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NOTE ON THE OIL POSSIBILITIES OF THE NORTH-WEST BASIN AND THE DESERT BASIN

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by

Chief Geologist

W.F. Schneeberger

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A visit of one month was paid by the writer to the North-West Basin and the Fitzroy Area of the Desert Basin. It is largely due to the careful planning of the excursions by the Senior Geologists in charge that a coherent picture of the stratigraphical and tectonical conditions was obtained within the comparatively short time at disposal. This note contains a few remarks on the stratigraphy and tectonics of both areas in connection with oil prospects.

A. The North-West Basin.

a. Stratigraphy.

For the stratigraphical sequence reference is made to the existing publications, reports and notes.

A striking feature of the Devonian-Carboniferous sequence is the cyclic alternation of transgressive (limestones) and regressive (sandstones) facies types. A marine environment is attested for the majority of the stratigraphical members by the abundant occurrence of marine fossils. The change from one type of facies into the other is in most cases transitional. Reworked limestone fragments in the basal parts of sandstone members seem to be absent, a fact which proves the absence of any period of emergence separating limestone from succeeding sandstone members.

Similar cyclic processes are also in evidence during Permian time which was ushered in by the Gondwana glaciation. Fluvio-glacial material and erratics of various dimensions were deposited in a shallow marginal sea. The contact with the overlying Callytharra is transitional through local intercalations of pebble beds in the basal Callytharra.

After the termination of the Gondwana glaciation, similar cyclic processes are also in evidence in the depositional record of the Permian, especially in the Wooramel - Kennedy interval, through the regular alternation of clay-shale-siltstone with sandstone members. The pattern is repeated in miniature in the rhythmic succession of sandy micaceous shales with interbedded fine sand- and siltstones in the Coyrie and the clay-shale members of the Kimbera Group. The environment indicated by this type of deposition is one of quiet, shallow water in a near-shore position (carbonaceous matter) with gradual changes within narrow limits.

The regional overlap of the Cretaceous on the Palaeozoic succession is one of the most spectacular features in the North-West Basin. Its significance for oil prospects shall be discussed later.

b. Facies and Oil Prospects.

Although the problem of oil generation is still a matter of controversy, general agreement has been reached that only under certain conditions organic matter as a source material was preserved. Such conditions are fulfilled when the organic matter is sealed off and protected against the influence of atmospheric agents from the moment of its deposition. This seems generally to be the case in marine areas where pelitic or calcareous material is deposited under absence of currents. The presence of H_2S above its normal concentration might also be a factor in the process of preserving of organic matter. Darkgrey to black shales, clays and limestones with a certain amount of pyrite, absence of benthonic but presence of planktonic and nektonic forms are therefore mainly considered as prototype of source rocks. Examples are the Oligocene "Cornu" Shales of Roumania, the Miocene Globigerina Marls of the East Indies, the Upper Cretaceous Mowrie and Thermopolis Shales of the Rocky Mountain Region, the Colorado - Montana Shales of Western Canada etc.

There are, however many exceptions to this rule where oil occurs in limestones without a typical subjacent source series being present, such as the Ordovician Trenton Limestone of Ohio and Indiana, the Cretaceous Tamasopo Limestone of Mexico, the Mississippian Madison Limestone of the northern Rocky Mountain Region. The remarkably rich accumulations of oil in these limestones in combination with the absence of pelitic source rocks have led to the assumption of the origin of the oil within the limestones themselves. The porosity is generally caused by contemporaneous or subsequent (diagenetic) dolomisation, solution at or near ancient landsurfaces. Tectonical fracturing is the cause for the porosity of the Cretaceous Cogollo - La Luna Limestone of Western Venezuela. In this case the prolific production is restricted to such fractured zones, but the oil is thought to have originated in the subjacent and intercalated shales and marls, since the limestone, where it is unaffected by tectonical fracturing, is dense and devoid of any porosity.

The significance of reef limestones will be discussed in a later section.

The question now arises whether one or more of the conditions mentioned above are fulfilled in the North-West Basin. The Palaeozoic sequence include several limestones, which together with the intercalated marls might theoretically be considered as source formations. Direct evidence in the form of residual bitumen, however, is lacking, but is not expected in case of light oils of a waxy base. Assuming that one or several of the limestone sequences actually were source formations, then the numerous intervening sandstone members would naturally function as reservoir rocks.

Apart from the limestone series which might be assigned the function of source beds, attention is drawn to the clay-shale-siltstone sequences of the Coyrie and to those of the Kimbers Group which appear to have certain characteristics of source rocks, such as dark grey colouration, the possible presence of foraminifera, bituminous siltstones - indications for a deposition in an undisturbed quiet water environment. It is therefore advisable to investigate the extent and composition of the foraminifera fauna suspected in these sediments.

The significance of the Cretaceous overlap is to be discussed briefly. The monoclinal, locally slightly folded, but generally strongly block-faulted Palaeozoic succession is regionally unconformably overlain by the Cretaceous. Overlap conditions are in many parts of the world the cause for oil accumulations, the condition being that the migration within the truncated beds has taken place after the deposition of the overlapping formation. Accumulations are to be expected in the truncated members as well as along the old landsurface and possibly in the basal beds of the transgressive series. In case of an asphaltic oil, basal sandstones in outcrops are usually saturated with residual oil. The most impressive example of such an overlap are the tar sands of the Athabaska River in Western Canada (western slope of the Canadian Shield) where Lower Cretaceous sandstones are overlapping Devonian limestones. The oil has its origin in the underlying limestones and accumulated in the overlapping sandstones. On account of the absence of caprock it was subsequently transformed into a heavy tar after all the lighter fractions have escaped.

Progressive overlaps within the Tertiary series on the northern slope of the Guiana Shield are the cause for pools producing in several fields of Eastern Venezuela. The presence of accumulations along the plane of overlap and in the basal members of the Cretaceous in the North-West Basin can therefore theoretically be visualized, There is, however, a conspicuous lack of impregnations in outcrops and absence of oilshows in water bores in the Cretaceous.

c. Structural Features and Oil Prospects.

The regional gentle dip to the West-South-West of the Palaeozoics in the North-West Basin is disturbed by a steepening within the Devonian sequence along the eastern edge of the basin and by numerous faults which are responsible for the repetition of various stratigraphical members. Block-faulting therefore is the predominant type of structure with superimposed or accessory folding in the central and western part of the area. Folding, however, is setting in to the North-West (Barrabiddy anticline) and reaches its maximum in the coastal anticlines (Giralia, Cape Range), which represent major structures.

The question whether the folding of the Cretaceous-Tertiary series as it is in evidence at the surface, is caused by faulting in the Palaeozoics and the Basement Complex to which the comparatively thin overlapping series reacted in the form of "epidermic" folding, or whether we have to deal with normal folding of the Palaeozoics gently reflected in the overlapping series, is difficult to decide. The writer, however, is rather inclined to accept the latter alternative until further evidence has been obtained through seismic investigation, for the following reasons :

a. An increase of the total thickness of the Permian sequence alone from 7,300 to 9,000 feet (23%) in an east-west direction over a distance of only 40 miles (Moogooree-Wandagee) is reported (Condon). A similar increase for the Carboniferous and the Devonian sediments in the same direction is not excluded.

b. Corresponding to the increase in thickness in a basinward direction a change from a nearer shore to a deeper water facies i.e. from a psammitic to a pelitic phase of the clastics and a decrease of the calcareous elements is to be expected, resulting in a lower degree of competency of most of the stratigraphical units. The enhanced plasticity in its turn effected a different type of reaction of these sediments to diastrophic forces. Folding therefore might to a large extent have replaced block faulting in the western, deeper parts of the basin. The presence of folding within the Permian sequence (Wandagee area) appears to support this contention.

c. Reflection of folding in the overlapping Mesozoics induced by Palaeozoic anticlines is known from certain parts of Queensland and to a large extent from many parts of the U.S.A., as for instance Kansas, where anticlines and domes in the Permian were found through their reflection in the overlapping Cretaceous.

Faults within a regional monocline can, theoretically speaking, act as traps for the migrating oil, provided of course they are antedating the actual migration. Production on such traps is obtained in many oil producing areas of which mention is made of the Kern River Fields on the northeastern edge of San Joaquin Valley in California and several fields on fault traps within the Miocene overlapping on the gentle northern slope of the Guiana Shield in Eastern Venezuela. Since most of such traps have little lateral closure, a prolific source of oil is required in order to ensure commercial accummulations. It is therefore not thought that such longitudinal faults would offer first-rate prospects in the North-West Basin. They could, however, be tested subsequent to the discovery of commercial quantities of oil in the tectonically more favourable areas.

There is no doubt that the most favourable location for the testing of the Palaeozoic sequence is one of the major anticlines in the coastal area. A location for a first well, however, is only to be selected after the results of a seismic reflection survey have become available.

B. <u>The Desert Basin (Fitzroy Area).</u>

a. <u>Stratigraphy.</u>

The geological history and consequently the stratigraphical record of this area are in striking contrast to those of the North-West Basin. Its main characteristics are the presence of Ordovician rocks. The prolific reef facies of the Devonian, the absence of sediments of Carboniferous age and the mainly terrestric facies of part of the Permian series.

The discovery of the <u>Ordovician</u> at Price's Creek is of considerable importance from a geological point of view. The lower division (Emanuel Limestone) with its alternation of fossiliferous limestones, shales and marls has the characteristics of source beds, whereas the sandy intercalations and the dolomites of the upper division (Gap Creek Dolomite) show sufficient porosity as to act as reservoir rocks.

Along the north-eastern margin of the Desert Basin great thicknesses of coral limestone have developed (in <u>Devonian</u> Time) partly as fringing and capping reefs on pre-Cambrian ridges which at that time must have formed part of a gradually subsiding continental shelf. Whether the outer shelf edge supported a barrier reef similar to the present day Great Barrier Reef of the north-east coast of Australia is unknown since it is covered by post-Devonian sediments.

It is interesting to note that the surface of the Pre-Cambrian was by no means a level plain (abrasion plane, peneplain), but had a quite rugged topography. This is clearly to be seen in the Rough Range uplift (vicinity of Mountain Home Spring) where a basal series of rhythmically deposited Devonian nodular marls and limestones with a basal arkosic grit occupies troughs between ridges and is completely missing on a pre-Cambrian ridge which is capped by the first massive stromatopora limestone of the Pillara.

Palaeontological evidence points to an initiation of reef forming in the Middle Devonian (Pillara limestone with great masses of bioherms and biostromes) extending in certain areas well into Mount Pierre time of the Upper Devonian (Stage I-III). It reached a second peak in Bugle Gap time of the Upper Devonian (Stage IV). The red limestone-shale-siltstone sequence with Goniatites of the Mount Pierre Group is clearly the inter-reef facies of contemporaneous reefs and is seen inter-fingering with the reef facies.

In the lower portion of the Bugle Gap Limestone zones of intra-formational breccias occur. In these zones the limestone is broken up into subangular to rounded fragments up to head size, embedded in a marly matrix and mixed with smaller and more angular fragments. Intra-formational breccias have yielded excellent production in various parts of the world. A typical example are the brecciated zones in the upper part of the Madison Limestone of Mississippian age in Western Canada, which in the Turner Valley Field represent the main producing horizons. The Madison breccias are predominantly composed of angular fragments, mainly produced by submarine chemical solution and partly recemented by subsequent deposition of calcareous ooze. The Bugle Gap breccias, however, are the result of the action of waves and currents on shoals in the Upper Devonian sea, their origin therefore is mechanical rather than chemical.

A very peculiar facies, largely contemporaneous with the Mount Pierre formation, is the J8 conglomerates, previously considered as being of Permian age and therefore associated with the Permian glaciation. There is, however, convincing evidence of interfingering of the conglomerates with the Devonian limestones even in Bugle Gap time. The intermixture of two facies types of such heterogeneous origin calls for a sudden and considerable uplift of the adjacent mainland (possibly orogeny), wherefrom the coarse clastic material was rushed into the shelf area through gaps or passages in the reefs. The position of the main mass of the J8 conglomerates as a continuous ridge in front of the reefs supports such a conclusion.

The Permian section of the Fitzroy area differs in a marked degree from that of the North-West Basin. The Grant Range series as the terrestric equivalent of the mianly marine Lyons shows all the characteristics of a glaciated series, such as tillites, varve shales, fluvio-glacial gravels, polished walls, slumping etc. There can be no doubt that this glacial series is of Permian and not Devonian age as Reeves had suggested, since the co-occurrence of a prolific coral reef fauna and a glaciation in close proximity would contradict geological and biological rules, quite apart from the fact that a Devonian glaciation would be a novum for Australia. Outliers of Grant Range glacials on the stripped pre-Permian surface of the Devonian limestone are to be seen east of Bugle Gap.

Indications for a marked unconformity between the Grant Range and the overlying Poole Range formation are to be seen in the Poole Range Area, where the former is crumpled through large scale slumping, and in the extensive jointing which has affected the Grant Range Formation only and is absent in the Poole Range sandstone. However, it is doubtful whether this break attains regional significance in any part of the area.

The remainder of the Permian sequence calls for no comment. There are gradual transitions between the various members from the uppermost Poole Range Sandstone through the Noonkanbah into the Liveringa. None of these members has the characteristics of a source formation.

b. Some Remarks on the Tectonics.

The structural pattern of the Fitzroy region shows peculiarities which are indicative for a comparatively shallow basement and a high competency of the overlying sediments. Transverse and longitudinal faulting is much in evidence, the former largely confined to the major structures such as Poole; St. George and Grant Range, Mount Wynne and Nerrima. Sudden changes in strike and different tectonical behaviour of adjacent fault blocks indicate that some of the transverse faults are antedating the folding, but the majority appears to be contemporaneous with or even slightly younger than the folding process. They are the expression of a high degree of competency of the sediments involved and might have their origin in a basement fault pattern. Basement buried ridges with fringing and/or capping Devonian reefs might therefore be assumed to form the core of such structures.

The strike fault which appears to be of regional significance is the fault zone which according to Reeves' map (1 inch = 10 miles) trends approximately north-east to south-west from Geegully Creek through Moulamen Hill, Mt. Arthur, Mt. James and Mt. Fenton. Its continuation to the north-west is unknown, but the possibility of its extension along the east coast of Dampier Land is not excluded. To the east it might extend as far as Wolf Creek.

There is evidence of a down-throw on the outer side of this arcuate zone and considerable tectonical movement is indicated by the occurrence of lenses and faulted blocks of Grant Range sandstone (Mt. Arthur) along its trend. It separates two areas of entirely different surface appearance. On its north-east and north side the major folds show up clearly in the morphological lay-out, whereas the area to the west and south(Dampier Land and Desert Basin) are, excepting some low ridges of Upper Permian and Jurassic, a perfect peneplain.

The correct interpretation of this fault zone is of great importance for a proper understanding of the regional relationship between the Fitzroy Region, Dampier Land and the Desert Basin proper. Two alternatives can be visualized:

a. The Mt. Arthur fault zone is situated near or on the Devonian-Permian shelf edge and consequently would separate the shelf area to the north and east from a deep sea region to the south and west. It would represent a tectonical step caused by deep seated fault movements in the basement complex. Within the area to the south and west a pelagic facies correlative to the neritic facies of the shelf zone could be expected. The weakness or even absence of surface evidence of folding could be explained by a regional decrease of tectonical movement with increasing distance from the basin edge and an unconformable superposition of the Permian and younger sediments on the older Palaeozoics. Preservation of the Ordovician and the occurrence of Carboniferous strata could be expected in this deeper part of the basin.

b. The fault zone indicates the eastern and northern edge of a rigid segment of the basement, a shield in miniature, bordering on a shallow, fault-bounded geosyncline (taphrogeosyncline, Kay, 1945) of which King Sound as its deepest part, is still occupied by the sea. From there it gradually rises to the south-east and east. The sea has in the past repeatedly transgressed on and regressed from this embayment, overlapping possibly for short periods on to the margin of the southern mainland, which on account of its stability had gradually been worn down to a peneplain. The rigidity of the basement complex in this area and the reduced thickness or even absence of the older Palaeozoics would account for the weakness or practical absence of folding.

In case a. the Fitzroy region would represent the shelf area of a wide basin reaching south to the Patterson Range. In case b. it would be a graben or trough bounded on three sides by basement forming the ancient mainland and open to the sea on the north-west. The absence of Devonian sediments and the overlap of the Permian on the basement along the south-western edge of the Desert Basin (Patterson Range) would rather support the second alternative. However, there seems to be little possibility to solve this problem with surface geology, only geophysical methods, gravity and seismic refraction shooting in the first place, could give a final answer which is of vital importance for a proper evaluation of the oil prospects in this region.

c. <u>Stratigraphical and structural Aspects of Oil Prospects.</u>

Excepting faint oil smell in some Ordovician limestones and reports of oil shows in the Price's Creek, Poole Range and Mt. Wynne bores, there are no direct indications for oil in the Fitzroy area. An evaluation of the oil prospects has therefore to be based entirely on regional stratigraphical and structural considerations.

Nowithstanding its favourable facies, the Ordovician can not be considered as an object for a first drilling campaign largely on account of its unknown distribution. It is not excluded that it is only preserved as erosional remnants in depressions between pre-Cambrian buried ridges or in deeper parts of the basin.

The formation which in the Fitzroy area should offer good prospects is the reef facies of the Devonian. In this connection reference is made to the occurrence of Devonian reefs in Western Canada (Alberta) which have recently been found to be prolific producers. Three reef zones (DI-3) are recognized there; the highest one (DI), being non-productive, is covered unconformably by Lower Cretaceous. Evaporites and red shales separate the DI from the D2 zone which was found productive in the discovery well, whereas this zone again is separated from the main producing D3 zone by intercalated green shales.

Although the time gap in Western Canada between the Devonian reef deposition and the overlapping Lower Cretaceous is considerable greater than the Upper Devonian - Permian interval in the Fitzroy area, the oil accummulations there were not affected by atmospheric agents, excepting possibly those in the non-productive DI zone.

In view of this fact the exposure of the Bugle Gap limestone to erosion in the Upper Devonian - Permian interval should in itself not necessarily be a detrimental factor, since the impermeable Mount Pierre shales and siltstones might have effectively sealed off the intra-Mount Pierre - and Pillara reefs.

From a structural point of view the prospects in the Fitzroy region appear to be very good. The major structures, although strongly affected by transverse faulting are not only of considerable size but have also quite extensive collecting areas. Whether prospects are confined to the Fitzroy area proper or are extending south and west into the Desert Basin and Dampier Land, is still an open question. As mentioned before, the whole problem hinges on the regional significance of the Mt. Arthur fault line, which we would extend to the north-west along the east coast of Dampier Land and to the east to Wolf Creek. In case it is a step fault situated on or near the edge of the shelf and possibly was in existence in Devonian time already, then bathyal facies equivalents of the shelf deposits should be present to the south and west of this line. Should it, however, indicate the north and east boundary of a peneplaned rigid basement segment (Desert Basin and Dampier Land) whereon the sea transgressed only intermittently and for very short periods, with the probability of long range erosion periods, then the prospects would be confined entirely to the Fitzroy area.

C. <u>Recommendations.</u>

a. <u>North-West Basin</u>

Testing of the coastal structures (Cape Range, Giralia) is the logical first step for a drilling campaign in the North-West Basin. In view of the great thickness of sediments to be tested, it is advisable to shoot at least one seismic section across each structure, wherever practicable from syncline to syncline. Refraction shooting would be of great assistance in determining the total thickness of the post-Cambrian sediments involved.

b. <u>Kimberley Area.</u>

The following work should be carried out prior to the beginning of a drilling campaign:

1. <u>Air-mapping</u> of the entire Desert Basin including its south-western margin, followed by a careful analysis of the photographs by an experienced photogeologist. It is not excluded that through a careful study of the erosional remnants, which are known to occur, the extent and pattern of their spread, the drainage and other morphological features, certain areas can be lined out which might indicate a reflection of the folding in depth and therefore could lead to a selection of areas to be subjected later to geophysical investigation.

2. If possible an <u>air-borne magnetometer</u> survey should be carried out, covering the whole Desert Basin and Dampier Land. As an alternative at least four <u>gravity</u> sections, starting from the Mt. Arthur fault zone and extending at least 60 miles into the Desert Basin, and a reconnaissance of Dampier Land along the main road from Broome to Derby and Broome - Cape Leveque with additional traverses along trafficable roads are recommended.

3. Based on the results of the magnetometer and/or gravity survey areas should be selected for <u>seismic</u> investigation. It might be advisable to do refraction as well as reflection shooting, the former of course only in localities where the depth of the basement

has to be determined.

4. The surface geological survey of the Fitzroy area should be completed. Special attention should be paid to the Mt. Arthur fault zone and the surface mapping should be extended to the north-west and west. It might be advisable to make a special study of the reef formation by mapping in detail selected areas which give a proper insight of the forming of reefs and their relation with the off-reef and inter-reef sediments.

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