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PETROLEUM PROSPECTS

OIL PERMITS 43 & 46

NORTHERN TERRITORY, AUSTRALIA

MAGELLAN PETROLEUM CORPORATION

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by
H. I. Harris

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INTRODUCTION

At the request of Mr. Benjamin W. Heath, President of Magellan Petroleum Corporation, hereinafter referred to as the "Company", I made a preliminary geologic examination of the Amadeus area in March 1960. Shortly thereafter I recommended the Company should apply for a permit covering what then appeared to be the most promising part of the area. Preliminary exploratory work, which was done under my technical supervision, has now been completed and five drilling prospects have been delineated. Six other prospects have been partly delineated.

This report, prepared at Mr. Heath's request, is an exploratory appraisal of the Amadeus area and its prospects. The main objective of the report is to provide management with technical data for planning future exploratory operations.

Section One of the report deals briefly with stratigraphy and refers the reader to Appendix A of the report for a more complete discussion of the same subject. Section Two deals with the evolution of the Amadeus area and introduces the evidence for an ancient geosynclinal trough situated north of the present location of the Macdonnell Ranges. Section Three deals with petroleum geology and discusses the source potentials of the sediments in some detail. Section Four describes prospects that have been sufficiently well defined by surface mapping to qualify as drilling prospects. Section Five describes various prospects requiring geophysical work for the delineation of traps and Section Six of the report deals with the demand for petroleum products in Australia.

Appendix A of the report, entitled "Early Sequence of Interesting Shelf Deposits, Central Australia", was written by Dr. Charles R. Stelck and Mr. Roy M. Hopkins, Jr. Appendix B, prepared by Mr. H. I. Harris, summarizes the Northern Territory regulations covering exploration for oil and gas. Northern Territory Ordinances No. 5 of 1954 and No. 14 of 1954 are enclosed in the pocket on the back of the report.

Maps and illustrations for the report are bound separately in the Map Folio.

ACKNOWLEDGEMENTS

The Company retained Dr. Charles R. Stelck, Professor of Geology, University of Alberta, to undertake a stratigraphic evaluation of the Amadeus area in 1960-61. Dr. Stelck is well qualified for this work having specialized in the Paleozoic stratigraphy of Western Canada and having worked for various oil companies. He did excellent work for the Company and provided the basic stratigraphic framework for later structural studies.

The full burden of the field investigation was shifted to

Mr. Roy Hopkins after Dr. Stelck's departure from Australia. Mr. Hopkins, assisted by Messrs. J. W. Gwinn, Keith M. Williams, and C. M. Laing, completed the structural work and did excellent geological work under climatic conditions which, at times, were very difficult. Mr. Gordon W. Hoffer, a relative novice in drafting, did creditable work in the Company's Alice Springs office.

We are deeply indebted to officers of the Bureau of Mineral Resources. Mr. M. A. Condon directed our attention to the Amadeus area in March 1960 and since then he has shared our interest in the geological concepts emerging from the Company's work. Mr. John N. Casey has been most helpful and Mr. Terry Ouinlan, our first guide to the Macdonnell Ranges, has continued to help the Company's field parties in innumerable ways. Messrs. R. F. Thyer, K. R. Vale, S. Watson and B. Barlow, of the Geophysical Branch of the B.M.R., have reviewed the results of the Company's gravity work in the Amadeus area and have made helpful contributions in the interpretation of data. Finally, we are grateful to Mr. H. S. Taylor-Rogers, Chief Petroleum Technologist of the Bureau of Mineral Resources, and his group, who graciously agreed to run residual hydrocarbon analyses on samples of potential source rocks and to run porosity and permeability analyses on some potential reservoir rocks.

This section on acknowledgements would be imcomplete without expressing my personal gratitude to Mr. Herbert I. Harris, Chief Geologist of Magellan Petroleum Corporation. He had the difficult job of

planning field operations which involved many logistic problems, maintaining efficiency in the field and, last but probably not least, keeping me informed. Many of his suggestions have added significantly to the content and appearance of this report and the Map Folio. For all of these contributions, I am very grateful.

SOURCES OF DATA

The technical section of the report is based on field work that started in June 1960 and continued with only short interruptions until January 15, 1962. This field work consisted of surface reconnaissance work supported by photogeologic interpretations, detailed measurements of stratigraphic sections and semi-detailed mapping of individual prospects using either transit or plane table and alidade for control.

This geologic work was supplemented by numerous "cross-structure" gravity profiles. The gravity survey conducted by International Resource Surveys, Incorporated, of Tulsa, Oklahoma, started in December 1960 and was completed in July 1961.

Geologic and gravity data obtained by trades with other operators were used in planning field work and were found to be particularly useful in defining problems that required further study.

PERMITS

Figure 1 shows the location of the Company's permits in the southern part of the Northern Territory. The Company's permits cover 9,957 square miles divided between O.P.46 (2,818 square miles) and O.P.43 (7,139 square miles). The area of these holdings is close to the Northern Territory legal limit of 10,000 square miles.

TECHNICAL DATA

SECTION ONE

STRATIGRAPHY

STRATIGRAPHY

Geologic reconnaissance work has been done in the Amadeus area by geologists of the Australian Bureau of Mineral Resources and by geologists with oil companies. Prichard and Quinlan (1960, pp. 5-6) outline the work done by the Bureau of Mineral Resources. Frome-Broken Hill Co. Pty. Ltd. had several field parties in the Amadeus area during 1958 and 1959. The results of their work are summarized in reports by Leslie (1960), Wulff (1960), and Taylor (1959). More recently Conorada Petroleum Corporation completed a stratigraphic reconnaissance of the area (Jaccard, 1961). The locations of Frome's sections and panel diagrams are shown on Figure 5 and the locations of Conorada's panel diagrams are shown on Figure 6. The Frome and Conorada reports are available for reference in Dallas.

Since Dr. C. R. Stelck and Mr. Roy M. Hopkins have outlined the stratigraphy of the Amadeus area, the reader should now refer to their report in Appendix A and use Figures 2, 3, and 4 in the Map Folio for geographic and geologic orientation. The following notes on the Company's panel diagrams presuppose that the reader has followed this suggestion and is familiar with the stratigraphic succession in the Amadeus area.

PANEL DIAGRAMS

The east-west panel diagram following the trend of the Macdonnell

Ranges (Figure 7) includes most of the type sections in the Amadeus area. The diagram illustrates the following:

(1) Carbonates, which are the principal Cambrian facies in the east, grade westward into clastics.

(2) The shale-to-sand ratio of the Ordovician sediments increases from east to west and their thickness increases in the same direction.

(3) The overall thickness of the interval from the base of the Pacoota down to the top of the Heavitree appears to be fairly constant insofar as can be determined from the data now available.

The east-west panel diagram (Figure 8) crossing the foreland about 30 miles south of the Macdonnell front has little stratigraphic control below the Cambrian. It does, however, show the facies changes from carbonates to clastics in the Cambrian; the overall westerly increase of shale-to-sand ratio in the Ordovician and the westerly increase in thickness of formational units in the Ordovician. In addition, the diagram shows that the carbonate facies of the Pertatataka at Ooraminna grade westward into a fine clastic facies thus apparently conforming, in part, to the Cambrian facies pattern.

North-south panel diagrams (Figures 9, 10 and 11) linking sections along the Macdonnell front (Figure 7) with sections on the foreland (Figure 8) clearly demonstrate southward thinning of the Ordovician and suggest some southward thinning (Figure 10) of the Cambrian.

NEW FORMATIONAL NAMES

The Mission and Gardiner formations of Cambrian age shown on Figures 8 and 10 are new formational names introduced in this report. Their type localities are located about 5 miles west of Kapatapa Gap (Figure 2).

Prichard and Quinlan (1960) and Stelck and Hopkins (Appendix A) correlated these beds with the Arumbera on the basis of stratigraphic position and lithology. The Arumbera formation generally consists of sandstone, pebble conglomerate, and siltstone.

Three distinct lithologic units are present in the type localities of the Gardiner and Mission formations. The basal unit, consisting of medium grained, pebbly sandstones, is about 450 feet in thickness at Nev's Gap. The name Arumbera is retained for this unit.

The middle unit, consisting of shale and limestone containing Cambrian fossils, is about 500 feet in thickness. This is now mapped as a separate unit and named the Mission formation. Because of its lithologic and faunal affinities with the Hugh River-Jay Creek complex, I believe that the Mission may be a tongue of this complex. Mr. Hopkins and Mr. Harris (personal communication), who do not agree with this interpretation, regard the Mission as a fossiliferous facies of the Arumbera.

However, no fossils have been found elsewhere in the Arumbera.

The upper unit, consisting of sandstone, is about 350 feet in thickness in the hills south of Kapatapa Gap (Figure 2). It is lithologically similar to the Arumbera sandstones seen elsewhere in the Amadeus area. The unit is now mapped separately as the Gardiner formation.

The Arumbera, Mission and Gardiner units have been traced for over 60 miles to the east of Nev's Gap (Figure 8). The abnormal thickness of sand shown in the Mission at Areyonga is due to an error in field measurements that was not corrected until after Figure 8 was completed.

These formational units should be encountered in the subsurface on the James Range "A" and "B" anticlines. Since the Mission contains residual hydrocarbons and has adequate thickness to serve as capping for the Arumbera, this tripartite division serves a useful function in defining exploratory objectives on these structures.

SECTION TWO

EVOLUTION OF THE AMADEUS AREA

EVOLUTION OF THE AMADEUS AREA

The Amadeus area shown on Figure 3 covers part of the ancient Amadeus foreland, part of a deeply eroded positive structural unit bordering the foreland area on the north and part of a post-Ordovician trough filled with continental sediments. The spatial relationships of these various geologic units to one another are shown on the schematic sketch depicting my interpretation of the geologic evolution of the area (Figure 12).

According to this interpretation marine deposits ranging in age from late Proterozoic to late Ordovician accumulated continously in shallow water environments on a shelf forming the southern flank of the Amadeus miogeosyncline. Angular discordances between the various formations comprising this thick sequence are rare and, where present, they appear to be due to local structural growth and not to regional tectonism. Shoal water features include wave ripple marks, crossbedding, biostromal limestones, extensive algal development in the Bitter Springs and Pertatatataka formations, and gypsum and salt in the Bitter Springs and Stokes formations.

The thickest sedimentary section in the area is along the Macdonnell Ranges. Northward thickening of the Ordovician is clearly shown on Figures 9 and 10 and northward thickening of the Cambrian is indicated on Figure 10. Finally, northward thickening of the Proterozoic is suggested by the regional gravity pattern.

The strong negative gravity gradient northward across the foreland is well shown on the Bureau of Mineral Resources gravity map (Figure 13). This gradient of about 1 milligal per mile does not appear to be related to northward thickening of the Pertnjara formation as I had originally assumed. This assumption was tested by comparing Bouguer values in localities where pre-Pertnjara rocks are exposed in the cores of anticlines. The gradients determined by this procedure in the ranges south of the Missionary Plains are higher than the regional gradients obtained by using stations located in areas underlain by the Pertnjara formation. Since the strong gravity gradient now appears to be due mainly to horizontal changes in density in the Cambro-Ordovician and older rocks and since the gradient is higher than would be expected from the observed northward thickening of the Cambro-Ordovician sequence, part of the gradient must be related to density changes in the pre-Cambrian rocks. Either northward thickening of the Proterozoic or northward thickening of salt in the Bitter Springs formation or some combination of the two appear to be responsible for the gradient. A quantitative approach to the gradient using model studies would furnish additional information that would be useful in interpretive work.

The foregoing observations relate to the portion of the foreland covered by the Company's oil permit 43. Extensions of the foreland to the east and west of the permit have not been definitely established. Gravity work done by Mines Administration Pty. Ltd. (Burbury, 1960) for

Flamingo Petroleum Pty. Ltd. on oil permit 54 (Figure 1) indicates the sediments on the foreland thin markedly towards the east. Scattered exposures of basement rocks are present east of oil permit 54 thus indicating that the Amadeus foreland is now separated from the Great Artesian downwarp in Queensland by a basement ridge.

Geologists of the Australian Bureau of Mineral Resources who have been engaged in reconnaissance geologic work along the western extension of the Amadeus foreland have concluded that there was a lower Paleozoic and upper Proterozoic connection between the Amadeus area and the Canning Basin in Western Australia according to Mr. M. A. Condon (personal communication). Their conclusion is certainly not inconsistent with the regional gravity data (Figure 13) which indicate that the strong negative gravity anomaly located south of the Macdonnell front persists to the western edge of the area covered by the gravity map.

The geosynclinal cycle terminated in a post Ordovician orogeny. The Cambro-Ordovician and older rocks were closely folded and uplifted to form a welt located north of the present position of the Macdonnell Ranges. The foreland area to the south was downwarped and became a basin in which the synorogenic Pertnjara clastics were deposited. These continental deposits containing clasts derived from erosion of the welt are up to 20,000 feet in thickness immediately to the south of Macdonnell Ranges. They become finer grained and their thickness appears to decrease markedly to the south.

Folds and diapiric structures in the foreland started to grow long before the mid-Paleozoic orogeny as is shown in unconformities in the Cambro-Ordovician sequence (Figure 8) and by thinning of Ordovician formational units across the Goyder Pass diapir (Figure 20). Upward growth of both the folds and diapirs is attributed to salt flowage in response to differential loading. The folds continued to develop during the mid-Paleozoic orogeny as is demonstrated by the tilted Pertnjara sediments on the flanks of the foreland structures.

The evolutionary sequence outlined on Figure 12 has several features in common with the classical geosynclinal cycle. The intensity of deformation increases from foreland towards the trough; the degree of alteration increases in the same direction; tectonism at the close of geosynclinal deposition created a welt and bordering furrow; and, finally, there is some evidence of igneous activity in the area. Radioactive dating of pegmatitic rocks located northeast of Alice Springs established a Devonian age for this intrusion according to Mr. Terry Quinlan of the Bureau of Mineral Resources (personal communication).

No evidence of any post-Pertnjara orogeny has been found in the area. The major elements of the present topography antedate the epeirogenic subsidence responsible for the deposition of marginal marine to marine, Mesozoic deposits in the area. Flat-lying to gently tilted erosional residuals of these Mesozoic sediments are preserved in the canoe-shaped depressions along the axis of anticlines where they have been partly protected from erosion by resistent rim rocks on the flanks of the folds. Thus the present valley and ridge topography of the foreland folds antedates Mesozoic deposition. During deposition the old surface was partly to completely buried and then exhumed during the present cycle of erosion.

SECTION THREE

PETROLEUM GEOLOGY

DUNCAN A. MCNAUGHTON

PETROLEUM GEOLOGY

Most of the essential requirements for oil accumulation appear to be present in the Amadeus area. Potential reservoirs, potential capping, potential traps are adequate. In addition, there is evidence of structural growth during deposition. Source conditions constitute the greatest uncertainty due to (1) the age of some of the potential source beds and (2) the depositional paleoenvironments.

Since source beds appear to be the critical element, they are discussed first.

SOURCE BEDS

An overall appraisal of the source potential in the Amadeus area requires the evaluation of the following:

(1) Hermannsburg oil seep.

(2) The paucity of oil seeps in the Amadeus area.

(3) Residual hydrocarbons in Cambrian and Ordovician sediments.

(4) Residual hydrocarbons in Proterozoic sediments.

(5) Foreland depositional environments.

(6) Trough depositional environments.

1. Hermannsburg oil seep

The location of the seep and the data obtained from the analysis of oil in the seep are shown on Figure 14. Other data on the seep are included in the following letter from Mr. Roy Hopkins:

"A probable oil seep in alluvium is present along a creek bank about four miles north of Hermannsburg. It consists of sand which appears to be impregnated by oil. The sand has an oily smell, and when it is mixed with water an oily scum floats on the surface. A greasy coating is left on the hands when the sand is rubbed and sifted through the fingers. A small hole dug at the site encountered two feet of loose sand underlaid by gravel. I collected a sample of the sand and sent it to you by air freight so that you may have it analyzed.

"I first learned about the possible seep from Mr. Wally Jutner of Hermannsburg who brought a sample of the sand to the office. It had been given to him by some Aborigines who said that the seep had been there for years.

"If this is a bonafide oil seep we should be thinking about potential structural traps beneath the central Missionary Plain. One possibility that comes to my mind would be a structure formed by the downwarping of the pre-Pertnjara strata along the Macdonnell Ranges front resulting from the great thickness of Pertnjara sediments that were deposited along the front."

After receiving the sample and the analysis of the sample we became concerned with the possibilities of either intentional or unintentional "salting" with crankcase oil and we cabled asking Mr. Hopkins for additional information on the seep. He excavated the seep to a depth of six feet and found saturated sand to that depth (Figure 15) thus eliminating our concern with salting. Consequently my thinking on the source potential of the area is now based on the conviction that there is one verified oil seepage in the area.

The source of oil in the seep is not known. Alluvium in the Hermannsburg area rests on an erosion surface that cuts across gently tilted Pertnjara sandstones as is shown on Figure 14. The Pertnjara is a continental deposit dumped into the depression formed during the mid-Paleozoic orogeny. With the possible exception of a shale member exposed at the base of the formation in the hills south of Hermannsburg, it does not have any of the commonly accepted source bed characteristics. If this shale is the source of the oil, the problems involved in migration differ only in amount of vertical migration since both the shale and Cambro-Ordovician sources require upward, transverse-to-bedding migration for several thousand feet. A marine source appears to me to be more probable even though it involves a substantially greater distance of vertical migration than the shale at the base of the Pertnjara.

2. <u>Paucity of oil seeps in the Amadeus area</u>.

The discovery of the oil seep at Hermannsburg is a salutary reminder that our knowledge of this sparsely settled area is only fragmentary. Nevertheless, I would be very surprised if many seeps are discovered on

Magellan's lands. The present topography dates back to the Mesozoic, as was explained previously, so we are dealing with very old land surfaces. The chances of seepages being maintained for 70 million or more years are rather remote in my opinion.

3. Residual hydrocarbons in Cambrian and Ordovician sediments.

Residual hydrocarbon analyses of outcrop samples were made in the Bureau of Mineral Resources Laboratory in Canberra. The results of these analyses are shown in Figure 16. Samples 7-29-1 (Jay Creek), 7-29-2 (Jay Creek), 7-29-3 (Jay Creek), 8-2-1 (Horn Valley), 8-2-2 (Horn Valley), 8-2-3 (Horn Valley), 8-3-1 (Jay Creek), and 8-8-61 (Mission) are from the lower Paleozoic. With the exception of sample 7-29-1, all samples were collected by the writer from limestones possessing either a foetid odor or a sour "refinery odor." Sample 7-29-1 was obtained from an outcrop of limestone that appeared to be fairly characteristic of several hundred feet of underlying and overlying limestones. It had no odor.

The residual hydrocarbon content of these samples ranged from zero (7-29-1, 8-2-2 and 8-3-1) up to a 44 barrels per acre foot (8-2-1). This range is comparable to that reported by Hunt and Jamieson (1958, p. 736) who state, "The quantity of hydrocarbons in non-reservoir rocks such as shales was found to range from as little as 0.2 barrels per acre foot in the Morrison formation of Wyoming to as much as 65 barrels per acre foot in the Woodford shale of Oklahoma. These non-reservoir rocks contain no visible evidence of oil, even under close microscopic examination."

4. Residual hydrocarbons in Proterozoic sediments.

Positive residual hydrocarbon analyses have been obtained from outcrop samples of the Bitter Springs and Pertatataka formations.

The first suggestion of source potential in the Proterozoic rocks was from Dr. Stelck (personal communication) who pointed out that geologic conditions in the Amadeus area were unique, at least from the North American viewpoint, in that deposition was more or less continous from the late Proterozoic to the late Ordovician; the Proterozoic sequence was completely unaltered, and life appeared to be abundant in the Proterozoic. His final observation that the "little critters raining down on the bottom were, in their ignorance, quite unaware of the significance of the dawn of the Cambrian," appeared to be somewhat whimsical to me - I had been well indoctrinated with the concept that the source potential of sediments decreased rapidly in the lower Paleozoic and was negligible, for all practical purposes, below the Ordovician.

The discovery of residual hydrocarbons in these old rocks supported Dr. Stelck's original appraisal and weakened my initial prejudice. The first inkling of this support was found in a Frome-Broken Hill memorandum that was written by Mr. A. A. Weegar (Leslie, 1960) who stated, "Although neither is given a high rating, the Pertatataka, Proterozoic and the Pertaoorta (Cambrian group as used by Frome) formations appear to have had the greatest potential as source beds. Laboratory analysis of one sample of Pertatataka limestone from Illalgra yard (24°20'S, 132°55'S) indicated fair source rock." Subsequently, Mr. Harris and I discussed this test with Mr. Osborne, General Manager of Frome-Broken Hill Pty. Ltd., and he informed us that the sample was sent to United States where it was analyzed in the Jersey Production Research Laboratory.

Still another surprise was in the offing - several geologists with the Bureau of Mineral Resources who had been working near the Western Australian border along the projected trend of the Amadeus foreland visited the Company's office in Alice Springs in July 1961. During a general discussion they mentioned they had obtained positive hydrocarbon analyses (up to 15 barrels per acre foot) from dolomitic limestones that appeared to be equivalent in stratigraphic position to similar rocks in the Bitter Springs formation in the Amadeus area.

These positive analyses led to the initiation of a trial sampling program in August 1961. After receiving some encouragement from this program (Figure 16) we started more detailed sampling particularly of the Pertatataka and Bitter Springs formation. Analyses of these samples are not yet available.

While these positive analyses do not constitute proof that the Proterozoic source material was adequate to generate commercial quantities of oil - only a commercial discovery can accomplish this - they do prove that some source material was present in the rocks. This, in itself, is encouraging since Proterozoic source and reservoir beds are in contact over large areas on the Amadeus foreland (Figure 16).

5. Foreland depositional environments.

The coarser clastic sediments in the Proterozoic, Cambrian and Ordovician show unmistakable evidence of deposition in shallow water shelf environments. The finer clastic sediments, calcareous sediments, and evaporites, although also deposited mainly in shallow water, show evidence of more complex depositional paleoenvironments. Reference to Figure ~~16~~ 17 may be helpful to the reader in following the discussion of source potential in individual formational units.

Bitter Springs - the presence of salt and gypsum in the formation indicates deposition in barred basins which may have been legacies from silled basins in deeper water as has been noted elsewhere in the world (Weeks, 1958, p. 17).

The association of dark colored carbonates and shales is reminiscent of some of the Cretaceous sequences in northern Colombia and western Venezuela. If the Bitter Springs formation was Cambrian or younger, I believe most geologists would consider it to be a potential source rock.

Pertatataka - this unit has not been studied in sufficient detail to interpret depositional paleoenvironments. Although thick shale members in the formation are confined mainly to valleys where outcrops are partly to completely covered, composite sections could be compiled from detailed work in several areas in the foreland. This investigation will be undertaken by the Company in 1962.

The Pertatataka contains a greater variety of lithologic types than other formational units. Sandstones, calcarenites, oolitic limestones, limestones including some with petroliferous odors, green shales, red shales, etc. are present in the formation. Glauconite is a rather common mineral in the sandstones, calcarenites and oolitic limestones. It appears to be authigenic in origin. The complexity of the lithologic suite indicates variations in depositional environments and variations in sources of sediments.

Jay Creek - limestones having petroliferous odors and residual hydrocarbons appear to be associated with a basal reefoid facies.

Mission - this unit, composed of fossiliferous limestones, black limestones (petroliferous odor), green shales, etc., appears to have been deposited in relatively quiet waters. The Mission has interesting source possibilities in my opinion.

Hugh River - this unit, composed mainly of shale and thinly bedded limestones, grades westerly into sandstones and easterly into calcareous rocks. It is shown as a possible source unit on Figure 16 primarily due to its deposition in relatively quiet waters. A more detailed study of this formation will be undertaken by the Company.

Stokes-Horn Valley Complex - the Stokes and Horn Valley formations had varied depositional paleoenvironments as is indicated by the presence of some gypsum and salt in the section, the presence of marcasite nodules and the irregular development of Stairway sandstone members in the complex - please refer to Figures 17 and 20. In my opinion, the Stokes-Horn Valley complex has fairly attractive source possibilities particularly in the western part of oil permit 43.

6. Trough depositional environments.

Erosion during the mid-Paleozoic orogeny removed the trough sediments (Figure 12) from the Amadeus and thereby compounded the already complex source potential problem. Since the foreland sediments thicken northward, fluids expelled from the rocks during the compaction process probably migrated southward from the trough across the foreland. This situation is not unique to the Amadeus area since it is characteristic of all foreland-geosynclinal transition zones. Elsewhere in the world where the trough deposits accumulated in deeper water than the shelf deposits, shelf margins are favorable locii for the accumulation of oil due to the proximity of source and reservoir beds. Unfortunately, these relationships cannot be demonstrated in the Amadeus area since the trough sediments are not present.

RESERVOIRS

Rocks having reservoir characteristics are well distributed throughout the stratigraphic section (Figure 17). With the exception of superficial silicification due to deposition of chalcedony, none of these potential reservoirs is altered in the central Amadeus area. Most of the sandstones are clean and friable. Selected samples submitted to the Bureau of Mineral Resources Laboratory for porosity and permeability determinations had good to fair reservoir rock characteristics with porosities ranging from 22 up to 37 percent and permeabilities ranging from 18.5 up to 7,400 md. Sandstones in the Areyonga formation, a poorly sorted fluvioglacial deposit containing a high percentage of clay minerals, have low porosities and permeabilities.

Most geologists who have visited Alice Springs for the purpose of examining the section have seen these rocks only in the classical localities along the Macdonnell front. The sandstones in these localities are thoroughly indurated and are perhaps best described as quartzites. Some geologists with the Bureau of Mineral Resources have attributed the induration to superficial silicification (personal communication), but this process, although responsible for some "case hardening", is obviously less important than "pressure welding" due to deep burial and movements associated with folding (Figures 18 and 19). Low grade metamorphic rocks are present in the Heavitree and Pertatataka formations in several localities a few miles north of the Macdonnell front thus indicating the increasing degree of deformation from foreland northwards towards the ancient trough.

Thus, to summarize these observations, most of the foreland sandstones have fair to good reservoir characteristics. These favorable characteristics decrease northward and may be absent on any prospect that is discovered along the Macdonnell front.

Potential reservoirs in limestones and dolomites were not examined in any detail. Porous dolomitic members are present in the Pertatataka formation and porous limestone members are present locally in the Jay Creek formation.

Potential fractured reservoirs are present in the Bitter Springs formation. Evaporitic members have flowed as the result of loading and tectonism and the carbonate members have crumpled during flowage.

Differences in plasticity of the various units is well illustrated in numerous localities along the Macdonnell front. One of the most striking illustrations is located immediately east of Undoolya bore which is 20 miles east of Alice Springs (Figure 2). Here the highly deformed Bitter Springs is preserved in a strike valley separating steeply tilted, massive flatirons of the Heavitree and Pertatataka. Isoclinal and recumbent folds with random orientations characterize the Bitter Springs whereas the underlying and overlying beds trend easterly and dip southerly for as far as the eye can see.

The omnipresent network of healed fractures in the Bitter Springs are the legacies of this deformation. Since much less deformed calcareous rocks entirely lacking in significant primary porosities have proved to be excellent reservoirs elsewhere in the world, and since there are residual hydrocarbons in the unit, I consider the Bitter Springs formation as a potentially important exploratory objective in the Amadeus area. For this reason, I recommend that tests of structures in the eastern Amadeus area should include penetrations of the upper part of the Bitter Springs as is shown on Figure ~~16~~ 17.

CAPPING

Shales are well distributed throughout the section as is shown on Figure ~~16~~ 17.

TRAPS

Anticlinal folds and domal uplifts associated with salt intrusions create large potential traps for oil accumulation in the area.

STRUCTURAL GROWTH

Structural growth during deposition, while not an absolute essential for oil accumulation, is an encouraging "plus" in any area. At least some of the structures in the Amadeus area have this desirable characteristic.

The Goyder Pass diapir (Figure ~~19~~ 20) started to grow in the late Cambrian or early Ordovician and continued to grow through the Ordovician. The Pacoota and younger formations thin across the crest of the structure thus indicating that doming due to salt intrusion created a submarine bank over the structure. The relationships shown on the photomosaic (Figure 19) may be regarded as a cross section of the structure prior to tilting during the mid-Paleozoic orogeny as was noted by Prichard and Quinlan (1960, p. 43-44). However, Prichard and Quinlan attributed the structure to tectonism at the close of the geosynclinal cycle and they did not recognize that structural growth was initiated long before this mid-Paleozoic orogeny.

The Goyder Pass diapir is not unique. Similar though much less deeply eroded structures are responsible for Gosse's Bluff, the Carmichael prospect and possibly other prospects. Since most of the anticlines appear to have salt cores and since there is no evidence of regional folding prior to the mid-Paleozoic orogeny and since disconformities are fairly common throughout the section (Figure ~~16~~ 17), I believe that salt movements in response to loading started probably in the late Proterozoic and continued through the mid-Paleozoic orogeny. If this interpretation is correct, structural conditions for the entrapment of oil should have been favorable throughout the Cambrian and Ordovician.

SECTION FOUR

DESCRIPTIONS

OF

DRILLING PROSPECTS

Five drilling prospects located on closed anticlines have been delineated by surface geologic mapping. These anticlinal traps contain large volumes of potential reservoir rocks as is shown in the following tabulation.

Prospect Name	Estimated Volume of Potential Reservoirs (Acre-Feet)
Ooraminna	17,000,000
James Range "A"	12,300,000
James Range "B"	21,900,000
James Range "C"	1,390,000
Todd River	19,700,000
TOTAL	72,290,000

Ooraminna Anticline

The Ooraminna anticline is located about 25 miles southeast of Alice Springs (Figure 2). The road from Alice Springs to Santa Teresa Mission crosses the structure and the Alice Springs-Port Augusta Railway is close to the structure as is shown on Figure 21.

A broad, relatively low relief anticlinal fold constitutes the potential trap. The fold is slightly asymmetric with a steeper southern limb as shown on the cross section on Figure 21. A well defined negative Bouguer gravity anomaly (Figure 22) is present along the crest of the fold to the east of the proposed well location. Since the anticline is located on the southeastern flank of the regional depression containing the Amadeus foreland deposits, the regional gravity gradient is to the northwest. Subtraction of this regional gradient would extend the residual negative anomaly eastward along the crest of the fold.

Primary objectives of the proposed test of this potential trap are the sandstones in the lower part of the Areyonga formation and fractured carbonates in the upper part of the Bitter Springs formation - please refer to Figure 17 and the composite subsurface section at proposed location on Figure 21. Secondary objectives include sands in the upper part of the Pertatataka formation as well as any porous carbonates that may be present in this unit. All of these objectives will probably be penetrated by a 6,000 foot test.

Figure 23 shows the structural and isopachous data on which the following volumetric estimates are based.

Name of Potential Reservoir	Estimated Area of Closure (Acres)	Est. Rock Volume in Trap: Total Vol. (Thousands) (Ac-ft)	Est. Rock Volume in Trap: Res. Vol. (Thousands) (Ac-ft)
Lower Areyonga	23,000	8,700	7,000 (1)
Bitter Springs	23,000	10,000	10,000 (2)
Estimated total volume potential reservoir rocks			17,000

(1) Sandstones

(2) Fractured carbonates

An access road about 2 miles in length must be constructed from the northern margin of the Arumbera core to the well site. This construction will not be difficult or expensive. Water for drilling purposes will require a shallow water well either at the drill site or in the nearby creek bottom.

James Range Anticline "A"

This large anticline shown in the frontispiece of the Map Folio is located about 70 miles southwest of Alice Springs. A track from Orange Creek Homestead (Figure 2) on the Alice Springs-Adelaide road provides access to the structure.

The James Range "A" structure is one of the anticlinal culminations along an uplift extending about 120 miles southeasterly from the north end of the Gardiner Range to the Alice Springs-Adelaide road. Figure 24 shows the surface geology, structural cross sections, Bouguer profile and the negative residual gravity anomaly along the axis of the anticline. This anomaly is attributed to the proximity of salt in the Bitter Springs formation.

Primary objectives of the proposed test of this potential trap are sandstones in the Gardiner, Arumbera, and Areyonga formations and fractured carbonates in the Bitter Springs formation (Figure 17). Secondary objectives include sandstones and any porous carbonates that may be present in the Pertatataka formation. All of those objectives will probably be penetrated by a 7,000 foot test as shown in the generalized columnar section at the proposed location (Figure 24).

Figures 25 and 26 show the structural and isopachous data on which most of the following volumetric estimates are based.

Name of Potential Reservoir	Estimated area of Closure (Acres)	Est. Rock Volume in Trap Total Vol. (Thousands) (Ac-Ft)	Res. Vol. (Thousands) (Ac-Ft)
Gardiner	13,000	5,600	3,900(1)
Arumbera	10,000	4,800	3,400(1)
Areyonga	6,000	4,000	1,000(1)
Bitter Springs	5,000	4,000	4,000(2)
Estimated total volume potential reservoir rocks			12,300

(1) Sandstones

(2) Fractured carbonates

This James Range "A" anticline is the most attractive prospect that has been mapped to date by the Company in my opinion. It is less deeply eroded than most of the other drilling prospects; source and reservoir facies are relatively favorable; and the structure appears to be simple.

The proposed location is about 125 miles from Alice Springs by road. Only a jeep track exists for the final 15 miles so some clearing and grading of this track will be necessary before moving drilling equipment to the well location. Water for drilling purposes and camp use is available throughout the year in the Finke River which is about 4 miles west of the proposed location.

James Range Anticline "B"

This large anticline is an en-echelon continuation of the James Range "A" anticline. It is about 60 miles southwest of Alice Springs.

The "B" structure has more structural relief and is more deeply eroded than "A" as may be seen by comparing Figures 27 and 25. It is slightly assymetric with a relatively steep southern flank where dips up to 45° have been recorded. No gravity work was done on the structure.

Primary objectives of the proposed test of this potential trap are sandstones in the Arumbera and Areyonga formation and fractured carbonates in the Bitter Springs formation. Secondary objectives include sandstones and any porous carbonates that may be present in the Bitter Springs formation.

Figures 28 and 29 show the structural and isopachous data on which most of the following volumetric estimates are based.

Name of Potential Reservoir	Estimated area of Closure (Acres)	Est. Rock Volume in Trap: Total Vol. (Thousands) (Ac-Ft)	Est. Rock Volume in Trap: Res. Vol. (Thousands) (Ac-Ft)
Arumbera	14,000	6,700	4,700(1)
Areyonga	12,000	8,900	2,200(1)
Bitter Springs	10,000	15,000	15,000(2)
Estimated total volume potential reservoir rocks			21,900

(1) Sandstones

(2) Fractured carbonates

The proposed location is about 75 miles from Alice Springs by road. Only a jeep track is available for the final 22 miles so some clearing and grading of this track will be necessary before moving drilling equipment to the well location.

A shallow water well will be needed in order to provide water for drilling purposes and camp use. Mr. Roy M. Hopkins has selected a location for the well about 2 miles southeast of the proposed test.

James Range Anticline "C"

This structure located about 50 miles south of Alice Springs is an en-echelon continuation of the James Range "B" anticline.

The James "C" anticline is the weakest drilling prospect. Surface geological work has demonstrated that the fold is closed and has a minimum closure of about 500 feet. However, the south flank of the fold is partly concealed by alluvium (Figure 30) so the structural picture is less definitive than on other drilling prospects. Before drilling the structure, it would be advisable to shoot several lines across the south flank in order to verify and possibly strengthen the structural interpretation shown in Figure 31.

The primary objectives of the proposed 9,000 foot test will be any porous carbonates in the Jay Creek; the sandstones in the Gardiner, Arumbera and Areyonga formations; and fractured carbonates in the Bitter Springs formation. The test will be located in an area where there appears to be a transitional facies change from the Hugh River-Gardiner-Mission-Arumbera sequence on the west to the Jay Creek-Arumbera sequence on the east as is shown on Figure 17.

Because of this transition, the volumetric estimates summarized in the following tabulation are subject to some uncertainty.

Name of Potential Reservoir	Estimated area of Closure (Acres)	Est. Rock Volume in Trap: Total Vol. (Thousands) (Ac-Ft)	Res. Vol. (Thousands) (Ac-Ft)
Gardiner	3,300	600	400 (1)
Arumbera	2,600	500	360 (1)
Areyonga	2,600	500	130 (1)
Bitter Springs	2,600	500	500 (2)
Estimated total volume potential reservoir rocks			1,390

(1) Sandstones

(2) Fractured carbonates

The proposed location is about 55 miles southwest of Alice Springs. The Alice Springs-Adelaide road crosses the structure. Water for drilling purposes can be obtained from a bore about two miles south of the proposed location.

Todd River Anticline

The Todd River anticline is about 30 miles southeast of Alice Springs (Figure 2). The Alice Springs-Todd River Homestead Road is located about 1/2 mile north of gravity station No. 1024 shown on Figure 13.

A broad, relatively low relief, anticlinal fold constitutes the potential trap (Figure 33). This structure is complicated by faulting south of gravity station No. 1009 but elsewhere it appears to be fairly simple.

A strong negative gravity anomaly coincides spatially with the axis of the anticline - please refer to Figure 13 and note the reading of minus 105.1 milligals at station 1009. This anomaly is attributed to the proximity of salt in the Bitter Springs formation (Figure 33).

Primary objectives of the Todd River test are sandstones in the lower part of the Areyonga formation and fractured carbonates in the Bitter Springs formation. Secondary objectives include sands in the Pertatataka formation as well as any porous carbonates that may be present in this unit. All of these objectives could be tested by a 4,000 foot well unless thrust faults are encountered in the subsurface.

Figure 33 shows the structural and isopachous data on which the following volumetric estimates are based.

Name of Potential Reservoir	Estimated area of Closure (Acres)	Est. Rock Volume in Trap Total Vol. (Thousands) (Ac-Ft)	Res. Vol. (Thousands) (Ac-Ft)
Lower Areyonga	21,000	9,600	7,700(1)
Bitter Springs	21,000	12,000	12,000(2)
Estimated total volume potential reservoir rocks			19,700

(1) Sandstones

(2) Fractured carbonates

The proposed location is about 37 miles by road from Alice Springs. Only a jeep track exists for the final 7 miles so some clearing and grading will be necessary before moving drilling equipment to the location. A shallow water well along the creek draining the valley in the core of the structure should provide sufficient water for drilling and camp use.

SECTION FIVE

DESCRIPTIONS OF OTHER PROSPECTS

Traps suitable for drilling cannot be defined by surface geologic work on a number of structures due to possible structural complications (Waterhouse); masking of structure by recent deposits (Mereenie, Gosse's Bluff, Northwest Ooraminna and Carmichael); and possible masking of structure by the Pertnjara formation (Palm Valley). Partial definition of some of these structures may be possible with gravity work whereas others will require seismic work.

All of these prospects, with the probable exception of the Carmichael prospect, are located in areas where source and reservoir facies are relatively favorable in the Ordovician or in the Cambrian or in both systems.

Since these prospects are less deeply eroded than the drilling prospects described in the previous section of the report, they will be more attractive to geologists having a strong aversion to exploration in the lower Cambrian and the upper Proterozoic. Furthermore, the oil seep at Hermannsburg is on the flank of one of the structures so the physical proximity of oil and structure in this area may appeal strongly to many geologists.

Waterhouse Anticline

The Waterhouse anticline is located about 25 miles southwest of Alice Springs (Figure 2). The road from Alice Springs to Adelaide skirts the eastern end of the structure as is shown on Figure 34. A track along the Hugh River valley provides access to the valley in the core of the fold.

The Waterhouse structure is one of the larger anticlines on the Amadeus foreland. It can be traced for at least 30 miles and the fold, or an en-echelon fold may extend westerly well beyond the area covered by Figure 34.

A positive gravity anomaly appears to coincide spatially with the Waterhouse axis. This relationship may be unique in the Amadeus area since negative anomalies have been found along the crests of most anticlines. These negative anomalies are attributed, by the writer, to thick salt masses in the Bitter Springs formation which are relatively close to the surface along the crestal zones of the anticlines. The apparent absence of a negative anomaly along the Waterhouse axis suggests that either the Bitter Springs formation is thin or absent in this area or that the Waterhouse anticline differs in structural morophology from the other anticlines. The first explanation does not appear to be probable in my opinion since there is evidence of salt on all sides of the Waterhouse anticline.

The second explanation appears more probable since the Waterhouse anticline is structurally complex in comparison to the other anticlinal prospects in the Amadeus area. The dips on the flanks of the fold are 10° to 15° higher than on other prospects and the Jay Creek shales and limestones in the core of the fold are crumpled in some localities. Although the latter may simply be a manifestation of incompetency in the Jay Creek unit and the structure in the underlying competent Arumbera unit may be much simpler, these features preclude drilling without making a preliminary seismic investigation.

If seismic work demonstrates that the fold is not overly complex, the Waterhouse anticline will have a large potential because of its size and closure. Primary objectives will be the thick sandstones in the Arumbera, sandstones in the Areyonga, and fractured carbonates in the Bitter Springs.

Mereenie Anticline

The Mereenie anticline is located on the western part of oil permit 43 between the Gardiner and Middle Ranges (Figure 2). It is about 140 miles southwest of Alice Springs.

This structure is one of the anticlinal culminations along an uplift extending from the north boundary of oil permit 43 southeasterly for at least 70 miles. The northwesterly extension of the structure is concealed by recent deposits including sand dunes and for this reason it was not possible to demonstrate closure on the anticline (Figure 35).

Potential source and potential reservoir beds are present in the Ordovician in the ranges located north and south of the Mereenie structure - please refer to Figures 9 and 17 for stratigraphic orientation. A relatively shallow test to a depth of 5,000 feet would penetrate the important Ordovician objectives at point X on profile A-A' (Figure 35).

The Mereenie anticline appears to have all of the essential elements for oil accumulation except closure. Residual hydrocarbons are present in the Horn Valley formation along the Macdonnell Range (Samples 8-2-1 and 8-2-3, Figure 16); marcasite nodules are present in the same formational unit along Macdonnell Range thus suggesting reducing conditions during deposition; the Horn Valley and Stokes formation are highly fossiliferous so there was abundant organic material in these units; the structure is about 30 miles south of the Macdonnell Ranges and is thus well removed from the disturbed zone where the reservoir rocks are altered;

and finally, drilling objectives are relatively shallow. If northwesterly plunge can be demonstrated on the Mereenie anticline, it may be the most promising Ordovician prospect in the Amadeus area.

A gravity survey along the covered area in United Canso's oil permit 56 should provide sufficient information to determine whether or not the Mereenie anticline plunges to the northwest. The limited amount of gravity work done in the area during July 1961 demonstrated that a negative residual gravity anomaly coincides spatially with the axis of the anticline along profile B-B' (Figure 35) and that gravity values increase downdip along the plunge of the fold. A short spur line following the axis of the fold for 3 1/2 miles east of profile B-B' showed a positive gradient in that direction of about 0.8 milligals per mile. Since the spur line is nearly normal to the regional gradient, this gradient along the axis of the fold is attributed mainly to local structure, i.e., increasing depth to salt in the Bitter Springs formation. Similar anomalies should be encountered along the trend of the fold in the covered area if a reversal of plunge is present and if there is comparable structural relief on the reversal. Alternatively, if the anticline plunges southeasterly under the sand cover this should also be evident from the data that will be obtained from the gravity survey.

The Mereenie anticline is about 190 miles from Alice Springs by road, track and jeep trail. Some bulldozing would be necessary to clear the tracks and trails before moving heavy equipment into the area.

Gosse's Bluff

Gosse's Bluff is about 100 miles southwest of Alice Springs. The annular hills surrounding the low central core of the structure rise abruptly from the flat floor of the Missionary Plains to create the most striking landmark in the Amadeus area. Speculations concerning the origin of the hills have run the gamut from a meteor-impact crater to doming due to igneous intrusion to doming due to salt intrusion. Of these, only the latter is supported by geologic evidence.

The low central core of Gosse's Bluff has been eroded from steeply tilted shales, thin limestones and calcareous siltstones of the Stokes formation. The core is surrounded by steeply dipping to overturned Mereenie sandstones that form the imposing ramparts of the structure. These sandstones are offset by numerous radial faults especially along the south side of the structures, as is shown in Figure 36. Pertnjara sandstones and conglomerates overlying the Mereenie are exposed in a few localities around the Mereenie rim.

The hills at Gosse's Bluff are surrounded by a broad, saucer-shaped depression as is suggested by the annular drainage pattern shown on Figure 36. The depression probably reflects a rim syncline around the structure - please refer to Figures 36, 37 and 38.

Gosse's Bluff appears to be the surface expression of a comparatively shallow, piercement salt dome comparable in some respects to the

Goyder Pass diapir (Figure 20). However, growth of the Gosse's Bluff structure continued during Pertnjara deposition in contrast to the Goyder Pass structure where tilting during the mid-Paleozoic orogeny terminated upward growth of the dome.

Although the domal uplift around Gosse's Bluff has created a large potential trap for oil accumulation, the delineation of individual traps suitable for testing will require seismic work. The problem in the seismic investigation should not be greatly different than those encountered in the Gulf Coast Province in United States unless conglomeratic facies in the Pertnjara formation create velocity and reflection problems.

The generalized composite stratigraphic column on Figure 36 shows the stratigraphic units that are present on the flanks of Gosse's Bluff. In estimating drilling depths to various objectives some allowance should be made for updip convergence on the structure. However, it is manifestly impossible to estimate the amount of convergence without subsurface control so only regional thicknesses are shown on Figure 36.

The Gosse's Bluff structure is one of the most attractive prospects in the Amadeus area. Relatively favorable source facies are present in the Proterozoic, Cambrian and Ordovician sediments (Figure 17). The structure is not too close to the disturbed zone along the Macdonnell front so welding of reservoir facies should not have destroyed all primary porosity. Growth of the structure probably started at a fairly early date thus creating a trap that was strategically located to intercept oil and gas migrating southward from the old Amadeus trough. Finally, Gosse's Bluff is in the same geologic environment as the oil seep at Hermannsburg (Figures 2 and 3).

Palm Valley Anticline

This structure responsible for the hills directly south of the Hermannsburg oil seep was named after Palm Valley, which is one of the tourist attractions in the Amadeus area. It is about 80 miles southwest of Alice Springs.

The Palm Valley anticline is another large structure which, like the Mereenie anticline, requires additional work in order to establish closure. Erosion on the fold has not breached the Pertnjara so a complete Cambro-Ordovician sequence may be preserved under the Pertnjara. Like Gosse's Bluff it is well located from the standpoint of source beds in the Cambrian and Ordovician.

The anticline south of Gilbert Spring tank (Figure 40) appears as a low relief flexure interrupting the regional, north dipping homocline in the western Krichauff Ranges (Figure 2). The amplitude of the fold increases to the east where it becomes a large surface structure in the hills south of Hermannsburg.

The morphology of the fold in the Pertnjara formation is not encouraging insofar as closure is concerned. Field work done by Mr. Hopkins suggests a weak westerly plunge to the structure but the amount of closure would not be large. However, it is important to remember that there is a regional unconformity at the base of the Pertnjara and that structures in the Pertnjara may differ radically from structures in the Cambro-Ordovician - please refer to Figures 20 and 39 for excellent illustrations of the latter statement.

We do not have sufficient gravity control on the structure to be certain that gravity cannot be used effectively to delineate the structure in the older rocks. However, the results of our gravity work to date are not encouraging. Furthermore, terrain effects in the hills might be a troublesome factor in interpretation. For these reasons, I believe that delineation of a trap will require seismic work.

Carmichael Prospect

Only the western flank of this structure is located in oil permit 43. For this reason, we made no attempt to map the structure in detail.

The prospect is on the north side of the Missionary Plains about 130 miles west of Alice Springs (Figure 2). The reconnaissance geologic map (Figure 39) showing northward dipping and northward facing Pacoota and Stairway sandstones projecting up through the Pertnjara mantle summarizes our present knowledge of the area.

The structure is associated with a gravity minimum which may be comparable in size to the gravity minimum around Gosse's Bluff. Like Gosse's Bluff, the structure is probably due to uplift and doming by salt intrusion.

Unfortunately, the prospect is close to the disturbed zone along the Macdonnell front where welding has altered potential reservoir rocks. However, if production is found around Gosse's Bluff, this prospect will require further examination.

Northwest Ooraminna Gravity Anomaly

This large negative gravity anomaly is located on the Missionary Plains about 16 miles southeast of Alice Springs. It is comparable in size to the Ooraminna gravity anomaly (Figures 41 and 22) and agrees in trend with the Todd River anticline (Figure 33). The Todd River drainage pattern is somewhat anomalous near the gravity anomaly but aside from this there does not appear to be any surface evidence of structure.

The anomaly could be more precisely defined by a small amount of gravity work and then delineated by seismic work. Since a complete section of the Cambro-Ordovician sequence may be present in the area, the anomaly deserves further study.

Other Prospects

The foreland folds crossing oil permit 43 are long, fairly continous features and there are culminations along these anticlines which are not mentioned in this report (Figure 3). Although none of these culminations appear to be as favorably located as the James Range structures, they may become interesting targets for exploration if oil is discovered in the Amadeus area.

Finally, the area around the Hermannsburg oil seep may be prospective for shallow accumulations in the Pertnjara formation. One or more of the Pertnjara sands must be charged with oil, assuming that the oil moved through the Pertnjara to reach the seep. The only other possibility would be that the Pertnjara beds near the seepage were charged by downward migration of oil from a Mesozoic reservoir that has since been removed by erosion. A few shallow core holes around the seep should furnish useful information for further evaluation of the seepage area.

SECTION SIX

DEMAND FOR PETROLEUM PRODUCTS IN AUSTRALIA

DEMAND FOR PETROLEUM PRODUCTS

The demand for petroleum products in Australia has been increasing steadily as is shown on Figure 42. Current annual consumption of about 90 million barrels will exceed 100 million barrels in 1964 barring unforeseen developments such as an economic recession or war in the Far East.

The per capita consumption of petroleum products in Australia is now about 9.8 barrels per year which is low compared to 21 barrel consumption in United States. Thus there appears to be ample room for growth in demand in Australia.

All crude used in Australia has been imported, mainly from Borneo, Indonesia, and the Middle East. This situation will change over the next few years if Union Oil Company of California has discovered major reserves in Queensland.

Respectfully submitted,

Duncan A. McNaughton

Duncan A. McNaughton

SIGNED: February 8, 1962

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APPENDICES

APPENDIX A

EARLY SEQUENCE OF
INTERESTING SHELF
DEPOSITS, CENTRAL
AUSTRALIA

by
C. R. Stelck and Roy M. Hopkins, Jr.

EARLY SEQUENCE OF INTERESTING SHELF DEPOSITS

CENTRAL AUSTRALIA

By C. R. Stelck and Roy M. Hopkins, Jr.

INTRODUCTION

An unmetamorphosed shelf sequence of Late Proterozoic to Ordovician rocks is retained in the Amadeus downwarp, south and southwest of Alice Springs in the Northern Territory, Australia. These deposits are of particular interest in that they seem to represent continous deposition over the later portion of the Lipalian interval into early Paleozoic. The sequence carries many thick sands that, even in the Proterozoic portion, have a high porosity and are uncemented to the degree that they may be crushed with the fingers. Proterozoic and Cambrian carbonates carry similar appearing beds of pelletoids, coarse calcarenites and glauconitic limestones which still retain some intergranular porosity. Organic content was high throughout the section as carbonaceous silts at the top of the basal sand are succeeded by foetid algal limestones and these latter build biohermal masses even within the Proterozoic portion. Worm trails and faecal pellets throughout foreshadow the fossil skeletal remains of the Paleozoic portion of the section. The pre-Cambrian fossils recorded by Dr. Glaessner (Scientific American, March 1961) from South Australia show wide variety from the Proterozoic seas; but the soft rocks of the Amadeus downwarp make it difficult to collect similar soft bodied impressions.

Structurally, the Amadeus downwarp appears to be a folded half-basin caught between the earlier pre-Cambrian terrains of the Musgrave-Mann foreland to the south and southwest and the upthrown Macdonnell Ranges "Arunta" complex to the north. Assymmetrical synclines and low angle overthrusts indicate that the compression came from the north, starting after Ordovician time. This compression has given a general east-west trend to the structures of the Amadeus downwarp, which in spacing may reflect basement fabric. Although the Amadeus downwarp is a structural low, overthickened deposition did not develop there until the Macdonnell Range uplift had initiated continental sedimentation some time after the Ordovician. Prior to this, the deep part of the depositional basin lay over the mobile Arunta complex region to the north of the present Amadeus downwarp, and, in the main, only the shallow-water shelf sequences have been retained within the latter.

Facies patterns of Late Proterozoic, Cambrian and Ordovician strata transgress the present structural lineations. In general, within the Amadeus downwarp, the marine sequence shows more carbonates introduced into the eastern portion and an increase in the relative amount of clastics to the west (Figure 2). Epicontinental flooding from seaways lying to the east, also implies transgression of both the Amadeus region and the Macdonnell Ranges "Arunta" arch by late Proterozoic, Cambrian and Ordovician waters. Shorelines were in the west and to the south against the Musgrave-Mann complex.

The bulk of marine sediment is from a western source and the thinning of the mantle of sediments to the south suggests a very low relief for the Musgrave-Mann complex at the start of Paleozoic with possible intermittent inundations of the latter. There seems to be no indication of a break-through of the sea to the Canning Basin to the west-northwest until on into Ordovician time. The advent of continental sedimentation in middle Paleozoic in the downthrown Amadeus block brought greater erosion of the Ordovician strata in the eastern part of the downwarp and pinchouts of the mid-Paleozoic continental members to the east. This would imply, locally at least, drainage opening to the west for the final fillings of the Amadeus low by the rising Macdonnell Ranges.

The sediments infilling the Amadeus downwarp fall into four natural groupings: a late Proterozoic sequence of a basal sand followed by a carbonate succession yielding to clastics; a Cambrian sequence of basal sand, thin shale and carbonate beds topped by sandstones; an Ordovician sequence of basal sand, followed by sand and shale with occasional carbonates; a post Ordovician continental clastic sequence.

Age	Formation	Lithology	Thickness range feet	Thickness Ellery Crk. feet
Post Ordovician	Pertnjara	continental ss., cgl., sandy shale	10000+- 0	10000+
	Mereenie	cross-bedded clean ss.	2500 - 0	1200
Ordovician	Stokes	silty shale, ls.-beds at base, ss.-beds at top; fossiliferous	1800+- 0	eroded
	Stairway	clean ss., minor siltstone	1300 - 480	1300
	Horn Valley	siltstone, argill.ss., minor shale & ls., v. fossiliferous	650 - 200	450
	Pacoota	clean well-sorted ss., locally silicified, scolithid tubes	2500 - 1000	2500
Cambrian	Goyder	ss., silst., silty sh. thin ls. at base	2400 - 0	1150
	Jay Creek	ls., algal ls., pellet ls., silty sh., well-sorted ss. at top	3500 - 0	1400
	Hugh River	shale, silty shale, ls. bands, algal lenses	2040 - 0	1275
	Arumbera	greywacke, well-sorted ss., local cgl., silst.	1240 - 450	1100
Upper Proterozoic	Pertatataka	silty sh., algal ls. members, thin clean ss.	3000 - 1500	1860
	Areyonga	soft arkosic greywacke, cgl., minor ls., periglacial?	1400 - 0	1400
	Bitter Springs	ls., algal ls., silty sh., gypsum	5000 - 2500	2700
	Heavitree	sandstone, well-sorted silicified ss., minor silty sh.	?	1500

Late Proterozoic. The Heavitree formation represents the transgressive sand phase of the late Proterozoic sea. The peneplain developed upon the underlying Arunta metamorphic complex seems to have slowly subsided under diastrophic tilting giving adequate winnowing and sorting to the arkosic sands being laid down. The basal shale member shows neither shearing or silicification so the quartzitic nature of the main portion of the formation is assumed to be a surface phenomenon developed sometime after the structures were formed within the area. Worm trails in the sandstone and carbonaceous argillaceous siltstones at the top of the Heavitree formation anticipate the abundance of life in the succeeding Bitter Springs formation.

The Bitter Springs limestone formation which follows the Heavitree conformably and transitionally represents a quiet period of extensive inundation. The extensive algal development (Collenia) within the Bitter Springs, beds of gypsum near the base at Jay Creek, pelletoids and glauconitic beds indicate shallow water conditions throughout. Algal reefing has good biohermal expression only in the area east of Ellery Creek and this may represent some basinal barrier as the formation thickens to the west along the Macdonnell mountain front by the introduction of shale members, some of which seem to have supersaline affinities. East of the Ellery Creek section the Bitter Springs thins and foetid limestones and calcarenites play a more dominant role. The uppermost member of the Bitter Springs formation is a sandy limestone that anticipates in part the coming clastic content of the overlying Areyonga formation. Sixty miles east of Alice Springs this top member is made up of cross-bedded porous calcarenites and sandy calcarenites that mimic cross-bedded sandstones, and form a matrix for thin conglomerates.

Interbedded with and transitionally overlying the Bitter Springs is the soft clastic Areyonga periglacial (?) formation. The Areyonga deposition seem to be the product of eustatic lowering of the sea as, in the eastern portion of the Amadeus downwarp, the gravels and sands are intermingled with limestones at the base and thinly bedded (varved) limestones occur in the top of the formation. The main body of the formation is a coarse sandstone with conglomeratic phases, silts and unsorted conglomerate. The boulders are of Arunta and Bitter Springs; the sands are arkoses or lithic greywackes. Even if the clastics have had some glacial history, as erratics in the silt and flattened boulders suggest, they were laid down in waters probably marine for glauconitic portions are known and advanced algae are found in the top. The formation as a whole is lenticular, for example, 1400 feet thickness at Ellery Creek dropping down to 455 feet at Jay Creek to the east and to 150 feet at Glen Helen to the west. The lenticularity suggests outwash material built out in delta fashion from rivers that carried seasonal ice but no immediate glacial ice. These deposits may have been peripheral to the Sturt tillites of South Australia. The soft habit of the Areyonga formation is encountered even in the Macdonnell mountain front and weathers recessive at dips over 30°.

The Pertatataka formation, conformably overlying the Areyonga formation, is a silty shale formation, well-bedded, with several sands appearing in the section in the western portion, and an algal limestone member appearing near the top in the eastern part of the Amadeus downwarp. It seems to represent the infilling as the eustatic level of the sea was restored to about the same position it had been at the middle of Bitter Springs time. Similar Collenia biostromes, and foetid and pelletoid limestones reappear in the Pertatataka. The shales of the Pertatataka slack in cold water with a slight working with the fingers, the well-sorted sand members are permeable and porous and there is even occasional fine erratic porosity in the limestones. The shales carry worm markings and appear to be marine although their weathered surface is red and green.

In the western part of the Amadeus downwarp additional sandstones come within the section and the identification of the upper contact with the overlying Arumbera sandstone becomes arbitrary.

Cambrian. The basal sand of the Cambrian succession is called the Arumbera formation. This formation carries conglomerates in the Deep Well area and large scale scour channels and slump structures in the western parts of the Macdonnell mountain front. On the other hand, within the Ooraminna dome, midway between Loves Creek and Deep Well, the Arumbera sandstones are soft, well-sorted and quite porous, representing the maximum winnowing on the shelf. The conglomerates to the south are considered to be lag gravels representative of minor diastems. A homotaxial shift upwards stratigraphically is indicated in an east-west direction as Volborthella and obolellids found above the Arumbera in Loves Creek area are found in thin glauconitic limestones within the Arumbera in the Areyonga area. It is assumed, however, that the unconformity is contained within the Arumbera and the lower part of the Arumbera in the west represents sandy equivalents of the upper Pertatataka formation.

The Arumbera formation is succeeded by the Hugh River shale in the western part of the Macdonnell mountain front and by carbonates in the eastern portion. The Hugh River shale carries sand members in the western portion and limestone members in the eastern and central portions. The change over to a carbonate facies in the eastern portion is entirely by interfingering through a distance of 120 miles (Figure 2). Where carbonates dominate, algal-archeocyathid reefs develop. The latter at Loves Creek rest directly on the Arumbera but are positioned about 120 feet above the base southwest and west of Loves Creek. The term Jay Creek limestone is used to include the carbonate equivalents of the Hugh River shale in the northeast. As the Hugh River clastics thicken, the boundary with the Jay Creek carbonates rises diachronically to the southwest and west, thinning and finally eliminating the carbonate section. The presence of eoorthids, obolellids and Volborthella in the archeocyathid reefs indicates a position fairly high in the Lower Cambrian for the Hugh River shale.

The tongue of Cambrian limestone that extends farthest west constitutes the type Jay Creek limestone. Its shallow water origin is shown by oolitic, pelletoid and algal limestones that carry Girvanella and rarely trilobite fragments. Foetid limestones are common but, except for the reefoid portions near the base, lime porosity is confined to very thin stringers in outcrop. The Jay Creek limestones interfinger with clean soft porous sands in the region west of Jay Creek and finally disappear just west of Glen Helen. Here the succeeding Goyder sandstone facies extends downward to embrace the stratigraphic interval of the carbonate.

The Goyder formation transitionally and with interfingering succeeds the Jay Creek carbonates. The Goyder sandstones and siltstones mark the introduction of coarse clastics to the section and probably reflects true uplift within the source area to the west. Except for the basal portion west of Glen Helen the Goyder is fairly tight and poorly sorted though soft. Shoestrings of porosity develop as the Goyder gives way to the shales and carbonates of the Jay Creek formation to the east.

The unsorted Goyder sands carrying upper Cambrian elements such as Prosaukia are overlain without break by the well sorted sands of the basal Ordovician Pacoota formation.

Ordovician. (Figure 3) The Pacoota sandstone is a blanket formation carrying scolithid tubes (Tigillites). Very clean and very porous over most of the area, the Pacoota shows intensive silicification along the Macdonnell mountain front but only surface and upland silicification in the downwarp to the south. The population of Scolithus was enormous extending over an area some 300 miles by 100 miles with concentrations in some of the individual beds exceeding 3000 per square foot. This gives a total population of the order of 10 to the sixteenth power. The cleanliness of the sands may, in some measure, be attributed to these scavengers. The wide extent of the population suggests a very stable depositional shelf although a basal autoclastic breccia and unconsolidated flow figures at Glen Helen gorge suggest initial tectonic shocks.

The clastic sequence continued after the scolithids waned and the few trochoid snails and trilobites in the Pacoota were replaced by the very full fauna of the Horn Valley formation. This latter is recessive weathering and its silty beds carry thin, very fossiliferous glauconitic limestones with a lower Ordovician fauna of ellesmereoceratids, endoceratids, cyrthochoanitic straight nautiloids, asaphid trilobites, Raphistomina, Lophospira, Palaearca, Ctenodonta, orthid brachiopods, plectambonitids, Lingulella(?) and graptolites. The presence of graptolites west of Areyonga would imply embayments wide open or perhaps even a breakthrough to the Canning Basin to the northwest.

Increase in sand content in the section introduces the Stairway formation, a return to the Pacoota type of environment, only worm tubes (Diplocraterion) and clam(?) burrows take the place of the scolithids. The sands of the Stairway are not as well sorted as those of the Pacoota but carry a few more gastropods, pelecypods and trilobites than the latter. The different beds and porous members have a local extent, interfingering with the Horn Valley and with the overlying Stokes formation.

The Stokes formation is known only from the western part of the Amadeus downwarp as uplift after the Ordovician (eroding as low as Goyder in the east) had removed the Stokes from the area east of the James Range and east of Ellery Creek. Thick sections of Stokes shale occur west of Areyonga with coquinoids in the lower part and sandstone members in the upper part. The coquinoids are in places porous and carry brachiopods including Orthid leviensis, straight nautiloids, Lophospira and nuculid pelecypods. It is assumed that the seaway was common between the Amadeus downwarp and the Canning Basin during the latter part of the Ordovician and the expulsion of the sea was finally through the Canning Basin as the rise of the "Arunta" arch uplifted the eastern end of the Amadeus embayment.

Post Ordovician. On the eroded Ordovician surface, the Mereenie formation was deposited, pinching out to the east and developing tremendous cross-bedding (noticeable on aerial photographs) in the western portion. It is without shale members except at the very base where salt-casts are found in the silt beds. It is a clean continental sandstone and porosity is not uncommon. The overlying Pertnjara sandstone is a dirty continental sand with conglomerates carrying boulders of all the previous formations down to the Arunta as well as the waterworn fossils from those. Extra members are added to the Pertnjara in the western portion so the drainage of the Amadeus downwarp is assumed to have been westward in the upper Paleozoic. The Pertnjara beds are thickest along the Macdonnell front.

They probably formed a series of coalescing fans infilling the downthrown half graben of the Amadeus block with detritus culled from the old deep mobile part of the marine depositional basin.

Since it is the stable shelf deposits that have been retained without excessive deformation within the Amadeus downwarp, a potential petroleum province could be anticipated here in the heart of Australia.

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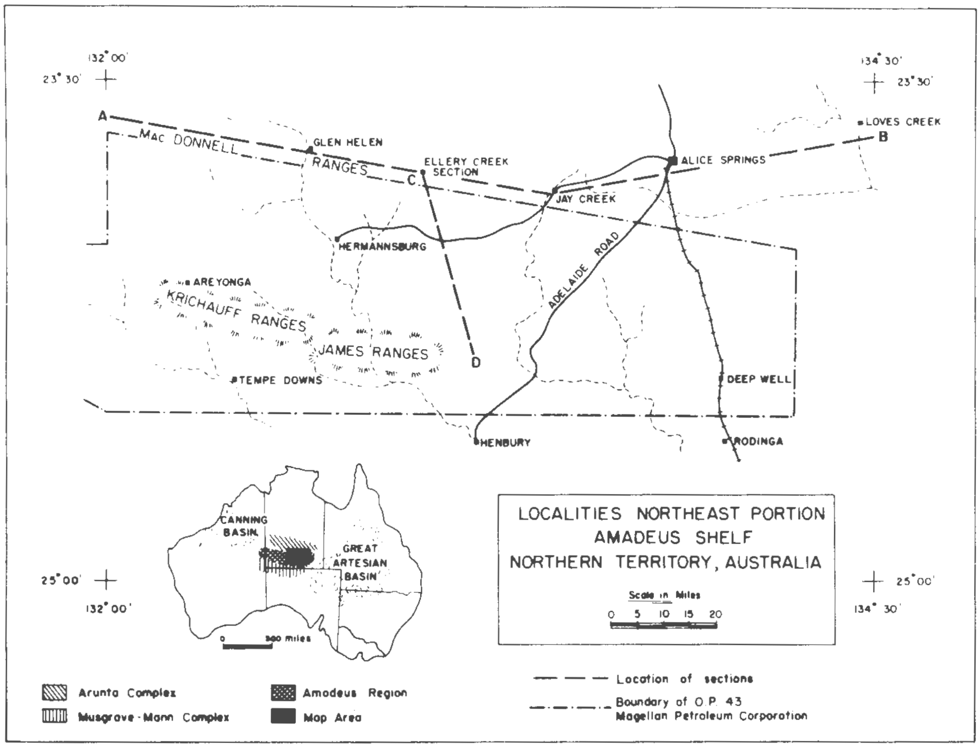
Stratigraphic terminology corresponds to that used in "The Geology of the Southern Part of the Hermannsburg 4-Mile Sheet" by C. E. Prichard and T. Quinlan, B.M.R. Records 1960/104.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A
B
MAC DONNELL RANGES
GLEN HELEN
ELLERY CREEK SECTION
C
D
ALICE SPRINGS
LOVES CREEK
JAY CREEK
HERMANNSBURG
ADELAIDE ROAD
AREYONGA
KRICHAUFF RANGES
JAMES RANGES
TEMPE DOWNS
DEEP WELL
HENBURY
RODINGA
CANNING BASIN
GREAT ARTESIAN BASIN
25°00'
132°00'
25°00'
134°30'
LOCALITIES NORTHEAST PORTION
AMADEUS SHELF
NORTHERN TERRITORY, AUSTRALIA
Scale in Miles
0 5 10 15 20
Arunta Complex
Musgrave-Mann Complex
Amadeus Region
Map Area
Location of sections
Boundary of O.P. 43
Magellan Petroleum Corporation

Figure 1

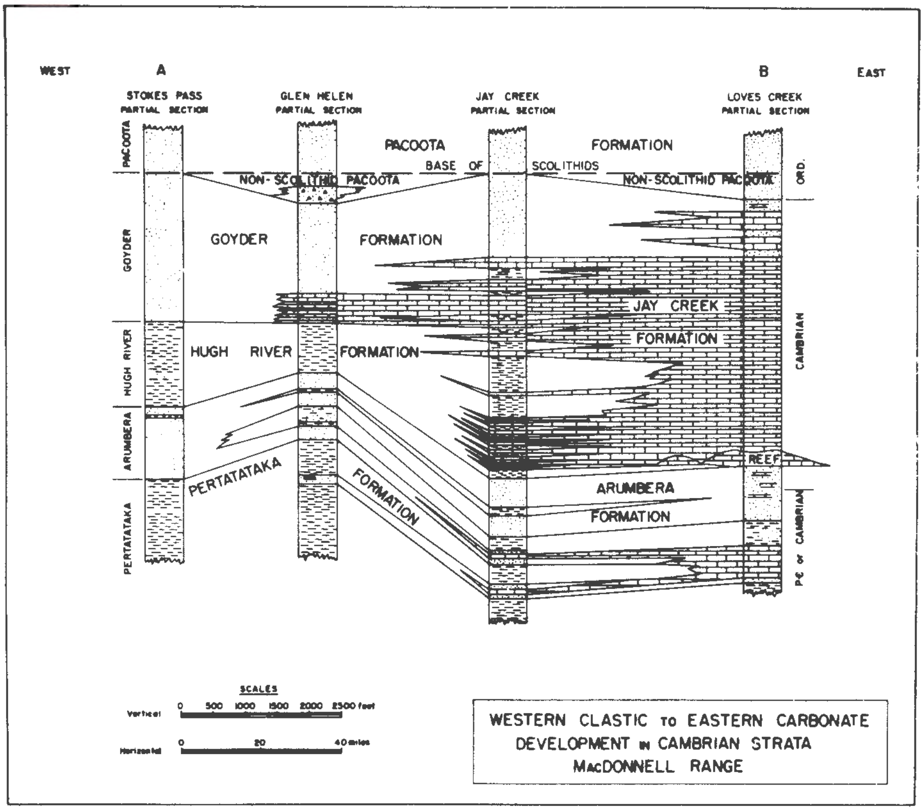

Figure 2

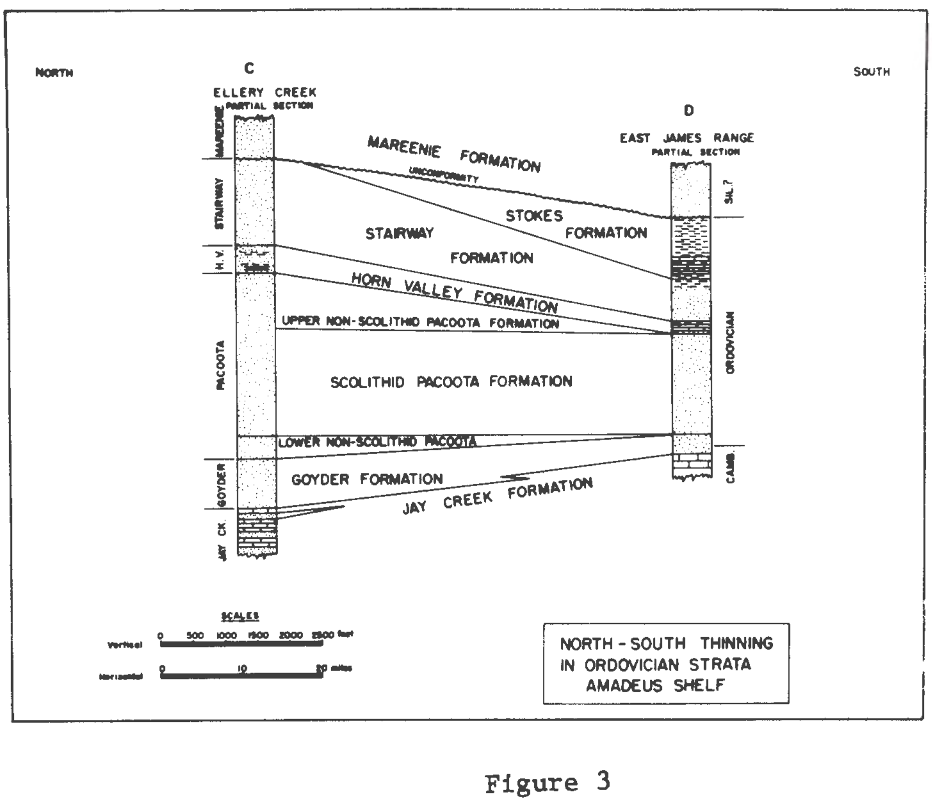

Figure 3

APPENDIX B

SUMMARY OF MAJOR FEATURES

OF NORTHERN TERRITORY

PETROLEUM LAWS AND WORK COMMITMENTS

by

H. I. Harris

SUMMARY OF MAJOR FEATURES OF NORTHERN TERRITORY PETROLEUM LAWS AND WORK COMMITMENTS

INTRODUCTION

Exploration for and development of petroleum reserves in the Northern Territory of Australia are controlled under the provisions of Ordinance No. 5 of 1954, "To regulate prospecting and mining for petroleum" and of Regulations 1955, No. 1, "Regulations under the Petroleum (Prospecting and Mining) Ordinances 1954." Copies of these regulations are enclosed in the pocket on the back cover of this report. Additional copies may be obtained by writing to Director of Mines, Northern Territory Administration, Darwin, Northern Territory, Australia.

The Ordinances have been amended from time to time (No. 14 of 1954, No. 20 of 1957, No. 16 of 1960, No. 15 of 1961) but the changes are not of a basic nature.

A permit giving the exclusive right to explore for petroleum is limited to 10,000 square miles in not more than three blocks. Licenses are limited to 2,500 square miles per license. Leases are limited in area to 500 square miles.

WORK COMMITMENTS

PERMITS

No rental is payable for permits. According to the principal ordinance (No. 5 of 1954, para. 26), a holder of a permit must start within six months of its grant to make a reconnaissance survey (geological and/or geophysical); make petrological, paleontological or other scientific examinations of specimens obtained from the land to which the permit applies; retain representative samples obtained and to make them available to the Administrator; and furnish a progress report every three months. After completing the reconnaissance work, the permit holder must furnish a detailed report giving results of the survey, with copies of field observations; furnish a geological map at a scale of one to one hundred thousand or larger; or, if detailed work has been carried out, to present also a map on a scale of one to twenty-five thousand or larger; furnish a report on the results of the examinations of specimens; in the case of an oil discovery, to furnish a report and carry out operations to prove the quality and quantity of petroleum.

It should be noted that total exploratory expenditures are not defined nor does the law attempt to be specific as to the type of exploratory work which should be done. In practice, the following arrangements have come into force between the permit holders and the Northern Territory Administration. In the original application the applicant advises what work he will carry out during the first year if the permit is granted.

Ordinarily the Administration will be agreeable to any reasonable opening program and will issue a permit document listing commitments. These commitments are sometimes copied directly from the applicant's own proposed work program.

At the end of eleven months the operator must apply for his first extension (good for from one to three years). Once again he must present his exploratory program, giving reasons for his choice of exploratory methods. This procedure is repeated for each extension that is desired. With extensions, a permit may be held for ten years.

A logical work program for a given area ordinarily unfolds as work proceeds. The petroleum law relating to permits and extension of permits allows the operator to plan by yearly steps while advising the government of his progress. On the other hand, the government is able to wield control quickly over operators who carry out no program, thus freeing acreage almost immediately. Government officials have been both helpful and cooperative and extensions have always been granted to companies engaged in serious exploratory work.

LICENSES

It is necessary to proceed to the license stage before drilling since only a license holder may apply for a lease. A lease is necessary before any oil may be produced.

Permitees may apply for one or more licenses within the permit area to a maximum area of 2,500 square miles per license. A license has an initial term of two years and can be extended for one year at a time for a total term of eight years. Rental is payable starting at the rate of one shilling per square mile per year in the first year to twenty shillings per square mile per year in the eighth year (equivalent to $.11 and $2.25 respectively at the current exchange rate).

The work commitments for license holders are similar to those detailed for permit holders, differing only in that they specifically refer to detailed work. There is no drilling commitment connected with a license.

LEASES

A lease is applied for upon the discovery of oil which is considered to be commercial. Production can only be taken by a leaseholder, who must pay a 10% royalty to the government on the gross value at the well head of all crude oil, casinghead petroleum spirits and natural gas produced.

Leases are granted only to license holders and may cover an area of from 10 to 500 square miles and may not omit a portion of a geological structure, part of which is included in the lease. A lease has a term of twenty-one years. After granting of a lease the remaining part of the license remains in force for at least three more years. A lease may be renewed for a further twenty-one years.

Upon the grant of a lease, development drilling operations must be started within six months. Throughout the remainder of the lease, operations must be continued in workmanlike manner. A report must be furnished yearly concerning production, etc.

Rents during the first five years are at the rate of approximately A£15 per square mile, A£30 per square mile during the second five years, and A£50 per square mile in each subsequent year. (Corresponding approximately to U.S. $ 35, 70, 112 respectively.)

SUMMARY

The petroleum ordinances and regulations for the Northern Territory in Australia are not onerous in comparison with other countries. Furthermore, the Australian government officials have been both helpful and cooperative with operators engaged in determined exploratory work.

H. I. Harris