PROJECT PACOOTA BOOST

GEOLOGICAL REPORT

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FOREWORD

The following report on the geological aspects of Project Pacoota Boost was compiled at the request of Mr. B. W. Heath, President of Magellan Petroleum Corporation. Mr. Heath also specified that the report should contain sufficient information on Mereenie and Palm Valley fields in central Australia so that officers of the United States Atomic Energy Commission and officers of the United States Bureau of Mines could make a preliminary technical appraisal of the feasibility of fracturing Pacoota oil and gas reservoirs with nuclear explosives. We have attempted to follow these instructions by supplementing the report with technical data from Mereenie and Palm Valley fields.

SUMMARY

Project Pacoota Boost is proposed as a field experiment to determine the utility of nuclear explosives in increasing rates of oil production from tight reservoir rocks of the Pacoota formation in central Australia. Unlocking 15 to 20 percent of the large amount of oil in place in this formational unit in the Mereenie field would reduce Australia's dependence on imported oil and thereby reduce the nation's foreign exchange requirements.

Large quantities of hydrocarbons are present in the Pacoota formation in Mereenie and Palm Valley fields and large quantities of hydrocarbons are probably present in this formational unit in defined but, as yet, untested prospects in the northern Amadeus basin. The Pacoota is a thick sheet sand which has considerable storage capacities in traps having large areas of closure despite the low average porosity in Pacoota reservoirs.

Nuclear explosive stimulation of Pacoota reservoirs is geologically feasible. The Pacoota formation is composed of hard, brittle rocks which should fracture extensively when subjected to the forces generated by nuclear explosives. Sediments overlying the Pacoota in the Mereenie field are of sufficient thickness to satisfy all safety requirements, according to published test data.

The Mereenie area is uninhabited at present so there is no possibility of damaging any buildings by ground shock.

Because of the magnitude of beneficial effects that would result from successful nuclear stimulation of Pacoota reservoirs, we recommend that the feasibility of Project Pacoota Boost be determined.

INTRODUCTION

Project Pacoota Boost is proposed as a field experiment to determine the utility of nuclear explosives in increasing rates of oil production from tight reservoir rocks of the Pacoota formation in central Australia. To date tests of these rocks in the Mereenie field, Northern Territory (Figure 1), have failed to recover oil at commercial rates.

Although recent oil discoveries elsewhere in Australia will decrease the nation's dependence on imported oil, Australia is far from self-sufficient insofar as oil reserves are concerned. Oil imports cost the nation about $280 million a year -- nearly 10 percent of the total import bill. Furthermore, oil consumption is now increasing at the rate of over 7-1/2 percent per year. If nuclear explosive stimulation succeeded in unlocking 15 to 20 percent of the large amount of oil in place in Pacoota reservoirs in the Mereenie field, it could reduce Australia's dependence on imported oil and thus would result in a significant saving in foreign exchange.

The beneficial effects of successful nuclear stimulation in the Mereenie field will not be limited to this one field and they may not be limited to the Pacoota formation. Tight Pacoota reservoir rocks are also present in the Palm Valley field and they are probably present in the undrilled prospects which have been defined by geophysical work in the northern part of the Amadeus basin. Gas shows have been encountered in tight Stairway sandstones in both Mereenie and Palm Valley fields so this formational unit may also be prospective for nuclear stimulation. Similarly, some of the Cambrian sandstones in the northern part of the Amadeus basin appear to have marginal reservoir characteristics.

Project Pacoota Boost, if successful, will reduce the number of wells required for drainage of oil and gas reservoirs in the Amadeus basin thereby reducing the basic cost of energy in central Australia. This should have a significant impact on the development of mineral resources (Figure 2) which to date has been handicapped by the high cost of fuel imported from coastal cities. Reductions in the cost of energy should also stimulate agricultural developments by reducing the present high cost of pumping water from the extensive aquifers of the Amadeus basin. The basin has a very long growing season and soil conditions suitable for raising cotton, citrus fruits, dates, etc.

HISTORY OF PETROLEUM EXPLORATION IN THE NORTHERN AMADEUS BASIN

Frome-Broken Hill Company Pty. Ltd., an exploratory combine of Esso, Mobil, British Petroleum and other companies, conducted semi-reconnaissance, stratigraphic and structural investigations in the Amadeus basin (Figure 3) during 1958 and 1959. The Company then withdrew from the area after concluding that petroleum source rock conditions were generally poor and that marketing conditions were unfavorable because of the geographic position of the Amadeus basin in central Australia. Magellan Petroleum Corporation entered the Amadeus basin in 1960 and since then the Company has carried out a scientifically oriented exploratory program for the purpose of evaluating petroleum prospects on oil Permits Nos. 43 and 56 covering about 20,000 square miles (Figure 3).

The preliminary results of this work were compiled in 1962 for the purpose of interesting other companies in wildcat drilling and seismic exploration on various tracts. Subsequently, agreements were concluded with Exoil Pty. Ltd., Centralia Pty. Ltd., Freeport Sulphur Company of Australia, Farmout drillers, N. L. and Canada Southern Petroleum Ltd. These companies have completed work and earned interests in various tracts shown in Figure 4.

Exoil Pty. Ltd., in its third wildcat well, discovered a large accumulation of hydrocarbons in the Mereenie field in February, 1964. Four shut-in gas wells, one temporarily abandoned gas well and one unsuccessful oil well have now been completed in the field. Another test of the oil zone will be drilled in 1967 and if natural flow rates from the oil reservoirs are low, artificial stimulation of the reservoir rocks will be attempted for the first time in the Amadeus basin.

Magellan Petroleum Australia Ltd., in its first wildcat well, discovered gas in the Palm Valley field in March, 1965. Although the extent and nature of the Palm Valley hydrocarbon accumulation cannot be determined from this one well, the Palm Valley anticline, as defined from surface mapping, is a very large structure so this field like the Mereenie field may be a major discovery.

Wells in both Mereenie and Palm Valley fields produce from the Pacoota formation of Ordovician age so it now appears that this formation is highly prospective on any closed structure where it is overlain by thick impermeable cappings and an adequate cover of younger sediments to protect the cappings.

The search for oil and gas in Cambrian and late Precambrian sediments underlying the petroliferous Ordovician sequence has been less successful. Five wildcat wells have been spudded in lower Ordovician or older sediments and none of these wells has found commercial quantities of hydrocarbons. Oil and gas shows were found in most of the wells but either reservoir rock conditions were poor or the reservoirs were flushed by fresh water which displaced the hydrocarbons originally present in the rocks. However, Cambrian and Precambrian tests drilled to date have been confined mainly to deeply eroded anticlinal structures where potential reservoir rocks had little, if any, protection from downward percolating surface waters. The next well in the Mereenie field, East Mereenie #4, will test these rocks under a thick cover in what should be a much more favorable geologic environment for the preservation of hydrocarbons.

PETROLEUM GEOLOGY

The Amadeus basin, as it has been defined by reconnaissance work, is a westerly trending structural depression between the Arunta basement complex on the north and the Musgrave basement complex on the south. A marine and continental sequence of sediments up to at least 30,000 feet in thickness fills the northern part of the structural depression.

The marine sequence ranging in age from late Precambrian to late Ordovician consists of clastics, carbonates and evaporites which were deposited in shoal water shelf to marginal marine environments. The continental sequence of Siluro-Devonian age consists mainly of synorogenic clastic deposits which thin and become better sorted and finer grained towards the south. These continental deposits were derived mainly from erosion of highlands formed along the northern margin of the basin during the mid-Paleozoic Alice Springs orogeny.

The basin has had an interesting structural history starting with salt flowage in late Precambrian time and culminating with regional folding during the Alice Springs orogeny. A considerable variety of structural features including large folds, intricately folded nappes, thrust faults, diapiric structures, etc. are preserved in the Amadeus basin and along its northern margin.

Detailed geologic work has been done in the Amadeus basin for the purpose of determining the distribution of possible petroleum source rocks, reservoir rocks and impermeable rock units which have served to confine hydrocarbons within the reservoir rocks during the several hundred million years since oil and gas pools accumulated in the sediments. The results of this work may be summarized as follows: petroliferous sediments have been found in Precambrian, Cambrian and Ordovician sequences in the basin; reservoir rocks are more common in younger sediments than in older sediments and, finally impermeable cappings plus some minimum protective cover over cappings appears to be one of the geological essentials for the retention of hydrocarbons in Amadeus basin reservoir rocks.

PETROLEUM SOURCE ROCKS

Petroliferous members are known to be present in late Precambrian sediments (gas flow in Ooraminna No. 1 and geochemical analyses of various rock units); in Cambrian sediments (oil and gas shows in Alice No. 1, Orange No. 1, Ochre Hill No. 1 and East Johnny's Creek No. 1) and in Ordovician sediments (oil and gas in the Mereenie and

Palm Valley fields). These wells are distributed across the northern part of the basin as is shown on Figure 4. Thus within this area all of these sediments regardless of their age apparently contained petroleum source rocks.

RESERVOIR ROCKS

The identification of petroleum reservoir rocks from outcrops is subject to some uncertainty arising from changes in rock characteristics as the result of chemical leaching of some constituents, chemical deposition of other constituents, etc. in the zone of surface weathering. Identifications of reservoir rocks based on core analyses and on quantitative interpretations of electric logs are far more reliable. However, extrapolation of reservoir parameters obtained from a few inches or feet around a well bore to thick rock units extending miles in all directions from the well bore also has obvious limitations as we have learned from experience in the Amadeus basin. These limitations should be kept in mind while reading the following resume on reservoir rocks.

The most favorable reservoir rock unit in the Amadeus basin is the Mereenie sandstone of late Ordovician or early Silurian age. This unit is a blanket sand present throughout the northern part of the basin. It is the main source of water for the town of Alice Springs and it has yielded water at high rates in all wildcat wells which have penetrated the sand. Since the sand is over a thousand feet in thickness in most areas, it is a very attractive target for testing on any structure where capping is present. There is a possibility of encountering hydrocarbons in this unit on the crest of the Palm Valley structure and in prospects located northwest of Palm Valley.

The Stairway sandstone of Ordovician age contains gas in the Mereenie and Palm Valley fields but porosity development is restricted to thin zones. Fractured facies of this unit may have better reservoir characteristics in some of the undrilled prospects in the northern part of the Amadeus basin.

The Pacoota sandstone, the main reservoir rock in Mereenie and Palm Valley fields, has been mapped in some detail. The unit thickens from zero at its southern extremity to over 2500 feet along the northern margin of the basin (Figure 5). Pacoota reservoir rock characteristics range from poor to fairly good. For example, in the Mereenie field the average porosity is 6 percent and the range is from 2 to 14 percent as determined from measurements on 524 core-samples. The permeability range on these same core-samples is from less than 1/10 millidarcy up to 500 millidarcies.

Pacoota reservoir volumes within the area of closure on large structures such as Palm Valley, Mereenie, and most of the Amadeus basin prospects are very large because of the thickness of the unit. This, together with the known petroliferous character of the formation establish the Pacoota sandstone as the most favorable exploratory target found to date in the Amadeus basin.

The middle and upper Cambrian sequence in the Amadeus basin changes from predominently carbonates in the area south of Alice Springs to predominently clastic in the area around Mereenie field. Very much more subsurface control is needed before the reservoir characteristics of this group of intertonguing sediments can be determined. Lower Cambrian sands which are well developed in the area south of Alice Springs have fair to good reservoir characteristics on the Ooraminna structure where they were penetrated by Exoil's wildcat well, Ooraminna No. 1. These sands thin markedly between Ooraminna No. 1 and Highway No. 1 thereby suggesting interesting stratigraphic pinchout possibilities.

Although reservoir characteristics of the late Precambrian sediments appear to be less promising than in the Ordovician and Cambrian deposits, there is very little subsurface control on which to base a reservoir rock evaluation.

CAPPING

The importance of thick impermeable cappings plus a protective cover of sediments over cappings is illustrated graphically in the sketch section (Figure 6) summarizing the results of wildcat drilling on several structures in the northern part of the Amadeus basin. The sketch shows the position of Paleozoic erosion surfaces, the present erosion surface, the fluid content of rocks penetrated by wells, the distribution and thickness of impermeable cappings and finally the thicknesses of protective covers over these cappings on structures tested by the various wells.

Starting with Exoil's wildcat well, East Johnny's Creek No. 1, it will be noted that the present erosion surface cuts well down into the Stairway sandstone on the crest of the East Johnny's Creek anticline so that there is only a thin protective cover above the Horn Valley shale. This "roof" above the Pacoota reservoirs leaked and, as a result, fresh water percolating downward from the surface displaced both oil and salt water from the Pacoota sandstone. Only residual traces of oil remain of what was once a very large oil accumulation.

Moving easterly to the Mereenie and Palm Valley structures, it will be noted that the hydrocarbons in the Pacoota sandstone are covered by thick shale cappings under mantles of younger rocks. Their "roofs" remained tight throughout geologic history and, as a result, hydrocarbons are still present in the reservoir rocks.

Moving still farther east it will be noted that the Ordovician shale cappings (Stokes and Horn Valley formations) thin in this direction and that they are absent on the Orange and Alice structures. Both Alice No. 1 and Orange No. 1 encountered "sand-on-sand" sequences in beds overlying the Pacoota sandstone. Once again fresh water percolating downward from the present erosion surface or from the Paleozoic erosion surfaces displaced salt water and any hydrocarbons that may have been present in the Pacoota formation.

MEREENIE FIELD

The Mereenie field (Figure 7) was discovered in February, 1964 when Exoil Pty. Ltd.'s wildcat well, Mereenie No. 1, came in following a drill-stem test of upper Pacoota reservoirs. The well flowed wet gas at an estimated daily rate of 12 million cubic feet before it was capped.

Six wells have now been drilled on the structure. The Mereenie hydrocarbon accumulation as it is now defined is about 22 miles in length and has an average width of about 1.6 miles. The maximum thicknesses of the gas and oil zones are about 1000 feet and 330 feet respectively (Figure 8). In addition, the Stairway sandstone reservoirs contain wet gas. However, flows from the Stairway reservoirs are relatively small -- usually less than one-half million cubic feet on the drill-stem tests run to date. There is a possibility of employing artificial stimulation to increase the natural production rates from the Stairway sandstone and this may be attempted if stimulation of Pacoota oil reservoirs is successful.

The gross volume of all Pacoota sandstones in the gas reservoir is estimated at 6.6 million acre feet and the gross volume of all Pacoota sandstones in the oil reservoir is estimated at 4 million acre feet. Thus the Mereenie field must be classified as a major discovery in terms of gas and oil in place (See Appendix 1 and Enclosures Nos. 1, 2, 3, 4, 5, & 6).

The amount of economically recoverable oil in the Mereenie field cannot be determined until the factors responsible for low rates of oil production are determined. It may be a commercially significant percentage of the large amount of oil in place if the low natural flow rates encountered to date in Mereenie oil tests are atypical or if the Pacoota reservoir responds favorably to one or more of the conventional reservoir stimulation methods.

At present we cannot predict the results of conventional stimulation methods in the Mereenie field with certainty. However, reservoir rocks lithologically similar to the Pacoota orthoquartzites have responded favorably to stimulation in fields in the United States to the extent that non-commercial flow rates from these rocks have been increased to commercial flow rates.

Only the upper few hundred feet of the Cambrian sequence underlying the Pacoota formation in the Mereenie field has been tested.

East Mereenie No. 4, the next well in the field is programmed to test these older rocks down to a depth of 9000 feet. Since oil shows were encountered in Cambrian sediments in nearby wells, Ochre Hill No. 1 and East Johnny's Creek No. 1 (Figure 4), East Mereenie No. 4 will almost certainly be penetrating Cambrian reservoirs containing hydrocarbons. These reservoirs have been well protected from downward moving surface water, i.e., from flushing. Thus the main exploratory uncertainty in the Cambrian sequence is the quality of its reservoir rocks.

PALM VALLEY FIELD

The Palm Valley field (Figure 9) was discovered in March, 1965 when Magellan Petroleum Corporation's wildcat well, Palm Valley No. 1, encountered gas in the Stairway sandstones at a depth of 5200 feet. The initial flow of 2.5 million cubic feet per day increased to 12 million cubic feet as the well penetrated the Pacoota sandstone at a depth of 5573 feet. This heavy gas flow necessitated changing from air to mud drilling. Subsequently, the well was drilled to 6,658 feet in the Pacoota sandstone (See Palm Valley No. 1 Completion Report, Enclosure 7 for complete well history).

A gas-water contact was encountered about 6,200 feet thereby indicating that the thickness of the gas zone is about 1,000 feet.

Heavy mud, and lost circulation materials added to the mud, damaged the Pacoota reservoir as was determined later by pressure transient tests conducted by H. J. Gruy and Associates, Inc. of Dallas, Texas (Enclosure 8). This "skin" damage was severe as is evident from comparisons of flow rates prior to mudding up with the current absolute open flow potential which is calculated to be 6.3 million cubic feet of gas per day.

This "skin" damage is confined to reservoir rocks close to the well bore and because of this the rate of flow from this well could be increased markedly by using one of the conventional reservoir stimulation techniques. This work will be done when there is sufficient demand for Palm Valley gas to justify the costs of stimulation.

The size of the Palm Valley gas accumulation cannot be determined from the geologic control available at present. Closure on the structure appears to be at least 1000 feet as is indicated by the thickness of the gas zone penetrated in Palm Valley No. 1. The morphology of the structure as determined by surface geologic mapping and north flank seismic control is shown on Figure 9. The structure appears to have lower structural relief than the Mereenie anticline and to have a very much larger area of closure than Mereenie.

Primary porosities in the reservoir rocks penetrated by Palm Valley No. 1 are lower than at Mereenie. However, secondary porosity resulting from fracturing is more extensive than in the Mereenie wells. Primary porosity may be better developed at the proposed location for Palm Valley No. 2 than in Palm Valley No. 1 if changes in reservoir rock characteristics follow the pattern in the Mereenie field where porosity appears to be better in crestal wells than it is in wells on the flanks of the fold. Palm Valley No. 1 is low structurally and the Palm Valley No. 2 location is on the surface culmination of the Palm Valley anticline.

The Cambrian sequence underlying the Pacoota formation in the Palm Valley field has not been tested. Petroleum source rocks are almost certainly present in the Cambrian and any oil or gas accumulations present in deeply buried Cambrian reservoirs could not have been dissipated to the atmosphere -- the problem encountered by Exoil Pty. Ltd.'s wildcat wells on the deeply eroded Ochre Hill and East Johnny's Creek anticlines. Thus once again the exploratory uncertainty in the Cambrian sequence can be reduced to the quality of its reservoir rocks, i.e., whether or not there is adequate development of primary porosity in the rocks and whether or not the extensive fracture systems in the Pacoota sandstones have their counterparts in fractured Cambrian reservoirs.

OTHER PROSPECTS

Five prospects having Pacoota reservoir rocks under capping with ample protective cover were defined by seismic work in 1965 and 1966. Their locations and some pertinent data on the prospects are shown on Figure 10.

The dry hole risk on most of these prospects is very low in our opinion. The possibilities of encountering reservoir rocks having low rates of natural flow of oil and gas are higher. However, the technological tools for improving natural flow rates are available if they are needed.

The Dingo prospect in the southeastern part of the area covered by Figure 10 may have Horn Valley shale capping in the Pacoota formation and, if this is the case, it is a very promising Ordovician prospect. The lower Cambrian Arumbera sand is also prospective on the Dingo structure as it is on the Orange structure.

Orange No. 1 failed to reach the Arumbera sand which, as was mentioned previously, has fair to good reservoir rock characteristics in Ooraminna No. 1 (Figure 4). Testing this sand on at least one of the above structures is an essential part of an evaluation of Cambrian prospects in the Amadeus basin in our opinion.

NUCLEAR EXPLOSIVE STIMULATION OF PACOOTA RESERVOIRS

Nuclear explosive stimulation of Pacoota reservoirs may be a partial solution to a group of geoeconomic problems that have retarded the development of hydrocarbon reserves in this formational unit.

The geologic problems can be summarized as follows:

(1) High original porosities in most Pacoota sandstones have been reduced by welding. Residual porosities are fair in coarse grained, well sorted facies and poor in fine grained facies.

(2) Extensive bioturbation (organic reworking) has mixed sand and silt sized particles in some of the sandstones creating tortuous channelways for movements of fluids thereby reducing permeabilities in these reservoirs.

(3) Geostatic pressures will be higher in most of the Pacoota prospects shown on Figure 10 than in Mereenie and Palm Valley fields because of the greater thicknesses of sedimentary cover over the Pacoota. For this reason, we do not anticipate any decrease in welding of the Pacoota sandstones in these prospects.

(4) The sediments overlying the Pacoota formation are hard, abrasive rocks. Drilling through this cover is very expensive -- the cost per foot ranging upwards from about $50 to over $100.

The economic problems arising from the foregoing are obvious. Rates of oil and gas flow are low from highly welded members in the Pacoota formation and well costs are high. Thus any economic method of increasing production rates from these members could change non-commercial petroleum deposits into valuable oil and gas reserves.

The geologic characteristics of the Pacoota formation are favorable for nuclear explosive stimulation in our opinion. The Pacoota is composed mainly of hard, brittle orthoquartzites which should fracture extensively when subjected to forces generated by explosives. Shale and siltstone members in the Pacoota are thoroughly indurated semi-brittle rocks. Further, the marked planar anisotropicity in the Pacoota sequence will favor block caving from the roofs of cavities produced by explosives.

The Pacoota is a thick sheet sand which is covered by younger deposits throughout most of the northern part of the Amadeus basin. These sheet sands were folded and in places large anticlinal traps, such as Mereenie and Palm Valley, were formed. Storage capacity in most of these traps is high despite the average low porosity in Pacoota reservoirs because of Pacoota thicknesses, large vertical closures and large aereal extents of closure in most traps.

Thicknesses of sediments overlying Pacoota reservoirs in Mereenie and Palm Valley fields and in the Pacoota prospects shown on Figure 10 range upward from a minimum of 3600 feet at Mereenie to over 10,000 feet at Tyler. Thus there is no danger of radioactive contamination of the atmosphere according to published test data on the extent of fracturing resulting from nuclear explosives.

The blanket of sediments separating the Pacoota from the Mereenie formation -- the principal aquifer in the Amadeus basin, is over 2000 feet in thickness on most Pacoota prospects shown in Figure 10. Thus, there is no danger of radioactive contamination of groundwater from nuclear devices having less than 500 kiloton yields according to published test data.

The Mereenie field is about 50 miles from the nearest cattle station and about 100 miles from Hermannsburg Mission (Figure 1) the nearest large permanent settlement. There are no buildings other than skid-mounted sheds at Mereenie so there is no possibility of damaging any permanent buildings by ground shock.

The utility of nuclear stimulation of Pacoota reservoirs could be determined in either Mereenie or Palm Valley fields. However, the cost of the emplacement well would be lower in the Mereenie field where the cover on the Pacoota is much thinner (Figure 6). Furthermore, there is no market for Amadeus gas at present so there is little economic incentive to develop a high deliverability gas well in the Palm Valley field until such time as markets for Amadeus gas are found. In contrast to this, there are strong incentives to "unlock" the Pacoota oil reserves in the Mereenie field.

With these thoughts in mind, we have prepared a sketch showing a nuclear chimney in the Mereenie field (Figure 11) and estimated the size of the chimneys, fractured zones, etc. using the U.S. Atomic Energy Commission parameters for nuclear devices with 50, 100 and 200 kiloton yields (Appendix 2).

The latter exercise demonstrated that there is large storage space in the chimney and a commercially significant amount of oil in place in the fracture envelope surrounding the chimney. This, in turn, led to speculation but no definitive answers on the following questions:

(1) What percentage of the oil in the chimney debris would not be vaporized? What percentage of this oil would be recoverable and what would be the production rates?

(2) What percentage of the oil in the fractured envelope would move into fractures and drain into the chimney? What would be the production rates from the fractured envelope?

(3) What would be the natural oil production rates from Pacoota reservoir rocks located beyond the fractured envelope around the chimney?

(4) Would water coning from below and gas coning from above constitute serious production problems?

We suspect that definitive answers to most of these questions will not be available until a full-scale field test is completed. However, it may be possible to estimate natural production rates from "unstimulated" Pacoota oil reservoirs by analyzing pressure build-up curves obtained from tests of Pacoota reservoirs in East Mereenie #4.

CONCLUSIONS & RECOMMENDATIONS

Nuclear explosive stimulation of Pacoota reservoirs is feasible from a geologic viewpoint. Determining the utility of this stimulation method in the Mereenie field will probably require a full-scale field test.

Because of the magnitude of beneficial effects that would result from successful nuclear stimulation of Pacoota reservoirs, we recommend that the feasibility of Project Pacoota Boost be determined.

Submitted:

Duncan A. McNaughton

William A. Huckaba

Signed: March 31, 1967

APPENDIX 1

ESTIMATES
OF
GAS AND OIL IN PLACE
IN
MEREENIE FIELD

Ap· ·1 6, 1965

MEMORANDUM

To: Dr. Duncan A. McNaughton

From: W. A. Huckaba

Subject: Gas and Oil in Place
Mereenie Field

It is estimated that 1.18 trillion cubic feet of gas and 564 million barrels of oil are in place in the Pacoota reservoir of the Mereenie field. These volumes represent the total gas and oil in place in porous Pacoota sandstone. No attempt was made to omit that portion of the gas and oil that occupies porous zones of low permeability that might not be counted as "pay" in an estimate of recoverable commercial reserves.

In making these estimates, it was assumed that the Pacoota section penetrated by the four wells in the field is representative of the reservoir and that the arithmetic average porosity and total water saturation of sandstone intervals cored is representative of all the sandstone in the Pacoota section.

The areas, average gross thicknesses, and gross volumes of the Pacoota reservoir are as set forth in my memorandum dated March 1, 1965.

Factors used in making these estimates are as follows:

Average Porosity of Pacoota Sandstone (524 core analyses)	6.05 %
Average Interstital Water of Pacoota Sandstone (equals average total water saturation, 267 core analyses)	44.9 %
Reservoir Pressure (estimated at midpoint of reservoir from test pressures)	1,795 psia
Reservoir Temperature (estimated from log temperatures and rule-of-thumb)	165° F
Gas Gravity (from gas analyses)	.74
Gas Supercompressibility Factor (Z)	.82
Estimated Oil Formation Volume Factor (assumed GOR of 800-1 and oil gravity of 50°)	1.5
Area of Pacoota Gas Reservoir	30.571 sq. mi.
Average Gross Thickness of Pacoota Gas Reservoir	478 feet

Factors used in making these estimates (continued):

Gross Volume of Pacoota Gas Reservoir	9,353,285 ac. ft.
Area of Pacoota Oil Reservoir	38.751 sq. mi.
Average Gross Thickness of Pacoota Oil Reservoir	232 ft.
Gross Volume of Pacoota Oil Reservoir	5,756,930 ac. ft.
Portion of Gross Pacoota That is Sandstone (estimated from logs and cores)	70 %

The above factors give in place estimates of 126 MCF of gas per gross acre-foot of Pacoota in the gas zone, and 98 barrels of oil per gross acre-foot of Pacoota in the oil zone. The estimated average gas in place per square mile is 38.6 billion cubic feet and the estimated average oil in place per 80 acres is 1.82 million barrels.

WAH:lp

APPENDIX 2

NUCLEAR EXPLOSIVE CALCULATIONS

MEREENIE FIELD

PACOOTA RESERVOIR, MEREENIE FIELD, NORTHERN TERRITORY, AUSTRALIA

CALCULATED RUBBLE CHIMNEY STORAGE CAPACITY AND FRACTURED ROCK RESERVOIR VOLUME
RESULTING FROM
CONTAINED UNDERGROUND NUCLEAR EXPLOSIONS

Explosive Energy, Kilotons (W)	50	100	200
Constant for Rock Medium (C)[1]	265	265	265
Average Overburden Density, Grams/cc (ρ)	2.45	2.45	2.45
Depth of Overburden, Feet (h)	4,800	4,800	4,800
Constant for Rock Type (k)[1]	5	5	5
Chimney Radius, Feet (Rc)[2]	94	119	149
Chimney Height, Feet (H)[3]	470	595	745
Chimney Volume, Cu. Ft. (Vc)[4]	13,000,000	26,500,000	52,000,000
Estimated Chimney Porosity (ϕ)	.25	.25	.25
Chimney Pore Space, Ac. Ft. (Cp)[5]	75	152	298
Thickness of Oil Zone, Feet (To)	330	330	330
Oil Shrinkage Factor (F)	1.5	1.5	1.5
Chimney Oil Capacity, Bbls. (Oc)[6]	270,000	435,000	680,000
Unit Gas in Place, 1000^2 Cu. Ft./Ac. Ft. (Gu)[7]	5.4	5.4	5.4
Chimney Gas Capacity, MMCF (Gc)[8]	120	365	895
Fractured Rock Constant (α)[9]	3 to 5	3 to 5	3 to 5
Fracture Radius, Feet (Fr)[10]	282 to 470	357 to 595	447 to 745
Fractured Rock Area, Acres (Fa)[11]	5.1 to 15.2	8.2 to 24.5	12.8 to 38.4
Net Oil Column Sand, Feet (Tn)	200	200	200
Oil in Place in Fractured Rocks, Bbls. (Of)[12]	175,000 to 515,000	280,000 to 835,000	435,000 to 1,305,000

(1) Estimated from data from fifteen underground nuclear explosions.
(2) $Rc = (CW^{1/3})/(\rho h)^{1/4}$
(3) $H = kRc$ Measured from shot point to apex.
(4) $Vc = \pi Rc^2 H$ Assumed cavity volume to be equal to volume of a cylinder having these dimensions.
(5) $Cp = (\phi Vc)/43560$.
(6) $Oc = (Cp(To/H)7758)/F$ Oc limited to interval between gas-oil and oil-water contacts in reservoir. If H is less than To omit To/H from equation. F represents loss in volume of reservoir oil due to escape of solution gas when oil is raised to the surface of the ground.
(7) Gu is volume of gas that will occupy 43,560 cubic feet of space at a temperature of 165° f. and a pressure of 1,795 pounds per square inch absolute (in standard cubic feet of gas at 60° f. and 14.7 psia).
(8) $Gc = Cp((H-To)/H)Gu$ Gc limited to portion of chimney above gas-oil contact.
(9) Measured and calculated distances from shot point to limit of fracture enhanced permeability resulting from nuclear explosions range from 2 to 8 times the radius of the chimney.
(10) $Fr = \alpha Rc$
(11) $Fa = ((\pi Fr^2)-(\pi Rc^2))/43560$.
(12) $Of = (FaTn)170$ Oil in place estimated to be 170 barrels per acre-foot on the basis of 6% porosity, 45% interstitial water, and oil shrinkage factor of 1.5.