85° to axis of core. Up to 3 mm wide. Partings 0.5 to 1.0 ft. apart Open Vivianite coated. Joints. Closed 10 to 20° to axis of core. Vivianite filled. Faulted by sulphide.	

CAMBRIAN - KANMANTOO GROUP
NAIRNE PYRITE NO. 1 ORE ZONE
A WASTE ZONE
NO 2 ORE ZONE



WEATHERING
Fresh
Slightly weathered
Moderately "
Highly "
Completely "
FRACTURE LOG
1 4 8 64 Fracture fractures per foot of core
0 3 ½ ⅛ - Fracture diameter

CAMBRIAN
KANMANTOO GROUP
NAIRNE PYRITE MEMBER

LEGEND
Quartz - biotite Granofels
SCHIST
GNEISS & METASILT
GRANOFELS CALCSILICATE
Breccia Zone
Major Joint
Bedding Trend
Altered Zone

METALLIC MINERALS SECTION
DRILL No. 24
TYPE E1000
DRILLER KRUZE
START 8 July '67
FINISH 20 July '67
LOGGED BY R. BUC[illegible]
DATE 24 Ju[illegible] '67
TRACED [illegible]
CHECKED [illegible]
SHEET 2 OF 3
DRG No. S600[illegible]

NAIRNE PYRITES PTY LTD LOG OF DIAMOND DRILL HOLE 109

6-0/69

FEATURE IRONSTONE RIDGE

LOCATION BRUKUNGA (4 MILES SOUTH)

SECT 4414

CO-ORDINATES 4000S 45E (67-5/3 Plan)

ANGLE FROM HORIZONTAL 31° [illegible]

DIRECTION 254° True

R. L. [illegible] 977.6

R. L. Core 978.0

Datum arbitrary (67 [illegible])

PRIMARY STRUCTURES

Ag. angle

GNEISS brown fine grained 20% mica 40% quartz 5% hematite after sulphides. Rest weathered feldspar

Limit of oxidation

① GNEISS - METASILT - light grey fine grained 14% coarse grained Fe sulphides and as fine grains within the mass 70% of Fe sulphides in bands parallel to layering 0.5 to 5 mm wide 3 to 25 mm apart. 55% quartz 8% phlogopite. Rest feldspar

④ Few coarse grains galena and sphalerite in pyrite bands

⑤ Below 112 ft sulphide bands thicker (5mm) and further apart (40 to 50 mm). Average 13% Fe sulphides.

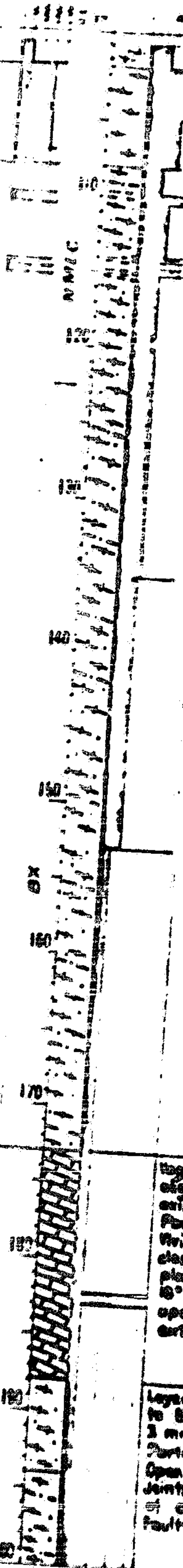
⑥ Below 133 ft [illegible] Fe sulphides. Bands 0.2 to 0.3 ft apart - Decreases to 10% at 132 ft

Layering good. Partings 0.05 ft apart Hematite coated [illegible] Schistosity 80° to axis of core. Relaxation joints.

Layering - very distinct. Average 80 to 85° to axis of core, planar, up to 3mm wide - discontinuous pyrite lenses.

Movement along the coarse pyrite bands is shown by faulted joints. Movement is only of a few mm and is variable in direction. Compare with deformation in lower sulphide bed. Partings - along sulphide lenses. Vivianite coated 1 to 1mm wide 0.5 ft apart. [illegible] closely spaced at 10[illegible], 116 and 115 ft. Kaolin coated near limit of oxidation.

Joints - closed 5 to 15° to axis of core. Vivianite lined. Mainly less 0.5 mm wide and from 5mm to 2.0ft. in length. Often 2 to 10 mm apart. Less common and mainly of at least half length below [illegible] ft.



GRANOFELS - CALCSILICATE white fine grained. 2% fine grained Fe sulphides randomly scattered. 8% brown phlogopite. 60% plagioclase 10% quartz. Rest tremolite, actinolite

Vague layering due to alignment of mica 80° to axis of core.
Partings 1.0 ft. apart planar. Vivianite coated. Open. Joints closed 0.5 to 1 mm. wide planar Vivianite. Filled 5 to 15° to axis of core. 2.0 ft apart. Faulted to minor extent 1 mm movement.

Gradational boundary

GNEISS - METASILT - light grey fine grained. 7% Fe sulphides 10% below 194 ft. Mainly as coarse grained bands 2 to 5 mm wide 1.0 ft apart

0.2 ft apart below 194 ft. 60% quartz 3% phlogopite. Rest plagioclase. 10% of coarse Fe sulphides is pyrrhotite

Layering very good planar. 80 to 85° to axis of core. Up to 3 mm wide. Partings 0.5 to 1.0 ft apart. Open. Vivianite coated. Joints Closed 10 to 20° to axis of core. Vivianite filled. Faulted by sulphide.

WEATHERING

LEGEND

▨	Quartz-biotite Granofels	••• Breccia Zone
▨	SCHIST	⟍ Major Joint

METALLIC MINERALS SECTION

24