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AN APPRAISAL OF THE RESERVOIR GEOLOGY OF MOOMBA GAS FIELD

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DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY
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AN APPRAISAL OF THE RESERVOIR GEOLOGY OF MOOMBA GAS FIELD

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CONTENTS

TABLES	Page

FIGURES	Drawing No.

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ABSTRACT

Moomba is the largest gas field discovered to date in the Cooper Basin. Eighteen wells have been drilled to evaluate and develop its resources; three into the smaller northern culmination, and the other fifteen into the southern culmination. Gas production is from the Toolachee Formation and Daralingie Beds. Minor, as yet undeveloped, reserves occur in the Patchawarra Formation.

The Daralingie Beds are interpreted to have been deposited during a lacustrine regression. Reservoirs exist in delta front sheet sands. The Toolachee Formation can be subdivided into three units whose depositional environments grade upwards from deltaic plain, through alluvial floodplain, to a senile landscape dominated by lakes and coal swamps.

The controls on pay sand distribution within the field are complex. They depend on the interplay between structure, lithology, water and porosity/permeability variations. There is no uniform base level of pay, due to the low degree of interconnection between reservoir sands.

Studies should be carried out to learn the cause(s) of variation in porosity and permeability. Trends in gas deliverability from the reservoir sands should be mapped and the controls on these trends understood.

Two appraisal wells are required. These will not only boost the gas reserves of the field, but also throw light on the distribution of pay within the Patchawarra Formation, map the extent of high productivity sands in the Daralingie Beds and provide more well control with which to define Toolachee Formation field limits.

INTRODUCTION

General

Moomba is the largest gas field discovered in the Cooper Basin to date. It is located near the southwestern margin of the basin on the eastern flank of the Nappamerrie Low. The field comprises two broad anticlinal structures, each trending in an approximately north-westerly direction, separated by a narrow trough. The top of Permian ("P" Horizon) ranges from

7 500 - 8 000 ft below sea level (Fig. 1). The total area of these two structures exceeds 100 000 acres.

Economic amounts of gas have been discovered from three formations, namely the Toolachee Formation, Daralingie Beds and Patchawarra Formation. Table 1 shows which wells were productive from these formations. Of the eighteen wells drilled so far, three are non-productive. These are Moomba 3, 4 and 13. In addition, Moomba 7 was shut in after completion, because of low permeability, to await formation fracturing.

TABLE 1

MOOMBA GAS FIELD - KNOWN GAS BEARING FORMATIONS

WELL NO.	1**	2**	3	4	5**	6**
Toolachee Formation	5.8MM	6.52MM	45 M	44 M	4.5 MM	5.35 MM
Daralingie Beds		187 M				
Patchawarra Formation	133 M			-	-	7.3 MM

WELL NO.	7*	8**	9**	10**	11**	12**
Toolachee Formation	485 MM	7.5 MM	4.6 MM	9.2 MM	5.0 MM	9.0 MM
Daralingie Beds		2.1 MM	9.1 MM	G	G	9.4 MM
Patchawarra Formation	82 M			-	-	-

WELL NO.	13	14**	15**	16**	17**	18**
Toolachee Formation		G	Est.7.96 MM (after completion)	Est. 13 MM (after completion)	5.26 MM	G
Daralingie Beds					4.24 MM	9.5 MM (after completion)
Patchawarra Formation	-	-	-	-	-	-

N.B. 1. Figures show the maximum recorded flow rates in cubic ft per day (CFD) during drill stem testing. RTSTM's have not been recorded.

2. ** = Gas well producing from those intervals from which flow rate exceeds 1 MM.

3. * = Shut-In Gas Well.

4. G = Known to be gas bearing from log analysis, but untested by DST.

5. - = Not drilled.

Historical

Moomba was the second gas field to be discovered in the Cooper Basin, after the initial find, the Gidgealpa Field. The Moomba discovery well was the eighteenth exploration well drilled in or around the Cooper Basin. In 1966, Moomba 1 on the southern, and larger, structure flowed gas during DST No. 3 at the rate of 4.37 MMCFD from the Toolachee Formation. Moomba 5 successfully tested the northern culmination one year later, and then Moomba 6 discovered economic volumes of gas from the Patchawarra Formation in this structure. Moomba 9 was the first well drilled for development purposes, and since that time Moomba 11, 15-18 have also been drilled as development wells. The remaining wells fall into the appraisal category. The most recent well, Moomba 18, was completed in June, 1975.

PURPOSE AND SCOPE

Purpose

The purpose of the study is to obtain a better understanding of the geology of the field, and thereby a clearer picture of the controls on the distribution of gas pay sands.

Guidelines

In order to achieve the aims set out above, the study has been conducted using the following guidelines:

For the Toolachee Formation and Daralingie Beds -

1. Correlate lithological units throughout the area of the field on wireline logs.
2. Determine, as a result of detailed log correlation, whether or not there is evidence for any loss of section between the Toolachee Formation and the Daralingie Beds.
3. Subdivide the section incorporating the Toolachee Formation and Daralingie Beds into "process controlled genetic units" (Weimer, 1975).
4. Determine the lateral extent of individual sands or genetically related groups of sands.
5. Determine the maximum lateral extent of pay within the individual sands, assuming no structural control on distribution.
6. Investigate whether there is any relationship between pay/non-pay sand and the distributions of porosity, permeability and water saturation.

For the Toolachee Formation, Daralingie Beds and Patchawarra Formation -

7. Look for criteria by which to define the limits of pay sand.
8. Using (7), assess possible boundaries to the gas field.

9. Assess the optimum areas for the location of future wells, from the points of view of:

   (a) maximum pay sand thickness;

   (b) maximum gas deliverability;

   (c) maximum potential for expanding the gas field boundaries.

Method of Approach

The first part of this report deals with the Toolachee Formation and Daralingie Beds together. In a later section, the Patchawarra Formation is considered on its own.

METHODS

(TOOLACHEE FORMATION AND DARALINGIE BEDS)

Geological Cross Sections

Location: Three geological cross sections have been drawn through the Daralingie Beds and Toolachee Formation for the purpose of correlating lithological units (Figs. 2-4). Section A (Fig. 2) has been compiled in the vicinity of Moomba 15, where well control is greatest and therefore correlations between the wells are most likely to be correct. Section B (Fig. 3) ties in the remaining wells on the southern culmination with Section A. Section C (Fig. 4) attempts to correlate the units between the two culminations. The wide well spacing on this section, relative to the extent of individual sands must be acknowledged before considering the validity of correlation.

Description: The sections show the gamma-ray and lithological log for each well at a scale of 2 in: 100 ft (1:600). A horizontal scale of 1:10 000 is used, giving a vertical exaggeration of 16.6. Coals, sandstones and pay sands are correlated from one well to the next. Stratigraphic boundaries are marked.

Datum: The datum for the three cross sections is the radioactive shale band near the top of the Toolachee Formation. This shale is most clearly seen in the wells drilled in the western part of the field, for example in Moomba 12 at 7 737 ft and Moomba 16 at 7 658 ft. The shale does not have such a distinctive log character in the wells on the northern culmination, but nonetheless is identifiable. It is considered to be a chronostratigraphic marker band. Attempts to discover the cause of the high radioactivity, by means of autoradiography and Xray diffraction, have proved negative (Thornton, 1972).

Principles of Correlation: A set of rules was applied uniformly to correlate the wells in the three sections. The first three of the six were developed empirically:

1. Coals provide the basis for correlation because they seem to be the most laterally continuous lithology. This concept is perfectly reasonable when one considers the modern analogue of the Mississippi River and Atchafalaya Swamp. A very large proportion of the Mississippi alluvial valley comprises swamp, whereas the river, with its attendant point bar, channel and levee deposits, is confined to a narrow corridor along the eastern side of the valley.
2. Coals essentially have flat top and bottom surfaces, and do not take facies "steps" in the same manner as sandstones. The implication is that they represent a long period of non-clastic deposition and their boundaries more closely approximate to synchronous time horizons than any other lithological break.
3. Gamma-ray log character is not an essential correlation criterion between sandstones. The only exceptions to this rule are the two major gas bearing sandstones of the Daralingie Beds. Grain size and shale content of a fluviatile sand vary from one location to another, depending on the particular position within a point bar or channel deposit. Thus the gamma-ray log shape for any one sand also can vary with geographical location. However, in the case of the closely spaced wells, many sands do maintain a similar log character.
4. The other criterion for sandstone correlation is its situation between two coal seams that have been correlated. By and large, sandstones, unlike coals, do not have flat top and bottom surfaces because there is a significant lateral component to their deposition. Thus, they take facies "steps".

5. Pay sand intervals have not been used as factors in lithological correlation. They were marked onto the sections afterwards. Thus, the correlation of pay sands between wells in no way involves circular reasoning.
6. Pay sand intervals have been correlated within one sand from well to well on the basis of increase or decrease in an arithmetic progression. Where pay does not extend from one well to the next, a halfway cut-off has been used between the producing and non-producing sands. This approach reduces the inevitable error to a minimum.

Choice of Stratigraphic Boundaries

In order to understand the depositional history of Moomba it was necessary to divide the Toolachee Formation and Daralingie Beds section into a number of stages, each of which could be studied separately. At the same time, it was considered most important that the subdivision be into "process controlled genetic units" (Weimer, 1975) because boundaries between such units mark a change in the physical and/or biological processes operating within the environment at the time of deposition.

From examination of the geological cross sections, five stratal breaks have been selected to give four units. Three of these units occur within the Toolachee Formation (informally named Units I-III), and the fourth is the Daralingie Beds. The depths to the top of each of the five boundaries, together with the unit thicknesses are listed in Table 2.

TABLE 2

MOOMBA GAS FIELD - STRATIGRAPHIC TABLE

WELL NO.	Toolachee Formation		Unit III		Unit II		Unit I		Daralingie Beds		Roseneath Shale
	Depth Top (ft)	Thickness (ft)	Depth Top (ft)	Thickness (ft)	Depth Top (ft)	Thickness (ft)	Depth Top (ft)	Thickness (ft)	Depth Top (ft)	Thickness (ft)	Depth Top (ft)
1	7 602	354	7 602	116	7 718	170	7 888	68	7 956	214	8 170
2	7 410	381	7 410	145	7 555	182	7 737	54	7 791	136	7 927
3	7 705	389	7 705	159	7 864	176	8 040	54	8 094	130	8 224
4	7 709	400	7 709	163	7 872	182	8 054	55	8 109	111	8 220
5	7 936	353	7 936	93	8 029	179	8 208	81	8 289	?	?
6	8 004	351	8 004	106	8 110	182	8 292	63	8 355	89	8 444
7	7 868	365	7 868	158	8 026	167	8 193	40	8 233	194	8 427
8	7 641	303	7 641	94	7 735	147	7 882	62	7 944	84	8 028
9	7 632	358	7 632	139	7 771	158	7 929	61	7 990	120	8 110
10	7 563	381	7 563	149	7 712	182	7 894	50	7 944	142	8 086
11	7 736	396	7 736	150	7 886	175	8 061	71	8 132	116	8 248
12	7 593	429	7 593	183	7 776	190	7 966	56	8 022	136	8 158
13	7 822	399	7 822	180	8 002	161	8 163	58	8 221	(?) 219	(?) 8 440
14	7 481	376	7 481	144	7 625	169	7 794	63	7 857	144	8 001
15	7 671	379	7 671	142	7 813	182	7 995	55	8 050	153	8 203
16	7 577	361	7 577	118	7 695	183	7 878	60	7 938	137	8 075
17	7 647	359	7 647	116	7 763	182	7 945	61	8 006	132	8 138
18	7 674	421	7 674	183	7 857	195	8 052	43	8 095	161	8 256

Pay Sands Defined

In every case, pay sands have been defined from quantitative log evaluations. For Moomba 1 - 10 revised pay and thickness estimates produced by C.R. Porter in December, 1972 (see relevant SR files) have been used. However, in the case of Moomba 1, 6 and 10, my thickness definition is more conservative than Porter's. The results of log analyses on Moomba 11-18, contained in the relevant well completion reports, have been used for the pay sand definition. C.R. Porter carried out the analyses for Moomba 11-17, and N.J. Hamilton of Santos Ltd. did the evaluation for Moomba 18.

With a few exceptions, a pay sand is defined by porosity, $\emptyset \geq 10\%$ and hydrocarbon saturation, S hyd. $\geq 50\%$. S hyd. $= 100 - S_W$. Most of the exceptions are sandstone intervals which comply with these criteria but which have permeabilities too low to permit significant gas flow. Some sandstone intervals comply with the criteria, but are very thin and interspersed with water saturated sands, and are considered not to be pay. In a few cases, pay sands have either $\emptyset < 10\%$ and/or S hyd. $<50\%$, which is generally because these are weighted averages and the interval as a whole is considered productive.

Pay sand thicknesses for all the wells are shown in Table 3, together with the figures for "net feet of gas" (pay thickness x $\emptyset$ x S hyd.). Contouring of the net feet of gas figures produces a hydrocarbon pore volume map. Data on pay sand intervals, porosities and hydrocarbon saturations are contained in Appendix I.

TABLE 3

MOOMBA GAS FIELD - PAY SAND THICKNESSES

WELL NO.	Pay Sand Thickness (ft) (e)	Net Feet of Gas (ft) (e x Ø x S hyd.).
1	88	8.89
2	87	8.44
3	0	0
4	0	0
5	27	2.29
6	66	5.00
7	45	3.10
8	123	6.76
9	76	6.79
10	59	6.49
11	43	3.52
12	57	5.16
13	0	0
14	18	1.92
15	53	4.49
16	56	5.10
17	50	4.43
18	28	1.92

Isopachous Maps

Purpose: Four types of isopach have been compiled for each of the four genetic units. These are:

(a) isopachs of each Unit (Figs. 5, 8-10);

(b) isopachs of pay sand within each Unit (Figs. 13-15);

(c) individual isopachs of the major sands within each Unit (Figs. 6-7; 18-19; 22-25);

(d) isopachs of pay sand for each individual gas bearing sand within each Unit (Figs. 11-12; 20-21; 26-29).

The major reasons for drawing these maps are:

1. To determine the lateral extent of the Units and of the individual sands within them.
2. To determine whether there is any relationship between structures and thickness of either the Units or the sands within them.
3. To see if the sand bodies within the Units show any directional trends.
4. To examine the geometry of the individual sand bodies to see whether they can be used to indicate depositional environment.
5. To compare genetic unit isopach patterns with those of the relevant pay sand isopachs. Dissimilarities would suggest that overall thickness is not a controlling factor in pay sand distribution.
6. To determine whether the extent of pay within a sand can be related to structure, geographic location or vertical position within the section. The object is to develop criteria by which to define limits of pay.
7. Ultimately, to provide pay sand volumes for reserve calculations.

Method of Compilation: (a) General - The isopachs have been contoured solely on the basis of arithmetic gradation between the 18 control points. To this end, a scale of 1:100 000 has been chosen for all the maps produced. The "P" map was not used as a control during compilation because one of the major reasons for the study was to determine the degree to which structure affects pay sand distribution.

: (b) Daralingie Beds - The two gas bearing sands of the Daralingie Beds (S1 and S2) were subdivided into the three categories of pay sand, sand and silt, on the basis of gamma-ray log character and quantitative log evaluation. Therefore, three isopachs have been prepared for each sand. Firstly, a total isopach was compiled and on this map the extent of sand was outlined. The eastern limits of S1 and S2 were defined by the midpoints between wells which did and did not encounter the sands. After the total isopach had been drawn, a sand isopach, and then a pay sand isopach were compiled.

: (c) Units I and II - Individual sands were correlated across Moomba using the geological cross sections (Figs. 2-4), and the limits of these sands have been determined from these sections wherever appropriate.

The only sands mapped on the northern culmination were those that correlated with sands on the southern culmination. This is because of the very limited well control.

: (d) Pay Sand Isopachs - Zero lines have been drawn on the pay sand isopachs for both the whole units and individual sands half way between dry wells and producers. Pay thickness contours have been drawn on the basis of arithmetic gradation between the zero lines and the control points. The unit isopachs were used as control for the contouring of pay sand isopachs for the whole units where they appeared to help.

S1 and S2 Diagrammatic Cross Sections

Two cross sections showing the "P" Horizon and the distribution of S1 and S2 have been drawn north-eastwards across the south-western flank of Moomba (Fig. 30). The purpose is to examine the relationship between present day structure, thickness, lithological variation and pay sand distribution. They were compiled as follows:

1. Plot the "P" Horizon on a vertical scale of 1 cm = 100 ft.
2. Plot the depths at which S1 and S2 were intersected in the wells on the cross section.
3. Draw a phantom horizon, which is midpoint between S1 and S2, across the section using the "P" Horizon as control.
4. On an expanded vertical scale of 1 cm = 10 ft. plot the total, sand and pay sand thicknesses for S1 and S2 from the isopachs. The distance between S1 and S2 is arbitrary. Pay sand, sand and silt at each well are in their correct relative positions.

STRATIGRAPHY

(TOOLACHEE FORMATION ANDABALINGIE BEDS)

Description of Stratigraphic Boundaries:

Base of Daralingie Beds: This boundary is usually visible on both the gamma-ray and sonic logs. The sonic log shows a change in character upwards from uniform to much larger variations in Interval Transit Time. On the gamma-ray log the boundary is the base of the lowermost siltstone or sandstone band in the Daralingie Beds.

Base of Toolachee Formation and Unit I: The base of the Toolachee Formation is marked by a hiatus, which in some wells is indicated by loss of section in the Daralingie Beds. Res

Results of palynological studies of sediments elsewhere in the Cooper Basin strongly suggest that there is an erosional break between the Late Permian Toolachee Formation and Early Permian Daralingie Beds (Price, 1973). Unfortunately, there are no palynological data over the Moomba field, primarily owing to carbonisation of the palynomorphs.

In the structurally high areas of the Cooper Basin, such as Gidgealpa, the presence of a time break is clearly shown by the fact that Toolachee Formation sediments overlie Early Permian sediments with a strong angular unconformity, associated with a significant loss of section. However, in the structurally low areas, such as Moomba,any difference in dip between Early and Late Permian sediments is either negligible or non-existent. In addition, commonly the loss of section is not obvious.

Therefore, recognition of the boundary between the Daralingie Beds and Toolachee Formation in Moomba has required the observation of loss of section from one or more wells, followed by the careful correlation of this level throughout the whole area. Moomba 8 is the only well that clearly indicates the absence of the upper portion of the Daralingie Beds, although

Moomba 3, 5 and 6 also seem to have some of the section missing. None of the other wells show any evidence for a hiatus.

<u>Base of Unit II</u>: This level marks the boundary between a suite of thin sands, minor coals and dominant shales below, and a sandstone dominated sand-shale-coal unit above. It is most clearly seen on the logs from the wells on the western side of the field, such as Moomba 10, 15, 16 and 18 but can be correlated throughout with ease.

<u>Base of Unit III</u>: The top of Unit II is marked throughout most of the field by a thick coal, exemplified by Moomba 11. In some cases, this level consists of two thinner coals, as in Moomba 4. The boundary between Units II and III is at the top of the major coal, or at the top of the uppermost of the two thin coals. There are a few exceptions, such as Moomba 1, where the major coal thins along the cross section and correlates with what has become the lowermost of two thin coals.

<u>Top of Unit III</u>: The top of Unit III is taken as the top of Toolachee Formation. This is a rather dubious time boundary because it is overlain conformably by the Early Triassic Napamerrie Formation (Papalia, 1969). However, diachronity is thought to be not too severe. This is because the palynological *Protohaploxypinus reticulatus* Assemblage Zone occupies a very narrow interval (Helby, 1973) and occurs at the top of the Toolachee Formation wherever identified.

The top of the Toolachee Formation is normally clearly distinguishable in the gamma-ray and sonic logs, using the criteria described by Gatehouse (1972) in his definition of the Toolachee Formation.

<u>Lithological Description of Units</u>

This description of the units, and the distribution of the various lithologies within these Units, is largely the result of observations made from the geological cross sections (Figs. 2-4) and core descriptions, together with isopachs of individual sands.

<u>Daralingie Beds</u> - (a) <u>Observation</u>: On the western half of the field, extending from Moomba 6-12, the base of the Daralingie Beds is marked by one, or two (where best developed) sands with a distinctive log character. The remainder of the Daralingie Beds consist of siltstone and shale, with only a few thin sands and coals.

The basal sands are informally described as S1 and S2 on the sections. As shown from the gamma-ray log, both sands have a gradational lower boundary from the underlying shale, and the grain size coarsens upwards. (In fact, the gamma-ray curve indicates a decrease in shale content, associated with an overall increase in grain size). Invariably, the upper contact of S1 is very sharp with the overlying shale, but in some cases the contact of S2 is gradational.

The only wells in which these two sands have been cored are Moomba 15 and 18. In Moomba 15 the sands are not as fully developed as in some of the more westerly wells. Nonetheless, S1 shows an upward gradation from shale, through interbedded shale and sandstone, to sandstone. The sandstone is light grey, fine grained, and well sorted. It contains wavy discontinuous shaley and carbonaceous laminae (Zwigulis, 1974). The sharp upper log contact is not obvious from the core description. S2 comprises interbedded sandstone and shale. In Moomba 18, S2 shows an upward increase in grain size from very fine to medium grained (Vegh, 1975).

So far, Moomba 12 has intersected the maximum combined thickness of S1 and S2, which is 30 ft. S1 consists of 9 ft sand + 3 ft silt, and S2 comprises 12 ft sand + 6 ft silt. S2 is split with a thin sand developed beneath the main one. But this stringer "silts out" before reaching Moomba 18. Where S1 and S2 both exist, they occur about 10 ft apart.

The complete Daralingie Beds section attains its maximum thickness in the south-eastern part of the field, around Moomba 1, 13 and 7. Although shale and siltstone dominate, sandstone and coal development is greater than elsewhere. The sands, however, are discontinuous from one well to the next.

(b) <u>S1 and S2 Isopachs - General</u>: Because the S1 and S2 sands have such a distinctive log character, their distribution can be mapped with a fair degree of confidence (Figs. 6-7). In order to draw these maps, the lithology for each of the sands has been interpreted as sand (on the gamma-ray log: API $<$ 100), siltstone (140 $\geq$ API $>$ 100), or coaly sand (as indicated from the sonic log). Moomba 6 is the only well where the sands appear to be coaly.

(c) <u>S1 Total and Sand Isopachs</u>: The known area extent of S1 is 25 x 10 km and the locus of maximum thickness appears to trend north-northwest through Moomba 12, 18, 10 and 9 (Fig. 6). However, sand is restricted to an area of 20 x 6 km, although it is also thickest through Moomba 12, 18 and 9 (Fig. 11). The contours on both isopachs closely parallel one another and eastwards thinning is an equally gradual process. Evidence for thinning to the west is provided only by Moomba 11. But in this well, gamma-ray and sonic logs were not run successfully across S1 and therefore the thickness estimate and lithological determination are open to considerable doubt.

The diagrammatic cross-sections (Fig. 30) show that sand occurs above silt, and that silt extends eastwards from beneath the sand. At Moomba 11, which is an unreliable control point, there is only sand. This is the only indication that silt does not extend westwards further than sand.

If S1 extends as far west of the line of maximum thickness as it does east, then it is a widespread sheet covering an area of about 25 x 16 km. Perhaps sand occurs only within the central 20 x 12 km. On the other hand, it might be the dominant lithology on the western side of the sheet.

(d) <u>S2 Total and Sand Isopachs</u>: S2 has a very similar sand body geometry to S1, although it is slightly larger (25 x 11 km) and thicker (Fig. 7). The sand fraction extends over an area of 19 x 8 km (Fig. 12).

If the thickness and lithology estimates at Moomba 11 are correct both the total thickness and the sand fraction of S2 thins westwards. The diagrammatic cross section (Fig. 30) shows that silt occurs above as well as below sand at Moomba 15.

In a similar manner to S1, S2 could be a sheet with the dimensions of about 25 x 16 km.

<u>Unit I</u> - (a) <u>Observation</u>: Unit I compared with the other three subdivisions, is thin, ranging from 40-80 ft. The unit consists of interbedded sandstones and shales, and is characterised by the variability in amount and type of sandstone. Coal is sparse throughout the section.

On the southwestern side of the field, the dominant lithology is shale, with sands subordinate to shale and almost no coal. Moomba 14 and 17 are exceptions, however, with good sand development. Elsewhere in the field sandstone is as important a lithology as shale, although coal is insignificant. Only one well, Moomba 3, intersected a major, 6 ft coal seam.

Moomba 13 intersected a 39 ft thick sand with, on the gamma-ray log, sharp top and bottom contacts and a "barrel" shape (Pirson, 1970, p.37) which implies little upwards fining of the sand body. Moomba 8 contains two sandstones within Unit I. The lower one is 42 ft thick and its log pattern is not dissimilar to the Moomba 13 sand described above. Core from Moomba 8 shows it to comprise fine to medium grained sandstone interbedded with minor coaly shale laminations and siltstone patches. Shale laminations are regularly distorted, and dip at high angles, probably as a result of slumping. In the lower part, the sandstone is cross-bedded at angles of 25^{o} (Nugent, <u>et al</u>., 1968).

Moomba 9, 10 and 15 each intersected a sandstone with very obvious fining upwards characteristics shown on the gamma-ray log. Generally, those sands appear to correlate laterally with more "barrel" shaped sands.

(b) Isopachs of Individual Sands: The oldest sands in the southwestern portion of Moomba are the only laterally continuous ones. Very few of the other sands can be correlated even between two neighbouring wells (Figs. 18-19).

The most extensive sand, No. 2 has an even thickness of generally between 10 and 17 ft (Fig. 18). In addition, it occurs at the base of Unit I near Moomba 8 but climbs up the section in a southeasterly direction.

Unit II - (a) Observation: Unit II is the most uniformly thick of the four units, varying in thickness from 147-195 ft. It is also the major sand-bearing unit. It contains minor amounts of shale and coal.

Correlation of the sands shows that they are frequently displaced up or down the section from one well to another (by facies "steps"). This implies a large degree of mobility of depositional processes, and an ability of the sands to maintain their continuity, and not be swamped, in spite of environmental change. In addition, thickness and gamma-ray log character (which gives a qualitative indication of lithology) do not remain uniform from one well to another.

The basal contact of most of the sands is sharp, and not gradational. Frequently, these sands directly overlie coals. In many cases, the sands have fining upwards top boundaries.

Sand to shale to coal successions abound. In Moomba 18, 5 out of 7 coal bands are directly overlain by sand. Of those 5 sands, three are followed by shale-coal.

In the cores from Moomba 9 (Lunt, 1971) virtually every sandstone body shows upwards graded bedding, frequently from coarse grained, and even cobbly, to fine or very fine grained. 75 mm bands of cobble conglomerate are common, especially near the base of sands overlying coals. The sandstones are strongly current bedded. They contain carbonaceous material disseminated throughout.

Most of the coals in this interval are thin (5 ft thick or less). The exception is the coal that marks the upper boundary of Unit II, which reaches a maximum thickness of 11 ft, at Moomba 3. This coal is also the most extensive, covering virtually the whole of the field area without a break.

(b) Isopachs of Individual Sands: The oldest sands are mostly thin and discontinuous. As a general observation they become thicker and more extensive up the succession (Figs. 22-25).

The very complex nature of the sands is best indicated by Nos. 28, 2a, 2b and 3, all of which are interconnected (Fig. 22). The implication from this is that many of the sands are "multi-storey" lithologies deposited during two or more periods of sand deposition.

The lateral extent of sand No. 8 could be contoured with more certainty than most other sands because of its wide range of thickness (Fig. 25). The resultant shape is probably the only one that might imply a depositional environment.

Unit III - (a) Description: Shale is the major lithology in Unit III. Unit thickness varies considerably from 90-180 ft.

Throughout the field, the lower part of this interval is dominated by a shale. The shale horizon is thickest in the south and west (53 ft at Moomba 9) but thins towards the north (21 ft at Moomba 5 and 27 ft at Moomba 6). Within this shale band there are only a few thin (1 ft) coals. The exception to this is Moomba 18, where three sands (6 ft, 5 ft and 5ft thick) cut the shale.

Overlying the shale is a coal zone comprising one or two, generally thick, coals (at Moomba 15, 16 ft and 18 ft thick). The coal is almost continuous throughout the field, but at Moomba 12 a thick sand splits it in two. This sand is 29 ft thick and differential compaction around it is indicated on cross section "A" (Fig. 2). Moomba 6 and 8 also have a major sandstone at the same level as the thick coal zone in the other wells (Fig. 4).

Above the thick coal most of the section is dominated by shale with minor sands and a few coals. However, Moomba 18 contains a very thick sand (40 ft thick) which thins towards Moomba 12 (Fig. 2). At the same stratigraphic level as this sand, shale occurs at Moomba 14 and 15. A thin coal occurs above this interval in the four wells, and the considerably thinner section in Moomba 14 and 15 is thought to indicate drape around the sand.

Near the top of the unit, one sand is continuous over much of the southern area of the field. Elsewhere silts, thin sands and shale occur.

Environmental Interpretation of Units

Daralingie Beds: Deposition of the Daralingie Beds followed deposition of the Roseneath Shale without a break. Therefore, the S1 and S2 sands, which occur at the base of the Daralingie Beds, were most probably deposited in a transitional environment during a (?) marine/lacustrine regression. Transitional environments can be classified as deltaic or coastal interdeltaic (Le Blanc, 1972). By a process of elimination, described in the next four paragraphs, it appears that S1 and S2 are delta front sheet sands, as shown pictorially by Gould (1970, Fig. 11).

Le Blanc (1972) states that deltaic reservoirs are of two types: delta front sands or distributary channel sands. "(Delta front) sands are sheet like, and their landward margins are abrupt (against organic clays of the deltaic plain). Seaward, these sands grade into finer prodelta and marine sediments. Distributary channel sandstone bodies are narrow, they have abrupt basal contacts, and they decrease in grain size upward". As described previously, S1 and S2 have gradational basal contacts, are sheet like and increase in grain size upwards. Therefore, if they have a deltaic origin they are delta front sands.

In the opinion of Le Blanc, interdeltaic sandstone reservoirs "consist of beach and shoreface sands associated with barrier islands and tidal channels which occur between the barriers. Barrier sand bodies are long and narrow ...., and are characterised by an upward increase in grain size ...... Tidal channel sand bodies have abrupt basal contacts and range in grain size from coarse at the base to fine at the top".

Because S1 and S2 show upwards coarsening with gradational basal contacts, channel sand can be deleted as a potential origin, leaving the barrier sands.

Barrier sands consist of barrier island sand bodies and chenier sands. Barrier islands are long (usually tens of kilometres) and narrow (3-10 km), and reach a maximum thickness of 50-60 ft. Cheniers are similar, except that they are usually only a third as thick (Le Blanc, 1972).

As shown in the description of S1 and S2, the sands are at least 10 km wide, and probably double that. In addition, the greatest thickness so far encountered for any one sand is 18 ft (at Moomba 12). For these reasons, S1 and S2 are not thought to be barrier deposits but instead delta front sands.

Additional evidence for the above interpretation is provided by the distribution of sand and silt within S1 and S2. Silt extends much further east than sand, which overlies it (Fig. 30). This internal geometry can be explained by the process described by Gould (1970) of progradation in shoal-water deltas (such as the Lafourche delta). By progressive outbuilding a continuous sand sheet (the delta front sand) is developed. Subsidence of the delta during deposition results in a sandy body somewhat thicker than the depth of water in which it is deposited, which rarely exceeds 20-30 ft. Silts and clays are deposited ahead of the delta zone, and provide a platform necessary for delta advance. With continued outbuilding marsh deposits of the deltaic plain advance across the sheet sands.

Gould (1970) states that cutting through the sheet sands, there are associated channel fill sands, which in the Lafourche delta attain a maximum thickness of 100 ft. To date, no channel fill sands have been identified in Moomba at the same stratigraphic level as S1 and S2. But, if they occur, they could be important reservoirs.

The cored interval through S1 in Moomba 15 (Zwigulis, 1974) shows upwards gradation from silt to sand, together with other characteristics described previously, which appear very similar to the shallow-water delta facies described by Gould (1970, Fig. 13). In this example there is an upwards gradation from silty clay, to interlaminated clayey silt and sand, to interbedded burrow-mottled sand and silt, to clean, cross-bedded and laminated sands with thin layers of organic debris and plant fragments.

In conclusion, it is considered that S1 and S2 were deposited at the front of a prograding delta and that outbuilding occurred in either an easterly, or less likely, southerly direction. The relationship which puts the depth of water at somewhat less than the thickness of the sand body suggests a water depth of about 10 ft.

The sharp upper contact of S1 indicates a sudden change in depositional environment. This can be explained by the delta lobe shifting its position laterally because of a major stream diversion in the upper deltaic plain. With continued subsidence, prodelta silts and shales were deposited on top of it, preceding a second phase of delta building, with the resulting deposition of S2. Delta plain sediments overlie S2. In most cases the change to swamp conditions was sharp, in a few cases gradational through levee deposits. The two sands have very similar areal distributions, indicating that the delta must have been in much the same position during their deposition.

If S1 and S2 are delta front sheet sands, probably only about half their areal extent has been defined by drilling. The fact that siltstone extends further east than sandstone implies an easterly direction of progradation because in the model of progressive outbuilding proposed silts are deposited ahead of the delta zone. There is, however, the possibility that the portion of S1 and S2 so far discovered represents one side of the delta lobe. Certainly the interpreted coaly nature of the sands at Moomba 6 suggest that there is a northwards facies change from delta front sand to back swamp. This implies a northerly origin for the delta. However, the coal interpretation is based solely on sonic log character, and there is no corroborative evidence.

Unit I: Unit I is interpreted as representing deposition on a deltaic plain where the distributary channels rapidly change direction due to crevassing. The supporting evidence is the lack of coal, the variability in the amount of sandstone, gamma-ray log shape of sands in two wells, and a core description from one well.

The lack of much coal is interpreted to mean that the depositional surface was undergoing rapid change at the time of Unit I deposition, thus preventing the formation of coal swamps for long periods of time. It is suggested that the most likely environment for this to happen is the deltaic plain. The lack of continuity of sands noted above can be explained by the frequent changing of channel direction by avulsion.

Possible corroborative evidence for this interpretation is provided by the thick sands at Moomba 8 and 13. The gamma-ray log pattern of these sands is very similar to the SP log patterns of deposits interpreted as distributary channel fill from the Cisco facies of the North Texas Pennsylvanian delta systems (Fisher, et al., 1969, Fig. 98(2)).

The lithological description of the Moomba 8 core appears to list many of the diagnostic characteristics of channel fill facies tabulated by MacMillan (1974: also in Weimer, 1975, Table 11.2). These include planar to trough cross-stratification in the sandstone near the base, and finely laminated siltstone drapes, minor slumpage and convolute bedding in the sandstone above. The scale is similar too. MacMillan (1974) shows that the channel fill deposits range from 30 - 50 ft in thickness, and extend laterally for 600 m $\pm$.

If the Moomba 8 and 13 sands are channel fill deposits, their correlation on cross section B (Fig. 3) is probably incorrect. Presumably they would not extend as far as shown, especially for Moomba 8 where the sand correlates to one in Moomba 9.

The fining upwards sands of Moomba 9, 10 and 15 have log characteristics very similar to some shown by Fisher, et al., (1969; Fig.98 (4a+b)) to be delta plain aggradational channel fill, characterised by abrupt erosional lower boundaries and fining upward sequences. This further supports a delta plain theory of origin for Unit I.

Unit II: The depositional environment of Unit II was alluvial floodplain. Evidence for this interpretation is the dominance of upwards fining successions, the upwards migration of sand bodies, core data and the thinness of the coals.

The upwards fining succession of sandstone, to shale, to coal is diagnostic of deposition within an alluvial floodplain (Allen, 1964; Visher, 1965). The upwards migration of sands (as shown by facies "steps" in the geological cross sections) fits exactly the proposed model of point bar sands being deposited by lateral accretion.

Core data provide strong corroberative evidence, especially the upwards graded bedding of the sands, and the bands of cobble conglomerates. The cobble conglomerates, in many cases, are probably channel log deposits which were covered by point bars in their lateral movement. Thus, the occurrence of conglomerates within a sand body may well indicate the commencement of another stream deposit incising an earlier point bar.

The thinness of the coals is characteristic of the fluviatile model. There was just not time enough for a thick seam to develop before the next point bar swept across. On the other hand, the areal extent and thickness of the uppermost coal indicates the close of a period of mainly point bar and overbank deposits and replacement by a long stable period when the whole of Moomba was covered by coal-farming swamp.

<u>Unit III</u>: Unit III deposition was dominated by lakes, with intermittent periods of coal-swamp conditions and minor rivers.

At the beginning of Unit III the whole of Moomba was inundated, drowning the coal swamp. Lacustrine conditions commenced throughout. Intermittently, conditions became suitable for local coal development, presumably by a lowering of the water level on the margins of the lake. Moomba 18, however, marks the site of periodic influxes of coarse sediment, where minor fluvial fan or perhaps delta outbuilding commenced and then died out again.

The lake eventually dried up enough for tree growth to occur and the area reverted to swamp. The thick sand at Moomba 12 probably marks the path of a major channel through this swamp. The sands at Moomba 6 and 8 also indicate a region of channel development.

For a second time, lacustrine conditions prevailed, and again channels developed in the western part of the area, as shown by the sand at Moomba 18.

As the gradient between source area and the basin became very low (Thornton, 1973) deposition of fine clastics dominated. Finally, the depositional environment of the Toolachee Formation was terminated by the onset of aridity in the Lower Triassic (Wopfner, 1972).

ISOPACHS AND PAY SAND ISOPACHS

(TOOLACHEE FORMATION DARALINGIE BEDS)

Observations - Unit Isopachs

Daralingie Beds (Fig. 5): The Daralingie Beds isopach varies in thickness more than any of the other isopachs. It is very thick in the east, around Moomba 7, 1 and 13, where the sediment pile exceeds 210 ft. Thickness decreases northwestwards towards Moomba 6 and 8, where the thinnest section was encountered (84 ft). There is minor thickening around Moomba 18, which reaches 161 ft.

There is no similarity between this isopach and the structure of Moomba, as shown by the "P" map (Fig. 1).

Unit I (Fig. 8): Thickness variation is only slight, from 40 ft at Moomba 7 to 81 ft at Moomba 5. Even so, trends of thickening and thinning complement the Daralingie Beds isopach so that a "thick" on one map is a "thin" on the other.

Unit II (Fig. 9): Relatively, the Unit II isopach shows the least amount of variation of any of the units, from 147 ft at Moomba 8 to 195 ft at Moomba 18. Thickness variations are so slight that the 5 wells in a group around Moomba 16 are all either 182 ft or 183 ft thick. But, it can be seen that thickening trends are at right angles to contours on the "P" Map, particularly in the southwest.

Unit III (Fig. 10): Thickness varies between 93 ft at Moomba 5 to 183 ft at Moomba 18. Thickening trends are very different from the other isopachs, and in the southern half show a very close similarity with "P" Map contours. The thin areas around Moomba 1, and 16 and 17 relate to structural highs, while the thick region to the southwest compares closely with the deepest part of the southern culmination.

Overall, the unit thins towards the northwest. This overall trend would remain true even if greater well control in the vicinity of Moomba 5, 6 and 8 were to indicate a greater degree of parallelism between thickness and structure contours.

Observations - Individual Sand Isopachs

These isopachs were described in the Stratigraphy section.

Observations - Pay Sand Isopachs

Daralingie Beds - (a) General: Pay is confined to the western side of the field, and is held in the two sands, S1 and S2.

(b) S1 (Fig. 11): Only four wells contain pay sand, and of these, Moomba 9 has the greatest thickness (6 ft). Moomba 11 indicates westward thinning, but the evidence is too tenuous to define a western limit of pay.

(c) S2 (Fig. 12): S2 is both thicker and more extensive than S1. Of the seven productive wells, Moomba 9 has the thickest section (9 ft). In a similar manner to S1, Moomba 11 indicates thinning of pay to the west. The contour pattern, and zone of maximum thickness are very similar for the two sands.

Unit I (Fig. 13): Pay occurs in two distinct regions. Moomba 1, with 13 ft of pay, is separate from the main area of pay sand development up the western side of the field. Moomba 8 contains 47 ft of pay, whereas the next highest value is only 5 ft at Moomba 9, 12 and 18. There is no indication of a western limit of pay.

Unit II (Fig. 14): This is the only Unit in which all the field producing wells contain pay. Thickness ranges from 14 ft at Moomba 18 and 15 ft at Moomba 14, to 75 ft at Moomba 1. A zero thickness line is clearly marked along the south and southeast of the field, but nowhere else. A central region without pay is defined by Moomba 3, from where pay development increases outward towards the west, north and northeast.

Unit III: (Fig. 15): Only 5 wells produce from this Unit, in two separate areas. In the northwest, Moomba 6 and 8 are related with thickness increasing towards 30 ft at Moomba 8. There is no indication of an outer limit.

In the south, three wells contain pay. They are almost completely surrounded by non-producers,nearly providing a well defined zero boundary.

Composite Isopach (Fig. 17): This has been prepared by adding together the pay thickness for the Daralingie Beds and Units I-III. It therefore shows the maximum possible thickness, assuming no structural control on pay distribution.

Apart from the zones around Moomba 3, 4 and 13, no zero edge is defined. Except for slight indication of thinning to the west of Moomba 8 and south of Moomba 12, thickness contours are normal to structural trends all around the structure.

Observations - Individual Sand Pay Sand Isopachs

Unit I (Figs. 18-19): Pay is limited to seven sands, only one of which extends for any distance. This is sand No. 2, which has two separate regions of pay.

Unit II (Figs. 26-29): There is very little pay in the lowermost sands. Most of it occurs in the middle or at the top of the Unit. The thickest sand, No. 30, is 28 ft thick at Moomba 1 and extends to both Moomba 5 and 7.

Unit III (Fig. 16): Sz is the only major producing sand. Being nearly completely surrounded by non-producing wells, its limit is clearly defined on all but its southern margin.

Comparison of Isopachs and Pay Sand Isopachs

Daralingie Beds: There is no similarity between the total isopach and the S1 and S2 pay sand isopachs because pay is confined to these two western sands. Individually, however, there is very close parallelism between pay and thickness contours for S1 and S2.

Unit I: There is virtually no similarity between the isopach and pay sand isopach.

Unit II: Both isopach and pay sand isopach indicate a thick region around Moomba 2, 10, 15, 16 and 17. Apart from this, the thickness trends on the maps are dissimilar.

Unit III: There is no similarity between the isopach and pay sand isopach.

Composite: A composite isopach of Toolachee Formation and Daralingie Beds has not been compiled for this report. But the above results indicate that any comparison would be purely coincidental.

Comparison of Individual Sand Isopachs and Pay Sands Isopachs

Unit I: There is no great similarity between pay and thickness except that in most cases pay is not nearly as extensive as its host sand.

Unit II: Ecept for the oldest, most sands contain pay. The limit of pay within one of these sands appears to be related to structure (as shown by the "P" Map). This sand, No. 8, is very thick and contains a lot of pay. The sand itself extends over much of the southwestern part of the structure. But pay is confined to a narrow northwesterly trending region coincident with the apex of the southern culmination.

Unit III: With two minor exceptions (Moomba 2 and 12), pay in the southern area originates from a single sand, Sz. Comparison of the isopach of Sz with pay from within it (Fig. 16) shows that only the eastern end is productive. The sand thickens westward, but thickness does not seem to affect pay sand distribution as much as position within the sand.

Conclusions

Similarity between thickness and structure: For the Daralingie Beds and Units I and II, variations in sediment thickness should be considered from the point of depositional control. This is because there is very little similarity between the unit isopachs and the "P" Map. However, for Unit III conformity between the isopach and structure contour maps indicates structural control on deposition.

The non-parallelism between thickness and structure maps indicates one of two things. Either well control is not sufficient to contour accurate isopachs; or that for the order of thickness of the individual units, structural growth and/or differential compaction were not a major factor affecting deposition. Assuming the latter to be correct, the explanation is perhaps that in the Daralingie Beds, and Units I and II, sedimentation was a relatively rapid process, with deltas prograding and point bars laterally accreting. Thus, depositional processes were the dominant influences.

The very slight thickness variations in Unit II are indicative of uniform floodplain deposition throughout the area. The whole of Moomba was in the zone of river meandering and the streams took no preferred path, either over or around the structure.

On the other hand, the isopach and structure contours for Unit III are very similar. Unit III is dominated by shales gradually deposited over a long period of time. In this case depositional influence was outweighted by structural growth, and, in particular, differential compaction (see Geological Cross Sections).

<u>Similarity between pay, thickness and structure</u>: There is virtually no similarity between Unit isopachs and pay sand thickness. It is only when individual sands are mapped that any conformity with the extent of pay becomes clear. Even then, only in the Daralingie Beds is the relationship at all important for defining limits of pay.

For the Daralingie Beds, the very close parallelism between pay and thickness contours for S1 and S2 is caused firstly by thickness variations and secondly by the eastwards silting out, of the sand.

In Unit II, sand No. 8 contains pay only along the structural crest of the southern culmination. This is a clear indication that for this sand, at least, structure is a very important factor controlling gas accumulation.

The structural affect on pay sand distribution that is shown in sand No. 8 points to the invalidity of the unit pay sand isopachs, which were contoured assuming no structural control. In addition, the fact that no account was taken of the trough between the two culminations implies that the isopachs are extremely optimistic.

RESERVOIR GEOLOGY

(TOOLACHEE FORMATION AND DARALINGIE BEDS)

Distribution of Pay Sands

The role of water: Most of the gas producing wells contain water saturated sands within the Toolachee Formation or Daralingie Beds (Table 4; Appendix I). Most of these water saturated sands have low porosity and low permeability, especially in the cases where they are intercalated with thin pay sands.

TABLE 4

Moomba Gas Field - Wells containing Water Saturated Sands

Water saturated sands	occur above pay sands at:	Moomba 17
	in between pay sands at :	Moomba 1, 6, 8, 11, 12, 14, 17, 18
	Intercalated with pay sands (thin pay sands separated by water sands) :	Moomba, 8, 13, 18
	below pay sands at :	Moomba 1, 7, 8, 10, 12, 14, 15, 18
	throughout :	Moomba 4 (for most of Unit II)

The presence of a gas/water interface is not necessarily indicated by water sands beneath gas sands, because most of the water sands are tight. In addition, the tops of the water sands occur at depths as varies as -7 715 ft at Moomba 14 and -8 105 ft at Moomba 18, and could not all be part of one simple interface.

At Moomba 17 a tight water saturated sand overlies porous and permeable gas saturated sands. That the water was not replaced by gas is either because there is no interconnection with the water sand or that very early diagenesis made the water sand impermeable, thus keeping out the gas. This case exemplifies the problem, relevant to all the producing wells with water sands, of whether the low porosity and permeability prevented gas emplacement, or whether low porosity and permeability are the result of gas emplacement not having occurred.

The role of porosity and permeability: Low porosity and permeability are a major factor in the non-production from Moomba 3, 4 and 13 and the shut-in status of Moomba 7. As shown in Table 5, all these wells contain gas saturated sands, but non-product at an economic flow rate.

TABLE 5

Moomba Gas Field - Low Porosity and Permeability Sands in Non-producing Wells

Moomba 3 :	9 gas saturated sands in Unit II. One sand has $\emptyset$ = 11.5% and S_{hyd} = 74.5% and flowed gas at 45 MCFD; another has $\emptyset$ = 9.0% and S_{hyd} = 69% and probably flowed gas at 38 MCFD. Core data indicate low overall $\emptyset$ and k.
Moomba 4 :	Above water saturated zone in Unit II, 56 ft of sands are gas saturated, but with low k. One has $\emptyset$ = 12.7%, S_{hyd} = 70% and flowed at 44 MCFD. Below water saturated zone, 33 ft of sands are gas saturated.
Moomba 7 :	45 ft of pay but a very low flow rate (< 1 MMCFD) due to very low k.
Moomba 13 :	6 sands, distributed throughout all 4 units, that satisfy pay sand criteria. All are thin, low productivity zones which flow at RTSTM.

The role of structure: Undoubtedly, the structural location of a well in Moomba has some effect on its ability to produce gas. In the first place, gas emplacement occurred because of Moomba's anticlinal nature. And it is highly unlikely (although not disproven) that there are gas bearing sands in the structural low between the two culminations. However, unlike fields such as Big Lake and Della where gas is confined between an anticlinally folded seal above, and water beneath, structure is not the only important controlling factor. Not only is there no gas/water interface, but there is no one lowest closing contour either (Fig. 1). Therefore, field limits cannot be defined purely on structural criteria.

On the northern culmination, the contour at about -7 950 ft appears to fully enclose the structure. This fits the data for the bottom of the lowermost pay sand for Moomba 7 (-7 948 ft) and Moomba 5 (-7 955 ft). But at Moomba 6 the base of pay is at -8 123 ft (Fig. 1).

The situation is more complex in the southern culmination, where a major fault separates Moomba from Big Lake (Fig. 1). The lowest closing contour for most of the southern culmination is -7 950 ft. But at the southern end of the field, near Big Lake 4, no contour closes against the fault. In addition, at its south-western end the fault probably does not cut the "P" Horizon, which would mean that there is lithological continuity across it.

If there is lithological continuity between fields in this region, it would be logical to assume from an inspection of the "P" map that there may also be some reservoir continuity. The lowest closing contour at Big Lake coincides with its gas/water interface at -7 678 ft (S.G.M. J.V.T.S.C., 1974). All the pay sands in Moomba 11 and 18 are at depths greater than that, as are most of the sands for the other nearby wells. So there must be separation between the reservoirs of the two gas fields intersected so far.

An inspection of Fig. 1 shows that in many of the wells in the southwest of Moomba the base of pay occurs at depths considerably greater than the nearest closing contour. This implies that there is no interconnection between sands in this region, otherwise they would have a uniform base of pay at or near, the level of the closing contour.

The above paragraphs show that structure alone does not control the outer field limit. But in some cases the limit of pay in a particular sand within the field is structurally controlled. ~~by lithological variation.~~ This is demonstrated by sand No. 8 in Unit II where gas is confined to the crest of the southern culmination. However, the diagrammatic cross sections of S1 and S2 (Fig. 30) clearly show that the eastern limit of pay within these sands is controlled by lithological variation.

Conclusions

The inevitable conclusion from these data must be that structure controls the entrapment of gas in individual sands because the gas is held in the updip end of the reservoir. However, there is no uniform level of base of pay. Therefore, there is a low level of lateral and vertical interconnection between reservoirs.

It is assumed that the geological conditions during deposition were the same at Moomba as at other areas such as Big Lake and Della. Therefore, it is probable that sands are as contiguous at Moomba as these structures where lateral continuity of reservoirs is excellent. Thus, the low level of interconnection between reservoirs in Moomba must be due to permeability barriers.

PATCHAWARRA FORMATION

General

Of the first 9 wells drilled in Moomba, all but Moomba 4 and 5 were drilled into the Patchawarra Formation (Table 1). Moomba 5 was stopped prematurely because of drilling problems. No well after Moomba 9 has intersected the Patchawarra Formation. Therefore, the whole of the southwestern side of the field is untested with regards to gas potential from this formation.

Because of the Patchawarra Formation's limited amount of data and known potential, its stratigraphy, depositional environment and reservoir geology have not been studied to the extent of the younger reservoirs.

Pay Sand Distribution

Three wells have produced measurable amounts of gas. These are Moomba 1 (133 MCFD), Moomba 6 (7.3 MMCFD) and Moomba 7 (82 MCFD). Only Moomba 6 contains an economic amount of gas, contained within one 4 ft thick sand right at the top of the section. The other two wells contain their gas each in one, or two, thin sands near the middle of the Formation (approx. 700 ft thick at Moomba 7).

Because Moomba 5 did not test the Patchawarra Formation it is possible that pay sands occur throughout much of the northern culmination. However, known distribution is limited to the vicinity of Moomba 6 over an area very similar in location and size to that bounded by the -7 900 ft contour in Fig. 1 (see Thornton, 1973b; Map 9, for a pay sand isolith map).

Lithology

The Patchawarra Formation consists of interbedded sandstones, shales and coals. A core cut through the reservoir sand at Moomba 6 shows it to be fairly massive, with very occasional thin coal and shale laminae. Quartz is fine grained and fairly well sorted (Gausden, 1968). A log evaluation (carried out by C.R. Porter in 1973) gives the sand $\emptyset$ = 10%; S hyd. = 69%.

APPRAISAL WELL SITES

Introduction

An appraisal well is drilled as a step out to increase gas reserves, in addition to enlarging a field's producing capacity. By this definition, there are two areas where the drilling of an appraisal well is warranted. These are in the vicinity of Moomba 6 and Moomba 8. Other possible well sites probably have no greater potential for increasing reserves, and bear a greater risk of being non-productive.

Well near Moomba 6

A well site should be chosen near Moomba 6 to test the lateral and vertical extent of pay in the Patchawarra Formation, and to increase Toolachee Formation reserves.

Moomba 6 intersected a porous, gas saturated sand at the top of the Patchawarra Formation. Because the sand is thin, the proven-probable reserves are very slight. Another well is necessary to discover the extent and thickness of this sand.

Another major reason for drilling near Moomba 6 is to drill completely through the Patchawarra Formation in a region known to be gas bearing. Moomba 6 only intersected 211 ft. In Moomba 1 and 7, where measurable gas flows have been recorded, the flows have come from a stratigraphic interval lower than was reached in Moomba 6.

In the upper reservoir, Moomba 6 contains the fifth thickest section of pay sand. It is the eighth most productive well when thickness is weighted by $\emptyset$ and $S_{hyd.}$ (Table 3). Pay sands occur well beneath the lowest closing contour on the "P" Horizon (-7 950 ft) for the northern culmination, in fact, down to -8 123 ft. The potential for increasing the field area is great therefore.

Choice of the optimum site will depend on the results of the Tooroopie Seismic Survey. But from the point of view of maximising the possible areal extent of both the upper and lower reservoirs a site should be chosen as far as possible west of Moomba 6, while still remaining within the -7 950 ft contour (for safety's sake).

Well near Moomba 8

A A well should be located northwest of Moomba 8 in order to confirm the existence of pay in the Toolachee Formation, and to provide control for the mapping of the Daralingie Beds delta front sands. In addition, it could be drilled through the Patchawarra Formation if the appraisal well near Moomba 6 were successful.

It is necessary to evaluate the region around Moomba 8 more fully. Moomba 8 contains the thickest section of pay intersected in the field (123 ft), although in terms of net feet of gas it ranks only fourth (Table 3). It is sited near the north-western corner of the southern culmination. Because of lack of any other well control, possible volumes of pay in this region have to be discounted from the proven-probable category.

The delta front sands, S1 and S2 are high deliverability sands. They are therefore optimum targets. Moomba 8 is the most northerly well to have encountered pay from S1 and S2 (Figs. 11-12). From an investigation of Fig. 12 it appears likely that S2 would produce from anywhere within 2-3 km of Moomba 8. However, drilling somewhere in the western arc between north and southwest would provide very valuable information of the shape of this important sand body.

From an investigation of the "P" Map (Fig. 1), the optimum well locations would seem to be either northwest or southwest from Moomba 8. A well to the southwest has the greater chance of successful production from the Daralingie Beds sands, but a well to the northwest is more likely to increase the overall reserves by significantly extending the field area.

There is one other reason why the northwestern well should be chosen. If the Patchawarra Formation were to produce from the appraisal well west of Moomba 6, this second well should also be drilled through the Patchawarra Formation, even though the interval was not encouraging in Moomba 8.

The closer the well is to prospective Patchawarra Formation to the north, the more likely is it to be successful.

The exact location of the well site will depend on results of the Tooroopie Seismic Survey. But, in principle, the well should be sited on the -7 650 ft "P" Horizon contour at its most northwesterly point. The -7 650 ft level is chosen for two reasons. Firstly, this level marks the lowest closing contour around the Moomba 8 structure on the southern culmination. Secondly, the deepest level at which the "P" Horizon has been intersected to date is -7 689 ft at Moomba 13. Moomba 13 is probably just too deep to be a producer. Therefore, -7 650 ft is chosen as the depth at which a well is likely to considerably increase reserves and yet still have a very strong probability of being a gas producer.

<u>Other Well Sites</u>

Four other possible well sites are worth mentioning, one on the northern culmination, and three in the south.

On the northern structure a well near Moomba 5 is necessary to evaluate the Patchawarra Formation. Moomba 7 produced 82 MCFD on drill stem testing. This indicates that there may be gas throughout the length of the structure because Moomba 5, in the middle, was not drilled through the Patchawarra Formation. However, this site is not recommended as the first appraisal well because of the poor reservoir characteristics of Moomba 5 in the upper reservoir, (it ranks 14th and 14th respectively in pay thickness and net feet of gas).

The next appraisal well site is northwest of Moomba 1, which has the highest value for net feet of gas (Table 3). However, the non-prospectivity of Moomba 13 has downgraded the potential of the region to provide a greatly increased volume of gas over that shown by Moomba 1. Nevertheless, a Patchawarra Formation test will ultimately be necessary in the region of Moomba 1 because of the gas recovered from this well.

Thirdly, a deep test well should be sited to investigate the extent of pay in the Daralingie Beds and Toolachee Formation down the southwestern flank of the field. There is no defined limit of pay along this side and it is possible that pay sands extend to even greater depths than have been tested so far.

Finally, the relationship between the Early Permian sediments of the southwestern flank of Moomba and the southwestern end of Big Lake requires testing. Big Lake contains gas in both the Patchawarra and Tirrawarra Formations. But no well to the south west of Moomba 2 has been drilled through the complete Permian section. The potential for increasing gas reserves by a well in this vicinity is large, but so are the risk and cost of such a well.

CONCLUSIONS

Depositional Environments

1. The Toolachee Formation can be divided into three process controlled genetic units, Units I, II and III upwards.
2. The Daralingie Beds were deposited in a prograding deltaic environment. The reservoirs in the southwestern part of the field are delta front sands.
3. Unit I sediments are delta plain deposits.
4. Unit II sediments were deposited on an alluvial floodplain.
5. Unit III deposition was dominated by low energy lacustrine and coal swamp environments.
6. For the Daralingie Beds, and Units I and II, sedimentation was rapid enough for depositional processes to have a dominant influence on unit thickness.
7. For Unit III, sedimentation was a relatively slow process so that sediment distribution was controlled by structural growth and differential compaction.

Similarity between pay, thickness and structure

8. There is virtually no similarity between unit isopachs and pay thickness.
9. Only in the Daralingie Beds do isopachs of individual sands assist in defining limits of pay.
10. Within S1 and S2 the distribution of the sand fraction controls the distribution of pay.
11. The Unit pay sand isopachs which have been contoured without structural control are excessively optimistic.

Reservoir Controls

12. Structure controls the entrapment of gas in individual sands because gas is held in the updip end of the reservoir.

13. The small amount of lateral and vertical interconnection between reservoir sands is indicated by the lack of a uniform level of base of pay.
14. The low degree of interconnection between reservoirs is due to the presence of permeability barriers.

RECOMMENDATIONS

Reservoir Evaluation

1. Because porosity/permeability variations control pay sand distribution these variations should be studied in order to develop a model that explains them. In particular, an attempt should be made to discover whether low porosity and permeability prevented gas emplacement or whether they are the result of gas emplacement not having occurred.
2. Until a model is developed that satisfactorily accounts for the distribution of pay sands, the following procedure should be adopted in the calculation of gas reserves. The field should be divided into as many areas as there are wells. For each area the lowest closing contour should be defined by the base of pay encountered in the relevant well. An arbitary boundary would have to be defined along the southwestern flank of the southern culmination, and in the vicinity of Moomba 6.

Drilling

3. An appraisal well should be drilled as far west as possible from Moomba 6, while still remaining within the -7 950 ft "P" Horizon contour, in order to evaluate the extent of reservoirs within the Toolachee Formation, Daralingie Beds, and Patchawarra Formation. The well should be drilled to intersect the complete Patchawarra Formation section.
4. An appraisal well should be drilled as far northwest of Moomba 8 as possible, while still remaining with the -7 950 ft "P" Horizon contour. Primarily, the purpose of the well would be to evaluate the extent of the Daralingie Beds sands, and to increase gas reserves. If the appraisal well near Moomba 6 obtained encouraging results from the Patchawarra Formation, then this section should also be drilled.
5. Current knowledge of reservoir distribution within the Patchawarra Formation is such as to indicate that the next wells throughout the northern culmination, and in the vicinity of Moomba 1, should be drilled through to pre-Permian rocks.

6. A well should be drilled on the southwestern flank of the southern culmination through to pre-Permian rocks to evaluate the Patchawarra Formation section.

<u>Gas Deliverability</u>

8. The order in which production wells are drilled largely depends on the variation between current and future demands for pipeline gas. It is therefore essential to understand trends in gas deliverability across the field. Production test data should be used to prepare maps showing the distribution of good and bad gas deliverability areas. This study would be related to any study of porosity/permeability trends.

RCNT:ΦdeA R.C.N. THORNTON

1/4/76

REFERENCES

Allen, J.R.L., 1964. Studies in fluviatile sedimentation: six cyclothems from the Lower Old Red Sandstone, Anglo Welsh Basin. Sedimentology, 3: 163-198.

Fisher, W.L., Brown, L.F., Jr., Scott, A.J. and McGowan, J.H., 1969. Delta systems in the exploration for oil and gas. A Research Colloquium. Bureau of Economic Geology, The University of Texas at Austin, Austin, Texas.

Gatehouse, C.G., 1972. Formations of the Gidgealpa Group in the Cooper Basin. Australas. Oil Gas Rev. 18(12):10-15.

Gausden, J., 1968. Moomba No. 6 well completion report (S. Aust. Dept. Mines Env. 839 - unpublished).

Could, H.R., 1970. The Mississippi delta complex. In Deltaic Sedimentation, Modern and Ancient, Soc. Econ. Palaeont. Mineral. Spec. Publ. No. 15.

Helby, R.J., 1973. Review of Late Permian and Triassic palynology of New South-Wales. In Isobel Cookson Commemorative Volume, Spec. Publ. Geol. Soc. Aust., 4: 141-155.

Le Blanc, R.J., 1972. Geometry of sandstone reservoir bodies. In Am. Assoc. Petroleum Geologists Memoir 18, 133-190. Also in Sandstone Reservoirs and Stratigraphic Concepts I, Amer. Assoc. Petroleum Geologists Reprint Series No. 7.

Lunt, C.K., 1971. Moomba No. 9 well completion report (S. Aust. Dept. Mines Env. 1836 - unpublished).

MacMillan, L.T., 1974. Stratigraphy of the South Platte Formation (Lower Cretaceous), Moorison-Weaver Gulch area, Jefferson County, Colorado: Colorado School of Mines, M.Sc. Thesis T-1626, (unpub.), 86 p.,.

Nugent, O.W., Baarda, F. and Kapel, A.J., 1968. Moomba No. 8 well completion report (S. Aust. Dept. MinesEnv. 948 - unpublished).

Papalia, N., 1969. The Nappamerri Formation. J. Aust. Petrol. Expl. Assoc. 9(2): 108-110.

Pirson, S.J., 1970. Geologic Well Log Analysis. Gulf Publishing Co., Houston, Texas, 370 p.

Price, P.L., 1973. Cooper Basin palynology (Mines Administration Pty.Ltd., unpublished and confidential report).

Sydney Gas Market Joint Venture Technical Sub-Committee, 1974. Big Lake Field reserve study (unpublished and confidential).

Thornton, R.C.N., 1972. Pilot lithofacies study in the Toolachee Formation Gidgealpa-Moomba-Big Lake area, Cooper Basin, South Australia. S. Aust. Dept. Mines unpublished report. Rept. Bk.No. 770.

Thornton, R.C.N., 1973a. Lithofacies study in the Toolachee Formation, Gidgealpa-Moomba-Big Lake Area, Cooper Basin, South Australia. J. Aust. Petrol. Expl. Assoc. 13(1): 41-48.

Thornton, R.C.N., 1973b. The reservoir geology for gas reserve estimates, Moomba and Gidgealpa Fields, Cooper Basin. S. Aust. Dept. Mines unpublished report. Rept.Bk.No. 774 - Confidential.

Vegh, E., 1975. Moomba No. 18 well completion report (S. Aust. Dept. Mines Env. 2652 - unpublished).

Visher, G.S., 1965. Use of vertical profile in environmental reconstruction: Amer. Assoc. Petroleum Geologists Bull., 49(1): 41-61.

Weimer, R.J., 1975. Stratigraphic principles and practices: Energy resources of detrital sequences. Australian Mineral Foundation, Adelaide, unpublished lecture notes.

Wopfner, H., 1972. Climate and deposition in Permian and Early Triassic in South Australia: Abstracts, 44th ANZAAS Congress, Sydney.

Szigulis, M., 1974. Moomba No. 15 well completion report (S. Aust. Dept. Mines Env. 2510 - unpublished).

APPENDIX I

MOOMBA GAS FIELD

PAY SAND DATA

MOOMBA GAS FIELD - PAY SAND DATA

Well No. (KB)	Unit	Depth (ft)	Pay (e) Thickness (ft)	Av. Ø (%)	Av. S_{hyd} (%)	e x Ø x S_{hyd}.	Comments
1 (129.06)	II	7731-43) 46-49) 52-59) 61-67)	28	15.6	69	3.014	
		7783-95	12	16.6	71.5	1.424	
		7800-11	11	13.0	72.5	1.037	
		7816-18) 20-21)	3	14.7	63	0.278	
		7832-38		8.5	39		
		7838-41	3	10.8	52	0.168	
		7849-59	10	14.0	64.3	0.900	
		7873-81	8	12.6	60.4	0.609	
	I	7891-98	7	12.1	62	0.525	
		7912-18	6	22	71	0.937	
		7932-35) 37-40)		8.8	42		
	Daralingie	7988-91		10.0	43		
			TOTAL: 88			TOTAL: 8.892	
2 (115.67)	III	7440-49	9	10.2	62.6	0.575	
		7491-96	5	7.5	53	1.988	
	II	7577-79) 81-85)	6	13	71.4	0.557	
		7590-99	9	14.5	80.5	1.051	
		7606-9) 11-13) 13-15)	7	9.7	64.4	0.437	
		7622-24) 26-28)	4	11.5	71	0.327	
		7639-43	4	10.5	67	0.281	
		7658-69	11	11.3	75.2	0.935	
		7678-87	9	10.6	70.5	0.673	
		7696-7702	6	8.6	77.7	0.401	
		7708-16	8	12	77	0.739	
		7719-25	6	8.3	55	0.274	
		7734-37	3	10.5	64	0.202	
			TOTAL: 87			TOTAL: 8.440	

Well No. (KB)	Unit	Depth (ft)	Pay (e) Thickness (ft)	Av. Ø (%)	Av. S_{hyd}. (%)	e x Ø x S_{hyd}.	Comments
3 (158.45)	III	7750-53		8.0	40		
	II	7880-84		8.0	53		
		7889-7902		10.2	62.8		Total of 60 ft of sandstone where S_{hyd}. > 50%.
		7914-19) 29-36)		7.7	57.7		Ø ranges 5.5-12%, Av. Ø < 10%. Av. Core k = 19 md
		7951-59		7.9	54.5		
		7971-74		11.5	74.5		
		7983-95		8.2	51.4		
		8006-11		7.9	72.6		
		8013-19		6.5	51		
		8022-30		9.0	69		
	I	8084-86		9.0	52		
		8091-93		11.0	65		
			TOTAL = 0				
4 (125.50)	III	7724-39		11.5	68.4		
		7800-22		9.7	58.9		
	II	7893-98		8	32		
		7900-04		12.7	70		Low Ø gas zones with low k
		7911-14		10.5	72.5		
		7924-30		12	64		
		7941-44		11	61		
		7955-57		11.5	62		
		7966-80		9.6	44		Predominantly water zones. Low Ø & k.
		7989-8000		8.3	42		
		8014-26		8.6	48		
		8036-52		8.4	52		
	I	8071-83		7.4	54.5		Low Ø gas zones
		8096-98		10.5	72.5		
			TOTAL = 0				

Well No. (KB)	Unit	Depth (ft)	Pay (e) Thickness (ft)	Av. Ø (%)	Av. S_{hyd}	e x Ø x $S_{hyd.}$	Comments
5 (160)	II	8088-8115	27	11 (core)	77(core)	2.287	No resistivity logs
			TOTAL = 27			TOTAL : 2.287	
6 (135)	III	8051-60		7.1	41		
		8060-69	9	10.1	62	0.564	
	II	8134-62	28	11	66.5	2.048	
		8181-90	9	12.1	62.5	0.681	
		8211-19		9.1	37		
		8226-28) 30-34)	6	11.5	77	0.531	
		8245-59	14	12.5	66.5	1.164	
			TOTAL: 66			TOTAL: 4.988	
7 (144.30)	II	8055-79	24	10.5	68.5	1.726	
		8103-06	3	10.5	54	0.170	
		8120-25	5	10.7	73.5	0.393	
		8168-73	5	10.8	69	0.373	
		8184-92	8	8.2	67	0.440	
	I	8210-16		6.1	35		
			TOTAL = 45			TOTAL: 3.102	
8 (118)	III	7678-7708	30	8.4	52	1.310	
	II	7759-67	8	8.5	64	0.435	
		7792-7805	13	12.0	67	1.045	
		7814-23	9	13.2	75	0.891	
		7831-39	8	10.5	64.5	0.542	
	I	7884-95	11	11.0	54	0.653	
		7898-7942	36	9.5	46	1.573	← Thin zones of pay interbedded with thin water saturated zones.
	Daralingie	7981-89	8	8.25	46.5	0.307	
		7995-97		8.0	41		
		7997-99		5.0	5		
			TOTAL = 123			TOTAL: 6.756	

Well No. (KB)	Unit	Depth (ft)	Pay (e) Thickness (ft)	Av. Ø (%)	Av. S_{hyd} (%)	e x Ø x S_{hyd}	Comments
9 (134)	II	7787-7800	13	11.2	69.5	1.012	
		7823-33	10	12.9	75.6	0.975	
		7850-55	5	12.7	69	0.438	
		7862-82	20	12.7	77	1.956	
		7888-90) 91-94)	5	10.9	59	0.322	
		7913-16	3	11.7	70	0.246	
	I	7978-83	5	12.8	67	0.429	
	Daralingie	8072-81	9	14.5	85.5	1.116	
		8092-98	6	9.0	54	0.292	
			TOTAL : 76			TOTAL: 6.786	
10 (135)	III	7589-92		9.0	61		Thin low Ø, low k. Not effective pay
		7607-18		8.9	59		
	II	7728-32		8.5	54		
		7741-43		9.5	57		
		7757-64	7	16.0	80	0.896	
		7769-71	2	14.5	73	0.212	
		7773-86	13	14.6	82	1.556	
		7795-7806	11	13.1	75	1.081	
		7825-35	10	12.8	75	0.960	
		7844-50	6	12.9	69	0.534	
	I	7934-36	2	14	72.5	0.203	
	Daralingie	8029-37	8	15.4	85.0	1.047	
		8037-40		5.0	44		
			TOTAL: 59			TOTAL: 6.489	

Well No. (KB)	Unit	Depth (ft)	Pay (e) Thickness (ft)	Av. Ø (%)	Av. S_{hyd} (%)	e x Ø x S_{hyd}	Comments
11 (138)	III	7774-87		7.7	38.1		
	II	7905-11		6.7	38.0		
		7926-30	4	13.6	64.5	0.351	
		7937-42		8.8	45.0		
		7943-44) 47-49)	3	14.5	60.0	0.261	
		7962-68		9.5	38.0		
		7968-81	13	12.7	53.2	0.878	
		7986-94	8	15.3	78.5	0.961	
		8006-09		7.8	32		
		8011-16	5	10.7	52	0.278	
		8038-40		8.5	50		
	I	8117-19		9.5	51		
		8120-22	2	10.7	56	0.120	
	Daralingie	8227-31	4	13.5	65	0.351	
		8243-47	4	16.0	50 (assumed)	0.320	Probable Pay No.Dual l
			TOTAL: 43			TOTAL: 3.520	
12 (117)	III	7639-40		6.0	56.0		Tight
		7641-45	4	10.0	52.0	0.208	
		7720-31	11	12.8	73.4	1.033	
	II	7832-46	14	12.6	78.0	1.376	
		7860-69	9	11.4	66.0	0.677	
		7883-87	4	11.6	63.5	0.295	
		7903-06	3	16.1	71.0	0.343	
	I	8008-11) 12-14)	5	10.1	58.9	0.297	
	Daralingie	8123-30	7	15.7	85.1	0.935	
		8145-50		9.8	47.5		
			TOTAL: 57			TOTAL: 5.164	

Well No. (KB)	Unit	Depth (ft)	Pay (e) Thickness (ft)	Av. Ø (%)	Av. S_{hyd} (%)	e x Ø x S_{hyd}	Comments
13 (133)	III	7849-60		5.4	41		
		*7896-7900		11.5	61		
		7970-80		8	49		
	II	8027-30		9.5	46		
		*8030-37		11.8	60		
		8037-41		5	28		*The only possible pay sands, but all are thin, low productivity zones.
		8048-51		8	49		
		8051-55		6.5	3.7		
		*8069-74		10.7	50		
		8074-84		9.0	37		
		8092-97		8.0	46		
		8122-35		9.7	39		
		*8135-40		11.0	56		
		8150-57		9.4	26		
		8172-75		5.3	0		
	I	*8180-82		10.7	54		
		8182-8205		10.5	27		
	Daralingie	*8430-32		15.0	80.5		No G.R. but good microlog separation
			TOTAL: 0				
14 (115)	III	7522-26		5.0	29		
	II	7633-36		7.0	68		
		7652-56		8.0	64		
		7669-72		9.0	62		
		7706-11	5	17.5	86.5	0.757	
		7736-41	5	11.5	69.0	0.397	
		7753-56		7.0	65		
		7756-61	5	12.7	82.5	0.524	
	I	7813-16	3	12.0	66.5	0.239	
		7830-52		6.7	47		
			TOTAL : 18			TOTAL: 1.917	

Well No. (KB)	Unit	Depth (ft)	Pay (e) Thickness (ft)	Av. Ø (%)	Av. S_{hyd} (%)	e x Ø x S_{hyd}	Comments
15 (145.37)	III	7701-3		8.7	64		k = < 0.3
		7703-4) 5-7) 8-13)	8	10.0	59	0.472	
	II	7828-39	11	13.1	69	0.994	
		7859-61) 62-63)	3	10.3	67	0.207	
		7881-83	2	11.0	67	0.147	
		7895-98) 99-7902)	6	11.3	67	0.454	
		7922-33) 35-40) 42-45)	19	13.4	73	1.859	
		7956-60	4	12.3	72	0.354	
	Daralingie	8074-76		10.8	48		k = 0.24
			TOTAL : 53			TOTAL: 4.487	
16 (121.60)	III	7591-7604		7.5	57		
	II	7707-28	21	12.5	80	2.100	
		7753-59	6	14.4	82	0.708	
		7794-98	4	10.8	74	0.320	
		7808-10) 11-15)	6	10.2	73	0.447	
		7817-21) 24-26)	6	12.0	79	0.569	Tight: 7821-24
		7834-42	8	12.5	78.5	0.785	
	I	7929-31	2	12.0	70	0.168	
			TOTAL : 56			TOTAL: 5.097	

Well No. (KB)	Unit	Depth (ft)	Pay (e) Thickness (ft)	Av. Ø (%)	Av. S_{hyd} (%)	e x Ø x S_{hyd}	Comments
17 (123.31)	III	7662-77		9.3	36		
	II	7782-7804	22	11.2	71	1.749	
		7817-22	5	12.7	78	0.495	
		7829-33) 33-37)	7	16.7	81	0.947	
		7852-57	5	10	63	0.315	
		7876-78) 80-87)	9	12.1	69	0.751	
	Daralingie	8089-91	2	11.2	77	0.172	
			TOTAL : 50			TOTAL: 4.429	
18 (121.60)	III	7706-13		7.0	29		
		7730-46) 58-64)		8.5	24		
		7795-98		7.7	35		
		7831-33		6.5	33		
		7844-7846		5	15		
	II	7873-76		8	21		
		7893-96		8.5	30		
		7896-7900	4	13.5	60	0.324	
		7919-26		5.6	5.7		
		7936-45		6.7	16.9		
		7945-48	3	13.7	58	0.238	
		7961-65		7.5	23		
		7968-75	7	11.6	48	0.390	
		7986-89		6.7	27		
		7994-99		9.3	21		
	I	8088-93	5	12.7	52	0.330	
	Daralingie	8201-07	6	14.3	54	0.463	
		8207-10		8.0	41		
		8222-25	3	12.3	47	0.173	
		8227-30		7.5	18		
			TOTAL : 28			TOTAL: 1.918	

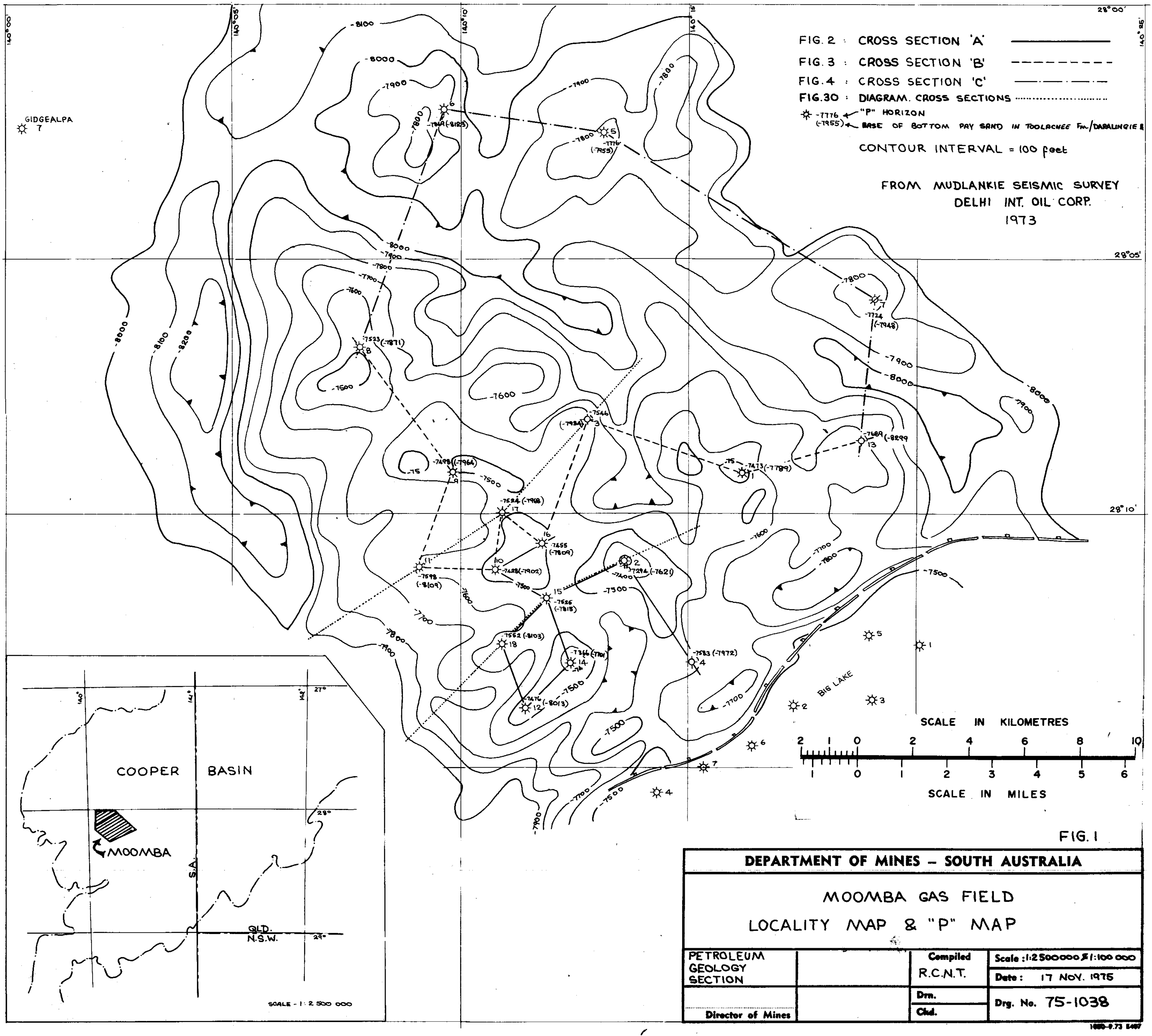
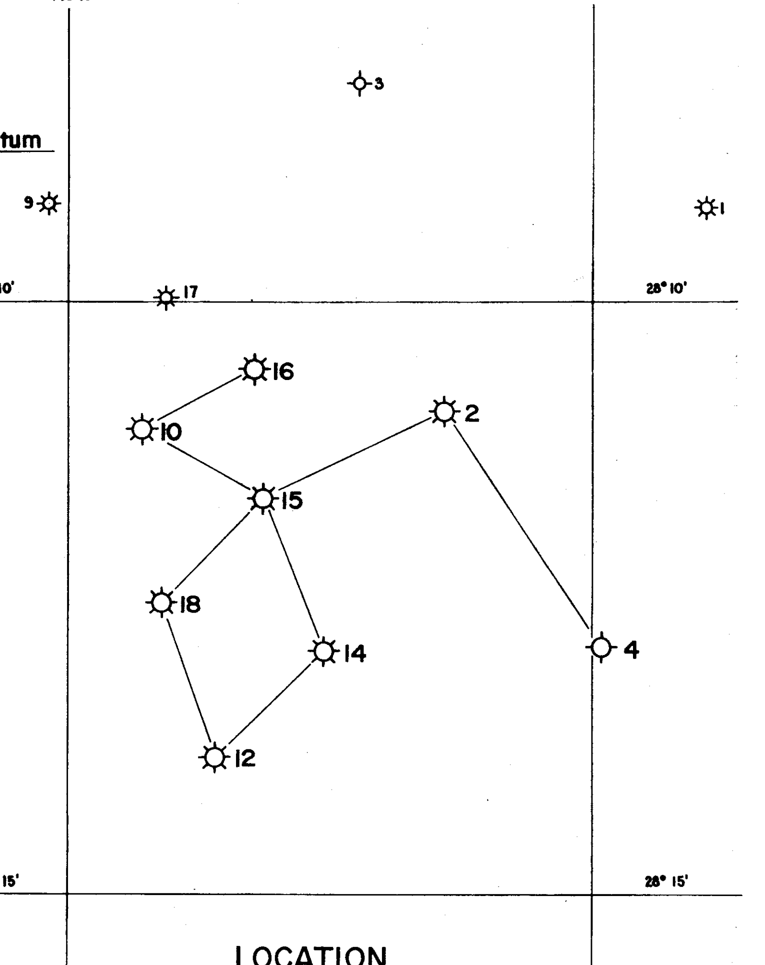


FIG. 2 : CROSS SECTION 'A'
FIG. 3 : CROSS SECTION 'B'
FIG. 4 : CROSS SECTION 'C'
FIG. 30 : DIAGRAM. CROSS SECTIONS
-7776 "P" HORIZON
(-7955) BASE OF BOTTOM PAY SAND IN TOOLACHEE Fm./DARALINGIE Fm.
CONTOUR INTERVAL = 100 feet
FROM MUDLANKIE SEISMIC SURVEY
DELHI INT. OIL CORP.
1973
GIDGEALPA 7
BIG LAKE
SCALE IN KILOMETRES
SCALE IN MILES
COOPER BASIN
MOOMBA
S.A.
QLD.
N.S.W.
SCALE - 1: 2 500 000
DEPARTMENT OF MINES - SOUTH AUSTRALIA
MOOMBA GAS FIELD
LOCALITY MAP & "P" MAP
PETROLEUM GEOLOGY SECTION
Director of Mines
Compiled R.C.N.T.
Drn.
Chd.
Scale : 1:2500000 & 1:100 000
Date : 17 NOV. 1975
Drg. No. 75-1038

FIG. 1



LOCATION

SCALE IN METRES

200 0 200 400 600 800 1000 1200

HORIZONTAL 1:10000

VERTICAL 1:600

$\frac{H}{V} = 16\cdot6$

DEPARTMENT OF MINES – SOUTH AUSTRALIA			
MOOMBA GAS FIELD GEOLOGICAL CROSS SECTION 'A'			
PETROLEUM GEOLOGY SECTION	R.C.N. THORNTON GEOLOGIST	Compiled R. [illegible]	Scale Date: AUGUST '75
Director of Mines		Drn. L.C. Chd.	Drg. No. 75-816

FIG. 2

6941

DEPARTMENT OF MINES – SOUTH AUSTRALIA			
MOOMBA GAS FIELD GEOLOGICAL CROSS SECTION 'B'			
PETROLEUM GEOLOGY SECTION	R.C.N. THORNTON GEOLOGIST	Compiled R.C.N.T.	Scale :
			Date : OCTOBER '75
Director of Mines		Drn. L.C.	Drg. No. 75-959
		Ckd.	

FIG.3

SCALE IN METRES

HORIZONTAL 1:10 000
VERTICAL 1:600
$\frac{H}{V} = 16{\cdot}6$

FIG.4

DEPARTMENT OF MINES – SOUTH AUSTRALIA

MOOMBA GAS FIELD
GEOLOGICAL CROSS SECTION 'C'

PETROLEUM GEOLOGY SECTION	R.C.N. THORNTON GEOLOGIST	Compiled R.C.N.T	Scale :
			Date : NOVEMBER '75
Director of Mines		Drn. L.C.	Drg. No. 75-1018
		Ckd.	

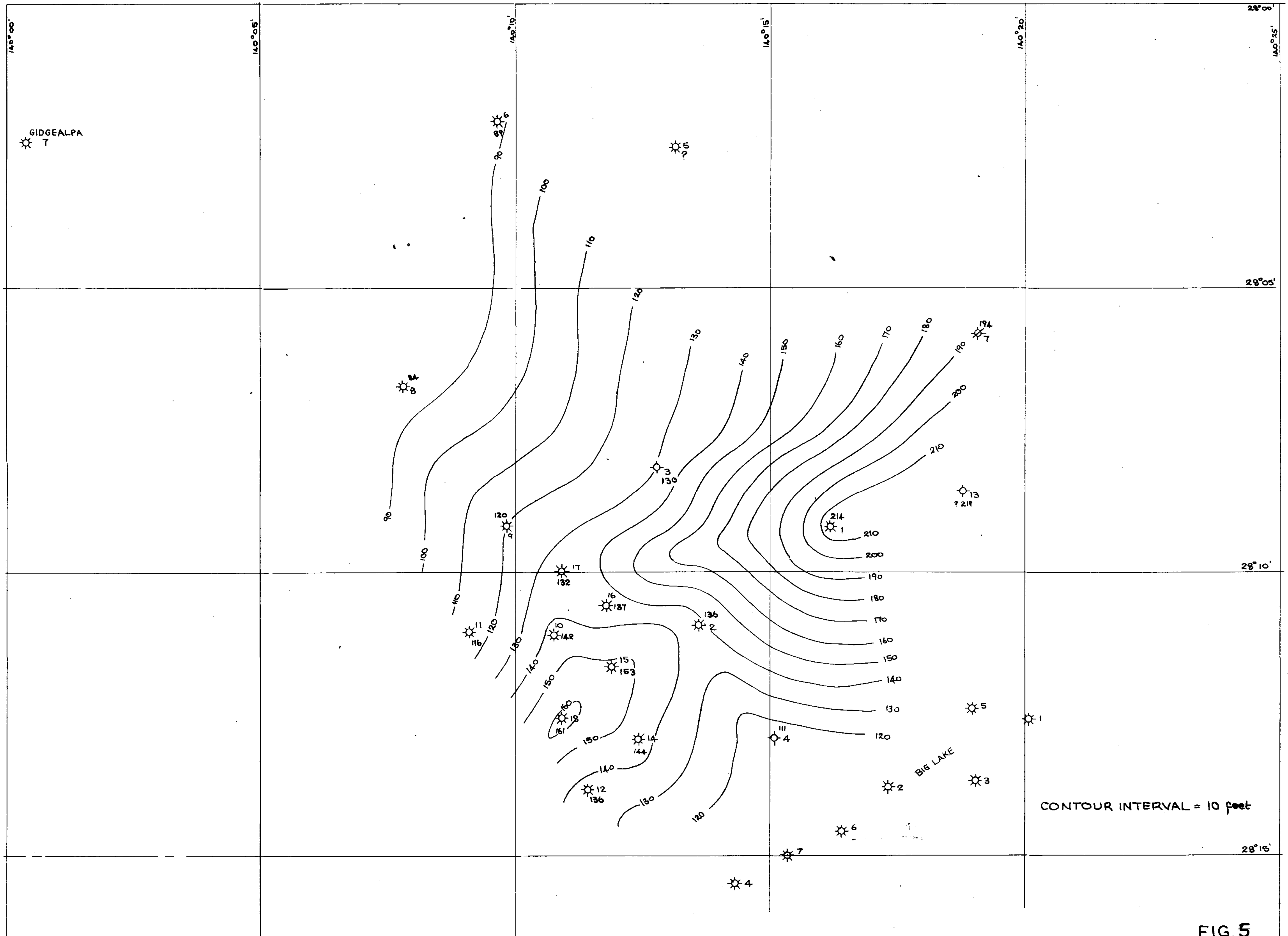


FIG. 5

DEPARTMENT OF MINES – SOUTH AUSTRALIA

MOOMBA GAS FIELD

DARALINGIE BEDS - ISOPACH

PETROLEUM GEOLOGY SECTION	Compiled R.C.N.T.	Scale : 1 : 100 000	Date : 17 Nov. 1975
Director of Mines	Drn. / Ckd.	Drg. No. 75-1040	

1000-9.73 E407

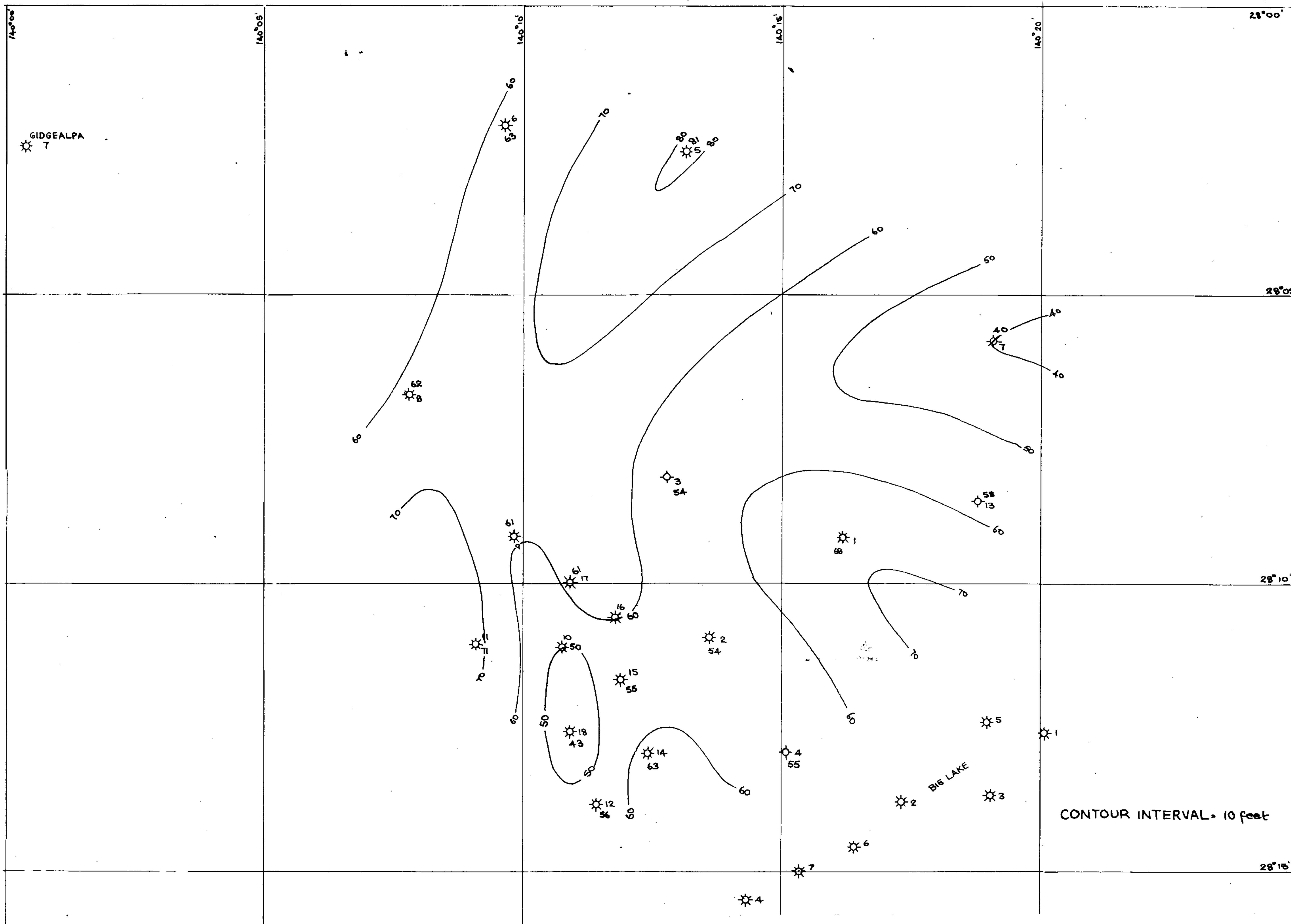
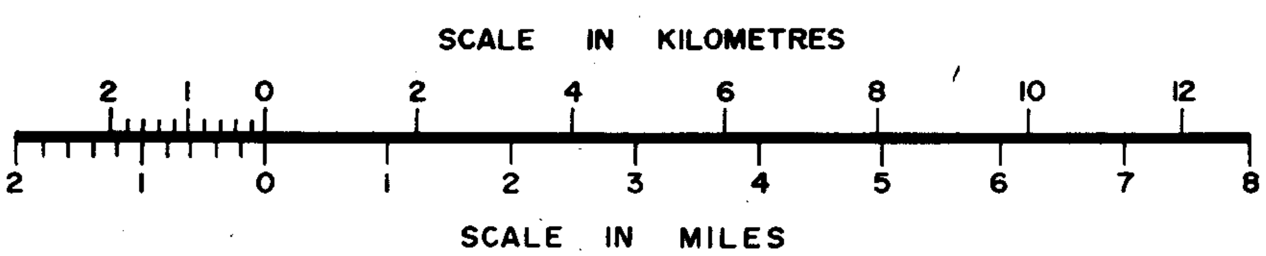


FIG. 8



DEPARTMENT OF MINES – SOUTH AUSTRALIA			
MOOMBA GAS FIELD UNIT I - ISOPACH			
PETROLEUM GEOLOGY SECTION		Compiled R.C.N.T.	Scale: 1:100 000
			Date: 17 Nov. 1975
Director of Mines		Drn. / Ckd.	Drg. No. 75-1041

1000-9.73 E407

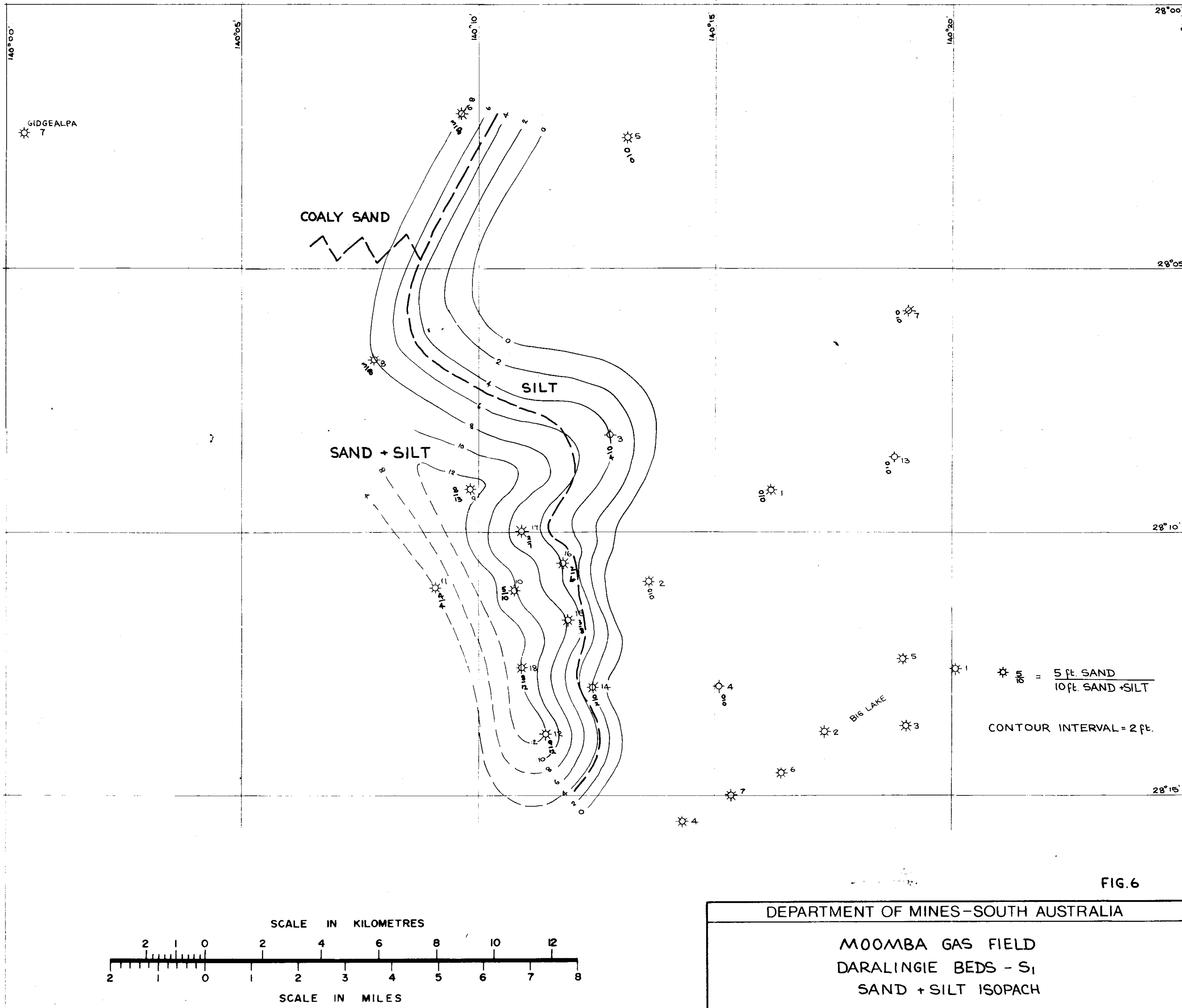
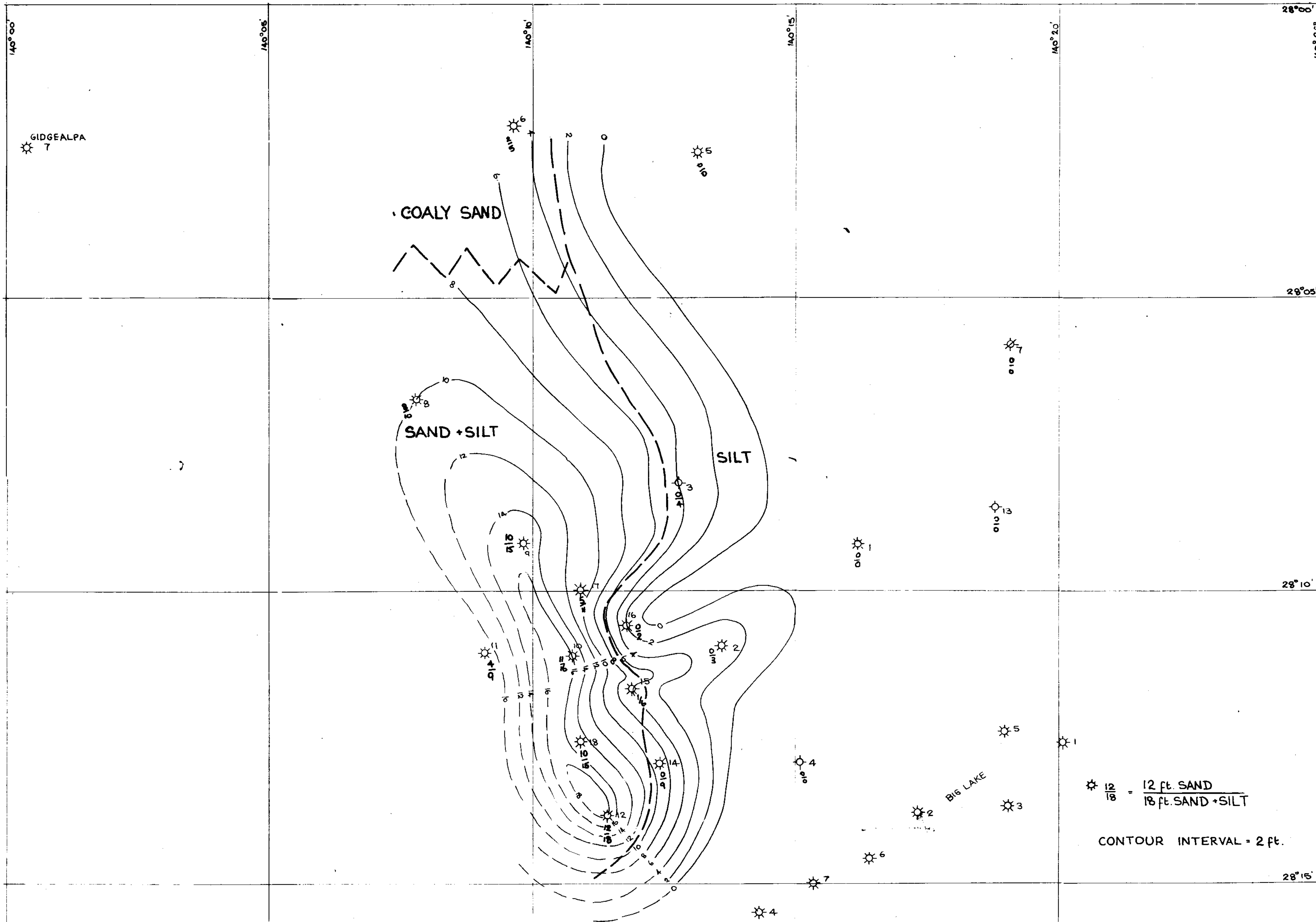


FIG. 6

DEPARTMENT OF MINES - SOUTH AUSTRALIA				
MOOMBA GAS FIELD DARALINGIE BEDS - S_1 SAND + SILT ISOPACH				
PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER 76-200
DIRECTOR OF MINES		CKD	DATE 25-3-76	



SCALE IN KILOMETRES

2 1 0 2 4 6 8 10 12

2 1 0 1 2 3 4 5 6 7 8

SCALE IN MILES

FIG.7

DEPARTMENT OF MINES–SOUTH AUSTRALIA				
MOOMBA GAS FIELD DARALINGIE BEDS - S_2 SAND + SILT ISOPACH				
PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER 76-201
DIRECTOR OF MINES		CKD	DATE 25-3-76	

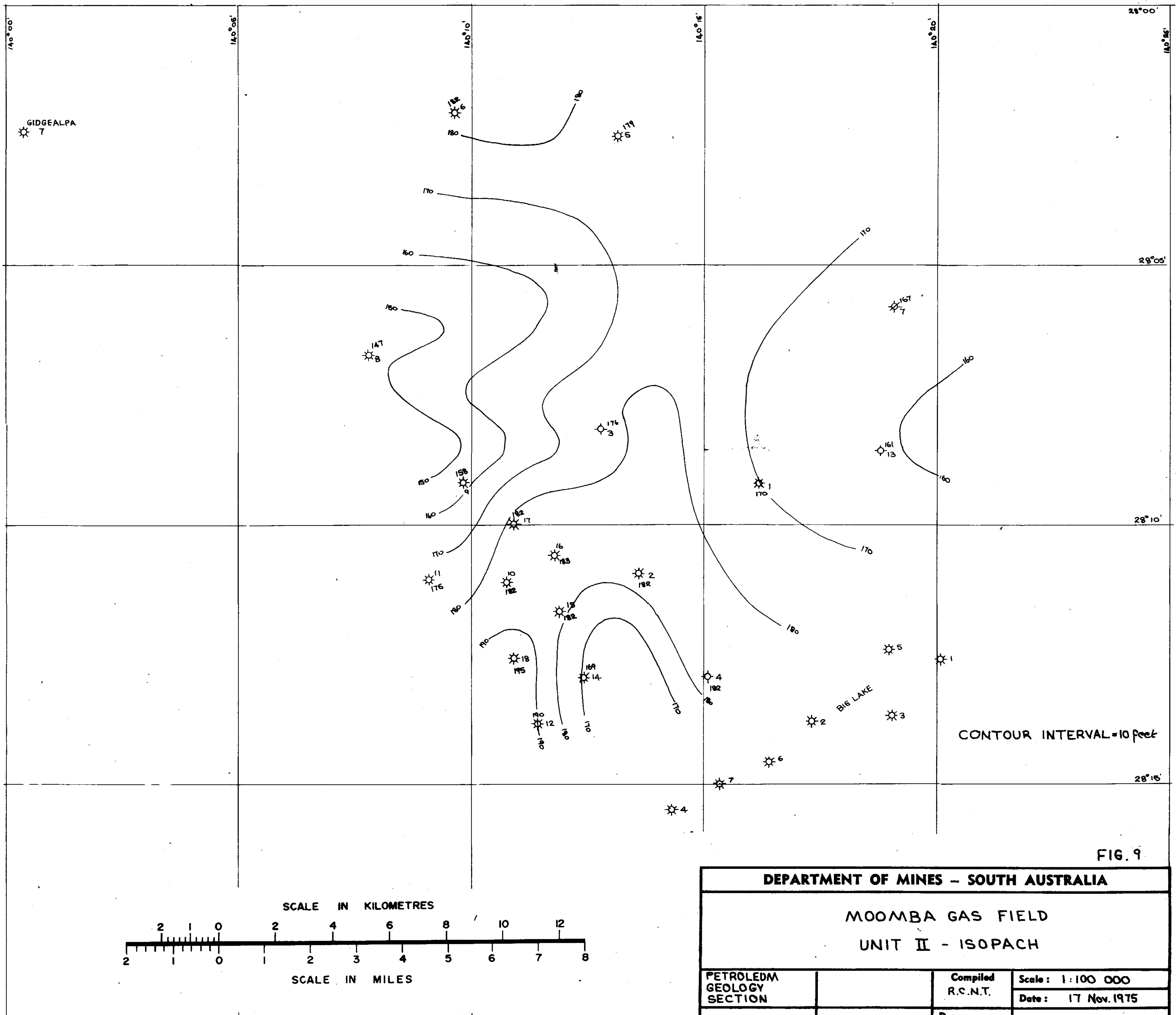


FIG. 9

DEPARTMENT OF MINES – SOUTH AUSTRALIA

MOOMBA GAS FIELD

UNIT II - ISOPACH

PETROLEUM GEOLOGY SECTION		Compiled R.C.N.T.	Scale: 1:100 000
			Date: 17 Nov. 1975
Director of Mines		Drn.	Drg. No. 75-1042
		Ckd.	

1000-9.73 E407

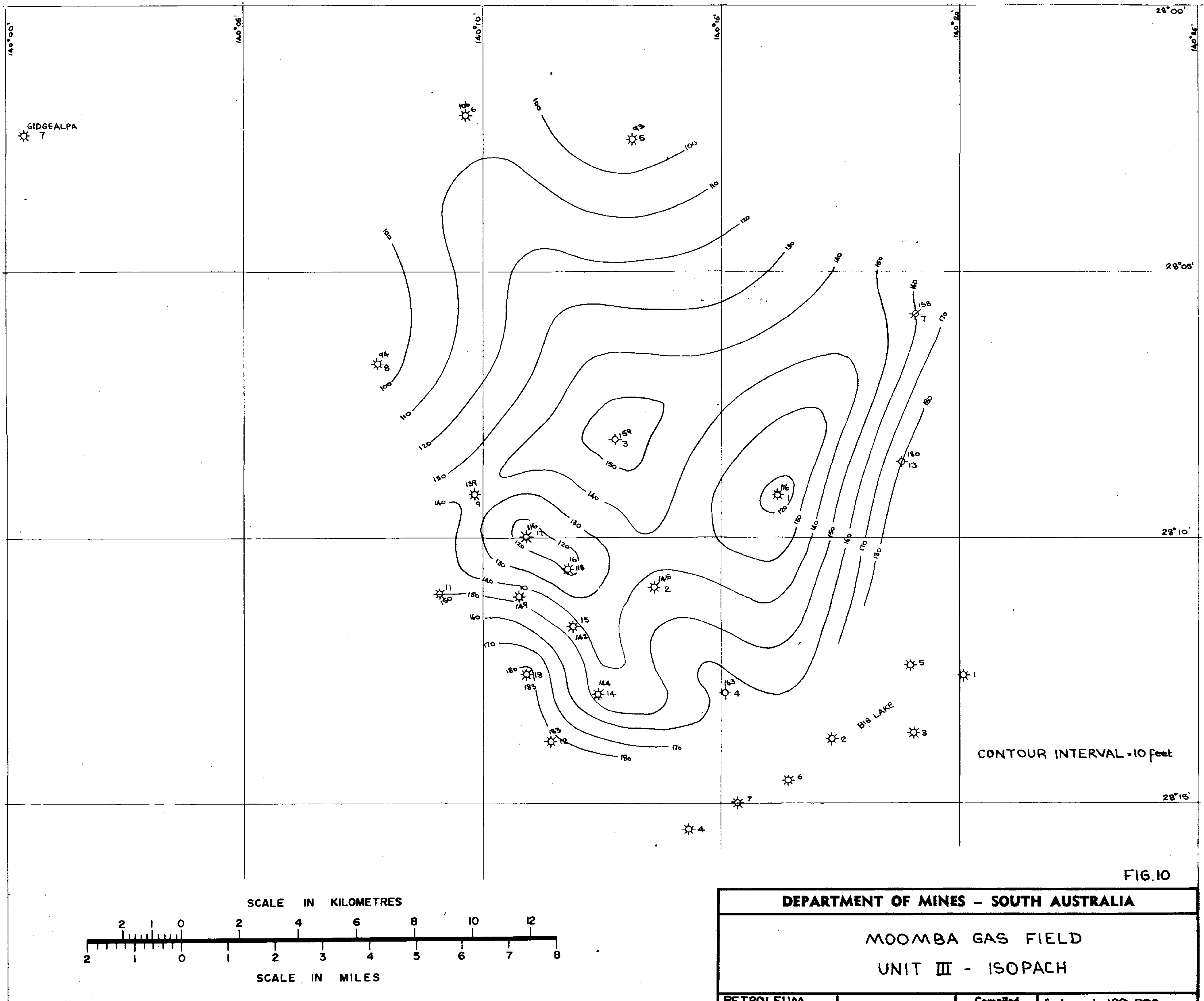


FIG. 10

DEPARTMENT OF MINES – SOUTH AUSTRALIA			
MOOMBA GAS FIELD UNIT III – ISOPACH			
PETROLEUM GEOLOGY SECTION		Compiled R.C.N.T.	Scale: 1:100 000 Date: 17 Nov. 1975
Director of Mines		Drn. Ckd.	Drg. No. 75-1043

1000–9.73 E407

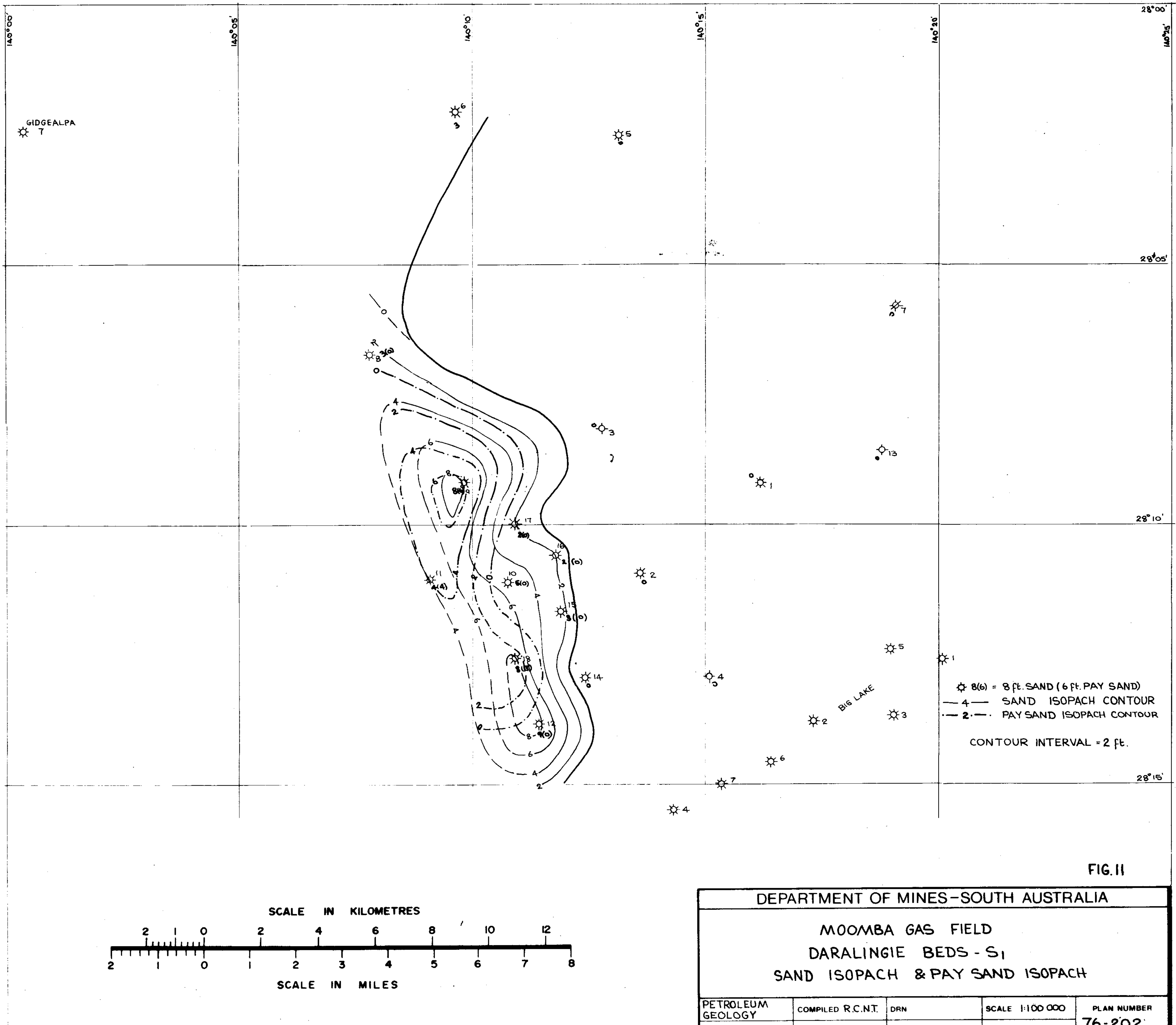


FIG. 11

DEPARTMENT OF MINES–SOUTH AUSTRALIA				
MOOMBA GAS FIELD DARALINGIE BEDS - S_1 SAND ISOPACH & PAY SAND ISOPACH				
PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER 76-202
DIRECTOR OF MINES		CKD	DATE 25-3-76	

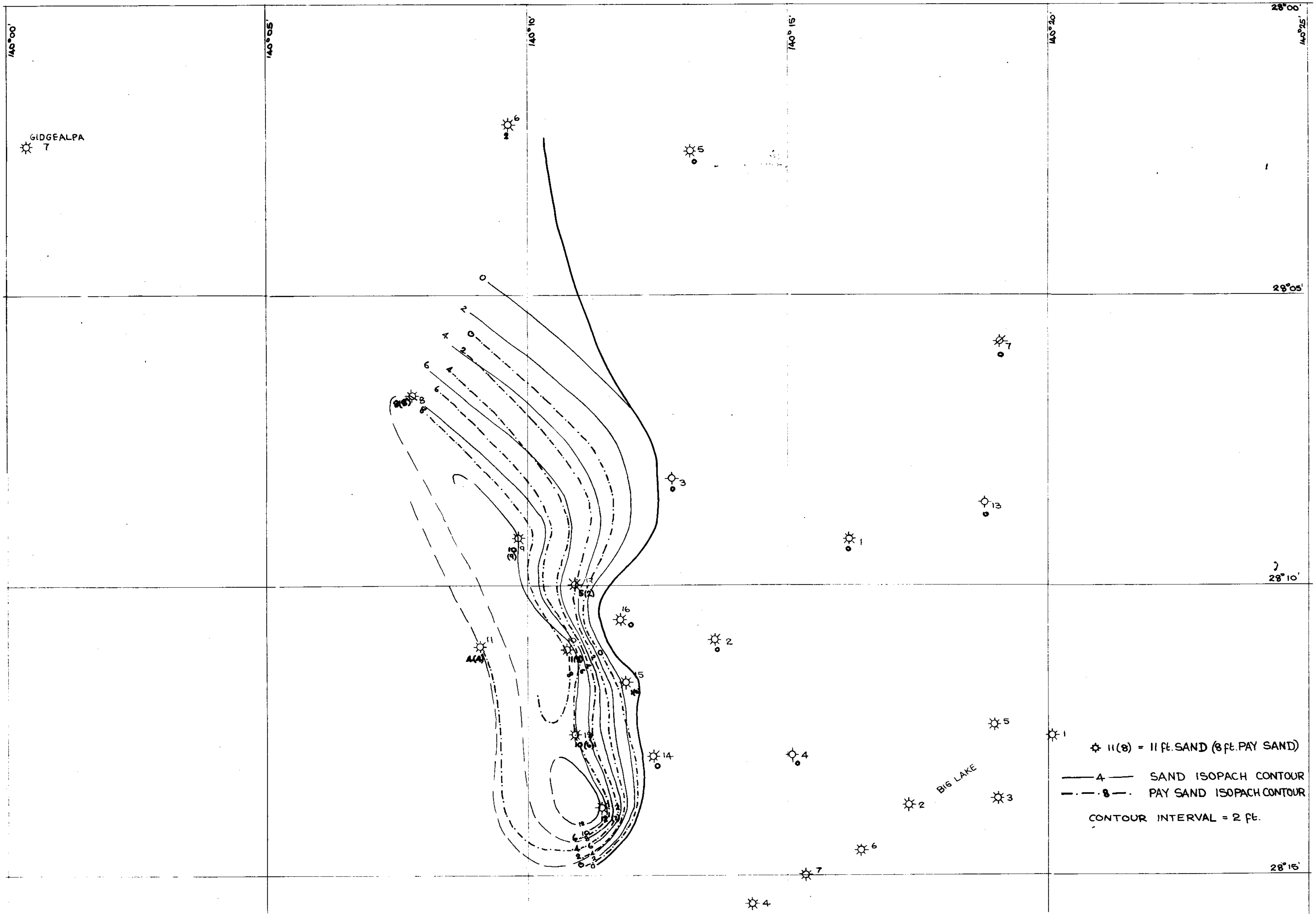
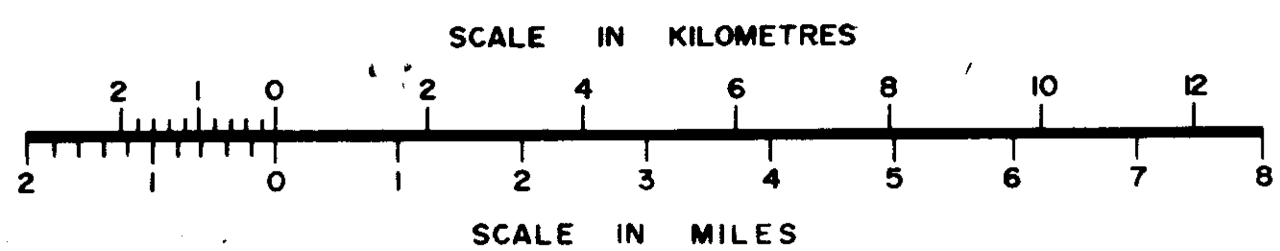


FIG. 12



DEPARTMENT OF MINES–SOUTH AUSTRALIA				
MOOMBA GAS FIELD DARALINGIE BEDS – S_2 SAND ISOPACH & PAY SAND ISOPACH				
PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER
DIRECTOR OF MINES		CKD	DATE 25-3-76	76-203

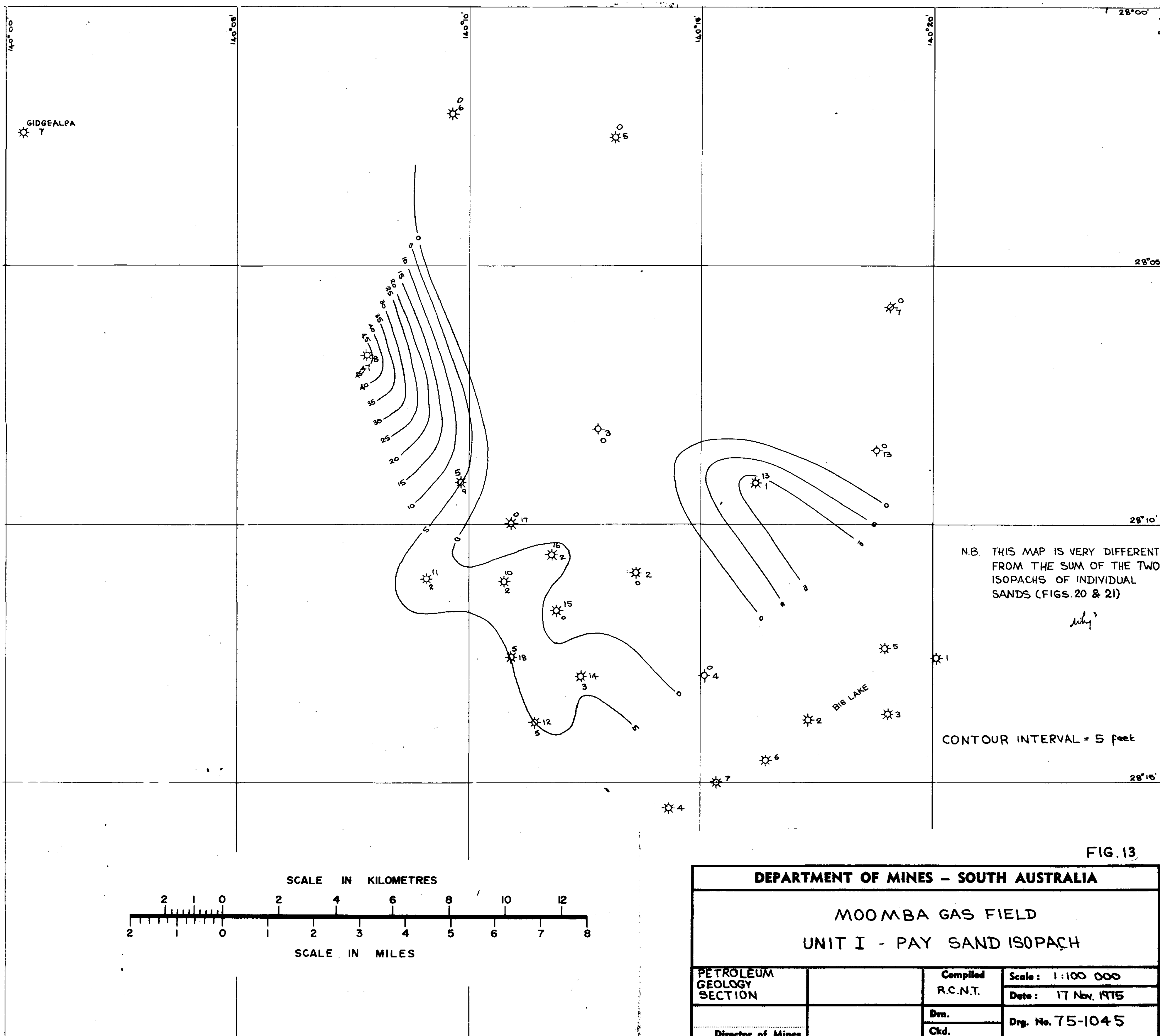
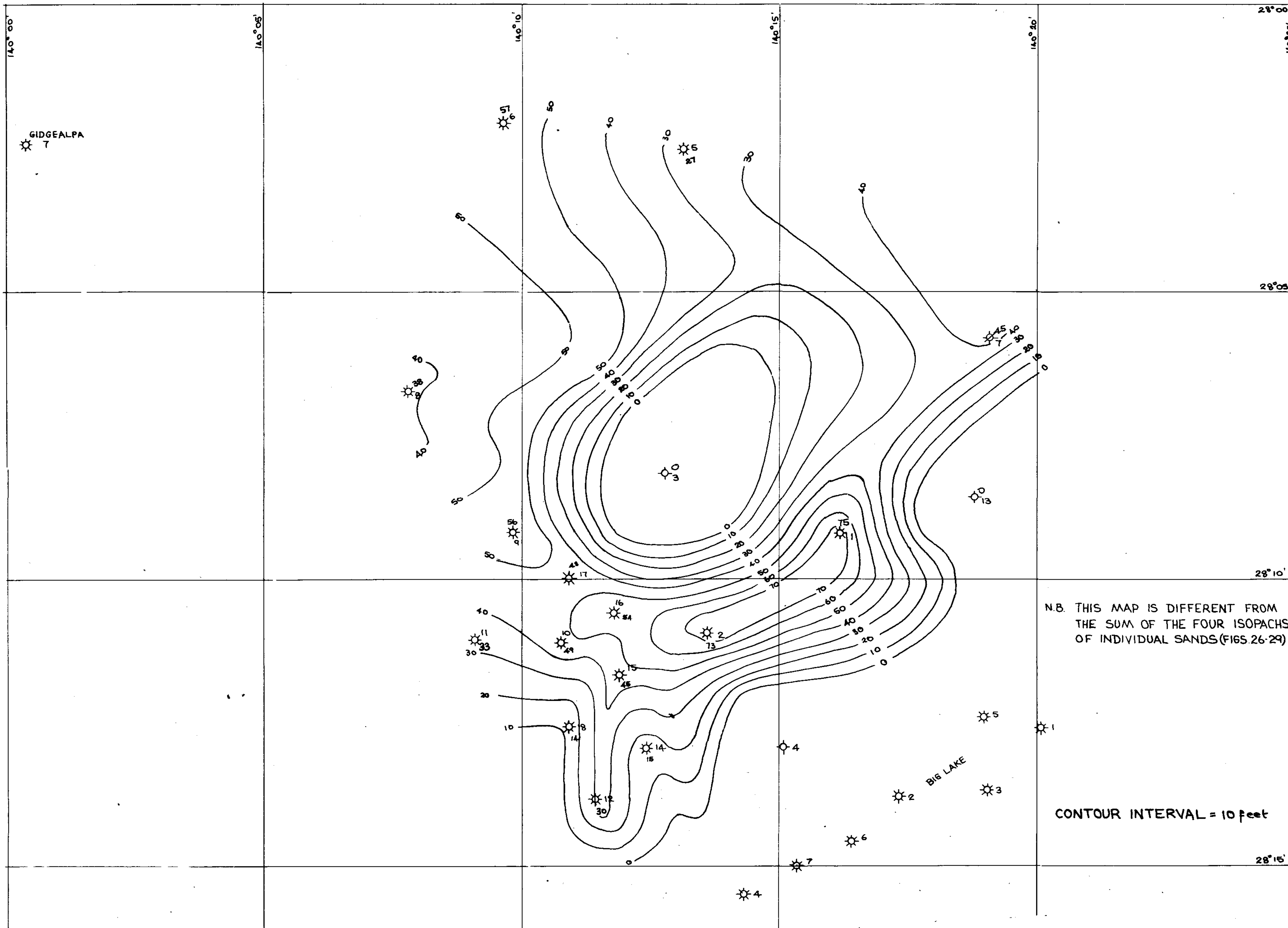


FIG. 13

DEPARTMENT OF MINES – SOUTH AUSTRALIA			
MOOMBA GAS FIELD UNIT I - PAY SAND ISOPACH			
PETROLEUM GEOLOGY SECTION		Compiled R.C.N.T.	Scale: 1:100 000 Date: 17 Nov. 1975
Director of Mines		Drn. Ckd.	Drg. No. 75-1045

1000-9.73 E407



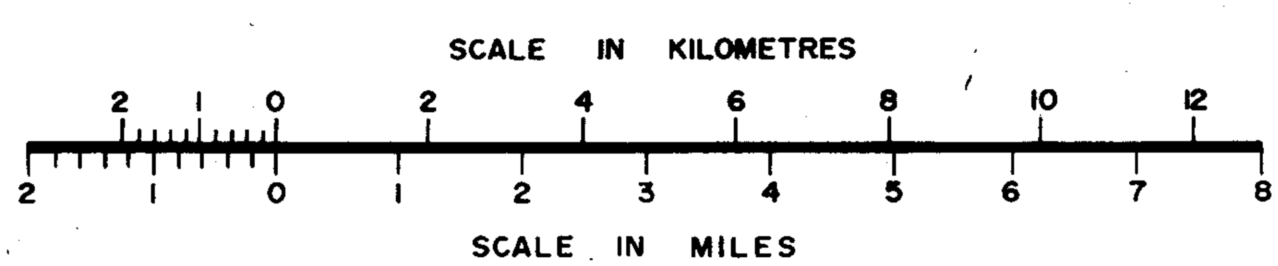
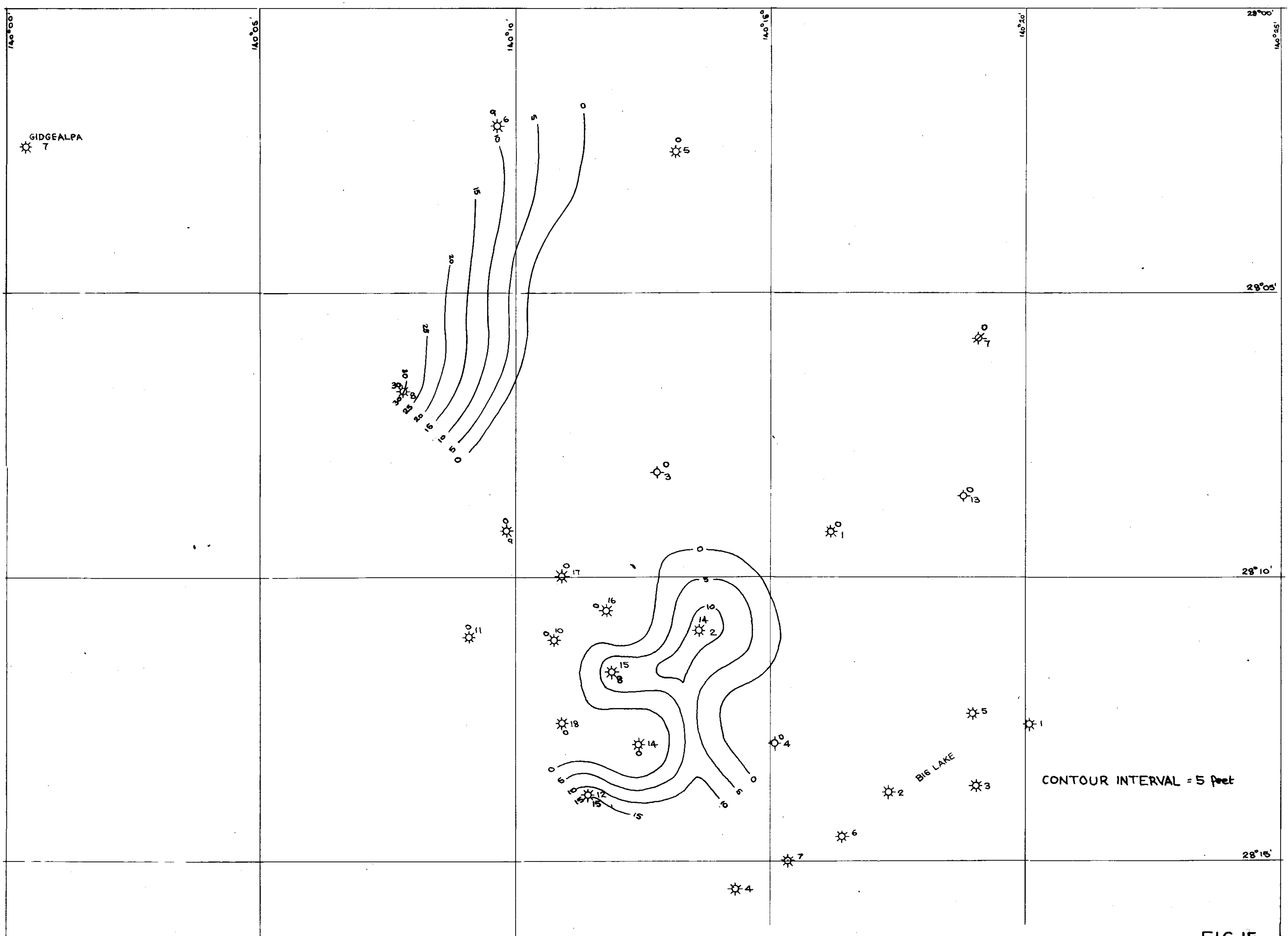


FIG. 14

DEPARTMENT OF MINES – SOUTH AUSTRALIA			
MOOMBA GAS FIELD UNIT II - PAY SAND ISOPACH			
PETROLEUM GEOLOGY SECTION		Compiled R.C.N.T.	Scale: 1:100 000 Date: 17 Nov. 1975
Director of Mines		Drn. Ckd.	Drg. No. 75-1046

1000-9.73 5487



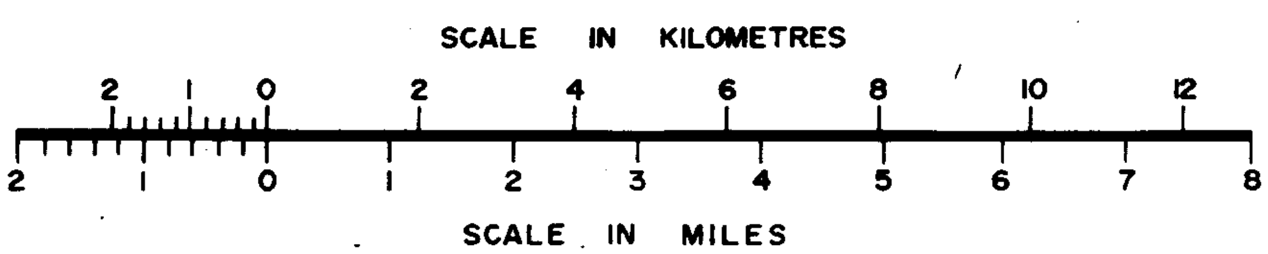


FIG. 15

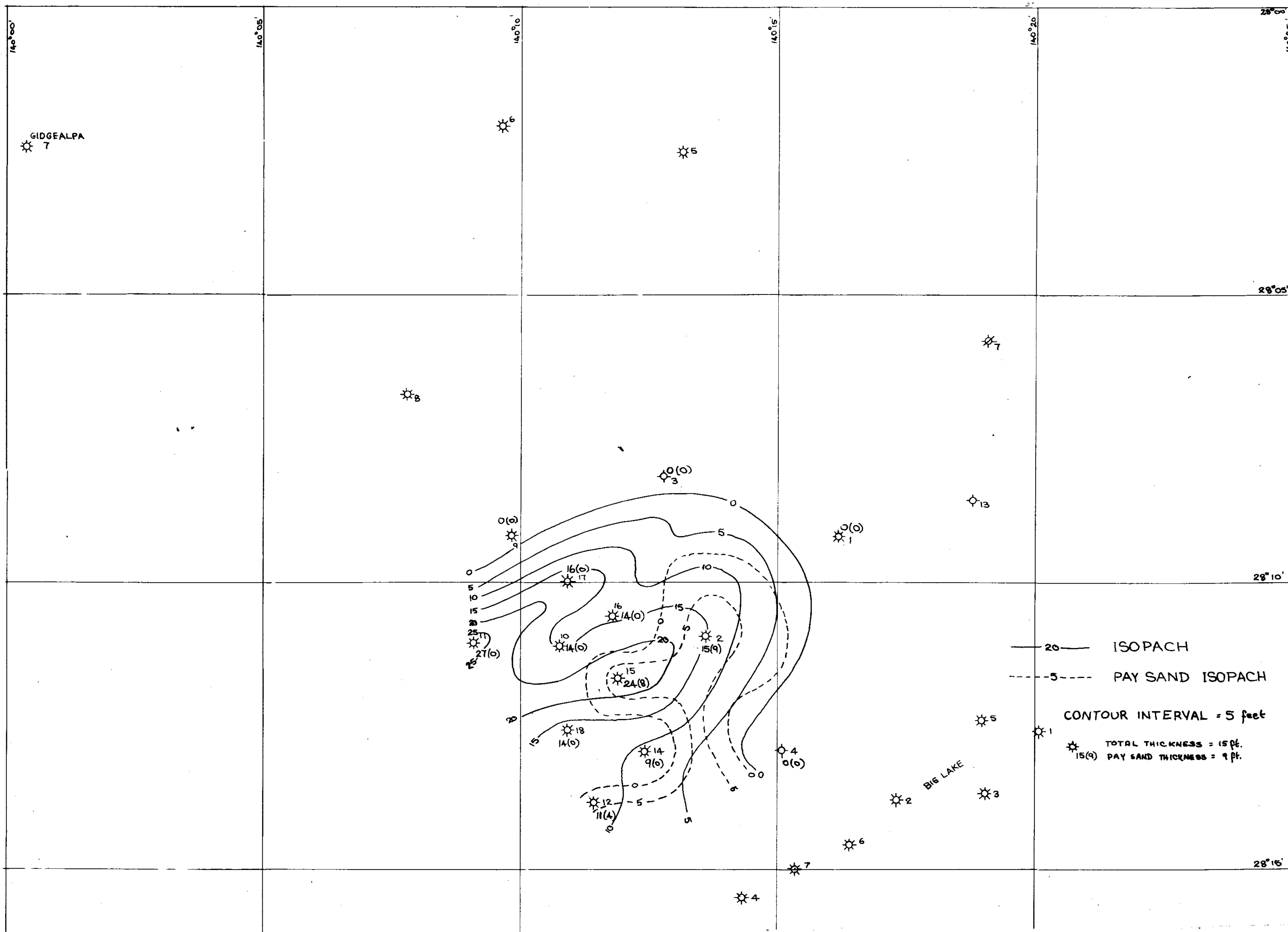
DEPARTMENT OF MINES – SOUTH AUSTRALIA

MOOMBA GAS FIELD

UNIT III – PAY SAND ISOPACH

PETROLEUM GEOLOGY SECTION		Compiled R.C.N.T.	Scale: 1:100 000
			Date: 17 Nov. 1975
Director of Mines		Drn.	Drg. No. 75-1047
		Ckd.	

1800-9.73 E467



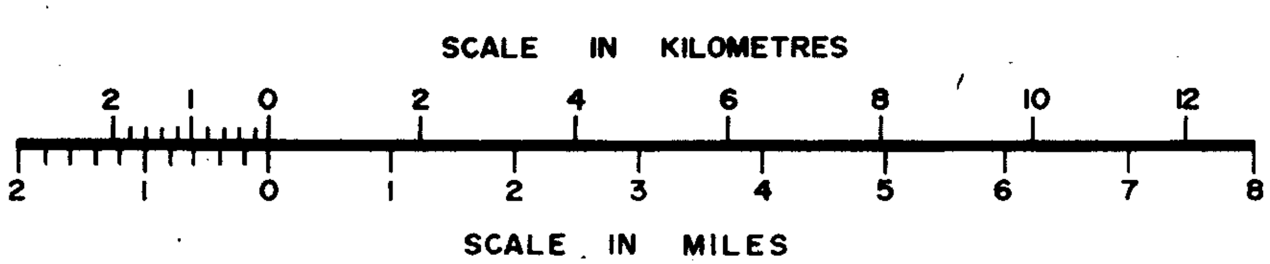


FIG. 16

DEPARTMENT OF MINES – SOUTH AUSTRALIA

MOOMBA GAS FIELD

UNIT III - S_z - ISOPACH & PAY SAND ISOPACH

PETROLEUM GEOLOGY SECTION		Compiled R.C.N.T.	Scale: 1:100 000
			Date: 17 Nov. 1975
Director of Mines		Drn.	Drg. No. 75 - 1048
		Ckd.	

1000-9.73 E407

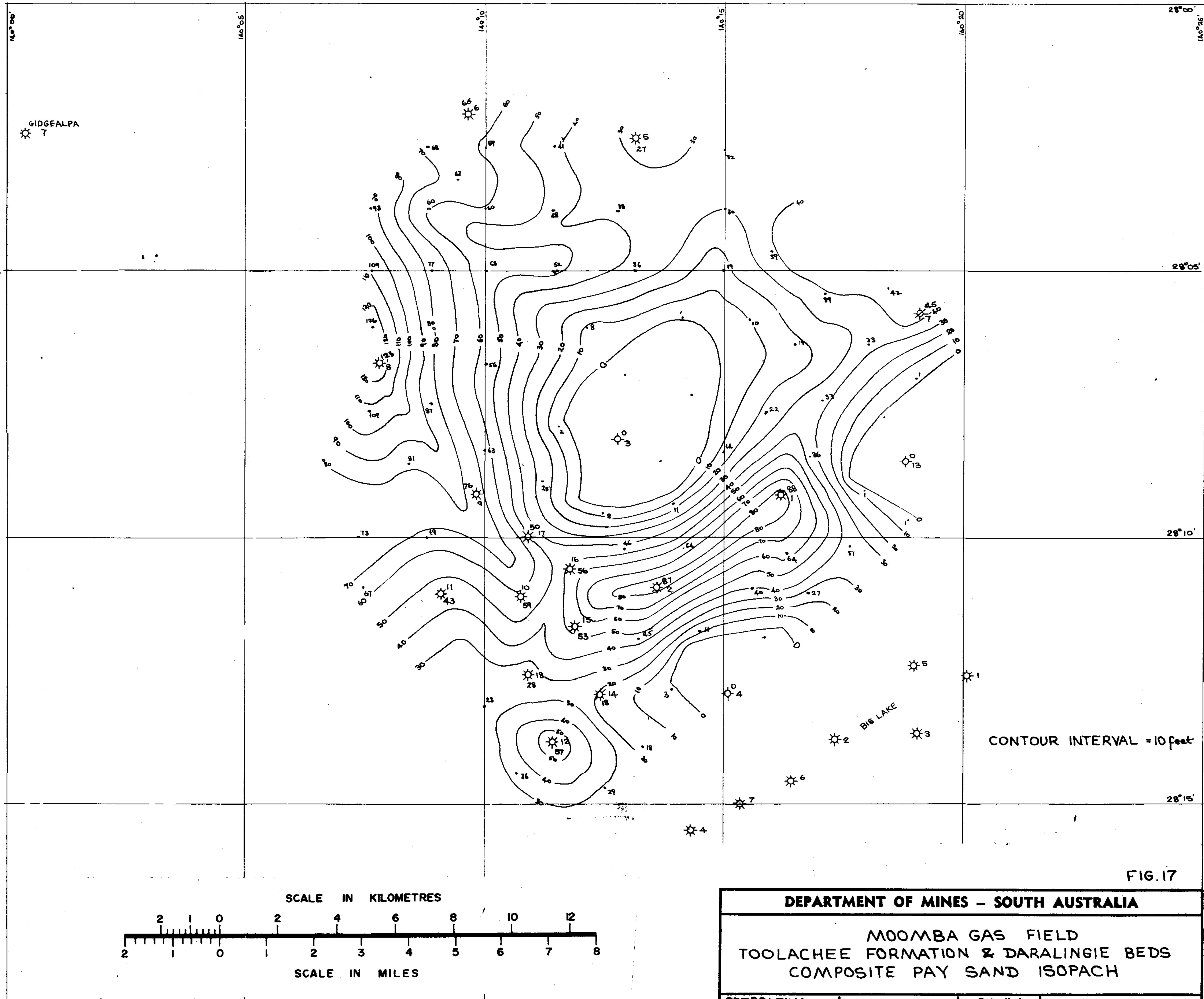


FIG. 17

DEPARTMENT OF MINES – SOUTH AUSTRALIA

MOOMBA GAS FIELD
TOOLACHEE FORMATION & DARALINGIE BEDS
COMPOSITE PAY SAND ISOPACH

PETROLEUM GEOLOGY SECTION		Compiled R.C.N.T.	Scale: 1:100 000
			Date: 17 Nov. 1975
Director of Mines		Drn. / Ckd.	Drg. No. 75-1049

1000-9.73 E407

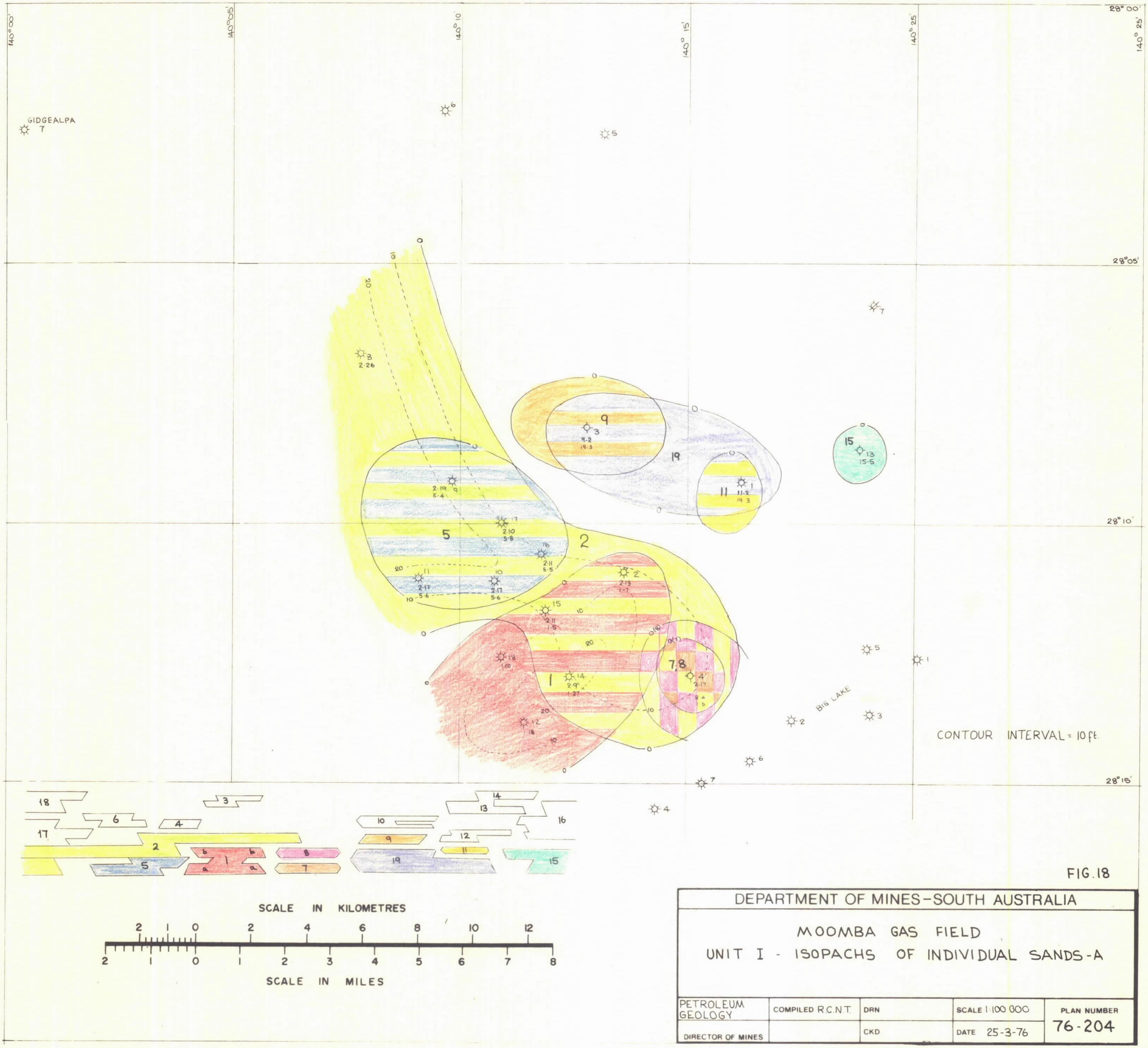


FIG. 18

DEPARTMENT OF MINES – SOUTH AUSTRALIA

MOOMBA GAS FIELD

UNIT I - ISOPACHS OF INDIVIDUAL SANDS - A

PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER 76-204
DIRECTOR OF MINES		CKD	DATE 25-3-76	

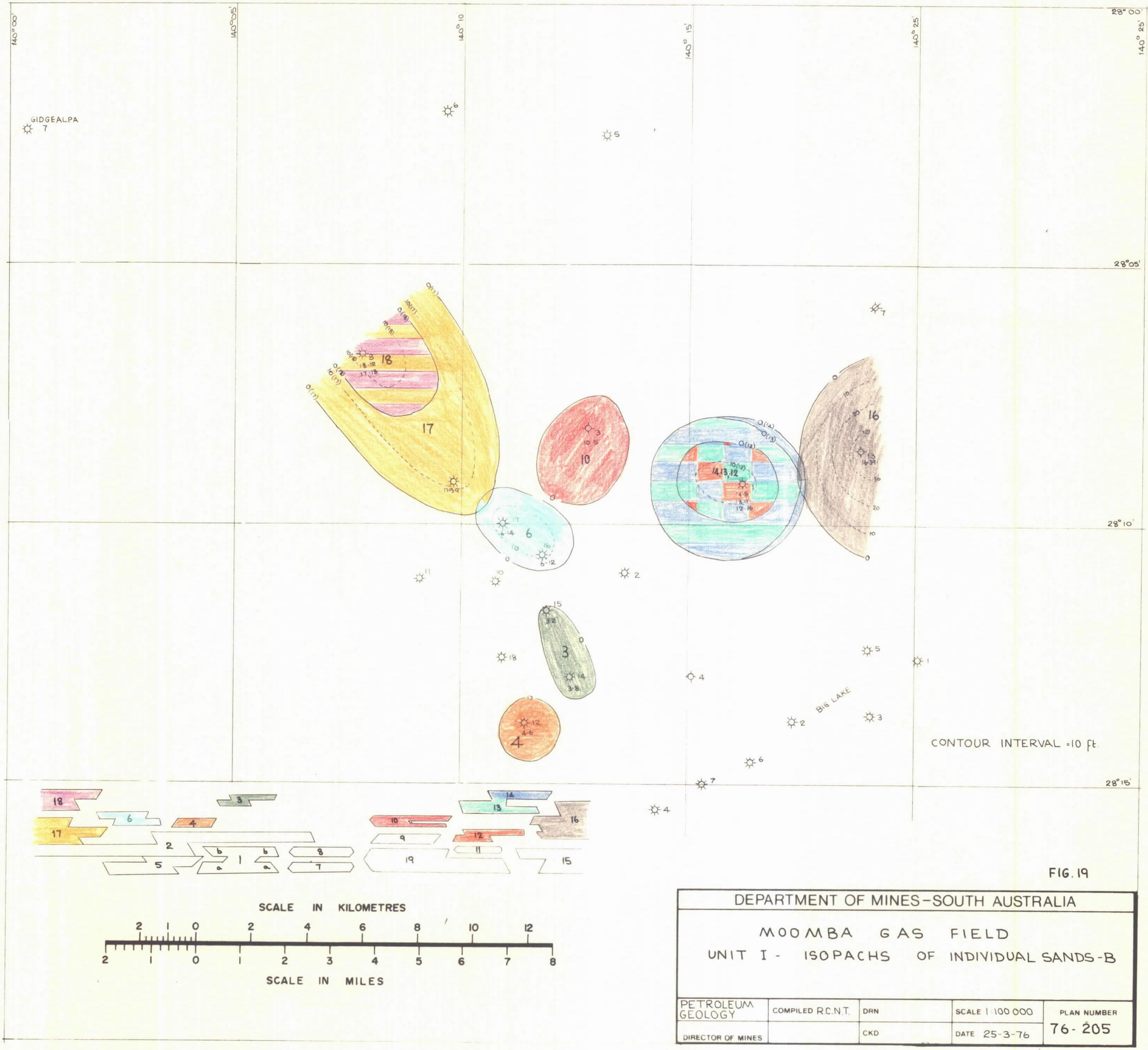


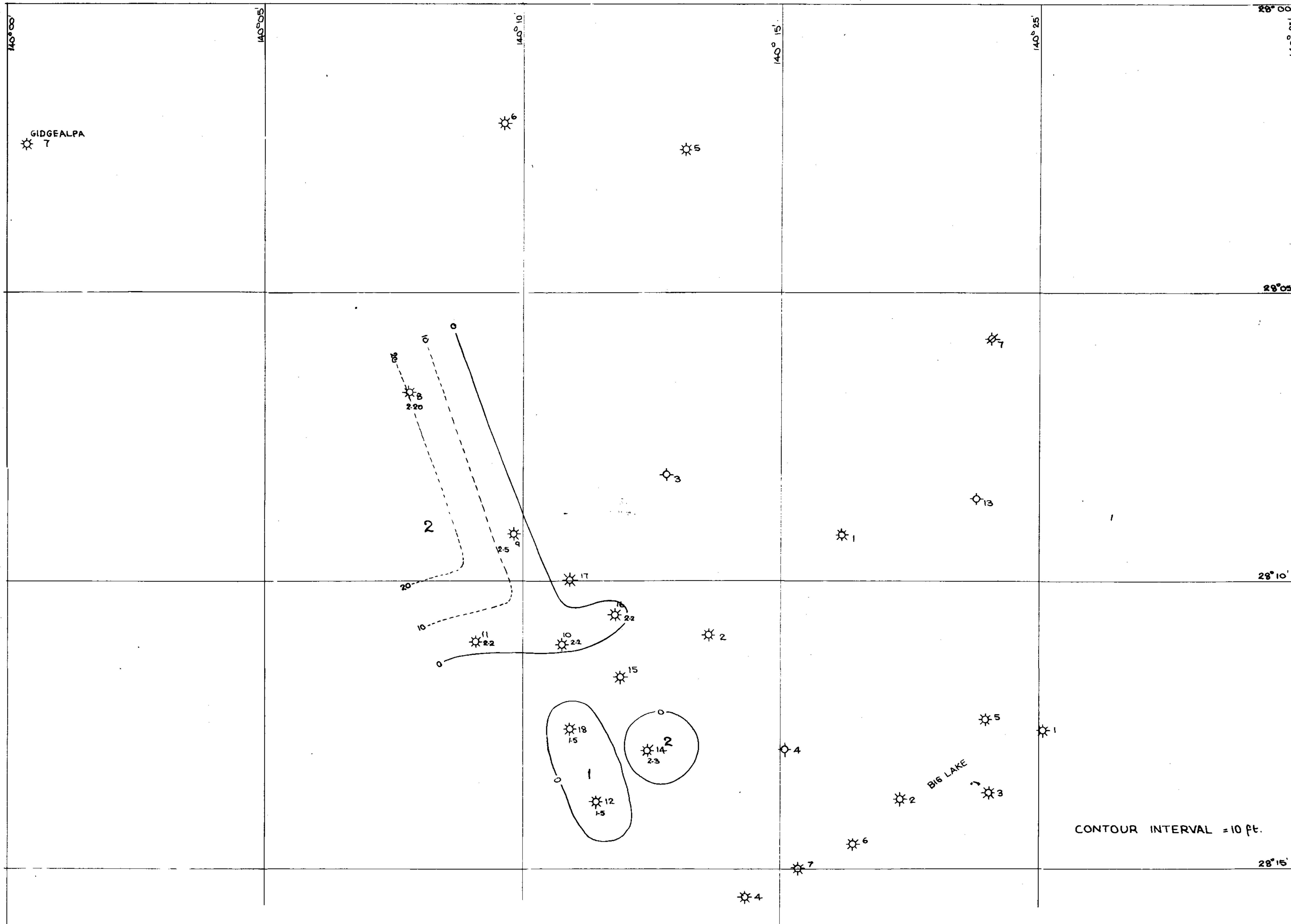
FIG. 19

DEPARTMENT OF MINES-SOUTH AUSTRALIA

MOOMBA GAS FIELD

UNIT I - ISOPACHS OF INDIVIDUAL SANDS-B

PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER
DIRECTOR OF MINES		CKD	DATE 25-3-76	76-205



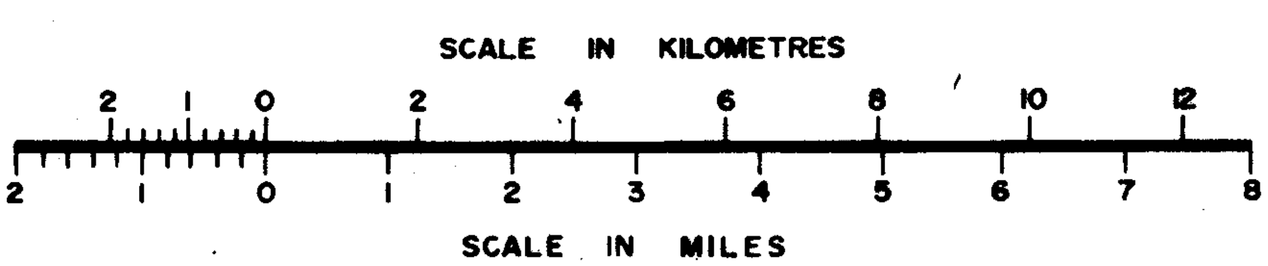
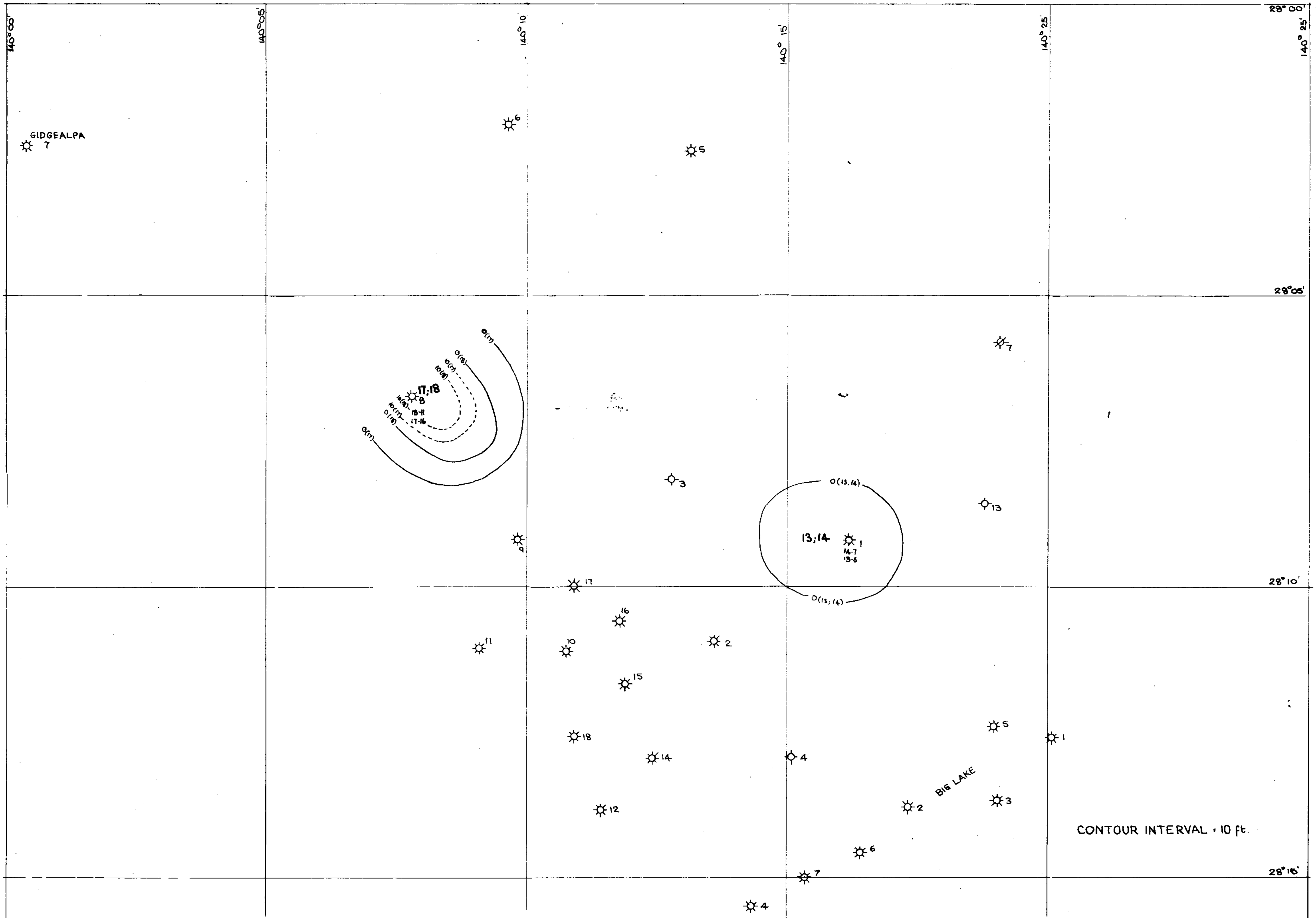


FIG. 20

DEPARTMENT OF MINES–SOUTH AUSTRALIA				
MOOMBA GAS FIELD UNIT I - PAY SAND ISOPACHS OF INDIVIDUAL SANDS-A				
PETROLEUM GEOLOGY	COMPILED: R.C.N.T.	DRN	SCALE 1 : 100 000	PLAN NUMBER 76-206
DIRECTOR OF MINES		CKD	DATE 25-3-76	



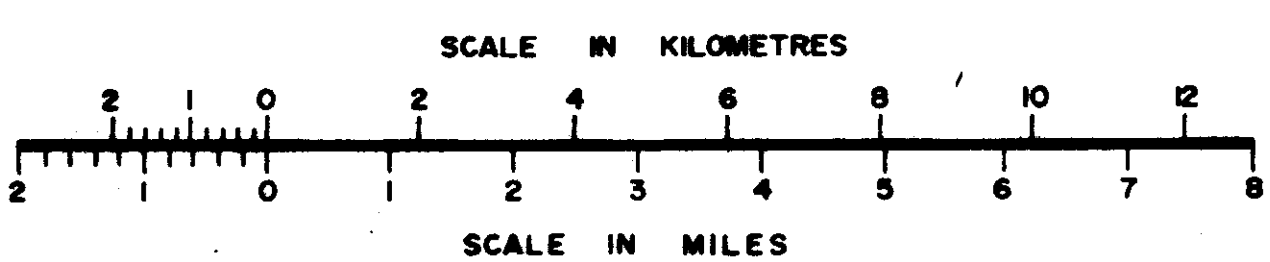


FIG. 21

DEPARTMENT OF MINES–SOUTH AUSTRALIA				
MOOMBA GAS FIELD UNIT I - PAY SAND ISOPACHS OF INDIVIDUAL SANDS - B				
PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER 76-207
DIRECTOR OF MINES		CKD	DATE 25-3-76	

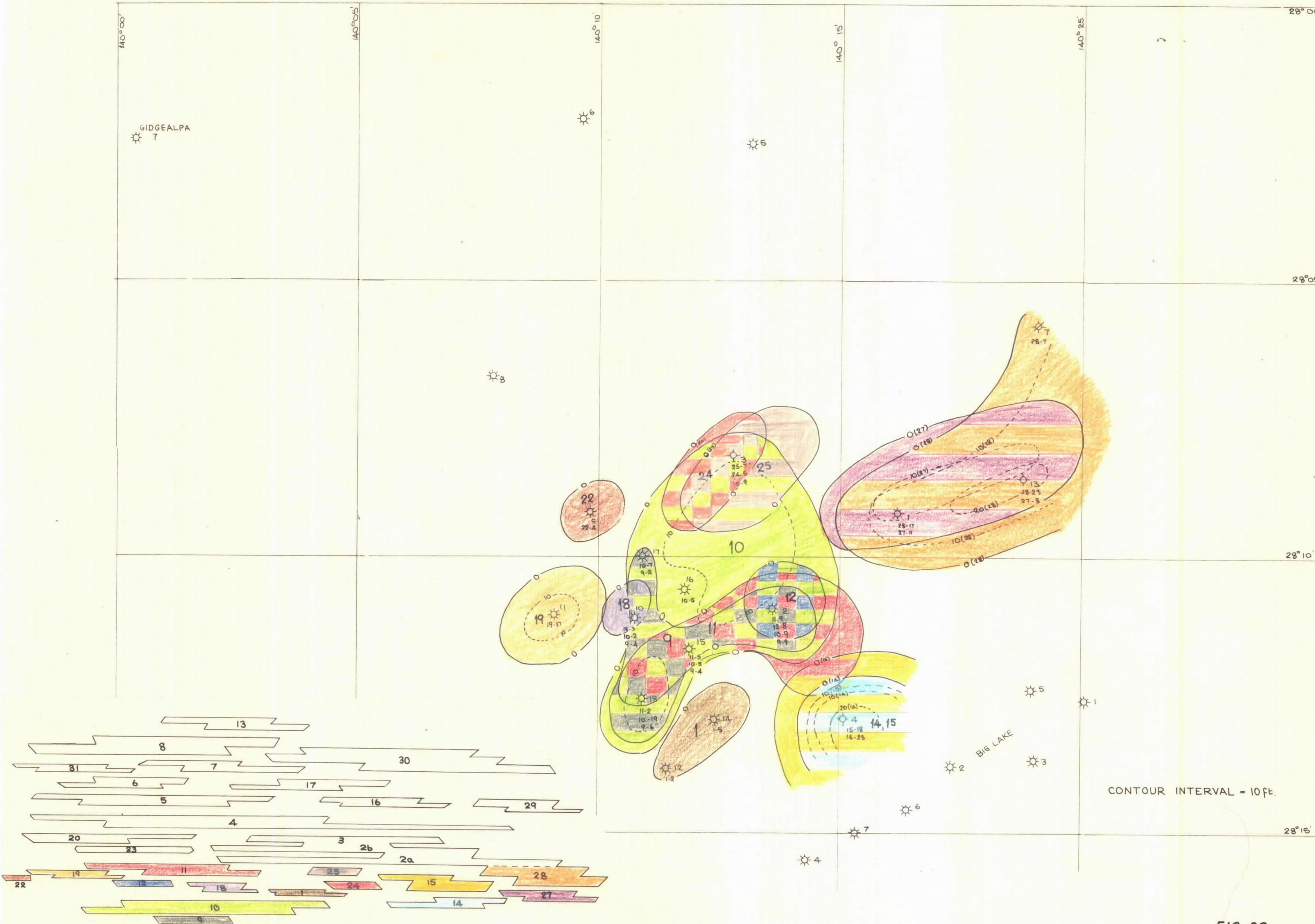
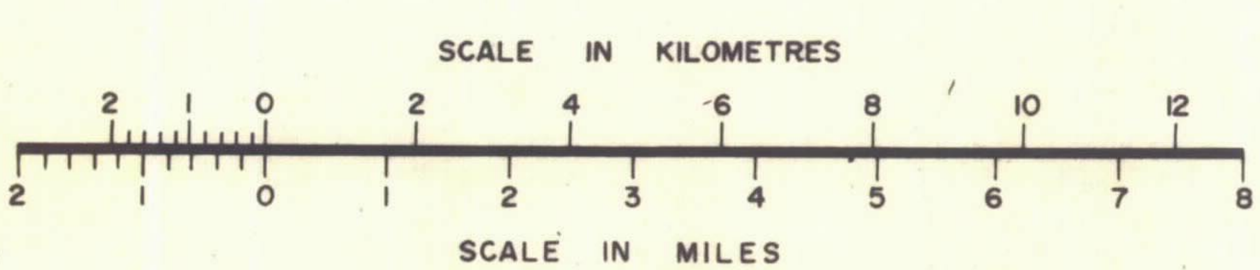


FIG. 22



DEPARTMENT OF MINES–SOUTH AUSTRALIA

MOOMBA GAS FIELD

UNIT II - ISOPACHS OF INDIVIDUAL

SANDS - A

PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER 76-208
DIRECTOR OF MINES		CKD	DATE 25-3-76	

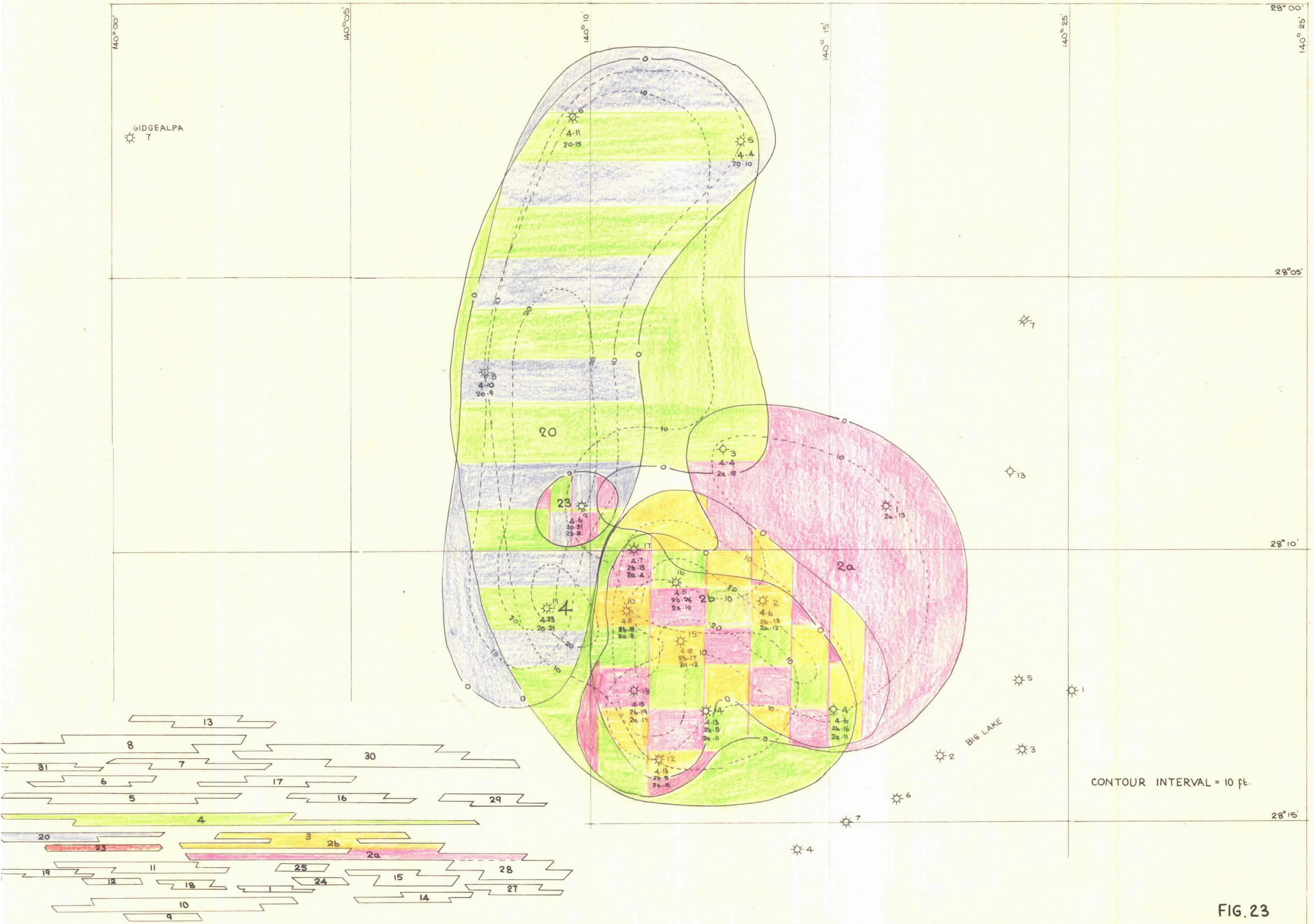
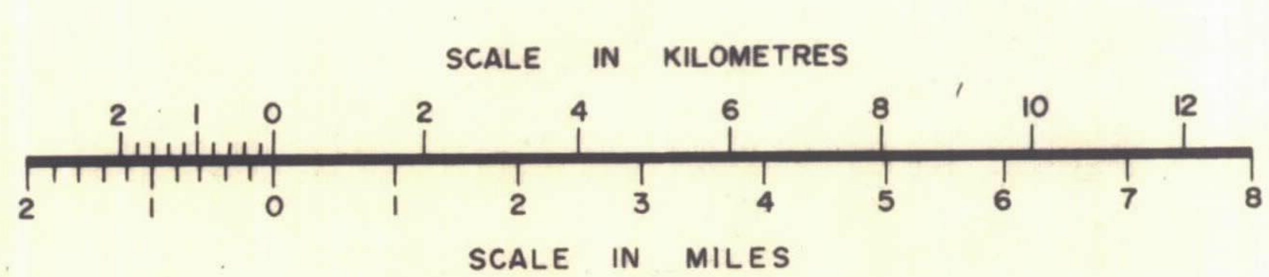


FIG. 23



DEPARTMENT OF MINES-SOUTH AUSTRALIA

MOOMBA GAS FIELD

UNIT II - ISOPACHS OF INDIVIDUAL SANDS - B

PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER 76-209
DIRECTOR OF MINES		CKD	DATE 25-3-76	

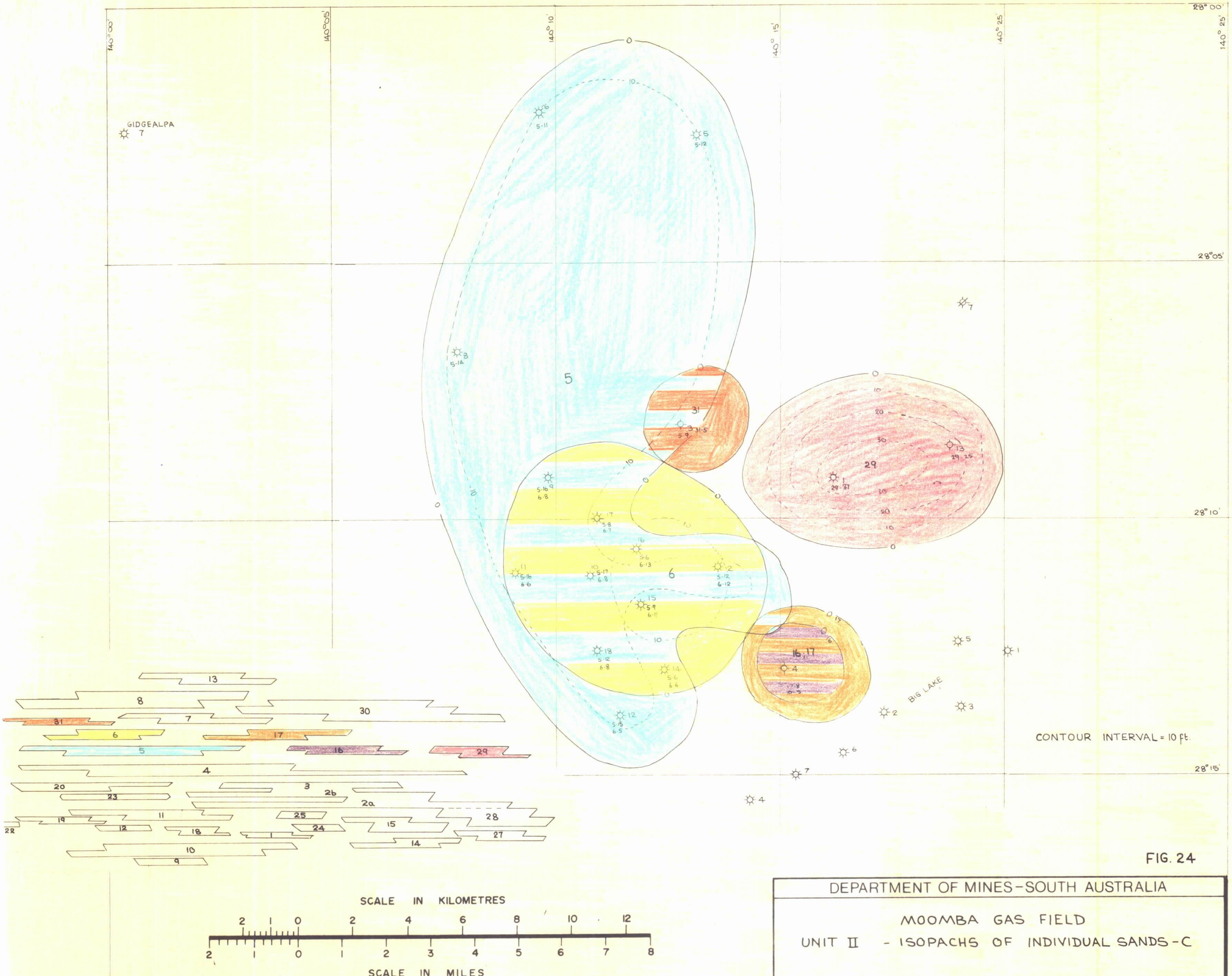


FIG. 24

DEPARTMENT OF MINES – SOUTH AUSTRALIA				
MOOMBA GAS FIELD UNIT II - ISOPACHS OF INDIVIDUAL SANDS - C				
PETROLEUM GEOLOGY	COMPILED RCNT	DRN	SCALE 1:100 000	PLAN NUMBER
DIRECTOR OF MINES		CKD	DATE 25-3-76	76 - 210

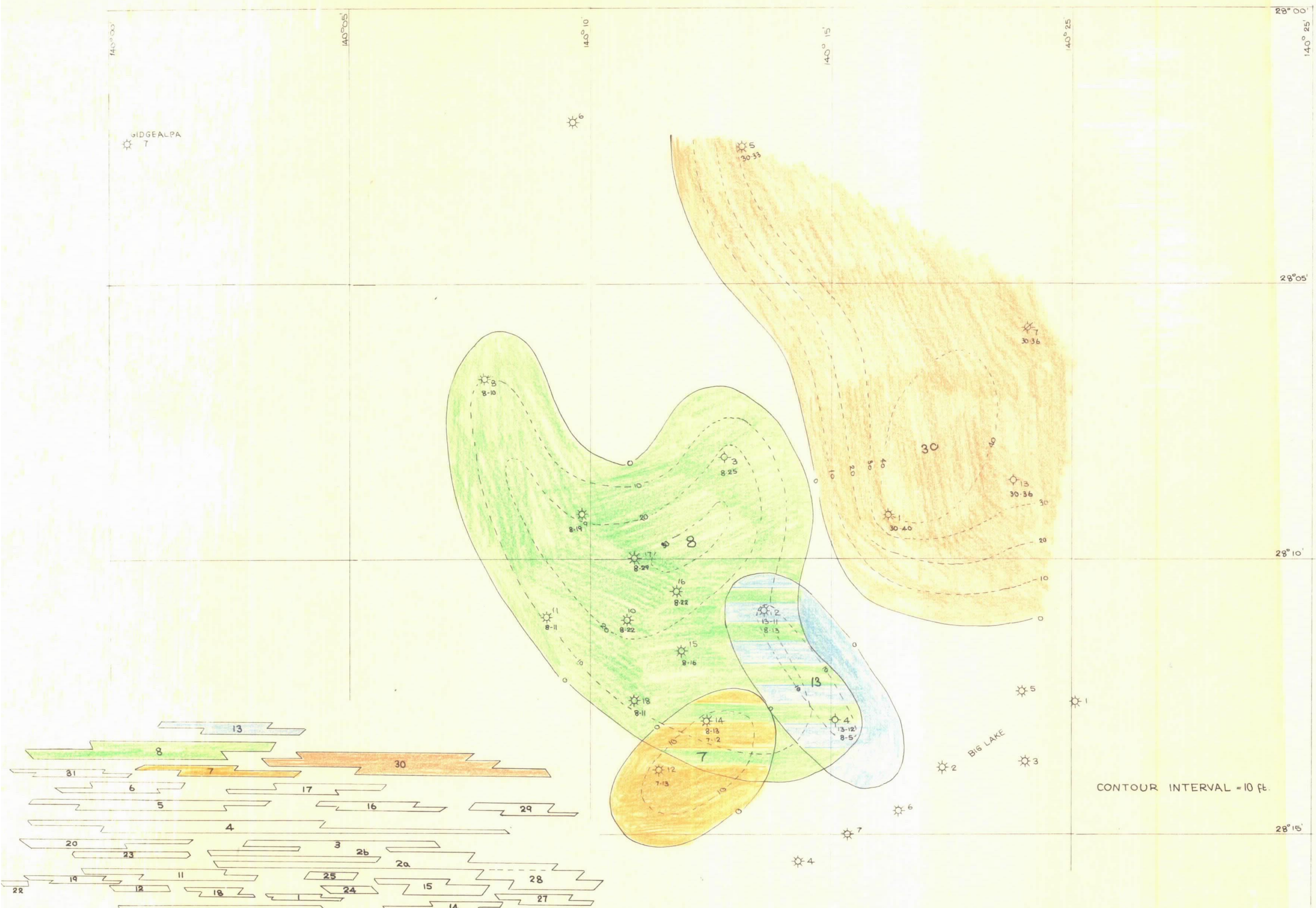


FIG. 25

DEPARTMENT OF MINES - SOUTH AUSTRALIA

MOOMBA GAS FIELD

UNIT II - ISOPACHS OF INDIVIDUAL SANDS - D

PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER 76-211
DIRECTOR OF MINES		CKD	DATE 25-3-76	

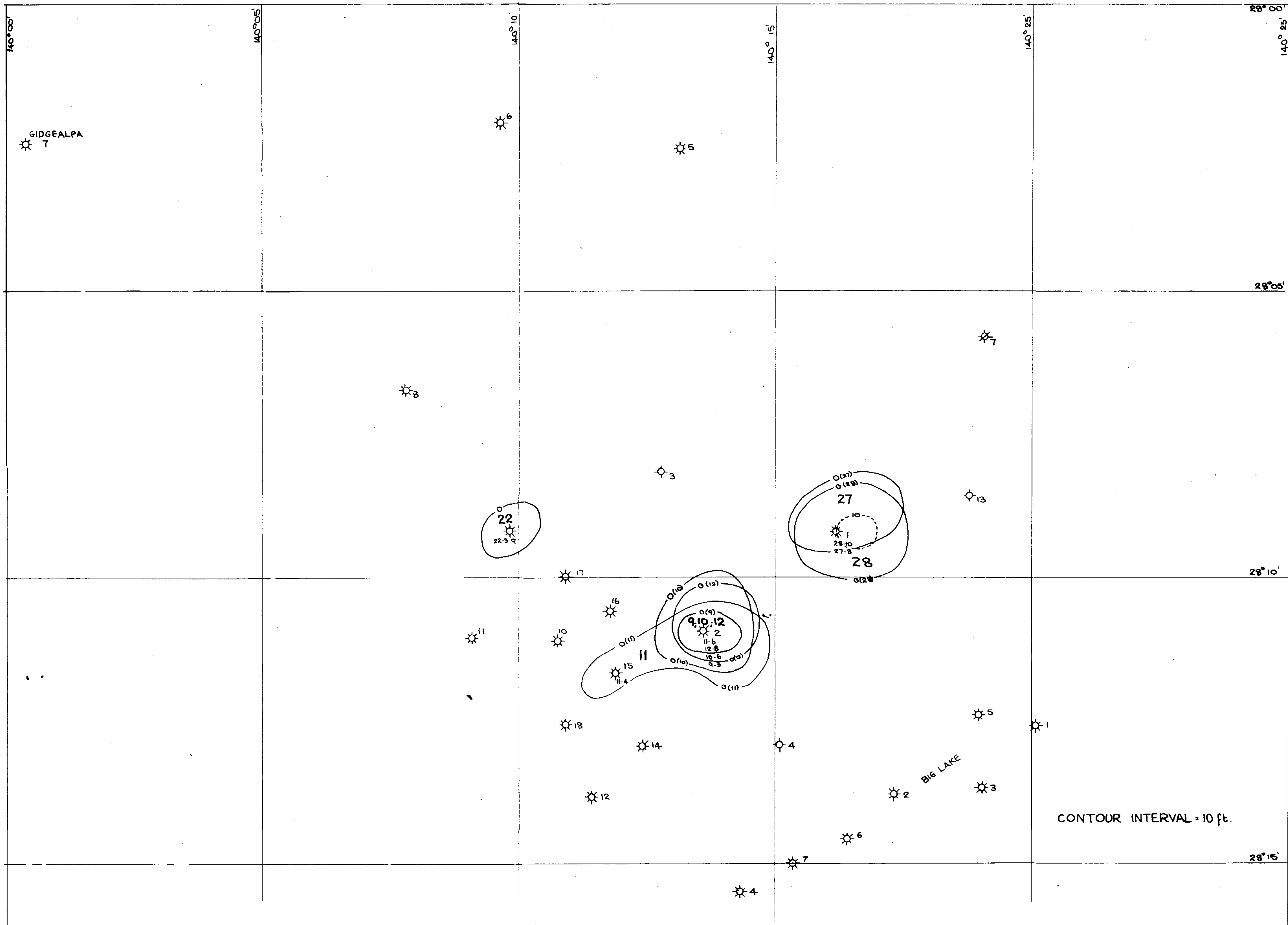
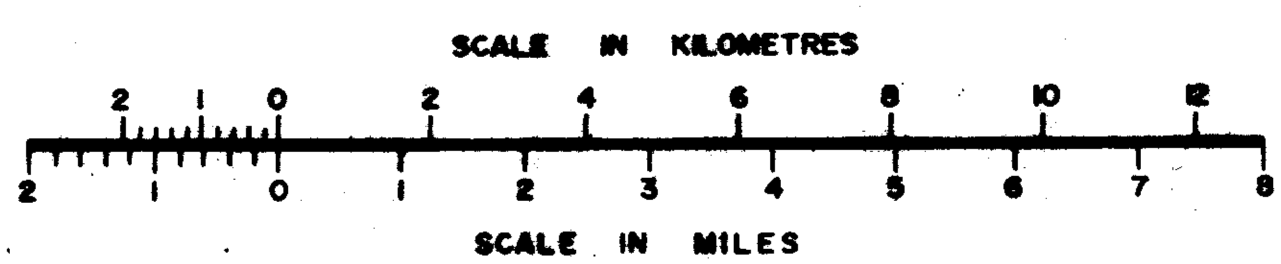


FIG. 26



DEPARTMENT OF MINES–SOUTH AUSTRALIA

MOOMBA GAS FIELD
UNIT II - PAY SAND ISOPACHS
OF INDIVIDUAL SANDS – A

PETROLEUM GEOLOGY	COMPILED: R.C.N.T.	DRN:	SCALE: 1:100 000	PLAN NUMBER 76-212'
DIRECTOR OF MINES		CKD:	DATE: 25-3-76	

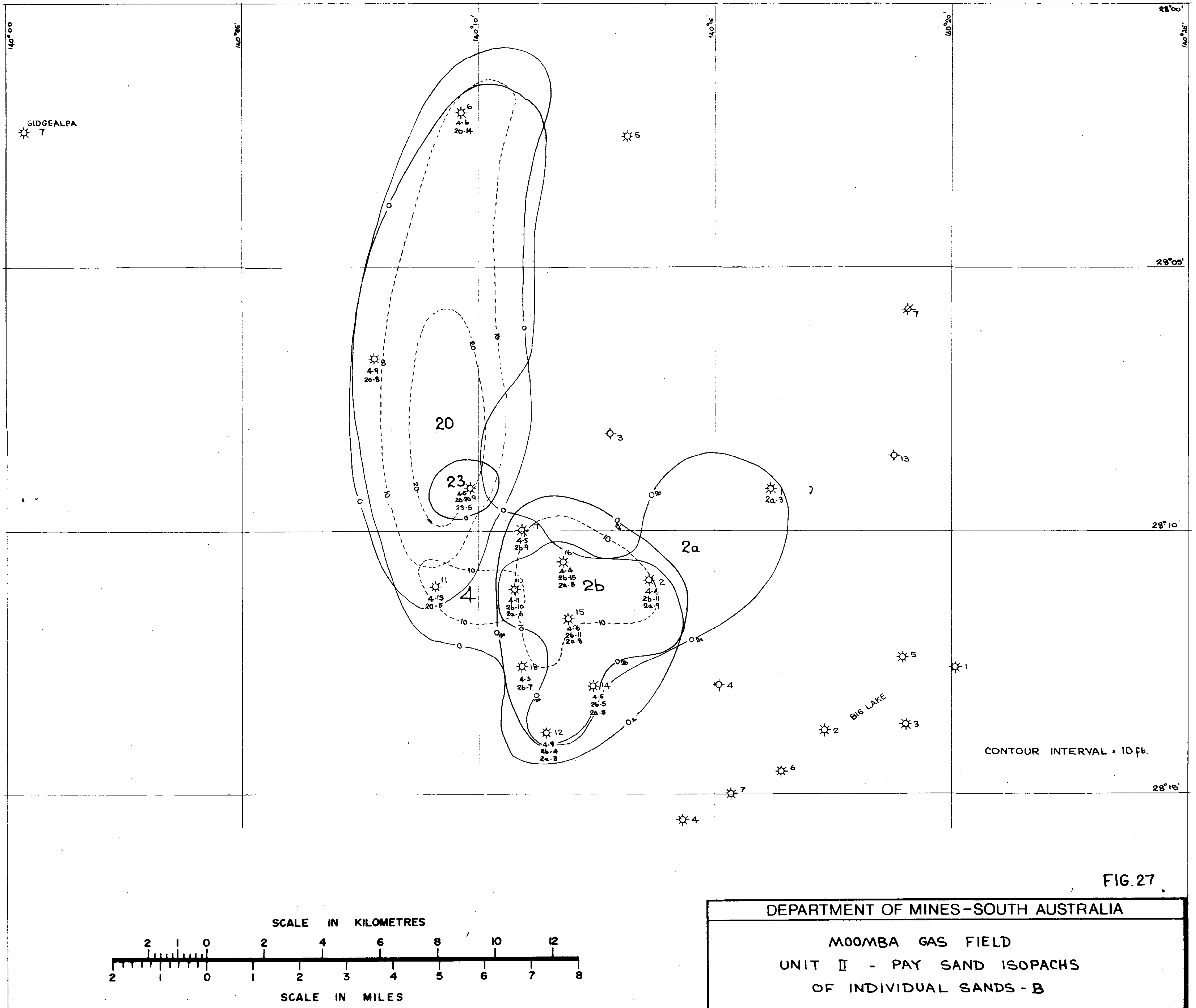


FIG. 27

DEPARTMENT OF MINES–SOUTH AUSTRALIA				
MOOMBA GAS FIELD UNIT II - PAY SAND ISOPACHS OF INDIVIDUAL SANDS - B				
PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER 76-213
DIRECTOR OF MINES		CKD	DATE 25-3-76	

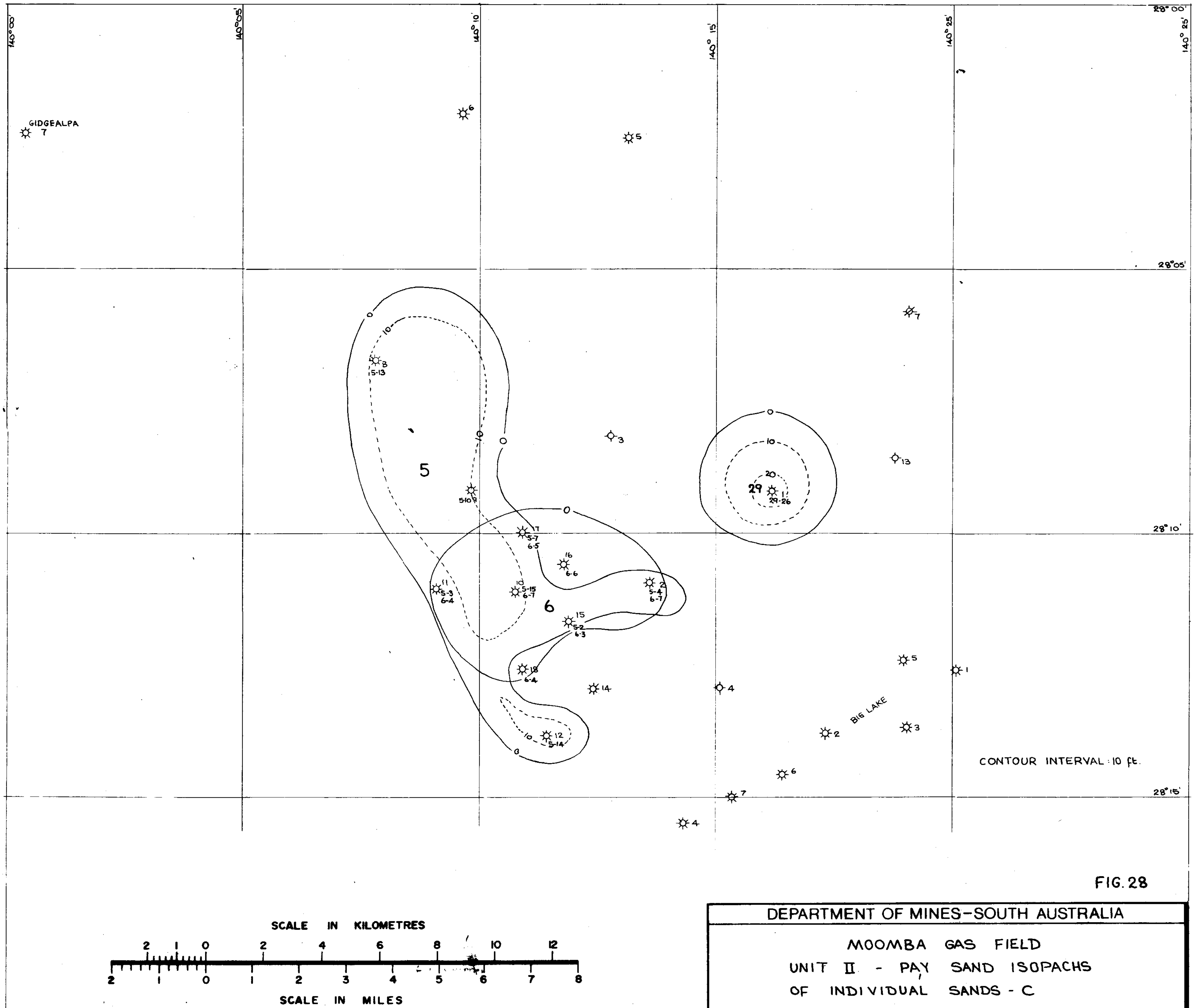


FIG. 28

DEPARTMENT OF MINES-SOUTH AUSTRALIA

MOOMBA GAS FIELD
UNIT II - PAY SAND ISOPACHS
OF INDIVIDUAL SANDS - C

PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER 76-214
DIRECTOR OF MINES		CKD	DATE 25-3-76	

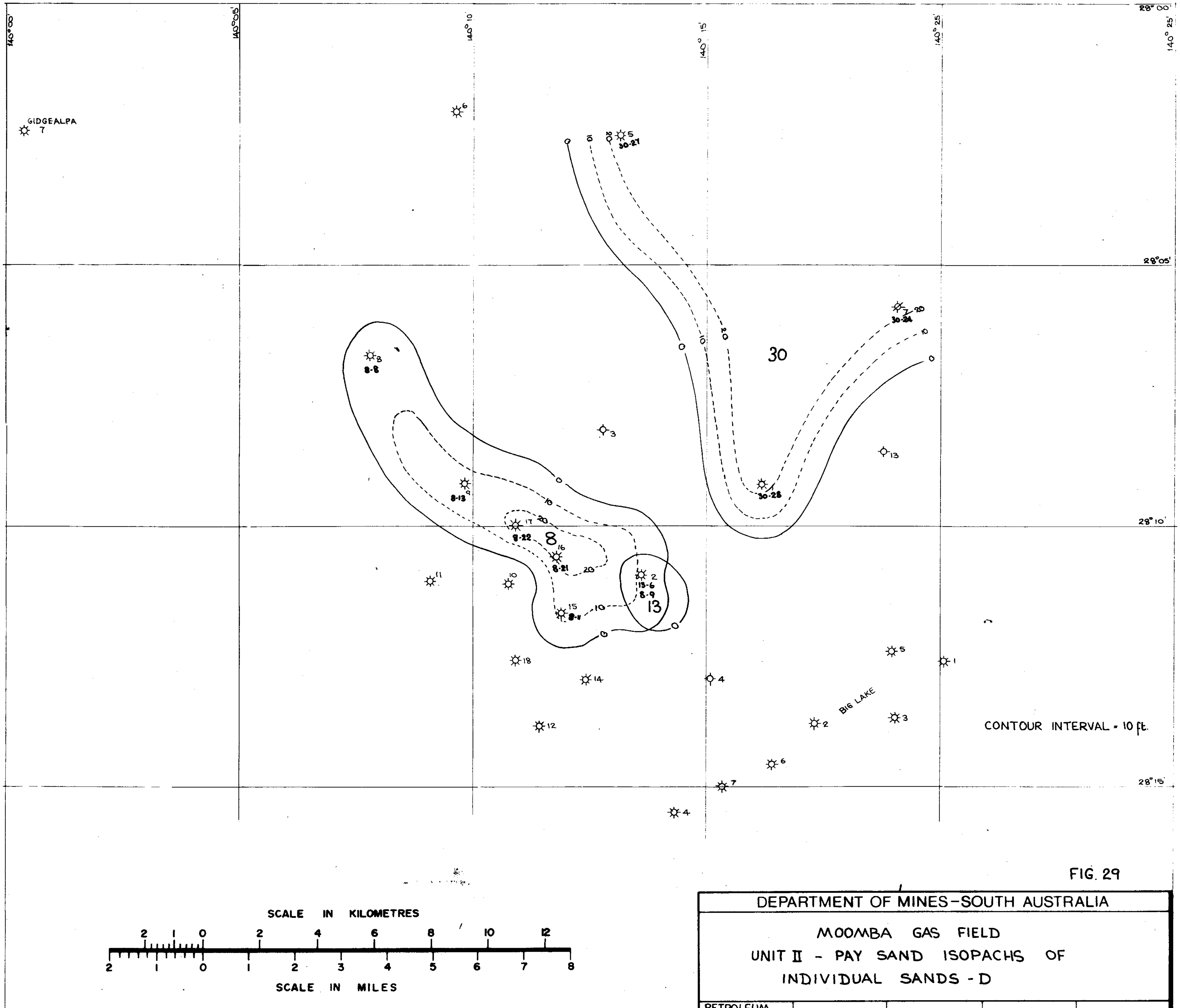


FIG. 29

DEPARTMENT OF MINES-SOUTH AUSTRALIA

MOOMBA GAS FIELD

UNIT II - PAY SAND ISOPACHS OF INDIVIDUAL SANDS - D

PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE 1:100 000	PLAN NUMBER 76-215
DIRECTOR OF MINES		CKD	DATE 25-3-76	

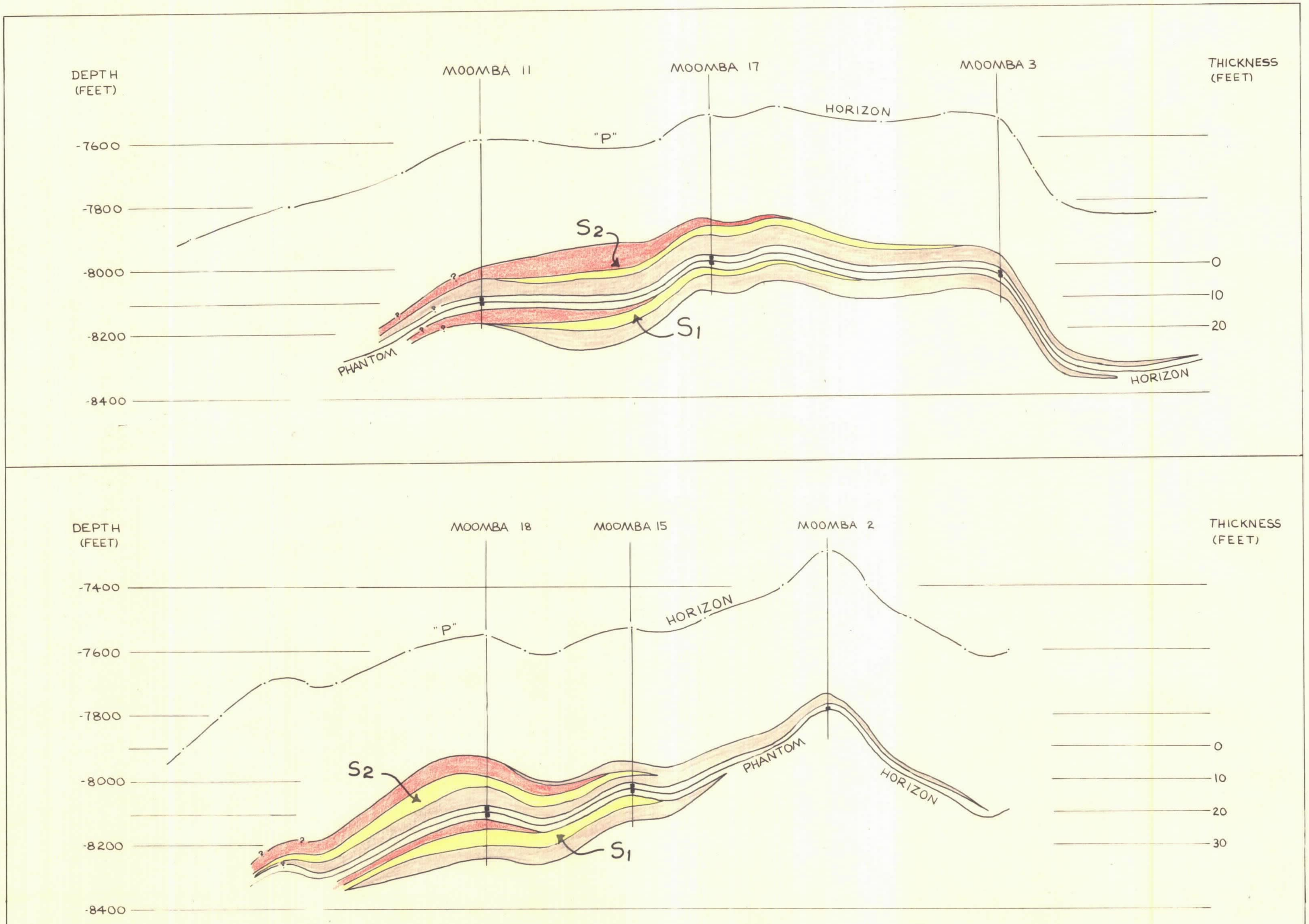


FIG.30

PAY SAND | SAND | SILT

DEPARTMENT OF MINES–SOUTH AUSTRALIA				
MOOMBA GAS FIELD $S_1 + S_2$ DIAGRAMMATIC CROSS SECTIONS				
PETROLEUM GEOLOGY	COMPILED R.C.N.T.	DRN	SCALE HORIZ. 1:50000	PLAN NUMBER 76-216
DIRECTOR OF MINES		CKD	DATE 25-3-76	