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DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Bonaparte Gulf Gravity Survey Western Australia, 1959

BY

GULF OIL SYNDICATE

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DEPARTMENT OF NATIONAL DEVELOPMENT

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DIRECTOR: J. M. RAYNER

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FOREWORD

In 1959 the Commonwealth Government enacted the Petroleum Search Subsidy Act 1959. This Act enables companies that drill for new stratigraphic information, or carry out geophysical or bore-hole surveys in search of petroleum, to be subsidized for the cost of the operation, provided the operation is approved by the Minister for National Development.

The Bureau of Mineral Resources, Geology and Geophysics is required, on behalf of the Department of National Development, to examine the applications, maintain surveillance of the operations and in due course publish the results.

A gravity survey was carried out under the Petroleum Search Subsidy Act 1959 over an area in the western part of the Bonaparte Gulf Basin, in the far north-east of Western Australia, by Gulf Oil Syndicate. This Publication deals with that survey and contains information furnished by, or on behalf of, Gulf Oil Syndicate and edited in the Geophysical Branch of the Bureau of Mineral Resources. The final report on the gravity survey was written by W.F. Schneeberger, geological consultant to Gulf Oil Syndicate. A report on the field operations was written by L.J. Starkey of Mines Administration Pty Limited. The survey methods and the results obtained are presented in detail.

J.M. RAYNER
DIRECTOR

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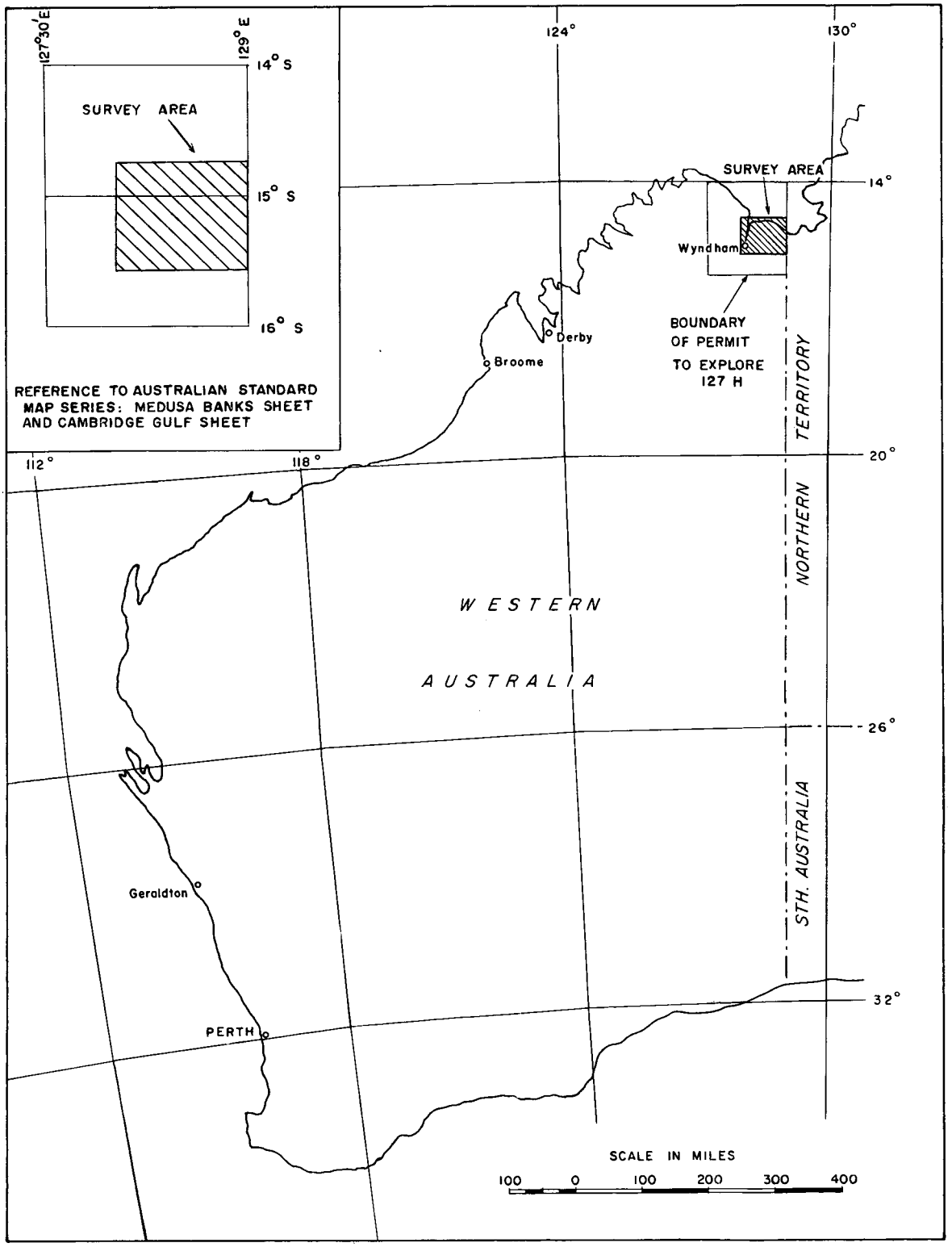

Fig. 1. LOCALITY MAP

SUMMARY

This report describes a gravity survey conducted in the Bonaparte Gulf Basin, Western Australia, by Mines Administration Pty Limited, for Gulf Oil Syndicate, during September, 1959. The survey took place over part of Permit to Explore 127H. Simultaneously, a field geological reconnaissance along the western margin of the Basin was made by E.P. Utting, consulting geologist, to help evaluate the area.

The gravity survey was intended to extend a regional gravity survey of the southern and north-eastern portions of the Basin previously undertaken by the Bureau of Mineral Resources, Associated Australian Oilfields N.L., and Westralian Oil Limited.

Gravity values were observed and plotted over an area of approximately 1400 square miles, bordered on the north by Joseph Bonaparte Gulf and on the east by the Western Australia/Northern Territory border.

The gravity results have, to some extent, indicated the shape of the basement surface of that part of the Bonaparte Gulf Basin covered by Gulf Oil Syndicate's Permit to Explore 127H. Gravity stations are too widely separated to support the computation of a residual maximum. Bouguer "highs" are interpreted as features on the basin floor which may have encouraged Devonian reef development.

INTRODUCTION

Gulf Oil Syndicate was granted Permit to Explore 127H by the Western Australian Department of Mines. The Permit covers the western part of the Bonaparte Gulf Basin, in the far north-west of Australia, and includes all that part of the Basin which lies within Western Australia. The nearest town is Wyndham, which is a deep-water port (Fig 1).

The Syndicate engaged Mines Administration Pty Limited to make a gravity survey over part of its Permit. E.P. Utting, consulting geologist, was engaged by the Syndicate to plan the gravity survey, which took place during September, 1959. Simultaneously with the gravity survey, Utting made a field geological reconnaissance along the western margin of the Basin. The results of that survey, which was made with emphasis on lithological studies of the Devonian limestones and their suitability as reservoir rocks, were presented in a report entitled "Surface Exploration and Oil Prospects of Permit 127H, Western Australia", which has been filed in the Bureau of Mineral Resources and is available for reference.

Prior to the gravity survey, which is the subject of this report, a regional gravity survey had been made in the Bonaparte Gulf region by the Bureau of Mineral Resources, from July to October, 1956. Underwater gravity observations had also been made by the Bureau at places off-shore between Keep Inlet and Wyndham. Gravity surveys had been undertaken in the Keep River area east of the Western Australia/Northern Territory border by Associated Australian Oilfields N.L., and Westralian Oil Limited. A regional gravity map incorporating these existing gravity data was made available to the Gulf Oil Syndicate by the Bureau of Mineral Resources in an unpublished Record by Thyer, Stott and Neumann (1959).

Although the southern and north-eastern portions of the Bonaparte Gulf Basin were adequately covered by the Bureau's gravity stations, there was a gap of about 850 square miles between the Carlton Basin Seismic Traverse A and the off-shore stations in the estuaries of Cambridge Gulf. As the north-western continuation of the Upper Devonian limestone ridges could be expected in this area, and more detailed information on the configuration of the western slope of the Basin was desirable, W.F. Schneeberger, as consultant to Gulf Oil Syndicate, recommended an additional gravity survey in the area.

L.J. Starkey was in charge of the Mines Administration Pty Limited crew that carried out the gravity survey. The topographical surveying was done by A. Dawson and J. Ritchie, surveyors of the Western Australian section of the Commonwealth Department of the Interior. The planning of the gravity traverses and positioning of the gravity stations were arranged by E.P. Utting. The final report on the gravity survey was written by W.F. Schneeberger; it included data from a report on the field operations by L.J. Starkey and also made use of E.P. Utting's report mentioned above.

GEOLOGY AND PURPOSE OF THE SURVEY

The geology of the Bonaparte Gulf Basin is described by Traves (1955). He used the name "Bonaparte Gulf Basin" for the area occupied by "all the Palaeozoic sediments that crop out in the vicinity of Joseph Bonaparte Gulf", and divided it into two sub-basins, the Burt Range Basin in the east and the Carlton Basin in the west, separated from each other by the Pincombe Ridge, which is a spur of Proterozoic sediments plunging under the Palaeozoic rocks in a north-east direction.

Carboniferous sediments crop out at scattered places over most of the eastern part of the area surveyed. These rocks are underlain by older Devonian, Ordovician and Cambrian sediments resting on the basement of Proterozoic sediments and metamorphics. Devonian limestones outcrop in a strip along the western flank of the Carlton Basin and are locally exposed on the eastern flank. Much of the area surveyed consists of a featureless sand-covered plain.

Within Permit 127H, the gravity survey made by the Bureau of Mineral Resources between 1956 and 1958 covered the southern part of the Carlton and Burt Range sub-basins and the intervening ridge, whereas the present survey, made by Mines Administration Pty Limited on behalf of Gulf Oil Syndicate, covered the north-western margin and slope of the Carlton Basin.

According to Matheson and Teichert (1948) and Traves (1955), the Bonaparte Gulf Basin contains sediments of a total thickness of 12,000 to 13,000 feet ranging in age from Middle to Upper Cambrian and from Upper Devonian to Lower Carboniferous. These authors maintain that possibly in no part of the Basin is the total thickness of sediments preserved; however, they give no definite reasons for this assumption.

The purpose of a gravity survey of this kind is to provide data on the regional configuration of a basin floor. If there is sufficient contrast between the densities of the basement rocks and the overlying sediments, variations in thickness of the sediments are revealed by variations in gravity.

The Table below shows the densities of rock samples from the Basin, measured by Thyer, Stott and Neumann (1959):

Sample density[1] (g/cm^3)	Age	Formation
2.00	Upper Devonian	Cockatoo Sandstone
2.05	Lower Carboniferous	Sandstone above Spirit Hill Limestone
2.11	Lower Carboniferous	Point Spring Sandstone
	Mid-Upper Cambrian	Clark Sandstone
2.13	Lower Carboniferous	Enga Sandstone
2.22	Mid-Upper Cambrian	Hart Spring Sandstone
2.53	Upper Proterozoic	Locality: Pincombe Ridge
2.61	Lower Carboniferous	Spirit Hill Limestone
2.62	Upper Devonian	Burt Range Linestone
2.63	?	Locality: Sandy Creek (?Spirit Hill Ls.)
2.64	Lower Carboniferous	Septimus Limestone
2.66	Lower Carboniferous	Spirit Hill Limestone
2.79	Middle Cambrian	Skewthorpe Formation (?Limestone)
2.80	Lower Cambrian	Antrim Plateau Volcanics

The independence of density and age, and the close connexion between density and lithology, are much in evidence. The Upper Devonian/Lower Carboniferous limestones range in density between 2.61 and 2.66 g/cm^3.

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(1) Footnote by Bureau of Mineral Resources:

The most recent evidence, from Spirit Hill No. 1 Well, suggests that some of these values may not be representative. This point will be discussed in a forthcoming Basin Study Report on the Bonaparte Gulf Basin.

The highest density (2.80 g/cm^3) is represented by the Lower Cambrian Antrim Plateau Volcanics, whereas the only Upper Proterozoic sample, very probably a 'Nullagine' quartzitic sandstone from Pincombe Ridge, has a density of 2.53 g/cm^3. The sample with the second highest value, 2.79 g/cm^3, comes from the Middle Cambrian Skewthorpe Formation, and is probably a limestone.

Density contrasts can be expected to occur at the contact of the Upper Proterozoic and the overlying Palaeozoic sediments. This is the case at Pincombe Ridge, where the outcropping Upper Proterozoic rocks induce a gravity maximum, which can be followed in the Bouguer contour pattern to the north-east as a plunging spur or buried ridge dividing the Carlton and Burt Range sub-basins.

The section of interest in Permit 127H is the Upper Devonian limestone which is, in places, developed in a biostromal and an organic-clastic reef-slope facies similar to its stratigraphic equivalent in the Fitzroy Basin.

Upper Devonian limestones crop out as an intermittent zone of limestone hills from south of the abandoned Ninbing Station to the north-north-west, where they disappear a short distance south of Knob Peak (Plate 1). Around Ninbing Station these limestone hills coincide with an elongated and pronounced gravity "high" of + 3.21 milligals. There is another, but less pronounced, maximum with a closing contour of minus 2.00 mgal, about six miles south of Knob Peak. It is interesting to note the close coincidence of these gravity maxima with the outcrop of Upper Devonian limestones. A density of about 2.62 g/cm^3 for the limestones can be expected to cause such an effect, but the possibility that the maxima are caused by an underlying ridge of Proterozoic rocks cannot be excluded.

South of Ninbing Station a reversal of dips at the surface was observed, thus indicating an anticlinal structure there, coinciding with the Ninbing gravity maximum.

Basinward, i.e. in an easterly direction, the gently dipping limestones are overlain by Lower Carboniferous sediments. In these latter rocks the dips, wherever observed, are gentle; no indication of anticlinal structure has yet been found, but there is some evidence of faulting.

However, by analogy with the Fitzroy Basin, it can be expected that basinward of the limestone outcrop there may exist a platform and that the reef limestone may extend onto such a platform.

It was shown in the Table that a density contrast exists between the Proterozoic basement rocks and the overlying Palaeozoic rocks. Regular gravity gradients basinward should therefore indicate regular increase of sedimentary thickness. Conversely, wider spacing of the Bouguer contours in places would indicate a flattening of the slope in the form of terracing. The gravity pattern should reveal plunging basement spurs, for instance the buried part of Pincombe Ridge.

As it is postulated that there is a basinward extension of reef conditions on shallow shelves on or around basement spurs or ridges, information on the possible configuration of the Basin floor immediately east of the limestone outcrop is of the greatest importance. A partial solution of this problem was expected from a gravity survey of the western part otf the Bonaparte Gulf Basin, or Carlton sub-basin, within the limits of Permit 127H.

FIELD WORK

The gravity survey was essentially a regional reconnaissance with observation stations at half-mile intervals along a network of widely spaced traverses totalling 160 miles.

Base maps used were photo-mosaics compiled by the Lands and Survey Department of Western Australia. They were at a scale of one mile to one inch and showed latitudes each 15 minutes and longitudes each 30 minutes. Observation points were set out using air-photo pairs supported by compass, vehicle speedometer or pacing, and previous survey data. A plan accuracy to within 0.1 minute of true geographical position is claimed for this work. Observation points were marked by numbered hardwood pegs placed at half-mile intervals over 135 miles of traverse and at one-mile intervals over 25 miles of traverse along top high water mark bordering the northern tidal flats.

A Zeiss automatic level was used to level most of the points, but some minor traverses were levelled with a Cook, Troughton and Sims precise level. A double-reading staff was used throughout and, where possible, readings were made in closed loops. Levels were tied to Shot-point 1 of the Bureau's Carlton seismic traverse.

The western loop between Shot-points 54 and 109 showed a vertical misclosure of 0.9 foot over the total distance of approximately 50 miles. The eastern loop from Shot-points 54 to 35 and gravity stations 9 to 176, closed back on Shot-point 54 with an error of 1.0 foot in 24 miles. The remaining traverses closed onto a well-defined top high water mark and were continued along it to check the consistency of the level. It was found to vary between Reduced Levels of minus 0.53 foot and +1.15 feet, relative to the BMR assumed datum value of 192.6 feet above low water mark, Wyndham, for Shot-point 1. Therefore all values used in this and previous surveys could be 27 feet too high (the approximate figure for highest spring tides).

Two hundred and eighty gravity stations were established with a Worden gravity meter (No. 207) which had a sensitivity of 0.10135 mgal per scale division and an anomaly accuracy of $\pm$ 0.05 mgal.

REDUCTION OF RESULTS

Gravity meter readings were corrected for drift by reoccupying gravity stations every two hours. The latitude for each station was calculated (from the plot) and the theoretical gravity for that latitude was read from tables based upon the International Ellipsoid formula. This was then subtracted from the observed gravity to give an anomaly corrected for latitude. A Bouguer density factor of 0.06726 mgal/ft was used in the elevation correction factor.

No terrain corrections were applied. There are possibly three stations that require terrain correction, viz. Stations 70, 35, 95. However it is not thought that the terrain correction for these would be more than 0.5 mgal.

An observed gravity of 978.40491 gals was assumed for Peg 58 situated at Old Ninbing Homestead. However, at Shot-point 1 the Bouguer anomaly based on this assumed gravity was 11.82 mgal higher than that of the BMR. Therefore a correction of 11.82 mgal was applied to all stations.

Mention has already been made of the possibility of error in the BMR height datum, and if this error exists it would produce a mis-tie between the underwater gravity survey and the land survey by approximately 2 mgal.

Plate 1 shows the Bouguer anomaly contours with contour values in milligals, at 1-mgal intervals. It also shows formation contacts.

The accuracy of the survey was estimated by considering the respective accuracies of the gravity observations, the latitude corrections, and the elevation corrections. These are considered to be 0.05, 0.03, and 0.01 mgal respectively. The total error, which equals the root mean square of these three errors, is 0.06 mgal.

The following information has been filed in the Bureau of Mineral Resources, Canberra and Melbourne, and is available for public inspection:

(i) Table of principal facts for all the gravity stations.

(ii) Report on "Gravity survey in Permit 127H, Western Australia", by L.J. Starkey, Mines Administration Pty Limited.

(iii) Report on "Surface exploration and oil prospects of Permit 127H, Western Australia" by E.P. Utting, consulting geologist to Gulf Oil Syndicate.

RESULTS

The results of the survey are shown on Plate 1.

Three sets of gravity "highs" can be seen, with a roughly north-north-westerly trend. The westernmost of these, with a highest value of +8 mgal, coincides with an area of Cambro-Ordovician outcrop. The next to the east, has a maximal value of +7 mgal; it falls in an area of (?) Upper Devonian sandstone outcrop. From field observations, both these gravity "highs" seem to coincide with anticlines or horsts. They are separated from each other by a narrow zone of gravity "lows".

The most interesting feature, however, is a trend exhibited by two elongated maxima of +3 and minus 2 mgal. They coincide closely with ridges of Upper Devonian limestone on the west border of the Basin, and extend from a point a few miles south of Ninbing in a north-north-westerly direction to a point where the minus 10 isogal crosses the coast east of Shakespeare Hill. This positive trend is paralleled to the west by a series of gravity minima which seem to connect with the gravity minimum at the BMR gravity station M (west of Elephant Hill).

Field observations indicate that north and south of Ninbing, within the outcropping Devonian limestone, there is a structural reversal that coincides closely with the gravity positive, although at the surface and in the airphotos some secondary folds can be observed.

It appears, therefore, that the cause of this prominent trend of gravity maxima is the dense limestone.

In order to tie the present survey to the most important BMR gravity survey of the entire Bonaparte Gulf Basin, the map is extended south to cover the prominent feature of Pincombe Ridge "high". This "high" has a distinct east-west trend, but its terminal part (in the Weaber Range) swings into a north-easterly direction.

These marginal features are the structural framework of the Bonaparte Gulf Basin proper. A compilation of the new data with those of the BMR gravity survey and the recent surface mapping by E.P. Utting leads to the following conclusions:

(i) The important gravity minimum, whose lowest value (minus 25 mgal) lies just across the border in Northern Territory, extends into the eastern part of Permit 127H.

(ii) The minimum of minus 20 mgal at Pelican Island, observed during the BMR underwater gravity survey, extends on-shore and assumes a south-easterly trend.

(iii) The minima under (i) and (ii) are separated from each other by a "gravity ridge" manifested as a zone of widely spaced contours, extending from the Ninbing "high" in a north-easterly direction and connecting with the gravity maximum of +10 mgal off Keep Inlet.

(iv) The north-easterly trends of this feature and of the north-eastern end of the Pincombe Ridge are in marked contrast to the practically north-south trend of the other features. However, it should not be overlooked that the eastern margin of the Bonaparte Gulf Basin and its marginal fault zones have the same north-easterly trend. This is in line with the regional setting of the Basin as a wedge-shaped embayment between the regional positive features of the Sturt Block in the east and the Kimberley Block in the west.

(v) There is no very clear indication of faulting in the gravity picture except perhaps in the area north-east of Knob Peak, where the rather steep gravity gradient may indicate faulting parallel to that observed there at the surface. Field observations and the study of photographs revealed two distinct fault trends, one north-north-west or north-west, the other north-north-east.

CONCLUSIONS

It is postulated that reef growth, similar to that in modern seas, was also in the the geological past associated with gently sloping epicontinental shelves, shallow platforms, and submarine ridges; even with rising volcanic cones (Central Pacific).

Therefore it should be possible by means of lithologic-stratigraphic studies of the reef outcrop along the margin of the Basin, and an approximate reconstruction of the configuration of the Basin floor by means of gravity observations, to outline certain areas which, by analogy with modern and ancient basins of similar configuration, might support reef growth.

The analogy with modern seas is provided by the Australian continental shelf of north-western and north-eastern Australia and its reefs; the analogy with an ancient sea is provided by the Fitzroy Basin, which has many reefs of Devonian age along its northern shelf.

Assuming that the greatest density contrast is between the Proterozoic rocks and the Palaeozoic rocks, it seems feasible to correlate the gravity picture with the shape of the Basin floor. However, density variations within the basement complex may influence the Bouguer anomalies, and it is impossible to separate such effects from those produced by the basement floor.

Assuming now that the above premise is correct, it should be feasible to outline areas of possible Devonian reef growth, not only along the margin of the Basin (fringing reefs) but also in shallower areas of its central part, i.e. on or around basement ridges and off-shore platforms. Such localities of possible reef development are therefore:

(i) the northern flank and plunge of the buried part of Pincombe Ridge; and

(ii) the platform connecting the Keep Inlet gravity maximum with that of Ninbing.

Both these areas are shaded on Plate 1.

The Bouguer anomalies do not indicate any anticlinal features in the deeper parts of the Basin. However, such reversals of the regional slope could only be detected in a residual map, and the observations made are too widely spaced to allow the computation of residual values.

Summarizing, it can be said that the gravity survey by Mines Administration Pty Limited, in combination with the Bureau's regional gravity survey, has greatly helped in defining the configuration of the floor of that part of the Bonaparte Gulf Basin covered by Permit 127H.

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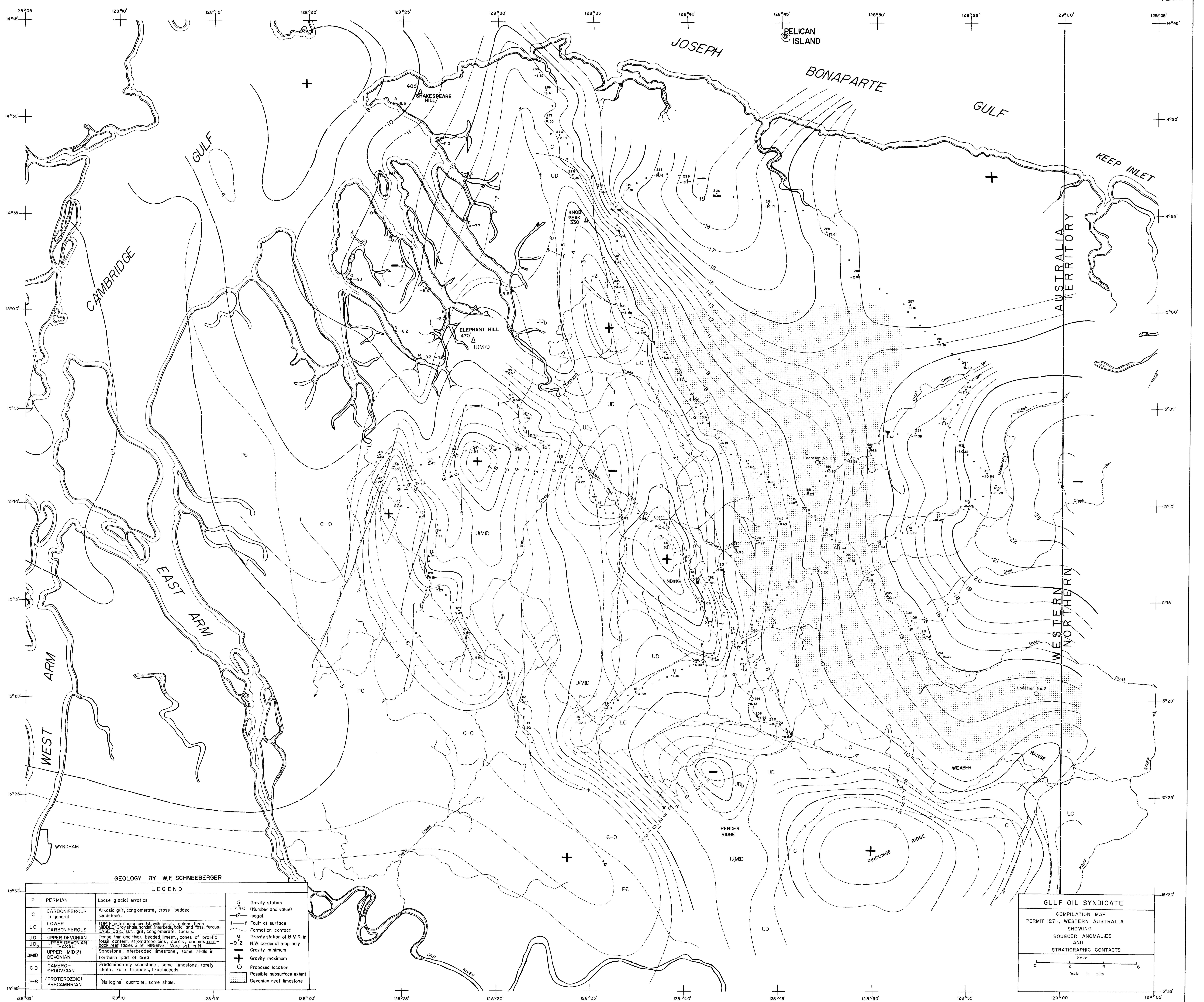
PLATE 1


JOSEPH
BONAPARTE
GULF
PELICAN ISLAND
KEEP INLET
CAMBRIDGE
GULF
EAST ARM
WEST ARM
WYNDHAM
SHAKESPEARE HILL
ELEPHANT HILL 470'
KNOB PEAK 330
NINBING
PENDER RIDGE
PINCOMBE RIDGE
WEABER RANGE
Location No. 1
Location No. 2
WESTERN AUSTRALIA
NORTHERN TERRITORY
GEOLOGY BY W.F. SCHNEEBERGER
LEGEND
P PERMIAN Loose glacial erratics
C CARBONIFEROUS in general Arkosic grit, conglomerate, cross-bedded sandstone.
LC LOWER CARBONIFEROUS TOP: Fine to coarse sandst., with fossils, calcar. beds. MIDDLE: Gray shale, sandst., interbeds, calc. and fossiliferous. BASE: Calc. sst., grit, conglomerate, fossils.
UD UPPER DEVONIAN
UDb UPPER DEVONIAN BASAL
Dense thin and thick bedded limest., zones of prolific fossil content, stromatoporoids, corals, crinoids, reef-back reef facies S. of NINBING. More sst. in N.
U(M)D UPPER-MID(?) DEVONIAN Sandstone, interbedded limestone, some shale in northern part of area
Є-O CAMBRO-ORDOVICIAN Predominantely sandstone, some limestone, rarely shale, rare trilobites, brachiopods.
P-Є (PROTEROZOIC) PRECAMBRIAN "Nullagine" quartzite, some shale.
Gravity station (Number and value)
Isogal
Fault at surface
Formation contact
Gravity station of B.M.R. in N.W. corner of map only
Gravity minimum
Gravity maximum
Proposed location
Possible subsurface extent Devonian reef limestone
GULF OIL SYNDICATE
COMPILATION MAP
PERMIT 127H, WESTERN AUSTRALIA
SHOWING
BOUGUER ANOMALIES
AND
STRATIGRAPHIC CONTACTS
Scale
0 2 4 6
Scale in miles