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ENG. GEOLOGY SECTION

GEOLOGICAL SURVEY

DRILLING FOR CAVES ON THE EYRE HIGHWAY NEAR WHITE WELL.

P.D. JOHNSON.

Department of Mines
South Australia —

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DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY

ENGINEERING DIVISION

DRILLING FOR CAVES ON THE EYRE HIGHWAY NEAR WHITE WELL

- HIGHWAYS DEPARTMENT -

by

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ENGINEERING GEOLOGY SECTION

17th September, 1974

Rept. Bk. No. 74/188
G.S. No. 5504
D.M. No. 1034/73
Eng. Geol. No. 1974-23

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DEPARTMENT OF MINES

SOUTH AUSTRALIA

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- Client: HIGHWAYS DEPARTMENT -

SUMMARY

Three minor gravity anomalies, detected by a previous survey, have been tested by rotary percussion drilling.

Small cavities were intersected in all holes, although only hole 6 (anomaly E) intersected cavities of the size predicted from the gravity interpretation. The following conclusions may be drawn from the results of this drilling programme:-

.....Present gravity techniques are not sufficiently reliable or economic for use in cave location along the highway route.

.....A practical test of the foundation strength of the road formation is recommended; possibly by towing a trailer which exceeds expected design loads.

.....Careful visual examination of the ground surface during construction will also be necessary. Existing topographic lows may indicate large caves at shallow depth and further drilling can be carried out on suspected sites.

INTRODUCTION

In a letter dated 16th May, 1974, the Commissioner of Highways requested the Department of Mines to drill a series of gravity anomalies as recommended by W.E. Wightman's (1973) report on the Cave Detection Study near Nullarbor Station. Figure 1 is a locality plan for the gravity traverse. A drilling rig became available in early August and drilling commenced on 8th August, 1974.

TOPOGRAPHY & VEGETATION

In this area of the Nullarbor Plain, the topography is flat, with only very gentle undulations. Small mounds, up to 1m in height usually indicate wombat burrows or rabbit warrens.

The rainfall this year has been quite high (350 mm to August) and consequently the vegetation cover is thicker than usual. The plain is a grassland with occasional large bushes and many low shrubs.

GEOLOGY

The following geological sequence, which dips shallowly to the east, has been identified in the White Well area.

Range Depth (metres)	Description
0 - 1.40	Calcareous light brown fine sand (Loveday Soil?, Recent)
0.20 - 1.90	cream-brown, fresh,* strong, sheet-like calcrete. (Ripon Calcrete, Middle Pleistocene)
1.20 - ?(about 30m)	cream-white, fresh, strong, dense, crystalline limestone containing bryozoal and molluscan casts and moulds. (Nullarbor Limestone, Lower Miocene)
?30.00-?130.00	white, fresh, weak chalk limestone containing bryozoa, brachiopods and molluscs in a matrix of finely crystalline calcite - it also contains flint nodules, often apparently in bands. (Wilson Bluff Limestone, Upper Eocene)

* See Appendix 1, "Soil and Rock Classification Charts"

Photograph 1. Looking into the White Well Cave. Note the jointing and fracturing of the Nullarbor Limestone.

In this drilling program, the holes were not deep enough to intersect the Wilson Bluff Limestone, but the sequence described above has been proven in groundwater drilling for the new highway. (Williams, A.F., 1973).

The Ripon Calcrete and Nullarbor Limestone are often broken by horizontal jointing and vertical fractures. This can be clearly seen in the photograph of the White Well Cave. It is interesting to note that a brown variety of crystalline gypsum was found infilling some cavities in the White Well Cave and a group of gypsiferous stalactites were found at the eastern end of the cave.

It is suggested that a correlation exists between sharp dips in topography (forming a basin) and the presence of caves beneath. These basins are surface expressions of subsidence into large shallow caves. In the case of the White Well Cave, the basin has a diameter of about 10-15m, and similar size basins were seen in the Koonalda Cave area.

DRILLING RESULTS

A Halco rotary percussion rig drilled eleven holes totalling 114 metres. The gravity anomalies were drilled in the order recommended by W.E. Wightman (1973). Drill hole logs are included in Appendix 2. A location plan and cross section for each anomaly is shown in Figure 2.

Anomaly G. (Holes 1,2,3 and 11)

Small cavities, ranging in size from 0.05m to 0.35m where found below 6.0m depth. These cavities should not adversely affect the foundation strength of the overlying limestone, and are too small to account for the total magnitude of the gravity anomaly.

Anomaly H. (holes 4 and 5)

In hole 4, a cavity 0.50m in depth was intersected at 11.70m.

In hole 5, a cavity 0.75m in depth was intersected at 8.50m.

Both of these cavities are thought to be too small to significantly affect foundation conditions, and are not large enough to account for the total magnitude of the gravity anomaly.

Anomaly B

This anomaly is situated on an extensive network of wombat burrows and it is thought that these could have caused the gravity low at this point. It was therefore decided to drill anomaly E (similar magnitude to B) in preference to this anomaly.

Anomaly E (Holes 6,7,8,9).

Hole 6 disclosed a very cavernous limestone in this region. A cavity 0.80m deep was located at 1.80m depth and from 6.05m to 12.20m, there was 4.75m of cavities. The lateral expanse of these cavities beneath the road is difficult to judge due to the drilling problems encounted, in holes 7 and 8. However, these cavities are thought to be large enough to significantly lower the bearing capacity of the limestone. The cavities intersected are large enough to account for the magnitude of the gravity anomaly.

Hole 10

This hole was put down 'between anomalies' to test the gravity results. Small cavities were found deeper than 11m, with a larger cavity from 11.50 to 12.10m. Small cavities were expected in this hole; the cavity at 11.50m is still probably too small to have a detectable gravity effect at the surface.

GENERAL DISCUSSION

Refinement of the gravity technique for cave detection will be necessary to improve the reliability of this method. Firstly the variation in the thickness of the surface sand (up to 1.20m) can cause a gravity anomaly of 0.04 mgals due to its density contrast (eg. density of surface sand is approx. 1.0 gm/cc, whereas the density of the underlying calcrete is approximately 2.5 gm/cc). In G.C. Colley's paper on "The Detection of Caves by Gravity Measurements", he considers that about 0.2 mgals directly over the centre of the cave, should be the minimum value required to be reasonably certain that a gravity low is due to a cave. In the comparatively uniform geological conditions of the Nullarbor Plain, this threshold value could probably be reduced to 0.15 mgals.

Besides the problem of deciding which anomalies are due to caves, there is also the difficulty of estimating the depth to the cave. The shape of the gravity curve indicates shallow or deep caves but it is impossible to produce a unique value for depth. For instance no large caves were intersected in anomalies G or H, due possibly to the fact that the cause of the anomaly may be deeper than the estimated depths.

To test an anomaly on a single gravity profile, it is necessary to drill a number of holes across the anomaly, at right angles to the traverse. The reason for this is that the cause of the anomaly may lie beneath, or to either side, of the survey line. If gravity readings were taken on a 20 foot grid pattern over anomalies which exceeded the threshold value, the anomalies could be contoured. A single drill hole would then be necessary to test each anomaly.

The Geophysics Section is presently evaluating the feasibility of designing a reverberation technique in preference to the gravity technique. The reverberation technique would transmit various frequencies which would be reflected by the air-rock contact in a cave. These reinforcing waves would cause a resonance which would be recorded. The extent of the cave might be found by moving the location of the receiver, and hopefully an analysis of the resonance would give an indication of the depth and size of the cave. However, such a technique has not been used before and it may suffer from the same drawbacks as the gravity technique. This technique would also require drilling for verification.

CONCLUSIONS

A practical test may be the best method of testing the foundation strength of the road over cavernous ground. The 'design' load could be towed along the route of the new road, thus making a field test of foundation strength. Obviously the problem is recovering or abandoning the weight if the foundation failed completely; however a progressive failure seems more probable.

Practical testing overcomes the following disadvantages of geophysical techniques.

(1) The problem of distinguishing caves from spurious anomalies.

(2) the problem of determining the cave's depth and size.

(3) the numerous problems encounted when drilling often causes the hole to be abandoned before the target depth is reached. (see Appendix 3)

(4) the problem of interpreting the drilling results in terms of foundation strength. (e.g. a cavity may be found close to the surface but the overlying rock may still be strong enough to support the road).

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17/9/74

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APPENDIX 1

Soil and Rock Classification Charts

DEPARTMENT OF MINES - SOUTH AUSTRALIA

ENGINEERING CLASSIFICATION OF SOILS

The Unified Soil Classification System

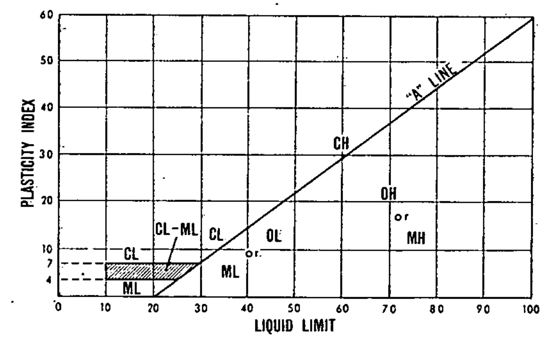
COARSE-GRAINED SOILS More than 50% of material is larger than No. 200 B.S. sieve size	FIELD INVESTIGATION PROCEDURES Excluding particles larger than 7·5cm and basing fractions on estimated weights			GROUP SYMBOL	GROUP NAME and typical materials	LABORATORY CLASSIFICATION CRITERIA	
	GRAVELS More than 50% of the coarse fraction is larger than 2mm. (retained on B.S.7 sieve)	CLEAN GRAVELS Little or no fines	Wide range in grain sizes, and substantial amounts of all intermediate particle sizes	GW	GRAVEL, well graded; gravel sand mixtures, little or no fines	$Cu = \frac{D60}{D10}$ Greater than 4; $Cc = \frac{(D30)^2}{D10 \times D60}$ Between 1 and 3	
			Predominantly one size or a range of sizes, with some intermediate sizes missing	GP	GRAVEL, poorly graded; gravel sand mixtures, little or no fines	Not meeting all gradation requirements for GW	
		DIRTY GRAVELS Appreciable amount of fines	Non-plastic fines—for indentification see ML below	GM	GRAVEL, excess silty fines; poorly graded gravel-sand-silt mixtures	Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Plastic fines—for identification see CL below	GC	GRAVEL, excess clayey fines; poorly graded gravel-sand-clay mixtures	Atterberg limits below "A" line or PI greater than 7	
	SANDS More than 50% of the coarse fraction is smaller than 2mm. (passing B.S.7 sieve)	CLEAN SANDS Little or no fines	Wide range in grain sizes, and substantial amounts of all intermediate particle sizes	SW	SAND, well graded; well graded sands, gravelly sands, little or no fines	$Cu = \frac{D60}{D10}$ Greater than 6; $Cc = \frac{(D30)^2}{D10 \times D60}$ Between 1 and 3	
			Predominantly one size or a range of sizes, with some intermediate sizes missing	SP	SAND, poorly graded; poorly graded sands, gravelly sands, little or no fines	Not meeting all gradation requirements for SW	
		DIRTY SANDS Appreciable amount of fines	Non-plastic fines—for indentification see ML below	SM	SAND, excess silty fines; poorly graded sand-silt mixtures	Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Plastic fines—for identification see CL below	SC	SAND, excess clayey fines; poorly graded sand-clay mixtures	Atterberg limits below "A" line or PI greater than 7	

GRAIN SIZE CURVES to be used to identify soil fractions

Coarse-grained soil classified on basis of percentage of fines, as follows

PERCENT OF FINES	GRAVELS	SANDS
Less than 5	GW GP	SW SP
More than 12	GM GC	SM SC
5 to 12	Borderline cases, use 2 symbols	

FINE-GRAINED SOILS More than 50% of material is smaller than No. 200 B.S. sieve size	FIELD INVESTIGATION PROCEDURES on fraction smaller than 0.4mm. (passing B.S. 36 sieve) SOIL CAST (soil wet)	SOIL THREAD	SHINE	DILATANCY	ODOUR	DRY STRENGTH	GROUP SYMBOL	GROUP NAME and typical materials
SILTS AND CLAYS Liquid limit less than 50	Forms fragile cast. Cracks form when kneaded while moist	Thick crumbly thread; easily broken	None to very dull	Distinct	Not significant	None to slight	ML	SILT SOIL, low plasticity; inorganic silts and very fine silty or clayey sands, rock flour
	Cast maybe handled freely without breaking. Can be kneaded moist without cracking. Material adheres to the hand	Thread can be pointed as fine as a lead pencil but is fragile	Moderate	None to slight	Not significant	Moderate	CL	CLAY SOIL, low plasticity; inorganic clays of low to medium plasticity; gravelly clay, sand, clays, silty clays, lean clays
	Cast fragile to cohesive material will adhere somewhat to the hand	Soft, weak thread	None to very dull	Slight to distinct	Decayed organic matter	Low	OL	ORGANIC SOIL, low plasticity; organic silts and silt clays of low plasticity
SILTS AND CLAYS Liquid limit more than 50	Moderately plastic and cohesive. Material adheres somewhat to the hand	Weak to medium thread. May be crumbly	Dull	None to slight	Not significant	Moderate. Powdered soil feels floury	MH	SILT SOIL, high plasticity; inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	Very plastic and cohesive. Material very sticky to the hand. Greasy to touch	Very tough thread, can be rolled to a pin point	Very glossy	None	Strong earthy	High to very high. Cannot be powdered by finger pressure	CH	CLAY SOIL, high plasticity; inorganic clays of high plasticity, fat clays
	Plastic and cohesive. Feels slightly spongy. Greasy to touch	Weak to medium thread. Often soft and fibrous	Moderate to very glossy	None	Decayed organic matter	Moderate to high. Powdered soil may be fibrous	OH	ORGANIC SOIL, high plasticity; organic clays of medium to high plasticity
	Readily identified by colour, odour, spongy feel and frequently by fibrous texture						Pt	PEATY SOIL; Peat and other highly organic soils



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS

NOTE: BOUNDARY CLASSIFICATIONS: Soil possessing characteristics of two groups are shown as a combination of two group symbols, eg. GW-GC, well graded gravel with clay binder.

Based on "The Unified Soil Classification System" United States Department of the Interior, Bureau of Reclamation "Earth Manual" First Edition, Denver COLARADO 1960.

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ENGINEERING CLASSIFICATION OF ROCK MATERIAL

1. ROCK CONDITION

TERM	ABBRN	DEFINITION
Fresh	(F)	No weathering effects visible to naked eye.
Weathered	(W)	Shows visible effects of chemical decomposition caused by air and groundwater. Can be subdivided:
Slightly weathered	(SW)	- change in appearance but no loss in strength
Moderately weathered	(MW)	- change in appearance but with significant loss in strength.
Completely weathered	(CW)	- has soil properties and often shows complete change in appearance.
Altered	(A)	Shows chemical and physical alteration to rock fabric caused by temperature, pressure or injection of other material.

2. ROCK STRENGTH

Can be correlated with unconfined compressive strength tested in the laboratory.

TERM	ABBRN	Kg cm^2 (p.s.i.)	FIELD TEST	
Very weak	VW	70 (1 000)	Breaks and crumbles easily in the hands.	
Weak	W	70-200 (1 000-3 000)	Breaks easily with hammer tap.	(Normal range of concrete)
Medium strong	MS	200-700 (3 000-10 000)	Rings and breaks to firm hammer blow	
Strong	S	700-1 800 (10 000-25 000)	(Very difficult to break with hammer and requires sledge)	
Very strong	VS	>1 800 (>25 000)		

3. USE OF CLASSIFICATION

Note that Condition and Strength terms do not necessarily correspond.

Strength depends on the type of rock while condition depends on external effects, e.g.

Rock Material	Condition	Strength
Granite	Fresh	Strong
Schist	Fresh	Weak

APPENDIX 2 - **Drill Logs.**

(See Fig.2 for Drill hole Location Plan)

Anomaly G.

Hole 1

0 - 0.40m	Calcareous light brown fine sand
0.40 - 1.50m	cream-brown fresh, strong calcrete (sheet-like)
1.50 - 10.60m	white, fresh, strong, fine crystalline limestone
	(cavities: 7.0 to 7.15m - sample lost
	7.80 to 8.00m
	8.80 to 9.00m
	10.00 to 10.05m
	10.50 to 10.60m)

Hole 2

0.00 - 0.40m	calcareous light brown fine sand
0.40 - 1.60m	cream-brown fresh, strong calcrete (sheet-like)
1.60 - 8.40m	white, fresh, strong fine crystalline limestone
	(cavities: 7.05 to 7.15m - no sample return
	8.30 to 8.40m)

Hole 3

0.00 - 0.30m	calcareous light brown fine sand
0.30 - 1.50m	cream brown fresh, strong calcrete (sheet-like)
1.50 - 14.60m	white fresh strong, fine crystalline limestone
	(cavities: 6.20 to 6.30m
	8.30 to 8.35m
	8.65 to 8.70m
	13.00 to 13.15m)

Hole 11

0.00 - 1.40m	calcareous light brown fine sand
1.40 - 1.75m	cream brown fresh, strong calcrete (sheet-like)
1.75 - 14.40m	white fresh strong, fine crystalline limestone
	(cavities: 7.30 - 7.35m
	10.00 - 10.10m
	10.50 - 10.85m
	13.30 - 13.50m)

Anomaly H

Hole 4

0.00 - 0.40m	calcareous light brown clay
0.40 - 1.20m	cream-brown fresh, strong calcrete (sheet-like)
1.20 - 13.30m	white fresh, strong, fine crystalline limestone (cavities: 4.80 to 4.85m 8.40 to 8.50m 11.70 to 12.20m - sample lost 13.00 to 13.20m)

Hole 5

0.00 - 0.35m	calcareous light brown clay
0.35 - 1.55m	cream brown fresh, strong calcrete (sheet-like)
1.55 - 9.35m	white fresh, strong, fine crystalline limestone (cavities: 8.50 to 9.25m - sample lost)

Anomaly E

Hole 6

0.00 - 0.30m	calcareous light brown silt			
0.30 - 1.40m	cream brown fresh, strong calcrete			
1.40 - 12.40m	white fresh, strong, fine crystalline limestone			
	(cavities:	1.80	to	2.60m
		4.60	to	4.80m
		5.10	to	5.20m
		6.05	to	6.50m - all sample lost
		6.90	to	7.20m
		7.75	to	8.40m
		8.60	to	10.10m
		10.20	to	10.40m
		10.45	to	11.35m
		11.40	to	11.95m
		12.00	to	12.20m)

Hole 7

0.00 - 0.30m calcareous light brown clayey silt

0.30 - 1.65m cream brown fresh, strong calcrete (broken, sheet-lik

1.65 - 4.60m white fresh, strong, fine crystalline limestone

(cavities: 2.00 - 2.20m)

(Bit could not penetrate broken ground; hole abandoned).

Hole 8

0.00 - 0.20m calcareous light cream brown silt

0.20 - 1.80m cream brown fresh strong calcrete (broken sheet-like)

1.80 - 1.85m white fresh, strong, fine crystalline limestone

(cavities: 1.30 - 1.40m

1.60 - 1.70m)

(up hole velocity lost, samples jamming bit; hole abandoned)

Hole 9 (Anomaly E, continued)

0.00 - 0.20m	calcareous light brown silt
0.20 - 0.65m	cream brown calcrete (rubbly)
0.65 - 1.65m	cream brown fresh, strong calcrete (sheet-like) (Cavity 1.50 - 1.60m)
1.65 - 10.50m	white fresh, strong, fine crystalline limestone (cavities: 2.40 - 2.45m 5.10 - 5.20m 5.25 - 5.30m 7.60 - 7.70m 8.10 - 8.30m 8.60 - 8.70m 9.10 - 9.20m - sample lost 9.80 - 9.90m 10.20m-10.25m)

Drilling between Anomalies

Hole 10

0.00 - 0.30m	calcareous light brown silt
0.30 - 1.90m	cream brown fresh strong calcrete (broken sheet-like) (cavity 1.30 - 1.45m)
1.90 - 14.50m	white fresh strong, fine crystalline limestone (cavities: 11.10 - 11.20 - sample lost 11.30 - 11.40m 11.50 - 12.10m)

APPENDIX 3

Drilling : Method and Problems.

Photograph 2. Halco Rotary Percussion Drilling Rig with compressor on the truck.

DRILLING : METHOD & PROBLEMS

A Halco Rotary Rig. No. 2 was used to drill the gravity anomalies. This is a rotary-percussion rig which is driven by compressed air. The drill pipe is rotated from the surface and the percussion action comes from a halco, down-the-hole hammer. (See Photograph 2.)

Some general notes on rotary-percussion drilling are as follows:-

(i) The 4½" hammer requires 100 p.s.i. pressure differential for operation.

(ii) An adequate volume of compressed air is required to lift the rock chips to the surface. This is commonly called, "Uphole-velocity".

(iii) The smallest diameter hole possible should be drilled to keep a high'up-hole-velocity'.

When drilling a row of holes across an anomaly, the holes were left open until the completion of the last hole. This was done in an effort to see if the caves were continuous from one hole to the other; however a fine dust sample continued to rise out of the holes for hours after they had been drilled and so it was not readily possible to detect extra air rising up the hole.

The tri-cone bit, the chisel bit and the button bit were all tested in the hard, crystalline limestone. The button bit gave the best penetration rate, (about 50 mins to 1hr for a 6 foot rod) with the chisel bit being the next best.

The following criteria were used to identify cavities:-

1. The hammer stops working and consequently there is an immediate drop in noise level.

2. There is no sample return as the up-hole-velocity is lost.

3. The drill rods descend quickly down the hole.

An indication of cavity volume can be deduced by variations in these criteria.

eg.: In small cavities:

1. A fine dust sample is returned but chip samples are still lost.

2. the bit may grind on the side of the cavity even though the hammer is not working.

3. the drill rods may descend in quick jerks rather than quickly and smoothly....however this also depends on the condition of the hole above the cavity.

4. Full sample return may be restored after a short time indicating that the cavity has been filled, or blocked off with sample chips.

Problems:

1. Ledges formed when drilling the jointed sheet calcrete, thus making the top of the hole very rough. A 6 foot downpipe was inserted where possible to prevent the bit and hammer jamming. Bit wandering was so bad in some holes that it was not possible to insert the downpipe; the calcrete was too hard to "ream off" the ledges.

2. The hammer would only work on a solid surface. For instance, the hammer would not operate under the following conditions:

a) loose rocks or rock chips on the bottom of the hole.

b) where the ground was well jointed and fairly broken.

c) where a cavity was not large enough to let the bit through.

3. On entering a small cavity, up-hole-velocity is lost and rock chips start filling the cavity or just continue to fall back onto the bit. These chips can then jam the bit, or hammer, against the side of the hole. The rods had to be rotated manually to free the bit. (It is essential to rotate the rods only in a clockwise direction or the bit could be lost down the hole).

4. The bit would often jam when entering a cavity, probably because the ground breaks crookedly into a cavity. This factor would also account for the bit jamming at the top of cavities when the rods are being pulled.

Williams, A.F., (1972) included in his report, an appendix on "Drilling Hazards Experienced by the B.H.P. Co. on the Nullarbor Plain". Most of the comments made by the B.H.P. are also quite relevant to this drilling project; especially the section on cavities and fissures.

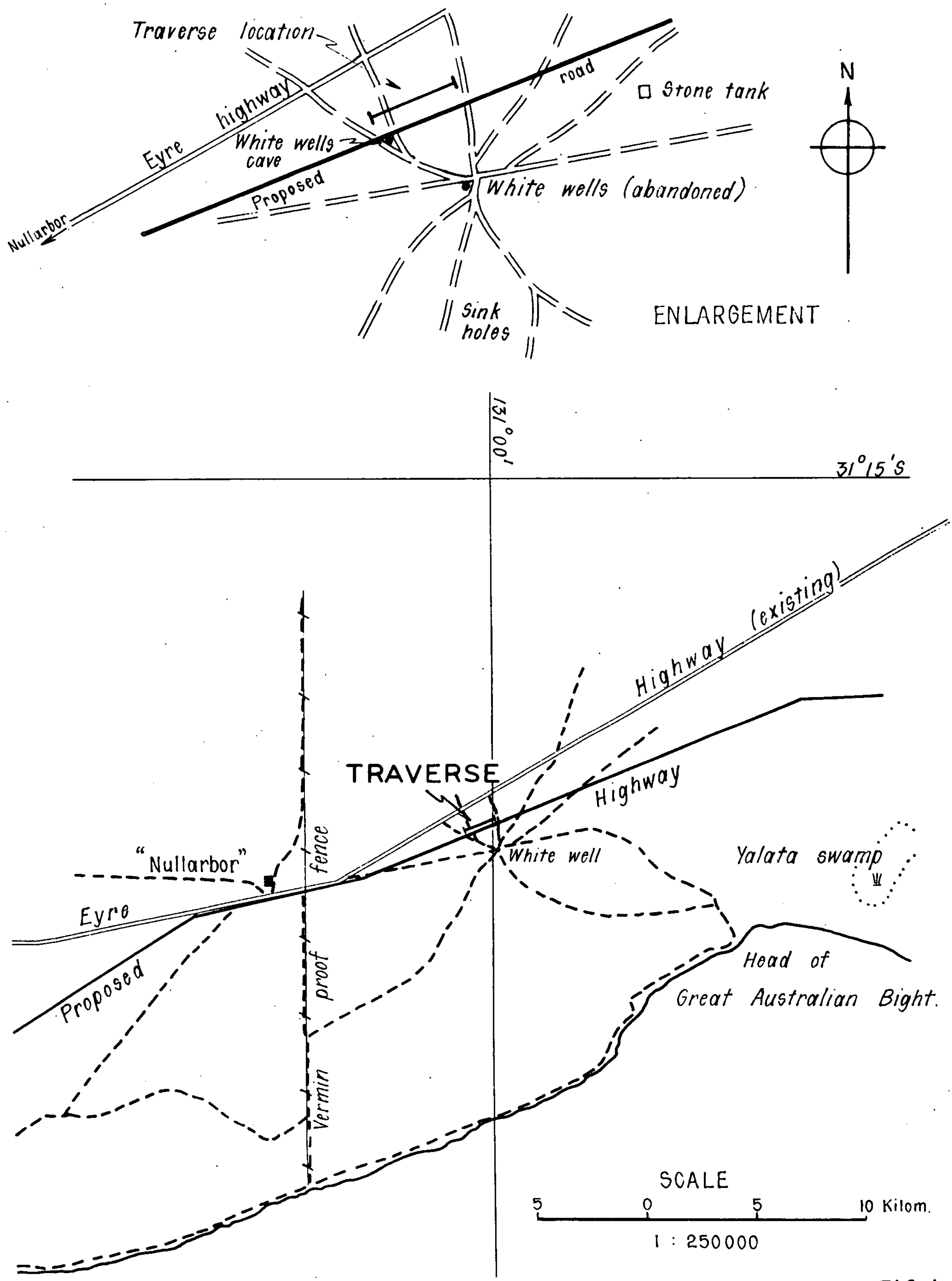

FIG 1

DEPARTMENT OF MINES — SOUTH AUSTRALIA

ENGINEERING GEOLOGY SECTION	**Drn.** P.J.	EYRE HIGHWAY WHITE WELL AREA TRAVERSE AND CAVE LOCATION PLAN	**SCALE:** 1: 250 000
	Tcd. B.W		S10987 Ac
	Ckd. P.J.		
	Exd.		**DATE:** 20th Sept. 1974

500-2.69 665

Note: Blackened areas represent cavities

* Nb. Chainage increases from the East (left hand side of plan) to the West (RHS)

FIG 2.

DEPARTMENT OF MINES — SOUTH AUSTRALIA

EYRE HIGHWAY – WHITE WELL AREA
CAVE DETECTION STUDY

ENGINEERING GEOLOGY SECTION	P. JOHNSON GEOLOGIST	Compiled P. JOHNSON	Scale: As shown
			Date: 19 Sept. 1974
Director of Mines		Drn. B.D.W. Ckd.	Drg. No. 74-779 Ac