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A DISCUSSION ON THE GRAVITY ANOMALIES OF THE PRECAMBRIAN SHIELD OF WESTERN AUSTRALIA

by

A.R. Fraser

Based on a lecture given to the Second International Conference on Geophysics of the Earth and the Oceans, Sydney, 15-19 January 1973.

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SUMMARY

Gravity surveys by the Bureau of Mineral Resources and private companies have covered the entire western part of the Australian Precambrian Shield and the adjoining basins, at a station density of at least 1 per 120 square kilometres. Bouguer anomaly contours show the distribution of the principal elements of the tectonic framework of the West Australian Shield and indicate that this framework differs in some significant respects from that proposed in previous literature.

An oval-shaped gravity province of disturbed contour pattern in the northwest of Western Australia corresponds to the Pilbara Nucleus which embraces both the exposed Archaean area known as the Pilbara Block and most of the Proterozoic Hamersley Basin adjoining it to the south. Broad elongate gravity ridges surrounding the Pilbara Nucleus are interpreted as the gravity expressions of Proterozoic mobile belts containing dense metamorphic rocks. One of these ridges extends southeastwards across the Canning Basin and is continuous with an east-trending gravity ridge coincident with the Musgrave Block, and with a southwest-trending gravity ridge which can be traced through basic granulite outcrops in the Fraser Range area to the south coast near Esperance.

A gravity province of disturbed contour pattern southeast of the Fraser Range metamorphic belt is believed to represent a shield block buried beneath the Eucla Basin sediments. An oblique collision of this block with the Yilgarn Block could account for the mass distribution, as deduced from gravity, in the Fraser Range area and would be consistent with geologic and geochronologic evidence. Low Bouguer anomaly values in the southeast of Western Australia are attributed to low-density rocks of the crystalline basement.

Gravity contours indicate that the Yilgarn Block extends beyond its exposed limit to form the basement of the adjacent parts of the Officer and Bangemall Basins. The block is flanked on all sides by elongate gravity depressions which in the west relate to Phanerozoic sedimentary basins, but elsewhere relate to mass deficiencies within the Precambrian shield. A province of high gravity in the southwest corner of the block corresponds to an area where a dense lower crustal layer may be unusually shallow.

The central part of the Yilgarn Block is divided into two gravity provinces along a sinuous line extending between Norseman and Wiluna. In the western gravity province, intense residual gravity highs are short and disjointed and trend predominantly north, whereas in the eastern gravity province residual gravity highs are longer, trend mainly north-northwest, and are of smaller amplitude and intensity. The boundary

between the two gravity provinces may represent the westward limit of the main nickel province in Western Australia, as structural lineaments associated with known nickel mineralization are all confined to the eastern side. The two gravity provinces are thought to correspond to discrete tectonic units - a cratonic nucleus comparable with the Pilbara Nucleus to the west, and a younger geosynclinal belt to the east.

1. INTRODUCTION

Gravity surveys by the Bureau of Mineral Resources and private companies have covered the entire western part of the Australian Precambrian Shield and the adjoining basins (Plate 1), at a station density of at least 1 per 120 square kilometres. The Bouguer anomaly contours show the distribution of the principal elements of the tectonic framework of the West Australian Shield and indicate that this framework differs in some significant respects from that proposed in previous literature. Particular elements and patterns, which are supported by regional aeromagnetic and geologic evidence, may be important in regard to the distribution of the major mineral deposits within the Archaean shield area.

2. GEOLOGY

The following resume of the available geologic and geochronologic information of the area under discussion should be read in conjunction with the Tectonic Map of Australia (Geological Society of Australia, 1971).

The shield area of Western Australia has been divided into a number of blocks or provinces, each of which is characterized by broad uniformity of age, rock type, or structure. These blocks are flanked or partly overlain by sedimentary basins. The oldest blocks are the Pilbara Block, whose rocks have been dated at between 3100 and 2800 m.y., and the Yilgarn Block where the rocks span a much larger age range of 3100 to 2200 m.y. The Pilbara Block consists mainly of tightly folded metamorphosed basic igneous rocks and metajaspilites overlain unconformably by metamorphosed sediments and intruded by a granitic complex. There is no predominant trend; the tightly folded rocks appear to wrap around oval-shaped granite masses. The block is overlain in the south by Lower Proterozoic sediments of the Hamersley Basin. These are relatively undisturbed in the north but become increasingly deformed southwards. Their deformation relates to the Ophthalmian Orogeny, during which the Gascoyne Block and the Paterson Province were formed. The Yilgarn Block is made up of gneisses with lenticular areas of well-preserved but tightly-folded igneous and sedimentary rocks in conformable sequence. Unlike the Pilbara Block, which lacks a predominant trend, the igneous and sedimentary outcrops have a predominant north to northwesterly trend. All rocks are intruded by massive granites and late Proterozoic quartz dolerite dykes. Small remnants of undeformed Upper Proterozoic sediments overlie the block close to its margins.

The Albany/Fraser Province to the south and southeast of the Yilgarn Block consists mainly of granites (1100 m.y. old), gneiss, and granulite (1350 m.y.). The predominant trend swings from easterly near Albany to northeasterly at Fraser Range, sharply truncating the north to northwest trends of the Yilgarn Block. Basic pyroxene granulites, intruded by a flatlying olivine gabbro sheet, crops out at Fraser Range (Wilson, 1969). These granulites are separated from granites of the Yilgarn Block by the Fraser Fault, probably reverse and southeast-dipping with a strong sinistral transcurrent component, which is associated with a mylonite zone and a steep gravity gradient. The Fraser Range granulites have been dated at 1328 $\pm$ 12 m.y. Arriens & Lambert (1969) have interpreted the unusual precision of this dating as evidence that metamorphism took place as a sharp episodic event, or was prolonged but terminated suddenly by rapid uplift.

The Musgrave Block is made up of granulite, gneiss and granite (1300 to 1400 m.y.) overlain by sediments (1100 m.y.). Structural trends are mainly northeast. At its western end, the block is intruded by a granite sheet and by the Giles Complex (1100 m.y.) which consists of four main gabbro sheets, each intruded separately. Running northeastwards across this area is the Giles Discontinuity, thought by Horwitz et al. (1966) to be a transcurrent fault.

The Naturaliste Block and the Northampton Block extend parallel to the edge of the Yilgarn Block but on the opposite side of the Perth Basin. The Naturaliste Block is made up of north-trending granulites and gneisses, dated about 670 m.y. The Northampton Block is similar lithologically but considerably older (1040 m.y.).

The shield blocks composed dominantly of crystalline rocks are partly overlain by Proterozoic or younger sedimentary basins. The Bangemall Basin, of Late Middle Proterozoic age, forms part of the Central Australian Platform Cover. It is possibly continuous with a thick Proterozoic section underlying Phanerozoic sediments in the Officer Basin, which contains sediments more than 5000 m thick. The Eucla Basin, to the south of the Officer Basin, consists of thin Tertiary and Cretaceous limestone, silt, sand, and conglomerate overlying a granitic or gneissic basement of Precambrian age. The maximum thickness of sediments has nowhere been found to exceed 1000 metres.

3. GRAVITY INTERPRETATION

The contoured area (Plate 2) has been divided into a number of regional gravity provinces to assist in the gravity interpretation. A gravity province covers a large area of fairly simple shape within which the gravity field is characterized by uniformity with respect to contour trend, Bouguer anomaly level, or degree of contour disturbance. In general, provinces of low gravity correspond to massive granitic bodies or sedimentary basins, provinces of high gravity to metamorphic belts, and provinces of disturbed contour pattern to igneous sedimentary complexes such as the Eastern Goldfields area. However, some provinces appear to have mainly deep crustal causes as they bear no spatial relation to surface geological features.

Pilbara Region

Province I, consisting of short, randomly oriented residual highs and lows, corresponds to the Pilbara Nucleus, which embraces both the exposed Archaean area, known as the Pilbara Block, and most of the Proterozoic Hamersley Basin adjoining it to the south. Its western and southern boundaries roughly coincide with the faulted boundary between the Hamersley Basin and Gascoyne Block. The basic igneous masses and intrusive granites of the exposed Pilbara Block are represented in the gravity contours by residual highs and lows respectively. Regionally low Bouguer anomalies in the south of the province are attributed to light granitic basement underlying the Hamersley Basin.

Following the periphery of the Pilbara Nucleus are broad elongated gravity ridges (Provinces II and III) which cover the Paterson Province and the northern part of the Gascoyne Block respectively. These are interpreted as the gravity expressions of highly mobile zones, composed of dense regionally metamorphosed sediments and volcanics, which developed around the unstable margins of the Pilbara Nucleus early in the Proterozoic. Similar gravity ridges, presumably the expressions of mobile zones, are found along the landward margins of the Kimberley Block (Whitworth, 1970).

Musgrave Block

Province II extends southeast across the Canning Basin, possibly following a deeply-buried margin of the Yilgarn Block. Near the western end of the Musgrave Block, it splits into two gravity ridges of widely divergent trends (Provinces IV and V).

Province IV, a narrow intense ridge with several peaks exceeding +40 mGal, can be traced eastwards for at least 500 km beyond the Western Australian border, and is broadly coextensive with the Musgrave Block. High Bouguer anomalies are attributable to dense high-grade metamorphic rocks of which the block is predominantly composed.

Fraser Range area

Province V, like Province II, appears to follow closely on the partly buried margin of the Yilgarn Block, extending southwest from the western end of the Musgrave Block to the south coast near Esperance. Gravity relief consists of a gentle swell of variable width, on which are superimposed residual highs, including a 400 km long ridge of striking linearity and intensity, extending northeast from the Fraser Range. This ridge can be correlated with the basic granulites, intruded by gabbro, which are exposed on the southeastern side of the Fraser Fault. The marked reduction in amplitude across Province V in the north reflects a density decrease of the metamorphic rocks underlying the Officer Basin, but may be attributable in part to the attenuating effect of a thick and laterally uniform sedimentary cover.

Relation between the Paterson Province, Musgrave Block, and Fraser Range area

The continuity of Provinces II, IV, and V is of considerable interest since it suggests a link between three widely separated Proterozoic units: namely, the Paterson Province, the Musgrave Block, and the Albany/Fraser Province.

However, the continuity of contour between Provinces II and IV is of doubtful tectonic significance. The gravity ridge over the Musgrave Block forms part of a system of east-trending ridges and troughs which dominates the gravity pattern in Central Australia, whereas Province II is the expression of a mobile belt, probably older than the Musgrave Block, which has a close spatial relation to the Pilbara and Yilgarn Blocks of the West Australian Shield. The continuity of Provinces II and IV may therefore represent no more than a juxtapositioning of dense metamorphic belts in dissimilar geological environments.

Greater significance is attached to the continuity between Provinces II and V. Both provinces extend along presumed cratonic margins which, as inferred previously, are logical tectonic settings for mobile belt development. The two provinces together girdle the Pilbara and Yilgarn Blocks, which implies that if the two blocks were ever separate continental masses, as suggested by Arriens (1972), then mobile belt activity postdated their coalescence.

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The influence of orogenic activity along the southeast margin of the Yilgarn Block may have extended into the western part of the Musgrave Block. This is evidenced by the continuity of Provinces IV and V, the occurrence of gabbroic sheet intrusions in both areas, and the approximate co-linearity of the Fraser Fault and Giles Discontinuity.

It is suggested that the Fraser Fault is a major fracture, possibly extending to the mantle (Mathur, 1973) along which dense granulite-facies rocks at the base of an incipient mobile belt system were uplifted and exposed about 1330 m.y. ago. Shear stresses associated with left lateral strike-slip movement in the Fraser Range area were transmitted northeastwards along the relatively weak mobile belt system and caused transcurrent faulting in the western Musgrave Block. Gabbroic intrusions found in both the Fraser Range and western Musgrave areas could have been emplaced as a result of upstreaming of basic magma along the fault zones corresponding to the Fraser Fault and Giles Discontinuity.

This mechanism is satisfactory in at least two respects: firstly it is consistent with the geochronological constraint that ending of metamorphism should be rapid; secondly it could produce a single mass anomaly of large dimension near the surface, which would satisfy the strikingly linear and intense gravity feature southeast of the Fraser Fault. The model is discussed in a wider context under the next heading.

Eucla Basin area

Over the thin Tertiary and Cretaceous sediments of the Eucla Basin, gravity relief is controlled mainly by lateral density contrasts in the basement. The contours therefore depict the regional subdivisions of the shield underneath the Eucla Basin. Two provinces can be discerned: Province VI, a gravity complex adjoining Province V to the southeast; and Province VII, a depression covering the eastern parts of the Eucla and Officer Basins.

In Province VI the disturbed contour pattern resembles that over the Yilgarn and Pilbara Blocks, suggesting that the basement is a fragment of a shield block. An oblique collision of this block against the southeastern Yilgarn could have provided the compression and shear stress needed to set in train major reverse faulting with consequent uplift and exposure of the Fraser Range metamorphics, and transcurrent movement along faults in the Fraser Range and western Musgrave areas. Such a collision between Precambrian blocks could be explained in terms of present-day theories of plate tectonics.

Low Bouguer anomalies in Province VII are attributed to granitic basement, at least in the south near Forrest where a borehole encountered granitic rocks at a depth of only 300 metres (Peers & Trendall, 1967).

Yilgarn Block

The Yilgarn Block, as outlined in the previous literature and including its probable subsurface extension as basement under the Officer and Bangemall Basins, is substantially covered by Provinces VIII, IX, and X, which together are surrounded on all sides by deep gravity depressions (Provinces XI, XII, XIII, XIV).

Except for Province XI, west of the Yilgarn Block, in which low Bouguer anomalies are correlated with thick Phanerozoic sediments of the Perth, Coolcalclaya, and Byro Basins, the gravity depressions are attributable to mass deficiencies in the Precambrian crust. North of Albany, an east-trending gravity low (Province XII) correlates with Archaean granites which crop out west of the Fraser Range area. The northward continuation of Province XII bears little relation spatially to the known shape and structure of the Officer Basin, suggesting that the Bouguer anomalies have a sub-basin source. Province XIV, a deep depression north of the Yilgarn area, extends over parts of the Gascoyne Block and Bangemall Basin and has no cause evident at the surface.

Provinces XII, XIII, and XIV are gravity depressions of such large amplitude and areal extent that it is difficult to envisage their being caused entirely by granitic masses in the upper crust. Their large dimensions and close spatial association with the major gravity ridges suggest they may be the expressions of regional mass deficiencies which resulted from isostatic compensation of the dense mobile belts. As such, the source of the strongly-negative provinces could be deep-seated and not necessarily related to surface geological features.

The regionally high Bouguer anomalies of Province VIII in the southwest of the Yilgarn Block may relate to a shallowing, from east to west, of a dense lower crustal layer (Everingham, 1965; Mathur, 1973). The province could be regarded alternatively as the expression of an ancient mobile zone, as high-grade metamorphic rocks such as granulite are found in the area.

The central part of the Yilgarn Block is divided into two provinces (Provinces IX and X) of differing gravity contour patterns. In Province X, the contour pattern consists of a series of elongated sub-parallel residual highs which have a predominant north-northwest trend, whereas in

Province IX, the residual highs are more disjointed, are of greater amplitude and intensity, and are mainly elongated along north axes. This contrast in gravity pattern represents a difference in geometrical configuration of basic igneous masses between the two areas. This difference is not discernible on published geological maps, which show north-northwest trends of the greenstone belts over the entire Yilgarn Block.

Other evidence supports this division of the Yilgarn Block. Major structural lineaments (Plate 2), definable from aeromagnetic and photo-geological maps, which have a close association with nickel mineralization are all confined to the eastern side. The westernmost of these lineaments coincides with a quasi-continuous belt of narrow residual gravity highs which extends from Norseman to Wiluna, parallel to the boundary between the two gravity provinces. The other lineaments show varying degrees of correlation with linear belts of residual highs in the eastern part of the Yilgarn Block.

Age dating and seismic evidence suggest that the western Yilgarn Block is older and of greater crustal thickness than the eastern area. Granites in the age range 3100-2800 m.y. are all confined to the western edge of the block; no rocks in this older age group have been found in the eastern area. Seismic evidence shows that the crust is unusually thick (44 km) in the west but thins out eastwards and approaches the normal thickness of continental crust (34 km) under the Eastern Goldfields (Mathur, 1973).

It is suggested that the western Yilgarn Block is an old stable cratonic nucleus, comparable perhaps with the Pilbara Block whose granites and gneisses fall into the same age group as the oldest rocks of the western Yilgarn Block.

The elongated sub-parallel nature of trends in the eastern area suggests that crustal evolution may have followed an accretionary process in which new orogenic elements were successively welded on to the unstable margin of the growing protocontinent. The elongated residual-gravity highs could therefore relate to ancient volcanic piles which are analogous to modern island arcs.

The Canadian Shield is thought by Goodwin (1972) to have evolved along such lines. He has delineated four main protocontinents which together constitute the Canadian Shield. Each protocontinent consists of a sialic nucleus and surrounding annular belts which are alternatively volcanic-rich and sediment-rich. As in the Yilgarn Block, most of the major nickel deposits are confined to the annular volcanic-rich belts rather than the older sialic nuclei.

4. ACKNOWLEDGEMENT

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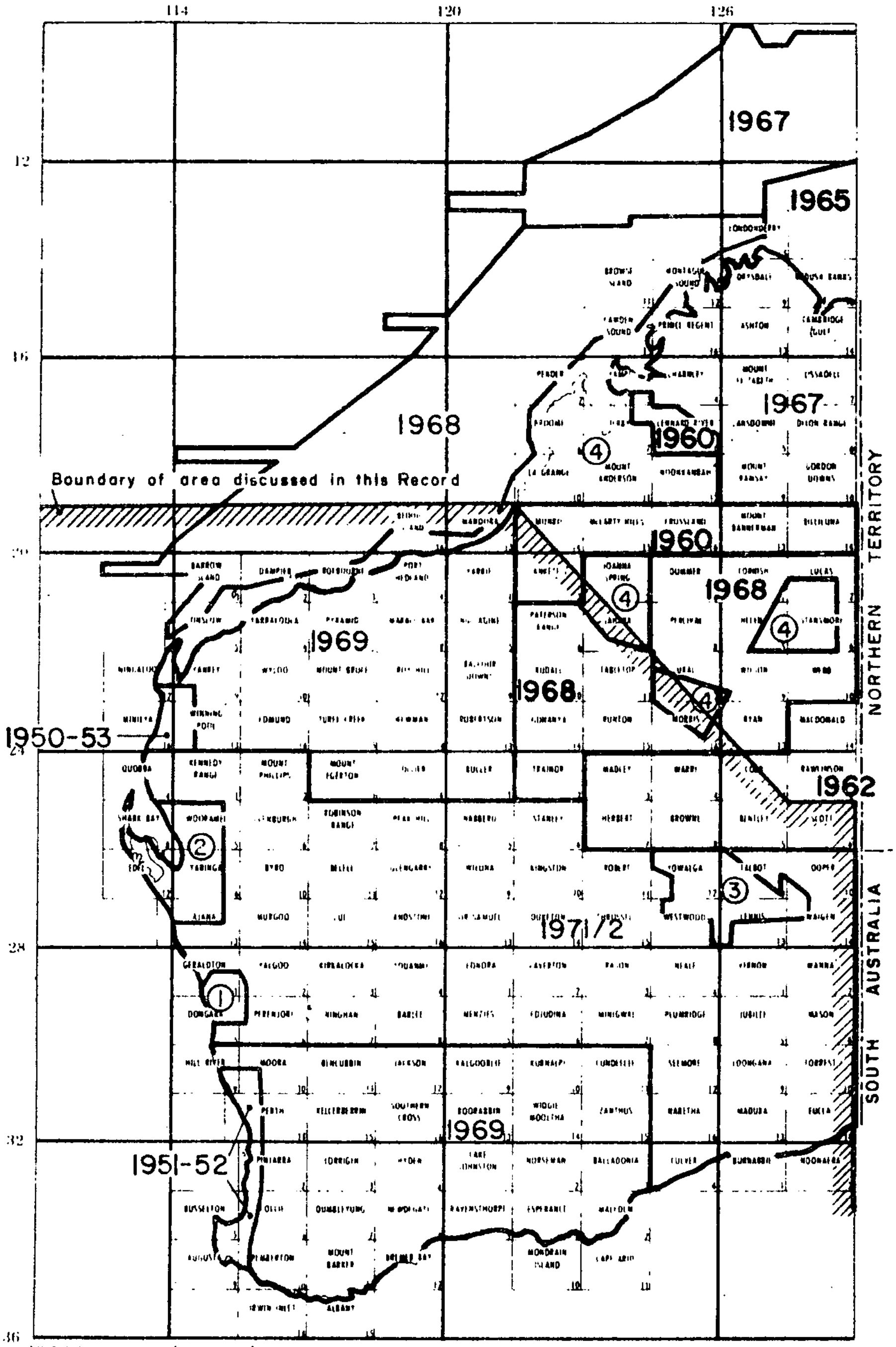

(BASED ON A/B2-23)

GRAVITY COVERAGE OF WESTERN AUSTRALIA

The gravity information from the areas indicated was used to compile a Bouguer anomaly contour map of Western Australia, of which Plate 2 is part. Areas covered by BMR are labelled with the year of survey. Areas covered by private companies are labelled with an encircled number, the key to which is as follows:

1. West Australian Petroleum Pty. Ltd., 1962
2. Barewa Oil and Mining N.L., 1970
3. Hunt Oil Company, 1964
4. Various

PLATE 2

(BASED ON A/B2-85)

LEGEND

///// Province boundary

VI Province number

═══ == Nickel-associated lineament

BOUGUER ANOMALIES AND GRAVITY PROVINCES

100 50 0 50 100 150 200 250 300 Kilometres

TO ACCOMPANY RECORD NO. 1973/105

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