Mineral Provinces

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A geological interpretation of the regional gravity and magnetic features of north Queensland
Record 1992/77

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AGSO

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

DEPARTMENT OF RESOURCE INDUSTRIES

A geological interpretation of the regional gravity and magnetic features of north Queensland
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A contribution to the National Geoscience Mapping Accord

NORTH QUEENSLAND PROJECT

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Minerals and Land Use Program

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TABLE OF CONTENTS

ABSTRACT

Proterozoic and Palaeozoic basement rocks crop out over about one third of the area of the North Queensland Project of the National Geoscience Mapping Accord, mainly on the higher ground. Elsewhere basement is overlain by cover rocks generally less than 1 km thick. Gravity and magnetic anomalies are used here to infer basement structures and rock types over both the areas of exposed and covered basement. Proterozoic basement, that underlies the western part of the area, can be subdivided into three belts, each north trending, and in the order of 700 km long. The western belt, situated along the eastern margin of the Gulf of Capentaria, is interpreted as a Proterozoic crustal rift, 100-150 km wide, co-linear with the Mount Isa Geophysical Domain, and with several bands of felsic intrusions. The central belt lies mainly under the Carpentaria Basin, but it crops out in the Croydon area. This is interpreted as Proterozoic crust that has not been intruded or reactivated since cratonization in the ?Middle Proterozoic. The eastern belt crops out extensively in the Georgetown and Coen Inliers, is more magnetized, and the eastern part was metamorphosed to the amphibolite facies or higher. This belt is inferred to be the present margin of continuous Proterozoic crust, that was reworked to 100 km from the edge by heating, intrusion and transpressional deformation. Different sectors of the margin were reworked at different times: Middle Proterozoic (1570 Ma ago), Cambrian-Ordovician, Siluro-Devonian, and Permo-Carboniferous. Palaeozoic basement, in the east and south of the area studied, can be subdivided into bands with different geological histories. Strips along the boundaries between these bands have been effected by events in both adjacent bands.

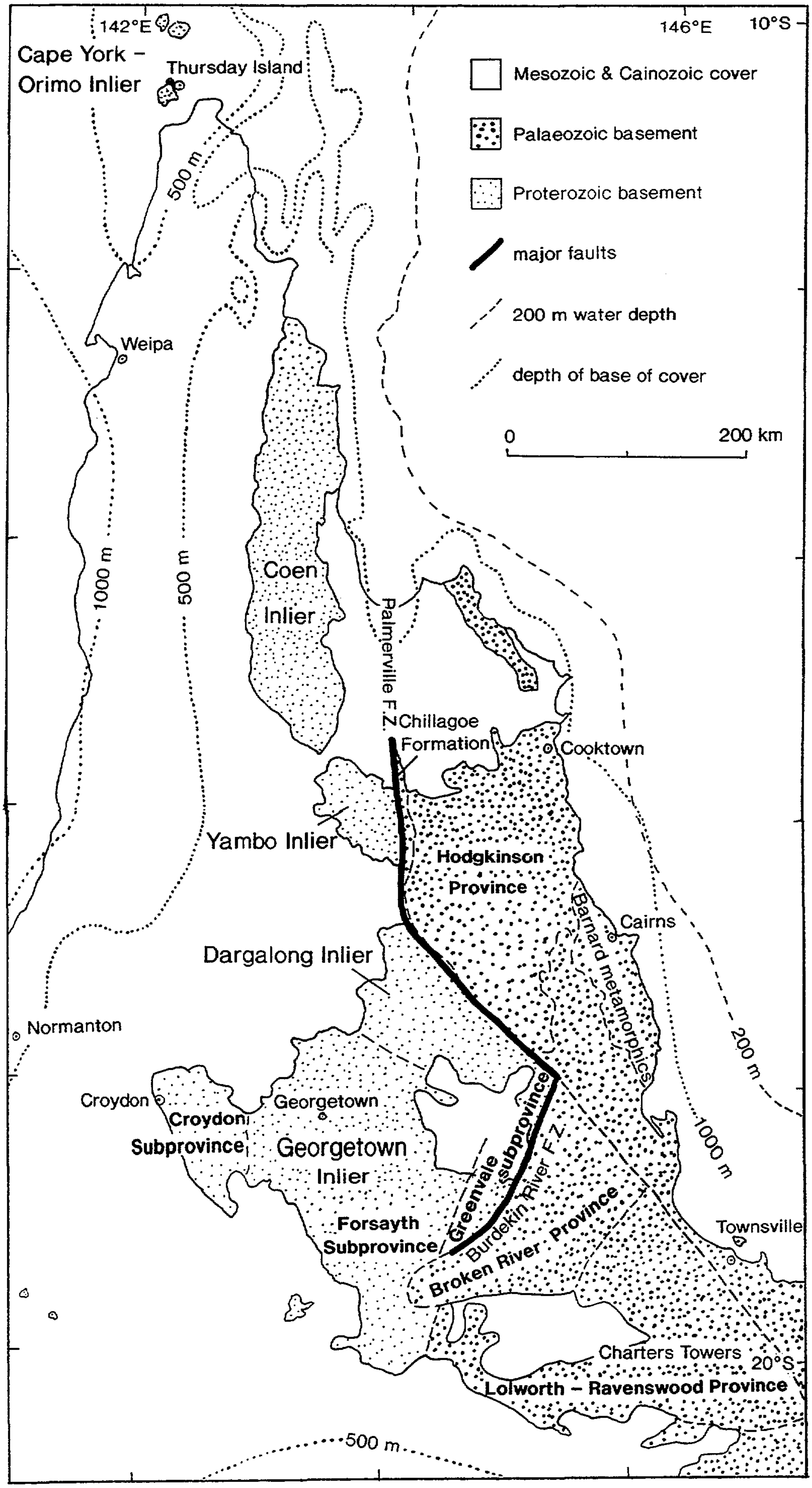

Fig. 1. Simplified outcrop geology of the study area (from Wellman, 1992b).

INTRODUCTION

In north Queensland basement crops out over about one third of the area (Fig. 1), the outcrops being concentrated on the highest land, and shallow basins forming most lowlands. These outcrops show that basement is Proterozoic along the highland axis, and Palaeozoic along the east coast and in the south. The cover rocks are generally less than 1 km thick (Fig. 1), and they contain important water resources, but there have been few wells drilled through these cover rocks to the underlying basement, so the basement under cover is poorly known.

The whole of the north Queensland area has now been covered by regional gravity and magnetic surveys. The various surveys have been integrated so that regional displays of the anomalies have been prepared. Using this regional pattern of gravity and magnetic anomalies, and known geology for control, I have inferred the regional geology of the basement. This study concentrates on the area of Proterozoic basement, because in these regions the data provide relatively easily interpretable information on the nature of the basement rocks. In the area of the Tasman Fold Belt the geophysical anomalies are more difficult to interpret unequivocally.

This paper is part of the North Queensland Project, a comprehensive study of the basement geology and regolith of north Queensland by the Australian Geological Survey Organization (AGSO)(formerly Bureau of Mineral Resources, BMR) and the Department of Minerals and Energy (formerly Queensland Department of Resource Industries), within the National Geoscience Mapping Accord. Figures 1 & 2 show the area studied and the names of the 1:250 000 sheet areas. These sheet areas are referred to in the text as names in capital letters.

GEOLOGY

Summaries of the geology of the area are given by Geological Survey of Queensland (1975), Henderson and Stephenson (1980) and Day & others (1983). The rocks can be divided into three main groups (Fig. 1) – Proterozoic rocks forming the basement over most of the area, Paleozoic rocks forming the Tasman Fold Belt basement in the south and east and occurring as intrusions and volcanics within the area of Proterozoic basement, and Mesozoic and Cainozoic age cover rocks.

Proterozoic rocks. Proterozoic rocks outcrop in a series of inliers – from south to north the Georgetown, Dargalong, Yambo and Coen Inliers (Fig. 1). These inliers form the Georgetown-Coen Province of Henderson (1980). The geology of the Georgetown Inlier is summarized by Withnall & others (1988) and Bain & others (1990). The inlier comprises three subprovinces – Forsayth Subprovince forming the main part of the inlier, Croydon Subprovince in the west, and Greenvale Subprovince along the southeast margin. The Forsayth Subprovince mainly contains Etheridge Group rocks of Early Proterozoic age – formed sometime between 2400 and 1570 Ma. These rocks are described by Withnall & others (1988) as "shallow-water, fine-grained, clastic metasedimentary rocks, and minor basaltic lavas and related dolerite intrusions". They were intruded by Middle Proterozoic trondhjemites and S-type anatectic granitoids, and overlain by Middle Proterozoic Langlovale Group sediments on its western margin. The rocks were deformed and metamorphosed (greenschist to granulite facies) during the Ewamin Orogeny at 1570 ± 20 Ma, and the Jana Orogeny at 1469 ± 20 Ma.The Croydon Subprovince contains subaerial felsic ignimbrite of the Middle Proterozoic Croydon Volcanic Group, and related subvolcanic S-type granitoids, overlain by thin sediments of the Late

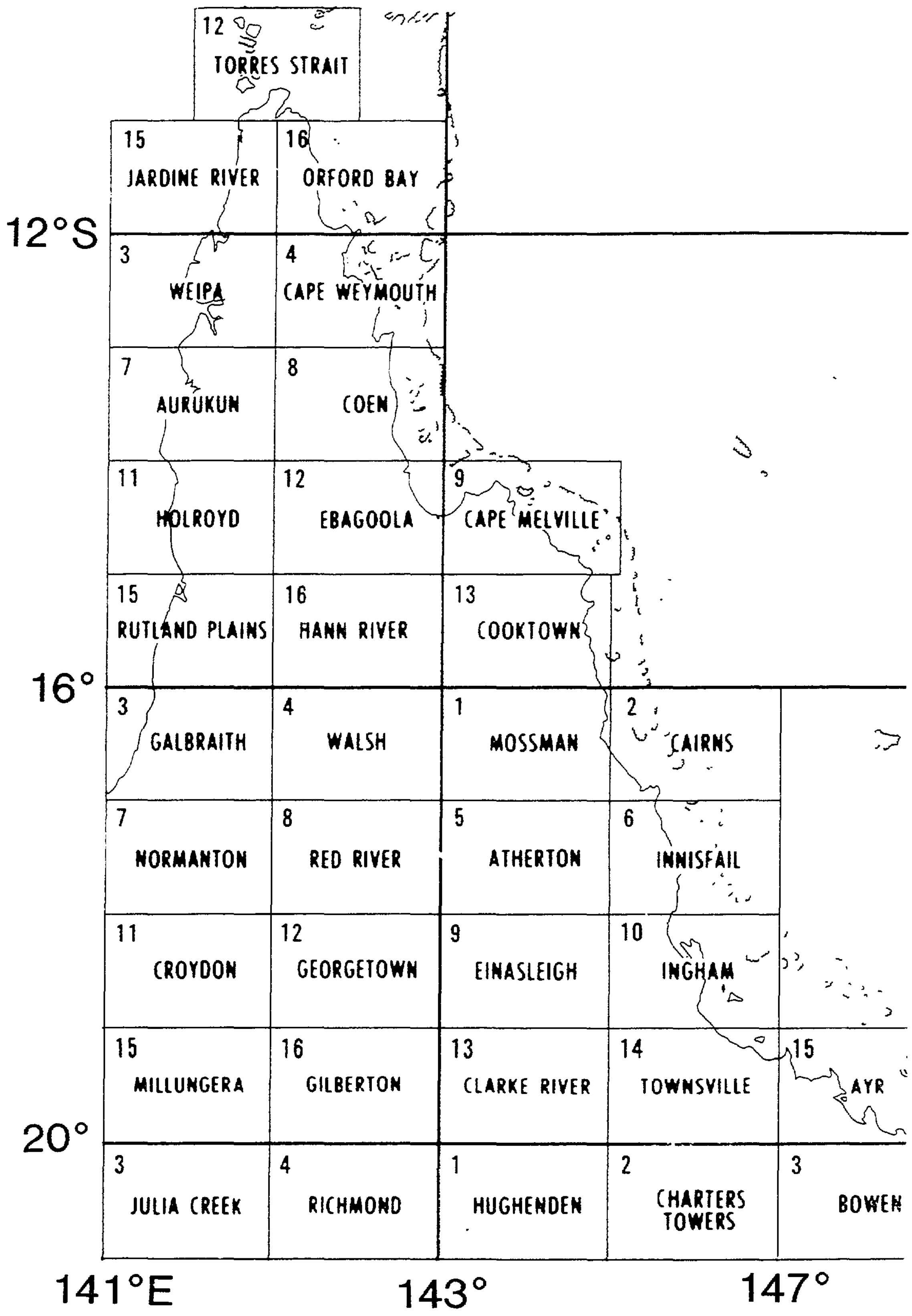

Fig. 2. Names of 1:250 000 map sheet areas.

Proterozoic or Early Palaeozoic Inorunie Group, all these rocks being unmetamorphosed and undeformed. Basement to the Croydon Subprovince is likely to be Etheridge Group rocks because they form the granite xenoliths, and are likely to be the source of the abundant graphite in the volcanics and felsic intrusives (D.E. Mackenzie, AGSO, 1991 pers. comm). A different and higher grade basement, similar to basement found by drilling through the cover to the west, is suggested by reported xenoliths of high metamorphic grade at one locality of the Croydon Volcanic Group.

The Greenvale Subprovince is separated from the Forsayth Subprovince by a major mylonite zone. The province is thought to mainly consist of early Palaeozoic (Withnall & others, 1991) metavolcanic and metasedimentary rocks that have underthrust Proterozoic rocks which are possibly part of the Etheridge Group. Two units of Proterozoic rock occur along the eastern edge of the subprovince; the Halls Reward Metamorphics and the Boiler Gully Complex of metagabbro, clinopyroxenite and serpentinite.Withnall & others (1980) considered that the Proterozoic rocks of the Dargalong, Yambo and Coen Inliers are lithologically similar to Etheridge Group rocks of the Georgetown Inlier, and that they are possibly the same age, but with somewhat different metamorphic and structural histories. The known limit of the Proterozoic rocks to the east is the Palmerville Fault System (Shaw & others, 1987), and to the south is the Burdekin River Fault Zone (Fig. 1). There are metamorphic rocks in the Lolworth-Ravenswood Province to the south that may be Proterozoic, or Cambrian/Ordovician.

Early Phanerozoic rocks. The geology of the Hodgkinson and Broken River Provinces is summarized by Arnold and Fawckner (1980). Both provinces have older sequences adjacent to the Proterozoic in the west, of flysch, basic volcanics and limestone, but are largely composed of thick clastic marine sequences of quartz-intermediate flysch. The two sequences are of Late Silurian-Early Devonian, and Devonian age in the Hodgkinson Basin, and ?Ordovician and Silurian-Devonian in the Broken River Province. The Lolworth-Ravenswood Province comprises volcanic and sedimentary assemblages of Late Cambrian to Early Ordovician age (Henderson, 1986), areas of metamorphic rock of either Cambrian or late Proterozoic age, and granitoids of Ordovician, late Silurian to early Devonian and late Carboniferous to early Permian age (Hutton & others, 1990). In the Anakie Inlier to the south of the area studied (near Clermont) the high-grade metamorphic rocks are similar to those of the Lolworth-Ravenswood Province; they have a minimum age of Late Ordovician, and may be late Proterozoic or Cambrian/Early Ordovician in age. Also present are some little-deformed Late Ordovician and middle Devonian sediments.

Palaeozoic igneous rocks. Palaeozoic granitoids in north Queensland have Cambrian-Ordovician, Silurian-Devonian and Carboniferous-Permian ages (Richards, 1980; Bain & others, 1990). Cambro-Ordovician granitoids forming the Mount Winsor Igneous Province occur in the Greenvale Subprovince and Lolworth-Ravenswood Province. Siluro-Devonian granitoids of the Cape York Plutonic Belt form a 100 km wide strip north-south along the eastern margin of the Proterozoic basement, and east-west along the Lolworth-Ravenswood Province. They are mainly S-type north of 16.5°S, and I-type to the south. Outcropping Permo-Carboniferous granitoids are concentrated along the eastern margin of the land area without known Proterozoic basement – the New England Fold Belt and Broken River and Hodgkinson Provinces. Occurrences within Proterozoic basement are mainly in the Dargalong Inlier, the northern part of the Coen Inlier, and in Torres Strait. These granitoids are of S- and I-type in the Hodgkinson Province, and I-type elsewhere.Volcanic rocks of Permo-Carboniferous age crop out throughout much of the studied area where basement is not covered by Mesozoic cover sediments. They do not occur in the eastern part of the Hodgkinson Province. They are most common in the area of the Georgetown and Dargalong Inliers and in the Cape Weymouth – Torres Strait area. The volcanic rocks mainly occur as shallow basins or troughs at the present level of exposure. There is a wide range of structures, from major volcano-tectonic subsidence structures that are the source for extensive ignimbrites, through ring dyke structures, to smaller fault bounded basins. The volcanics are comagmatic with granitoids of similar age.

PREVIOUS GEOPHYSICAL INTERPRETATION

Previous interpretations of geophysics in terms of geology are a study of the magnetic and radiometric anomalies of WALSH, MOSSMAN and CAIRNS by Shelley & others (1971), a study of the Mesozoic basins by Pinchin (1973), determination of the depth to magnetic basement in the northern Eromanga and Galilee Basins by Hsu (1974), a study of the gravity anomalies by Shirley and Zadoroznyj (1974), and a study of the magnetic anomalies of the Weipa area by Slade (1986). Stockill (1987) gives magnetic susceptibility measurements for CLARKE RIVER. Unpublished studies include one by K. Horsfall interpreting magnetic and radiometric data between 14 and 16°S, and two by M. Bacchin, R. Hegarty and D. Tucker on interpretation of the airborne geophysics and gravity of RUTLAND PLAINS, HANN RIVER and COOKTOWN, and geophysical ground follow-up on these sheets. Few studies have been carried out on crustal geophysics; Dooley (1980) reviewed the crustal geophysics, Cull & Conley (1983) reviewed heat flow data, and Zuber & others (1989) determined the effective elastic thickness of the lithophere.

GRAVITY ANOMALIES

The most important gravity information is that collected by BMR on an approximately 11 km by 11 km grid over the whole land area (Gibb, 1967; Gibb, 1968; Shirley & Zadoroznyj, 1974). These surveys used helicopter transport, and because altitudes are based on barometric measurements, the measured Bouguer anomalies have a standard deviation of about 12 $\mu m.s^{-2}$ (Barlow, 1977). During 1989-1991 BMR and GSQ carried out a 4 km spacing survey over the AYR, BOWEN and CHARTERS TOWERS 1:250 000 sheet areas. The only other land gravity surveys are isolated traverses such as Anfiloff (1983). Terrain corrections are not available for any of these surveys; this will introduce errors of less than 2 $\mu m.s^{-2}$ at most of the observed stations, but possibly as large as 20 $\mu m.s^{-2}$ at a few stations in the steep topography on the eastern margin of the highlands. The important marine gravity surveys are surveys of the Great Barrier Reef (Goodspeed & Williams, 1959; Dooley, 1965), a survey of the Gulf of Carpentaria by USS Shoup in 1963, the survey of the Coral Sea by the Continental Margin Survey (Mutter, 1974; Mutter & Karner, 1980), numerous traverses through Torres Strait by ships in transit, and a 50 km grid of traverses over the Gulf of Carpentaria in 1980 (Thomas & others, 1991, Hanson & Stainforth, 1982).

The data were analysed in terms of upper crustal geology using both simple Bouguer anomalies and short-wavelength anomalies. The two types of anomalies are complementary. Bouguer anomalies have the advantage of preserving all the observed wavelengths. However, because of the isostatic compensation of the topography, a portion of the anomaly is due to mass variation below the upper crust, so the long-wavelength part of the anomaly mirrors regional topography. Where this regional variation is steep the short wavelength anomalies due to upper crustal density variations are obscured. Gravity anomalies of less than 200 km wavelength (Fig. 3) more clearly reflect upper-crustal density variation.

MAGNETIC ANOMALIES

The main magnetic data set used in this study is the set of regional aeromagnetic surveys flown by BMR at 1.5 to 6.0 km flight-line spacing between 1966 and 1986 (Fig 4). The surveys cover the whole of the land area, and 0 to 50 km of the adjacent continental shelf. The surveys show an improvement in quality with time. The earliest surveys over JULIA CREEK, RICHMOND and HUGHENDEN are fortunately peripheral to the main aims of this study. These 1966 surveys have 3 to 6 km nominal flight-line spacing, were flown at 600 m above sea level using a proton precession magnetometer, and original data are available only in contour map form. Surveys of WALSH, MOSSMAN, CAIRNS, RUTLAND PLAINS, HANN RIVER, COOKTOWN, HOLROYD, EBAGOOLA and CAPE MELVILLE were flown between 1969 and 1974 using a fluxgate magnetometer at 1.5 to 3 km spacing at 150 to 250 m above ground level. The remaining surveys flown between 1982 and 1986, used a proton precession magnetometer, and were flown with a flight-line spacing of 1.5 km at 150 m above ground level. An exception was INNISFAIL flown at 1500 m above sea level.

Aeromagnetic surveys of the surrounding continental margin consist of a survey including parts of the INNISFAIL, INGHAM and AYR (Australian Gulf Oil Company, 1969), a survey covering parts of COOKTOWN, CAPE MELVILLE and COEN (Corbett Reef Ltd, 1968), traverses in TORRES STRAIT and DARU (Gulf Interstate Overseas Ltd, 1962), a major survey of part of the Gulf of Carpentaria including parts of TORRES STRAIT and JARDINE RIVER (Marathon Petroleum Australia Ltd, 1965), a survey including the western parts of WEIPA and AURUKUN by Comalco Aluminium Ltd (Slade, 1986), and a survey of strips of the Gulf of Carpentaria by Delhi Petroleum (Hartman, 1962). Marine magnetic surveys of the Gulf of Carpentaria are the early survey reported by USNOO (1967), and recording along the seismic lines with a 50 km spacing (Fig. 7 of Burgess, 1984). The results of the airborne surveys have been released by BMR as a series of contour maps at 1:1M scale. The results of most airborne surveys over land have been released by BMR as observed data on magnetic tape, and at 1:250 000 scale as plans of flight path, flight line profiles, and contours. For this study another series of plans was produced at 1:250 000 scale of the short-wavelength (<3 km) component of the flight line profile plotted at 200 nT/mm. Computer-produced images of the data at 1:1 000 000 scale consist of those by BMR of Cape York Region and Townsville Region (Anfiloff, 1988, 1989), and those by Geoimage Pty Ltd of Cape York, Northwest Queensland, and Northeast Queensland, (Geoimage, 1989, 1990 a & b), and a 1:2 500 000 image of Queensland (Geoimage, 1990c). An image of a detailed aeromagnetic survey of the Newcastle Range area is given by BHP Minerals (1987). In interpreting the magnetic anomaly data I have inspected all the above products. Structures that were equidimensional or elongated in the direction of the east-west flight lines were best studied either using images or contour maps. Structures with a northerly elongation were often best studied using flight-line profiles, as correlation between peaks is generally based on peak shape.

In the following areas the magnetic data is relatively less useful for geological interpretation. Over JULIA CREEK, RICHMOND and HUGHENDEN the surveys were flown high and have

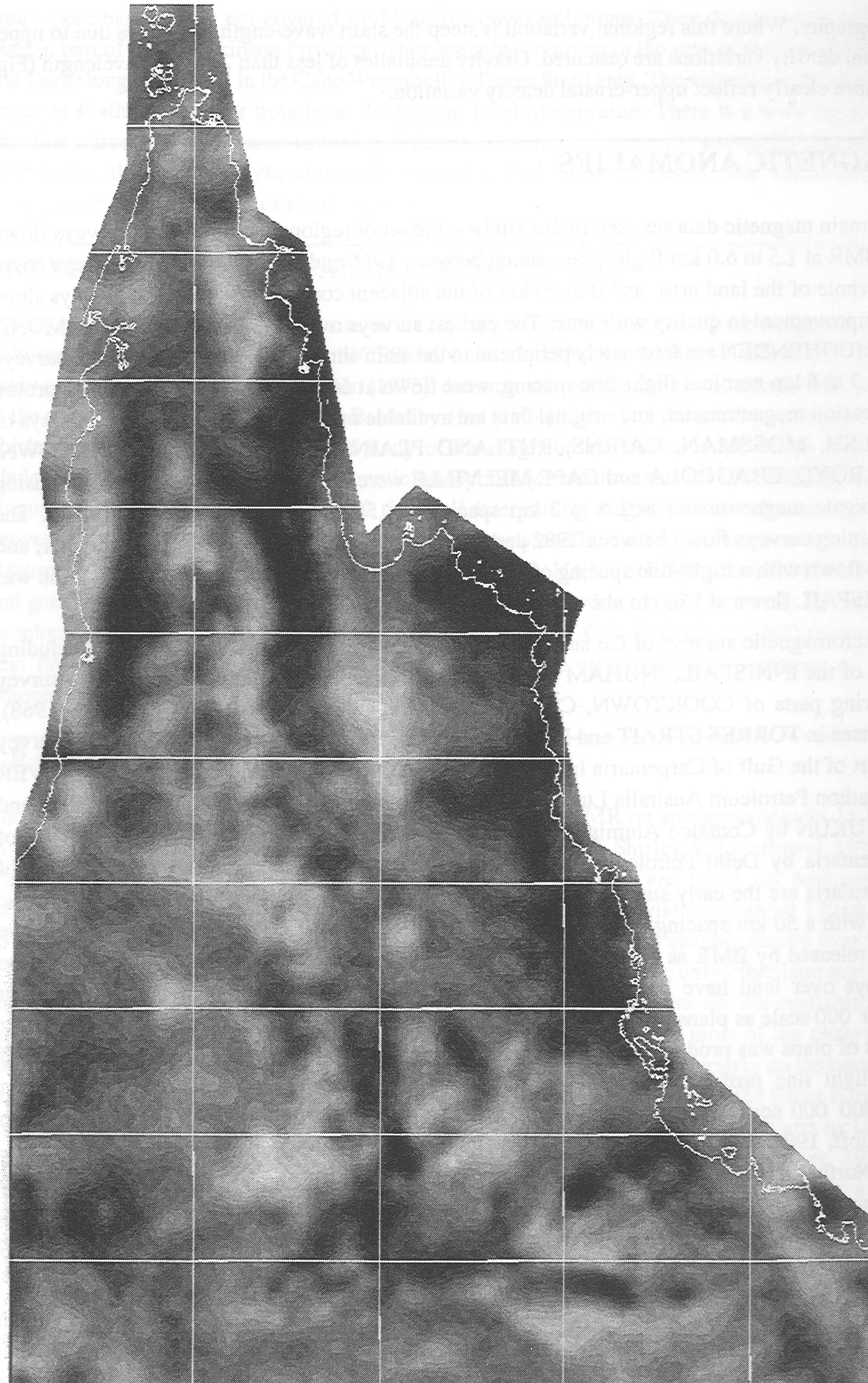

Fig. 3. Image of gravity anomalies <200 km in wavelength.

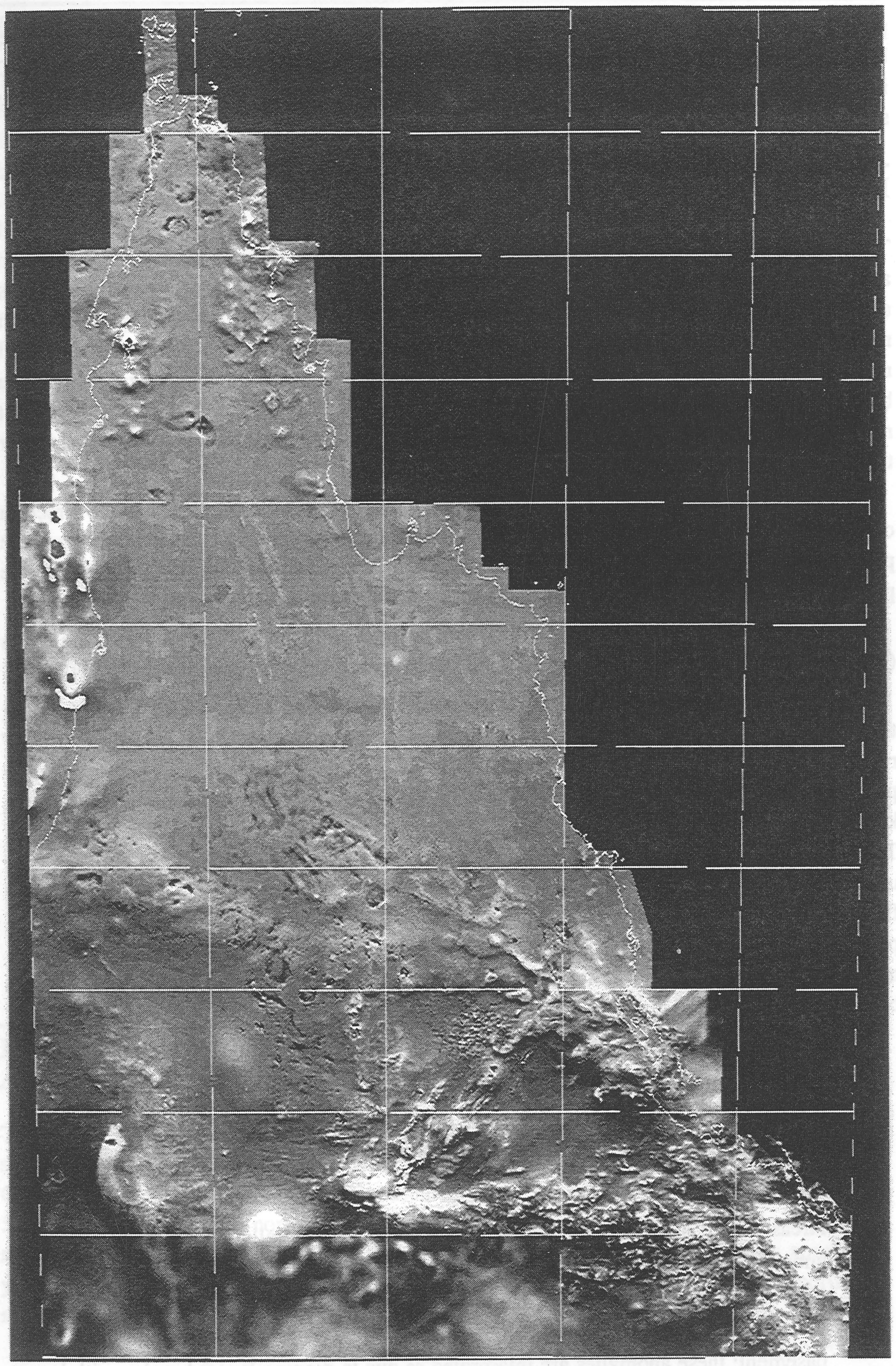

Fig. 4. Image of total magnetic intensity anomalies.

poor flight-line levelling. Over INNISFAIL no short-wavelength information could be derived because the survey was flown at 1500 m above sea level. Over GILBERTON and RICHMOND interpretation is difficult because the the effect of poor levelling between adjacent flight line is similar to the effect of the east-trending fractures.

INTERPRETATION OF MAGNETIC ANOMALIES

The magnetic anomalies are of two types – positive and negative features. Positive features have a dominant positive anomaly relative to the surrounding area, and their causative rock body has an apparent magnetization higher than the surrounding area. Negative features have a dominant negative anomaly relative to the surrounding area, and their causative rock body has an apparent magnetization lower than the surrounding area. The lower apparent magnetization may be because the induced and remanent magnetizations are both near zero, or because the remanent magnetization is in a direction reversed relative to the present Earth's field, and it is stronger than the induced magnetization.

The shape of an anomaly is a function of the body's three-dimensional shape and the direction of apparent magnetization. If it is assumed that the remanent component is in the direction of the present Earth's field, or is minor, then the direction of apparent magnetization is close to the present Earth's field, and the shape of the body can be inferred from the shape of the anomaly.

For convenience the magnetic anomalies are described in three components, short-wavelength (0.5-3 km), long-wavelength (3-50 km), and very long-wavelength components (50-300 km).

Short-wavelength magnetic anomalies essentially give information on the rock type forming the surface of the basement. The anomaly amplitude and texture can be interpreted in terms of rock type, and anomaly direction gives the strike of the lithological bodies. There is a major problem in separating and displaying short-wavelength anomalies, because the anomalies are known in better detail in the direction along the flight lines, compared with across the flight lines. The spatial distribution of the anomalies is best displayed as computer-produced images either using shade-illumination, or using gradient. The shape of the anomalies is best displayed by filtering the observed anomalies to isolate the short-wavelength, and preparing maps of flight-line profiles of filtered anomalies.The analysis of short-wavelength anomalies reported here was mainly based on the maps of filtered profiles. Two types of areas were recognized, and the boundary between them mapped:

- Areas where the short-wavelength magnetic anomaly was of generally low-amplitude and anomalies/noise on adjacent profiles could not be correlated. These areas were interpreted as having the upper part of the basement surface of low and uniform magnetization – either uniform intrusive rock, or thick sequences of sediment/felsic volcanics.

- Areas where short-wavelength anomalies is of a generally higher amplitude, and anomalies can be correlated between adjacent flight lines. In these areas the upper part of the basement has a significant and variable magnetization. Generally the anomalies are due to subparallel bodies that have a positive magnetization relative to the average basement; these anomalies are interpreted as due to dipping layered rocks, with layers of significantly different magnetization.

BOUNDARIES BETWEEN GEOPHYSICAL DOMAINS

The geophysical anomalies found at the boundaries between geophysical domains have been extensively discussed both in Australian and overseas papers (e.g. Gibb & Thomas, 1976; Klasner & King, 1986; Wellman, 1990). In general, it has emerged that two subparallel boundaries, 50 to 200 km apart, separate an older domain on one side, and a younger domain on the other, the two boundaries enclosing a band of what was previously older domain that has been 'reworked' at the time the younger domain was cratonized. The reworking entails heating, intrusion by granitoids, and transpresssional deformation. The two boundaries are called here the geophysical domain boundary (between the band of reworking and the younger domain) and the reworking boundary (between the older domain and the band of reworking). Geophysical features associated with these boundaries are as follows.

- A change in gravity and magnetic trends at the reworking boundary, with trends in the older geophysical domains oblique to the boundary, and trends in the reworked band and the younger domain parallel to the boundary.
- Due to the change in crustal structure across the geophysical domain boundary, and hence change in density profile, there is a long-wavelength gravity anomaly along the domain boundary. Generally there is a gravity high over the younger domain, and a gravity low over the reworked band, and the gradient between them is of a larger magnitude, longer, and more gently curved than gradients within the adjacent domains.
- Along the margin of the younger domain there is sometimes the extrusion of volcanic rocks causing short- and long-wavelength magnetic highs, or the emplacement of mid-crustal rocks to the surface causing a gravity and magnetic high.
- Reworking of the crust between the two domains has several effects. The heating usually decreases magnetization, so the short-wavelength magnetic anomalies have low amplitude, and the long-wavelength magnetic anomalies are negative. Granitoids are often intruded into the reworked band. The transpressional deformation causes systematic offset of trends of the older domain along sub-parallel faults, and both the displacement of the trends and the faults can be seen in the gravity and magnetic anomalies.

RELATIONS OF NORTH QUEENSLAND WITH SURROUNDING AREAS (Fig. 5)

The Proterozoic rocks of north Queensland have to the northeast Cretaceous and Cainozoic sea-floor basement of the Coral Sea Basin, to the southeast and south basement of the Tasman Orogenic System, and to the southwest basement of the Mount Isa Geophysical Domain (Fig. 5). To the northwest and north the adjacent basement rocks are unknown. Wellman (1992a) showed from crosscutting relations that the Mount Isa Geophysical Domain was apparently younger than the crust to the east and west, but is itself younger than crust to the north and southeast.

The southeast margin of the Mount Isa Geophysical Domain abuts the West Thomson Domain of the Tasman Orogenic System (Fig. 5), with strong long-wavelength gravity and magnetic

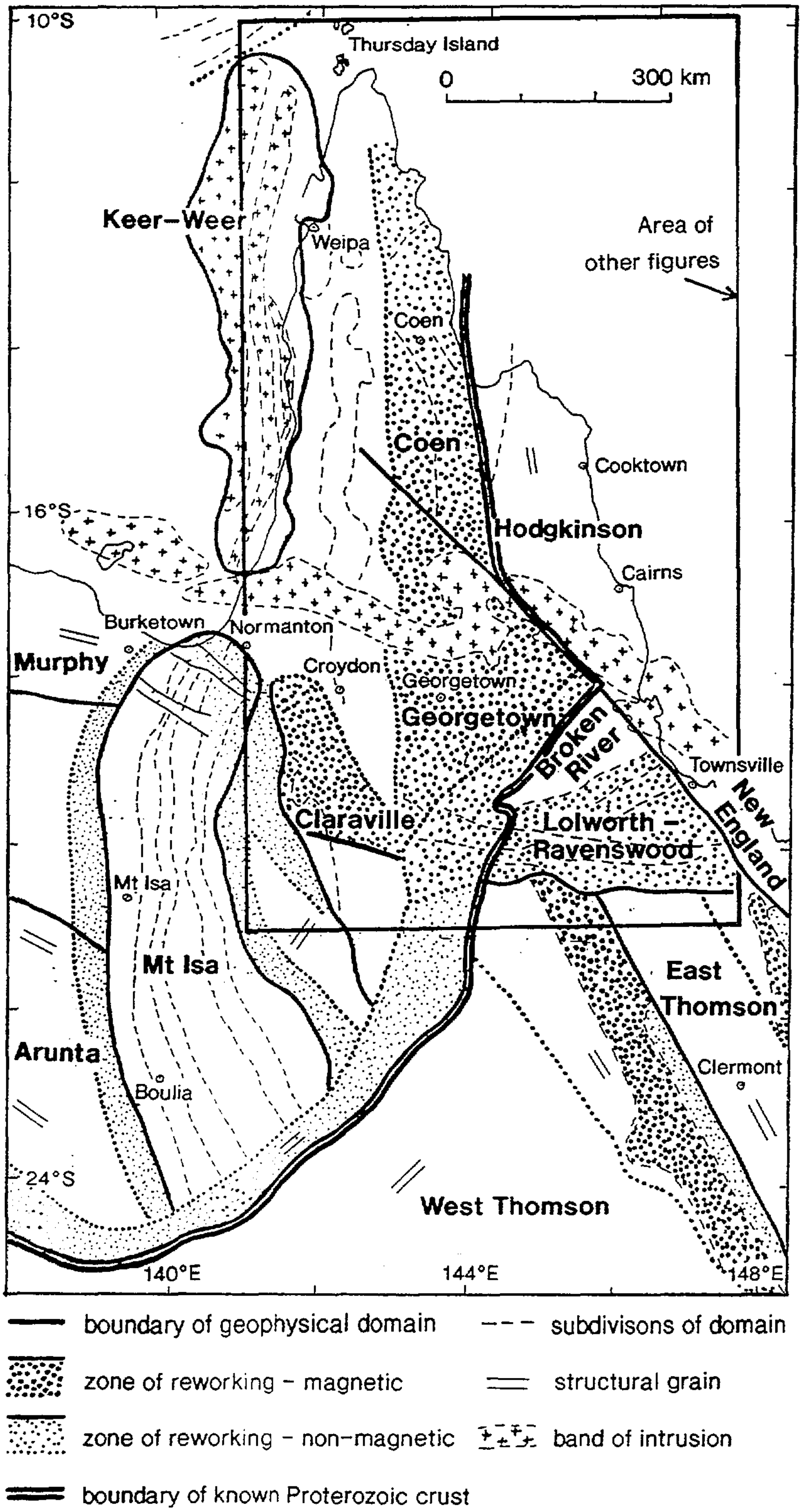

Fig. 5. Geological summary. The area covered by this figure differs from that of the other figures. Much of the variation in magnetization can be attributed to reworking of the margin of the continent during cratonization of adjacent crust (after Wellman, 1992b).

anomalies along the reworked band (Wellman, 1988, 1990, 1992a, in press; Murray & others, 1989). To the northeast this boundary between Proterozoic crust and the West Thomson Domain (Fig. 5) is less well defined. The preferred position of the reworking boundary is along a line that separates southeast trending gravity and magnetic anomalies due to Proterozoic structures from NNE trending gravity and magnetic anomalies due to Phanerozic structures of the Tasman Orogenic System margin. This line is a 170 km-long, NNE striking, high-amplitude magnetic high that is interpreted to be the southeast margin of the magnetic Proterozoic crust. The geophysical domain boundary is taken to be along the major gravity gradient with a low to the southeast, that is 100 km to the southeast. Between the Proterozoic Georgetown Inlier and the Palaeozoic Broken River Province is a reworked band, the Greenvale Subprovince (Fig. 1). The reworked band as a whole is a magnetic high. Within the band are northeast-trending high-amplitude magnetic anomalies coincident with northeast trending gravity gradients.

In the area of the Hodgkinson Province the margin of the Proterozoic (Fig. 1) is associated with no major change in magnetic anomalies, but a change in gravity anomalies of <200 km wavelength (Fig. 3) from positive over the Proterozoic to negative over the Hodgkinson Province.To the northeast the Australian continental crust abuts oceanic crust of Cretaceous/ Palaeocene age; the boundary is close to the outer margin of the Great Barrier Reef. The abrupt change in crustal thickness causes positive and negative free air gravity anomalies, with the positive anomaly approximately following the outer part of the Great Barrier Reef.

The north-trending structures of north Queensland are truncated in the north at 10.0-10.5^{o}S. To the north of this, magnetic anomalies east of Torres Strait have an east trend, and west of Torres Strait have a NE to ENE trend.

METHOD USED TO MAP GEOPHYSICAL DOMAINS

The north Queensland region was subdivided into geophysical domains and subdomains. Boundaries have been mapped where geophysical anomalies are best explained as due to a change in rock type. The four main changes in geophysical anomalies used are as follows:

- **Gravity anomalies.** Major gradients, particularly gradients that are relatively straight in plan.
- **Short-wavelength magnetic anomalies.** The change from areas with no or few correlatable anomalies, to areas where there are elongate correlatable anomalies.
- **Long-wavelength magnetic anomalies.** At a change in the type and/or trend of anomaly.
- **Very long-wavelength magnetic anomalies.** At an abrupt change in anomaly level.

A boundary has been classified as a domain boundary where most types of geophysical data show major changes, and as a sub-domain boundary where only minor changes occur in only a few types of data. Figure 6 shows estimates of the location of boundaries from the different data types. The estimates of the position of the boundaries do not generally differ by more than 10 km, so the mean boundary positions used in Figure 7 are probably accurate to 5 km.

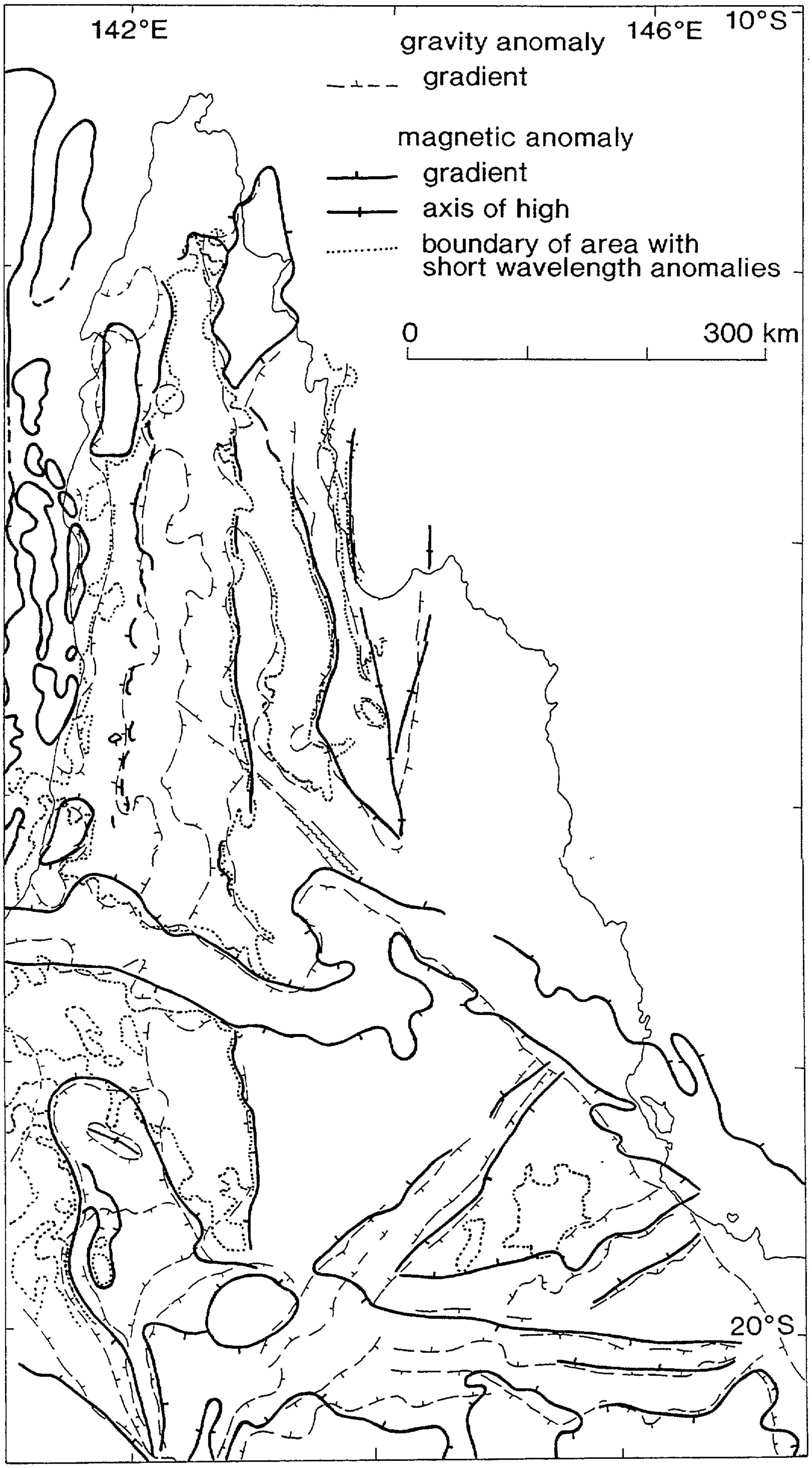

Fig. 6. Estimates of the location of geophysical domain boundaries.

DESCRIPTION OF THE GEOPHYSICAL DOMAINS (Fig. 7)

Domain F (Fig. 7) is the eastern band of the Mount Isa Domain (Fig. 5). At the boundary there is a gravity gradient (Wellman, 1992a) with the relative high on the domain F side, and a change from short-wavelength magnetic anomalies within domain F to few outside.

Domain G is unnamed and lies between the Mount Isa and Claraville Domains (Figs 5 & 7). Subdomain G1 is considered the non-reworked core of the domain. It has gravity and magnetic anomalies of wavelength 10-50 km with NE strike. Subdomain G2 is interpreted as the reworked margin of this domain, with trends parallel to the adjacent domains F, P and Q. The trends of G1 are truncated by adjacent domains, so this domain is interpreted to be the oldest.

Domain H is an elongate, magnetic high that crosses the north Queensland region with a general ESE strike (Fig. 7). It is a gravity low. It has a length of over 700 km, and an average width of 50 km. Where it crops out, in the Georgetown and Dargalong Inliers and Hodgkinson Basin, this domain correlates with Carboniferous/Permian igneous rocks. The igneous rocks are inferred to extend the whole length of the domain. The domain is likely to extend west to cause the magnetic and gravity highs over Mornington Island because Mornington Island 1 well bottomed in early Permian granite (Grimes, 1979).

Domain J has elongate magnetic anomalies with a wavelength of 20 to 30 km, amplitude 30-150 nT, and a strike varying from 40° in the southeast to 80° in the northwest (Fig. 8). The trends within the domain have a similar strike to the domain margin to the south, and they truncate the trends of domain K, so domain J is thought to be younger than domain K. Structures in the domain are thought to be caused by late Phanerozoic events of the craton margin in New Guinea to the north.

Domain K is located along the eastern margin of the Gulf of Carpentaria (Figs 4, 5, 7 & 8). Its most prominent feature are two, separated, north-trending belts of prominent magnetic anomalies that extend for about 700 km (K1, K2), with a minor belt 200 km long on their eastern side (K3). Anomalies in the central belt (K2) are either elongated north-south or approximately circular, of width 20-30 km, and amplitude 300-1000 nT. In the western belt (K1) anomalies are similar in shape to those in the east, but with a lower amplitude, and there are several anomalies across the width of the band. The major anomalies within the domain consists of a positive and negative with the positive twice the area of the negative. Within some anomalies there are north-south striking anomalies of 5-10 km wavelength. The gradients between associated high and low anomalies have near constant slope, consistent with the causative bodies having a significant depth extent. The bodies causing the anomalies have low density, are thick, with near uniform magnetization, and are little modified by later deformation, so they are thought to be thick post-orogenic granitoids. As the granitoids are magnetic, they are more likely to be I than S type. Crust between the magnetic granitoids is in places non-magnetic, and locally has elongate magnetic bodies with northerly-trends. The domain is a gravity low (Fig. 8), flanked to the east and west by a gravity high. The eastern boundary of domain K is not taken at the eastern margin of the intrusive rocks, but at the major gravity gradient that is sub-parallel and to the east (Figs 6 & 7), that approximates the boundary between where short-wavelength magnetic anomalies are present and absent (Fig. 6).

Domain K is interpreted to be a crustal rift of Middle or Late Proterozoic age, with granitoids, and intervening sediments and/or volcanics. It was named the Keer-Weer Geophysical Domain by Wellman (1992b). The Mount Isa Geophysical Domain (Wellman, 1992a) is a crustal rift of

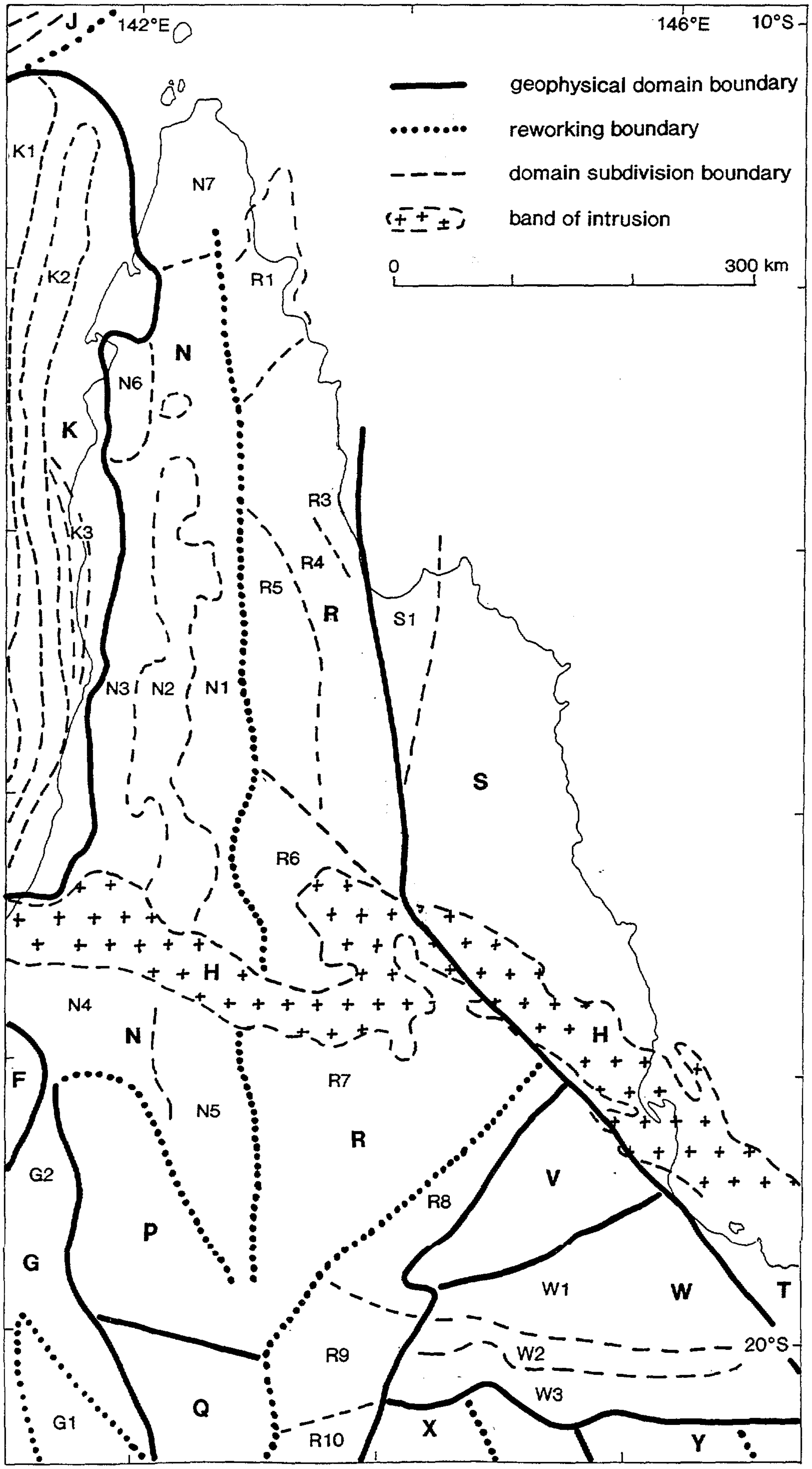

Fig. 7. Subdivision into geophysical domains.

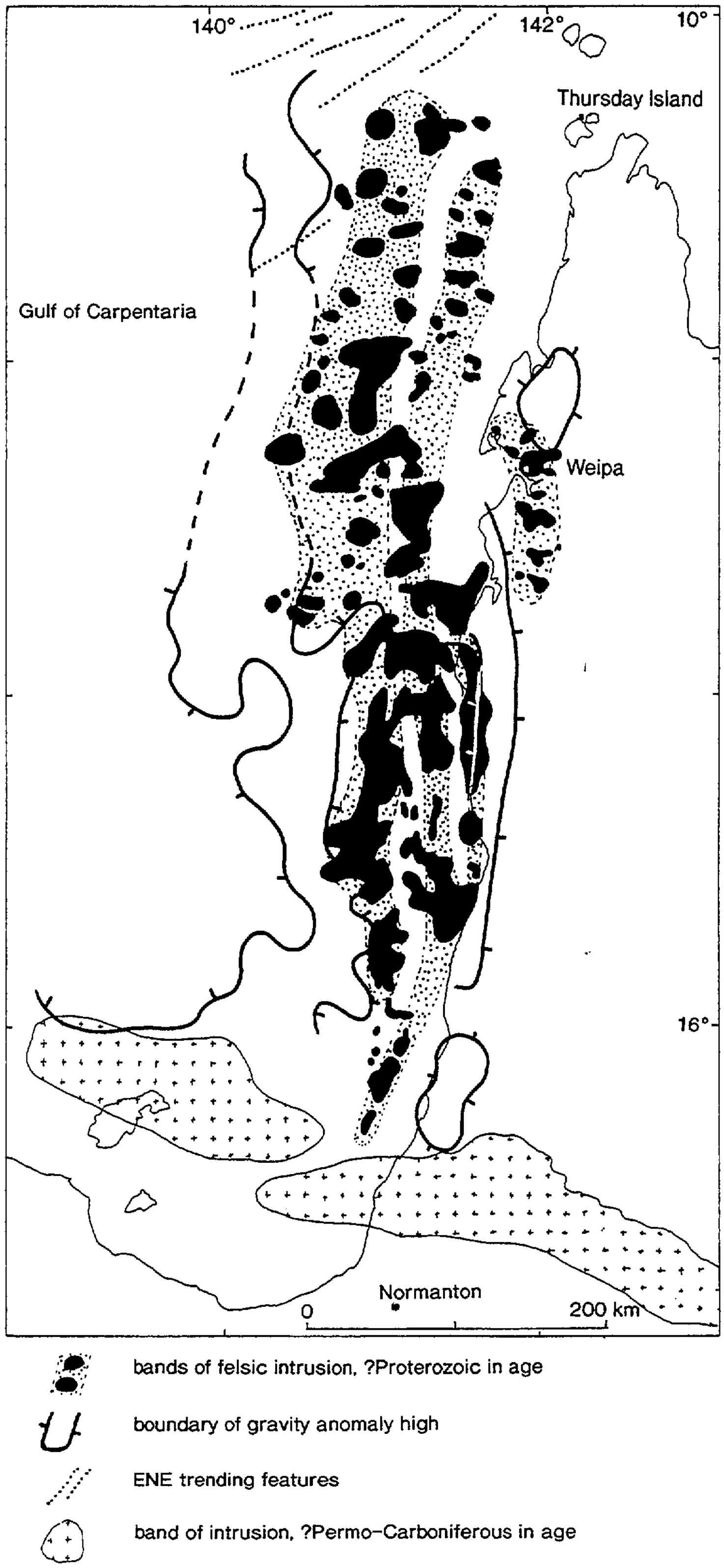

Fig. 8. Keer-Weer Geophysical Domain. The domain consists of several bands of felsic intrusions, probably in a major crustal rift. The area of the intrusions is a gravity anomaly low, and this low is bounded to the east and west by gravity highs. The domain is bounded to the north by ENE trending features, and to the south by intrusions of ?Permo-Carboniferous age.

possibly similar Proterozoic age, colinear and immediately to the south. Domain K may be an extension of the Mount Isa Geophysical Domain, however it differs from it in the pattern of the gravity and magnetic anomalies, and in largely being a gravity low rather than a gravity high.

Domain N is magnetically quiet with few medium- or short-wavelength magnetic anomalies, so the upper crust must be of low magnetization. Much of the upper crust has a relatively low density. Below the Carpentaria Basin sediments it is likely to be mainly granitic intrusion, and greenschist-facies metamorphics, but it could in part be low-magnetization felsic volcanics, or sediments. The domain crops out in the south in the Croydon area, where the Croydon Volcanics (about 1550 Ma old) overlie metamorphic rocks similar to those of the Georgetown area, and small areas of granite comagmatic with the volcanics. However this area is the only one in the domain with a large smooth magnetic high. If the intrusion causing the high is associated with the Croydon Volcanics, as seems likely, then the absence of similar anomalies elsewhere is consistent with the absence of similar volcanics. Boundary N/K is marked by a major gravity anomaly with only a gentle radius of curvature, so it is thought to be a major crustal break, with crust of different origin and composition on the two sides.

Boundary N/R is interpreted as the western limit of reworking, with enhanced magnetization of rocks to the east. Hence the boundary may not be a major change in Proterozic rock type or crustal structure. However, throughout its length this boundary is a weak gravity gradient, with lower gravity anomalies to the west (Figs 3 & 6). Hence it is possible that the low density and low magentization of domain N is in part due to granitoids, flat lying sediments, or flat-lying felsic lavas. The few bore holes into basement have only found granitoids and metamorphics.

Domain N can be divided into three north-striking zones. The central zone (N2, N5) has much higher gravity, and higher amplitude, medium- and short-wavelength magnetic anomalies relative to zones N1 and N3. These anomalies may be due to N2 and N5 being relatively dense and magnetic relative to N1 and N3, or to N1 and N3 having relatively low density and magnetization relative to the margin of domains K and R. Area N6 has numerous magnetic anomalies interpreted as due to post-cratonization, thick, steep-sided granitoids of possible Proterozoic age, so this area may be part of domain K.

Domain P is an area of magnetic high, and generally of gravity low, with a weak NNW dominant grain in short-wavelength magnetic anomalies. The higher magnetization of this domain relative to surrounding domains could be due to the domain being composed of 1) felsic igneous material of high initial magnetization, or 2) metamorphic rocks of low initial magnetization that had magnetization increased due to a heating event.

Domain Q has an average long-wavelength magnetic anomaly, and prominent gravity and magnetic highs and lows striking NNW. Magnetic anomalies are poorly defined, so the rock type is unknown. The western margin of the domains P and Q is thought to be a thrust in MILLUNGERA and JULIA CREEK, because the gravity gradient is displaced 10 km west of the magnetic gradient, the magnetic gradient is very steep, there is a subparallel fracture pattern to the east and west, and the shape of the margin is a smooth curve. Domains P and Q are thought to have been thrust west over domain G, as indicated by the abrupt edge of the magnetic anomalies. It is not clear whether domains P and Q have always differed from the surrounding area in rock types and history, or they initially had similar composition and history, and have subsequently changed in physical properties because of activity along their western margin.

Domain R contains outcrops of the Georgetown-Coen Province of mainly metamorphic rocks and granites. Elongate magnetic anomalies reflect lithological bands with a NNW trend. These trends appear truncated in the west against the north-striking domain boundary N/R. The anomalies continuity, width, amplitude and polarity varies regionally throughout the domain, presumably due to regional changes in rock type and metamorphic grade. An unusual feature is the negative magnetization of many elongate anomalies, particularly in the WALSH and RED RIVER sheets. Where these negative anomalies outcrop to the south in GEORGETOWN most are associated with Langdon River Mudstone, which contains carbonaceous and pyritic material. About one half the northern part of the domain has few short-wavelength magnetic anomalies, and is a gravity low; these areas correlate with outcropping granitic intrusions.

The difference between domains R and N is thought to be, not a difference in the original rock-type, but in domain R being subsequently magnetized when metamorphosed to amphibolite facies. The boundary between the central and eastern bands is broadly parallel throughout its length with both the slate/gneiss boundary (shown as 'mostly amphibolite grade gneiss' on Fig. 10 after Bain & others, 1990), and a band of Siluro-Devonian granitoids (Fig. 9). In both the Coen and Georgetown Inliers there is an overall decrease in metamorphic grade westward, with greenshist facies rocks along the eastern margin of both inliers. In the Coen Inlier there was a thermal event in the Siluro-Devonian (ca. 408 Ma) associated with prograde metamorphism, intrusion of granites and strong D2 deformation (Bain & others, 1992); this thermal event is thought to have caused the enhanced magnetization. In the Georgetown Inlier there were prograde metamorphic events at 1570 and 1470 Ma in the Middle Proterozoic, and a retrograde event in the Siluro-Devonian; the magnetization is probably due to the prograde Proterozoic events. High magnetization of the northern end of domain R (R1) may be due to the Siluro-Devonian thermal event, but may also be due in part to a thermal event associated with the intrusion of the Permo-Carboniferous granitoids into the northern portion of the domain (Fig. 9). Hence in this model, the rocks of the domains N and R are thought to be of similar origin in the Proterozoic, with the rocks of domain R having their magnetization subsequently increased one or more times by heating and re-crystallization. The thermal events have been restricted to what appears to the margin of the Proterozoic crust.

Within the Proterozoic Inliers the metamorphics can be subdivided into metamorphic units with different geological character (Fig. 10). In general these units have different magnetic anomaly patterns, so using magnetic images their extent can be mapped over the whole area of the magnetized band. There is a major basement fault co-linear with the northwest-trending part of the Palmerville Fault Zone (Figs 5, 6 & 10). This fault separates two metamorphic units in the Coen and Yambo Inliers to the north of the fault, from two metamorphic units to the south (Fig. 10), the fault also separates I-type Siluro-Devonian granites in the south from S-types to the north, and is thought to separate Middle Proterozoic basement to the south from ?Late Proterozoic basement to the north (Bain & others, 1992). The fault shows in magnetic images as a line separating areas with different texture in domain R, and on gravity maps as a line of gravity gradient in domain R and in area N1. The fault is coincident with the southeast end of the Alice-Palmer Structural Zone of Smart & others (1980).

Permo-Carboniferous I-type intrusions and volcanics crop out over the northern part of the Coen Inlier. The associated magnetic anomalies have high-amplitudes, positive polarity, are equidimensional in plan, and they indicate that the bodies have little depth extent. These bodies are thought to continue to the north under cover, forming most of area R1.

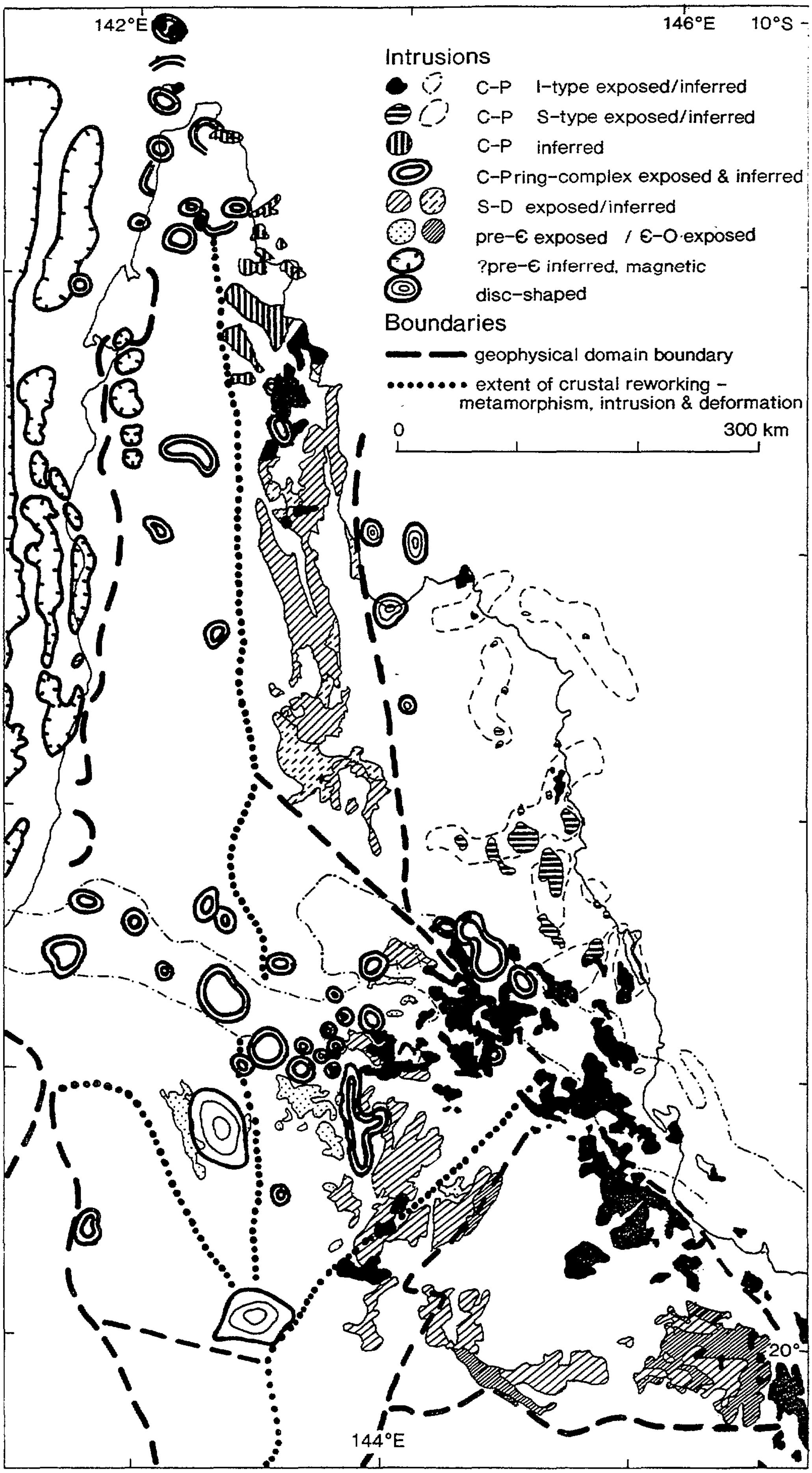

Fig. 9. Known and inferred intrusions (from Wellman, 1992b).

Area R2 has a flat magnetic pattern, which is due in part to the granitoids that crop out, and may be due in part to demagnetization due to deformation along the R/S domain boundary. Areas R8, R9 and R10 are interpreted as a band along the southeastern margin of the Proterozoic crust that was reworked by deformation, heating and intrusion in the Early Palaeozoic. Area R8 is the Greenvale Subprovince of Withnall & others (1980), in part an Early Palaeozoic magmatic belt (Withnall & others, 1991). Magnetic anomalies in area R8 are NE-striking, long, narrow, irregular highs, within a broad magnetic high, and gravity anomalies with NE-striking gradients. Generally each gravity gradient is overlain by a narrow magnetic high. Magnetic anomalies in area R9 are northwest trending and continuous with anomalies in domain W, while gravity anomalies are northeast trending.

Domain S corresponds with the Hodgkinson Province. The province is a relative gravity low (Fig. 3), consistent with its upper crust being of lower density than that of the Proterozoic crust to the west. The magnetic pattern is in general subdued, with scattered low-amplitude medium- and short-wavelength anomalies with a northerly trend. In the southern part of domain S there is a good correlation between relative gravity lows and outcropping Permian granites (Fig. 9); in the north where there are fewer outcrops the relative gravity lows may also overlie Permian granites. Area S1, containing prominent north-striking magnetic highs, continues to the north to at least 13.3°S. This area is thought to contain block faulted Chillagoe Formation (Arnold & Fawckner, 1980), as this crops out in the southern part of the area (Fig. 1). The magnetic anomalies in area S1 can be divided into two types. Anomalies along the eastern margin of the area and to the south, have a magnetic high in the east and a low in the west, and are associated with rocks that crop out (Chillagoe Formation) and the structures described by Shaw & others (1987). Anomalies within area S1 and forming its western margin are symmetrical magnetic highs, that are not associated with outcropping rocks, and may not be associated with a thrust system. The boundary between the Proterozoic and Palaeozoic crust could be either on the west or east side of area S1.

Domain T is the northwestern end of the New England Orogen.

Domain V corresponds with the Broken River Province. Most of the domain has smooth negative magnetic anomaly.

Domain W corresponds with the Lolworth-Ravenswood Province and its extension to the west. Gravity and magnetic anomalies have a similar character to the Greenvale Subprovince (R8); the domain is mainly a regional magnetic high, with short-wavelength high-amplitude elongate magnetic highs, the larger of which overly major elongate gravity gradients. Arcuate negative magnetic anomalies with a general east-trend correlate with outcrops of Cambrian-Ordovician sediments and metamorphics that occur in the southern part of the domain. In general gravity and magnetic trends in areas W1 have a NE to ENE trend, and in areas W2 and W3 have E to ESE trends. Area W3 is a gravity high containing most of the outcrops of Cambrian-Ordovician sediments.

Domains X and Y are the northern ends of elongate geophysical domains of Phanerozoic age, the East Thomson and West Thomson Orogens (Wellman, 1990; Wellman, in press) (Fig. 5).

IGNEOUS ROCKS (Fig. 9)

I have used the uniformity of magnetization of the body as a measure of the uniformity of composition, and the uniformity of the gradient between the magnetic high and low as a measure of the thickness of the body.

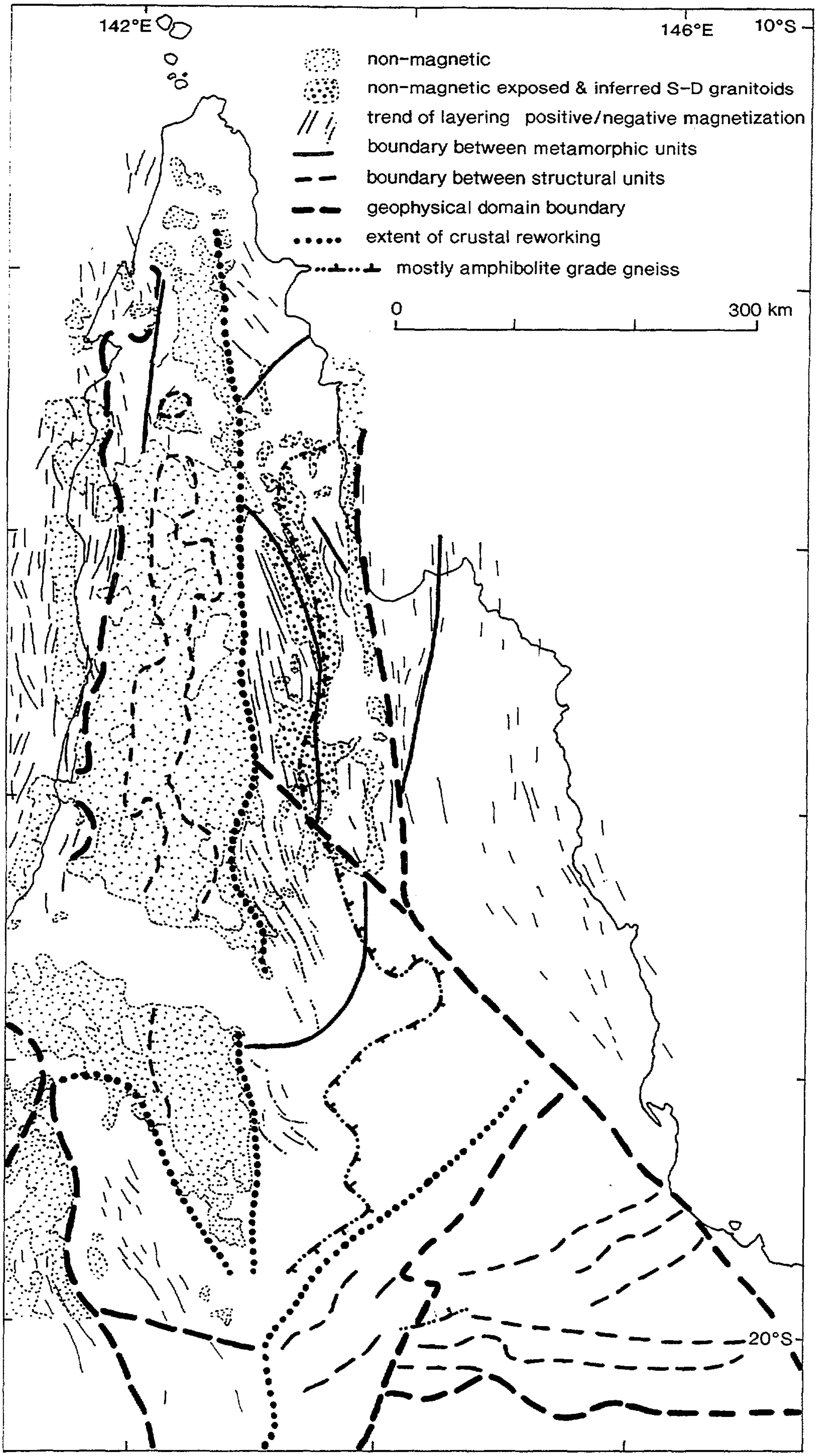

Fig. 10. Non-magnetic crust, and metamorphic units (from Wellman, 1992b).

Non-magnetic granitic intrusions. Areas underlain by non-magnetic granitic intrusions will in general be gravity lows, have low long-wavelength magnetic anomaly, have low-amplitude short-wavelength anomalies, and generally have abrupt margins with adjacent rocks. Large areas of non-magnetic granitic intrusions are known in area R, and are possible in area N.

Magnetic, thick, granitic intrusions. Within domain K and area N6 there are a large number of magnetic anomalies due to thick, low density bodies, with a fairly uniform magnetization; many are elongate north-south. The bodies are thought to be Proterozoic post-cratonization granitoids.

Large magnetic disc-shaped intrusions. Dome shaped highs with no short-wavelength anomalies occur in two areas; 4 highs, 15 to 30 km in diameter, occur in the northern part of the Hodgkinson Province (Domain S), and two highs, each 50 by 70 km, occur to the southwest in domains N5 and P (Fig. 9). The anomalies show no sign of a negative to the south, so the causative bodies must taper from thick at the centre to thin at the edges. In the Melbourne area similar anomalies are inferred to be caused by mafic intrusion underlying some centres of the Central Victorian Cauldron Volcanic Province of Upper Devonian to Lower Carboniferous age. A high may also be due to a felsic intrusion of laccolithic- or disc-shape. In the Clarence-Moreton Basin similar anomalies are caused by troughs filled in part by magnetic volcanics (Wellman & others, in press). The magnetic high in domain N5 is centred on the outcropping Croydon Volcanic Group and related granitic complex. The magnetic high may be due to the granitic complex, or to an underlying mafic intrusion. All these dome-shaped highs in the north Queensland area are thought to be due to upper crustal intrusions of disc shape and uniform composition that do not necessarily crop out at the basement surface.

Ring dyke complexes of Carboniferous-Permian age outcrop in the Georgetown and Torres Strait areas. These complexes have a characteristic magnetic anomaly, enabling their extent to be determined from magnetic images. The magnetic anomaly is circular or oval, and either magnetic high or low, with a short axis of 10 to 35 km, fairly uniform intensities within the anomaly, and generally with concentric, narrow, positive arcs. Where the complexes crop out the positive arcs are found to correlate with ring dykes. In some areas the well defined oval anomaly is surrounded by an area of diffuse magnetic high that is interpreted to be due to volcanic material outside the complex proper. About 42 complexes have an overall negative magnetization, and about 16 have overall positive magnetization. Positively magnetized complexes occur only south of 17.5°S and at the northern end of the Coen Inlier, negatively magnetized complexes occur elsewhere, with very little overlap between the two types. The density of the rocks forming the complexes must be generally less than surrounding basement, because 27 form gravity lows as against 4 forming gravity anomaly highs. The majority of the complexes occur in the Torres Strait area (12 complexes) or in the Georgetown-Dargalong Inlier area (28 complexes). Seven occur midway between these two areas, and one occurs in domain P to the south. The apparent negative magnetization of the majority of the anomalies can not be due to the complex having near zero magnetization, because the anomalies associated with the complexes have a similar amplitude whether the surrounding basement was of high magnetization (domain H) or of low magnetization (domain N). The preferred model is for the complexes to have a reverse apparent magnetization, due to a reverse remanent magnetic component. Even thought the time range of the volcanism is quite long this is quite possible, as there was a long period of reversed polarity from 320 to 250 Ma ago (mid Carboniferous to latest Permian) (Fig. 6.10 of Harland & others, 1990).

Volcanic and shallow-intrusive rocks. Magnetic anomalies due to thin bodies are fairly widespead in north Queensland. Irregular areas of magnetic low in area N are likely to be Carboniferous to Permian volcanics or high-level intrusions. Normally-magnetized bodies due to volcanics or thin laminar intrusions are common in areas N7, R1 and H.

Dykes can be recognized in some areas of low magnetic relief with sediment cover less than about 0.3 km. Dykes form short-wavelength anomalies with the form of a magnetized, thin, planar sheet. They often occur in parallel swarms.

STRUCTURE

In most of north Queensland the trends are NNW to NNE (Fig. 5). In the western part of north Queensland the northerly trends are of Proterozoic age, and determined by north-trending crustal rifts of the Mount Isa Geophysical Domain (domain F) and the Keer-Weer Geophysical Domain (domain K). In the eastern part of north Queensland (domains R and S) these northerly trends are a consequence of the Early Palaeozoic formation of a north-trending edge to the Proterozoic crust, giving north trends to the reworked margin of the Proterozoic crust, and to adjacent Palaeozoic crust to the east. In the southern part of north Queensland, where Palaeozoic trends are in various directions, trend direction in any domain is determined by the trend of the common boundary with the adjacent older crust.

The main geological elements of north Queensland as interpreted from the geophysics are sumarized on Figure 5. Proterozoic rocks have been extensively modified, by Proterozoic crustal rifting in the west, and deformation and heating along their east and southern margins. Within the area of Palaeozoic crust (Tasman Orogenic Zone) the trend directions are such that cratonization of the crust proceeded to the east and northeast with time. This cratonized Palaeozoic crust may be Proterozoic crust that was thinned in place, or may be crust that was formed or emplaced in the Palaeozoic.

This paper discusses the long-wavelength gravity and magnetic anomalies, and provides for the outcrop geology a large-scale tectonic framework. It does not address the distribution of all granites, sediments, volcanics and metamorphics, but it does draw attention to long-wavelength gravity and magnetic anomalies which are probably not indicative of surface-rock type. The basement model presented in this paper is simple and relatively self consistent. However, it leaves unanswered the following questions:

- What is the history and age of the crustal rift in the west (domain K; Keer-Weer Geophysical Domain), and the relationship (if any) of this domain with the different, but almost co-linear, Mount Isa Geophyiscal Domain?
- What is the control on the volcanism in crustal rifts such as the Mount Isa Geophyiscal Domain and the Keer-Weer Geophysical Domain, such that the rift can be divided into strips each extending the 700 km length of the rift, and of different igneous history?
- In this paper all the large gravity and magnetic anomalies are attributed to bodies and/or processes that occur a long time after cratonization – that is to later crustal rifting, to reworking of a domain margin, or to post-cratonization intra-cratonic igneous activity. The gravity and magnetic anomalies within a domain that are attributable to bodies present immediately after cratonization are relatively subdued and give little or no

indication of the process of cratonization. What is the process of crustal formation and cratonization?

- What is the heat source and geographic control on the Permo-Carboniferous granitoids in the western part of domain H? These granitoids are far from the active margin of the continent, which is their most likely heat source, and they do not seem to follow any previous line of weakness in crossing domains R and N.
- Have domains P and Q always differed from the surrounding area in rock types and history, or were they originally similar, but they have changed in physical properties because of activation along their western margin?

CONCLUSIONS

- Most of the variation in magnetization can be attributed to cratonized crust with low magnetization, having its magnetization enhanced by later thermal and intrusive events associated with either rifting within the continent, or reworking of the margin of the continent at the time of adjacent cratonization.
- A major feature of north Queensland is the crustal rift along the eastern margin of the Gulf of Carpentaria of ?Proterozoic age. This is co-linear with the Mount Isa Geophysical Domain, and like it in that it can be subdivided into strips of different igneous character that extend the length of the domain. The rock bodies giving the most prominent anomalies are thick felsic granitoids, of fairly uniform magnetization, forming bands of related intrusions. It differs from the Mount Isa Geophysical Domain in the type of magnetic anomalies, and being a gravity low rather than a gravity high.
- A major feature of north Queensland is a band of high magnetization, high-grade metamorphic rocks, that extends along the line of the Proterozoic outcrops of the Georgetown, Dargalong, Yambo and Coen Inliers. This feature is attributed to thermal, intrusive and deformational events at various times along what was the margin of continuous Proterozoic crust.
- The Palaeozoic crust in the southern part of north Queensland can be subdivided into domains differing in the direction of the trend of the major structures. The major gravity and magnetic anomalies are associated with the changes in physical properties across the boundaries of these domains, and with igneous and metamorphic processes acting on a band on the older side of these boundaries.
- The Siluro-Devonian granitoids differ greatly from Permo-Carboniferous intrusions. The Siluro-Devonian granitioids are restricted to a 110 km wide band, they form a large proportion of the crust within the band, and in the north they are associated with regional metamorphism and are elongated parallel to the belt. In contrast the Permo-Carboniferous intrusions, although they are concentrated in belts, occur over a wide area, they are generally smaller, without a preferred orientation, and are associated with contact rather than regional metamorpism.

- There is a major fault separating the Coen and Yambo Inliers in the north from the Dargalong and Georgetown Inliers to the south. This fault is collinear with the northwest trending part of the Palmerville Fault Zone, and is coincident with the southeastern end of the Alice-Palmer Structural Zone of Jurassic to Cainozoic age. This fault separates metamorhic rocks older than 1570 Ma to the south from rocks which are probably younger to the north, and Siluro-Devonian granitoids of mainly I-type to the south from mainly S-type to the north.

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REFERENCES

Anfiloff, V., 1983 - Gravity survey across the Agate Creek Vocanics, north Queensland. Bulletin of the Australian Society of Exploration Geophysicists, 14, 43-48.

Anfiloff, V., 1988 - Townsville Region, total magnetic intensity, 1:1 000 000 scale, aeromagnetic anomaly pixel map series. Four maps. Bureau of Mineral Resources, Australia.

Anfiloff, V., 1989 - Cape York Region, total magnetic intensity, 1:1 000 000 scale, aeromagnetic anomaly pixel map series. Four maps. Bureau of Mineral Resources, Australia.

Arnold, G.O., & Fawckner, J.F., 1980 - The Broken River and Hodgkinson Provinces. In, R.A. Henderson and P.J. Stephenson (Eds) The geology and geophysics of northeastern Australia. Geological Society of Australia, Queensland Division, Brisbane, 175-189.

Australian Gulf Oil Company, 1969 - Swains Reef Aeromagnetic Survey, Townsville Queensland 1969. Petroleum Search Subsidy Act unpublished company report (BMR file number 69/3012)

Bain, J.H.C., Withnall, I.W., Oversby, B.S. & Mackenzie, D.E., 1990 - North Queensland Proterozoic inliers and Palaeozoic igneous provinces - regional geology and mineral deposits. In, F.E. Hughes (ed), Geology and mineral deposits of Australia and Papua New Guinea, The Australian Institute of Mining and Metallurgy, Melbourne, 963-978.

Bain, J.H.C., Black, L.P., Blewett, R., Bultitude, B., Knutson, J., Mackenzie, D., Pain, C., Wilford, J., Dohrenwend, J., Sun, S-S., Trail, D., von Gnielinski, F., and Wellman, P., 1992 - Cape York Peninsula Update, Bureau of Mineral Resources, Australia, Research Newsletter 16, 18-22.

Barlow, B.C., 1977 - Data limitations on model complexity; 2-D gravity modelling with desk-top calculators. Australian Society of Exploration Geophysicists Bulletin, 8, 139-143.

BHP Minerals, 1987 - Towards success and excellence. BHP Minerals Exploration, Camberwell, 10-11.

Burgess, I.R., 1984 - Carpentaria Basin: a regional analysis with reference to hydrocarbon potential. Australian Petroleum Exploration Association Journal 1984, 7-18.

Corbett Reef Ltd, 1968 - Corbett Reef Aeromagnetic Survey, Queensland 1968. Petroleum Search Subsidy Act, unpublished company report (BMR file number 68/3010).

Cull, J.P. & Conley, D., 1983 - Geothermal gradients and heat flow in Australian sedimentary basins. BMR Journal of Australian Geology and Geophysics, 8, 329-337.

Day, R.W., Whitaker, W.G, Murray, C.G, Wilson, I.H. & Grimes, K.G., 1983 - Queensland geology, a companion volume to the 1:2 500 000 geological map (1975). Geological Survey of Queensland, Brisbane, Publication 383.

Dooley, J.C., 1965 - Gravity surveys on the Great Barrier Reef and adjacent coast, north Queensland. 1954-1960. Bureau of Mineral Resources, Australia, Report 73.

Dooley, J.C., 1980 - A review of the crustal structure of northeastern Australia. In, R.A. Henderson & P.J. Stephenson (eds), The geology and geophyiscs of northeastern Australia. Geological Society of Australia, Queensland Division, Brisbane, 27-45.

Geoimage, 1989 - North-east Queensland, computer produced images of total magnetic intensity, 1:1 000 000 scale. Four maps. Geoimage Pty Ltd, Queensland.

Geoimage, 1990a - Cape York, computer produced images of total magnetic intensity, 1:1000 000 scale. Three maps. Geoimage Pty Ltd, Queensland.

Geoimage, 1990b - North-west Queensland, computer produced images of total magnetic intensity, 1:1 000 000 scale. Two maps. Geoimage Pty Ltd, Queensland.

Geoimage, 1990c - Queensland, computer produced image of total magnetic intensity, 1:2 500 000 scale. Geoimage Pty Ltd, Queensland.

Geological Survey of Queensland, 1975 - Queensland Geology, Scale 1:2 500 000. Department of Mines, Brisbane.Gibb, R.A. 1967 - Western Queensland reconnaissance gravity survey, 1957-1961. Bureau of Mineral Resources, Australia, Report 129.

Gibb, R.A., 1968 - North Eromanga and Drummond Basin gravity surveys, Queensland 1959-1963. Bureau of Mineral Resources, Australia, Report 131.

Gibb, R.A., & Thomas, M.D., 1976 - Gravity signature of fossil plate boundaries in the Canadian Shield. Nature, 262, 199-200.

Goodspeed, M.J. & Williams, L.W., 1959 - Preliminary report on underwater gravity survey, Great Barrier Reef area, Thursday Island to Rockhampton. Bureau of Mineral Resources, Australia, Record 1959/70.

Grimes, K.G., 1979 - Mornington/Cape Diemen, Qld - 1:250 000 Geological Series. Bureau of Mineral Resources, Australia, Explanatory Notes SE/54-1&2.

Gulf Interstate Overseas Ltd, 1962 - Cape York Peninsula Aeromangetic Survey, Queensland 1962. Petroleum Search Subsidy Act, unpublished company report (BMR file number 62/1725).

Hanson, P., & Stainforth, J.G., 1982 - Hydrocarbon prospects of the Carpentaria Basin Shell permits Q17P and Q18P (Offshore Queensland). Petroleum Submerged Lands Act Report 80/18.

Harland, W.B., Armstrong, R.L., Cox, A.V., Craig, L.E., Smith, A.G. & Smith, D.G., 1990 - A geologic time scale. Cambridge University Press, Cambridge.

Hartman, R.R., 1962 - Completion report, Gulf of Carpentaria aeromagnetic survey, by Aeroservice Ltd for Delhi Australia Petroleum Ltd. Australian Petroleum Search Subsidy Acts Report 62/1719.

Henderson, R.A., 1986 - Geology of the Mt Windsor Subprovince - a Lower Palaeozoic volcano-sedimentary terrane in the northern Tasman Orogenic Zone. Australian Journal of Earth Sciences, 33, 343-364.

Henderson, R.A. & Stephenson, P.J., 1980 - The geology and geophysics of northeastern Australia. Geological Society of Australia, Queensland Division, Brisbane.

Hsu, H.D., 1974 - Aeromagnetic interpretation of northern Eromanga and Galilee Basins, Queensland. Bureau of Mineral Resources, Australia, Record, 1974/42.

Hutton, L.J., Rienks, I.P. & Wyborne, D., 1990 - A reinterpretation of the Ravenswood batholith, North Queensland. Pacific Rim Congress 90, Proceedings, 3, 179-183.

Klasner, J.S. & King, E.R., 1986 - Precambrian basement geology of North and South Dakota. Canadian Journal of Earth Sciences, 23, 1083-1102.

Marathon Petroleum (Aust) Ltd, 1965 - Northeast Carpentaria aeromagnetic survey, 1964-65. Bureau of Mineral Resources, Australia, Petroleum Search Subsidy Acts Report 64/4607 (unpublished).

Murrray, C.G., Scheibner, E. & Walker, R.N., 1989 - Regional geological interpretation of a digital coloured residual Bouguer gravity image of eastern Australia with a wavelength cut-off of 250 km. Australian Journal of Earth Sciences, 36, 423-449.

Muttter, J.C., 1974 - Marine geophysical survey of the Bismark Sea and Gulf of Papua, 1970. A structural analysis of the Gulf of Papua and northwest Coral Sea region. Bureau of Mineral Resources, Australia, Report 179.

Mutter, J.C. & Karner, G.D., 1980 - The continental margin off northeast Australia. In, R.A. Henderson & P.J. Stephenson (eds), The geology and geophysics of northeastern Australia. Geological Society of Australia, Queensland Division, Brisbane, 47-69.

Pinchin, J., 1973 - A geophysical review of the Carpentaria, Laura and Olive River Basins. Bureau of Mineral Resources, Australia, Record 1973/132.

Richards, D.N.D., 1980 - Palaeozoic granitoids of northeastern Australia. In, R.A. Henderson & P.J. Stephenson (eds), The geology and geophysics of northeastern Australia. Geological Society of Australia, Queensland Division, Brisbane, 229-246.

Shaw, R.D., Fawckner, J.F., & Bultitude, R.J., 1987 - The Palmerville Fault system: a major imbricate thrust system in the northern Tasmanides, North Queensland. Australian Journal of Earth Sciences, 34, 69-93.

Shelley, E.P., Downie, D.N. & Rees, J.E., 1971 - Southern Cape York Peninsula airborne magnetic and radiometric survey, Queensland 1969. Bureau of Mineral Resources, Australia, Record 1971/124.

Shirley, J.E. & Zadoroznyj, I., 1974 - Reconnaissance helicopter gravity survey, northern Queensland, 1966. Bureau of Mineral Resources, Australia, Record 1974/140.

Slade, J.C., 1986 - Final operations and interpretation report for the Weipa aeromagnetic survey, Carpentaria Basin, northern Queensland, carried out by Comalco Aluminium Limited, Exploration Department. Open file report on ATP 344P. Report number CR15017(A).

Smart, J., Grimes, K.G., Doutch, H.F., & Pinchin, J., 1980 - The Carpentaria and Karumba Basins, north Queensland. Bureau of Mineral Resources, Australia, Bulletin 202.

Stockill, B.D., 1987 - Magnetic susceptibility measurements from the Clarke River 1:250 000 sheet areas. Geological Survey of Queensland, Record, 1987/62.

Thomas, B.M., Hanson, P., Stainforth, J.G., Stamford, P. & Taylor, L., 1991 - Petroleum geology and exploration history of the Carpentaria Basin, Australia, and associated infrabasins. American Assoication of Petroleum Geology Memoir 51, 709-724.

USNOO, 1967 - USNS Shoup, US Naval Oceangraphic Office geomagnetic surveys informal report 68/3008.

Wellman, P., 1988 - Development of the Australian Proterozoic crust as inferred from gravity and magnetic anomalies. Precambrian Research, 40/41, 89-100.

Wellman, P., 1990 - A tectonic interpretation of the gravity and magnetic anomalies in southern Queensland. In, D.M. Finlayson (Ed), The Eromanga-Brisbane geoscience transect: a guide to basin development across Phanerozoic Australia in southern Queenland. Bureau of Mineral Resources, Australia, Bulletin 232, 21-34.

Wellman, P., 1992a - Structure of the Mount Isa region inferred from gravity and magnetic anomalies. In, Stewart, A.J. and Blake, D.H. (eds), Detailed studies of the Mount Isa Inlier. Bureau of Mineral Resources, Australia, Bulletin 243, 15-27.

Wellman, P., 1992b - A geological interpretation of the regional gravity and magnetic features of north Queensland. Exploration Geophysics, 23, 423-428.

Wellman, P., in press - Division of the Tasman Orogenic System into geophysical domains using the pattern of gravity and magnetic anomaly trends. Economic Geology.

Wellman, P., Williams, J.W. & Maher, A.R., in press - Interpretation of the gravity and magnetic anomalies in the Clarence-Moreton basin region. In, A.T. Wells & P.E. O'Brien (eds), The geology and petroleum potential of the Clarence-Moreton Basin, New South Wales and Queensland. Australian Geological Survey Organization, Bulletin, 241.

Whitaker, A.J., in press - The Precambrian of the Albany 1:1M sheet, Western Australia, as determined by magnetics, gravity and geology. Australian Journal of Earth Sciences. Withnall, I.W., Bain, J.H.C., & Rubenach, M.J., 1980 - The Precambrian geology of northeastern Queensland. In, R.A. Henderson & P.J. Stephenson (Eds), The geology and geophysics of northeastern Australia. Geological Society of Australia, Queensland Division, Brisbane, 109-127.

Withnall, I.W., Draper, J.J., Bain, J.H.C., Mackenzie, D.E. & Oversby, B.S., 1988 - Georgetown Inlier. In, L.A.I. Wyborne & M.A. Etheridge (eds) The early to middle Proterozoic in Australia. Tectonophysics, 40/41, 429-446.

Withnall, I.W., Black, L.P., & Harvey, K.J., 1991 - Geology and geochronology of the Balcooma area: part of an Early Palaeozoic magmatic belt in North Queensland. Australian Journal of Earth Sciences, 38, 15-29.

Zuber, M.T., Bechtel, T.D. & Forsyth, D.W., 1989 - Effective elastic thickness of the lithophere and mechanisms of isostatic compensation in Australia. Journal of Geophysical Research, 94, 9353-9367.