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Problems of Oil Exploration in Australia

with 14 figures

by W. F. Schneeberger, Männedorf ZH

Summary: A historic review of oil exploration in Australia is given. The sedimentary basins are briefly characterized and problems confronting oil exploration in the most important basins discussed.

Introduction and brief historical Review

The purpose of this paper is to give a brief historical review of oil exploration in Australia and to single out and discuss certain problems peculiar to that continent and with which the search for oil is confronted. Because of the considerable size of the area and the great number of different geological settings this can by no means be a comprehensive presentation of Australian petroleum geology.

Apart from occasional occurrences of lumps of bitumen of unknown origin on the beaches of South Australia and the Great Australian Bight, and free bitumen reported by sailors about 150 years ago from the Bonaparte Gulf Basin in northwestern Australia, no surface manifestations of hydrocarbons, liquid or gaseous, are known in Australia.

Wet gas was incidentally discovered in a water bore at the town of Roma in Queensland in 1900. It lead to some local drilling activity without further success. The first chance discovery of oil happened in 1924 at Lakes Entrance, Victoria. Subsequent drilling produced somewhat over 100,000 gallons of heavy oil between 1930 and 1941.

Light shows of oil or gas were reported over the years from a few of the many hundreds of artesian water wells drilled in the Great Artesian Basin. But sporadical drilling by local interests did not result in commercial discoveries. In 1935, Oil Search Limited, an Australian company, drilled one well each on Arcadia and Hutton Creek domes in Queensland. Gas flows up to 250,000 cubic feet per day were obtained (whereof 70 % was CO_2); both wells were abandoned as dry holes. Drilling on several domes in the northern Sydney Basin by the same company was also not successful.

From 1940 to 1944, a subsidiary of Royal Dutch/Shell carried out exploration over an area of approximately 130,000 square miles in eastern central Queensland. After an interruption of three years, activities were resumed and a well was subsequently drilled on a surface structure and abandoned as dry hole at 4,634 feet, whereupon Shell relinquished their Queensland holdings.

At about the same time (1940–42) Caltex Oil Development carried out reconnaissance surveys in the Fitzroy Basin of Western Australia, but stopped activities because of war conditions. It was in this basin that some Australian independents had previously drilled several wells and had reported oil shows in basal Permian and the underlying Ordovician.

In the late 1940ies, Ampol Petroleum Limited, an Australian distributor, took up permits of approximately 320,000 square miles in Western Australia. They were joined by Caltex in 1952 and an operating company, Western Australian Petroleum Pty Ltd (WAPET) was formed. The first well was drilled on Rough Range anticline. It struck oil unexpectedly in a basal Lower Cretaceous sand at about 3,600 feet at the rate of around 500 barrels per day. Subsequent drilling on the same structure failed to confirm production and Rough Range No. 1, the first flowing oil well in Australia was shut in.

The Rough Range discovery caused a vigorous increase of exploration all over Austrlia and from 1954 on a great number of wells were drilled in various basins, but no additional discovery resulted. But in May, 1961, Union Oil of California and its associates discovered oil in the Permian in southern Queensland. In December of the same year this was followed by a further strike in the same basin, at Moonie, out of which the first producing oil field in Australia has developed.

Similar to Rough Range in 1953, the Moonie discovery was followed by greatly increased geophysical and drilling activity especially in Queensland. Several potential oil and gas shows were obtained. The previously established gas reserves in the Surat — Bowen Basin were greatly increased through new discoveries, some of them very recent, and significant shows of oil or gas were obtained in widely scattered wells in Western Australia, South Australia and the Northern Territory.

At the moment of writing several companies are actively engaged in offshore exploration on the Sahul Shelf of northwestern Australia.

A factor, the importance of which should not be overlooked in reviewing oil exploration in Australia, is the role the Commonwealth Government has assumed. The Bureau of Mineral Resources, Geology and Geophysics (B. M. R.) was founded in 1947 as part of the Ministry of National Development. Its competent staff, recruited locally as well as abroad, carries out geological, geophysical, mineragraphic and palaeontological investigations, the results of which are made available to the private industry in the form of bulletins and reports. Apart from these services, the B. M. R. carries out the systematic mapping of the whole continent as the 4-mile geological sheet series. It issued recently the magnificent «Tectonic Map of Australia» in four sheets.

In order to stimulate oil exploration, the Commonwealth Government introduced the Subsidy Act, 1957–58 followed by the Petroleum Search Subsidy Acts Bill, 1959, whereby the Government undertakes to subsidize one half, in certain cases up to two thirds, of the costs of geophysical surveys and exploration drilling. From the end of 1957 to the end of 1962, these commitments amounted to 10,500,000 Australian Pounds or approximately one hundred million Swiss Francs. In 1962 it was decided to reduce the subsidy from 50 % to 30 % but, at the same time to double the sum allocated to subsidies. In addition to the subsidies, capital invested in oil search enjoys special tax exemptions.

Under this favourable legislative climate the sustained effort of the companies operating in Australia, some of them with world-wide experience, should ultimately be crowned with success.

Regional Geology

Australia, in its extent of 2,974,600 square miles (7,704,214 km^2) almost equal to that of the United States, is a land mass of comparatively low relief. Mount Kosciusko in the southeastern part of the continent is with 7,328 feet (2,234 m), the highest point. Regionally, the continent consists of a Precambrian shield in the western and central part. It contains several intracratonic basins and Proterozoic and Palaeozoic geosynclines. To the east it is bounded by the Tasman geosyncline which in Permian time has undergone a strong orogeny accompanied by extensive granitic intrusions. Superimposed on these early tectonic elements are several gently folded basins containing Mesozoic and Cainozoic marine and non-marine sediments.

Since the cessation of orogenic movments at the close of the Palaeozoic era, the Australian continent has behaved as a craton with displacements largely restricted to epeirogenic movements. This structural stability over long periods is the reason for the low relief and the absence of more intense and younger structural disturbances as they are found in most producing oil provinces of the world.

Basement Complex

Archean and Lower Proterozoic igneous, metamorphics and metasediments are effective basement. These ancient rocks form most of the Western Australien or Westralian Shield, several nuclei in the northern part of the continent, and occur also in the deeply eroded cores of severeal Lower Palaeozoic orogenic zones. Although in many areas Upper Proterozoic rock units occur in great thickness, are non-metamorphosed and contain beds with source rock characteristics, they are, rather for practical reasons, considered as basement rocks.

Because of the wide extent of the Mesozoic and Cainozoic cover, the actual eastern margin of the Shield is little known, but is generally taken along an arbitrary line separating metamorphic Devonian rocks of the Tasman Geosyncline from non-metamorphic rocks of the same age. However, in eastern central Queensland, gravimetric and surface observations have revealed a sudden change in trend from the northwest–southeastern coastal trend to a northeast–southwestern one which was attributed by the writer to the Shield. This change in trend is accompanied by considerable transversal faulting and deformation of anticlinical axes in Lower Carboniferous rocks.

Sedimentary Basins

The simplicity of the regional structure of Young Palaeozoic-Meoszoic Australia outside the Tasman Geosyncline, finds its expression also in the fact that there are only two types of sedimentary basins, i. e., intracratonic and epicratonic, and a complete absence of eugeosynclines in the sense of Marshall Kay. This is clearly shown in Fig. 1.

Of the two types, the majority is represented by intracratonic basins or troughs bordered by well-defined cratons. Some of them may extend unto the contiguous continental shelf. The others are epicratonic basins with their structural axis parallel to the coast. They are well-developed along the west coast, although several of Mesozoic age occur also along the south and east coast. They are comparable to Mesozoic-Cainozoic epicratonic basins of Africa's west coast.

In both, the intra- and epicontinental basins, the Palaeozoic sections can attain considerable thickness. In places, however, abrupt changes in thickness occur over short distances, brought about by differential vertical movements or pre-existent basement ridges. Stratigraphic gaps of major magnitude occur and whole formations may be present in the deeper parts of a basin, but are entirely absent from its margins.

Most of the intracratonic basins contain regular folds of the first order. In the epicratonic basins folding may occur as reflection of buried basement ridges or, it may be confined to the Meozoic-Cainozoic strata and does not persist at depth. As a rule, however, normal faulting, in places antithetic, is the prevailing type of structural dislocation.

Some of the post-Palaeozoic epicratonic basins contain Mesozoic sections of considerable thickness, as for instance the Maryborough Basin of Queensland. There, resting on indurated Permian, the Triassic is represented by 4,500 feet of sandstone, shale and conglomerate with plant remains, the Jurassic with 1,500 feet of non-marine, possibly lacustrine deposits, and the Cretaceous with a paralic sequence of reportedly more than 10,000 feet. Similar thicknesses of a paralic Jurassic-Cretaceous-Lower Tertiary section were found in wells drilled at Port Campbell in the Otway Basin in Victoria.

In the Gippsland Basin on the south coast, a fairly thin Lower Tertiary section rests either on Palaeozoics and metamorphics, or on Jurassic arkosic sandstone. A glauco-

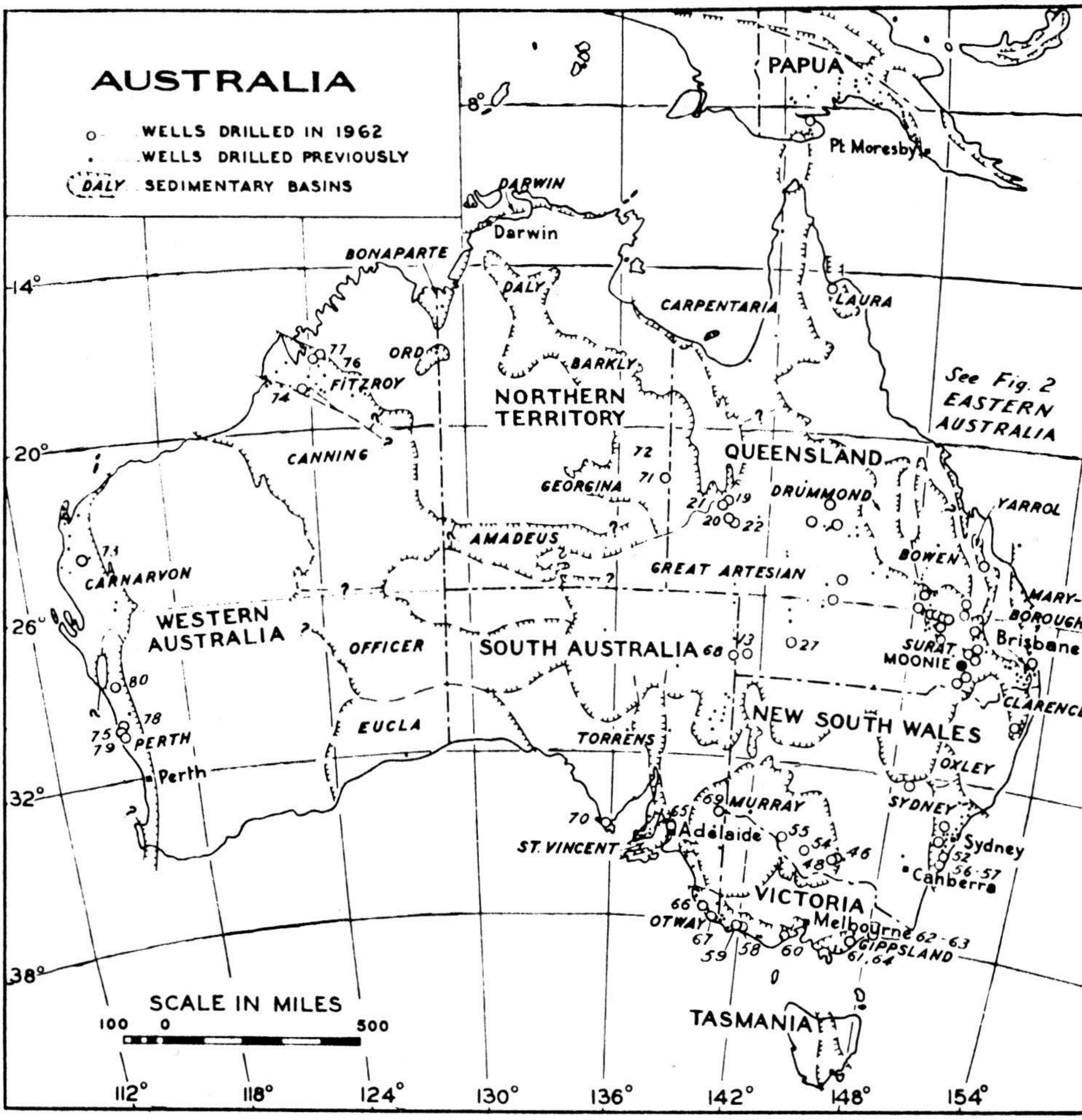

Fig. 1 — Sedimentary Basins of Australia and Exploration Wells (after RUDD in AAPG Bull., 1963).

nitic basal sand of the Eocene was found saturated with heavy oil in a great number of shallow wells. As some geologists believe, a thicker section and improved facies may occur beneath the waters of Bass Strait between the Victorian coast and Tasmania. This, of course depends on whether Bass Strait was then already in existence.

On the other hand, the Eucla Basin to the north of the Great Australian Bight, contains only about 1,500 feet of Cretaceous glauconitic sand overlain by Tertiary near-shore limestone. The sequence rests subhorizontally on basement. It is, therefore, not a basin in the proper sense.

The Mesozoic intracratonic basins, viz. the Carpentaria, Great Artesian and Murray basins, are large-scale downwarps containing moderately thick sections of non-marine, paralic and marine sediments of Mesozoic to Cainozoic age. Their substratum is little known, but is being more and more explored by deep drilling. In some cases the substratum was proved to be the subsurface continuation of known intracratonic basins or, in other cases to be formed by Proterozoic platforms with greatly reduced or missing Palaeozoics.

The major Australian basins can be conveniently classified as follows:

I. Intracratonic Basins

a) Palaeozoic Basins

Bonaparte Gulf	See Table I
Fitzroy – Canning	See Table I
Amadeus	Proterozoic – Ordovician, 11,000 – 21,000'. Marine sandstone, quartzite, siltstone, shale, some limestone. Indetermined Palaeozoic redbeds 7,000'. Several major anticlines.
Georgina	Proterozoic – Ordovician, 9,000 – 10,2000'. Devonian: non-marine sandstone. Ordovician: limestone, calcareous dolomite, sandstone. Cambrian: limestone, dolomite, sandstone, siltstone. Proterozoic: sandstone, conglomerate, siltstone, dolomite. Basement uplifts reflected in sediments.
Sydney	Permian – Triassic, 11,600 – 14,200'. Triassic: non-marine sandstone and shale. Permian: two non-marine (coal) sequences alternating with two marine sequences. Several domes in northeastern part of basin.
Surat – Bowen	Permian – Lower Cretaceous, 18,100 – 21,735'. L. Cretaceous: 2,805 mainly marine shale. Jurassic: 3,440 – 4,310' (in wells) sandstone, siltstone, shale, non-marine. Basal sand producing at Moonie field. Triassic: 2,200 – 4,470' (in wells) mainly non-marine sandstone, conglomerate, siltstone, shale. Permian: 9,650 – 10,150' in west, 1,827 – 2,750' in wells in centre and south. At base of sedimentary section 10,000+ of volcanics.

b) Mesozoic – Cainozoic Basins

Great Artesian	Jurassic – Upper Cretaceous, Triassic missing, Permian is non-marine and only sporadically developed. Thickness variable, 4,000 to 6,000'. Pre-Permian substratum: Precambrian to Devonian, little known, mostly non-marine, some marine incursions.
Carpentaria	Lower Cretaceous 2,360 – 2,958' (in wells), mainly shale with basal sand resting on basement. Recent downwarp.
Murray	Cretaceous – Tertiary 2,000'+. Tertiary: 1,000 – 1,500' shale, sand, bryozoan limestone, lignite. Cretaceous: paralic and marine sandstone and shale. Pre-Cretaceous substratum variable (metamorphics, Devonian redbeds, non-marine Permian). Slight folding.

II. Epicratonic Basins

a) Palaeozoic Basins

Carnarvon	See Table I
Perth	See Table I

b) Mesozoic – Cainozoic Basins

Otway	Jurassic – Tertiary 12,000'+. Tertiary: 4,235' sandstone, lignite, glauconitic sandstone. Cretaceous: 1,720'+ sandstone, pyritic shale, dolomite, siltstone. Jurassic: 5,000' – ?10,000' arkosic shaly sandstone, thin shale bands. Faulting, gas shows at Port Campbell.
Gippsland	Tertiary: up to 200', glauconitic sandstone, bryozoan limestone resting on arkosic-lignitic Jurassic of unknown thickness. Heavy oil in basal sand.
Clarence – Ipswich	Triassic – Jurassic 5,000' + sandstone, siltstone, shale, coal, continental to paralic, resting on metamorphic basement.
Maryborough	Triassic – Cretaceous ± 12,000' sandstone, shale, siltstone, conglomerate, plant remains. Mainly non-marine, some marine beds.

In the following sections three of the Western Australian basins, the Great Artesian Basin and the Surat – Bowen Basin will be treated in some detail. They are most active basins and consequently, considerable subsurface information has come to hand. The table overleaf is a synopsis of the Western Australian basins.

Synopsis of the West-Australian Basins

Name of Basin	Basin Type	Age and Total Thickness of Sediments (ft)	Lithological Types and Facies	Oil and Gas Indications
PERTH Appr. 23,000 square miles	Graben or half-graben, marginal to continent, parallel to coast, faulted, no surface evidence of folding.	Silurian to Eocene approx. 27,000' Devonian, Carboniferous missing.	Sandstones, shales, siltstones, some marine limestones, tillites in Permian, red beds in Silurian. Euxenic conditions (bit. shale) in U. Permian.	No indications except reported shows (marine Permian) in B. M. R.'s Beagle Ridge # 1.
CARNARVON Appr. 40,000 square miles	Marginal to continent, block-faulted. Anticlines in Tertiary and Cretaceous in coastal zone. Meridional basement ridge.	Silurian to Miocene appr. 45,000', great variation in thickness of Paleozoics. Cretaceous (Aptian) regional overlap. Jurassic (11,000+) in foredeep.	Mostly marine, 4,500 ft. partly marine glacial deposits in Lower Perm., euxenic conditions in U. Permian. Lack of potential source rocks in Devonian and Carboniferous.	Good oil shows in basal Cretaceous sand. Gas shows in Jurassic claystones. Prospects possibly confined to Cretaceous-Jurassic, ? U. Perm
FITZROY TROUGH Appr. 20,000 square miles	Graben with subsidence dating back to at least U. Carbonif. Several major anticlines. Lennard Shelf in North with Devonian reefs.	Ordovician to L. Cretaceous appr. 33,000'	Mainly marine, excepting glacial Lower Permian. Carbonate deposition in Ordovician, Devonian. Source facies in Ordovician, possibly Lower Carboniferous, and Devonian in deeper parts of basin.	Oil impregnation in Ordovician, oil shows in Devonian limestone, Permian basal (Grant) sandstone. Good prospects for Ordovician, Devonian and Carboniferous.
SOUTH Canning Appr. 150,000 square miles	Shelf platform with at least two basement ridges and more mobile Jugurra Terrace between Fenton and Dampier faults.	Reduced incomplete section, 2,500' Ordovician; Devonian, Carboniferous missing excepting 4,000' Devonian on Jurgurra Terrace. Permian reduced, Jurassic-Cretaceous thin.	Ordovician limestone, shale, sandstone, Devonian carbonate section and salt plug (Jurgurra Terrace), Permian glacials, Jurassic-Cretaceous marine, shelf facies.	Minor oil shows in Devonian (Jurgurra Terrace).
BONAPARTE GULF Appr. 8,000 square miles (on shore, large off shore area)	Triangular trough between Kimberley and Sturt Precambrian blocks.	Cambrian to Permian appr. 15,000'	Mainly marine, lower part of Devonian in arenaceous facies (Cockatoo Sandstone), upper part carbonate-marl-shale section, reef development in places. Carboniferous limestone-shale and sandstone-siltstone facies.	No deep tests. Fluorescence and slight impregnation in Milligans Beds (Carboniferous) in Spirit Hill # 1 strat-test.

The Fitzroy — Canning Basin

The basin covers an area of about 170,000 square miles. The northwestern part of it is shown in Figure 2. Structurally it consists of four elements each with a distinct set of stratigraphic development. From northeast to southwest they are: Lennard Shelf, Fitzroy Trough, Jurgurra Terrace and South Canning Basin or Platform. They are separated by the Pinnacle, Fenton and Dampier faults respectively. As an intracratonic basin it is bordered to the northeast by the Lower Proterozoic belt of the King Leopold Ranges and to the southwest by the northern part of the Westralian Shield. There is reason to assume that it extends to the west unto the continental shelf.

Lennard Shelf: This near-horizontal basement shelf supports in its southeastern part a section of 2,600 feet of Lower Ordovician fossiliferous limestone, calcareous, black, slightly bituminous shale, dolomite, dolomitic limestone, sandstone and shale.

The Ordovician or, in other parts of the shelf, the basement, is unconformably overlain by a variable reef complex with fore-, inter-, and backreef deposits of Middle to Upper Devonian age. The major reef bodies are stromatoporoid biostroms. The back- and interreef facies is characterized by calcarenites, red shales and minor bioherms, the forereef facies by calcarenites, isolated bioherms, reef talus debris and oolites. Fanglomerates, possibly derived from the close-by Devonian shore line, interfinger with the calcareous deposits, fill reef channels, and are even found in the forereef zone.

Reef development started in the Middel Devonian (Givetian) and continued interruptedly into the Upper Devonian when it reached a second maximum in places. Toward the close of the Upper Devonian, calcarenites, siltstones and sandy limestones were deposited over wide areas. About 3,500 feet of Devonian section was measured in wells.

In the outcrop, the karst platform formed by the reef complex, is overlain by remnants of Permian glacial beds, whereas in the northwestern, buried part of the shelf, a thin section of Lower Carboniferous was found in wells above the Devonian.

Fitzroy Trough: Separated from the Lennard Shelf by the Pinnacle fault and from the Jurgurra Terrace by the Fenton fault, this trough or graben was in existence as a subsiding area since at least Upper Carboniferous time. It contains 12,000 to 15,000 feet of Permian, more than 5,000 feet of Upper Carboniferous, and an unknown thickness of Devonian and possibly Ordovician. The Upper Carboniferous consists of sandstone, shale and siltstone with thin interbedded limestone, dolomite and anhydrite. The facies is mainly marine-neritic. This section is nowhere in evidence at bet surface and is known only from two wells.

The Upper Carboniferous is overlain unconformably by Permian glacial deposits and shallow-water arenites which grade upwards into fossiliferous neritic to bathyal shale and marly limestone. The Permian ends with a mainly non-marine, plant-bearing series with two shallow-water, fossiliferous intercalations. The total thickness of the Permian sections is 12,000 to 15,000 feet. A conglomeratic facies of the upper part of the Permian section close to the Pinnacle fault attests to movements along this fault line in Permian time.

The Mesozoic is represented by a relatively thin section (1,740 feet) of marine and non-marine Lower Triassic and a few hundred feet of marine Upper Jurassic.

Five major domes are arranged along two parallel trends at an oblique angle to the basin axis (Fig. 4). They show intensive, closely-spaced cross faulting. One of them, Grant Range dome, has been drilled.

Jurgurra Terrace: Separated from the Fitzroy Trough by the Fenton fault and from the South Canning Platform by the Dampier fault, lies a separate structural unit,

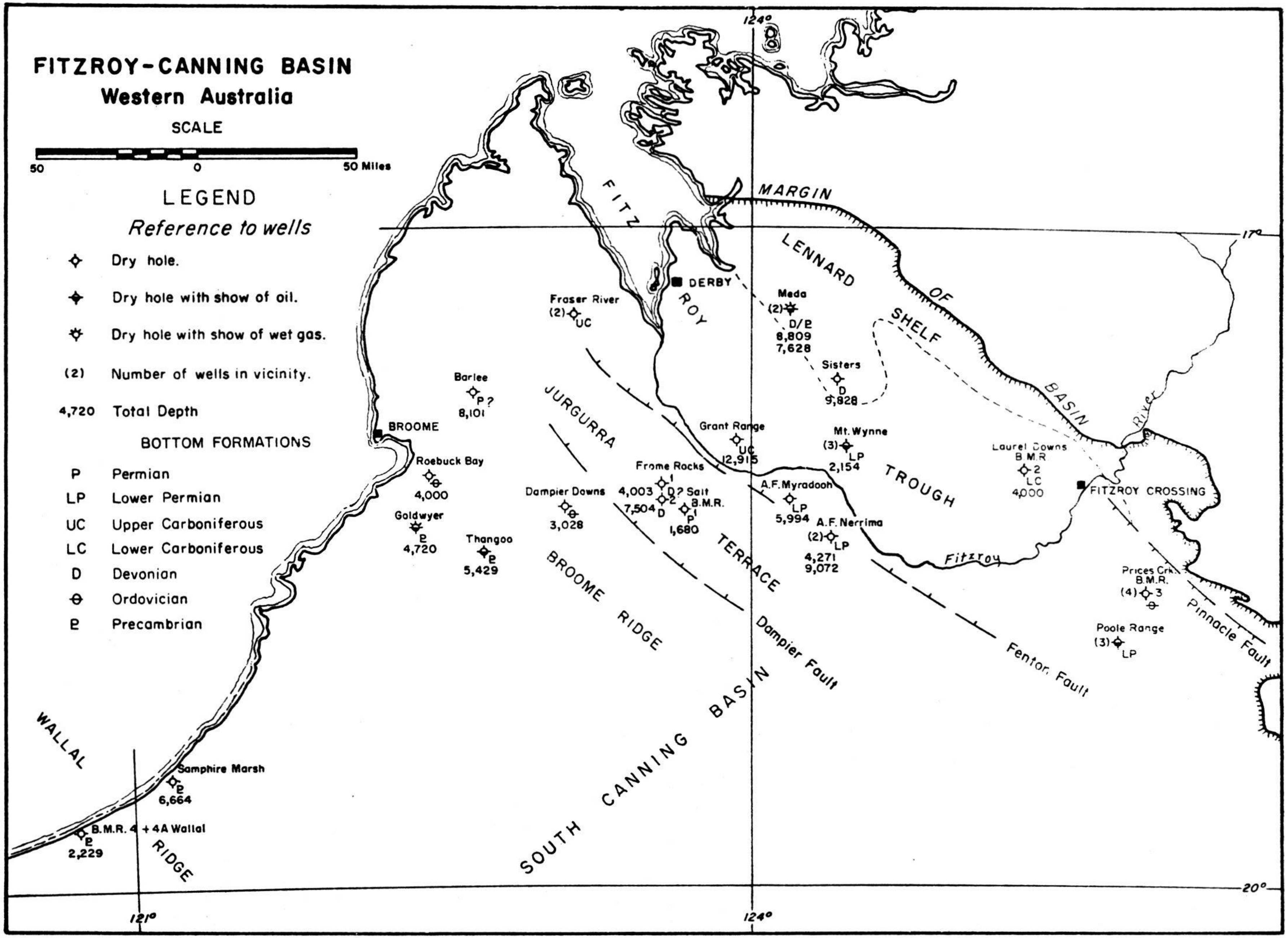

Fig. 2 — Fitzroy-Canning Basin, Western Australia, Structural Units and Exploration Wells.

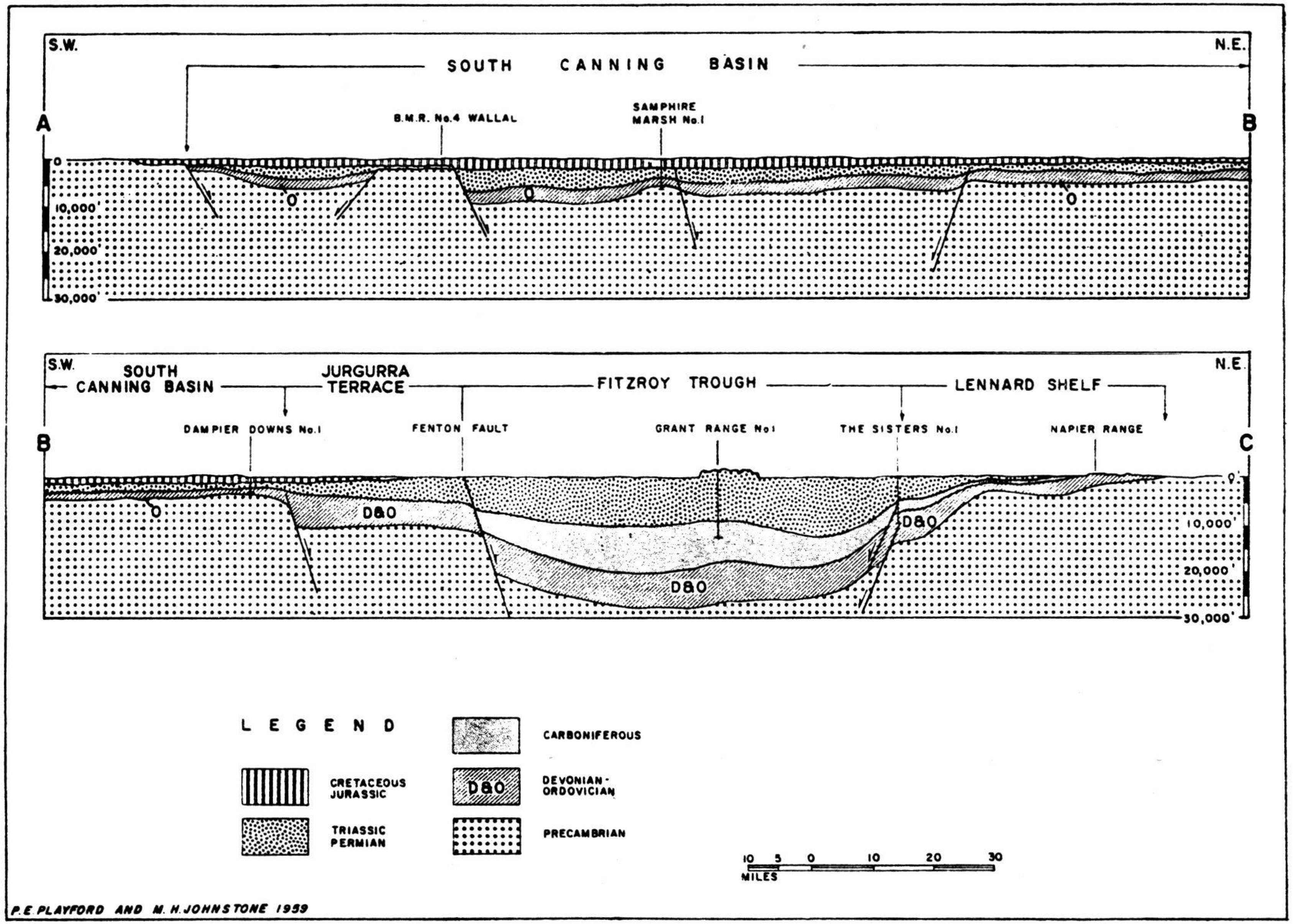

Fig. 3 — Fitzroy-Canning Basin, Western Australia, Structural Cross Section (after PLAYFORD and JOHNSTONE in Australasian Oil and Gas Journal, 1959).

the Jurgurra Terrace. Fenton fault was mapped at the surface. It is marked by a number of hot springs. It was proved by seismic to be a normal fault with up to 10,000 feet of downthrow to the north. Dampier fault has no surface expression and was only found by seismic. A zone of cross faulting connects the two major faults.

About 3,500 feet of Permian were found overlying at least 4,000 feet of Upper Devonian limestone and siltstone with the Carboniferous missing. One well penetrated nearly 1,800 feet of rock salt immediately below the Permian basal sandstone (Frome Rocks 1).

South Canning Basin: This is a shallow basin or shelf platform with a much reduced and deficient section. Two ridges (Broome and Wallal) separate shallow depressions which contain not more than 3,000 feet of Lower Ordovician overlain by 2,000 feet of Permian. Devonian and Carboniferous are missing from all the wells in the South Canning Basin.

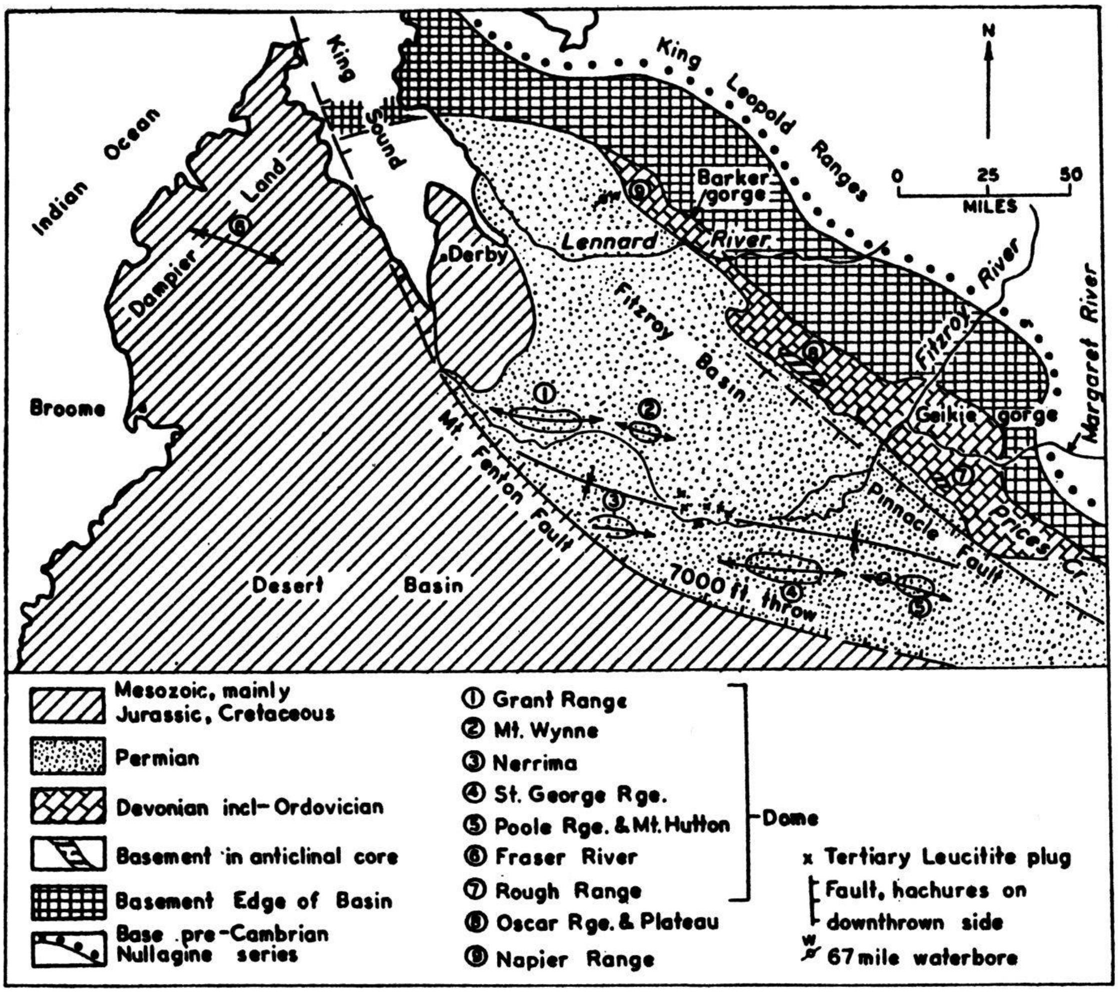

Fig. 4 — Fitzroy-Canning Basin, Western Australia, Structural Interpretation prior to Drilling (after SCHNEEBERGER in World Oil, 1954).

Wallal Ridge maintained its status as a ridge throughout most of the Palaeozoic time. It was innundated only in the Permian (reduced Permian on Precambrian). Broome Ridge on the other hand, supports an Ordovician section of unknown thickness.

A number of gravity lows in the eastern and southeastern part of the South Canning Basin may indicate greater thicknesses there, but no exploratory drilling was done so far in this remote area. There, Woolnough Hills, a dome-like structure with dolomite and gypsum cropping out in its core, possibly pre-Permian, may be a salt dome.

Oil and Gas Prospects of the Fitzroy–Canning Baisin

As Fig. 2 shows, a fair number of wildcat wells has already been drilled. Some more recent ones of which data are not released yet, are not shown. Oil shows were reported from the Ordovician on the Lennard Shelf and the South Canning Basin. Gas shows in the Devonian and oil shows in the Lower Carboniferous were reported from Meda 1 on the Lennard Shelf and good oil shows from the Devonian on Jurgurra Terrace.

Based on available data the following prospects can be postulated:

1) Ordovician:

a) Lennard Shelf: Slightly bituminous (source) facies below, reservoir beds (sand, vuggy dolomite) in upper part of section.

b) S. Canning Basin: Source formations observed, but reservoir rocks lacking in wells drilled. Sand possibilities in flanks of subsurface ridges.

2) Devonian:

a) Lennard Shelf: Prolific reef development, source rocks possibly in deeper parts of basin (Fitzroy Trough). Sealed reefs in structurally favourable position in northwest.

b) Fitzroy Trough: Possibility of fringing and capping reefs on basement cores of major domes. Should be tested at Poole Range where previous bores reported oil impregnations in basal Permian.

c) Jurgurra Terrace: Good shows in non-reef facies of Devonian may hint at good possibilities in structurally favourable position. Salt dome possibilities.

3) Lower Carboniferous:

a) Lennard Shelf: Because of good shows in Meda, prospects may be promising in structurally favourable areas.

The great variety of prospects as outlined above should ensure commercial success in the Fitzroy-Canning Basin. That this has not been obtained so far, may be attributed to several factors, the most important of which seems to be the repeated interruption of deposition and the subsequent prolonged exposure of the deposits to erosion, such as the Ordovician on the South Canning Platform, its possibly restricted occurrence on the

Lennard Shelf because of erosion, the secondary in-filling of cavities, pore space and vugs in the Devonian reef complex in the same area.

More complete sections, i. e., less severe erosion may be expected in the south and east of the Canning Platform where negative gravity anomalies may indicate deeper basins.

On the other hand, gravimetric and seismic surveys in the Fitzroy Trough suggest values of up to 20,000 feet for the basement floor. In addition to this, the unexpected occurrence of at least 5,000 feet of Upper Carboniferous there, with the added possibility of appreciable thickness of the Lower Carboniferous, may keep the Devonian out of reach of the drill in most of the major domes of the trough.

Judging by the information at hand, Jurgurra Terrace is the most attractive area. The salt there may offer new possibilities, although its source is still under debate.

The Carnarvon Basin

This is a typical epicratonic basin bounded to the east by the Westralian Shie.d, its basement consisting of down-faulted and down-warped shield elements, its western and northern extension concealed by the Indian Ocean. In the south it connects with the Perth Basin through a narrow channel between the basement high of Geraldton-Ajana and the Shield (Fig. 5).

Stratigraphy

Although the stratigraphical history of the basin comprises the time span Silurian – Tertiary, and the compound thickness of the sediments is in the order of 45,000 feet, this is not a complete record, nor does the full thickness of the section occur at any given point. In contrary, there are substantial gaps in the stratigraphic record and there occur rapid changes in thickness over short distances.

Devonian-Carboniferous

The Devonian Carboniferous section ranges from Middle Devonian to the Lower Carboniferous and comprises the following lithological groups::

Lower Carboniferous: 2,000 – 2,500 feet.

Quartzose sandstone with plant remains above, limestone alternating with sandstone, below.

Upper Devonian: 2,000 – 3,000 feet.

Arenaceous series of cross-bedded sandstone, subgraywacke, conglomerate and siltstone, possibly of continental origin.

Middle Devonian: 2,000 feet.

Dense limestone and marl, sandy limestone and siltstone with basal arkosic gritty sandstone unconformably on basement.

The total thickness of the Devonian-Carboniferous section is 6,000 to 7,500 feet. The cyclic alternation of two calcareous with two arenaceous formations is evidence of deposition in moderately deep water with progressive and regressive changes of the coast line. It is reported that this sequence penetrated by wildcat wells in the coastal region contains more shales, some of them black, than the outcrop section at the eastern margin of the basin.

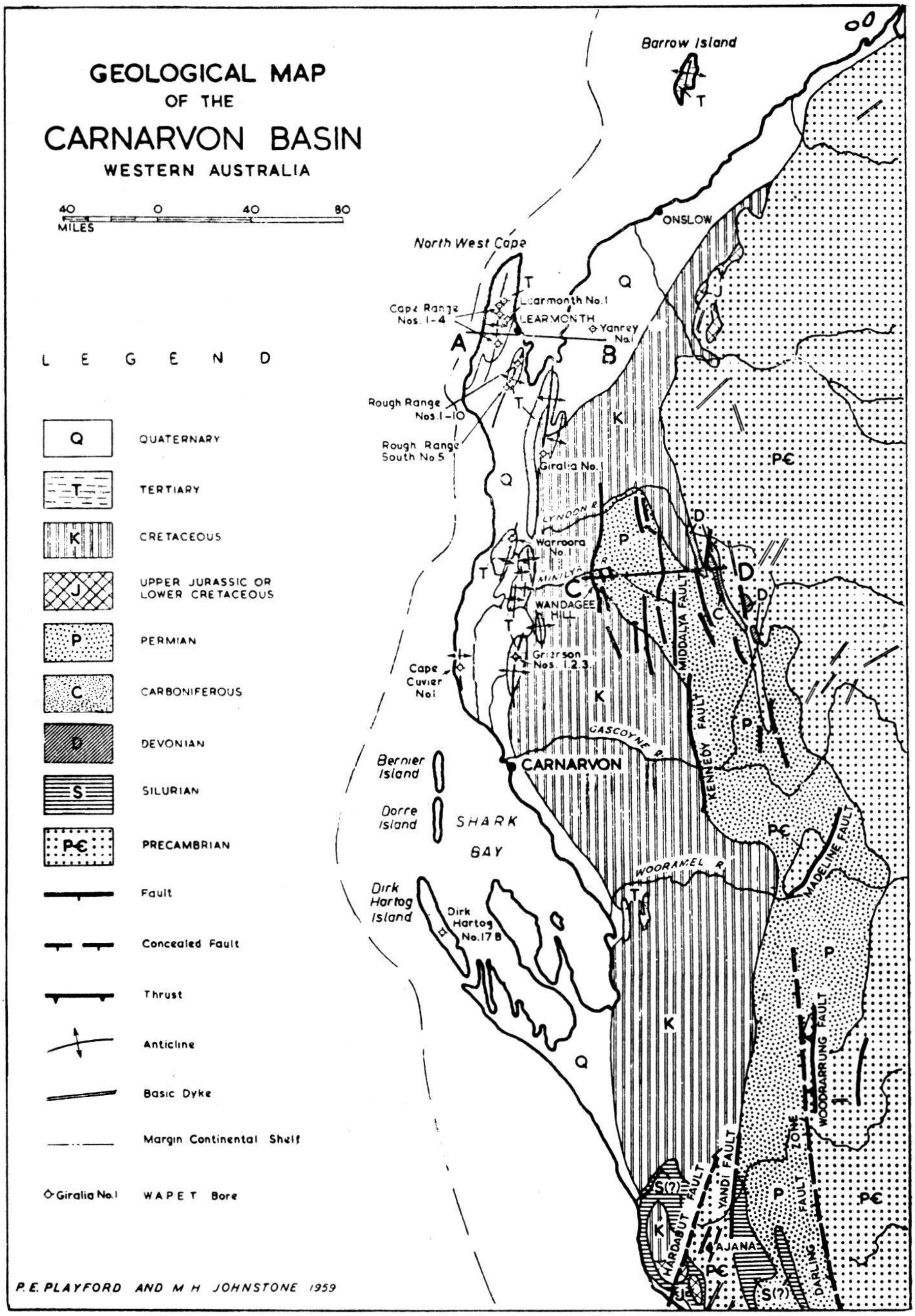

Fig. 5 — Carnarvon Basin, Western Australia, Geological Map
(after PLAYFORD and JOHNSTONE in Australasian Oil and Gas Journal, 1959).

Permian

After a period of non-deposition which comprises most of the Carboniferous, the Permian (Sakmarian) starts with fluvio-glacial and glacial deposits of close to 5,000 feet thickness. These are followed by about 760 feet of limestone and marl alternating with sandstone and containing a rich fauna of brachiopods, crinoids and bryozoa.

The remaining 6,000 feet of Permian is a marine (with some exceptions) sequence of various sandstones with two intercalations of black, carbonaceous pyritic shale with gypsum and phosphate nodules, of a compound thickness of about 1,500 feet. The facies suggests temporary landlocked conditions and has the characteristics of a source facies.

The spread of the Young Palaeozoics within the basin is shown in Fig. 6. The greatest thickness of the Devono-Carboniferous section is in a syncline between Wandagee Ridge and Cape Range, i. e. in the western part of the basin, whereas the Permian reaches its greatest thickness in the shallow syncline between Wandagee Ridge and Westralian Shield.

In the subsurface, marine Permian was found at Giralia and Warroora, but farther south it is truncated by basal Cretaceous on the north plunge of what we call Shark Bay Uplift with Silurian in its core (Fig. 7).

The depositional record of the Mesozoic is incomplete, the entire Triassic is absent from the Carnarvon Basin.

Jurassic

Prior to the drilling of exploratory wells, Jurassic rocks were known only from a few scattered outcrops in the northern part of the basin. However, in Cape Range No. 2 well (Fig. 6), more than 11,500 feet of bathyal Middle and Upper Jurassic clay and siltstone were found, and in Rough Range No. 1, twenty miles to the south-southeast, the section, identical in age, is only 2,561 feet thick and consists of sandstone, siltstone and shale with lignite bands. Consequently, the actual Jurassic shore line is to be expected only a short distance to the east, since BMR No. 5 and Yanrey No. 1 did not find a Jurassic section above either glacial Permian or Precambrian basement. It is logical to assume a continuation of the Jurassic rocks to the north -northeast on the continental shelf.

Cretaceous

Whereas the Jurassic is restricted to the northwesternmost part of the basin, the Cretaceous has transgressed over wide areas and overlaps all formations from the Precambrian up (Figs. 5, 6 and 7). The transgression was ushered in by the rapid spread of the basal Birdrong sheet sand, a highly glauconitic and feldspathic quartz sand which in the outcrop can be seen overlapping various Upper Permian formations with slight angular unconformity. It is an ubiquitous and excellent aquifer. It is in this sand that oil was found at Rough Range in 1953.

Upper Cretaceous – Tertiary

Various types of shallow-water carbonate rocks occur throughout the Albian - Danian interval and extend into the Palaeocene, Eocene and Miocene, with the Ypresian and Oligocene apparently missing. The thickness of the section is about 4,400 feet. Faunal relationship (large forams) points to sea connections with Indonesian basins. The Upper Cretaceous - Tertiary section is restricted to the coastal zone.

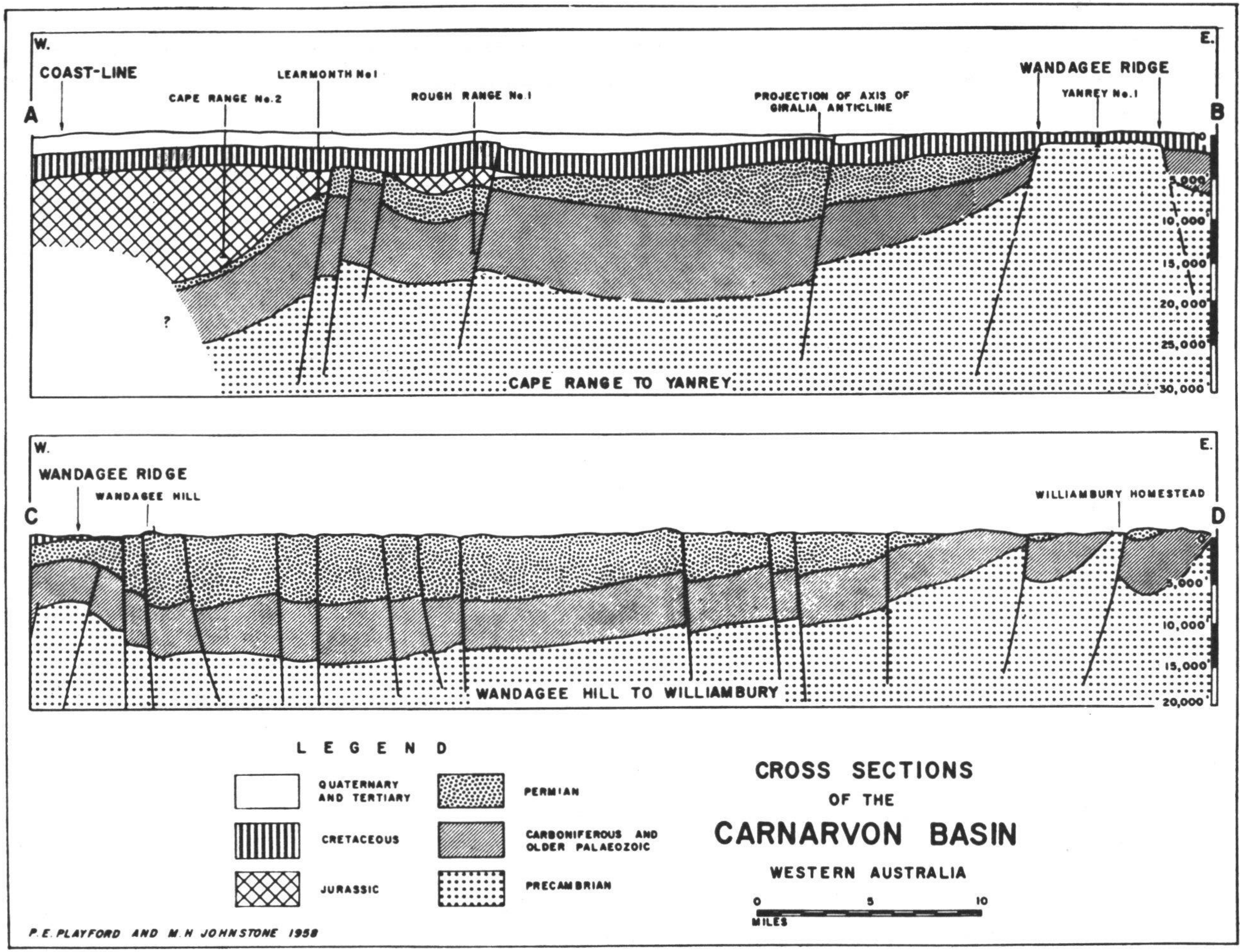

Fig. 6 — Carnarvon Basin, Western Australia, Structural Cross Sections (after PLAYFORD and JOHNSTONE in Australasian Oil and Gas Journal, 1959).

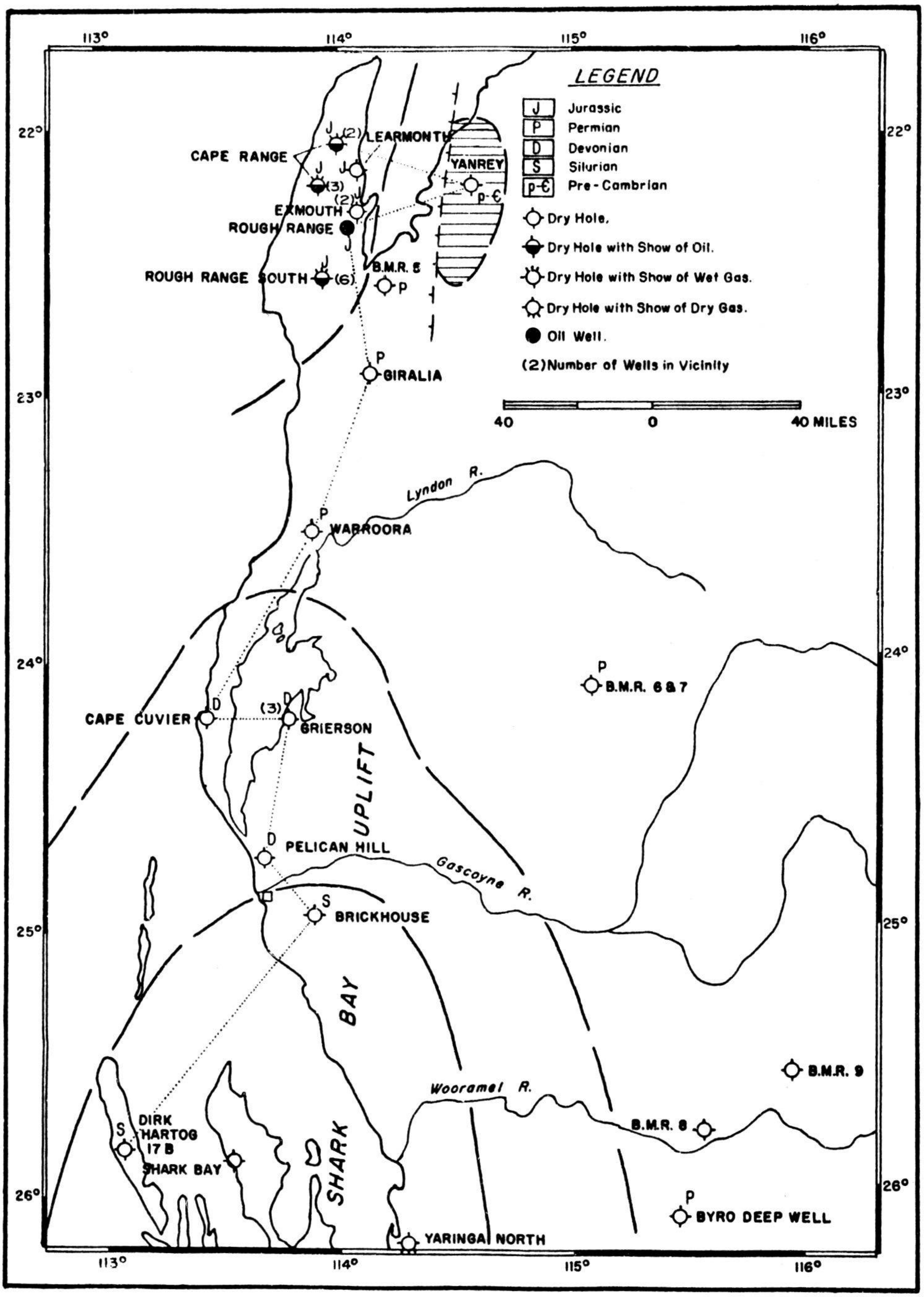

Fig. 7 — Carnarvon Basin, Western Australia, Subsurface and Exploration Wells.

Structural Pattern and Basin Mechanics

Gravimetric data, confirmed in local areas by seismic and over wider areas by subsequent exploration drilling, have revealed a fairly complete picture of the basement configuration and structural pattern.

A median basement ridge, named Wandagee Ridge (Fig. 6) extends from Wooramel River in the south to beyond Minilya River in the north. From there it connects through several positive anomalies with the basement high at Yanrey. The ridge was drilled at Wandagee and Yanrey and Precambrian was found at 1413 feet directly overlain by Cretaceous at Yanrey.

Wandagee Ridge divides the basin into two parts, an eastern trough with a slightly reduced Devono-Carboniferous section and a maximal development of the Permian, and a western trough with a thicker Devono-Carboniferous section and a considerably reduced Permian. To the west of the Learmonth Uplift it slopes gradually away under the Indian Ocean. In its westernmost part, at Cape Range, it contains the more than 11,500 feet thick Jurassic section (Fig. 6).

An antithetical fault pattern accompanies the down-warping of the basin between the Shield and Wandagee Ridge, and a similar block faulting pattern is in evidence also west of the ridge. The age of the faulting is pre-Cretaceous.

The western trough rises to the south and the Young Palaeozoics are gradually truncated by the Cretaceous. Shark Bay Uplift with its thick Silurian section is reflected in the gravity picture as a negative (—50 milligals) anomaly, whereas the 11,500+ feet of Jurassic claystone at Cape Range cause a positive anomaly of + 55 milligals. There is no explanation for this obvious discrepancy.

Several regular anticlines, some of them of considerable size, are developed in Cretaceous-Tertiary rocks in the northwestern part of the basin. Cape Range anticline is 60 miles long and 20 miles wide with a closure of 1,500 feet, Rough Range anticline, 45 miles long and 15 miles wide with a closure of 300 feet, and Giralia anticline, 80 miles long, about 20 miles wide and a surface closure of 700 feet. There is a certain disproportion between the size of these structutes and their relatively small closure. In some of them a marked discrepancy exists breween surface structure and structure at depth.

Fig. 8 is a combination of seismic and stratigraphic interpertation with gravity values added (dashed line profile). It shows a gentle anticline from the surface to a depth of about 3,600 feet, the base of the Cretaceous. Below that depth, the Young Palaeozoics form a syncline to a depth of 20,000 feet. In other words, an anticline near and at the surface is underlain by a deep-seated syncline. The gravity profile shows a strong minimum coinciding with the anticlinal axis at the surface, in other words, it reflects the syncline at depth and ignores the surface anticline. The phenomenon of a superposition of anticline and syncline is attributed to the irregularities of a pre-Mesozoic peneplain on the subsequently laid down Mesozoic section and resulting draping over the irregularities. Slight accentuation of the dips by lateral compression and faulting produced the surface anticline as it can be seen at present. Similar conditions were also found in other anticlines and, what appeared at first sight to be an ideal situation of a number of regular, drillable structures, turned out to be a complex problem of non-coincidence of surface and subsurface.

Oil and Gas Prospects of the Carnarvon Basin

WAPET, the operating company, selected Rough Range anticline for a first test in 1952 with the Young Palaeozoics as objective. However, unexpectedly, oil was struck

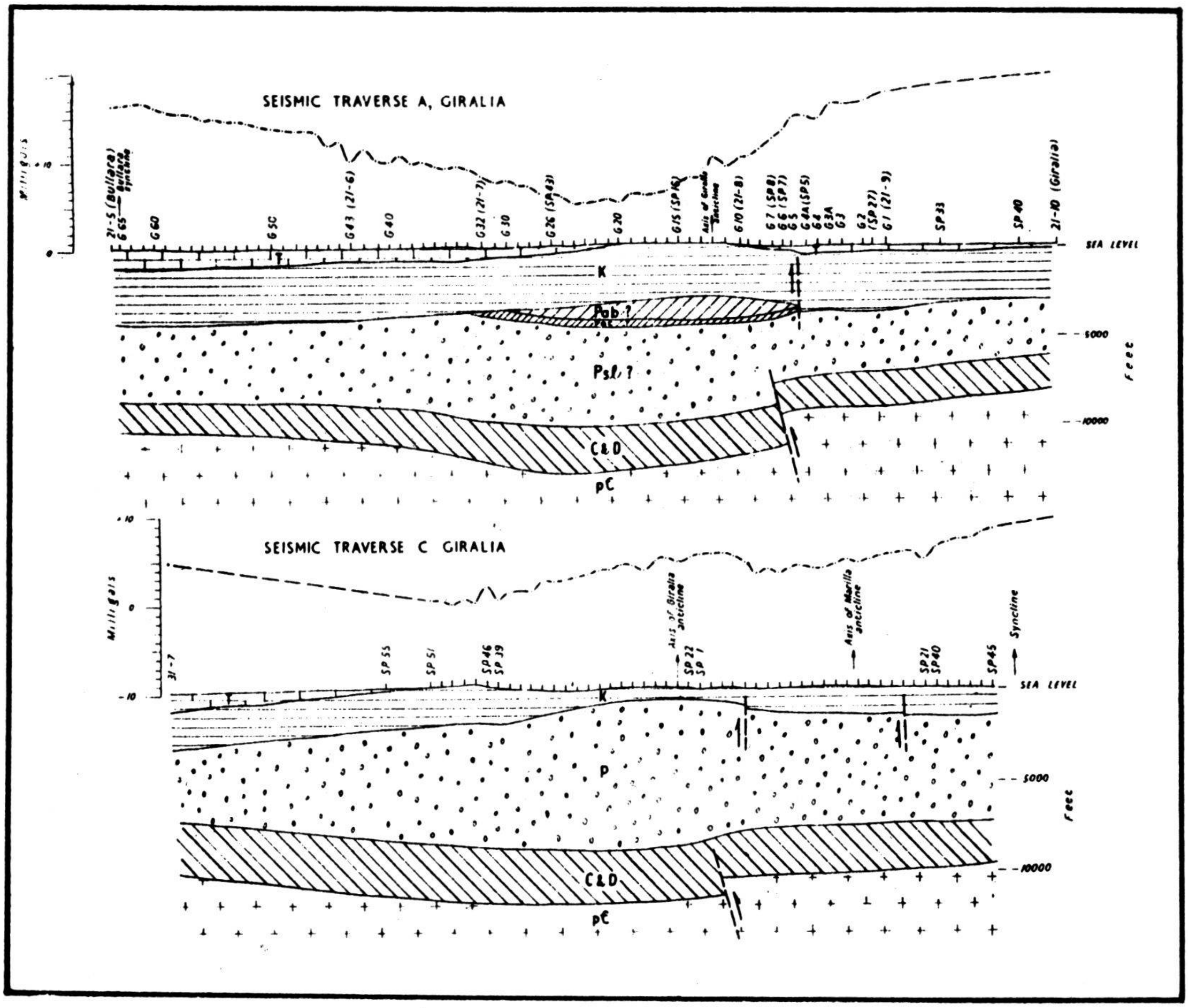

Fig. 8 — Giralia Anticline. Seismic, geological Section and Gravity Profile combined (after THYER, BMR, 1951).

in the basal Cretaceous sand at around 3,600 feet. The oil was highly paraffinic with a gravity of 39.6⁰ API. Daily production was at a rate of 500 barrels.

After an extended test series, the sand was cemented off and the hole deepened to 14,607 feet where it was abandoned for technical reasons. For the purpose of further testing, well 1A was drilled a few yards from No. 1. It produced at about the same rate, but some water was reported. Under an extended development programme, nine additional wells were drilled on Rough Range anticline. Although oil shows were obtained from several of them, they failed to confirm the production of Nos. 1 and 1A. Rough Range, therefore, remained a one-well field and, because of its remoteness, was shut in. Recently, more drilling was done on the southern continuation of the anticline, but no success was reported so far.

Four wells were drilled on Cape Range anticline and in the process, the thick bathyal Jurassic section was discovered. Encouraging shows were obtained in Nos. 1 and 2, of which the latter with its 15,170 feet, is believed to be the deepest well drilled in the

Southern Hemisphere. One well on Giralia anticline was also dry. So were a number of others drilled on various surface anticline, in spite of occasional shows of oil.

Summing up the situation, the following facts are apparent:

Positive Factors

1) Potential source rocks in the Devonian-Carboniferous section are reported from the deeper, northwestern, part of the basin from wells.
2) Potential source rocks in the upper part of the Permian section are exposed in the eastern part of the basin.
3) Although many of the Young Palaeozoic sands appear to be tight (clay-filled pore space), there are still a great number of potential reservoir sands.
4) The Jurassic bathyal section and its transition into a near-shore facies from west to east, is an interesting feature.
5) Favourable stratigraphic conditions along the north plunge of the median ridge as well as Jurassic shore line conditions can be assumed.

Adverse Factors

1) In the eastern part of the basin, between the Shield and Wandagee Ridge, there is a conspicous absence of anticlinal structures. The faults are tensional, not compressional, and show practically no fault closures.
2) In the western part of the basin, there is a discrepancy between surface and subsurface and the problem is to find drillable anticlines within the Young Palaeozoic section beneath the Cretaceous-Tertiary cover.
3) The oil in the basal Cretaceous at Rough Range is probably not indigenous, but has migrated either from Jurassic or Young Palaeozoic sources. As its reservoir is an aquifer, commercial accumulations can only be expected in well-sheltered positions, i. e., behind permeability barriers or in anticlines with exceptionally pronounced closure. Drilling has proved the latter possibility rather questionable.

Conclusions

The play in the Carnarvon Basin is for stratigraphic traps in connection with basement highs, unless closed anticlines in the Young Palaeozoics or in the Jurassic, the latter with near-shore conditions, can be outlined beneath the Cretaceous-Tertiary cover.

The Perth Basin

Perth Basin is a narrow, not more than 60 miles wide, and 450 miles long graben or half-graben extending from Cape Leeuwin in the south to the Precambrian uplift near Geraldton in the north. As Fig. 9 shows, its eastern margin against the Westralian Shield is marked by the Darling fault with a 70^0—80^0 hade to the west and a maximal throw of perhaps 30,000 feet. Movements along this fault line may have started in Lower Palaeozoic and continued interruptedly until recent times. The Darling Scarp is still a conspicuous physiographic feature.

In the gravity map (Fig. 10) the Darling fault shows up as an exceptionally steep gravity slope of about 15 milligals to the mile. The opposite rise toward the coast is gentler, 3 to 4 milligals per mile. Values of + 10 milligals were obtained at Jurien Bay, south of Geraldton. They compare with identical values on the shield immediately east of the Darling fault.

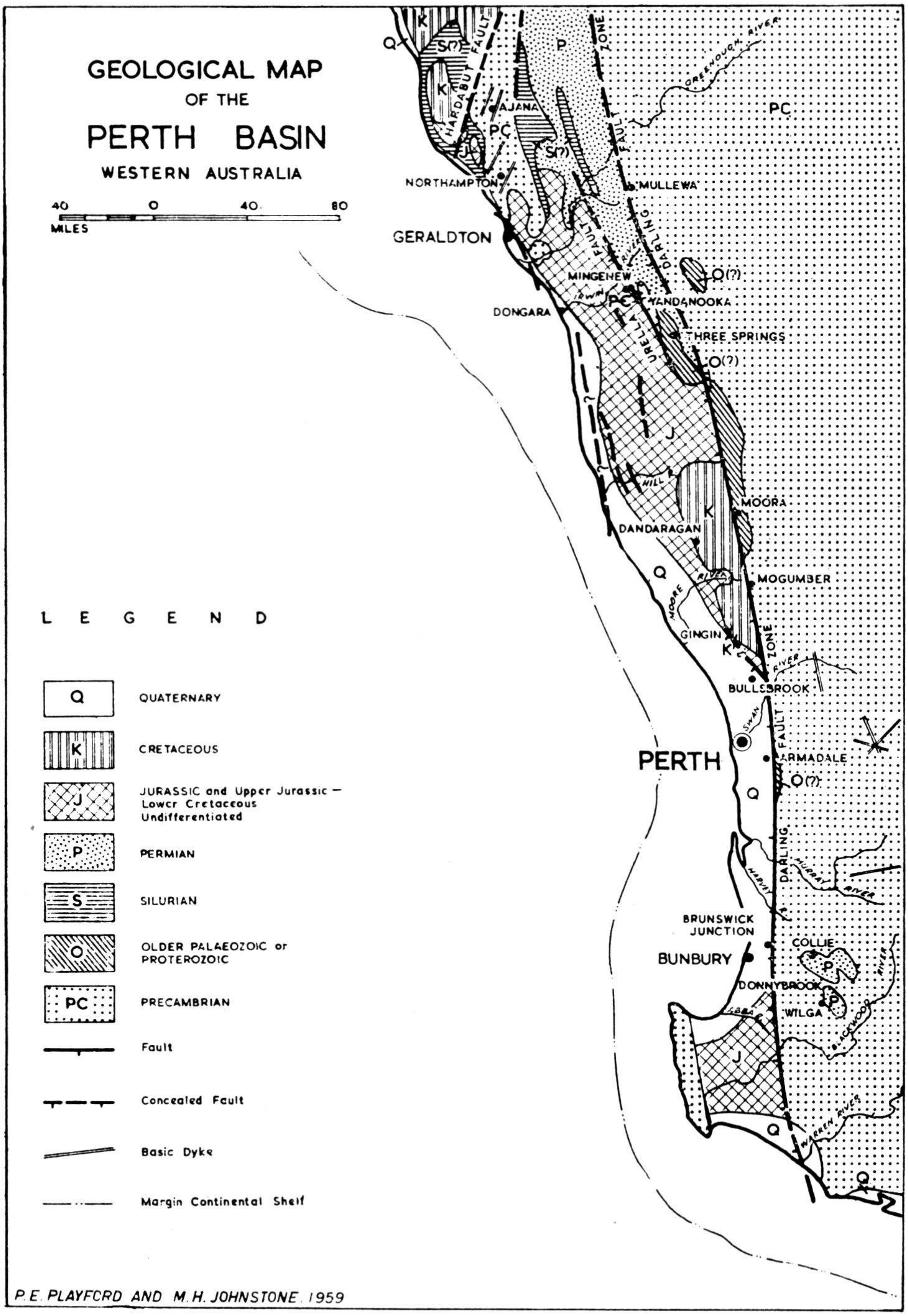

Fig. 9 — Perth Basin, Western Australia, Geological Map (after PLAYFORD and JOHNSTONE in Australasian Oil and Gas Journal, 1959).

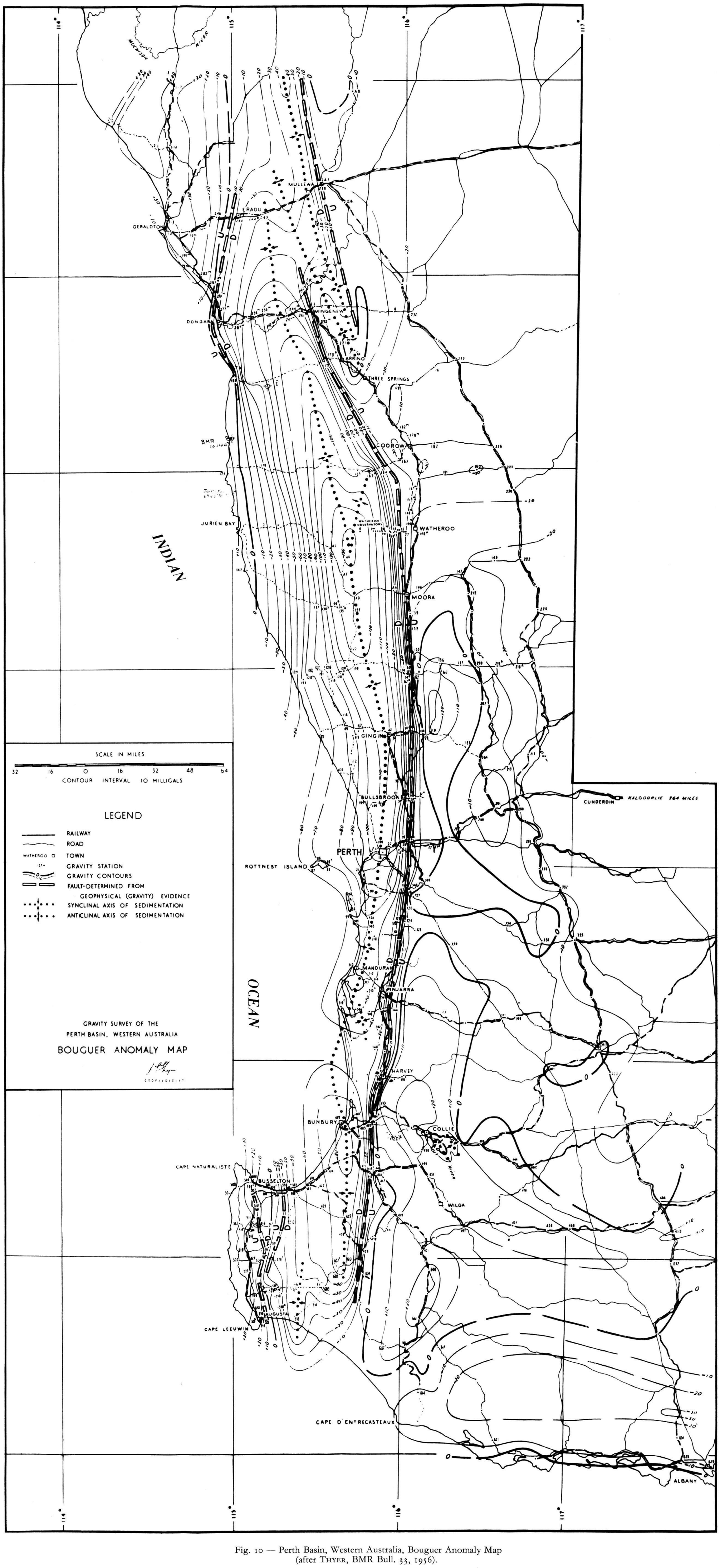

Fig. 10 — Perth Basin, Western Australia, Bouguer Anomaly Map
(after THYER, BMR Bull. 33, 1956).

Within the basin two gravimetric minima occur, one of the order of — 130 milligals north of Perth, the other one of — 80 milligals in the south. Both anomalies rise to the south and north. Since more than 40,000 feet of Upper Proterozoic and Lower Palaeozoic rocks are known from the northern part of the basin, it is probable that the exceptionally low gravity values are partly caused by these older rocks.

The western margin of the basin is for its greatest part submerged in the Indian Ocean, excepting in the south where on the peninsula between Cape Naturaliste and Cape Leeuwin (Fig. 10) the Precambrian is at the surface, upthrown along a fault zone. In the north, at Jurien Bay, Precambrian basement was found at 4,769 feet in Beagle Ridge 1A bore.

There are not many anticlinal structures known in the Perth Basin, block faulting seems to be the dominant type of tectonic displacement. There is a major surface anticline at Gingin, whereas Beagle Ridge appears to be a faulted basement high with draped over sediments rather than a true anticline.

Stratigraphy

Leaving the non-prospective Proterozoic and Lower Palaeozoic section aside, the Young Palaeozoic – Mesozoic section of the Perth Basin begins with the Permian, Devonian and Carboniferous have not been recognized. It ends with the Upper Cretaceous (Santonian).

Upper Cretaceous: 300'+
Marine chalk, sandstone and greesand (?Albian to Santonian).

Jurassic to Lower Cretaceous: 3,500'
Non-marine sandstone, conglomerate and siltstone, with only 120 feet of marine siltstone, fossiliferous limestone.

Triassic: 2,200' in Beagle Ridge bores
1,290 feet non-marine sandstone and siltstone
910 feet fossiliferous marine shale and siltstone.

Permian: 6,300'
2,500 feet non-marine sandstone, siltstone, conglomerate, some purple shale in upper part, *Glossopteris – Gangamopteris* flora.

300 feet non-marine sandstone, carbonaceous shale and coalbeds, Gondwana flora.
2,000 feet sandstone, dark grey shale with gypsum and markasite, lenses of limestone, marine, partly euxenic.
1,500 feet tillite, warve shale, siltstone, conglomerate, continental, glacial.

Late Precambrian to Silurian

To the east of the town of Geraldton, the Jurassic section was established by Arkell and Playford (1954). There, the sequence passes through a complete cycle from non-marine siltstone/sandstone via a transgressive sandstone phase to a fully marine limestone/sandstone section and back to a non-marine arenaceous phase. It seems to comprise the entire Jurassic from the Liassic to the Kimeridge.

Oil and Gas Prospects of the Perth Basin

The euxenic facies of the Permian is a potential source formation, possibly the only

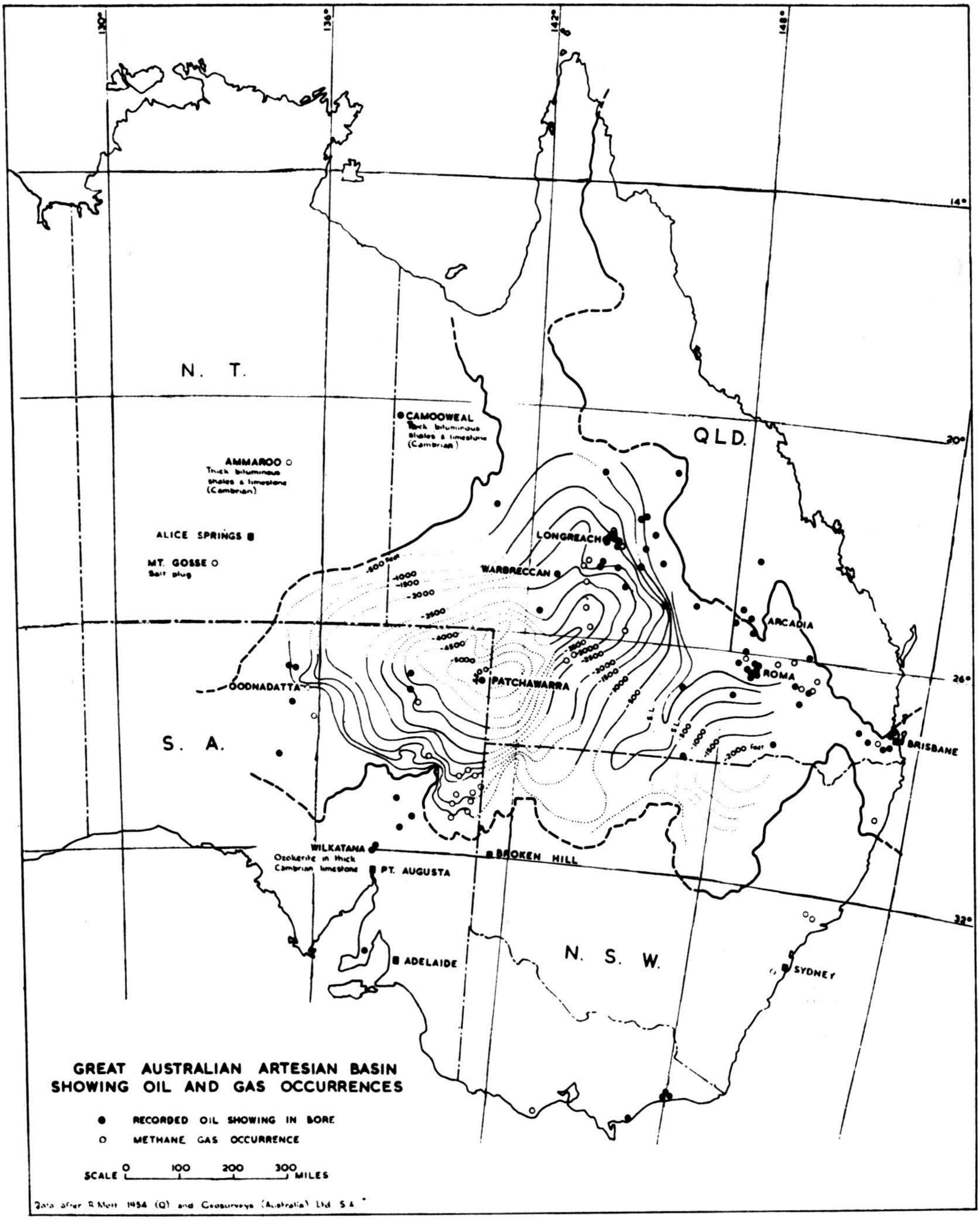

Fig. 11 — Great Artesian Basin, Contours on pre-Cretaceous Surface and Wells (after SPRIGG in AAPG Bull., 1958).

one in the whole section. There are a great number of sandstones with good reservoir characteristics.

Oil shows were obtained in one of the Beagle Ridge bores, but nothing positive has been reported from other wells drilled so far.

There is a scarcity of drillable anticlines and prospects may be confined to stratigraphic traps on or near basement buried ridges. However, with the little information at hand, it seems to be too early to draw final conclusions.

The Great Artesian Basin

As the name implies, this is an artesian basin with a number of Mesozoic sands as aquifers at relatively shallow depth. As a gentle down-warp of about 600,000 square miles, it came into existence toward the end of Mesozoic time (Fig. 11).

The Mesozoic stratigraphy is shown in Fig. 12. The section was penetrated by several thousand artesian wells to its base and was found to be remarkably persistent in lithology and thickness, varying between 4,500 and 6,000 feet. Triassic and Jurassic are non-marine, although in some parts, recent palynological investigations suggest a partly marine origin. The Aptian – Albian interval is represented by about 3,500 feet of marine shale, marl, glauconitic sand- and siltstone. The Upper Cretaceous is entirely non-marine. It reaches its greatest thicknesses, up to 4,000 feet, in the central parts of the basin.

As Fig. 11 shows, the regional structure of the basin is that of a concentric down-warp with its deepest part on the Queensland/South Australian border. However, along its margins, irregularities in the contours indicate subsurface (basement) features. At the surface, anticlinal folds are practically absent, excepting a swarm of major domes, elongated and arranged in a southwest - northeast direction, situated more or less in the deepest part of the basin.

Basement Configuration

In the early stages of systematic exploration in the Great Artesian Basin, 1940 to 1943, gravimetric surveys revealed a number of gravity maxima. Subsurface studies based on logs of hundreds of artesian wells revealed that those drilled on such gravity maxima, had struck basement at rather shallow depths whereas those wells drilled in gravimetric lows had not reached basement. For the first time an outline of the basement configuration was made by this simple expedient.

In the eastern third of the basin in southern Queensland, a basement ridge was found which separates the Great Artesian from the Surat Basin. It was named Dingwall Ridge, but is now referred to in the literature as «Nebine Ridge». It is reflected in the contours of Fig. 11.

To the west of it, a basement platform, named Eulo Shelf, was found. Mesozoics are resting on granite at shallow depth and the granite itself crops out in small areas at the surface.

In the northeast, a plunging spur was found. It was named Longreach Spur and has Mesozoics in contact with Precambrian on its crest and continental (glacial) Permian onlapping its flanks and plunge.

We consider also the swarm of major domes, part of which are shown in Fig. 13, as basement features, i. e., buried ridges which are reflected at the surface in Upper Cretaceous and Tertiary beds. They range in size from 15 to 50 miles length and 6 to 20

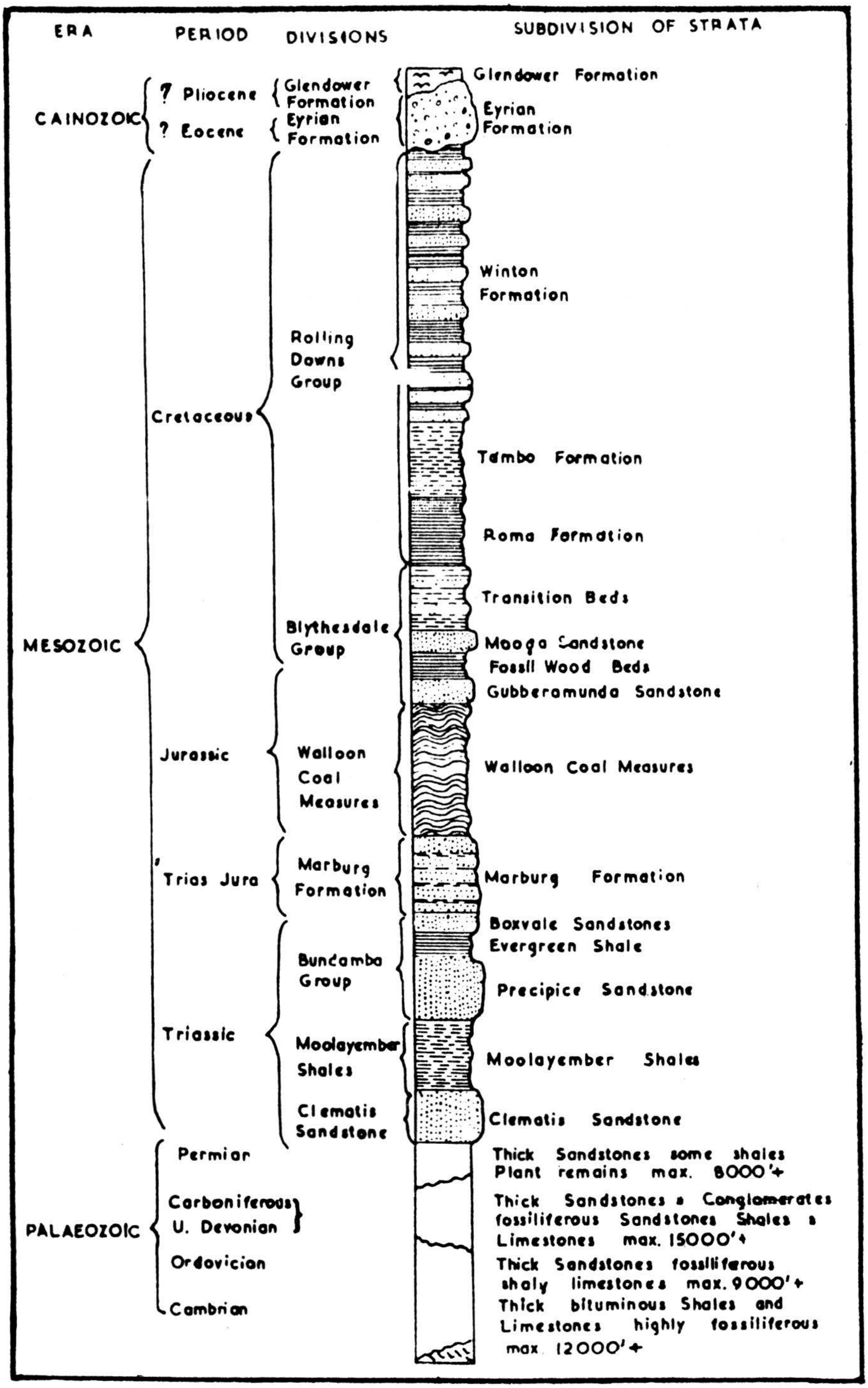

Fig. 12 — Great Artesian Basin, Generalized stratigraphic Column of the Mesozoics (after WHITEHOUSE, 1954).

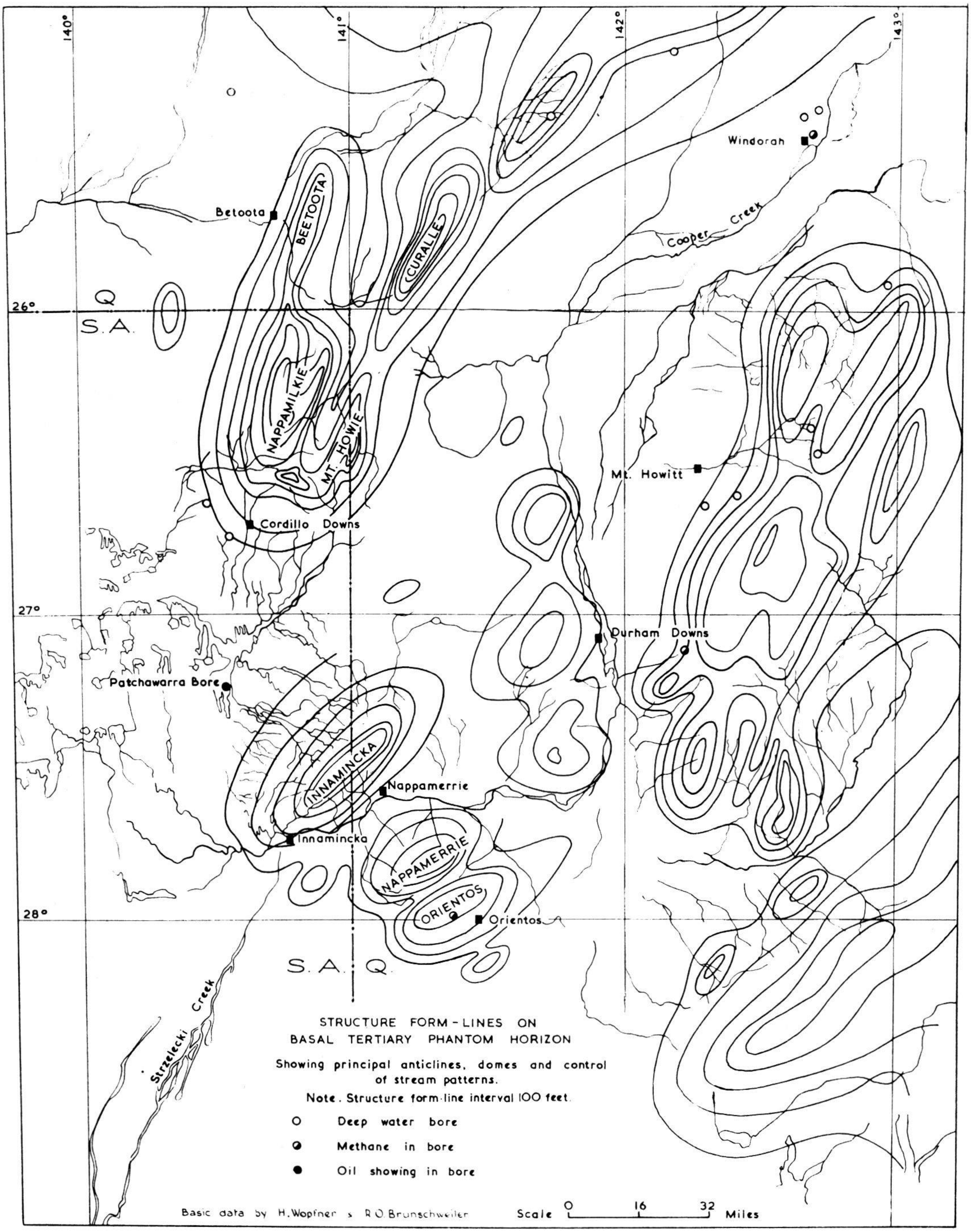

Fig. 13 — Great Artesian Basin, Major Structures reflecting Basement Highs (after SPRIGG in AAPG Bull., 1958).

miles width. Harmonious folding from the surface beds down to the Cambrian was postulated. However, two wells, Innamincka 1 and Betoota 1, disproved this assumption. Innamincka 1 found an angular unconformity between continental Permian and a multicoloured sequence dipping 25^0 at 7,050 feet. On scanty palaeontological evidence, the age of the multicoloured series below the unconformity is now assumed to be Silurian.

A similar unconformity was also found in Betoota 1 at a depth of 5,757 feet between near-horizontal Jurassic and a sequence of redbeds with conglomerates and boulder beds, partly chloritic and sericitic, and dipping at 50^0 to 85^0. There is no palaeontological evidence, but lithologically the sequence is closely comparable to, even identical with, the Upper Proterozoic Sturtian glacial series of the Adelaide geosyncline.

A number of other wells drilled on similar structures in the area, met the same unconformity between either continental Permian or Mesozoics and an indetermined, steeply dipping older sequence. Consequently, there is a possibility that the tectonic units of the Adelaide geosyncline, Flinders Range and Mount Lofty-Olary Arc, extend across the Great Artesian Basin as a buried cordillera which was in existence and controlled deposition since early Palaeozoic time.

A similar situation was found also in drilling various subsurface (seismic) structures in the southeastern part of the Great Artesian Basin, west of Dingwall (Nebine) Ridge. There, gently folded Jurassic was found resting unconformably on Devonian redbeds, folded or draped over basement cores. One of these wells found the Devonian in a marine facies, another demonstrated a marine Permian sequence resting on marine Ordovician shale.

Oil and Gas Prospects of the Great Artesian Basin

It is obvious that in spite of the disappointing results of deep tests on major structures, the prospects of the basin have by no means been fully assessed. The fact that such structures have on their crests either a reduced or completely missing Palaeozoic section, may direct further exploration toward their flanks and plunges where stratigraphic traps can be expected to occur, however, with the concomiant greater risk and higher costs.

Wide areas where Mesozoic rocks directly overlie basement, are non-prospective and will be abandoned in due course. The same applies to areas of non-marine Devono-Carboniferous and Permian. Possibly that part of the basin within the territory of South Australia may turn out to be the most prospective. There, a reportedly major gas discovery was made recently.

The Surat-Bowen Basin

We differ in nomenclature from other authors who consider the Surat Basin as part of the Great Artesian Basin. The following arguments in favour of our contention are advanced:

a) The Surat Basin is open toward the Bowen Basin in the north of which is is structurally the southern extension.
b) Dingwall Ridge and Eulo Shelf separate the Great Artesian and Surat basins effectively.
c) Devonian and Carboniferous, mainly in continental facies and great thickness, are present in the Great Artesian Basin but are absent in the Surat-Bowen Basin.

d) West of Dingwall Ridge and its northern extension, Anakie Uplift, the Permian is continental and glacial, without volcanics, east of the ridge it is partly marine with a thick basal volcanic series (Surat-Bowen Basin).
e) Triassic is restricted to the Surat-Bowen Basin and does not occur west of the Dingwall Ridge.
f) Only from the Jurassic (Bundamba) on are conditions in both basins more or less identical.

The discovery of non-commercial oil in the Permian at Cabawin (Surat Basin) in 1961, and commercial production in the transgressive Jurassic at Moonie in the same year, caused renewed interest in this part of the continent with the result that a great number of wells was drilled in recent years.

Stratigraphy

Surat-Bowen Basin is a synclinorium, approximately 600 miles long and 120 to 200 miles wide, filled with about 25,000 feet of Permian and Triassic rocks which in the south are transgressively covered by several thousand feet of continental Jurassic and marine Cretaceous.

In the western and central parts, several large regular anticlines are superimposed on the regional syncline, whereas the eastern part is structurally much disturbed. Tertiary basalt flows cover wide areas in the west and a number of granitic intrusions occur in the east. The latter are connected with the Permian orogeny of the Tasman geosyncline.

To the east, the basin is bordered by Lower Palaeozoic metamorphics and intrusives of the Coastal Cordillera, to the west by similar rocks of the Anakie Uplift and Dingwall subsurface ridge.

Devonian and Carboniferous are absent in the Surat-Bowen Basin and its history starts with the laying down of at least 10,000 feet of volcanics. This is followed by the deposition of about 10,000 feet of fluvial and marine sediments. The thickness varies considerably and is reduced drastically on several subsurface ridges of which Roma Ridge in the northwestern part of the Surat Basin is the best known.

The Permian is conventionally divided as follows:

Upper Bowen – Continental Facies	– Grey-green to khaki sandstone, siltstone, partly tuffaceous with shale interbeds. Fossilwood, coal measures with *Glossopteris*.	1,000 ft.
Middle Bowen – Paralic Facies	– Thin limestone and sandy limestone with rich brachiopod fauna.	50 ft.
	Shale, siltstone with bands of calcareous sandstone, marine.	1000 ft.
	Sandstone, some coal beds, bands of conglomerate, probably glacial. Plants and forams.	1,000 ft.
	Shale and interbedded sandstone, thin limestone and sandy limestone, marine.	3000—3500 ft.
Freshwater Facies	– Sandstone and shale with coal, *Glossopteris*.	Up to 4,600 ft.
Lower Bowen – Volcanic Facies	– Volcanic flows and tuffs, thin interbeds of marine and plantbearing sediments.	+ 10000 ft.

The Triassic, essentially a sequence of about 5,000 feet of continental shale and sandstone, follows the Permian without a break or unconformity. In the subsurface (Wandoan No. 1) in the eastern flank of the Bowen syncline, a gradual transition of uppermost Permian and Lower Triassic formations was found.

In the southern part of the basin, the Permo-Triassic sequence is overlapped by the Jurassic basal sandstone formation of the Bundamba which is not only the main aquifer in the Surat and Great Artesian basins, but is also the producing formation at Moonie field. Drilling in the central and eastern parts of the basin yielded new lithological data and a stratigraphy mainly based on palynological evidence. The following table gives the most recent stratigraphic nomenclature of the Surat-Bowen Basin.

Subsurface stratigraphy of the Surat-Bowen Basin

West side		100 Miles	East side
Lower Cretaceous	Roma Formation (marine)		2,805′ in south eroded in north
	Blythesdale Formation (continental)		1,335′ in south eroded in north
Jurassic	Walloon Formation (continental)		1,244 in south partly eroded in north
	Bundamba Formation (continental) * Moonie Field		2,196′ in south 1,777′ in north
		Wandoan Formation	
Triassic	Moolayember Clematis Rewan	Cabawin Formation (mainly continental)	2,195′ in south 4,468' in north
Permian	Undifferentiated Permina Rocks 3,600–6,000' in wells	* Cabawin No. 1 Kianga Formation (continental)	522′ in south + 1,451′ in north
		Back Creek Form. (marine)	1,305′
	«Lower Bowen» Volcanics	Cracow Formation (volcanic)	10,000′+

The table shows the stratigraphic position of Moonie field, i. e., in the basal Bundamba formation of Jurassic age, immediately above a regional unconformity, and that of Cabawin No. 1 well, in the upper part of the Permian Kianga formation.

Petroliferous gas in non-commercial quantities was discovered in a water bore at the town of Roma in 1900. The depth was only 3,683 feet. In 50 years of sporadic drilling, out of 37 wells drilled, 33 reported gas and or oil, non-commercial, though, at depths ranging between 3,000 and 4,000 feet.

Fig. 14 is an east–west cross section through the Roma area. It shows a granite core (Roma Ridge) with Timbury Hills formation, possibly of Lower Carboniferous age, in its flanks. Permian sediments wedge out in the east flank. Continental Triassic beds with basal sands which become gritty and conglomeratic at the contact with granite, overlap the entire uplift. Systematic seismic investigations instituted about 1956 by Associated Australian Oilfields, lead to the discovery of commercial quantities of gas in the wider Roma area (Hospital Hill No. 4 and Timbury Hills No. 1: 1,250,000 cubic feet per day each, Pickanjinnie No. 1: 6,500,000 cubic feet per day). This was followed by further discoveries of gas in several major structures north of Roma. At the moment, the construction of a pipeline to the coast is considered.

Flowing oil was first discovered by Union Oil of California in association with Kern Land Company and Australian Oil and Gas Corporation at Cabawin No. 1 in the southern part of the basin, early in 1961. The well started in Cretaceous Roma formation, hit the volcanics of the Cracow formation at 11,662 feet and was drilled to a total depth of 12,035 feet in volcanics. The producing sand of the upper part of the Kianga formation (Permian) at 9,930′ tested between 62 and 85 barrels of 42^0 API oil and a varying amount of gas. It settled ultimately at a non-commercial 60 barrels per day.

Cabawin East No. 1, on a separate closure four miles east of Cabawin No. 1, was abandoned as a dry hole at 12,091 feet in October, 1961, without finding the producing sand which reportedly had shaled out.

For a third test, Moonie anticline, a seismic structure, was chosen. There, the entire Permian sedimentary section had been eroded from the faulted crest of the structure and Lower Permian volcanics were directly overlapped by Jurassic Bundamba. Permian sediments were restricted to the flanks. Therefore, in Moonie, the objective was not the Permian section below the unconformity, but the gently folded Jurassic Bundamba above it. In this respect Moonie is a fundamentally different proposition than Cabawin, Cabawin East and the subsequently drilled Middle Creek which were Permian tests.

Moonie No. 1 was drilled to a total depth of 6,106 feet. It entered the Lower Permian volcanics (Cracow formation) at 5,933 feet. Casing was set at 5,950 feet and the well completed through perforations of the interval 5,798–5,840 feet in the lower part of the Jurassic Bundamba where shows were obtained on the way down. At the end of an eight-week testing period, production was established at 666 barrels of 45^0 API gravity oil and 124,000 cubic feet of gas per day through an 18/64th choke. Evaluation drilling followed rapidly. Seventeen wells were drilled to the end of 1963 of which only one was a failure and at least two are dual producers. A pipeline was completed recently to Brisbane and the field should be on production in the near future.

Moonie, apart from being the first producing field in Australia, has some interesting features: Firstly, it produces from an active aquifer and, to all practical purposes seems to be surrounded by freshwater. Secondly, permeability barriers, possibly just as much as structure, may be responsible for the accumulation and may be the agens which has prevented its flushing. Thirdly, the Jurassic reservoir is in immediate contact with the sterile Permian volcanics without intervening source rocks, although marine Permian sediments do occur in the flanks of the structure.

It is, therefore, probable that the hydrocarbons of Moonie have originated in the truncated marine Permian, migrated through the unconformity and accumulated in the overlapping porous Jurassic sands. An indigenous, Jurassic, origin is not entirely excluded since palynological evidence, recently discovered by the BMR, seems to indicate marine incursions in the Jurassic, unknown before.

The specific structural conditions of Moonie, i. e., that of a faulted anticline in the Permian, truncated and overlapped by Jurassic, was found by seismic in several other

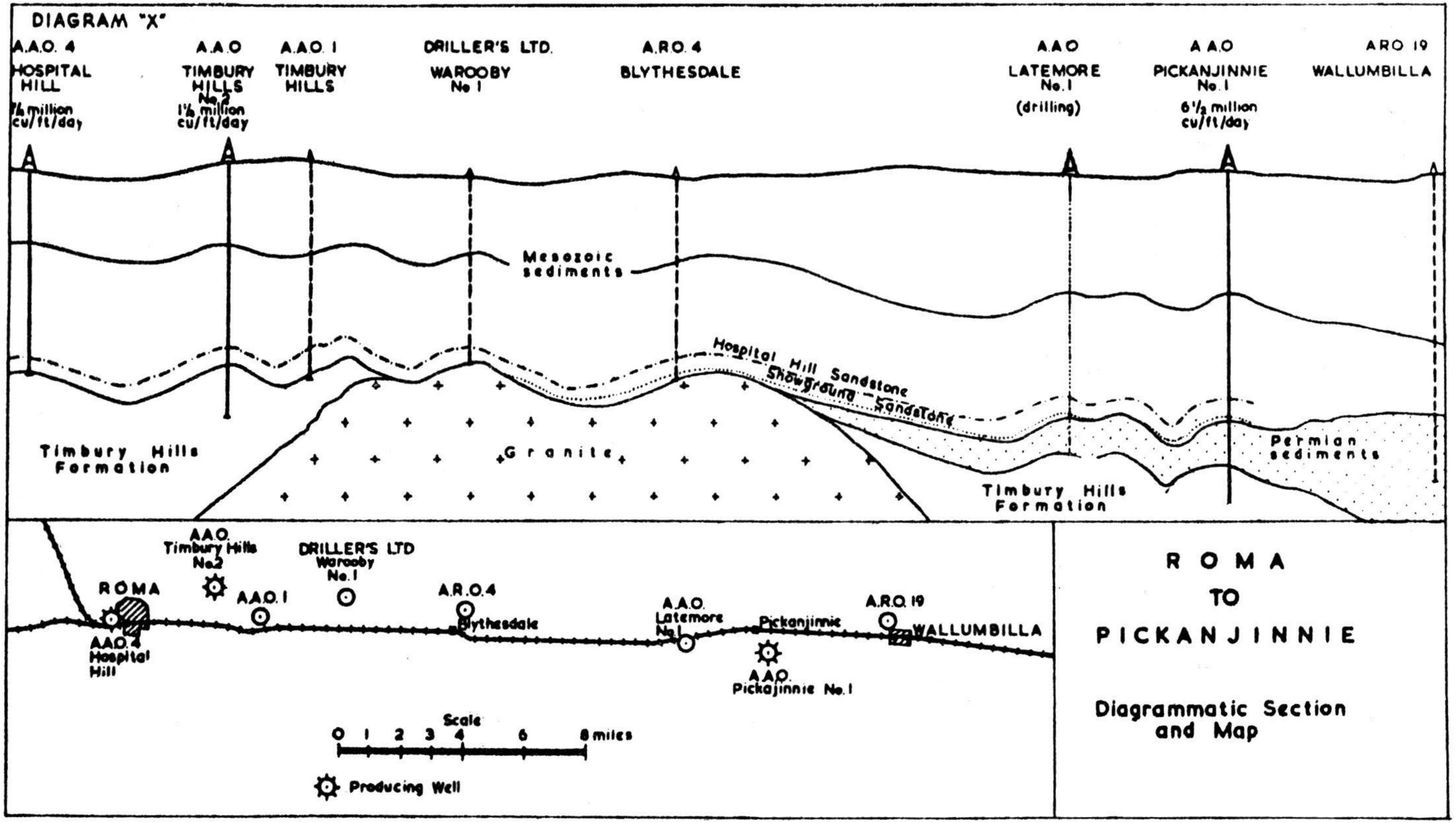

Fig. 14 — Surat-Bowen Basin, Queensland, Structural Cross Section through Roma Ridge (after TRAVES in Australasian Oil and Gas Journal, 1960).

localities in the northern part of the basin. However, on drilling, the Jurassic sands were found to carry freshwater only, although in places, strong fluorescence demonstrated the former presence of hydrocarbons and their susequent flushing.

Recently, several wells were drilled south and southeast of Roma and interesting discoveries were made in the Bundamba formation, but difficulties were met in maintaining the initial production in the order of several hundred barrels per day. In these cases after testing rapid decline set in, even to vanishing point. It was found that reservoir sands had primarily a low permeability which may be caused essentially by a clayey matrix. Upon contact with the water of the drilling fluid, the clay minerals have a tendency to swell and to close the pores of the reservoir. In other parts of the world, the problem was successfully overcome by using oil-base mud or by air-drilling.

Once these production difficulties are eliminated, there is reason to assume that the Surat-Bowen Basin will be established as an oil and gas producing province.

Conclusions

Concluding this short review of oil-geological problems in Australia, the following basic fact are in evidence:

Firstly: Flowing oil was found in two widely separated areas, in the one-well field of Rough Range in Western Australia, and in the producing field of Moonie in eastern Queensland.

Secondly: In both cases, overlapping Mesozoic sands – marine Lower Cretaceous in Rough Range, Lower Jurassic in Moonie – are the producers.

Thirdly: At Rough Range, the producing formation is underlain by several thousand feet of Young Palaeozoic and Jurassic rocks which contain several source formations, and at Moonie, by a partly marine Permian section with good oil and gas shows in other structures in the same basin.

Fourthly: In both cases it is assumed, that the oil originated in the older formations and migrated through the unconformity into the overlapping basal sands. However, neither in the Carnarvon Basin (west) nor in the Surat-Bowen Basin (east) has commercial production been obtained from the older formations below the unconformity. Judging by past performance, such chances look better for the Surat-Bowen Basin than for the Carnarvon Basin.

Recent discoveries – mainly gas – in wide-apart areas and from a wide range of geological formations, i. e. Ordovician of the Amadeus Basin to Jurassic in the western Great Artesian Basin, will undoubtedly supply the stimulus to the oil industry which is necessary for a sustained effort.

Acknowledgements

Although a certain proportion of the information presented in this paper is derived from my own experience in Australian geology, I have, none the less relied heavily on official publications. They are too numerous to quote them singly in a list of references, but they comprise records, reports and bulletins of the Commonwealth Bureau of Mineral Resources, Geology and Geophysics to whose Director and Officers I am greatly indebted for the generous supply of data over many years. The current series of completion reports of wells subsidized by the Commonwealth Government under

the Petroleum Search Subsidy Acts are a most valuable source of the ever increasing subsurface data.

The Geological Surveys and Mines Departments of the various States make the results of their investigations available in the form of bulletins, reports and quarterlies, whereas a rich source of general geological information is represented by the Journals and Proceedings of the States Branches of the Royal Society of Australia.

The Geological Society of Australia issues a Journal which covers the whole width of earth science. It has recently taken in hand the publication of the geology of the various States. In 1958, there appeared the «Stratigraphy of Western Australia» and «Geology of South Australia», in 1960 the «Geology of Queensland» and, in 1962, «Geology of Tasmania».

A few figures (11 and 13) are reproduced from the Bulletin of the American Association of Petroleum Geologists and from the Australasian Oil and Gas Journal (4, 5, 6 and 9). Several papers on Australian oil geology and exploration activities published in those journals, were also consulted.

Figure 10 is a reduction of gravity map of The Perth Basin by Thyer and Everingham (B. M. R. Bulletin No. 33, 1956).

Further, I have drawn on the «Petroleum Prospects in Australia, Preliminary Review of main sedimentary Basins», 1960, issued by the Institut Français du Pétrole, Bureau des Etudes Géologiques who, under the direction of D. TRÜMPY, have studied the petroleum possibilities of Australia in behalf of the Commonwealth Government.