DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

Rept. Bk. No.79/146

EXPLORATION FOR UNDERGROUND GAS STORAGE TARGETS IN SOUTH AUSTRALIA

Presented as a paper to the Australian Society of Exploration Geophysicists First Biennial Conference, AMF Adelaide, S.A., August 7th-9th 1979.

By

C.D. COCKSHELL

February 1980

D.M. No. 157/77

CONTENTS

FIGURES

DEPARTMENT OF MINES AND ENERGY
SOUTH AUSTRALIA

Rept. Bk. No. 79/146
D.M. No. 157/77

EXPLORATION FOR UNDERGROUND GAS STORAGE TARGETS IN SOUTH AUSTRALIA

ABSTRACT

Geophysical and geological surveys and drilling in the Northern Adelaide Plains of South Australia have located a Tertiary palaeochannel incised within Proterozoic bedrock. Present data indicate favourable reservoir and seal conditions for the storage of natural gas in the channel although the headward extent and configuration is not yet fully defined.

The channel is presumed to be filled with sands and gravels and is known to be capped by clays and lignites. Subsequent Cainozoic deposition has buried this channel to a depth of approximately 350 m below present-day ground surface. Based on seismic evidence, the channel is approximately 1 800 m wide and extends northeast from Port Gawler for at least 5 km, and possibly up to 10 km, and has a gentle south-west gradient. The infilling sands and gravels appear to have an average thickness of about 20 m and should have sufficiently high porosity and permeability to constitute a good reservoir.

The overlying caprock of clays and lignites is approximately 20 m thick and forms a sheet-like body which infills the uppermost part of the channel and directly overlies bedrock on either side. The under-lying bedrock of tight limestone and dolomite near Port Gawler and weathered clayey siltstone to the east, probably has low permeability, similar to that of the clays and lignites.

Assuming a realistic effective reservoir porosity of 15%, a gas storage pressure of 2 800 kPa (400 psi), and an onshore channel length of 7.5 km, estimated gas storage capacity is 280 million m^3 (10 BCF). This is the minimum requirement for optimum storage utilisation. It has been recommended that further drilling and geophysical surveys be done to define the reservoir geometry and engineering characteristics.

INTRODUCTION

The concept of storing natural gas underground in South Australia was initiated in 1964. This was in consequence to the proposed use of natural gas from the Moomba-Gidgealpa Gasfields via a pipeline to Adelaide. The task of exploring for suitable storage targets was given to the Department of Mines, which has worked on the project since 1964, culminating in three years of extensive exploration since 1976.

As with all exploration projects, the first step is to define a target. In underground gas storage, such a target can be defined as a reservoir of porous and permeable rock within which fluids are, or can be, both vertically and laterally restricted. That is, storage targets are typically very similar to oil and gas exploration targets, with or without native hydrocarbons. It is little wonder that in other parts of the world, particularly the United States, underground gas storage is most commonly accomplished by using depleted oil and gas fields. However, as suitably located depleted fields become scarcer, confined aquifers which have similar characteristics are becoming more important as gas storage targets.

To determine the suitability of a reservoir for gas storage, a number of constraints are placed on the potential target. First of all, the target must have sufficient size and porosity to accommodate the amount of gas required for storage. Secondly, the reservoir must be capped and have suitable lateral confining conditions to prevent the leakage of gas and thirdly, the target must be deep enough to allow for high gas storage pressures, needed for both capacity and high gas withdrawal rates. High reservoir permeability is also required for suitable withdrawal rates. Along with these geological constraints, a storage reservoir must be located as near as possible to both pipeline and market for economic and security reasons.

For the Adelaide market it was estimated that a storage with a minimum capacity of 280 million m^3(10 BCF) would be required.

Such a volume represents approximately 2 months supply and would required a target of 7 km^2 in area, 10 m thick, with an effective porosity of 15%. For an operative storage pressure of 1 800 kPa (400 psi) a minimum depth to reservoir of 250 m is required.

EARLY EXPLORATION

Exploration for underground gas storage targets in South Australia began in 1964 by choosing a sedimentary basin which satisfied the two spatial constraints of proximity to the pipeline and to Adelaide. It is obvious from Fig. 1 that the St. Vincent Basin suits these requirements remarkably well. Fig. 2 outlines the St. Vincent Basin in more detail, and indicates that the Northern Adelaide Plains, located between Balaklava and Adelaide, is the best region in which to explore for potential targets. Indeed, all exploration in the project has been confined to this area as shown in Fig. 2.

In 1964, it was initially suggested that a dome-shaped structure within the Inkerman Coalfield might afford a suitable target. The structure, already known from coal exploration drilling, has an indicated closure of 8 m over 5 km^2 at a depth of 76 m. However, as these parameters did not meet the minimum requirements, it was decided that exploration in the Two Wells area might find a deeper, more suitable structure.

Accordingly, a seismic reflection survey was carried out in the area (Fig. 3) by Seedsman (1964), with a stratigraphic drillhole, Light No. 1 being drilled at the completion of the survey (Cornish, 1964). The survey indicated a bedrock high extending north and east of Light No. 1 and that the Tertiary sediments dipped gently to the south. Later in 1964, a water observation bore was completed to bedrock at Port Gawler (Fig. 3).

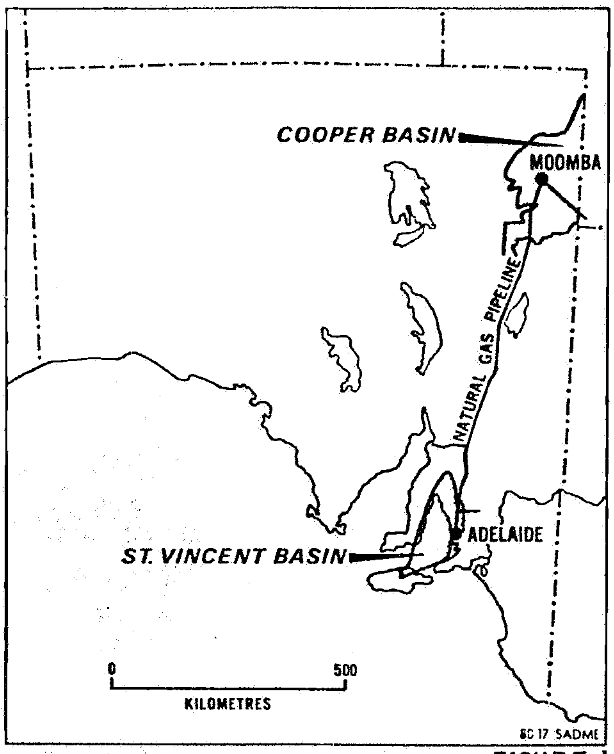

FIGURE 1

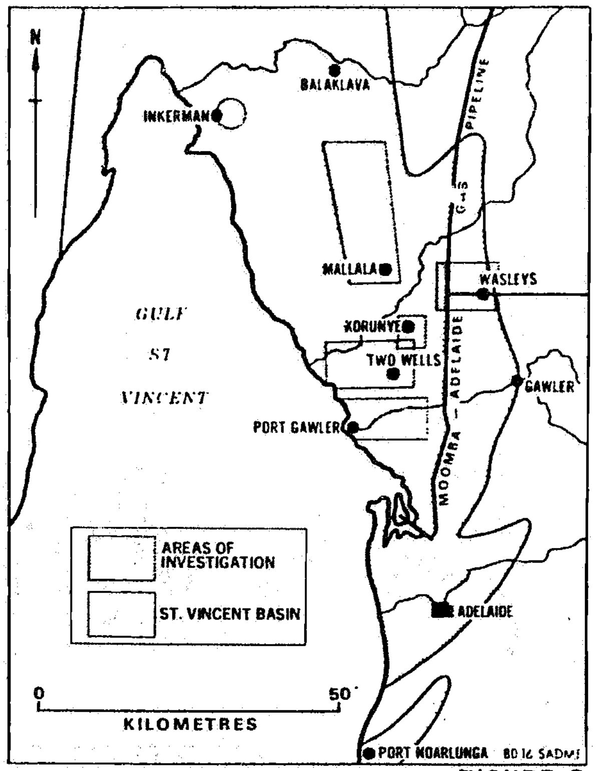

FIGURE 2

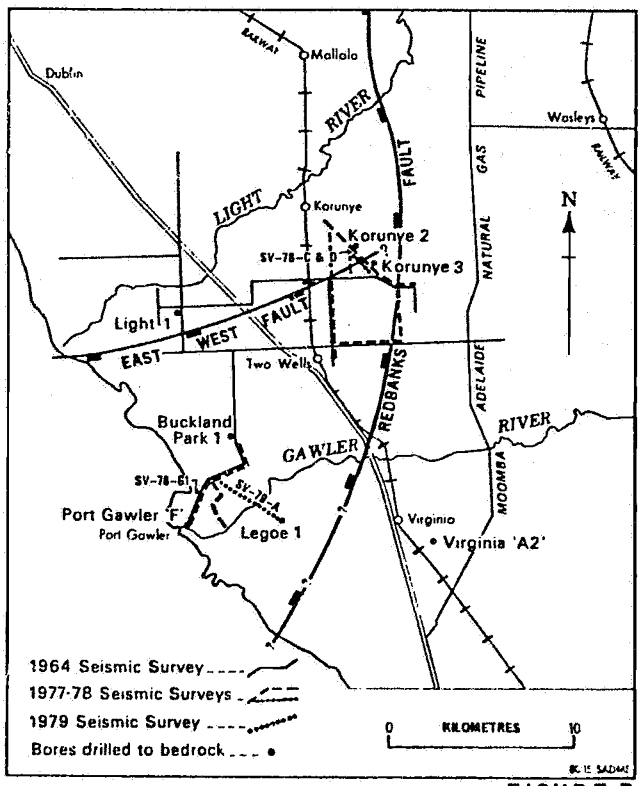

FIGURE 3

This bore showed a thick Cainozoic section including all Tertiary units known from the eastern St. Vincent Basin (Lindsay, 1965, 1969). However, the main interest in this bore is the presence of the two Maslin Sand units (see Fig. 4), overlain by apparently impermeable mudstones and clays, which are absent in Light No. 1. It was recommended that this apparent wedge-out against the bedrock high to the north be further investigated by means of a detailed gravity survey. However, interest in the project apparently flagged at this stage and the project lay dormant till 1975.

INVESTIGATIONS DURING 1975-1977

Interest was rejuvinated when a gravity high in the Wasleys area (Fig. 2) indicated a possible dome-shaped structure within the Tertiary succession. Accordingly, a detailed follow-up gravity survey was conducted over the feature in December, 1975. However, the anomaly was interpreted as being caused by an up-lifted bedrock block with only thin Cainozoic cover. The structure was therefore unsuitable as a gas storage target.

On the other hand, the study did indicate that the gravity low immediately west and northwest of this high was caused by a basin-like structure filled with Tertiary sediments. The two gravity anomalies are separated by what was believed to be the Redbanks Fault, having a throw of 200 to 250 m. It was recommended that this feature be further investigated to explore for confined Tertiary aquifers trapped against it.

Accordingly, between March 1976 and June 1977, several geophysical surveys were carried out in the Mallala-Barabba area (Fig. 2), mainly to define bedrock configuration, as very little was known of the subsurface geology at the time. Methods which were used included resistivity, seismic refraction, high resolution seismic reflection, detailed gravity and stratigraphic drilling, details of which are contained in a report by Cockshell, Nelson and Cooper (1978).

These surveys as well as the borehole information indicate a southerly dipping trough-like depression in Precambrian bedrock, infilled with Tertiary and covered by a blanket of Quaternary sediments. The eastern margin of the feature is well defined by the Redbanks Fault, a major north-south bedrock fault with a throw of approximately 200 m. The northern and western margins are probably marked by faults, but there is little direct evidence of this. In the south, a bedrock ridge located between Mallala and Korunye (Fig. 2) separates this area from the northern Adelaide Plains Proclaimed Area (Water Resources Act, 1976).

Drilling in the area verified the existence of Tertiary aquifers similar to those further south in the Adelaide Plains. The reservoir properties of the aquifer are good, but the overlying beds are much more marginal than those at Port Gawler and have moderate permeability, indicating poor capping conditions. As there was also some doubt concerning the lateral sealing of the aquifers against bedrock, the area appeared unfavourable for the storage of natural gas.

RECENT EXPLORATION

Having rejected the Mallala-Barabba area, interest was transferred to the Korunye area (Fig. 2), where the bedrock high indicated by the 1964 survey approached the Redbanks Fault (Fig. 3). It was expected that these bedrock features would provide a northerly and easterly wedge-out to the basal Tertiary aquifers found in Port Gawler Bore "F". It was further expected that the sediments would be less marginal than those

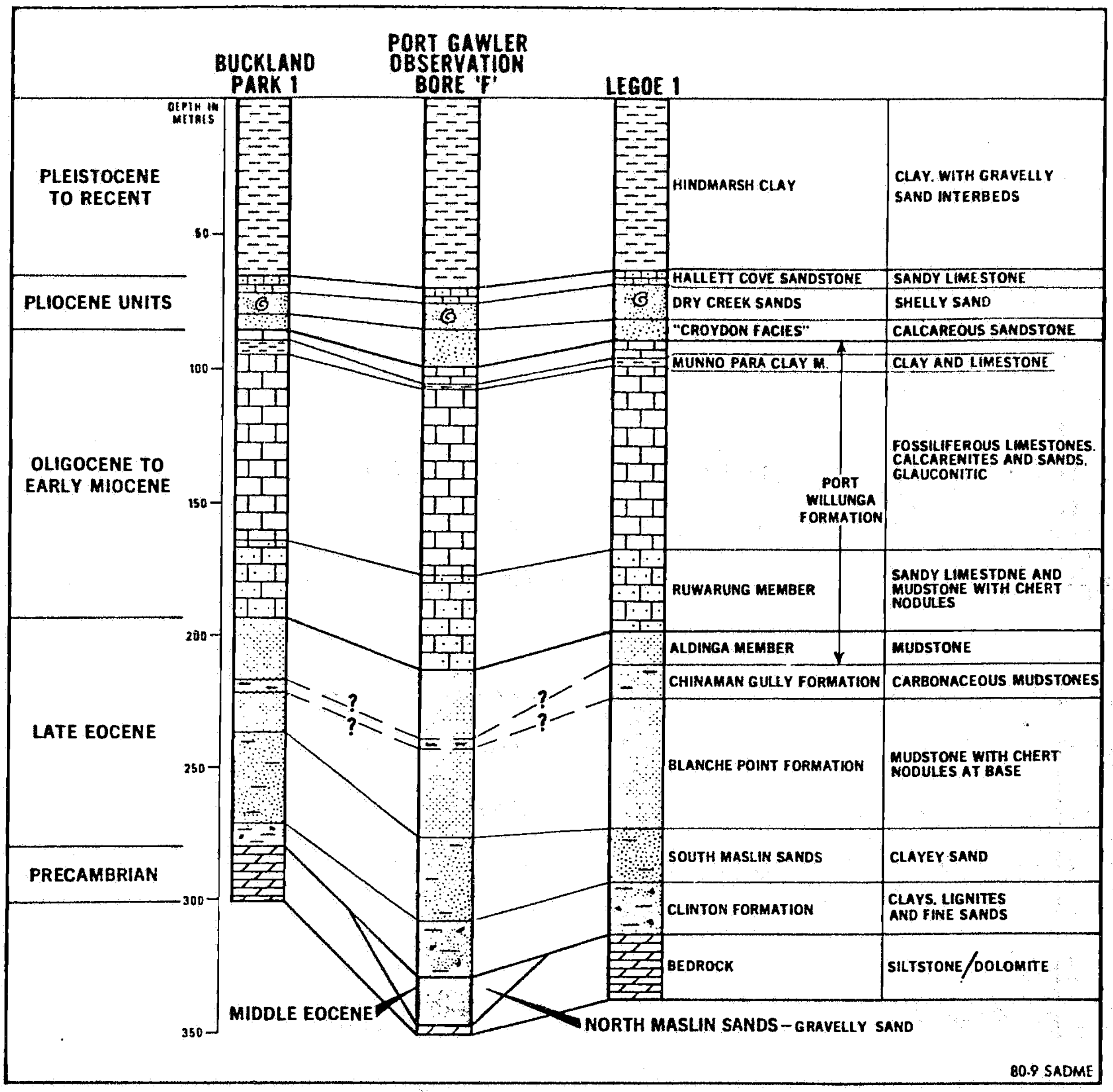

FIGURE 4

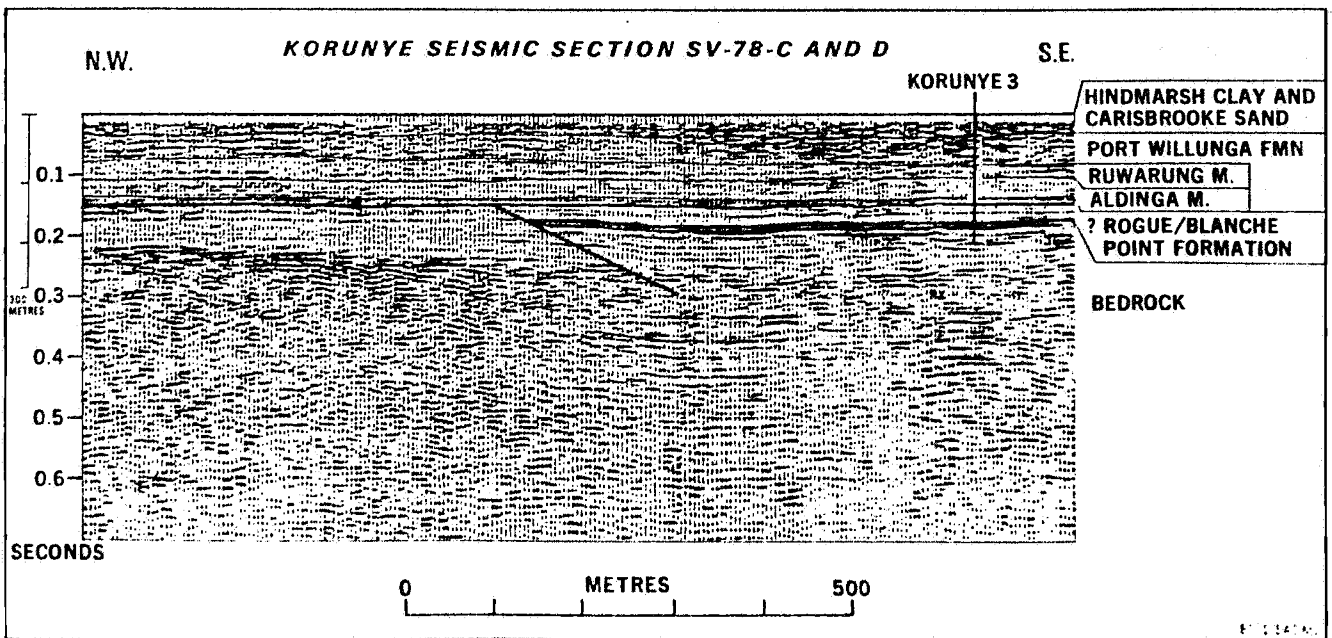

FIGURE 5

found in the Barabba area and therefore be more suitable as storage targets.

Exploration in the area began with a reconnaissance 2-fold high resolution seismic reflection survey in December 1977. The sections showed a number of Tertiary reflectors and an undulating bedrock surface, and also verified the presence of substantial bedrock relief across both bedrock features under investigation. To provide a clearer picture of these features, a series of more detailed 6-fold seismic reflection traverses were shot over them in February 1978. The section for lines SV-78-C and SV-78-D (Fig. 3) is typical of the data obtained and is shown in Fig. 5. The section shows a well defined bedrock surface, particularly where it is deeper, a number of Tertiary reflectors and the well defined fault. This southerly dipping fault delimits the southern margin of the east-west bedrock high, indicated by the 1964 survey. The fault has a throw of 30 to 40 m, which is similar to that of the Redbanks Fault in this area. Geological control of the seismic data was provided by two stratigraphic holes, Korunye Nos. 2 and 3 (Fig. 3) drilled in July 1978. Stratigraphically the Tertiary section intersected is relatively thin compared to that at Port Gawler, with both target aquifers being absent in this area. Lithologically the sediments are still marginal marine sediments similar to those found in the Mallala-Barabba area to the north.

The drilling information and the seismic data indicate that the Tertiary sequence gradually thickens to the south and west, and that the target aquifers wedge out south of this area. It was also expected that the sediments would become less marginal in nature to the southwest, and therefore be more suitable as aquifer confining units.

At this stage, new biostratigraphic evidence from other parts of the St. Vincent Basin (Cooper, 1979), indicated that the North Maslin Sands (Fig. 4), which formed the base of the Tertiary sequence, were fluviatile channel sediments restricted to deep depressions in the bedrock. The South Maslin Sands on the other hand are marginal marine sediments which are more sheet-like in distribution.

With the Clinton Formation in Port Gawler Bore F (Fig. 4) comprising mainly clays and lignites and probably providing hydrological separation of the two Maslin Sand units, attention was focused on the less expansive North Maslin Sands as a reservoir target.

PORT GAWLER AREA

Accordingly, a stratigraphic well, Buckland Park No. 1 was drilled as a stepout well from Port Gawler Bore F (see Fig. 3).

The hole was completed in September 1978 to a depth of 301 m, bedrock being intersected at 280 m (see Fig. 4). Directly overlying the weathered clayey siltstone bedrock is 8 m of muddy sands and clays of the Clinton Formation, the bottom 2 m of which comprises tight clay, forming ideal sealing conditions for the target North Maslin Sands, presumed to wedge-out further south. Overlying the Clinton Formation is a thick section of South Maslin Sands capped by a relatively thin Blanche Point Formation, which is moderately permeable in part and thus a poor capping unit for the South Maslin Sands aquifer.

Following the drilling of Buckland Park No. 1, a series of high resolution seismic reflection lines were shot between this bore and Port Gawler Bore F (Fig. 3) to determine the northern limit of the North Maslin Sands, and to determine the channel geometry east of Port Gawler. The survey used 4 - and 6 - fold CDP stacking to provide the required detail, but with a variety of shooting techniques being used to reduce the high drilling costs associated with normal rollalong shooting (see Fig. 6).

For the first line of the survey (SV-78-G1) reciprocal shots were fired 10 m off each end of the geophone spread, followed by a move-up of 6 stations and repetition of the process. As there appeared to be some NMO stretching, due to the length of the spread being comparable to the depth of section, a variation of this technique was used for the rest of the lines. The alternative technique was to fire shots between the 6th and 7th station from each end, followed by similar move-up procedures to the first line. For the lines shot with 6-fold CDP stacking an additional split-spread shot was added to the above technique for each spread.

For most lines, 6 m shotholes were drilled with shots comprising three separate 2 ounce charges strapped to a length of dowel. The charges were water tamped to allow for reshooting in poor record sections and for multiple shots required by the shooting technique. The data from the three individual shots were then vertically stacked by an Input/Output DHR1632 recording system to form the seismic record. As line SV-78-G1 was located along a causeway over mangrove swamp where shothole drilling is impossible, individual 1 ounce charges were polled, from a half to two metres, into the mud adjacent the causeway, fired and reloaded. To obtain suitable energy recovery, an average of eight charges were fired and vertically stacked to form each record.

An example of the quality of the data obtained is shown by the time section for the SV-78-G1 line (Fig. 7). The main features of the section are the marked southwesterly dip of the

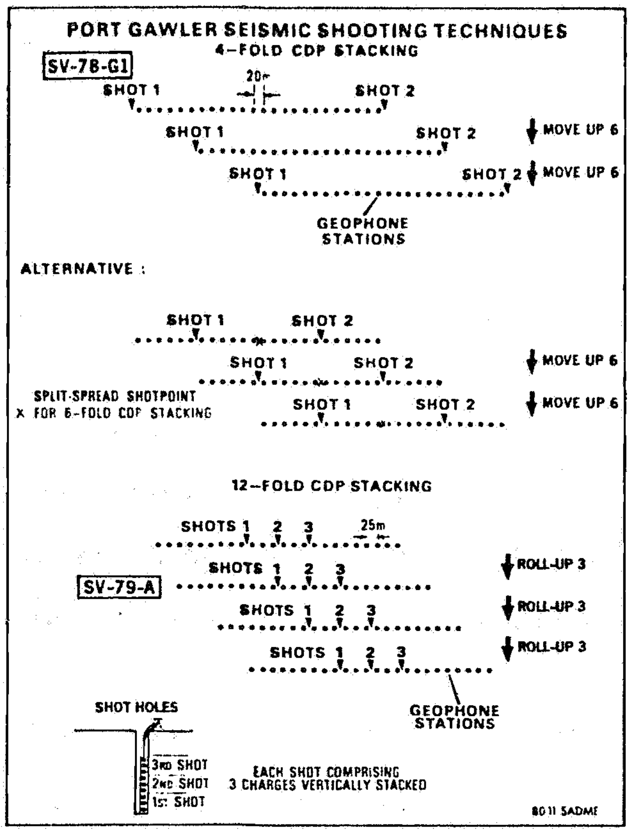

FIGURE 6

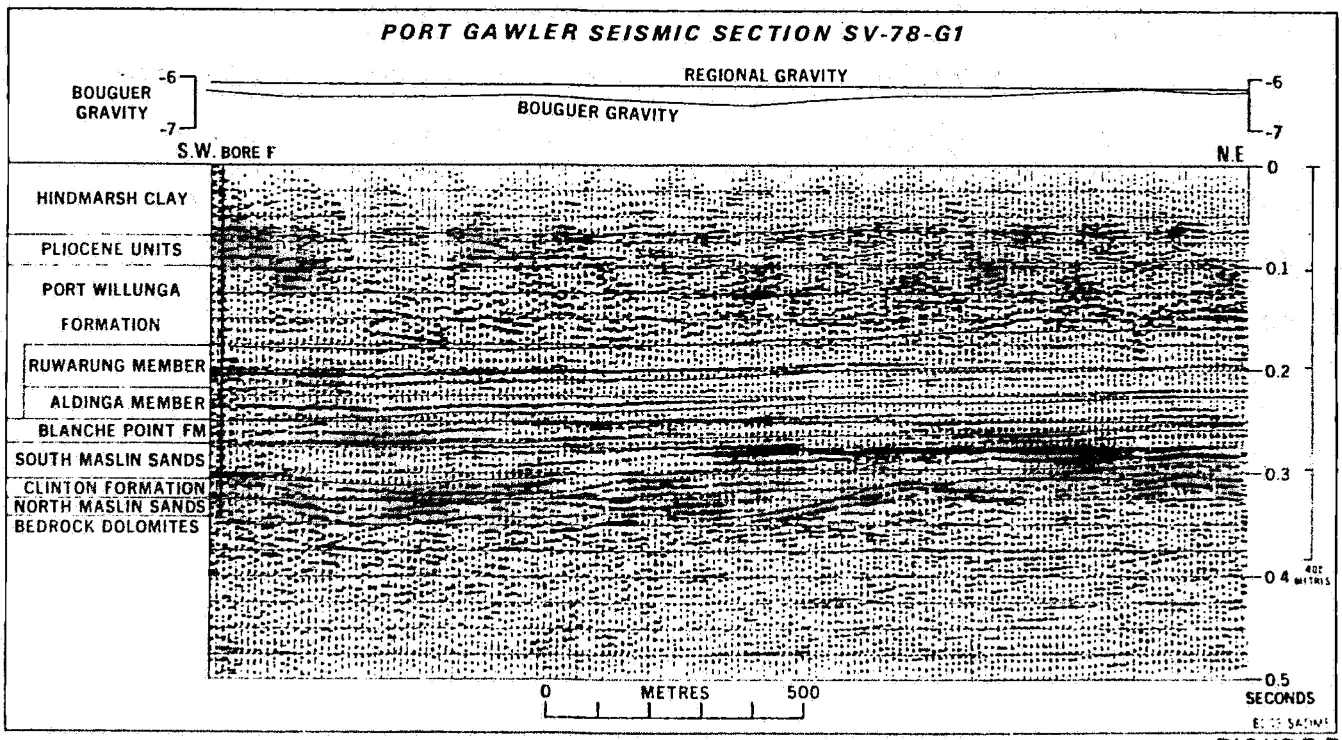

FIGURE 7

Tertiary sediments and a distinct northerly termination for the North Maslin Sands channel. A gravity survey was later conducted over the section and showed very good correlation between low gravity values and development of the North Maslin Sands channel.

The data from the lines to the east of the SV-78-G1 line were slightly poorer in quality due to the presence of a poorer shooting medium. However, a somewhat doubtful North Maslin Sand channel bank is indicated approximately due east of the bank shown on the SV-78-G1 section.

At this stage attention was drawn to Virginia Bore "A2" (Fig. 3), in which, overlying the bedrock, there are 11 m of sands which had been regarded as North Maslin Sands. However, reinterpretation of the borehole data indicated that correlation of these sands to any particular unit was doubtful. To test for linear connection between Bore F and the Virgina bore, a stratigraphic hole, Legoe No. 1 was drilled (Fig. 3).

The hole was drilled in December 1978 to a depth of 338 m, with weathered clayey siltstone bedrock being intersected at 314 m (Fig. 4). Directly overlying the bedrock is 21 m of Clinton Formation clays and lignites, again indicating very good sealing conditions for the North Maslin Sands. The overlying Tertiary units are similar to those found in Buckland Park No. 1.

Having eliminated the possibility of linear connection between Bore F and Virginia Bore A2, it was decided to explore the possibility of the channel deviating northeastward from Port Gawler and passing between Legoe No. 1 and Buckland Park No. 1. Accordingly, a high resolution 12-fold reflection line, SV-79-A, was shot in February 1979 (Fig. 3).

The shooting technique used for this line, (see Fig. 6), was similar to that of the earlier 6-fold lines except that the assymmetric shots were three stations either side of the split-spread centre shot rather than 6, followed by a roll-up of only 3 stations. The shothole loading technique was also slightly different in that each 12 m hole was loaded only once with nine individual 2 ounce charges strapped to lengths of dowel and dirt tamped. The bottom 3 charges were fired first and vertically stacked for the forward record, indicated by the number 3 in Fig. 6. Following the roll-up of 3 stations, the middle 3 charges were fired for the second record with the top 3 charges fired for the last record, indicated by the number 1.

The section, shown in Fig. 8, is of very high quality, making the identification of numerous Tertiary reflectors as well as a channel in the centre of the line quite easy. Legoe No. 1, located on the southeast end of the line provides stratigraphic control, while it is presumed that North Maslin Sands infill most of the channel. Again there is very good correlation between the channel and the low on the gravity profile.

CONCLUSIONS AND RECOMMENDATIONS

Collating all the available data, the indicated outline of the channel is as shown in Fig. 9. The northeast part of the channel is based purely on gravity data and is therefore not particularly well defined. The channel is approximately 1 800 m wide and extends northeast from Port Gawler for at least 5 km and possibly up to 10 km or more. The channel is presumed to be filled with an average thickness of 20 m of North Maslin Sands which should have sufficiently high porosity and permeability to constitute good reservoir. Subsequent Cainozoic deposition has buried this channel to a depth of approximately 350 m below present day ground surface. Near Port Gawler the channel has a southwest gradient of approximately 1 in 700; however, the gradient is expected to increase to the northeast to a more favourable value.

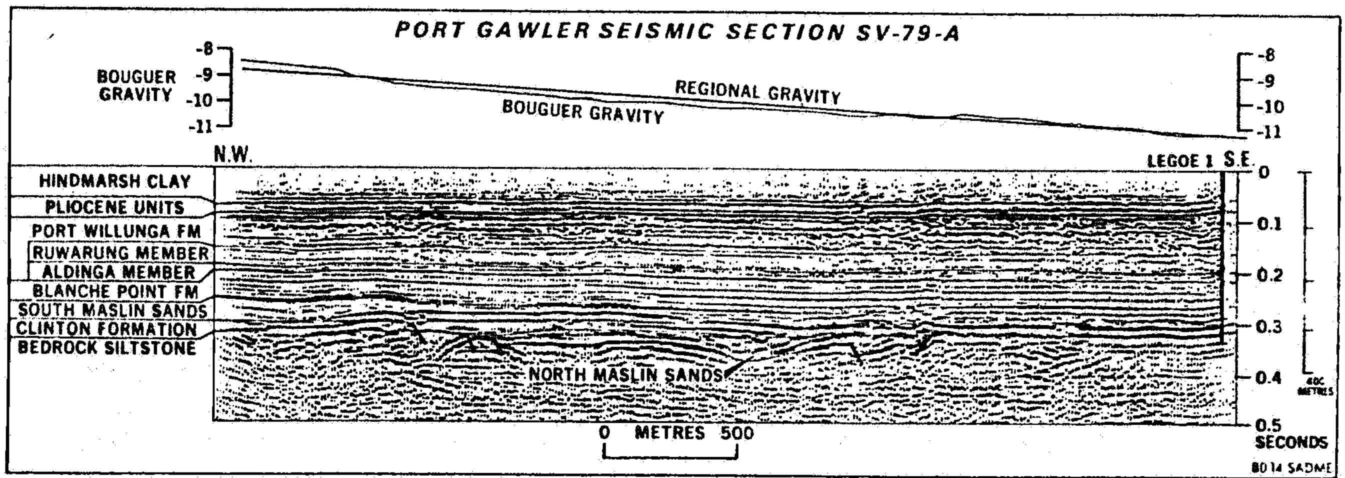

FIGURE 8

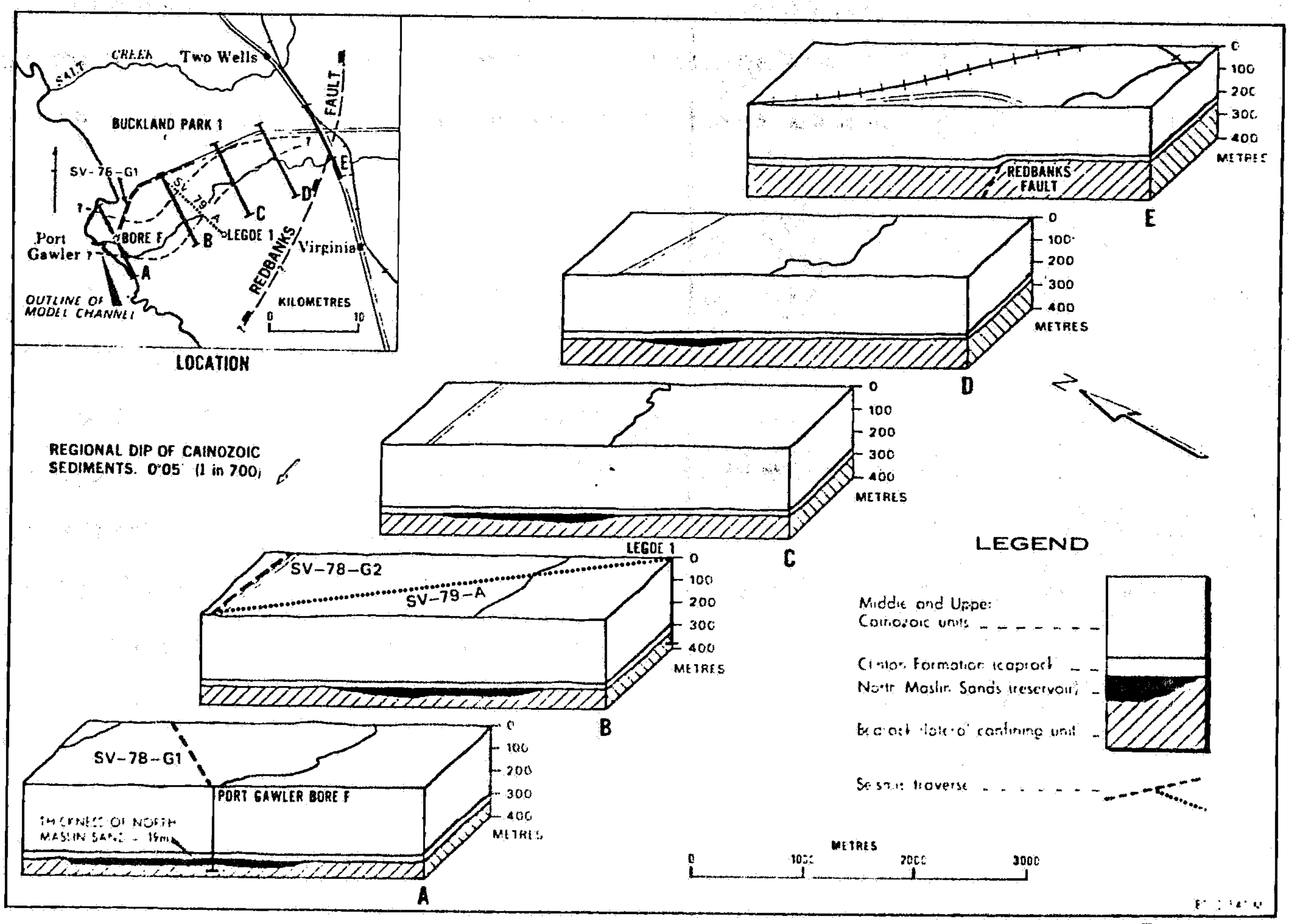

FIGURE 9

The overlying caprock of clays and lignites is approximately 20 m thick and forms a sheet-like body which infills the uppermost part of the channel and directly overlies bedrock on either side. The underlying bedrock, tight limestone near Port Gawler and weathered clayey siltstone to the east, probably has low permeability similar to that of the clays and lignites.

The present data therefore indicate favourable reservoir and seal conditions for the storage of natural gas in the channel, although its headward extent and configuration is not yet fully defined. At this stage the storage capacity of the reservoir is difficult to estimate, but a figure near the minimum requirement of 280 million m^3 (10 BCF) is expected.

That is the status of the project to date but a further three stage exploration programme has been recommended (Cockshell, 1979). The first stage is to drill a stratigraphic well in the centre of the channel on seismic line SV-79-A (Fig. 8) to confirm the presence of the potential reservoir and caprock. Following this stage, providing suitable results are obtained, a second well is proposed to test caprock integrity and reservoir characteristics. The third stage is the shooting of detailed high resolution seismic reflection lines northeast of Legoe No. 1 to define the channel geometry, the location of these lines being based on detailed gravity data.

These recommendations have been put forward to the Pipelines Authority of South Australia with a request for funding and it is hoped that the project will be continued to its logical conclusion.

ACKNOWLEDGEMENTS

I thank B.E. Milton of the South Australian Department of Mines and Energy for his useful suggestions in the preparation of this manuscript. I also thank W.K. Harris and J.M. Lindsay for their biostratigraphic studies during the project and their formation of a conceptual model of the Tertiary stratigraphy of the Northern Adelaide Plains.

CDC:NJK

C. D. COCKSHELL

REFERENCES

COCKSHELL, C.D., NELSON, R.G. and COOPER, B.J., 1978: Northern Adelaide Plains Gas Storage Study, Barabba Gravity Low. Unpublished Report S.A. Dept. Mines, Rept. Bk. 78/13.

COCKSHELL, C.D., 1979: Investigation of a Possible Site for Underground Gas Storage in the Northern Adelaide Plains. Unpublished Report S.A. Dept. Mines, Rept. Bk. 79/62.

COOPER, B.J., 1979: Eocene to Miocene Stratigraphy of the Willunga Embayment. Rep. Invest. Dept. Mines S. Aust. 50, pp.1-68.

CORNISH, B.E., 1964: Light No. 1 - Well Completion Report. Unpublished Report S.A. Dept. Mines, Rept. Bk. 59/113.

LINDSAY, J.M., 1965: Stratigraphy and Micropalaeontology of three deep bores, Hundred Port Gawler. Unpublished Report S.A. Dept. Mines, Rept. Bk. 60/51.

LINDSAY, J.M., 1969: Cainozoic Foraminifera and Stratigraphy of the Adelaide Plains Sub-basin, South Australia. Bull. geol. Surv. S. Aust. 42, pp. 1-60.

SEEDSMAN, K.R., 1967: Reflection Seismic Survey - Northern Adelaide Plains, 1964. Mining Review 121, pp 56-59.