The University of Adelaide
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# A REGIONAL GEOPHYSICAL STUDY OF THE BROKEN HILL BLOCK, N.S.W., AUSTRALIA

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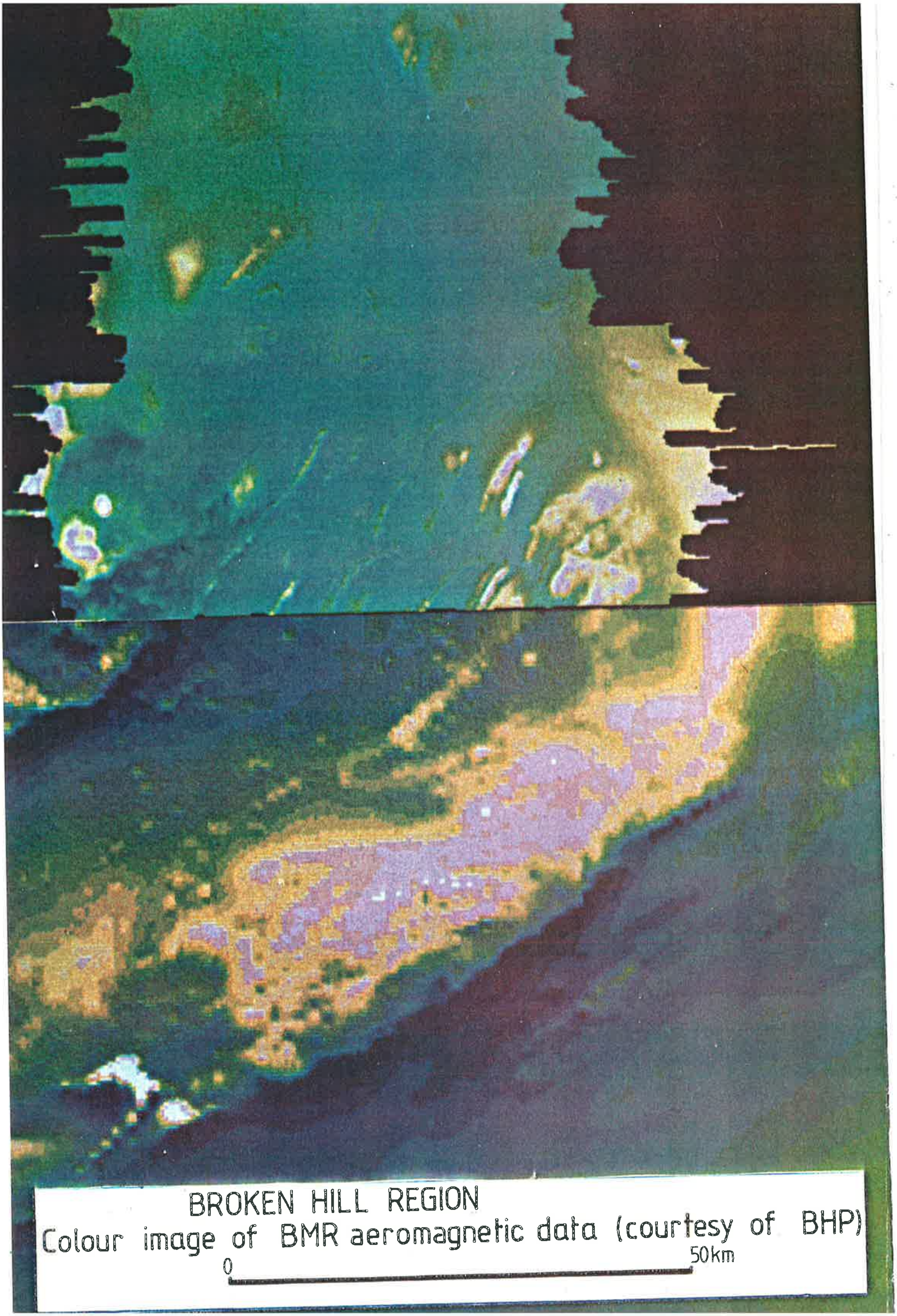


BROKEN HILL REGION
Colour image of BMR aeromagnetic data (courtesy of BHP)

## STATEMENT

To the best of the writer's knowledge and belief, and except where reference is made herein, this thesis contains no copy or paraphrase of previously published material nor any material that has been accepted for the award of any other degree or diploma in any University.

DAVID ISLES
July 1983

## Acknowledgements

This project was carried out by the author under the supervision of Professor D.M. Boyd. Professor Boyd's enthusiasm for the project and his astute guidance are gratefully acknowledged. Mr. J.I. McIntyre and Dr. D. Atchuta Rao contributed greatly to this work with fruitful discussions, suggestions and encouragement.

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I wish to thank Dr. P.I. Brooker, Mr. R.J. Smith and Mr. P.G. Harman for support and encouragement during critical stages of the project; Ms. Sharon Proferes and Mr. Evert Bleys for drafting and photographic work respectively; Mr. Koya Suto and many other colleagues for assistance in the field and Miss Lyn Wagner and Miss Lee-Anne Bartley for typing the text.

I wish to especially acknowledge the patience and support of my wife, Sue, and my family.

## ABSTRACT

The Broken Hill Block is a complex and abundantly mineralized Proterozoic metamorphic province, which includes the world class Broken Hill silver-lead-zinc mine. As part of a cooperative geological mapping and interpretation effort, the Regional Geophysical Study, presented herein, was carried out based largely on BMR airborne magnetic surveys and supported with broadly spaced gravity data.

The aeromagnetic data defines quite clear cut boundaries of the Broken Hill Block which were previously poorly mapped and poorly understood. An extensive magnetic complex, apparent at the margins of the Block, is interpreted to be basal to the main Broken Hill sequence and distinct from it.

This basal complex can be traced from the aeromagnetic data over much of the unexposed areas southeast and west of Broken Hill, downgrading these areas as possible hosts to Broken Hill type mineralization.

Within the main BH sequence, discrete, linear magnetic anomalies predominate and these have been grouped into four separate geographic domains, based on anomaly amplitude and, to a lesser degree, strike trends. Using these subdivisions, and the work of the NSW geological survey, which provided a comprehensive geological interpretation and which demonstrated that the main linear magnetic horizons were due to stratigraphically bound magnetite bearing horizons, a generalized stratigraphic interpretation of the magnetic data was effected. Magnetic horizons were found to be concentrated within the same stratigraphic interval in all domains but the abundance of magnetite within this stratigraphic interval was found to vary considerably between the domains. Since the magnetite is, in almost all cases, related to chemically precipitated sediments, the variation in magnetite abundance can be interpreted as reflecting original sedimentary environment differences between the domains.

While no geological subdivisions correlating with the domains have been recognised to date, it is notable that the Broken Hill lode horizon, a chemical sediment genetically related to the magnetite rich horizons, follows a similar pattern of distribution and abundance to that of the magnetic horizons. On this basis the "Central Domain", which is clearly the zone where magnetite is most abundant in the Broken Hill sequence, is interpreted as representing the depositional environment where Broken Hill type mineralization is most likely to occur.

Implementation of "traditions" interpretation techniques, such as anomaly source mapping and modelling, in selected areas demonstrated that reliable information on structural continuity and gross dip could be readily extracted from the airborne magnetic data.

Although the available gravity data contributes little to the detailed interpretation, it reinforces the broad magnetic subdivisions.

In particular, the correlation of extensive gravity lows with the "Basal Magnetic Complex" supports the interpretation of the latter as a distinct entity, separate from the main Broken Hill sequence. Regional gravity highs in the southern parts of the study area and around Broken Hill itself cannot be readily explained in terms of observed geology. It is suggested that their sources are deep seated (although their depths are poorly resolved in the existing data) and that an understanding of their nature may contribute greatly to the understanding of the tectonic framework of western NSW.

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# 1 INTRODUCTION

## 1.1 Broken Hill

Broken Hill is unique. In the 100 years since the Broken Hill mineralization was discovered, it has been the heart of Australia's mining industry.

The mine financed the BHP's successful establishment of steelmaking in Australia which expanded to ship building, coal mining and eventually the discovery of oil and gas in Bass Strait. It continues to fund the exploration efforts of CRA which have yielded such mines as Weipa (Bauxite), Hammersley (iron), Bougainville (Copper) and Argyle (diamonds).

Broken Hill's contribution to mining extends beyond Australia. Over a period of several years, the flotation process of mineral separation was invented and developed by the Broken Hill companies. The process is still widely applied and without it, many of todays great sulphide mines may not have been developed.

Above all, Broken Hill is famous (or infamous) as a union town; a centre where determination and resolve forged a pattern which has had far reaching ramifications in Australian industrial history.

While Australia owes much to Broken Hill, the future of the city is in some doubt, with only twenty years of mining remaining in the ore deposit. This thesis forms a small part of a renewed, cooperative exploration effort which reflects the urgency for the discovery of new mineable deposits in the Broken Hill region.

## 1.2 The MMA Project

Unlike most mineralized provinces, the Broken Hill Block is dominated by one huge deposit. The Broken Hill orebody originally contained in excess of 200 million tonnes of high grade lead, zinc and silver mineralization, three orders of magnitude greater than its nearest rival in the region. This glaring imbalance in the distribution of known 'Broken Hill' type mineralization has persisted over the century of mining at Broken Hill despite sustained exploration efforts involving a wide spectrum of personnel and a great deal of expenditure.

Following the important contributions toward the understanding of the geology of the Broken Hill mines due largely to company geologists (Radmanovich, 1968) the Broken Hill Mine Manager's Association (MMA), in 1971, initiated a major research project aimed at elucidating some of the fundamental geological aspects of the area which were either poorly documented or subject to spirited controversy. The main studies were on the genesis of the orebody, the regional structure, the stratigraphy and the metamorphism of the area. The project involved academic institutions (mainly Adelaide University, Monash University and the University of N.S.W.) and has been complimented by an intense lithogical mapping program carried out by the Geological Survey of N.S.W. The work presented here began in 1975, in the latter stages of the MMA project and so in many ways, reaped the benefits of the results of the various participants.

## 1.3 The Geological Problem

Although the Broken Hill region, and particularly the orebody itself, has attracted a great deal of attention in the geological literature, until recently, the regional geology was poorly understood. While this has undoubtedly been due to the combination of complex folding, high grade metamorphism and poor continuity of outcrop, it would appear that a disproportionate amount of time and effort had been expended in detailed studies of the orebody itself. King (1968) used the analogy of the six blind men and the elephant (Fable 1) to describe the various conclusions, from different lines of evidence, of the different workers who have studied the orebody.

# Fable (from King, 1968)

## THE BLIND MEN AND THE ELEPHANT[1]

It was six men of Indostan
To learning much inclined,
Who went to see the elephant
(Though all of them were blind),
That each by observation
Might satisfy his mind.

The first approached the elephant,
And happening to fall
Against his broad and sturdy side,
At once began to bawl:
"God bless me!—but the elephant
Is very like a wall!"

The second feeling of the tusk,
Cried: "Ho! what have we here
So very round and smooth and sharp!
To me 'tis mighty clear
This wonder of an elephant
Is very like a spear!"

The third approached the animal,
And happening to take
The squirming trunk within his hands,
Thus boldly up and spake:
"I see", quoth he, "the elephant
Is very like a snake!"

The fourth reached out his eager hand,
And felt about the knee,
"What most this wondrous beast is like
Is mighty plain", quoth he;
" 'Tis clear enough the elephant
Is very like a tree!"

The fifth, who chanced to touch the ear,
Said: "E'en the blinded man
Can tell what this resembles most;
Deny the fact who can,
This marvel of an elephant
Is very like a fan."

The sixth no sooner had begun
About the beast to grope,
Than seizing on the swinging tail
That fell within his scope,
"I see", quoth he, "the elephant
Is very like a rope!"

And so these men of Indostan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong,
Though each was partly in the right,
And all were in the wrong.

MORAL:

So, oft in theologic wars
The disputants, I ween,
Rail on in utter ignorance
Of what each other mean
And prate about an elephant
Not one of them has seen.

[1] A famous Hindu fable by J. G. Saxe.

The analogy of the elephant to Broken Hill research in general is probably no longer appropriate because the recent studies have consolidated and reinterpreted earlier work and have based their conclusions on data covering most of the Broken Hill Block. The fact that the different studies were carried out simultaneously has led to interaction between workers and consequently the recent generalized geological interpretations (e.g. Stevens et al, 1979 and Glen et al, 1977) are quite comprehensive. The controversy over the origin of the orebody has abated with the majority of workers (e.g. Stanton, 1976, Both and Rutland, 1976) regarding the orebody as stratiform, being produced by exhalative sedimentary processes.

With comprehensive interpretations of the stratigraphy, structure and metamorphism of the Block available and general agreement on the volcano-sedimentary nature of the Broken Hill sequence, the value of a regional geophysical study might be regarded as questionable. Regional geophysical surveys are most commonly thought of as pre-cursors to geological exploration in large and relatively unexplored areas, and in this capacity, (e.g. Emerson, 1973, (Western Australia) and Hunting Surveys Ltd., 1962, (Uganda)), they provide a broad framework on which ground geological investigations can be based.

In areas such as Broken Hill, where geological mapping is at an advanced stage, the contribution of geophysical surveys is less predictable, but commonly the value of geophysical data, as measured by its ability to extend geological understanding, increases as more geological knowledge is obtained.

Boyd (1967) cites examples from Europe where airborne magnetic surveys reveal major basement fractures not apparent from extremely detailed geological mapping. Clearly, aeromagnetic surveys may also be useful in tracing magnetic horizons or boundaries across poorly exposed areas, thereby providing structural information. While the extra information provided by aeromagnetics in particular, in exposed areas cannot normally be anticipated, the fact that a uniform coverage of an area in one characteristic of the rocks (their magnetite content) is achieved, often provides a useful basis for correlating widely separated areas.

At Broken Hill, several magnetite bearing rock types (banded iron formation, quartz-magnetite, amphibolite and several varieties of gneiss) had been documented prior to the earliest aeromagnetic surveys and since some of these rocks were known to have close affiliations with the Broken Hill orebody, the applicability of aeromagnetic surveys to exploration in the area, in retrospect, seems obvious. However, depsite the availability of good quality aeromagnetic data over most of the Broken Hill Block since the 1959 B.M.R. survey, no interpretive account of this data prior to the MMA project is known to exist. This is probably due in part to the dearth of geophysicists in the Australian mining industry during that period, but also probably reflects a lack of understanding, on the part of explorationists, of the range of geological information contained in aeromagnetic maps. Forwood (1968) in reference to the aeromagnetic data states "This information so far uninterpreted, is an important addition to the geological knowledge of the area".

## 1.4 Aims

The main aim of this thesis was to make a useful contribution to the future exploration at Broken Hill.

Specifically, the purpose of this work was to provide an interpretation of the largely pre-existing geophysical data. The primary task was to relate the observed aeromagnetic and gravity variations to the mapped and interpreted geology on a broad scale, encompassing the whole Broken Hill Block. Apart from this regional scale correlation, the possibility of extracting structural information from the prominent linear magnetic anomalies apparent in the area was also to be investigated.

Surprisingly few such interpretations are contained in the geophysical literature, particularly in Proterozoic provinces which are not only widespread but also usually contain an abundance of magnetic rock units. In Australia, Proterozoic provinces such as the Mount Isa Block (QLD), The Eyre Peninsula (S.A.) and Tennant Creek (N.T.) are examples of mineralized areas which, like Broken Hill have had aeromagnetic data available during periods of intense geological study. Despite limited outcrop in all of these provinces none of them has an available interpretive amount of the aeromagnetic data.

A secondary aim of this thesis was, therefore, to provide a model on which magnetic data in geological provinces similar to Broken Hill could be interpreted.

## 1.5 Scale and Philosophy of Study

Owing to the size of the study area (over 10,000 km, see fig 1.1) the interpretation presented here is, necessarily, generalized and recourse to detailed geological and geophysical maps has rarely been attempted. In most cases the maps used for this work ranged in scale from 1:250,0000 to 1:25,000 with the greater part of the analysis being carried out with 1:100,000 scale maps.

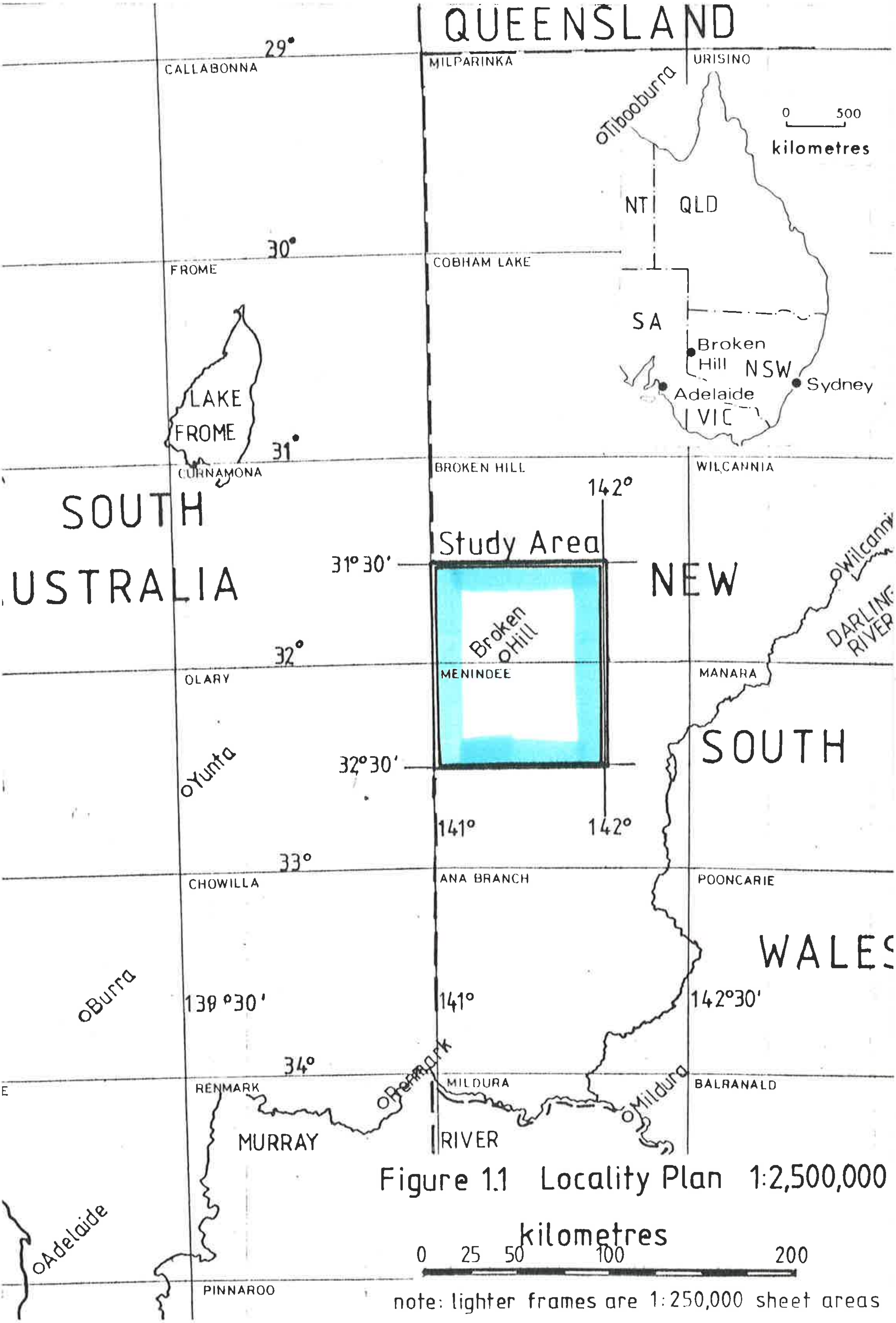



Figure 1.1 Locality Plan 1:2,500,000

Since a large part of the data set presented here existed prior to the inception of this project, only a small proportion of field data was collected by the writer. From the outset, the gravity data in the region was regarded as having secondary importance to the aeromagnetic data because of the coarse sampling and the corresponding generalized nature of the measured field. The gravity surveys carried out by the writer were planned to provide extra information in areas of very poor outcrop, that is, to provide additional geophysical control where geological control was lacking.

It is perhaps worth restating that this work has benefited greatly from the results of both geological and geophysical workers involved in the MMA project. In particular, the work of the N.S.W. Geological survey (Stevens et al, 1979 and McIntyre, 1979) has allowed geological significance to be attributed to what would otherwise have been predominantly geophysical observations. While the significance is, in part, conjectural, the approach adopted in this thesis has been to speculate, in an objective way, rather than to simply present observations. That is, the primary objective of this work has been to provide an interpretation of observations which can be tested by more detailed investigation.

## 1.6 Author's Note

A quick reference system for localities has been incorporated in the main geological map (Map 2). In most instances, localities referenced in the text are labelled on Map 2 but where absent the alphanumeric system gives the general position.

# 2 THE GEOLOGY OF THE BROKEN HILL BLOCK

In order to place the study area into geological perspective, the recent works of Stevens et al (1979), Glen et al (1977) and Thomson (1976) have been summarized. While these works are, themselves, interpretive, they are based on comprehensive field studies and take account of the large volume of geological data that has accumulated in the 90 years since the discovery of the Broken Hill mine.

## 2.1 Regional Setting of the Willyama Complex

The Broken Hill Block is one of three subdivisions of the Willyama Complex which is a highly deformed and metamorphosed Lower Proterozoic inlier situated in western N.S.W. (Fig. 2.1).

The other components of the Willyama Complex are the Olary Block to the west and the Euriowie Block to the east. The younger sedimentary domains surrounding the Willyama Complex range in age from Upper Proetozoic to Recent.

### 2.1.1 Adelaidean

Southwest of the Willyama Complex lies the extensive area of the Adelaide Geosyncline which contains over 5 km of sediments deposited during a large time interval inferred by Thomson (1970) to be 1400-600 Ma. This time interval covers the Upper Proterozoic era and is locally known as the Adelaidean.

Adelaidean sediments unconformably overlie the Willyama southwest of Broken Hill while further to the west in the Olary region, steep Palaeozoic reverse thrusts and shears separate the Willyama from the Adelaidean. Sediments of Adelaidean age also unconformably overlie the Willyama north and northeast of Broken Hill. The Adelaidean rocks are mainly continental and shallow marine sediments which are relatively unmetamorphosed and normally only gently folded.

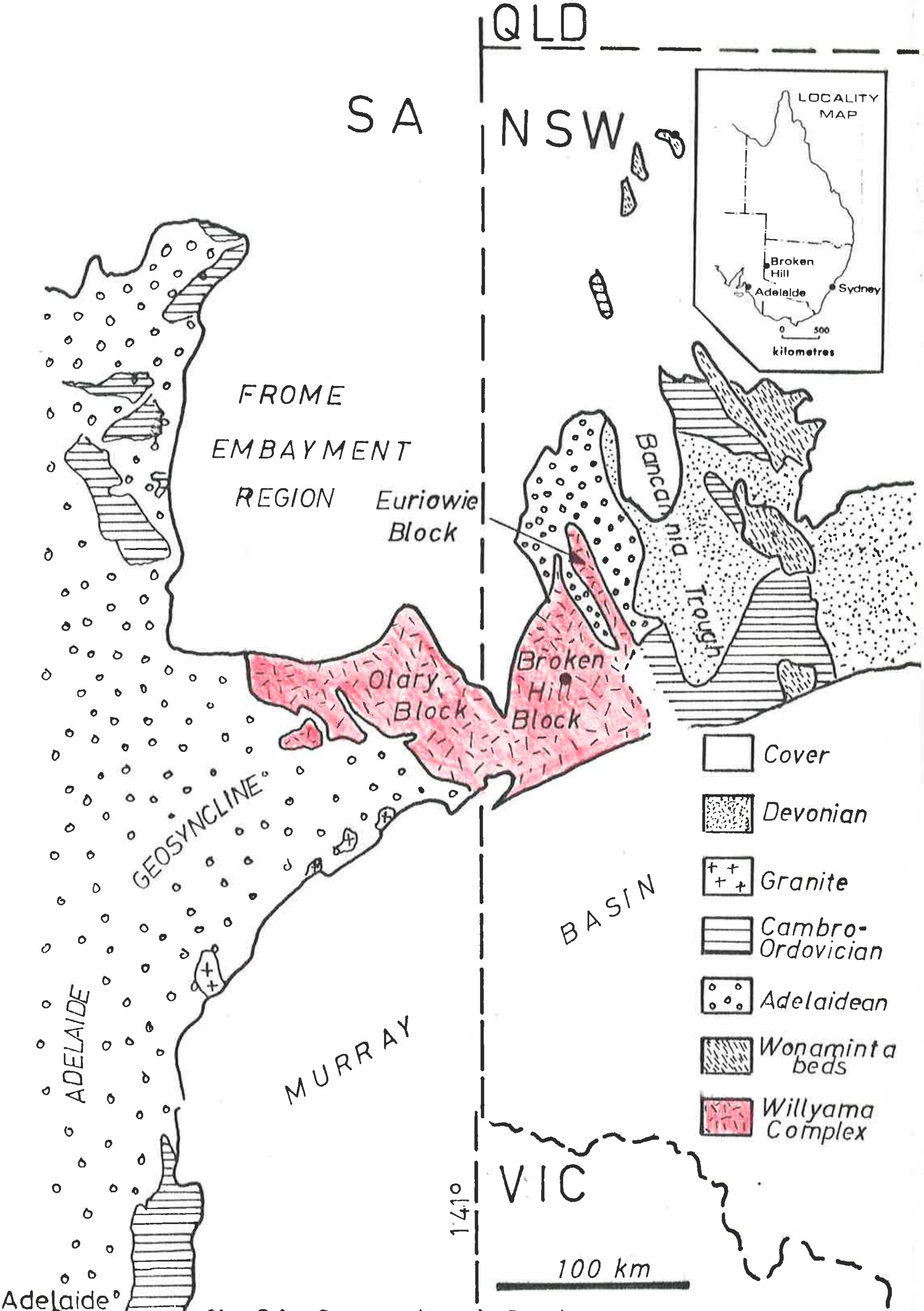



fig 2.1 Generalized Geology

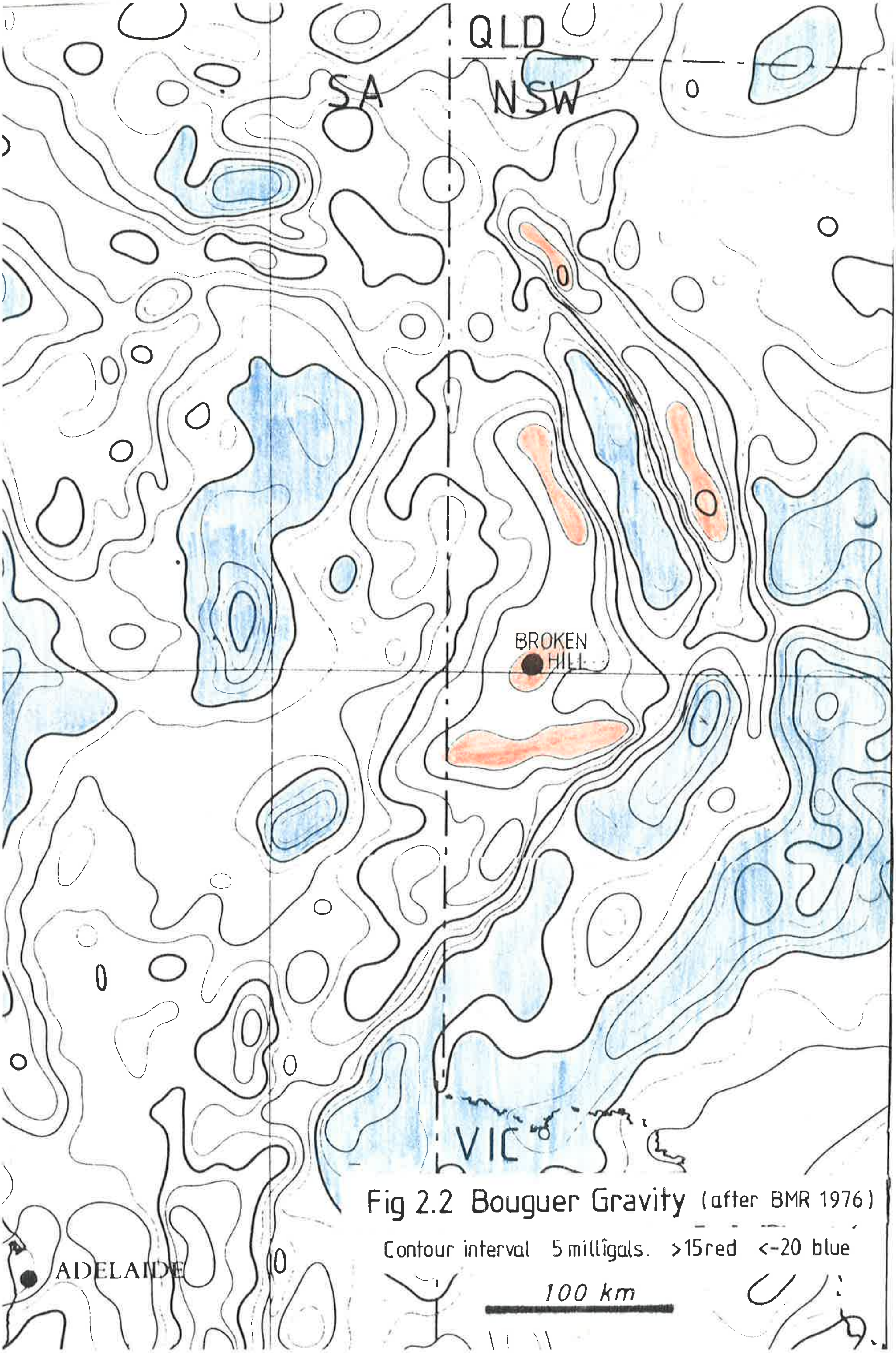



Fig 2.2 Bouguer Gravity (after BMR 1976)

Contour interval 5 milligals. >15 red <-20 blue

The western boundary of the Broken Hill Block is the prominent Mundi Mundi scarp which separates the Willyama from the Cainozoic and older cover of the "Frome Embayment Region" (Thomson, 1976). While Pre-Cambrian outcrops are absent in this region gravity and magnetic data (see Chapter 4) indicate that Adelaidean rocks are probably present at relatively shallow depths beneath the unconsolidated cover of Tertiary rocks.

### 2.1.2 Palaeozoic/Mesozoic

East and southeast of the Willyama outcrop area superficial cover obscures most of the pre Tertiary rocks but the presence of sedimentary basins, partly evident from outcrop is firmly established from oil exploration drilling and from gravity data.

East of Broken Hill, the Bancannia Trough is associated with a NNW trending gravity depression of some 35 milligals. The trough contains largely Devonian sediments to a depth, inferred by McIntyre and Wyatt (1978) from aeromagnetic data, of more than 7000 metres. The drill hole Bancannia South No. 1 intersected a thickness of over 3000 metres of Palaeozoic sediments.

The Menindee Trough lies south east of the Willyama Complex and is defined by a NE trending gravity depression of more than 40 milligals. While the area of low gravity values is covered by Tertiary and Quaternary sediments of the Murray Basin, drill holes in the northeast (Blantyre No. 1, Stackler and Brunt, 1967) of the trough indicate more than a thousand metres of Devonian sediments overlain by relatively thin sequences of Carboniferous, Permian and Tertiary sediments. The depth to Pre Devonian rocks has not been established in either hole but is known in both cases to exceed 2000 metres. McIntyre and Wyatt estimate the depth to magnetic basement within the Menindee Trough to be around 7000 metres.

### 2.1.3 Regional Gravity Data

Owing to the extensive areas of Cainozoic cover it is necessary to consider the regional gravity data in order to appreciate the gross geological structure of Willyama Complex and its environs.

As mentioned, the Palaeozoic sedimentary basins east and SE of the Willyama Complex are clearly defined in the region gravity map (Fig. 2.2). The Willyama Complex itself is generally associated with higher gravity values than adjacent areas particularly in N.S.W. The Adelaidean usually shows a small but discernable decrease in gravity compared to neighbouring Willyama rocks. The Olary Block gives rise to considerably lower gravity values than those observed on the Broken Hill and Euriowie Blocks. The cause of this has not been studied but it is possibly due to the greater proportion of quartz and feldspar rich gneisses and migmatites in the Olary province (Glen et al, 1977).

The gradual decrease in gravity westward from the Broken Hill Block is in marked contrast to rapid decrease in gravity associated with the Palaeozoic basins to the east and south. Although quite pronounced negative anomalies are observed they are broad features and coincide in part with Willyama Complex outcrop. They therefore appear to be related more to density changes in the Willyama rocks than to thickness of younger cover, although the latter probably contributes to some degree.

The high gravity region associated with the Willyama Complex is part of an arcuate belt which extends for hundreds of kilometres both to the north and southwest of Broken Hill. The Willyama Complex is one of the few areas along this belt where Pre-Cambrian rocks outcrop; the bulk of the features coincide with the areas of Tertiary and Quaternary cover. Several authors have suggested that Willyama Complex or equivalents may be the prime cause of this gravity feature (e.g. Tucker and Brown, 1973; Thomson, 1976). The gravity data is discussed in more detail in Chapter 7.

### 2.1.4 The Subdivisions of the Willyama Complex

The Willyama Complex comprises three "Blocks" of Early to Middle Proterozoic metasediments and metavolcanics. The Olary Block, lying almost entirely in South Australia is distinguished from the Broken Hill Block by its greater abundance of 'basal gneisses' and by minor differences in the stratigraphic sequences. Glen et al (1977) deduced that although the sequences in the two Blocks are comparable and suggestive of fairly shallow water deposition, the Broken Hill sequence represents a more distal environment than the Olary sequence.

Since the two Blocks are effectively separated by a zone where outcrop is either sparse or absent the boundary between them has never been formally defined and usually is taken arbitrarily to be the SA/NSW State border. There is, however a prominent geophysical boundary separating the two Blocks (see Chapter 4).

The Euriowie Block lies to the east of the Broken Hill Block and is separated from it by a linear NNW trending belt of Adelaidean (Torrowangee series) sediments. The rocks of the Euriowie Block are of lower metamorphic grade and structurally less complex than those of the Broken Hill and Olary Blocks, and Tuckwell (1978) has inferred that the greater part of the Euriowie Block lies at a higher stratigraphic level than the Broken Hill Block.

Because of these differences between the Broken Hill and Euriowie Blocks the latter has received much less attention in academic and exploration studies. Newmont Pty. Ltd., (Clarke, 1977) have however identified Broken Hill type lode horizon in the Euriowie Block but failed to locate significant mineralization.

The Broken Hill Block contains all but the highest parts of the Willyama stratigraphy and contains the greatest proportion of pelitic metasediments and "Mine Sequence" which lie in the middle part of stratigraphic succession.

## 2.2 The Broken Hill Block

The Broken Hill Block is best exposed in the Barrier Range, a prominent topographic feature which extends from the Thackaringa area northward for a distance of over 60 km (Map 1). The western margin of the Barrier Range is the Mundi Mundi fault scarp which elevates both Willyama and Adelaidean rocks 200 to 300 metres above the level of the Mundi Mundi Plain. Topographic trends in the Range are predominantly NNE, paralleling the Proterozoic structural trends and the greatest relief NW of Broken Hill in the Mt. Robe area where peaks rise more than 300 metres above the plain level.

To the south and southeast of Broken Hill, relief becomes progressively more subdued and consequently outcrop areas become more sparse. The area is deeply weathered and because of the low rainfall (around 250 mm per annum) weathering products are relatively immobile so that good exposures are largely confined to the higher topographic areas. Quaternary sand cover is present in the plain areas south of Broken Hill and drill holes in these areas show that the depth to relatively fresh rock may be over 100 metres.

### 2.2.1 Rock Units and Rock Types

The Broken Hill Block is largely composed of recognizable metasediments with lesser but substantial amounts of quartzo-feldspathic and basic rocks of probable volcanic origin. Minor rock types such as the zinc, iron and manganese rich "lode" rocks are distributed sporadically throughout much of the Block. Younger intrusive rocks include granites which occur largely in the north, pyroxenite plugs and dolerite dykes; the basic rocks being confined to the southern half of the Block. A brief description of the major rock types is given here following the scheme of Stevens and Willis (in prep) which has been designed to represent the rock units encountered in the course of the N.S.W. Geological Survey's 1:12,000 scale lithological mapping project.

Metasediments

The metasediments consist of a variety of pelitic, psammopelitic and psammitic rocks which are commonly interbedded. The original sediments corresponding to the pelites were mudstones and shales while the psammopelites were derived from clayey sandstones, siltstones and from lithic sandstones. The psammites lack clay minerals and are assumed to be derived from sandstones and siltstones. The more pelitic and psammopelitic rocks units are far more abundant than the psammites.

Composite Gneisses and Migmatites

The classification of these rocks is based on the relative porportions of mobile material (showing features attributable to melting or solution) and immobile material, and the nature of the immobile material.

Composite gneisses are defined as those rocks containing between 10 and 50% of pegmatitic or granitic material alternating in lithological layers with metasedimentary and/or metamorphic textured quartzo feldspathic material.

In the Migmatite units, mobile, medium to very coarse grained quartz feldspar material comprises more than half of the volume of the rock and the layering within the immobile component is more extensively disrupted.

The composite gneisses and migmatites are divided into metasedimentary and quartzofeldspathic types depending on the nature of the immobile component. The quartzofeldspathic types contain a substantial proportion of leucocratic and/or biotite rich quartzo feldspathic material which Stevens et al (1979) regard as possibly being of volcanic origin.

## Quartzofeldspathic Gneisses

There are two main varieties of quartzo-feldspathic gneisses. Common to both are a well developed gneissosity and a content of mafic minerals greater than 5% and usually exceeding 10%.

The more common variety is essentially quartz-feldspar-biotite gneiss displaying a wide range of grain sizes. The very coarse types often include well developed augen of feldspar. These have previously been called "granite gneisses" and "augen gneisses".

The less common variety differs from the above in that it contains essential garnet, sillimanite and/or magnetite. The garnet rich variety known locally as "Potosi Gneiss" has a close spatial relationship with the Broken Hill orebody (Johnson and Klingner, 1976) and is a characteristic component of the "mine sequence".

The Quartzofeldspathic gneisses are interpreted by most recent authors (Johnson and Klingner, Stevens et al, Stanton, 1976) to be of volcano-sedimentary origin. Although on compositional grounds they may be considered as intrusives or altered sediments, the combination of composition, internal structures (e.g layering) and gross relationships to neighbouring formations suggests that they are most readily interpreted as extrusive igneous rocks. Stevens et al regard the "granite gneisses" as rhyolitic to dacitic ashflows or lava flows while the "Potosi" type gneisses are considered to be Rhyodacitic airfall tuffs.

## Leucocratic Quartzpfeldspathic Rocks

The leucocratic quartzofeldspathic rocks contain less than 10% (and usually less than 5%) of mafic minerals. These include pegmatites and mixtures of pegmatite and quartz and feldspar rich rocks. The "aplites" referred to in older literature (Map 1) belong to this group but these are preferably called quartz-albite rock in the scheme of Stevens and Willis.

A volcano-sedimentary origin is also favoured for these rocks, the progenitors being acidic ashflows and airfall tuffs.

Basic and Ultrabasic Rocks

Most of the basic rocks within the Broken Hill Block are concordant with and have suffered the same metamorphism as the metasediments. They mainly exist as amphibolites or basic granulites with varying mineralogies. Layered calc-silicate rocks occur in the west of the Broken Hill Block and these are regarded as being derived from calcareous sediments. Chemical analyses of Binns (1964) demonstrate a consistently basaltic composition which favours an igneous origin for the great majority of the basic rocks as sills, flows or tuffs (e.g. Edwards, 1958, Vernon, 1969, Stevens et al).

Small basic and ultrabasic plugs are found chiefly in the southern half of the Block and since these lack high grade metamorphic textures, they post date the deformation and high grade metamorphism which affected the Willyama sequence.

Dolerite Dykes, commonly trending NW and rarely exceeding a few metres in width are also found in the southern half of the Broken Hill Block.

Post Folding Granitic Intrusives (Mundi Mundi Granites)

Virtually undeformed bodies of microadamellite outcrop mainly in the Mundi Mundi (I5) and Brewery Well (C8) areas. The emplacement of these granites clearly post dates the major metamorphic events and the presence of boulders of the granite in basal beds of the Torrowangee series (Adelaidean) indicates a pre-Torrowangee age for the Granite (Leslie and White, 1955).

## Zinc, Manganese and Iron Rich Rocks

These are granular and/or layered rocks and are commonly associated with sulphide mineralization. Although they occur in minor amounts they are widely distributed within the Broken Hill Block.

The zinc rich rocks contain quartz and gahnite with or without feldspar and garnet. Quartz-gahnite rock is typically associated with the lead zinc sulphide mineralization in the region.

Manganese garnet rich rocks are also usually associated with the sulphide mineralization and range from a fine grained garnet sandstone almost wholly comprised of garnet to medium and coarse grained varieties with quartz more abundant than garnet.

The main iron oxide and iron sulphide rich rocks are banded iron formations (BIF), which are finely layered fine grained magnetite-garnet rocks, and medium to coarse grained granular quartz magnetite rock (QM). BIF and QM are generally accepted as metamorphosed chemical sediments (Stanton, 1976).

The quartz-magnetites appear as pods and lenses with widths in the order of 10's of metres while the BIF's rarely exceed 1 metre in width and always have considerable strike extent.

## Sulphide Mineralization

Lead-zinc-silver mineralization is widely distributed through the Broken Hill Block. Apart from the Broken Hill orebody many much smaller uneconomic or abandoned deposits are known (Barnes, 1979) and are classified in two categories; the Broken Hill type and the Thackaringa type (Both and Rutland, 1976).

The Broken Hill type is characterized by apparent conformability of the mineralization with respect to the foliation of the enclosing rocks and have a very complex mineralogy. Broken Hill type mineralization is associated with "lode horizons" which in the absence of lead-zinc sulphides is recognized by the presence of the characteristic mineral assemblages contained in the previously discussed quartz-gahnite rock, manganese garnet and iron sulphide rocks.

The Thackaringa type deposits are veins occupying minor gently dipping fractures commonly associated with metamorphism retrograde and are inferred to have formed late in the geological history of the Willyama Complex; probably as a result of remobilization of base metals in the Willyama rocks (Both and Smith, 1975). The major commodities produced from these deposits were silver and lead, the extreme surface enrichment in silver in many of them being responsible for much of the early development of mining in the Broken Hill District. The main producers were the Umberumberka (J4), Pioneer and Gypsy Girl (N3) mines which yielded 40,000, 20,000 and 10,000 tonnes of ore respectively in the late 1800's (see Map 1 for mine locations).

### 2.2.2 Stratigraphy

A comprehensive stratigraphic intrepretation of the Broken Hill Block has been compiled by the Geological Survey of N.S.W. workers (Stevens, Stroud, Willis, Bradley, Brown and Barnes, 1979) on the basis of extensive detailed lithological mapping. The interpretation and the nomenclature proposed by these workers is closely followed herein. Their stratigraphic map, presented in Map 2, has been supplemented with outcrops, from the Broken Hill district map in areas not covered (at the time of writing) in the Geological Survey's mapping programme. Map 2 has been used as the main geological base in this work.

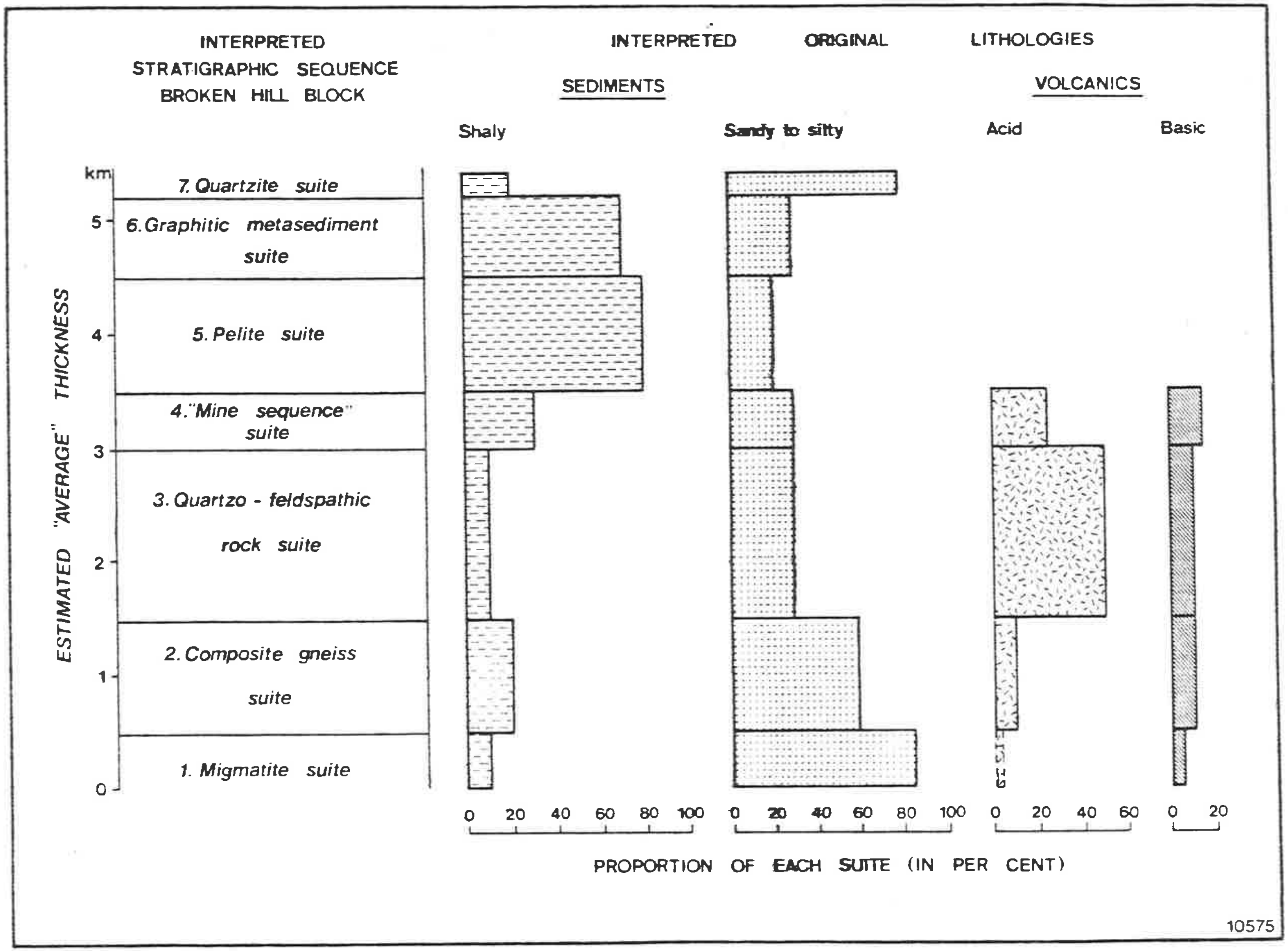



Figure 2.3 Interpreted compositions of metamorphic suites (after Stephens et al, 1979)

The stratigraphic system consists of seven metamorphic rock suites (Fig. 2.3) which can be broadly divided into three groups. The lowest three suites consist largely of quartz and feldspar rich rocks with minor amounts of pelitic material and amphibolite. Suite 4 contains significant proportions of pelite, quartzofeldspathic gneiss and amphibolite and is characterized by the presence of "Broken Hill type" mineralization. The upper three suites are composed entirely of metasediments.

Suites 1, 2 and 3

Outcrop of suite 1 (the Migmatite suite) is restricted to isolated anticlinal to domal cores in the central and western parts of the Block. The predominant rock unit is a migmatite or magmatic composite gneiss, with extensively disrupted 'layering' of various quartzofeldspathic metamorphic lithologies. Minor amounts of amphibolite are present in thin lenses. The top of the migmatite suite is defined by a relatively abrupt transition to a metasedimentary composite gneiss of mainly psammitic to psammopelitic character.

The Composite gneiss suite (suite 2) generally overlies suite 1 but may in part be laterally equivalent to it. The main rock unit is a metasedimentary composite gneiss comprising interlayering psammite and psammopelitic along with abundant pegmatitic to granitic segregations which are commonly associated with bedding disruption. Amphibolite makes up around 10% of the suite and narrow horizons of iron rich rocks (particularly quartz-magnetites) are common minor constituents.

The transition from suite 2 into suite 3 is signified by different rock type changes in different areas and, as with the suite 1/suite 2 boundary, some degree of lateral equivalence is considered possible.

Suite 3 (the Quartzofeldspathic Rock Suite) comprises composite gneisses and various metasediments with major proportions of leucocratic quartzofeldpathic rocks and quartzofeldspathic gneisses. Amphibolite again comprises about 10% of the suite. Suite 3 contains most of the granitic gneiss bodies of the Broken Hill Block including the augen rich varieties. Discontinuous quartz-magnetite quartz-pyrrhotite and quartz-garnet horizons are common but very minor constituents.

The suite 3/suite 4 boundary may be marked by the incoming of typical mine sequence or by the upper surface of a large mass of quartzofeldspathic gneiss or quartz-albite rock.

Suite 4: The Mine Sequence Suite

Suite 4 is termed the "mine sequence suite" because it contains the Broken Hill orebody and the associated mine sequence, and all of the known "Broken Hill type" mineralization in the region. It is a highly variable group of rocks which has great lateral continuity being absent only in the area north of Brewery Well (C8). Over most of the Broken Hill Block, suite 4 is characterized by one of two distinctive rock type associations or by a combination of these.

(i) amphibolite-"Potosi type" gneiss - quartz-gahnite rock
(ii) amphibolite-quartz albite rock - quartz-magnetite rock

Amphibolite is always present and accounts for around 15% of the suite.

Other rock types within suite 4 are quite variable. Metasediments usually predominate but the proportion ranges from 80% to 10%. Rock types such as granite gneiss and layered calc-silicate rock form important components in localized areas.

The top of suite 4 is defined by the phasing out of the distinctive rock types of associations (i) and (ii).

Suites 5, 6 and 7

The upper three suites are composed almost entirely of metasediments. Suite 5 is relatively widespread but suites 6 and 7 are confined to the northern parts of the Block. Suite 5 (the Pelite suite) overlies suite 4 and differs markedly from it in that amphibolites and quartzofeldspathic rocks are virtually absent. The suite consists almost wholly of well bedded pelites and psammopelites interlayed with very minor psammite.

Suite 6, the graphitic metasediment suite, is characterized by two distinctive types of graphitic rocks intercalated with units of psammopelitic schist. Layered calc-silicate rock is also a characteristic component.

Suite 7 (the quartzite Suite) is very limited in exposure and is composed entirely of metasediments; mainly fine grained psammitic types.

The Redan Gneisses

Not included in the above stratigraphic sequence are the important Redan Gneisses. This group of rocks is isolated from the rest of the Broken Hill Block, outcropping mainly in the neighbourhood of Redan (R14) and Farmcote (N15) homesteads.

The rocks have been described by Rayner (1949) and by Archibald (1973) as quartzo feldspathic gneisses with minor quantities of mica (usually muscovite) with magnetite (up to 4% by volume). In the same area, interlayered with the Redan Gneiss are sillimanite and sericite schists, abundant amphibolite, quartz-magnetite and very minor occurrences of quartz-gahnite rock. This assemblage of rocks lies in a distinctive magnetic anomaly zone quite different to that associated with the mapped suites 1-7. Rayner, on the basis of the magnetics and his own mapping, grouped them into one unit called the Redan Gneisses. They are regarded by the writer, on geophysical grounds, as a probable separate entity from the main Broken Hill sequence (see Chapter 4).

Compared to the other areas of the Broken Hill Block the Redan area has not been studied in detail, so that its relationship to the rest of the Block is uncertain. Glen et al (1977), on the basis of aeromagnetic comparisons suggested that the Redans possibly represent an older reworked basement complex similar to that observed on the Olary Block.

Mapping in progress, at the time of writing (Corbett, pers comm), suggests that the Redan gneisses may be subdivided into two main units. The more widespread unit is apparently readily correlable with suite 3 but the second unit, a hornblende rich quartzofeldspathic gneiss, has no equivalent in suites 1 to 7.

The stratigraphic position of the Redans is discussed in Chapters 7 and 8.

Depositional History

The depositonal history as interpreted by Stevens et al is concisely summarized in Fig. 2.3.

The significant features are the rapid increase in shaley sediments in suites 4 to 6, the absence of volcanics in suites 5 to 7 and the relatively high proportion of volcanic rocks in suites 3 and 4. The volcano-sedimentary nature of the Broken Hill sequence, although not established beyond doubt, provides a relatively straightforward explanation of the observed metamorphic rock types and their field relationships, and consequently most contemporary authors e.g. Johnson and Klingner (1976), Stanton (1976), Both and Rutland (1976) and Stevens et al (1979) subscribe to this theory.

Both and Rutland, in their examination of the origin of the Broken Hill orebody, concluded that the most reasonable interpretation of all available geological data on the Lode is that it is a stratiform deposit produced by exhalative sedimentary processes.

Stanton, in particular, relates the lode to emanations into the sedimentary environment during and related to late stage acid volcanism.

The important features from the geophysical viewpoint are the proportions of sandy and shaley sediments and the relative abundance of basic and acidic volcanics which suggest systematic changes in density and magnetite content may be observed between the suites. Section 3.3 examines the expected gravity response of the suites while their magnetic characteristics are discussed in Chapter 5.

### 2.2.3 Metamorphism and Geochronology

The metamorphism of the Broken Hill Block has been studied by Binns (1964) and later by Phillips (1977). Binns recognized a major prograde event (the Willyama metamorphism) and several subsequent retrograde events. Binns deduced that the grade of metamorphism produced by the prograde event increased from NW to SE and regarded the metamorphism as a high temperature, low pressure (800 degrees, 10 kb) type.

Subsequent work by Phillips (1977) resulted in a modification of the prograde metamorphic zones proposed by Binns but reiterated the increase in grade to the SE (Fig. 2.4).

Retrograde metamorphism is widespread, particularly in the northern parts of the Block. In the more southerly parts retrogression is largely manifest as distinct planar retrograde schist zones ("shear zones") such as the Thackaringa-Pinnacles shear (N5) and the Apollyon Valley shear (H7). Displacement along these shear zones is often but not always evident.

RB-Sr dating by Pidgeon (1967) and Shaw (1968) indicated that the Willyama metamorphism occurred at around 1700 Ma providing a younger limit for the age of the main Willyama sequence. Pidgeon also dated the emplacement of the Mundi

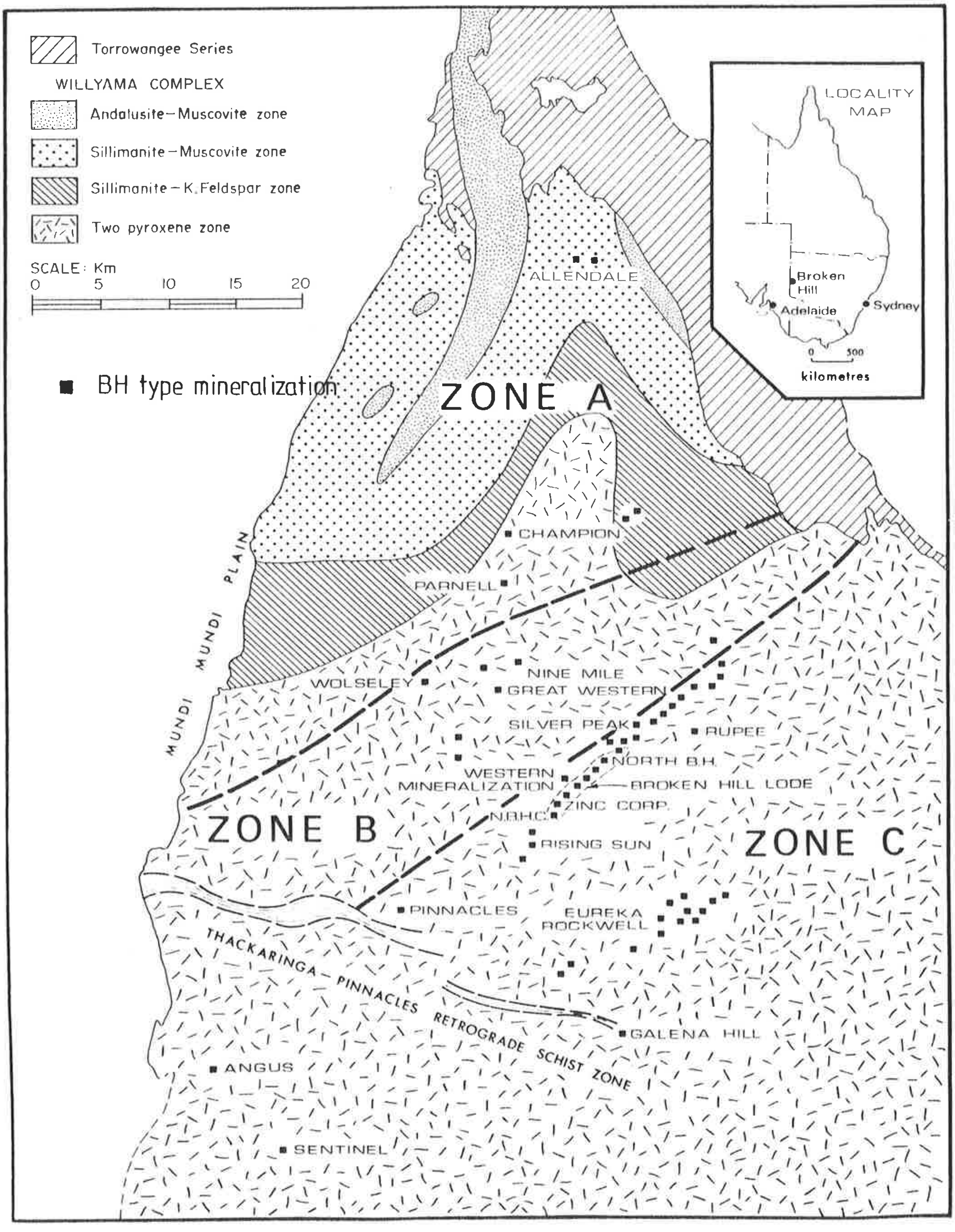



Figure 2.4 Comparison of Binns' metamorphic zones (A,B,C) with Phillips' zones. Grade increases to the SE.

Mundi granites at around 1500 Ma and this intrusive phase is generally regarded as signifying the end of the main deformation of the Willyama Complex.

Analysis by Richards and Pidgeon (1963) show that the total rock system become closed at around 500 Ma. Glen et al (1977) correlate this most recent isotopic event with the cessation of ductile movement on the retrograde schist zones coinciding with the end of the Cambro-Ordovician Delamerian orogeny, during which the Adelaidean and Palaeozoic sediments in the Adelaide Geosyncline and Kanmantoo Trough were folded.

### 2.2.4 Structure

Detailed and extensive structural studies were undertaken by the University of Adelaide as part of the MMA project. The results are documented in Marjoribanks, Glen, Laing and Rutland (1980) and a summary of the very regional scale structure and stratigraphy is presented in Glen, Laing, Parker and Rutland (1977). The following summary is based very largely on these works.

The Broken Hill Block has suffered three major deformational events, the first of which was by far the most intense, producing regional isoclinal folds and dominant high grade fabric of the rocks. Subsequent events modified these earliest recognizable tectonic structures and the features associated with the later deformations indicate that they were of lesser intensity. In contrast to the first deformation, the effects of later episodes were somewhat localized.

#### First Deformation

The first deformation was characterized by large scale isoclinal folds which were in part recumbent. Although only two "F1" fold closures have been positively identified. The continuity of bedding and the consistency of stratigraphic facing over large areas, combined with the recognition of macroscopic domains of upward and downward facing beds indicate the presence of F1 folds. The Stephens Creek fault (J10) separates the major domain of downward facing beds (to the south) from a domain of upward facing beds. Figure 2.5 shows the major structural elements of the Broken Hill Block. No differentiation between F1, F2 and F3 folds is indicated since no concensus has been reached by the various interpreters. The structures north of the Stephens Creek fault are those inferred by Stevens et al and their interpretation has been adopted in this area partly for the sake of consistency and party because their conclusions are based on a broader set of field observations. It should be noted however, that, in this northern area, the antiforms discussed in the later parts of this text have, in many cases, been interpreted by Marjoribanks et al as synforms and vice-versa.

Second and Third Deformations

The second deformation produced large scale folds only in the high grade rocks and mainly south of the Stephens Creek fault. The major structures in the vicinity of the Broken Hill Mines, i.e. Broken Hill synform, Broken Hill antiform, Hanging Wall synform are F2 structures.

The third deformation produced large and small scale F3 folds which refold F1 and F2 structures in high grade rocks and F1 structures in the medium and low grade rocks in the north and NE.

Figure 2.6 illustrates the complexity of folding in the Sundown-Broken Hill-Rockwell area and shows the development of the first and second generation of folds, as envisaged by Marjoribanks et al.

Shear Zones

The "shear zones" in the Broken Hill Block are linear zones of retrograde schists and are more correctly described as

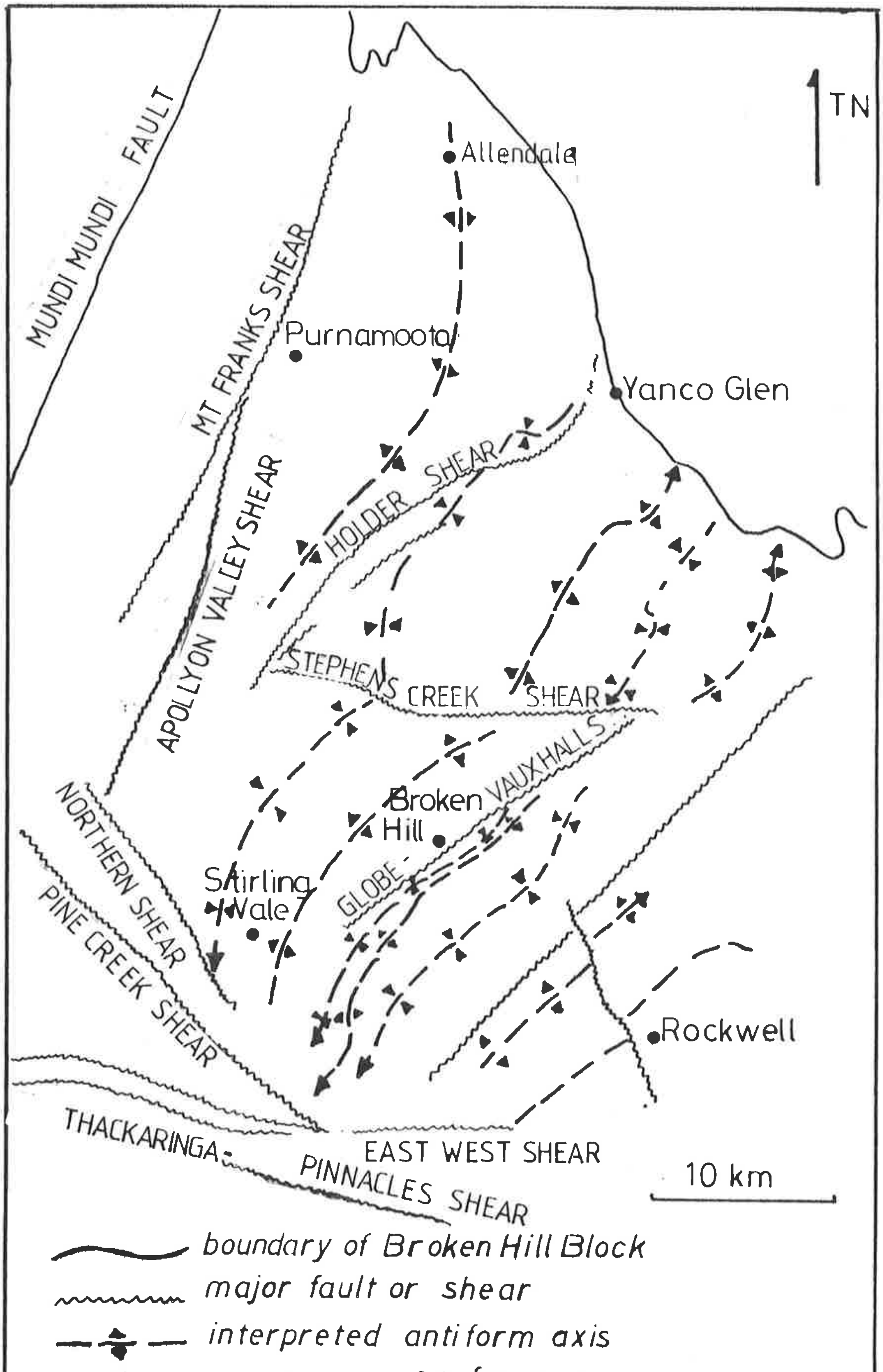
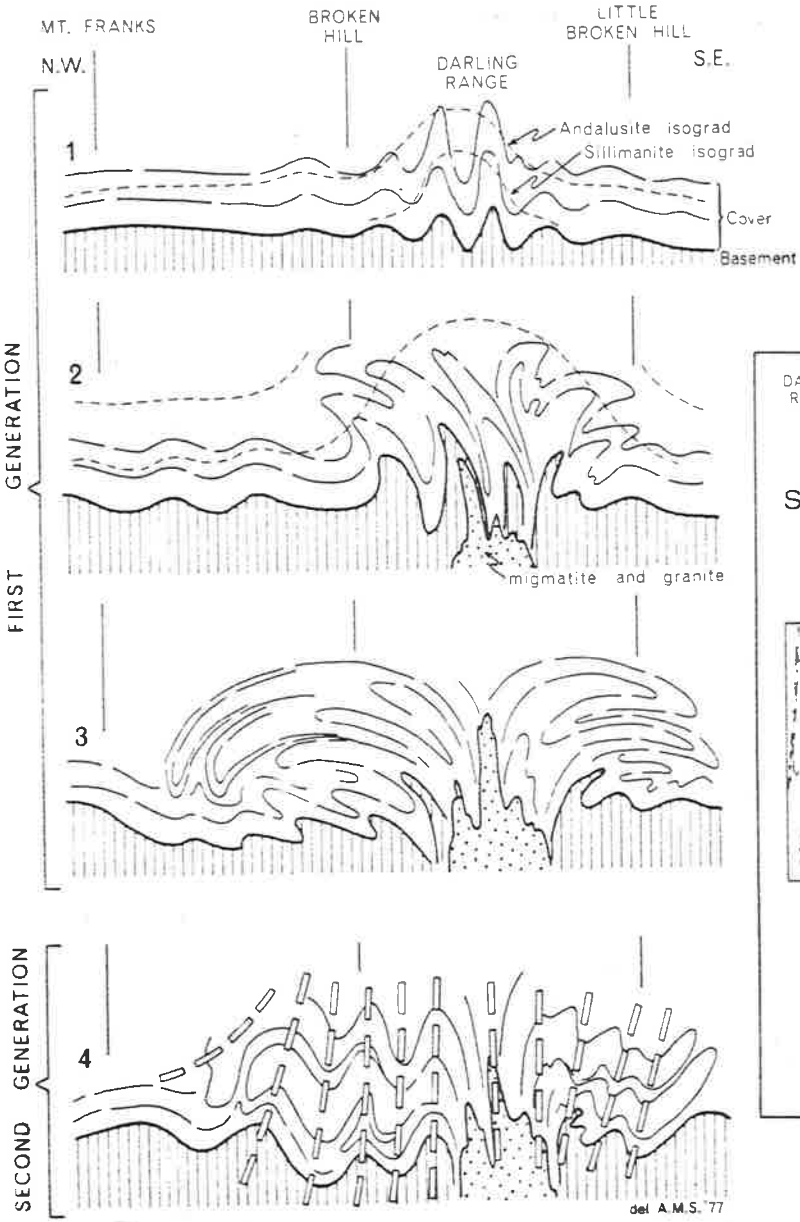


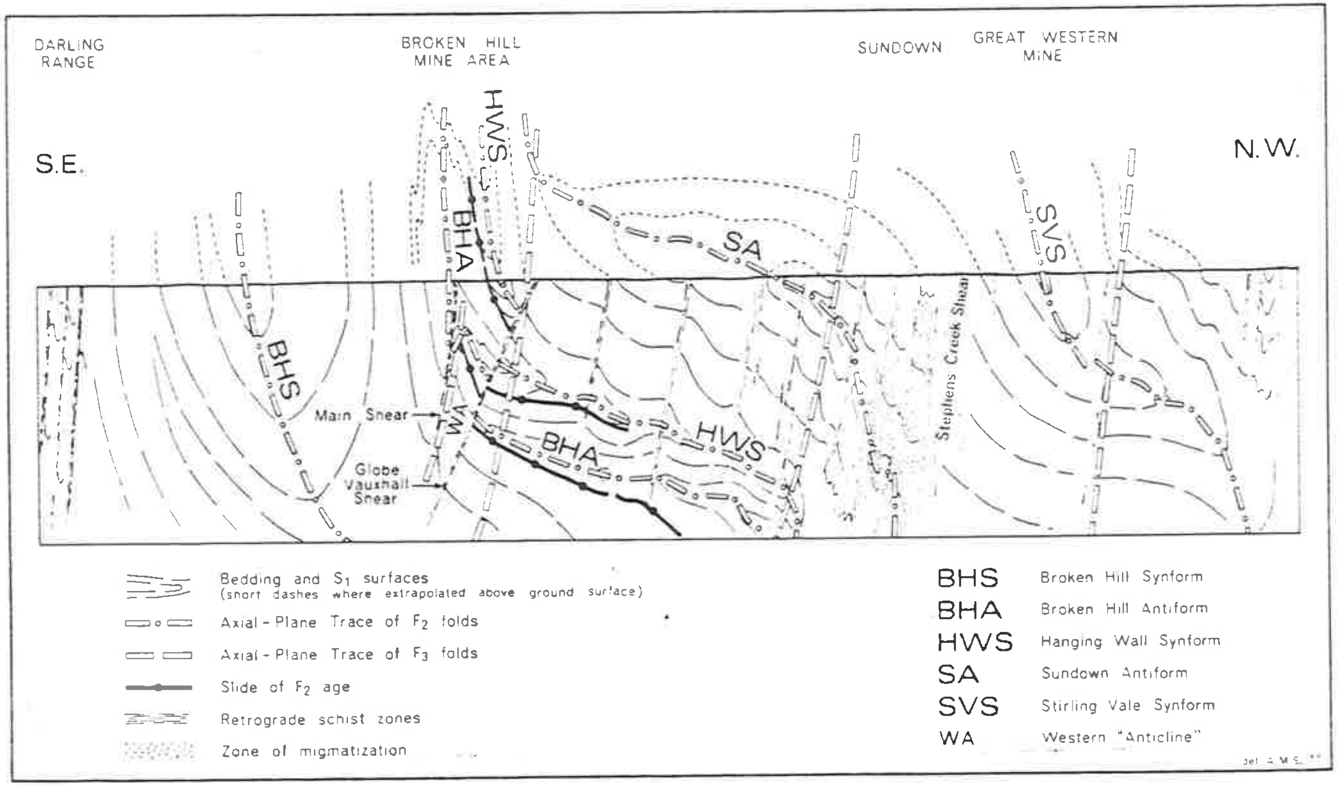

Figure 2.5 Large scale structures in the Broken Hill Block

Figure 2.6 Illustrations of structural complexity

(from Marjoribanks, et al ,1981)




a)generalized fold generation




b)structural section through the mine area

"Retrograde Schist Zones". They commonly represent zones of lateral and/or vertical displacement and for simplicity will be referred to in this text as "shears".

They fall into three main orientation groups. An ENE trending set with inferred dextral movement includes the Globe-Vauxhall shear (K10) in the Broken Hill mine area, the Apollyon Valley and Mt. Franks shears (I6) in the NW and the Hillston fault (R3) in the SW. A north to NNW set having sinistral movement includes the British and De Bavay shears (L10) in the mine area, the Northern shear (M7) in the Stirling Vale area and the Rockwell shear (N12). According to Both and Rutland (1976):-

"These two sets are approximately symmetrically oriented with respect to the NNE trending fold system so that both the fold systems and the conjugate retrograde schist zones can be related to an ESE trending maximum principal stress".

The third "shear zone" system trends almost at right angles to the fold system, i.e. approximately ESE and includes such major features as the Stephens Creek fault, the Pine Creek shear (L5) and the Thackaringa-Pinnacles shear. Nearly all of the features in this set show evidence of substantial displacement, the most outstanding example being the Thackaringa-
Pinnnacles shear with a dextral displacement of "several kilometres" (Both and Rutland, 1976).

Structural Subdivisions

The Broken Hill Block can be broadly divided into four structural entities bounded by major shear zones and faults.

As mentioned, the Stephens Creek fault separates a zone of upright F1 folds to the north from a major zone of recumbent F1 folds. This northern area is dominated by long linear F1 structures including the Mt. Vulcan Antiform (J13), the Stephens Creek Antiform (I11)and the Allendale structure (G9) which on stratigraphic and minimal structural evidence appears to be antiformal.

The area between the Stephens Creek fault and the Thackaringa-Pinnacles shear is also dominated by long linear NE trending structures.

West of the Apollyon Valley shear relatively small scale dome and basin type structures such as the Mt. Robe, Eldee, Ettlewood and Lakes Creek structures (Stevens, 1979) are found. This is also the lowest metamorphic grade area in the Broken Hill Block. The structure and metamorphic grade characteristics suggest that the Apollyon Valley shear has been a structure of considerable influence on the area.

The area south of the Thackaringa-Pinnacles shear is also characterized by small dome and basin type structures with a much lower proportion of the long linear features which dominate the area north of the shear. No change in metamorphic grade is apparent across the inferred structural boundary in this case.

Although the Broken Hill region is clearly very complex the recent studies have resulted in comprehensive interpretations of the stratigraphy, structure and metamorphism which, although probably requiring refinement, are accepted in general terms by company, academic and government geologists alike.

This sound geological base materialized largely in the middle to latter stages of the writer's project and enabled considerable geological significance to be attached to observations which had previously been predominantly geophysical.

# 3 MAGNETIC AND GRAVITY DATA IN THE BROKEN HILL REGION

Geophysical investigations in the Broken Hill area date back to the late 1940's and since that time a considerable amount of data has been collected. A significant proportion of the geophysical work has involved electrical and electromagnetic techniques but since these have generally been localized surveys they are outside the scope of this thesis and have not been considered for interpretation. Existing airborne radiometric data has been interpreted by authors such as McIntyre and Wyatt (1978) and Khan (1978), and will not be considered in any detail in this work.

Magnetic and gravity surveys cover the entire Broken Hill Block in varying amounts of detail. This chapter outlines the sources of these data and the sampling details, and briefly presents the major results of authors who have interpreted parts of the data set.

## 3.1 Magnetic Data

### Aeromagnetics

Nearly all of the outcrop area of the Broken Hill Block has been covered with detailed aeromagnetics. Most of the coverage is by the BMR, with companies contributing surveys in particular areas of interest. The locations of the surveys used in this project are illustrated in Fig. 3.1 and the details of the surveys listed in Table 3.1. Other aeromagnetic survey are known to exist in the area but these are not presented here either through confidentiality or because they exist in areas adequately covered in the surveys listed.

The surveys 1, 3 and 5 were flown with proton precession magnetometers sampled every second. The BMR 1975 surveys (2 and 3) used a fluxgate magnetometer sampled at 0.2 second intervals and were digitally recorded. To facilitate the production of contour maps by computer, the

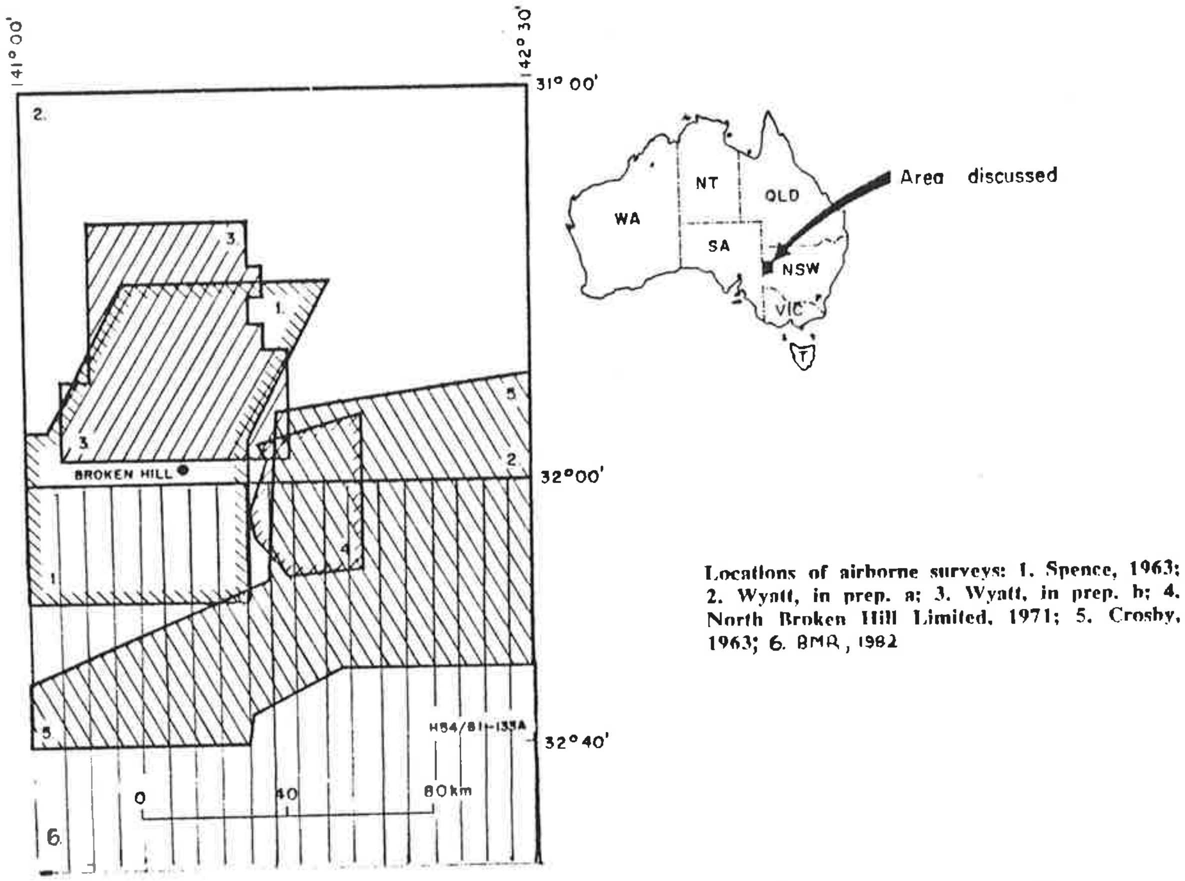



Figure 3.1 Index to aeromagnetic surveys discussed in this thesis

TABLE 3.1

DETAILS OF AEROMAGNETIC SURVEYS IN THE BROKEN HILL REGION

| No. | FOR | FLOWN BY | YEAR | FLIGHT DIRN | LINE SPACING | HEIGHT | POSITION CONTROL | REFERENCE |
|---|---|---|---|---|---|---|---|---|
| 1 | BMR | BMR | 1959 | EW | 400 | 150 | PHOTO | SPENCE |
| 1 | | | 1957 | VARIABLE | 300 | 150 | SHORAN | |
| 2 | | | 1975 | EW | 1500 | 100 | DOPPLER | WYATT |
| 3 | | | 1975 | EW | 300 | 100 | | |
| 4 | NORTH BH LTD | AUSTRAL EXPLN | 1971 | EW | 250 | 75 | PHOTO | ARCHIBALD |
| 5 | PLANT OIL NL | AERO SERVICE | 1963 | NW-SE | 11000 | 450 | PHOTO | CROSBY |
| 6 | BMR | BMR | 1981 | NS | 1500 | 100 | DOPPLER | BMR |

data from surveys 2 and 3 were resampled at 15 second and 3 second intevals respectively, prior to contouring. All of the surveys measured total magnetic intensity to ± 1 nT.

Surveys 1, 3 and 4 cover over 90% of the outcrop area of the Broken Hill Block in detail and have formed the basis for the aeromagnetic interpretation. A composite map including these surveys is presented at a scale of 1:250,000 in Map 3.

The coarse contouring interval in survey 1 causes a quite significant loss of detail. This is evident from a comparison between surveys 1 and 3, since survey 3 covered the northern half of survey 1. Where extra detail was required in this study reference was made to the original profile data (available as analogue records on 16 mm film) of survey 1. Survey 6 became available near the completion of this project and has not been fully integrated into the interpretation.

Ground Magnetic Data

Isolated ground magnetic traverses have been conducted by McIntyre (1979), Roberts (1971), Wood (1972) and Jenke (1972) to establish the causes of particular aeromagnetic anomalies. Unpublished vehicle-borne ground traverses recorded by J.I. McIntyre of the N.S.W. Geological Survey in February, 1979 have also been made available for this work. The locations of the ground traverses are shown in Fig. 3.2 and the results of the above authors are discussed in Section 3.3. A significant amount of company ground magnetic data is known to exist in the Broken Hill region. The data available was generally too detailed to be incorporated into this thesis, and no interpretive accounts of the data were available to the author.

Susceptibility Measurements

Roberts, Wood and Jenke all carried out magnetic susceptibility measurements to aid their ground magnetic

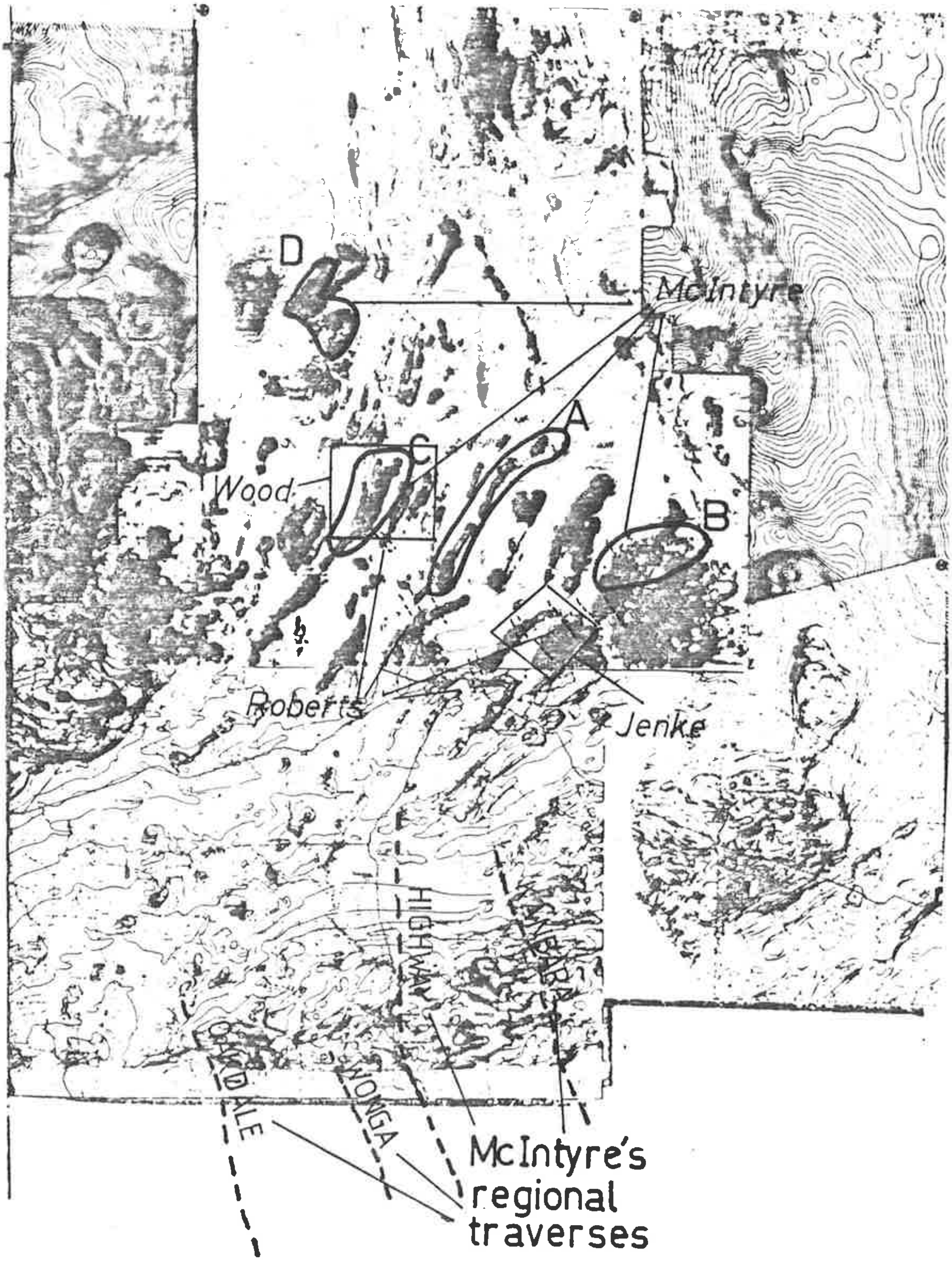



Figure 3.2 Location of ground magnetic data in relation to airborne surveys

work. Everle (1973) studied the susceptibility variations of amphibolites using exclusively drill core from the mine area.

Some isolated measurements have been made on core from the Galena Hill area (P9) (Anderson, 1975) and by the writer on samples of "Redan Gneiss" supplied by Dr. G. Corbett of the N.S.W. Geological Survey. Susceptibility values of the magnetic rocks encountered are summarized in Table 3.2.

No systematic study of the magnetic properties of the common rock varieties has been undertaken to date. Proprietary studies were however being carried out by both of the major mining companies at Broken Hill, at the time of writing.

## 3.2 Gravity Data

The Bouguer Anomaly map of the BH Region (Map 4) has been compiled from several sources. The distribution of gravity data within the study area is extremely variable. South and SE of BH quite adequate regional coverage exists whereas, to the north and west, coverage is rather poor. The main contributions to the existing gravity data have been as follows:-

CRAE

Conzinc Rio Tinto Australia (Exploration) (CRAE) made available plans from the detailed gravity survey carried out by Weiss (1940) for the then Zinc Corporation. Approximately 3000 stations were established, mainly in the vicinity of the BH mine. The extent of the survey is evident on map 4 as the area of 0.5 mGal contouring. The station spacing was 30 metres along lines 300 metres apart. The data is available only in graphical form and the precision of the survey is not documented. However, it is known to have been optically levelled and the plotted profiles show a "noise level" of less than 0.05 milligals. The data has been graphically incorporated into the Bouguer anomaly map.

ALLIANCE OIL N.L.

Geosurveys established around 380 gravity stations in the SE part of the study area during the course of a major oil exploration programme for Alliance Oil (Stackler and Brunt, 1967). Stations were levelled by theodolite along major roads and tracks at spacings typically around 1600 metres. The precision quoted was ± 0.06 mgal.

PECANEK

Pecanek (1975) contributed 500 stations with varying spacing and precision. Three optically levelled traverses were conducted with stations at 120 metre intervals. The remainder of the stations were read along major roads approximately every 1600 metres with one roving barometer as the height control. While the accuracy of the detailed lines was ± 0.04, uncertainities in the barometric heights along the regional traverses possibly exceeded 5 metres yielding a corresponding uncertainity in Bouguer Anomaly values of around 1 mGal.

BMR

In 1973 the BMR surveyed the BH and Menindee 1:250000 sheet areas using a helicopter for transportation. The station density was 1 per 50 square km on a roughly square grid pattern. Microbarometers were used as height control; the precision of heights normally given by BMR for this type of survey being ± 5 metres giving approximately ± 1 mGal uncertainity in the Bouguer Anomaly values. 520 BMR stations exist within the study area and 37 of these are located at NSW Lands Department bench marks.

The BMR has an Isogal station at BH airport (No. 6491.0241) and all of the surveys listed here have been tied to that station.

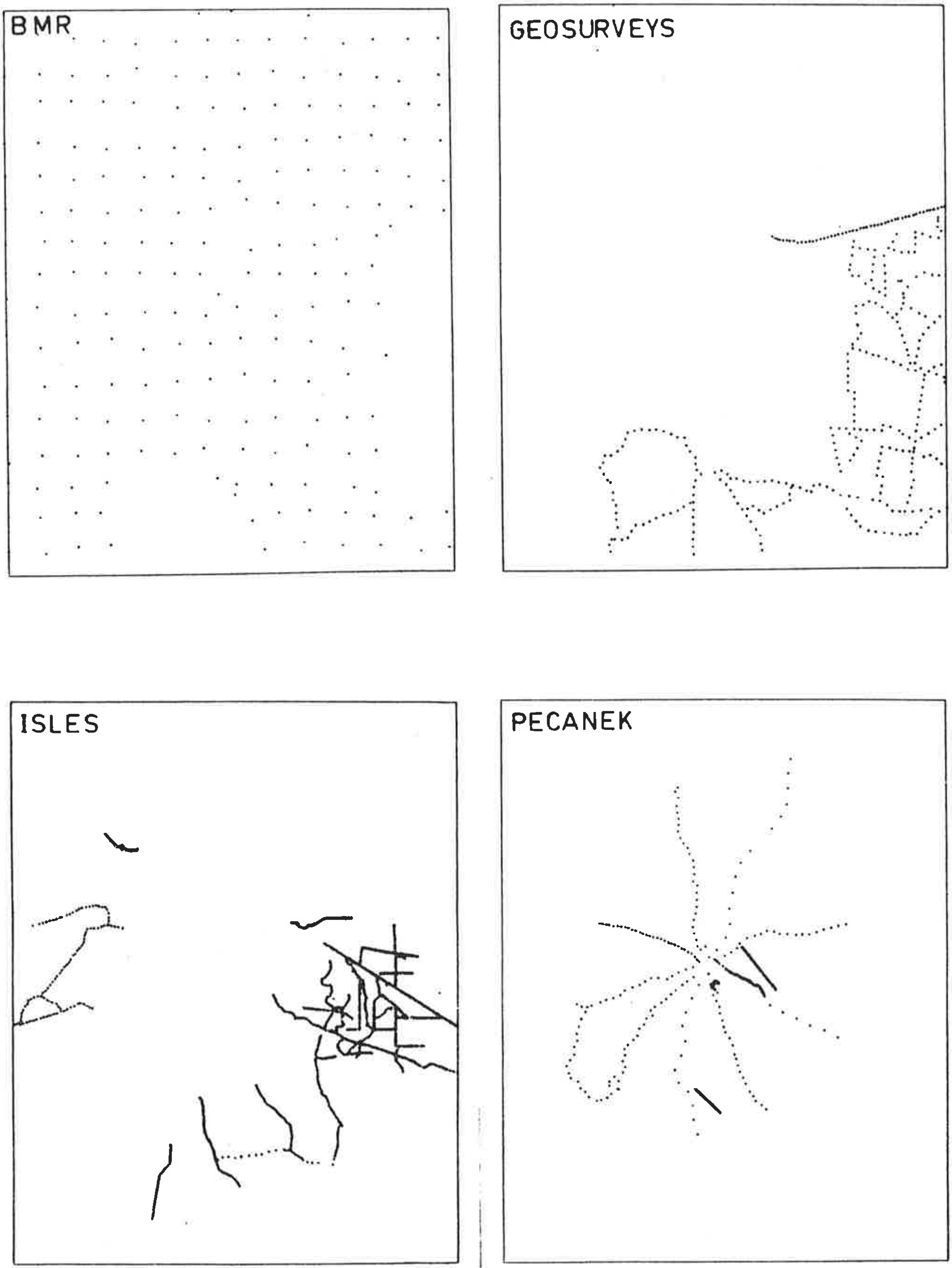



Figure 3.3 Distribution of regional gravity stations within the study area (see map 4 )

ISLES

The writer, assisted by many colleagues, established 1280 stations. 440 of these were optically levelled (Bouguer Anomaly ± 0.06 mGal) the remainder being levelled using microbarometers. Owing to the presence of height control (largely in the form of NSW Lands Department bench marks) the barometric data was found to be accurate to within ± 2 metres so that the overall uncertainity in the Bouguer gravity was limited to ± 0.4 mGal. Standard surveying and reduction procedures were used and these are described in Appendix I.

NORTH BROKEN HILL PTY. LTD.

Three traverses across the Mundi Mundi fault by North Broken Hill Ltd., (Leyh, 1980) were incorporated graphically into the Bouguer Anomaly Map.

The distribution of regional gravity data from the four main sources is illustrated in Fig. 3.3. A formal listing of the principal facts of all gravity stations used in the compilation of the gravity map is given in Appendix V. The company data of CRAE and NBH Ltd. is not listed here because it was not available to the author in numerical form.

Additional localized gravity surveys by Healey and Webster (1968), Day (1966) and Anderson (1975) were aimed at locating small features and were not tied to the Australian gravity network. Because of the small areas covered in these surveys no attempt was made to incorporate them into the Bouguer anomaly map.

## 3.3 Major Results from Previous Geophysical Work

Magnetics

The regional scale aeromagnetic surveys were interpreted by McIntyre and Wyatt (1978) whose work served to define the major bounding features of the Willyama Complex.

Ground magnetic work by Roberts (1971), Jenke (1972) and Wood (1972) was carried out to determine the causes of particular aeromagnetic anomalies and to examine the continuity of magnetic anomalies with respect to geological structures. Based on limited numbers of traverses, these workers were unable to produce positive interpretations regarding geological structures, but all found that strong magnetic anomalies stemmed from a wide variety of sources. Magnetite rich horizons were observed in sillimanite gneisses (mainly occurring in suites 4 and 5), granite gneisses (suite 3), amphibolites (suites 3 and 4) and in pegmatite (suites 3 and 4). Susceptibility measurements from drill core (mainly from the mine area) confirmed that most of the major rock types could contain enough magnetite to generate magnetic anomalies.

Everle (1973) studied the magnetic characteristics of the amphibolites in the mine area and found that the main "footwall" amphibolite consistently showed high susceptibilities while the "hanging wall" amphibolite horizon varied from highly magnetic in parts to non-magnetic. The highly variable susceptibility in amphibolites has also been observed by McIntyre (1979) in the Mt. Vulcan Antiform area (J13). Everle suggested that the rapid variations in magnetite content of the amphibolites and also their changes in width along strike could both be explained by considering them as originally being layered basic tuffs. The view that the amphibolites were originally of basaltic composition has been put forward from geological observations by several authors (e.g. Edwards, 1958) and is generally accepted. Stevens et al (1979) interpret the amphibolites as basaltic lava flows or ashflow with the possibility of some bodies of the layer being airfall ash.

Susceptibility measurements in core from the Galena Hill area (Anderson, 1975) showed the same features observed in the mine area. Amphibolites were found to be highly variable and magnetic horizons were found in a variety of rock types.

The susceptibilities of the main magnetic rock types encountered in the above works are listed in Table 3.2. Although this collection of measurements is far from being systematic, it demonstrates that most of the major rock types observed in the Broken Hill region may contain significant amounts of magnetite while, as shown by Roberts, all except the BIF's are commonly non-magnetic or very weakly magnetic.

McIntyre's Work

McIntyre (1979) conducted detailed ( 5 m station spacing) ground magnetometer traverses in four areas representing the different aeromagnetic anomaly types observed in the area covered by survey 3 (Fig. 3.1). This work was in areas where the NSW Geological Survey had detailed lithological mapping available and the aim was to establish the causes of aeromagnetic anomalies using the mapped geology, the ground magnetics and in situ susceptibility measurements.

This work produced two results crucial to the understanding of the magnetic variations in the Broken Hill area.

1. The major aeromagnetic anomalies investigated were found to be caused by magnetite in <u>metasediments</u>. Some minor (aeromagnetic) anomalies were found to be due to acid igneous rocks (interpreted as volcanics).

   Although amphibolites in some places generated large peaks, in no cases could they be directly correlated with the major observed airborne anomalies. Shear zones, with amphibolites, had previously been associated with many of the major aeromagnetic anomalies (e.g. Roberts, 1971) but although shear zones do sometimes coincide in position with magnetic anomalies, McIntyre has shown that the magnetite is contained within the pre-existing rocks which have been retrogressed and/or sheared. Furthermore, he observed that the shear zones often correlate with magnetic lows, and suggested the magnetite had been destroyed either by the retrograde metamorphism or by deep weathering within these zones.

2. The magnetic horizons within the metasediments are not confined to one lithology but are certainly confined within mapped stratigraphic limits.

   In the two prominent linear anomalies investigated (Areas A and C, Fig. 3.2) the magnetite rich horizons were found to form "anastomising branches" within a stratigraphically bound envelope consisting of a variety of rock types. Individual magnetite rich lenses were found to be no different in lithology to adjacent non-magnetic rocks except that they contained 1 or 2% magnetite. McIntyre explained this in terms of mixing of sedimentary detritus with chemically precipitated iron formations such as BIF, quartz-magnetite or sillimanite-magnetite rock, which can usually be found along strike from or in the neighbourhood of the magnetic metasediments.

   From these results he inferred that the anomalies investigated outline persistent stratigraphic marker horizons, and as such can be used to delineate large scale structures. In all of the four areas studied the magnetic interpretation has made significant contributions to the understanding of the structural geology.

Gravity

Regional Surveys

The regional gravity work by Geosurveys for Alliance Oil, although concentrated in the Palaeozoic/Mesozoic basin areas to the east and south of the BH Block extended well into the Willyama outcrop areas. The interpretation report (Stackler and Brunt, 1967) related the major gravity highs to the Pre-Cambrian (Adelaidean and/or Willyama) basement, and outlined the boundaries between these "basement" rocks and the younger sediments.

The BMR helicoper survey was carried out as part of the general gravity coverage of the continent (BMR, 1976) and has been used by McIntyre and Wyatt (1978) in the course of their regional geophysical interpretation. Extending the work of Stackler and Brunt, this work outlined the major boundaries between the various Pre-Cambrian and Phanerozoic provinces to the east and southeast of the BH Block (Fig. 2.2).

Pecanek's Work

The aims of the study by Pecanek (1975) were to establish facts about density variations in the Broken Hill mine area and to determine the likelihood of detecting "Broken Hill type" mineralization from detailed gravity surveys. To this end, he used the detailed gravity data of CRA (Weiss, 1949) in the mine area, and generated theoretical gravity models to match this data, based on interpreted geological sections and approximately 3000 density measurements.

Pecanek chose to model gravity profiles coinciding with geological sections which were well controlled by drilling. His density measurements were carried out on drill core from each section and so, with good control on both the geometry and the density of the rock unit within each section, he was able to clearly recognize their contributions to the overall gravity profile. Using the measured densities, and with only minor adjustments to the geometries obtained from the geological sections, close agreement was obtained between the observed and calculated gravity.

He concluded that "the detection of the Broken Hill orebody by a residual gravity anomaly would have been unlikely ". Although the orebody itself is denser than its immediate host rock, it is significantly less dense than

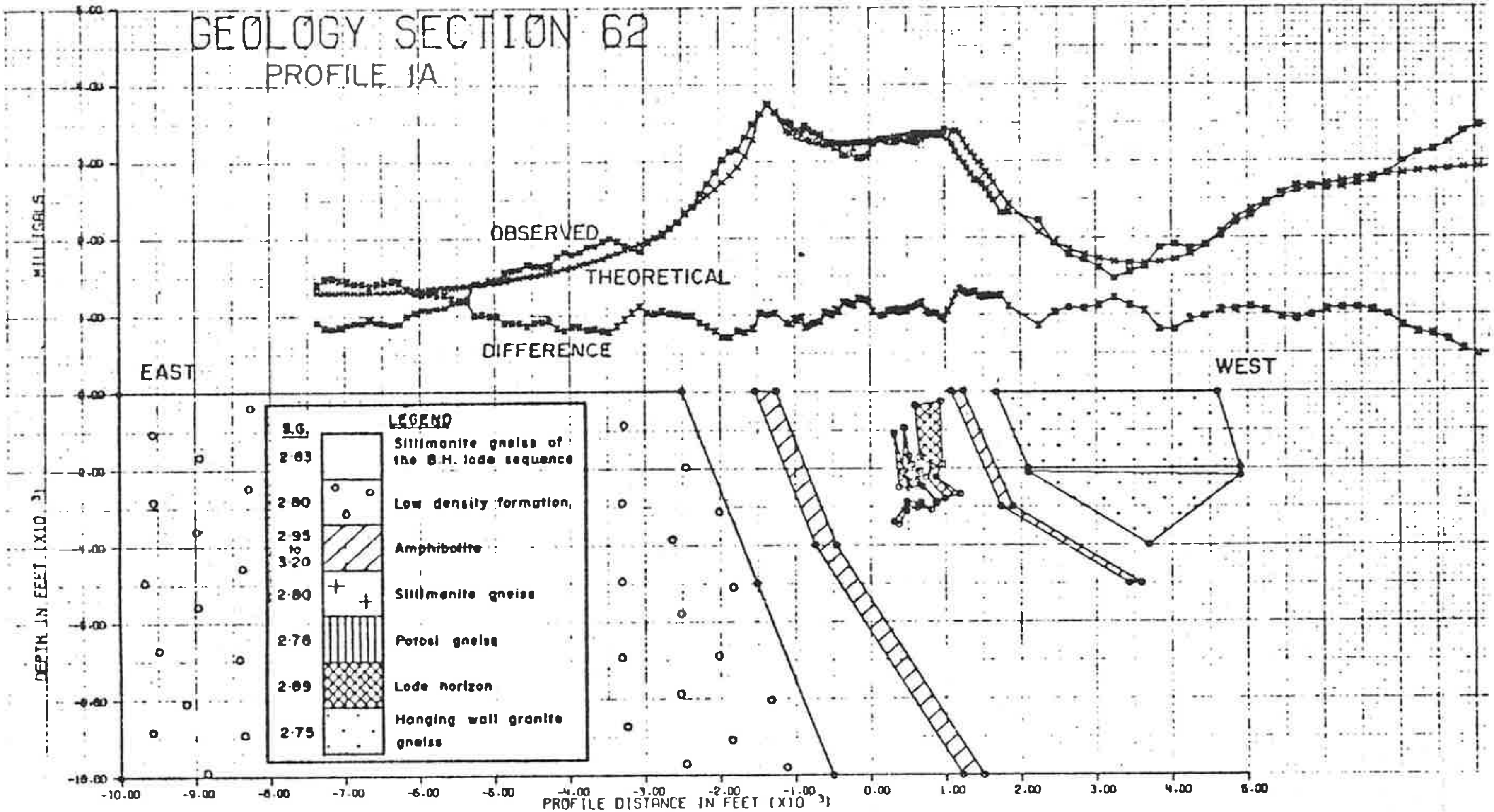



Figure 3.4 Gravity response of the Broken Hill mine area

(after Pecanek, 1975)

the amphibolites which abound in the mine area. Since the volume of amphibolite in the mine area greatly exceeds the volume of the lode, the prominent gravity highs were found to be due to amphibolites or amphibolite rich sequences.

Figure 3.4 shows the gravity response of the lode horizon on one of geological sections and the density model deduced by Pecanek for that section.

Pecanek's work also included some broadscale regional gravity and, on the basis of the limited coverage available at that time, (his own data, CRAE data, and the Geosurveys Data) he suggested that the major regional gravity highs reflected the presence of large volumes of pelitic and/or amphibolite rich rocks.

Wood (1972) and Jenke (1972) analysed the CRAE data from the "Hanging Wall Basin" and the "Broken Hill Basin" respectively. These structures appear to consist of basin shaped masses of granitic gneiss (Suite 3). Both authors deduced gravity models which matched the observed data and were consistent with the known geology and measured densities in the respective areas.

Density Measurements

The main results of density measurements used by Pecanek, Wood and Jenke are reproduced in Table 3.3. Measurements on rocks from outside the Broken Hill mine area (from various sources) are listed in Table 3.4.

Using these densities and the relative abundances of the various rock types within the metamorphic rock suites (Fig. 2.3), approximate bulk densities can be estimated for each of the metamorphic suites. Table 3.5 shows the results of these calculations and Figure 3.5 illustrates the gravity response of a hypothetical slab consisting of blocks with widths and densities estimated for the metamorphic suites. The diagram is meant to convey the relative differences in Bouguer gravity which might be expected between areas of differing stratigraphy. Considering the structural complexity of the area and variability in thickness and composition of the suites, this diagram serves as a guide to the expected gravity responses of the suites. However the simple form of the variation of density with stratigraphy suggests that regional gravity data should reflect the major large scale structures within the BH Block.

In particular, high gravity values would be expected to be associated with large accumulations of Suite 4 and 5 rocks.

TABLE OF AVERAGE BULK DENSITY OF ROCKS FROM THE BROKEN HILL LODE SEQUENCE

| Rock Type | O.W. Zinc | L.A.R. N.B.H.C. | R.J.W. U of A | G.P.J. U of A | R.B. N.B.H. | H.T.P. U of A |
|---|---|---|---|---|---|---|
| Pb Lode | 3.59 | 3.59 | | | | |
| Zn Lode | 3.22 | 3.22 | | | | |
| Enveloping Gneiss | 2.60-2.90 | 2.89 | | | | |
| Zinc Lode horizon | | | | | East 2.66 | 3.00 |
| Granite Gneiss | 2.72 | 2.72 | 2.74 (1) | 2.70 | 2.75-2.80 | |
| Sillimanite Gneiss | 2.80 | 2.64 | 2.84 (2) | 2.63 (3)<br>2.80 (5) | 2.75-2.85 | 2.83-2.80 |
| Thorndale Gneiss | 2.75 | - | | | | |
| Amphibolite | 3.15 | 3.15 | | | 3.2 -3.35 | 3.2 -3.3 |
| Pegmatite | - | 2.65• | | | | |
| Potosi Gneiss | - | 2.79 | | | | |
| Aplite | - | 2.67 | | | | |
| Garnet-haematite | - | 4.00 | | | | |
| Schist | - | | 3.005 | | | |
| Dolerite | - | - | 3.06 | | | |
| Garnet S/S | - | - | - | - | 3.38 | |
| Shears | | | | | 2.81 also 2.92 | |
| Lode | | | | | 2.93 | |

(1) 2.74 $gm/cm^3$ average for 56 readings with a st. dev. 0.044
(2) 2.84 $gm/cm^3$ average for 62 readings with a st. dev. 0.095
(3) 2.70 $gm/cm^3$ average for 76 readings with a st. dev. 0.069
(4) 2.63 $gm/cm^3$ average for 53 readings with a st. dev. 0.15
(5) 2.80 $gm/cm^3$ average for 72 readings with a st. dev. 0.06

Table 3.3 Densities of lithologies in the mine area (after Pecanek, 1975 )

TABLE 3.2

MAGNETIC SUCEPTIBILITY MEASUREMENTS FROM THE BROKEN HILL AREA

Sources and locations of samples

(1) Roberts (1971)........Northern mine area
(2) Jenke (1972)........Rupee area
(3) Wood (1972)........Parnell area
(4) Anderson(1975)........Galena Hill area
(5) Isles ........Redan area

| Rock Type | Probable Suite | Susceptibilities (x10-6 cgs) | Source |
|---|---|---|---|
| Sillimanite gneiss | 4 or 5 | 1275,6700,3700 | 1 |
| | | 800,1620 | 2 |
| | | 2500 | 3 |
| | | 15,2500 | 4 |
| Potosi gneiss | 4 | 3950,2990 | 1 |
| | | 11000 | 3 |
| Granite gneiss | 3 or 4 | 207,6500 | 1 |
| Amphibolite | 3 or 4 | 14700,110,18400,547 | |
| | | 170,130,7800,4050 | 1 |
| | | 75,5630,1400,40 | 4 |
| Pegmatite | 4 | 500 | 1 |
| | | 44,2300 | 3 |
| BIF | 4 | 8000 | 1 |
| | | 8750 | 4 |
| Redan gneiss | ? | 600 | 5 |
| Hornblende Redan gneiss | ? | 4000,120 | 5 |

TABLE 3.4

DENSITY MEASUREMENTS FROM OUTSIDE THE BROKEN HILL MINE AREA

Galena Hill area ..........Anderson(1975)

| Rock Type | Density (g/cc) | No. samples |
|---|---|---|
| Sillimanite gneiss | 2.875 | 18 |
| Amphibolite | 3.135 | 12 |
| Pegmatite | 2.70 | 1 |
| Schist | 2.85 | 17 |
| Overburden(weathered rock) | 2.56 | 5 |

Redan area................Isles

Redan gneiss

| | | |
|---|---|---|
| Qtz-Felds-magnetite rock | 2.67 | 1 |
| Qtz-Felds-hornblende-mag | 2.72 | 1 |
| " | 2.67 | 1 |

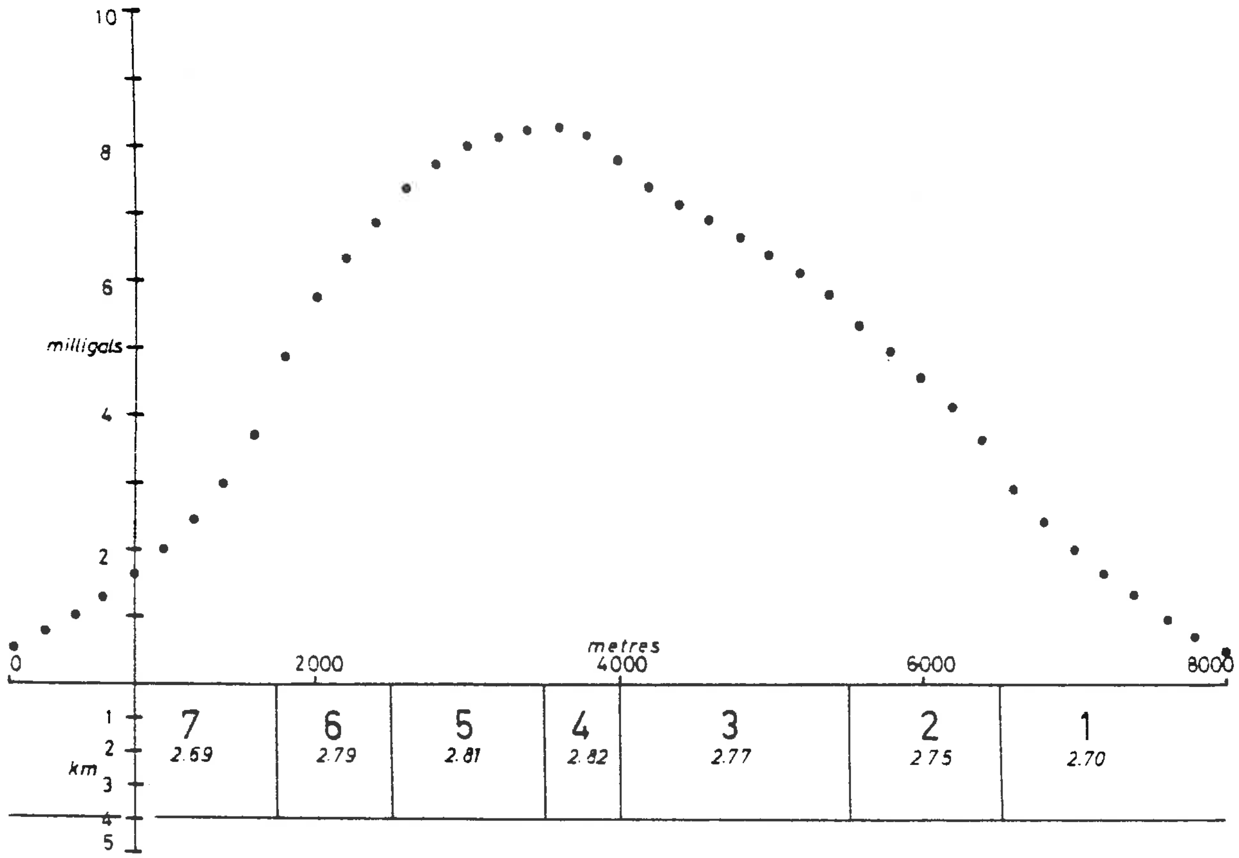



Figure 3.5 Hypothetical gravity profile across a slab consisting of the entire BH stratigraphy.
see table 3.5 below

TABLE 3.5

BULK DENSITIES OF METAMORPHIC SUITES

| Suite | (1)% | (2)% | (3)% | (4)% | Density (g/cc) |
|---|---|---|---|---|---|
| 7 | 20 | 80 | | | 2.69 |
| 6 | 70 | 30 | | | 2.79 |
| 5 | 80 | 20 | | | 2.81 |
| 4 | 30 | 30 | 25 | 15 | 2.82 |
| 3 | 10 | 30 | 50 | 10 | 2.77 |
| 2 | 20 | 60 | 10 | 10 | 2.75 |
| 1 | 10 | 85 | | 5 | 2.70 |

Explanation: The components of the metamorphic suites (fig 2.3) have been assigned densities(based on Pecanek's measurements) and a bulk density has been calculated for each suite using the proportions of the various components as weights.

The densities assigned to the components are as follows:
(1) Shaly sediment.........2.85(sillimanite gneiss)
(2) Sandy sediment.........2.65 (quartzite)
(3) Acid volcanics.........2.75 (granite gneiss)
(4) Basic volcanic.........3.20 (amphibolite)

e.g. Suite 1 10%(1)+85%(2)+5%(4) =
0.1x2.85+0.85x2.65+0.05x3.2 = 2.70

# 4 THE MAGNETIC SUBDIVISIONS OF THE BROKEN HILL BLOCK

The subdivision of aeromagnetic maps into zones of characteristic response is a common initial approach in the qualitative interpretation of such maps (e.g. Boyd, 1967, Emerson, 1973). These zones may be defined by the abundance of anomalies, by their shapes, preferred strike directions, by changes in the magnetic 'background' or by many other subtle, systematic changes in the magnetic contour pattern. Magnetic zones may correspond to major changes in rock type or may simply reflect changes in the magnetite content within an otherwise 'uniform' rock type. Volcanism or regional metamorphism may exert strong influence on the distribution of magnetite over large areas and these effects can impose a zoning on the measured magnetic intensity.

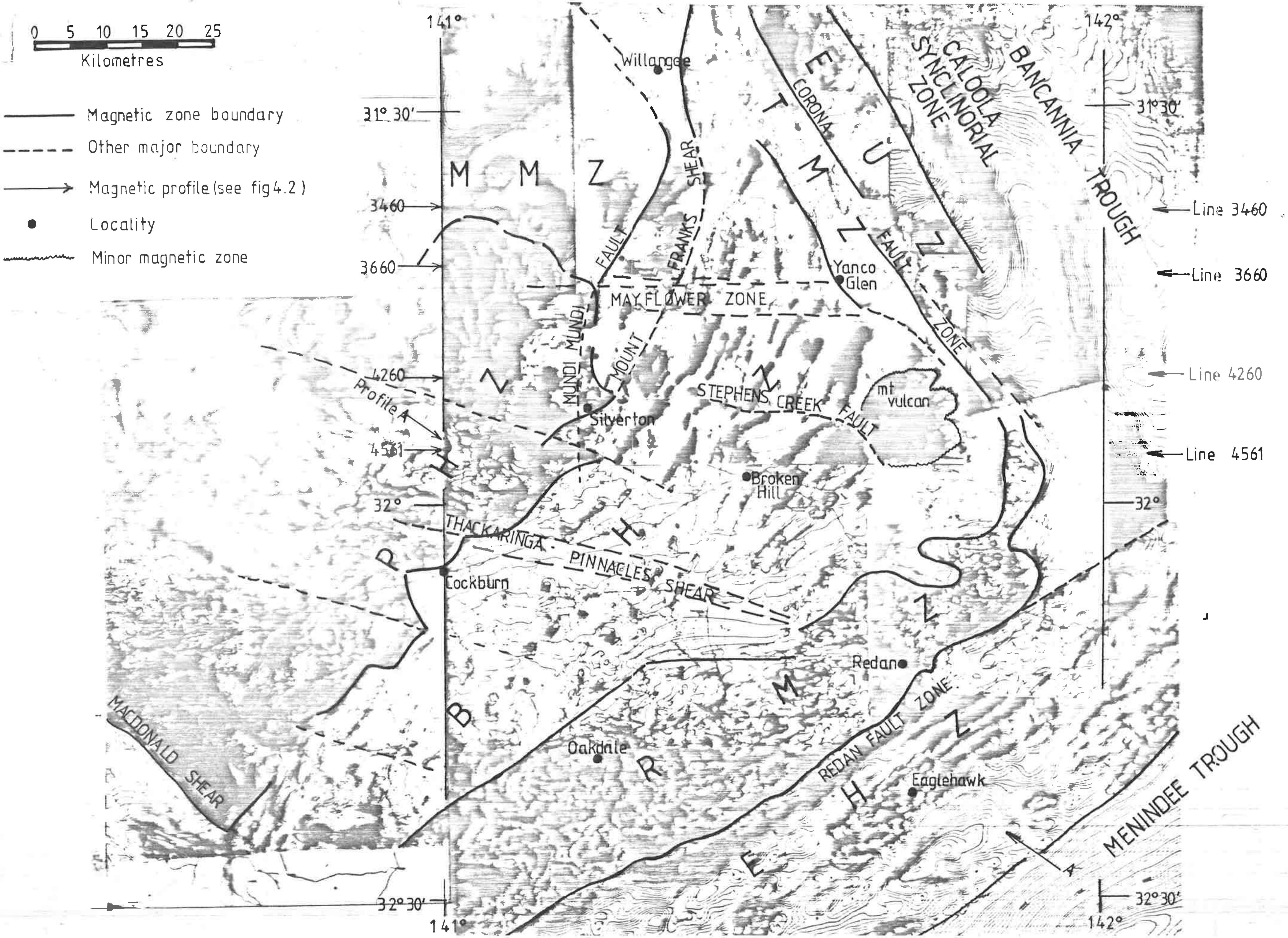
In the Broken Hill region, clear cut subdivisions are apparent in the aeromagnetic maps (Fig. 4.1). The differences in magnetic response between these zones are, in most cases, profound and the boundaries between zones are normally abrupt. Although the geological significance of the zones has not been established in all cases, (largely due to absence of outcrop in critical areas) it seems very likely that the magnetic zones represent distinctly different geological provinces.

## 4.1 Definition of Magnetic Zones

### 4.1.1 Broken Hill Magnetic Zone

Over 90% of the outcrop area of the BH Block shows a single, characteristic magnetic response. This area is termed the Broken Hill Zone (BHZ) and features a relatively low gradient background variation on which are superimposed discrete predominantly linear anomalies, trending NE in the southern parts of the Block and more to the North and NNW in the northern parts. The linear anomalies commonly have amplitudes between 200 and 500 nT, widths of around 500 metres, and near surface sources.

Figure 4.1 Composite aeromagnetic map showing interpreted subdivisions



The background changes from a persistent gradient of around 50 nT/km (increasing to the SE) in the south, to a smoothly undulating variation in the north. The 'average' level of magnetic intensity within the BHZ is significantly lower than that of surrounding zones (see frontispiece and Fig. 4.2) which McIntyre and Wyatt (1978) attribute to "major changes in magnetic properties through a considerable proportion of the earth's crust".

Within the BHZ, the Mt. Vulcan area is conspicuously out of character. It shows a generally high magnetic intensity and extreme variability in response having more in common with the highly magnetic zones to the west and SE of the BHZ. Because the Mt. Vulcan area occupies a relatively small area and is enclosed by the BHZ it is here initially treated as part of the BHZ.

The magnetic features within the BHZ are studied in detail in Chapter 5.

### 4.1.2 Redan Magnetic Zone

South and east of the BHZ lies a complex magnetic area called the Redan Magnetic Zone (RMZ). The RMZ is an area of high magnetic intensity level containing very steep gradients generated by an abundance of closely spaced anomalies, typically with peaks around 800 nT above the local background level. Although individual magnetic sources are difficult to decipher from the complex pattern, very strong trends are observed in the contours. The trends are dominantly ENE with some NE trends and two or three prominent EW trends.

While outcrop within the RMZ is very limited, most of the exposures are classified as "Redan Gneiss". As previously discussed, the Redan Gneisses are generally classified apart from the other Willyama rocks and since they are known to be very rich in magnetite (Rayner, 1949) there is little doubt that the observed rocks are the prime cause of the complex magnetic pattern of the RMZ.

Check Rayner

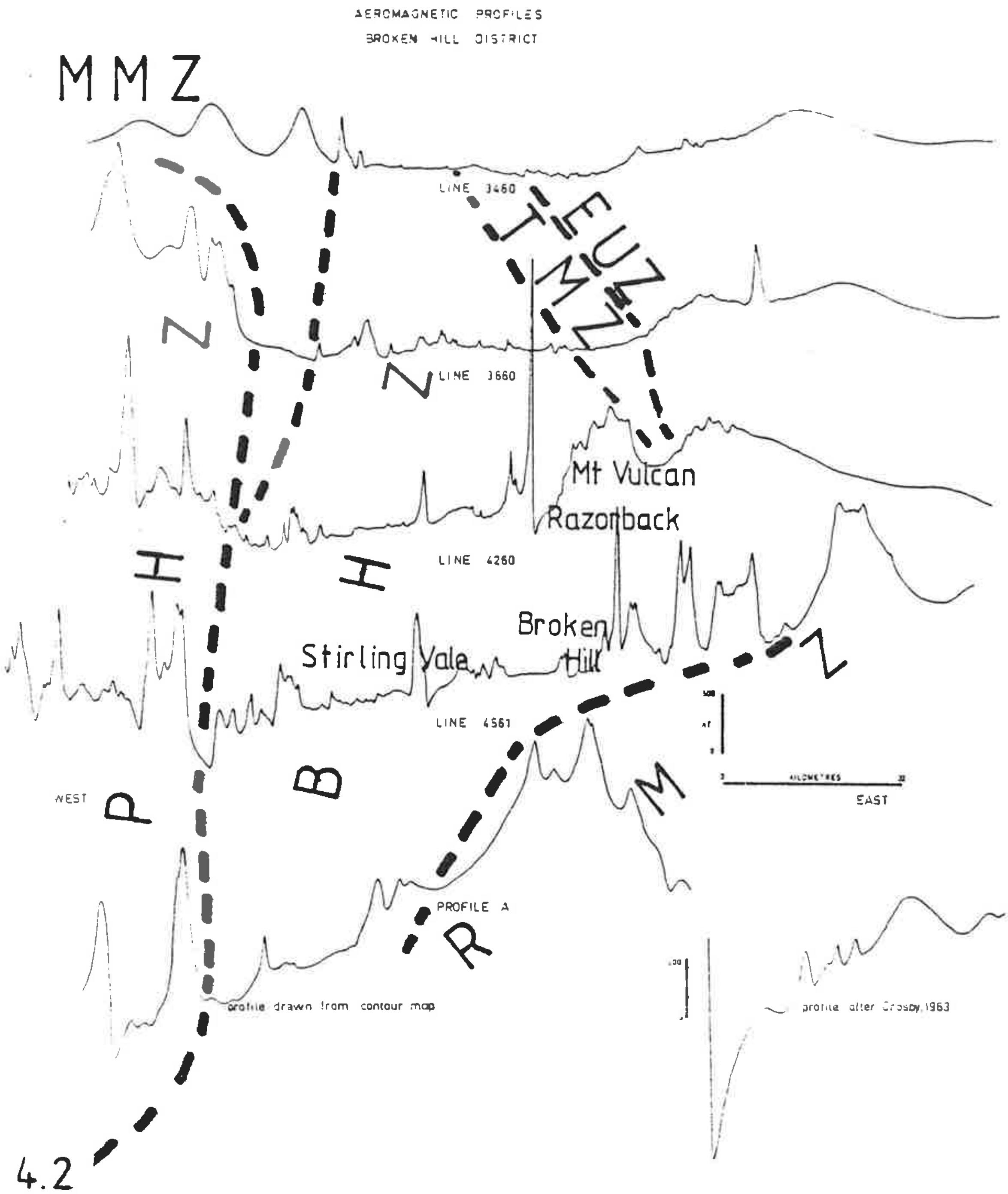



Figure 4.2

Representative magnetic profiles across the study area

### 4.1.3 Peak Hill Magnetic Zone

The Peak Hill Magnetic Zone (PHZ) lies west of the BHZ in an area almost entirely covered by unconsolidated Cainozoic sediments of the Mundi Mundi plain. The PHZ displays high gradients and peak anomaly amplitudes similar to those of the RMZ but shows some marked differences to the RMZ.

The background intensity level within the PHZ is very low since it lies largely within the regional magnetic low outlined by McIntyre and Wyatt. In addition to this it contains large areas of dominantly negative anomalies separted by generally sinuous positive peaks, contrasting the RMZ where relative magnetic highs cover most of the area. These differences are illustrated in the profiles of Figures 4.2 and Map 7, and in the coloured magnetic contour map (frontispiece), and possible reasons for the differences are discussed in Chapter 8.

The dominant trend direction of the contours is WNW with some strong NE trends also present. Depths to magnetic sources beneath the Mundi Mundi plain are commonly between 150 and 200 metres (see Map 5). An exploration diamond drill hole (by BH South) into a circular magnetic anomaly 8 km NW of Silverton (map 5) intersected an intrusive pyroxenite at 190 metres beneath the Mundi Mundi plain.

### 4.1.4 Mundi Mundi Magnetic Zone (MMZ)

North of the PHZ the Mundi Mundi magnetic zone shows an almost complete absence of near surface magnetic sources. A few, isolated anomalies are present which give some information on depth to magnetic 'basement' but the nature of this basement is uncertain. McIntyre and Wyatt (1978) found that source depths increase to the north from around 500 to over 1200 metres, and inferred the presence of Adelaidean and possible Palaeozoic sediments beneath the Cainozoic cover.

### 4.1.5 Torrowangee Magnetic Zone (TMZ)

The Adelaidean "Torrowangee Series" sediments lying in a narrow belt along the NE margin of the BH Block are clearly recognizable from their magnetic response. The Torrowongees generate a quite uniform pattern of low amplitude (less than 100 nT) anomalies having small areal extent and normally trending NNW. This noisy, weakly magnetic pattern is readily distinguishable from the more smoothly varying non-magnetic areas of the Willyama complex to the east and west, but is similar to the Willyama patterns associated with suites 6 and 7 in the far north of the study area.

Although the anomalies have low amplitudes, persistent horizons can be seen outlining major folds in the Adelaidean sediments (see Map 3, Fig. 4.1).

In the far northeast of the study area a small area of Adelaidean sediments from the "Caloola Synclinorial Zone" (McIntyre and Wyatt, 1978) is covered by the aeromagnetic survey. This small area shows very similar characteristics to the TMZ.

### 4.1.6 Euriowie Magnetic Zone (EUZ)

The Eurowie Block, although part of the Willyama complex, is considered to be a separate entity from the Broken Hill Block (Stevens et al, 1979), and is generally regarded as a horst block bounded by the Corona fault to the west and an unnamed fault to the east (e.g. Rose, 1968). The magnetic response associated with the Euriowie Block bears little resemblance to that of the major part of the BH Block. Very patchy anomalies are distributed irregularly throughout the zone. There are no persistent linear anomalies although there is an apparent preferred NW trend in the magnetic contours. In the NE part of the BH Block in the Yanco Glen-Allendale area, geological and magnetic trends bend to the NW and the magnetic pattern becomes irregular. In terms of magnetic response, this area is not unlike the EUZ so that although the BHZ and the Euriowie Block are seen geologically as separate tectonic units, there are some grounds for correlating the northeastern part of the BH Block with the Euriowie Block.

Newmont Pty. Ltd. (Clarke, 1977) reported BH type Lode Horizon in the southern part of the Euriowie Block. No detailed aeromagnetic data is available in this area.

### 4.1.7 Eaglehawk Magnetic Zone (EHZ)

Southeast of the RMZ the aeromagnetic data (Map 3, Fig. 4.1) shows an area of quite outstanding NE trending linear anomalies with source depths in the range 100 to 700 metres.

The boundary between the EHZ and the RMZ is very sharp and has a very pronounced magnetic low associated with it. The boundary has been considered by authors such as Rayner (1949), Archibald (1973) and McIntyre and Wyatt (1978) to represent a major fault (the Redan Fault), with substantial downward displacement in the SE side. This idea has rarely been questioned sice the magnetic feature called the "Redan fault" approximately marks the most southerly margin of Willyama Complex outcrops. (There are certainly no Willyama outcrops SE of the "Redan Fault"). Gravity however suggests that the Redan Fault is not a normal fault. A detailed interpretation of this area is presented in Chapter 7.

## 4.2 Magnetic Zone Boundaries

### 4.2.1 Northeastern Boundaries

The Corona fault marks the SW boundary of the Euriowie Block, separating it from the Adelaidean sediments of the Torrowangee zone. The fault is clearly recognizable from the aeromagnetics as a lineament across which a marked change in magnetic response occurs. The southern limit of the fault is difficult to pinpoint because of a gap in the detailed aeromagnetic coverage. It is probable that the Corona fault extends SE to intersect the Redan fault.

The NE boundary of the BHZ parallels the Corona fault but is an unconformity between the Willyama and the younger Adelaidean cover. The unconformity is marked by a distinct change in magnetic character and by a group of anomalies, north of Yanco Glen which run parallel to the unconformity and lie very close to it. Apparent continuity of some of these anomalies across the mapped position of the unconformity implies that the anomalies stem from sources within the Willyama rocks which underlie the Adelaidean at shallow depths beneath a shallowly dipping unconformity.

That the anomalies from within the Willyama parallel the unconformity is probably a consequence of the change in regional structural grain in the NE of the BH Block from NE to NNW. The Torrowangee zone, although having major Adelaidean fold axes running generally NS is bounded by features which parallel the older Willyama structural trends (see Glen et al, 1977, for a discussion of regional pre Cambrian tectonics of the Willyama Complex).

It is possible, however, that the magnetic anomalies lying on the Adelaidean side of the unconformity are generated by the basal Torrowangee beds. In the Brewery Well (C8) area, metamorphosed basic material which has been interpreted as basal Adelaidean lava flows unconformably overlying the Willyama (Laing, 1969), produces strong magnetic anomalies along the Torrowangee unconformity. T. Dickson (pers. comm., 1978) has suggested that the Torrowangee anomalies may be due to magnetite in the basal Adelaidean sediments. Observations, at a more detailed scale than the one used here, are required to resolve this question.

The trace of the unconformity vanishes from the aeromagnetic map south of Yanco Glen where, although major (BH Zone) NE trends are greatly attenuated, continuations are seen to persist beneath the mapped Adelaidean cover, suggesting that the cover is very thin in this area.

### 4.2.2 Western Boundaries

Although geologically (and also topographically) the Western limit of the Broken Hill Block appears to be a simple fault, the aeromagnetic data shows that it is a very complex boundary. The Mundi Mundi scarp, assumed to be a fault despite debate about the absence of direct geological evidence of faulting, extends north from around Thackaringa homestead for a distance of around 60 km where it appears to be offset slightly by the Kantappa lineament (Rose, 1968). Although the Mundi Mundi fault can be traced, for most of its length from the aeromagnetic map, its effect on the magnetic pattern varies from south to north (see Map 3 and Map 5).

Southern Parts of the Mundi Mundi Fault

To the south, the Mundi Mundi fault, although retaining its topographic expression, becomes subsidiary to the magnetic boundary between the PHZ and BHZ.

In the Peak Hill (L4) and Umberumberka (J4) mine areas, two major shear zones cross cutting the Mundi Mundi fault coincide precisely with the abrupt boundary between highly magnetic PHZ rocks and less magnetic rocks of the BHZ. Attempts to model these segments were unsuccessful due to the noisy magnetic response and the strong regional gradient seen in the BHZ. However, the very steep gradients and the absence of a pronounced negative component in the magnetic anomaly suggest that the boundary dips steeply to the east with a thickness of magnetic material likely to exceed 3000 metres.

South of Peak Hill the PHZ/BHZ boundary is extremely well defined and the aeromagnetic data (Fig. 4.1) of S.A.D.M.E. (1977) shows that it continues southward before being terminated by the MacDonald shear zone, which is the major boundary between the Willyama complex and the Adelaidean rocks in South Australia. The data here suggests that the PHZ is part of the Olary Block and hence the PHZ/BHZ boundary is proposed as a destinctive boundary between the Olary and Broken Hill Blocks.

Between Peak Hill and the MacDonald shear (Fig. 4.1) zone the PHZ boundary is segmented by WNW trending features which generally coincide with recognized shear zones (e.g. Thackaringa - Pinnacles and Pine Creek Shears). The aeromagnetic pattern suggests that there may have been substantial movement along these zones although it has not been possible to differentiate lateral and vertical movement from the aeromagnetics. Both and Rutland (1976) refer to a dextral movement on the Thackaringa - Pinnacles Shear of "several kilometres". There is an apparent dextral displacement of around seven kilometres in the NE trending PHZ/BHZ boundary across the Thackaringa - Pinnacles shear near the S.A./N.S.W. border.

Between the Umberumberka Mines (J4) and Mundi Mundi Creek (F5) the PHZ/BHZ boundary becomes harder to trace but is visible from a distinct change in background gradients (see Fig. 4.2, profile 4260). This section of the boundary coincides with the King Gunnia shear zone (I5) (Stevens, 1979) but is broken by a discordant magnetic feature which trends EW, cross cutting observed geological trends and surrounding magnetic trends. This is interpreted as a subsurface body of intrusive 'Mundi Mundi' granite. The discordant pattern of the magnetic contours here is similar to the effect caused by the large Mundi Mundi granite body at Brewery Well, although the latter body intrudes into very weakly magnetic rocks. Quite substantial amounts of Mundi Mundi granite have, in fact, been mapped (Stevens, 1979) within the area of the proposed intrusive body.

The area between the Mundi Mundi fault and the King Gunnia schist zone (the Umberumberka area) and the outcrop area west of Peak Hill almost certainly expose the highly magnetic rocks of the PHZ. While precise depth determinations within this complex magnetic area are difficult, the steep gradients observed suggested that magnetic sources are very close to the surface if not outcropping. The mapping of Stevens shows the Umberumberka area to comprise a complex assemblage of quartz and feldspar rich rocks which are not readily correlated with main BH Block stratigraphy. Stevens groups together in one complex zone rocks which he possibly correlates with suite 1, 2, 3 and 4, whereas Willis (1979) in the Peak Hill area interprets the rocks inferred here to be part of the PHZ as suite 1 or possibly suite 3.

Common to both areas are an abundance of quartzofeldspathic rocks with much pegmatitic and/or migmatitic material and the aeromagnetic data suggests that the rocks are moderately to strongly magnetic.

West of the Mundi Mundi fault depths to magnetic sources generally lie between 150 and 200 metres. A drill hole by Broken Hill South Limited centred on an outstanding circular magnetic anomaly encountered pyroxenite at around 190 metres (McIntyre and Wyatt, 1978). A reconnaissance gravity line traversed the magnetic anomaly and showed a "coincident" high of around 5 milligals. The geophysical data indicate a plug-like form for the pyroxenite, and it is related to the exposed post Willyama basic intrusives which are common in the southern part of the BH Block.

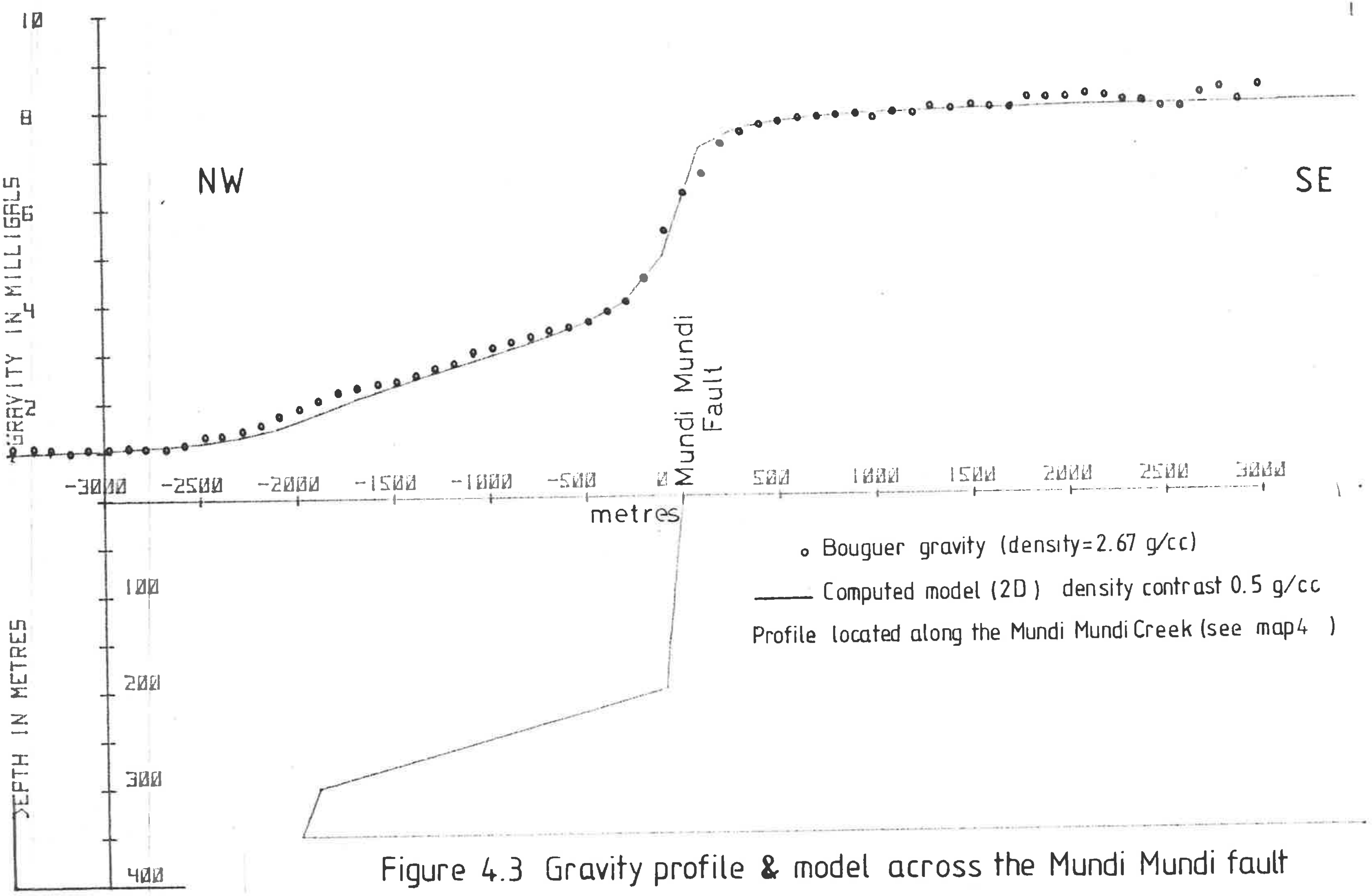
North Mundi Mundi Fault

North of Mundi Mundi Creek the fault clearly coincides with a marked change in magnetic gradients. West of the fault much lower gradients are observed, the main features being two discrete anomalies which yield source depths of 900 and 1050 metres (map 5) from simple 2-D modelling. The deeper of these sources follows a trend continuous with the strongly magnetic Diamond Jubilee Structure which consists of suite 1 type Willyama rocks. It is inferred that the deep magnetic sources in this area beneath the Mundi Mundi plain are from Willyama rocks.

A gravity traverse was conducted across the fault in the vicinity of Mundi Mundi Creek to further investigate the nature of the non magnetic material within the MMZ. Figure 4.3 shows the profile and a simple model computed to fit the data. The results show the Mundi Mundi fault, as apparent from the topographic scarp, to be associated with a steep change in gravity of four milligals which can be explained by a density contrast of 0.5 g/cc and a vertical throw of 200 metres. A further gradual westward decrease in gravity is modelled as a thickening of the low density cover to around 350 metres. Models with small density contrasts and larger thicknesses were found incapable of matching the observed data.

The implication of the gravity interpretation is that there is relatively unconsolidated material to a depth of no more than 350 metres beneath the Mundi Mundi plain leaving a "gap" of around 700 metres between the depth to "basement" inferred from gravity and that inferred from aeromagnetics. That is there is a thickness of some 700 metres of relatively non magnetic material overlying the inferred Willyama magnetic sources. This material has, however, a density close to that of the Willyama. On the basis of Tucker's (1973) density measurements and the proximity of Adelaidean rocks to the north (see map 2), it was considered likely that the denser non-magnetic rocks underlying the unconsolidated sediments of the Mundi Mundi plain were Adelaidean sediments.

Subsequently, North Broken Hill Pty. Ltd., explored for base metals beneath the Mundi Mundi plain. Three gravity traverses were carried out which showed the Mundi Mundi fault to be quite uniform in gravity response. One diamond hole was drilled on each gravity line. Maps 4 and 5 show the location of the holes and figure 4.4 shows how they relate to the gravity profiles. The northern hole (Willangee, A7) confirms the existence of Adelaidean rocks beneath Cainozoic clays and silts but, in the Eldee hole (E6) inferred Willyama rocks were encountered. However no definite Willyama rocks were identified as W. Leyh's (1980)




∘ Bouguer gravity (density=2.67 g/cc)

—— Computed model (2D) density contrast 0.5 g/cc

Profile located along the Mundi Mundi Creek (see map4 )

Figure 4.3 Gravity profile & model across the Mundi Mundi fault

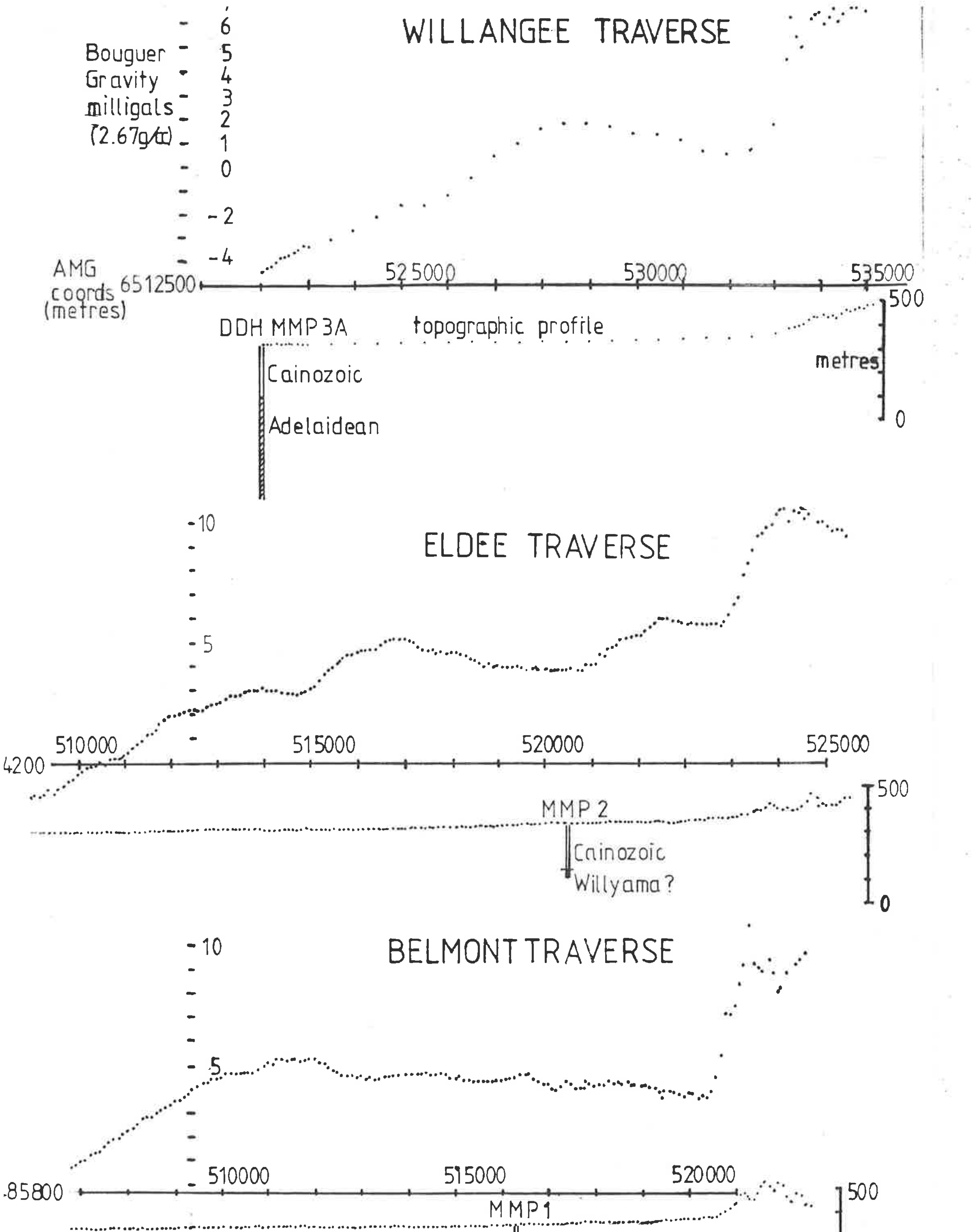



Figure 4.4

orth Broken Hill Pty Ltd gravity profiles
cross the MundiMundi fault

remarks on the drill log indicate - "Hole intersected interpreted highly decomposed schist of Willyama Complex from 215 - 229.5 m" (bottom of hole). The Belmont (I4) hole also intersected schists of probable Willyama origin. This is consistent with the magnetic interpretation of Willyama (PHZ) rocks beneath the plain in the Belmont area.

PHZ/MMZ Boundary

The boundary between the PHZ and the MMZ is seen in the Regional BMR aeromagnetics and in the S.A.D.M.E. surveys west of the N.S.W./S.A. state border. It is difficult to precisely define because the magnetic material associated with the PHZ is evident at moderate depths (c. 500 metres) for a distance of at least 10 km north of the EW fault (proposed by McIntyre and Wyatt) which marks the northern limit of shallow magnetic sources beneath the Mundi Mundi plain). The magnetic source depths (map 5) suggest a gradual deepening of PHZ rocks north of the proposed fault. A simple interpretation of the PHZ/MMZ boundary is an unconformity between PHZ and Adelaidean rocks.

Summary

The aeromagnetic and gravity data, therefore yield a complex picture of the Mundi Mundi fault (Fig. 4.5). West of the observed scarp a relatively uniform thickness of 150-200 metres of Cainozoic cover is inferred from gravity (north) and magnetic (south) data and this is confirmed from drilling. Depths to magnetic basement, however, suggest a "displacement" of around 1000 metres in the north which is not apparent in the south where magnetic features actually cross the scarp (Fig. 4.1). The highly magnetic PHZ rocks appear to directly underlie the cover in the south and are inferred to outcrop in the Umberumberka and Peak Hill areas east of the fault scarp. The large (c. 800 metres) thickness of non-magnetic material lying between probable BHZ rocks and cover in the northern Mundi Mundi plain is almost certainly predominantly Adelaidean, since

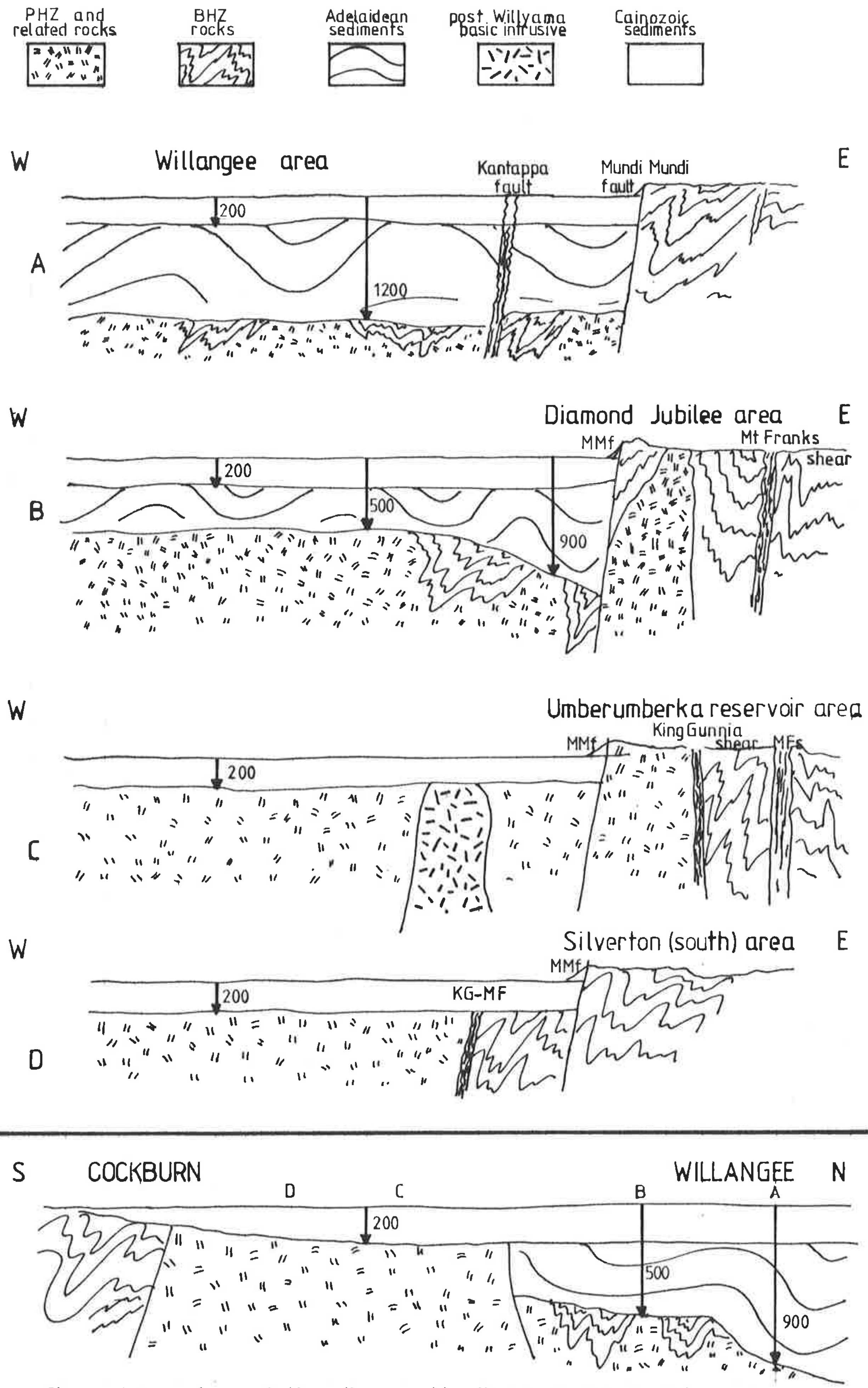



figure 4.5 Interpretation diagram, Mundi Mundi plain (not to scale)

Adelaidean rocks are present immediately north of the Kantappa fault, and have been encountered in a drill hole (Willangee) south of the Kantappa fault.

Fig. 4.5 illustrates the relationships between the PHZ, BHZ and MMZ, in the NW of the study area.

### 4.2.3 BHZ/RMZ Boundary

The boundary between the BHZ and the RMZ (Fig. 4.1) is very distinct and extends from SW of the study area in S.A. north east to the Corona fault zone where it fades, presumably due to deepening Adelaidean cover in the area. The boundary consists of long linear segments except in the Farmcote (N14) area where its trace appears to be strongly influenced by the neighbouring BHZ fold trends in the Rockwell (M13) area. In the Farmcote area magnetic trends within the RMZ also parallel the Rockwell structures inferring that the RMZ have been folded in the same manner as the BHZ.

The boundary is exposed in the Oakdale-Sentinel (S4) area where it marks a change in stratigraphy from suite 4 (Mine Sequence) to inferred suite 3 rocks which lie within the RMZ. In this area, the boundary lacks the abruptness seen to the northeast which may indicate that it is partly covered by non-magnetic BHZ rocks. That this area is not typical of the BHZ/RMZ boundary is alo evident around Oakdale where two magnetically 'flat' areas occur within the RMZ. These are the only flat-magnetic areas within the extensive RMZ and they display contour trend directions quite different to those seen elsewhere in the RMZ ( Map 3, Map 5). As discussed in Chapter 7, this area is also anomalous in its gravity response.

The boundary is also exposed in the Farmcote area but no detailed mapping is available from this area.

In the Balaclava area (P7) and at Quartz Reef (M16) the RMZ/BHZ boundary is sufficiently isolated from interfering magnetic sources to facilitate modelling. Models for both areas have been computed using the data from BMR (survey No. 6). In both areas the models suggest that the RMZ rocks dip at moderate angles beneath the BHZ (Fig. 4.6). This is a significant result because it implies that the highly magnetic RMZ rocks physically underlie the BHZ over a large area. The models also suggest that the vertical thickness of the RMZ rocks is at least 4,000 metres, that is, in the same order as the estimated thickness of the similarly magnetic PHZ rocks.

East of Quartz Reef a broad oblong NS trending anomaly is interpreted as a continuation of the RMZ, although it lacks the extremely variable pattern seen in the RMZ to the SW. Models for this anomaly suggest it is caused primarily by a prism shaped body at a depth of 500-600 metres below the surface. This is evident from the simple 2-D dyke models shown in figure 4.7. Clearly there are shallower sources associated with this anomaly and, to account for these, simplistic 2-D Talwani models were computed for lines 4660 and 4710.

Considering the crude nature of the model, quite good agreement was achieved between the observed and computed data. The shallow sources integrated into the basic model extend to within 150 metres of the surface. No attempt has been made to match the fine detail of these profiles but clearly sources shallower than those indicated in the Talwani models exist. Rule of thumb (Peters Length) depth estimates on the sharpest peaks suggest that many of the sources are within 50 metres of the surface. There is however, no outcrop mapped in the area.

Geologically, the source of this anomaly is grouped with the RMZ rocks because of its similarity in magnetic intensity and gravity "response" (see Chapter 7). Notably, the apparent magnetic susceptibility evident in the models of Fig. 4.7 are of the same order as those used for the

RMZ/BHZ boundary models (Fig. 4.6). On the broader scale, the coloured magnetic map (frontispiece) shows no signficant break in continuity or general response between the two areas. Likewise, the gravity variations over this magnetic feature show a dominant low enclosing subordinate highs: similar to the pattern observed in the RMZ area to the SW.

### 4.2.4 RMZ/EHZ Boundary - "The Redan Fault"

The striking "step-like" magnetic feature termed the Redan Fault (Rayner, 1949) marks the boundary between the RMZ and the EHZ. The geophysical interpretation of this feature has a large bearing on the geological nature of both of these magnetic zones since there is no pre Cainozoic outcrop along the Redan Fault or to the SE of it. While the magnetic profiles across the "fault" and corresponding computer models (fig. 4.8) suggest it is a simple steeply dipping boundary with a lateral magnetic contrast over at least 4 km of depth, gravity variations in this region paint a quite complex picture. For this reason the interpretation of the Redan Fault and the EHZ is presented with the interpretation of the regional gravity data in Chapter 7.

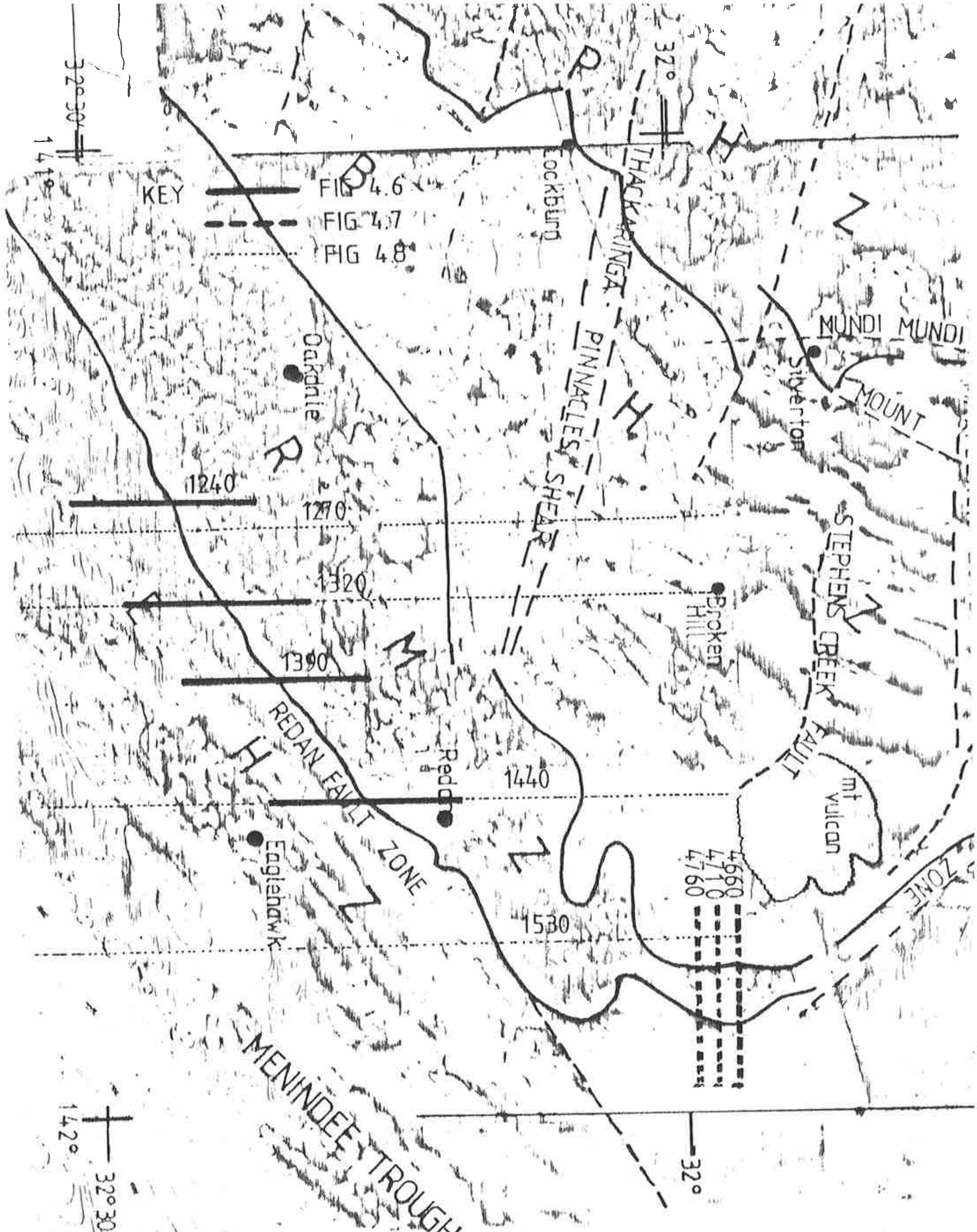



Figure 4. 6A Location of modelled magnetic profiles shown in figures 4. 6, 4.7 and 4.8

0 5 10 15 20 25

Kilometres

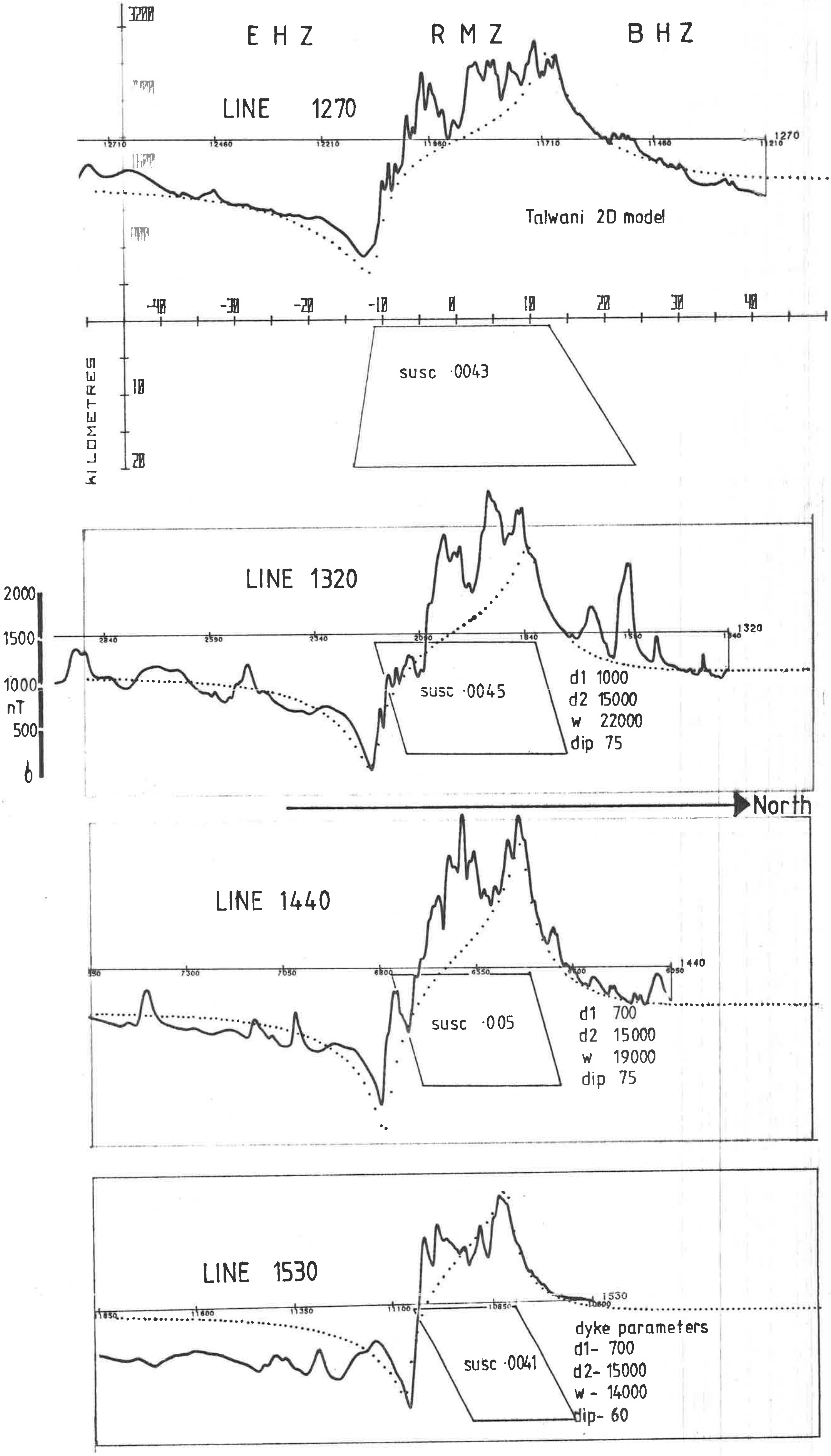
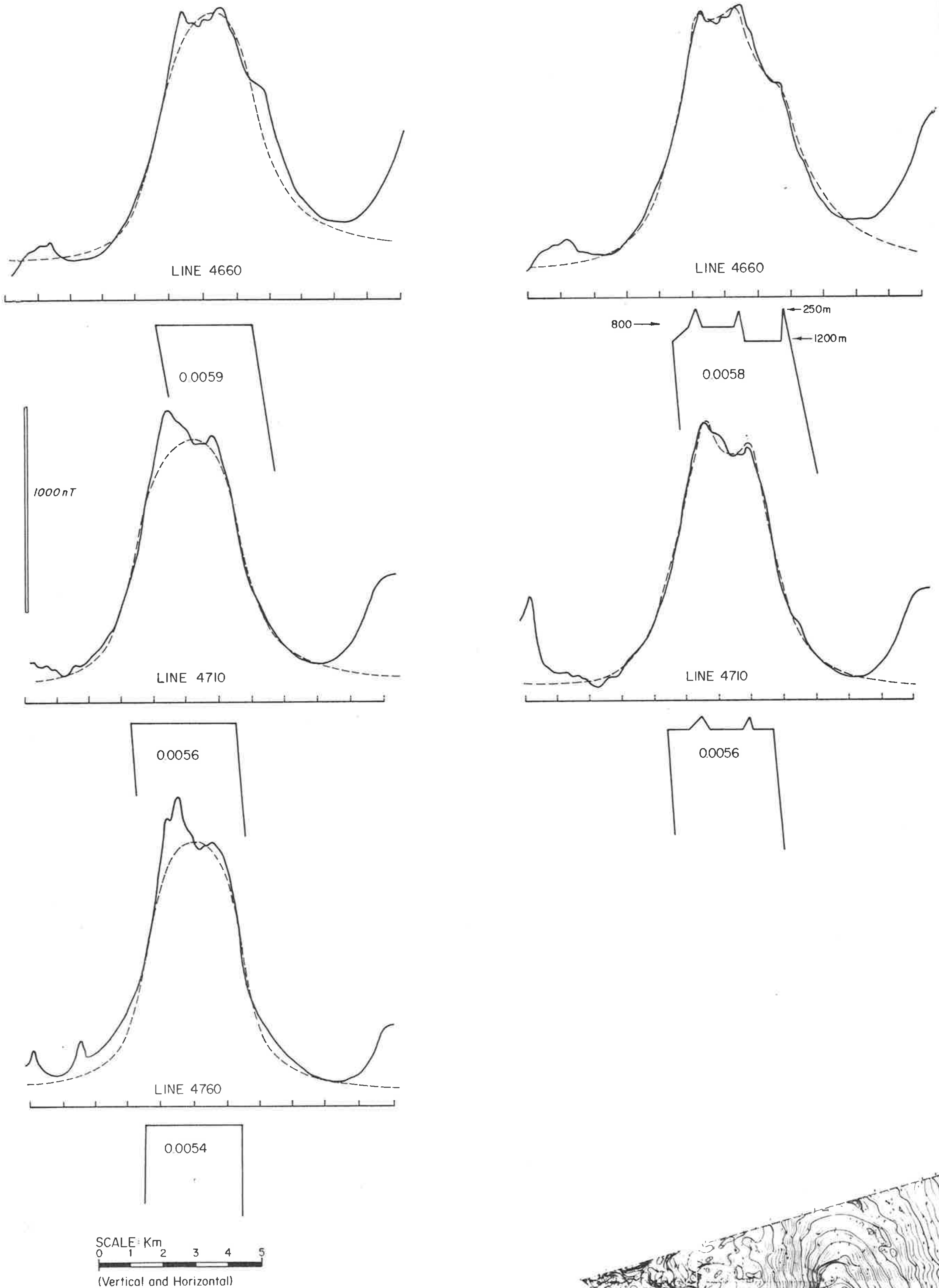
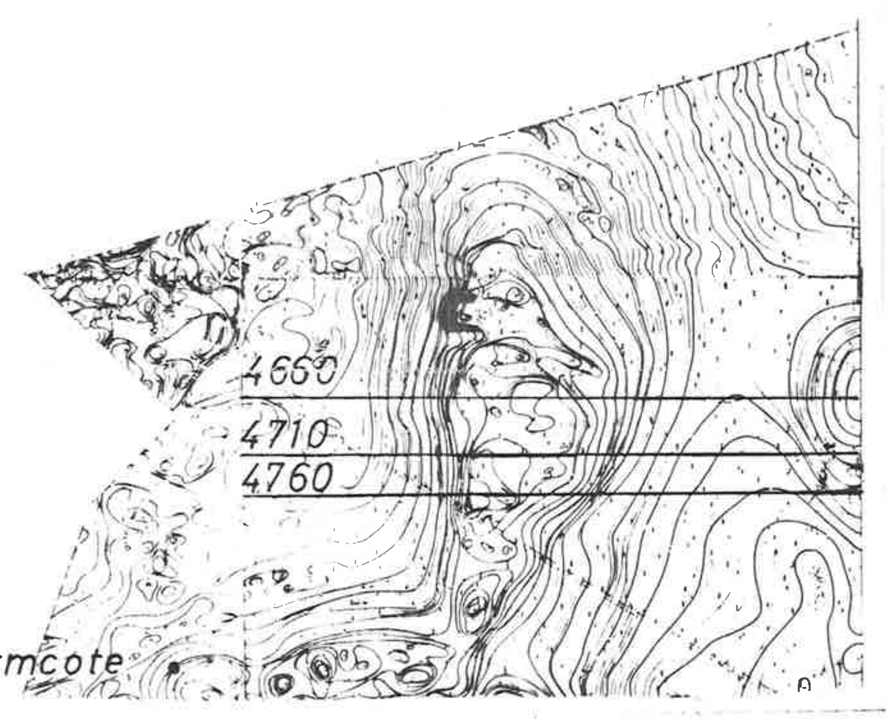



Figure 4.6 Magnetic profiles across the RMZ (from BMR,1982) showing simple block models computed to determine the nature of the BHZ / RMZ boundary. Distance scales (h&v) 1: 500,000




# MAGNETIC PROFILES AND 2-D MODELS NORTHEASTERN RMZ

NOTE: ALL PROFILES WEST TO EAST

BASE LINE REPRESENTS SENSOR ALTITUDE (75 m. ABOVE GROUND LEVEL)

MODEL PARAMETERS ARE GIVEN IN TABLE 4.1

figure 4.7

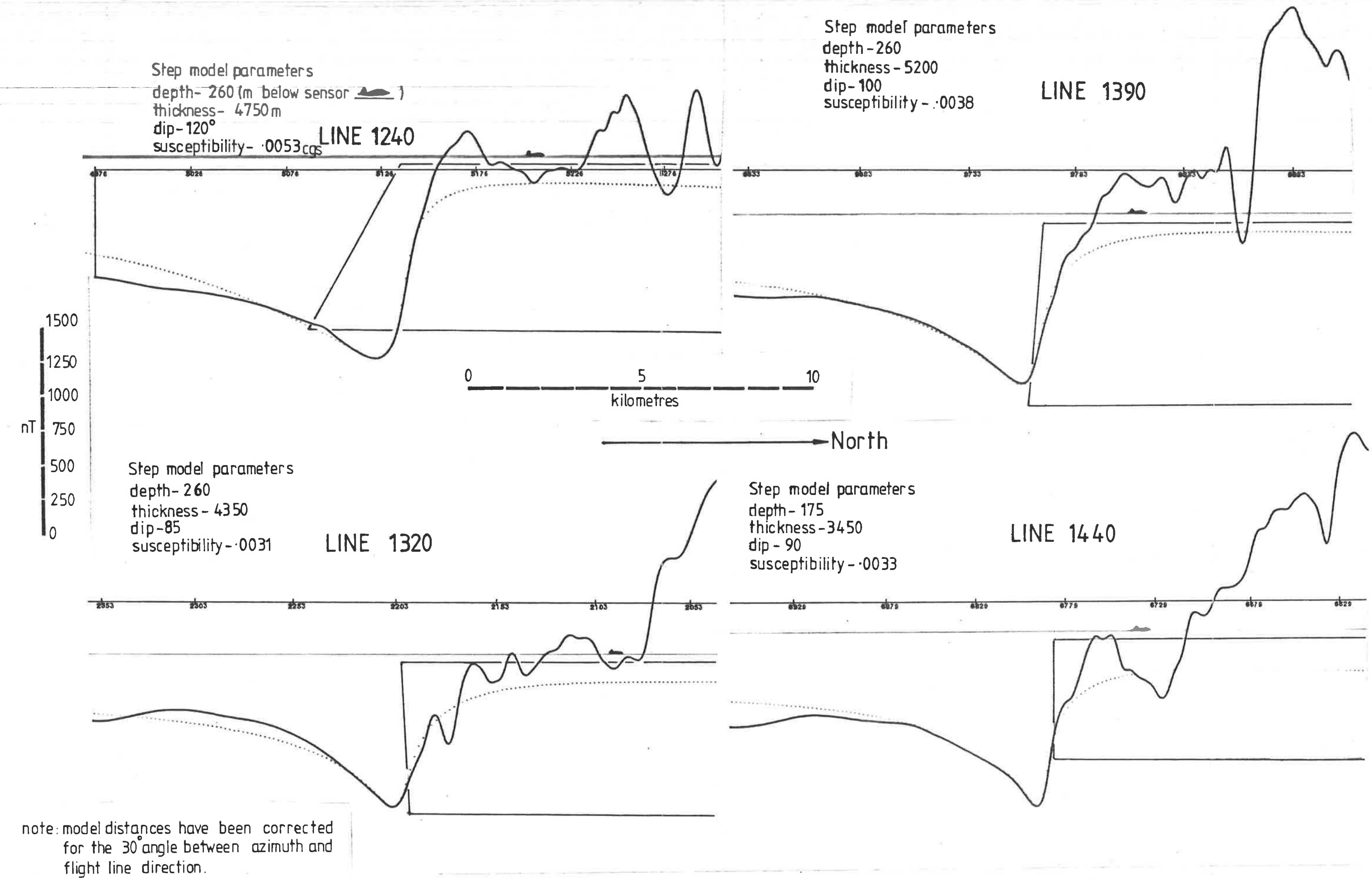



Figure 4.8 Modelled magnetic profiles across the Redan fault. Measured data (solid line) is from BMR 1982, computed model is due to a 2D step (dots).

# 5 THE BROKEN HILL MAGNETIC ZONE

The Broken Hill magnetic zone covers around 90% of the exposed area of the Broken Hill Block. It is typefied by discrete and commonly linear magnetic anomalies which closely follow structural trends. The detailed work of McIntyre (1979) has shown, in four of the more prominent magnetic areas of the BHZ, that anomalies are due to stratigraphically bound magnetite rich (1 or 2%) horizons which may be used as stratigraphic markers. Comparisons on a regional scale of the metamorphic suite map (Map 2) with the aeromagnetic map (Map 3), described in this chapter, show that magnetic anomalies rarely cross interpreted stratigraphic boundaries and furthermore, nearly all of the prominent magnetic anomalies appear to be caused by rocks lying within a quite narrow stratigraphic interval. With the exception of suite 2 which, as mapped, is magnetically heterogeneous, the metamorphic suites display characteristic magnetic patterns. In addition to the systematic distribution of magnetic horizons through the stratigraphy the abundance of magnetite within these horizons is controlled by a well defined spatial zoning which forms the basis for a subdivision of the BHZ into four magnetic "domains" (Fig. 5.1).

Although these magnetic domains do not conincide with any recognized geological subdivision they are interpreted to reflect subtle differences in rock compositions which may be related to different depositional environments.

## 5.1 Central Domain

The most highly magnetic of the BHZ subdivisions is centred around Broken Hill city. It is dominated by strong and persistent linear anomalies with amplitudes normally between 300 and 600 nT. The southern boundary of this "Central Domain" is the Thackaringa-Pinnacles shear, south of which magnetic anomalies lack the linear continuity evident in the Central Domain and are much lower in

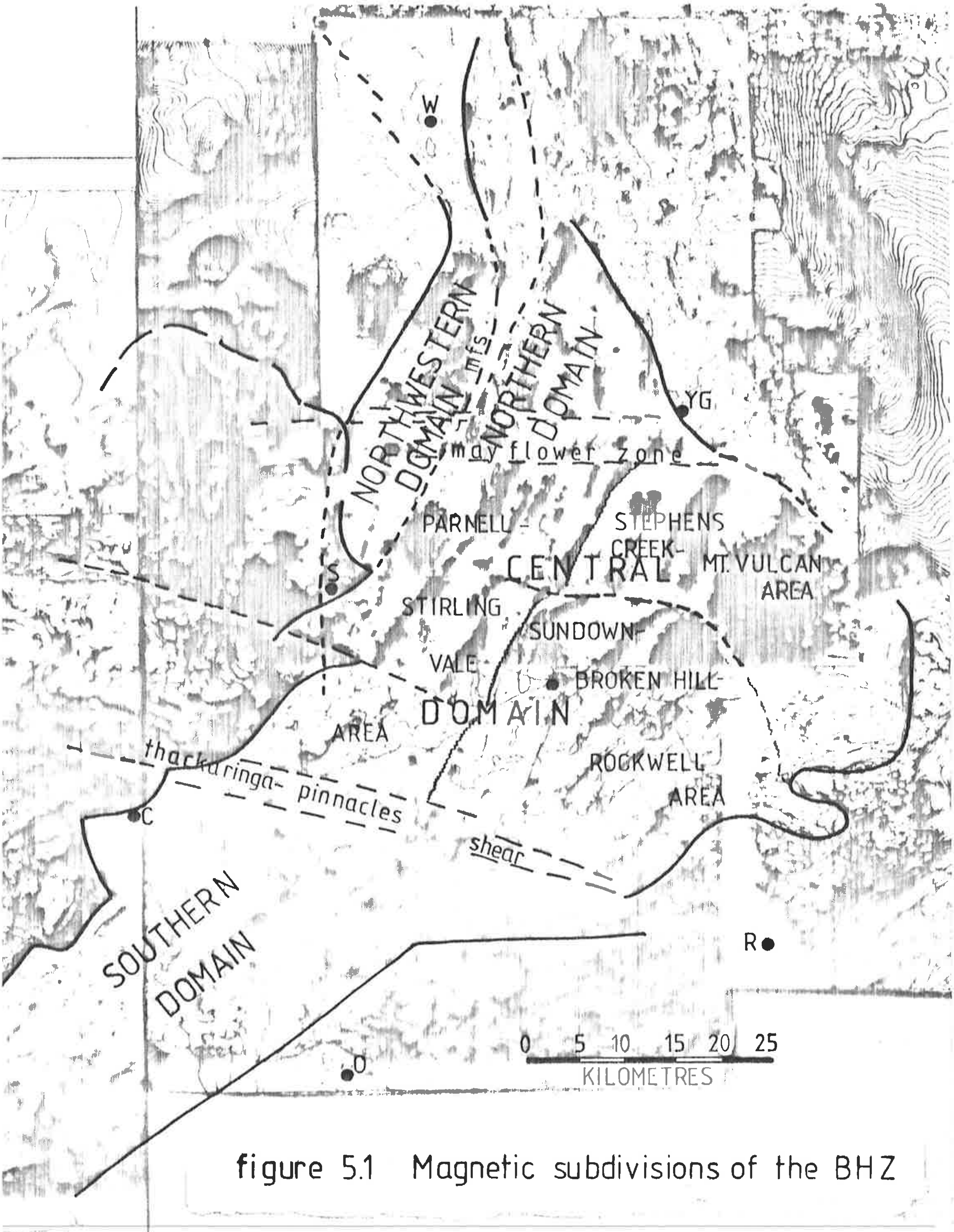



figure 5.1 Magnetic subdivisions of the BHZ

# KEY TO FIGURES 5.2, 5.4, 5.6, 5.7, 5.8, 5.9

Post Willyama basic intrusive

Mundi Mundi granite

**WILLYAMA COMPLEX**

7 Quartzite suite

6 Graphitic metasediment suite

5 Pelite suite

4 "Mine sequence" suite

3 Quartzo-feldspathic rock suite

2 Composite gneiss suite

1 Migmatite suite

Redan gneiss

Suite boundaries

Suite boundaries approximate

Interpreted lateral continuation of suite boundaries

Schist zone boundaries

Fault

Folds: plunge, antiform, synform

Trend of lithological unit within suite

Unconformity

Chemical sediment horizon

**MAGNETIC INTERPRETATION**

Magnetic zone boundary

Magnetic contour lineation

Discrete magnetic horizon

Complex magnetic feature

NOTE: The Geological base is the stratigraphic interpretation map of Stevens et al 1979 amplitude. The northern boundary is marked by an EW trending feature along which several major magnetic horizons terminate (Fig. 5.1).

The major structural features in the Central Domain are clearly outlined by magnetic horizons. Comparison of the stratigraphy and aeromagnetics has been carried out in three sub areas of the Central Domain which broadly constitute structural subdivisions.

### 5.1.1 Sundown - Broken Hill - Rockwell Area

This area is dominated by large scale downward facing structures such as the Sundown Antiform, the Broken Hill Synform (Majoribanks et al, 1977) and the Little Broken Hill Fold (Bradley, 1979). The major antiform in the Clevedale-Thorndale (L12) area is regarded by Majoribanks et al as the centre of generation of the F1 (first phase) folds (see Fig. 2.6).

The Broken Hill synform is outlined by two prominent magnetic horizons (fig. 5.2). The horizon in the Rupee area marks the closure of this structure and although the magnetic anomaly lies close to mine sequence rocks (suite 4) it appears to be largely if not wholly generated from suite 5 rocks close to the suite 5/suite 4 boundary. This folded horizon either terminates or is greatly attenuated in the vicinity of the North mine where it meets the de Bavay shear. It is bounded to the west by the Rupee shear zone.

Magnetic horizons in the same stratigraphic position occur on the western limb of the Hanging Wall synform and further west in the Sundown antiform.

The other prominent horizon in the BH synform lies in metasedimentary gneisses in the upper part of suite 3.

The Thorndale Magnetic Complex in the Thorndale-Clevedale area immediately east of the BH synform outlines the F1 anticlinal structure regarded by Majoribanks et al (1977)

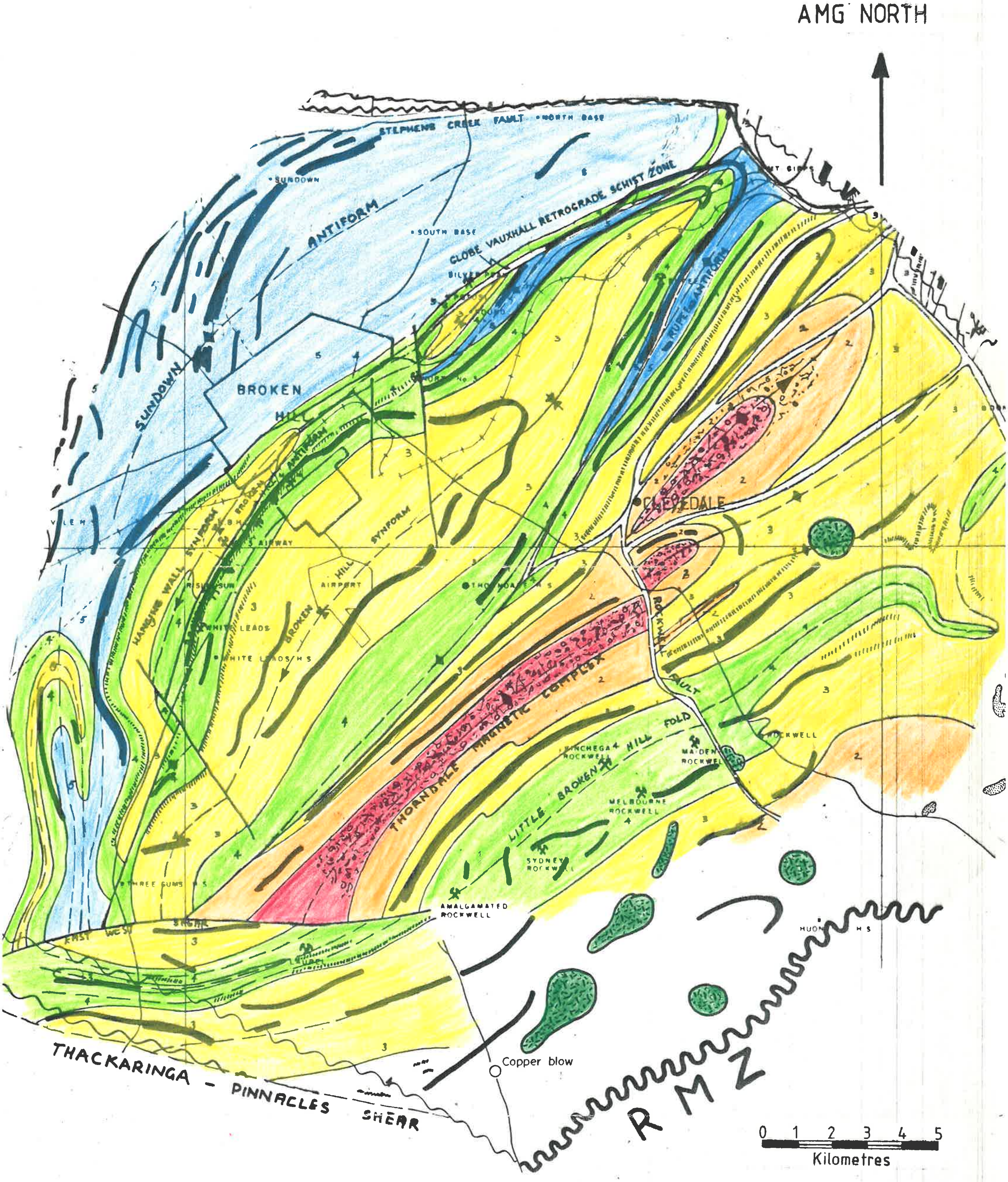



figure 5.2 SUNDOWN-BROKEN HILL-ROCKWELL area (CENTRAL DOMAIN)
Magnetic interpretation superimposed on interpreted geology.

as the central zone of deformation in the Sundown-Broken Hill-Rockwell area (Fig. 2.6). The antiformal core of the anticline is formed by suite 1 migmatite rocks which are moderately but quite uniformly magnetic. The interpreted gentle plunge to the north of the antiformal core north of Clevedale (Bradley, 1979) is supported by the continuation of the "suite 1" magnetic anomaly beneath non-magnetic suite 2 rocks. The core to the south of Clevedale is interpreted by Bradley to plunge steeply to the north and this is also evident from the magnetic anomaly which terminates absruptly.

In the southern part of the Thorndale Complex the bottom of suite 2 is marked by a very strong magnetic horizon which occurs only on the western side of the anticline. On the eastern side the mapped equivalent suite 2 rocks are non magnetic and the change from magnetic to non magnetic within these rocks occurs at the nose of the anticline. Several other mangetic horizons mapped on figure 5.2 occur on one limb of major folds. It is noteworthy that three outstanding suite 3 'chemical sediment' horizons mapped by Bradley (1979) similarly 'lens out' at anticlinal noses (see FIg. 5.2). This may be a consequence of an original elongation of the sedimentary horizons in the present strike direction. Both and Rutland (1976) have noted this physical characteristic in the BH orebody itself.

The suite 3 horizon seen in the BH synform is also present on both sides of the Thorndale Complex, where again it lies close to the suite 3/suite 4 boundary. Magnetic horizons of variable intensity in this stratigraphic position can be found throughout most of the Sundown-BH-Rockwell area. Where this magnetic horizon is absent garnet quartz and quartz sulphide rocks are found in a similar stratigraphic position. It is quite possible that these represent non magnetic stratigraphic equivalents of the magnetite bearing horizons (Stanton, 1976).

The Thorndale Magnetic Complex terminates in the south near the EW shear, but while the horizons within the complex attenuate rapidly they do not appear to be truncated by the EW shear. There is an indication that the suite 3 horizon continues to the south of the Thorndale Complex, bending to the west and running parallel to the EW shear. Outcrop is very poor in this area and the magnetic anomalies present are in some cases discordant with interpreted geological trends. In the Rockwell-Copper Blow area (P11) magnetic horizons are again quite predominantly in suite 3 rocks and close to the suite 3/suite 4 boundary. A prominent belt of anomalies extends from east of Copper Blow northeast for a distance of around 10 km. The peaks in the south of this belt are irregular and, in part, appear folded. These anomalies are located at the bottom of suite 4. The northern part of this belt contains very high amplitude peaks which are almost certainly due to the outcropping post Willyama serpentinite intrusives. There are several small basic intrusive bodies scattered throughout the southern parts of the BH block and without exception these give rise to high amplitude magnetic anomalies (see Maps 2 and 5).

In summary, the Sundown-Broken Hill-Rockwell area contains rocks of suites 1 to 5. The suite 1 rocks are, without exception, moderately to strongly magnetic. Suite 2 is non magnetic except for one very strong quartz magnetite horizon in the Thorndale Complex. There is a major group of persistent magnetic horizons near the suite 3/ suite 4 boundary. Most of these appear to be located in the upper part of suite 3. The lower part of suite 5 contains magnetic horizons which generally produce lower amplitude anomalies than the suite 3/suite 4 group but are equally persistent laterally. Figure 5.3 illustrates this "magnetic stratigraphy".*

* The term "magnetic stratigraphy" is used to describe distribution of magnetic horizons through the various stratigraphic (metamorphic) suites.

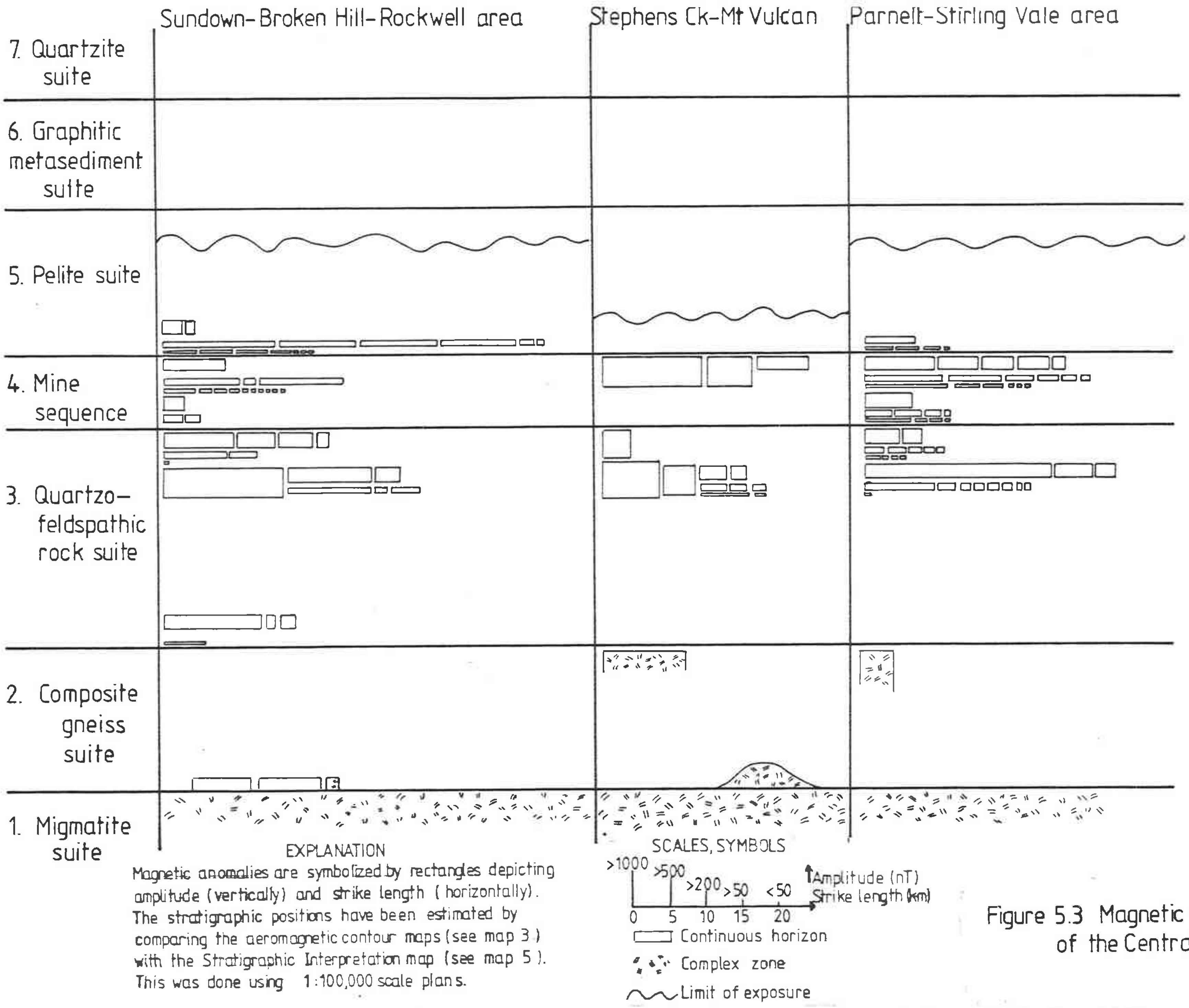



Figure 5.3 Magnetic stratigraphy of the Central Domain

### 5.1.2 Stephens Creek-Mt. Vulcan Area

The Stephens Creek fault system is a major geological break separating the complex "overturned" structural area of the Sundown-BH-Rockwell area from a domain of relatively broad upward facing structures whose geometry is controlled largely by upright F1 folds (Marjoribanks et al, 1977). No geological features span the Stephens Creek fault and it is conspicuous in the aeromagnetic map as a narrow zone where many prominent anomalies are truncated (Fig. 5.4).

The area north of this fault is dominated by two broad structures interpreted by Stroud (1979) to be north plunging antiforms. These structures expose largely suite 2 and suite 3 rocks and are separated by a synform containing rocks of suites 4 and 5.

The Mt. Vulcan antiform area has been studied by McIntyre (1979) who found that strong magnetic anomalies were broadly conformable with the mapped structure in the core of the antiform but were markedly discordant to the NE. He interpreted the discordant anomaly as being due to an underlying antiformal core (Fig. 5.4) and proposed a minor synform between this structure and the Mt. Vulcan antiform.

The magnetite bearing rocks in the core of the Mt. Vulcan antiform lie in the lower parts of suite 2. The very sharp boundary between highly magnetic and non magnetic composite gneisses on the western limb of the antiform is not recognized in any form as a geological boundary. This can be explained by the observed abundance of quartz magnetites in the core of the antiform and the absence of QM's in the west. The magnetic boundary must then be regarded as a major stratigraphic 'line' above which no QM's are present and below which they are common. The overall magnetic nature of the composite gneisses in this area has been regarded by McIntyre as an effect of their deposition in an 'iron rich' environment characterized by the development of quartz-magnetites (see McIntyre, 1979)

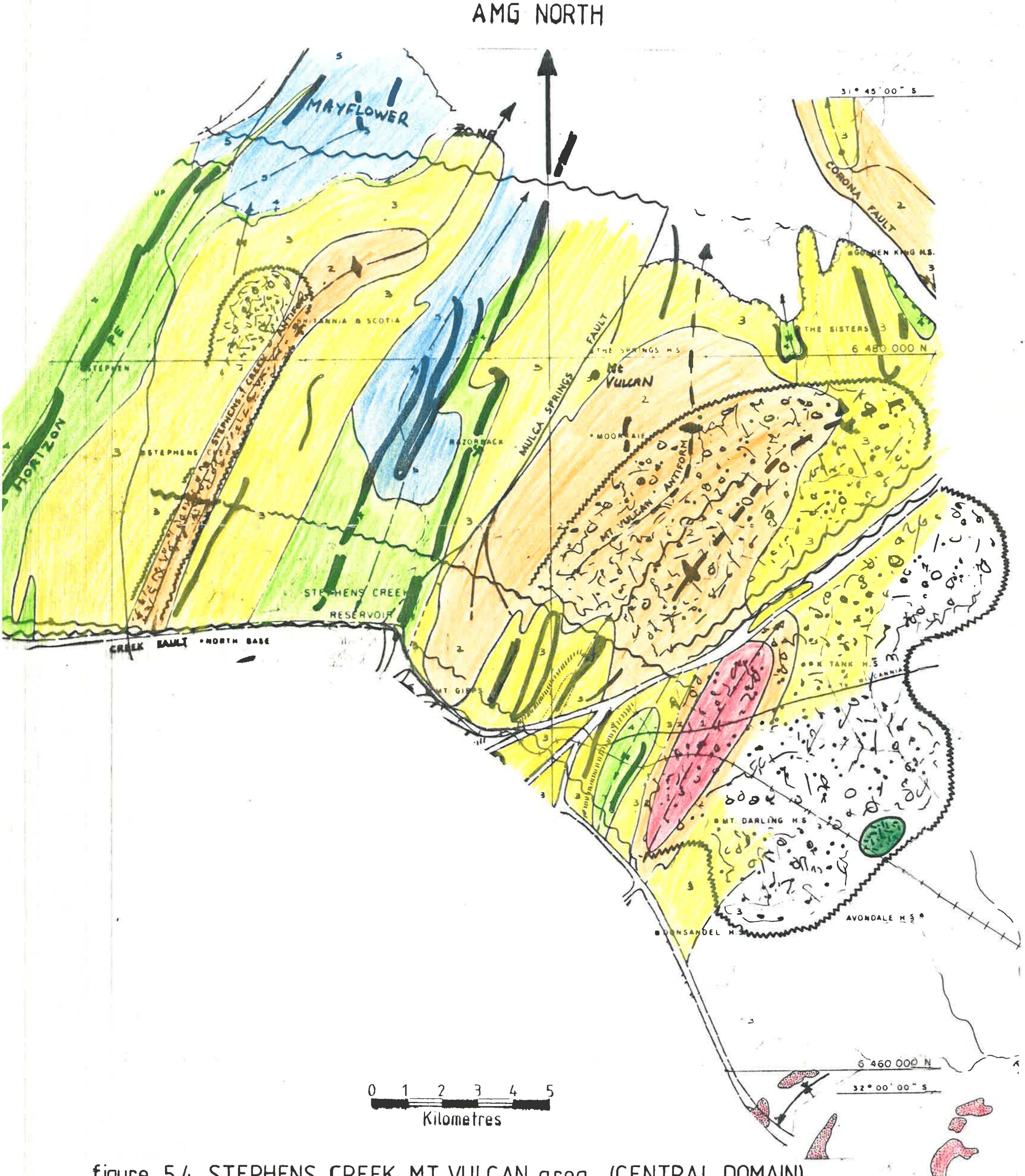



figure 5.4 STEPHENS CREEK-MT VULCAN area (CENTRAL DOMAIN)
Magnetic interpretation superimposed on interpreted geology.

East of the Mt. Vulcan antiform a braod NE trending shear zone is clearly seen as a magnetic low, within a generally complex magnetic area. East of this shear fairly simple dome and basin structures are interpreted from the limited outcrop but the magnetic contours show little correspondence with interpreted structural trends. The magnetics show a moderately intense and noisy pattern throughout suggesting that the area is dominated by the magnetite rich composite gneisses of the Mt. Vulcan area and by suite 1 rocks which are characteristically associated with a moderate magnetic response.

In marked contrast to the Mt. Vulcan area, the Stephens Creek antiform occurs largely in non magnetic rocks but the anomalies present are clearly conformable with the mapped structure. The core consists of sillimanite-quartz-feldspar rocks which Stroud places in suite 2. These generate a smooth magnetic anomaly. The eastern margin of the magnetic anomaly associated with these rocks is remarkably straight, suggesting that the boundary between the magnetic and non magnetic rocks (suite 3) is quite planar and near vertical. A much less rapid decrease in magnetic intensity to the west is strongly suggestive of a moderate dip in this direction (Fig. 5.5.)

While the surrounding quartzo-feldspathic gneisses are non magnetic these suite 3 rocks are fringed by continuous and highly magnetic horizons lying in the lower parts of suite 4. The western horizon, "PE" lies entirely in pelitic metasediments (anomaly 'A' of McIntyre, 1979) and detailed modelling of this horizon (see Chapter 6) yields a consistent dip of around 70 degrees to the west. The eastern horizon is closely linked with the Razorback quartz-magnetite belt. In the vicinity of the QM's, magnetic anomalies in excess of 2000 nT are recorded but these quartz magnetic horizons probably grade into magnetite rich metasediments because anomaly amplitudes drop considerably (to around 500 nT) along strike from the QM's and particularly to the west.

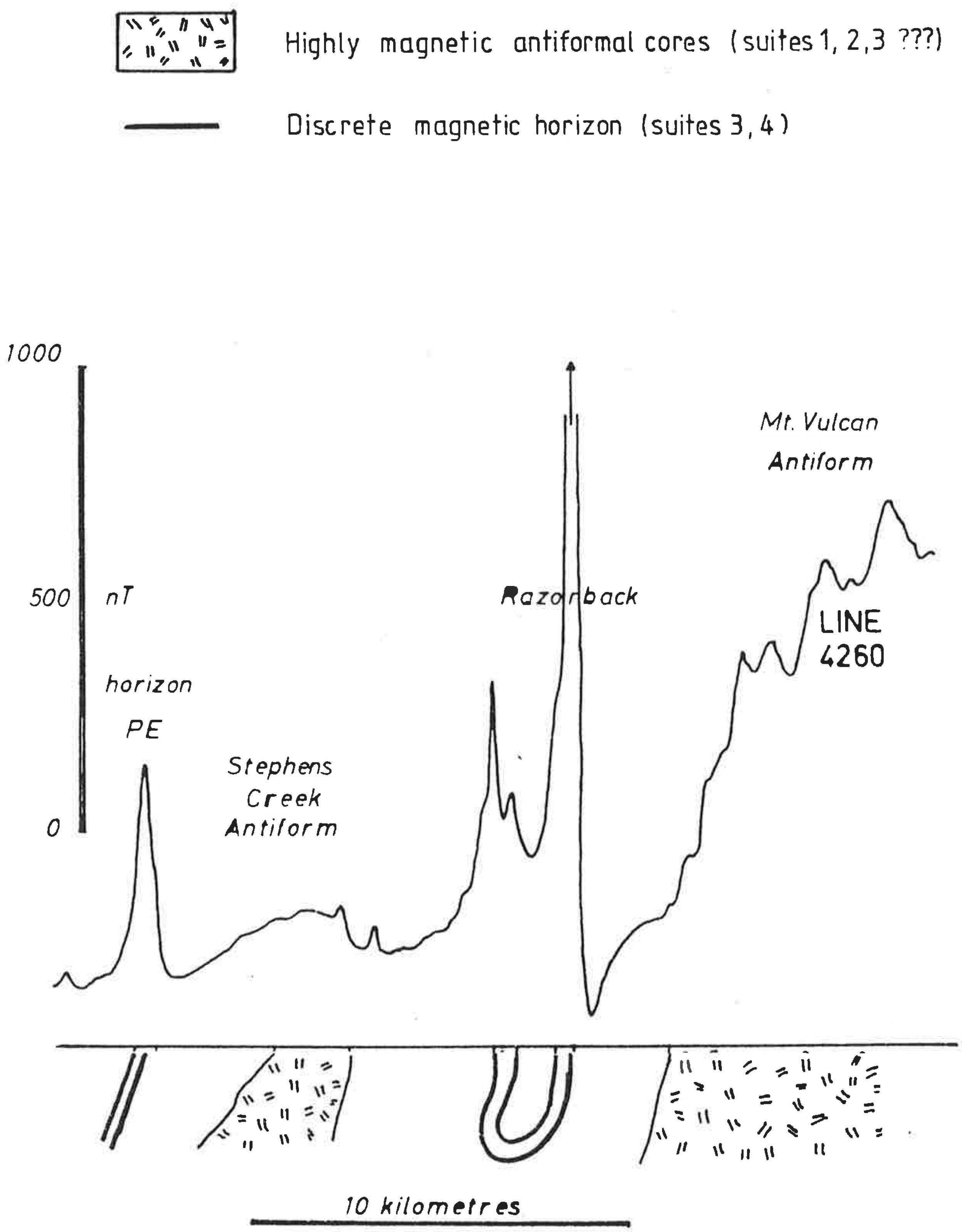



figure 5.5 Magnetic profile and generalized interpretation Stephens Creek - Mt Vulcan area

The Razorback area is interpreted by Stroud as the synform complimentary to the Stephens Creek and Mt. Vulcan antiforms. Quartz magnetite rock outcrops only on the eastern side of the synform, very close to the suite 3/suite 4 boundary, but similar high amplitude peaks on the western side may be simply interpreted as the equivalent magnetite rich horizon on the western limb of the synform. Detailed study of the area magnetics (Chapter 6) suggests that the western horizons dip moderately to the west while the eastern horizons appear to be near vertical with some suggestion of dip to the east.

Fig. 5.5 shows an aeromagnetic profile across the area and a generalised interpretation of the structure based on Stroud's mapping and the inferred dips of the magnetic units.

The Stephens Creek antiform is bounded to the north by the EW feature which marks the northern limit of the Central Domain. There is, however, some suggestion in the aeromagnetic map (Map 3) that the suite 4 horizons which border this structure to the east and west converge north of the antiform. They may, therefore, be lateral equivalents.

The distribution of magnetic horizons in the Stephens Creek-Mt. Vulcan area show marked differences to that of the Sundown-BH-Rockwell area. The prominent horizon seen in suite 3 in the Broken Hill area is not strongly developed and the suite 2 rocks, normally-magnetic in the Thorndale area are extremely magnetic here.

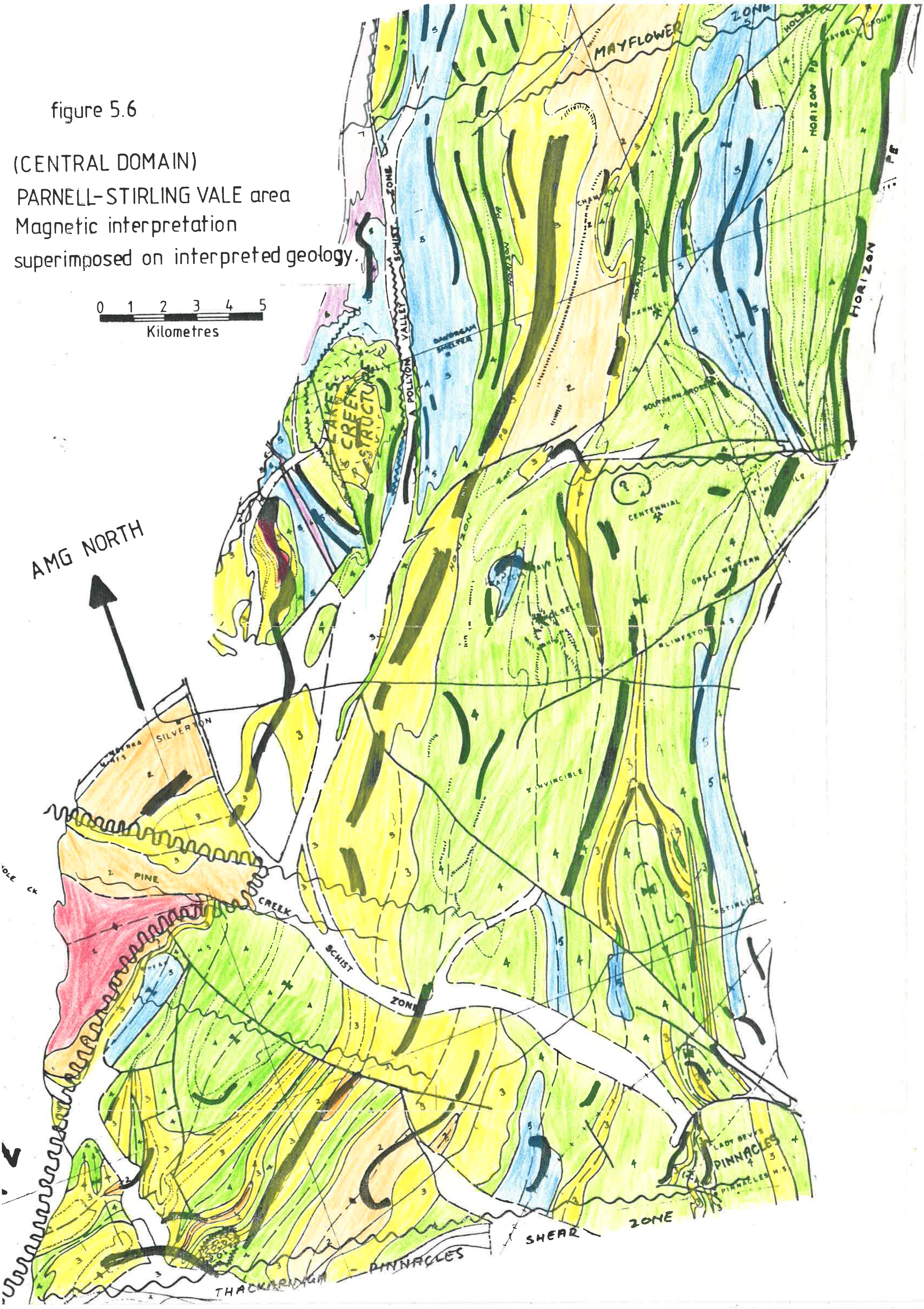
The magnetic stratigraphy of the Stephens Creek-Mt. Vulcan area is shown in Fig. 5.3.

### 5.1.3 Parnell-Stirling Vale Area

The Parnell-Stirling Vale area (Fig. 5.6) covers the western part of the Central Domain. The Stephens Creek fault persists through this area but its effects become

figure 5.6

(CENTRAL DOMAIN)
PARNELL-STIRLING VALE area
Magnetic interpretation
superimposed on interpreted geology.



less pronounced to the west. Although its mapped extension is present as far west as the Apollyon Valley shear it is considered by the writer to have only minor, if any, displacement in this area because it is crossed by a remarkably continuous linear magnetic anomaly (PB) which extends from the Pine Creek shear (L5) for 25 km to the north where it terminates at the northern margin of the Central Domain (Fig. 5.6). This anomaly lies within suite 3 rocks and retains essentially the same magnetic character over its entire length. Modelling of this anomaly (see Chapter 6) yields a steep dip to the east.

The northern part of the anomaly PB shows a complex pattern of separate magnetic horizons which appear to converge toward the main anomaly. The detailed structure of the area is not known but the magnetic horizons resolved in the airborne magnetic data give the impression of tight folding. Apart from the major horizon there is at least one and possibly two other horizons which coincide with interpreted suite 3 rocks. These may be folded equivalents of anomaly PB.

West of these horizons the prominent anomaly PA coincides precisely with a Potosi gneiss unit and hence lies in suite 4 (see McIntyre, 1979, Fig. 5).

East of anomaly PB two major structures occur. The Allendale antiform comprises a core of very weakly magnetic and non magnetic composite gneisses fringed by a small thickness of rocks interpreted as suite 3, which coincide with strong magnetic anomalies (PB and PC). These suite 3 rocks lose their magnetic character at the northern boundary of the Central Domain, although they are mapped as being continuous across this boundary, closing around the Allendale antiform about 8 km south of the Allendale Mine.

Between this antiform and the Stephens Creek antiform the presence of the Parnell synform is inferred by Bradley et al (1979) supporting the earlier interpretation of Rutland (1973). Within the Parnell synform linear magnetic anomalies are observed but they vary greatly in amplitude along strike and it is difficult to establish continuity of particular horizons. The horizons occur in the rocks of suite 4 and suite 5, largely concentrated near the suite 4/suite 5 boundary. The southern part of the Parnell synform is an exceedingly complex structural area which extends through the Southern Cross, Centennial and Great Western Mine areas (K8) and is centred around the Stephens Creek fault. Very disjointed magnetic anomalies are found in this area, in which only suite 4 rocks are mapped.

Further south the structural pattern is less complex but is still not well understood. Marjoribanks et al (1979) and also Brown (1979) have inferred the presence of an (F2) synform in the Stirling Vale area (N8) and both regard this fold as being overturned, making it analogous to the Hanging Wall synform in the mine area.

Brown has noted that the distribution of rock units about the axis of the Stirling Vale synform is not symmetrical and this observation can also be made from the magnetics. The western limb contains a strong and broad horizon lying in suite 4 rocks but this horizon is absent on the eastern limb. A more narrow, weaker horizon does appear to close around the synform and this horizon lies close to the suite 3/suite 4 boundary, probably in suite 3.

The Stirling Vale synform is cut obliquely by the Northern shear and this feature clearly truncates both magnetic horizons on the western limb of the synform.

Southwest of this feature lies another suite 3 magnetic horizon which is separated from anomaly PB by the Pine Creek shear and is also segmented by a subsidiary shear zone to the south. This horizon may represent the southern extension of anomaly PB.

The magnetic stratigraphy in the Parnell-Stirling Vale area (Fig. 5.3) closely similar to that of the Sundown-Broken Hill-Rockwell area.

## 5.2 Mayflower Zone

The Northern Domain (Fig. 5.7) is separated from the Central Domain by a broad (4 km wide), dominantly EW zone of disruption in the magnetic contours which extends right across the Broken Hill Block through Mt. Franks, Mayflower and Yanco Glen areas.

It is termed here the Mayflower zone and it bears striking similarities to the Thackaringa Pinnacles shear. Both are broad (3-5 km) zones of disturbance in the magnetic contours at which major continuous magnetic horizons either terminate or are greatly attenuated. Both zones are roughly perpendicular to the regional strike, but structural trends in the vicinity of these features commonly change direction tending towards the direction of these magnetic boundaries. Major folds commonly close at or close to both features.

The Thackaringa-Pinnacles shear is, however, recognized as an extensive and wide retrograde schist zone whereas the Mayflower Zone does not coincide with any mapped continuous geological feature. While there are some small faults mapped in the neighbourhood of the Mayflower Zone major rock units, particularly those within the Allendale antiform, are mapped as crossing the zone without any major changes, In contrast no major structures cross the Thackaringa-Pinnacles shear.

Possibly the most significant geological change across the Mayflower zone is the abrupt change in regional strike which occurs at the northern margin of the zone.

Inspite of the absence of direct geological evidence the Mayflower zone is interpreted here to be related to the set of shears and faults which run perpendicular to the regional strike and are spread throughout the Broken Hill Block (e.g. MacDonald, Thackaringa-Pinnacles, Pine Creek and Stephens Creek, see Fig. 4.1).

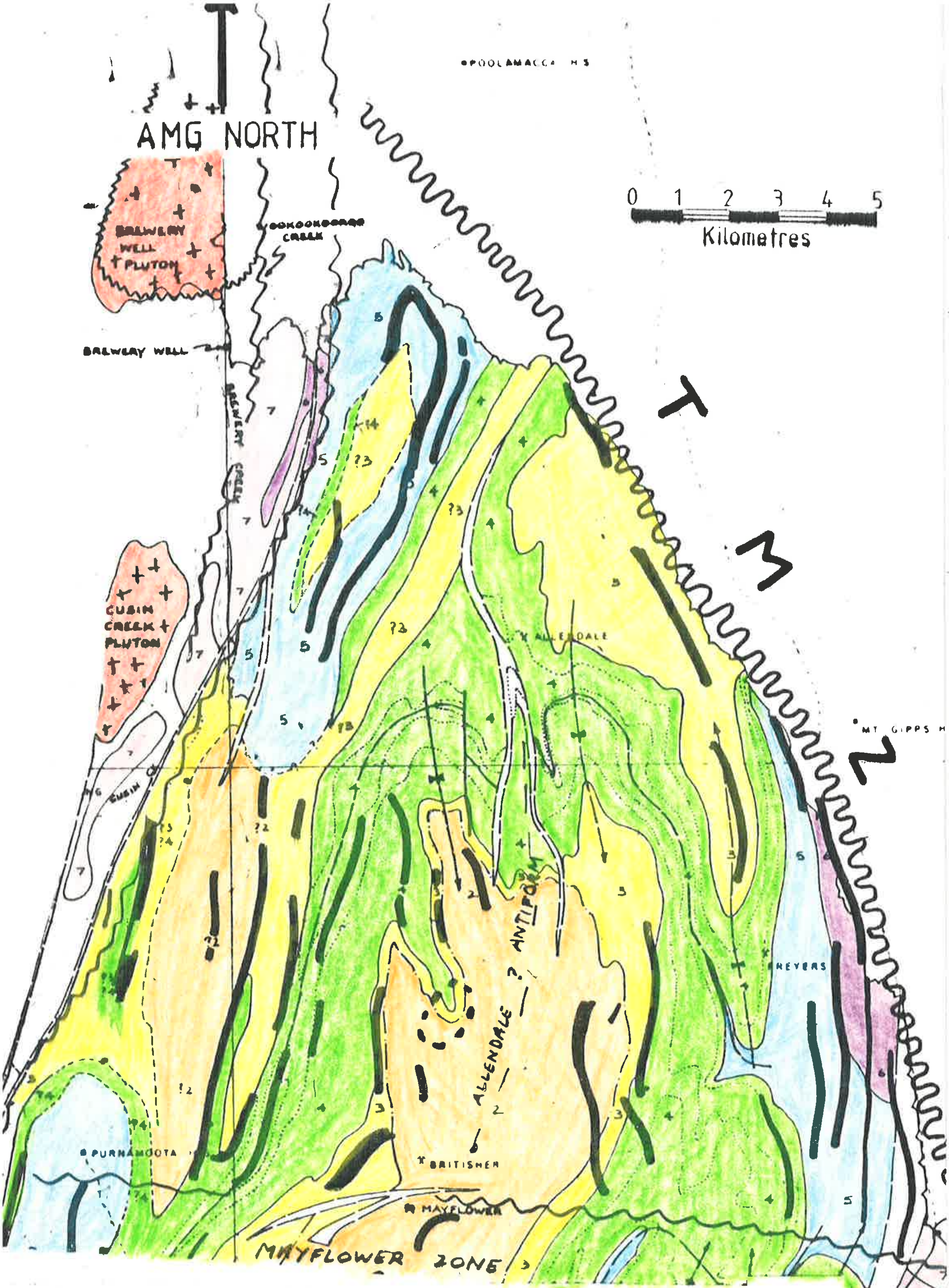



figure 5.7 NORTHERN DOMAIN : Magnetic interpretation superimposed on interpretive geology.

## 5.3 Northern Domain

The Northern Domain is bounded by the Apollyon Valley shear, the Mayflower Zone and the Adelaidean (Torrowangee) unconformity unit is characterized by a patchy distribution of predominantly linear but relatively low amplitude (less than 150 nT) magnetic anomalies. These anomalies trend NNE to NNW and are commonly truncated at the northern limit of the Mayflower Zone.

It is difficult to relate the magnetic horizons to the stratigraphy in this area partly because of the small number of persistent horizons but also because the stratigraphic boundaries are not well defined. This is apparent from the query marks on the interpreted rock suite numbers (Map 2, Fig. 5.7).

In particular the boundaries between suites 2 and 3 and suites 3 and 4 appear difficult to define.

The most prominant anomaly within the Northern Domain lies at its northern limit, wholly within pelitic metasediments (suite 5). Most of the other horizons lie in interpreted suite 4 rocks with small scattered horizons in suite 3 and possibly suite 2. Local, low amplitude anomalies also observed in Suite 6. At least one horizon transgresses stratigraphic and structural trends. This horizon is located 5 km NE of the Mayflower mine (Fig. 5.9) and cuts across the interpreted boundaries between suites 2 and 3 and suites 3 and 4.

Although the distribution of magnetic horizons through the stratigraphic succession in the Northern Domain lacks the clarity of those previously discussed, the horizons are concentrated in the same stratigraphic interval, viz. upper suite 3 - lower suite 5, as those in the Central Domain. The mapping of Bradley et al (1979) shows that the rock units in the Northern Domain are basically the same as those south of the Mayflower zone, so that, the absence of magnetic horizons cannot be attributed to major changes or rock types with the metamorphic suites.

The Northern Domain is then an area of relatively low magnetite content with rocks known to have high magnetite content in the Central Block. The preferred explanation for this observation is discussed in sections 5.7 and 5.8.

## 5.4 Southern Domain

The Thackaringa-Pinnacles shear marks the boundary between the Central and Southern Domains. It is the most outstanding retrograde schist zone in the Broken Hill Block and has had a profound influence on neighbouring structures. To the east it truncates NNE structures whereas in the west fold trends run parallel to it. It is discernible from the aeromagnetic map as a set of parallel lineations in the contour pattern and from the termination of magnetic anomalies, both to the north and south (Fig. 5.8).

The magnetic contour pattern south of the Thackaringa-Pinnacles shear is marked by a deficiency of prominent anomalies relative to the Central Domain. The magnetic anomalies which are present in the Southern Domain have irregular shapes and small (c. 2 square km) areal extents. There is only one notable linear magnetic anomaly which occurs in a non outcropping area 5 km west of Balaclava.

The irregular shapes of the anomalies appears to be a consequence of the structural geology of the area. The Southern Domain is dominated by small dome and basin type structures and the magnetic horizons, being stratigraphically bound, follow the trends of these structures. The overall deficiency in magnetite in this area is, however, not easy to explain. Most of the rock types and stratigraphic intervals seen in the Central Domain are present in the Southern Block but they are clearly poorer in magnetite in the Southern Block.

The magnetic anomalies in the Southern Domain are concentrated in two NE trending belts which lie largely in

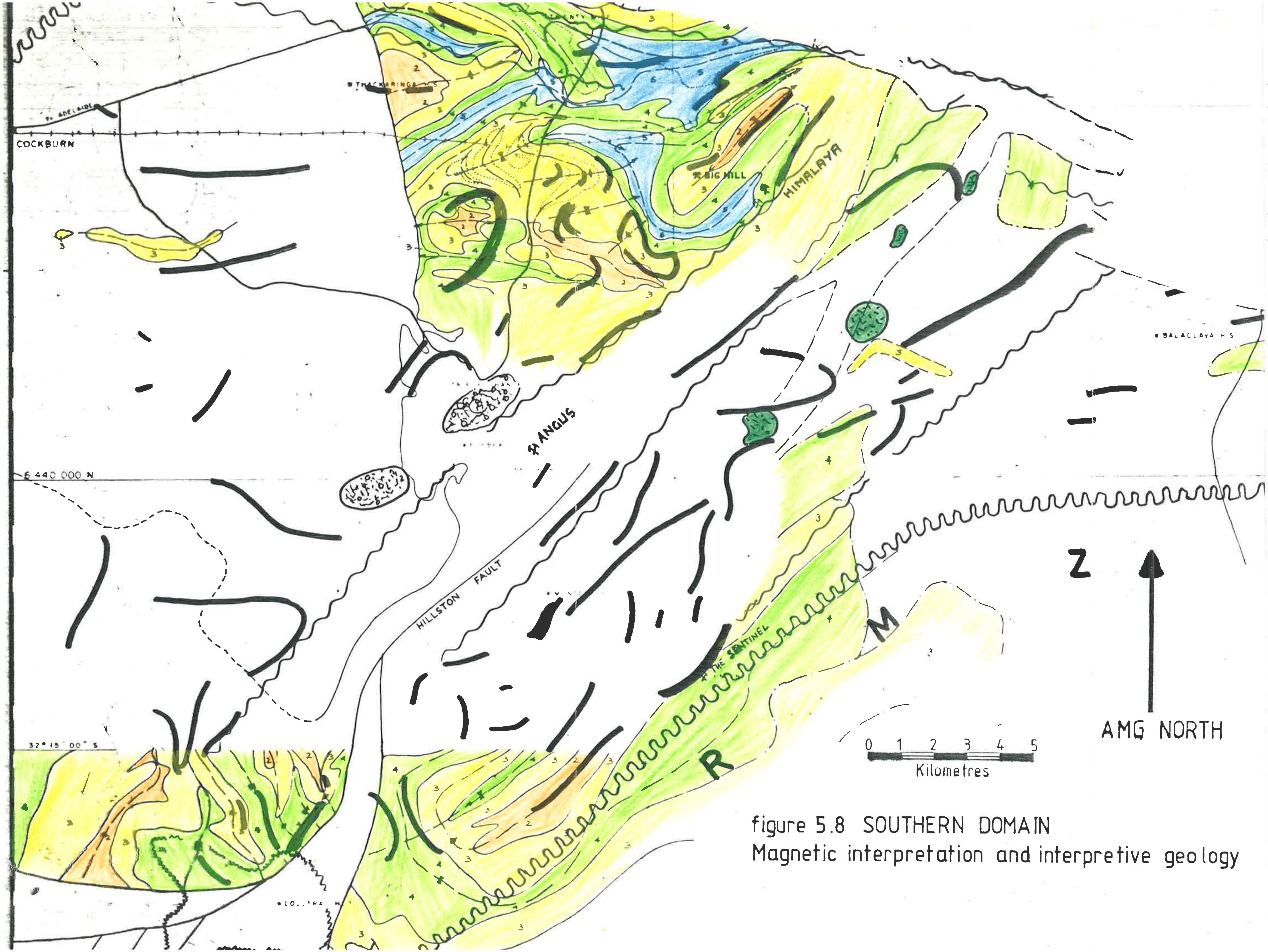


figure 5.8 SOUTHERN DOMAIN
Magnetic interpretation and interpretive geology

areas of poor outcrop. Within the Sentinel-Pinnacles belt patchy outcrop suggests that the anomalies lie in suites 3 and 4. The NW limit of this belt coincides with the Hillston fault.

The Angus-Himalaya belt similarly has magnetic sources concentrated in suites 3 and 4 with a very weak horizon possibly present in suite 2.

In the Coultra Hut area (T2) a broad magnetic rise is observed which encloses some quite prominent peaks. Although outcrop is largely absent in this area the anomalies appear related to suite 3 and suite 2 rocks. It is possible that this magnetic feature is part of the Redan Magnetic Zone but detailed aeromagnetic coverage ends immediately to the south, so this cannot be stated with any certainty.

Despite the limited outcrop and the small number of magnetic anomalies, the stratigraphic distribution of magnetic horizons in the Southern Domain shows the same concentration of horizons in suites 3 and 4 that is seen in the Central Domain. Although the observed horizons lie in much the same stratigraphic positions, the southern horizons are very weak by comparison with those of the Central Domain and thus, as was found to be the case in the Northern Block, the southern block constitutes an area where suites 3 and 4 of the Broken Hill Block sequence are relatively poor in magnetite.

## 5.5 Northwestern Domain

The Apollyon Valley/Mt. Franks retrograde schist zone system marks a profound change in regional geological conditions. East of this system, long linear structures, such as the Allendale antiform are dominant whereas to the west in the area defined as the "Northwestern Domain" (Fig. 5.9.) much smaller scale dome and basin type structures are present (e.g. Eldee and Ettlewood structures of Stevens, 1979). In addition to the change in structural style, the

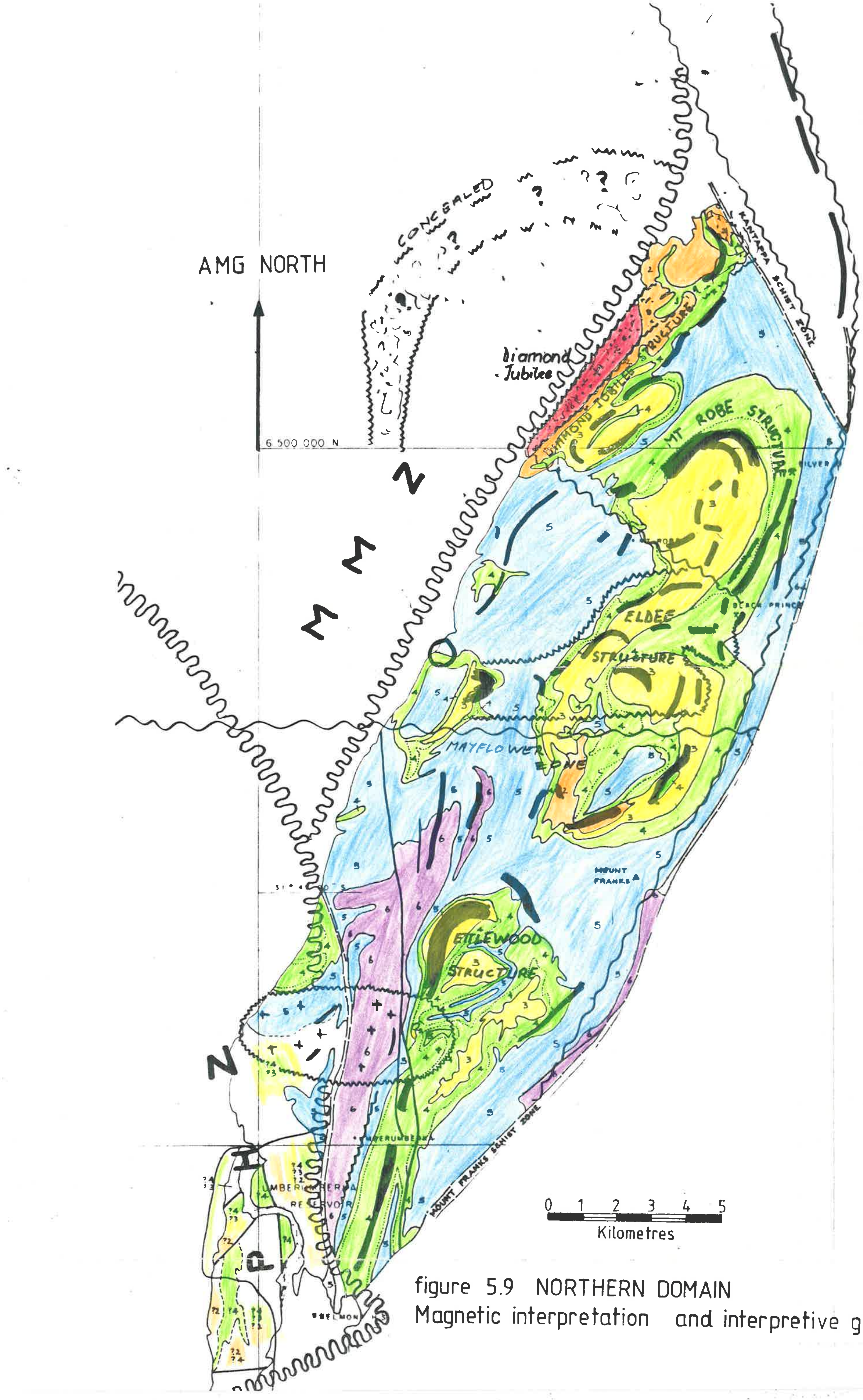



figure 5.9 NORTHERN DOMAIN
Magnetic interpretation and interpretive geology.

Apollyon Valley shear is a major prograde metamorphic boundary separating higher grade rocks in the east from lower grade rocks in the west. The Northwestern Domain lies in Phillips' (1977) Andulusite and Sillimanite-Muscovite zones while east of the Apollyon Valley shear Garnet k-feldspar and Granulite zones predominate (Fig. 2.4).

The Apollyon Valley and Mt. Franks shears are clearly defined lineations in the aeromagnetic map (Fig. 5.1 ). In particular the Mt. Franks shear can be traced from the northern limit of the study area to the Umbererberka area and may even extend through the PHZ.

The Northwestern Domain is bounded to the north by the Kantappa fault and to the south by a complex system of schist zones. It is an area of good outcrop which exposes large amounts of the metasedimentary suites (5,6 and to a lesser extent 7). Suites 3 and 4 are also well represented here with minor amounts of suites 1 and 2 occuring in antiformal structures in the Diamond Jubilee and Mt. Franks areas.

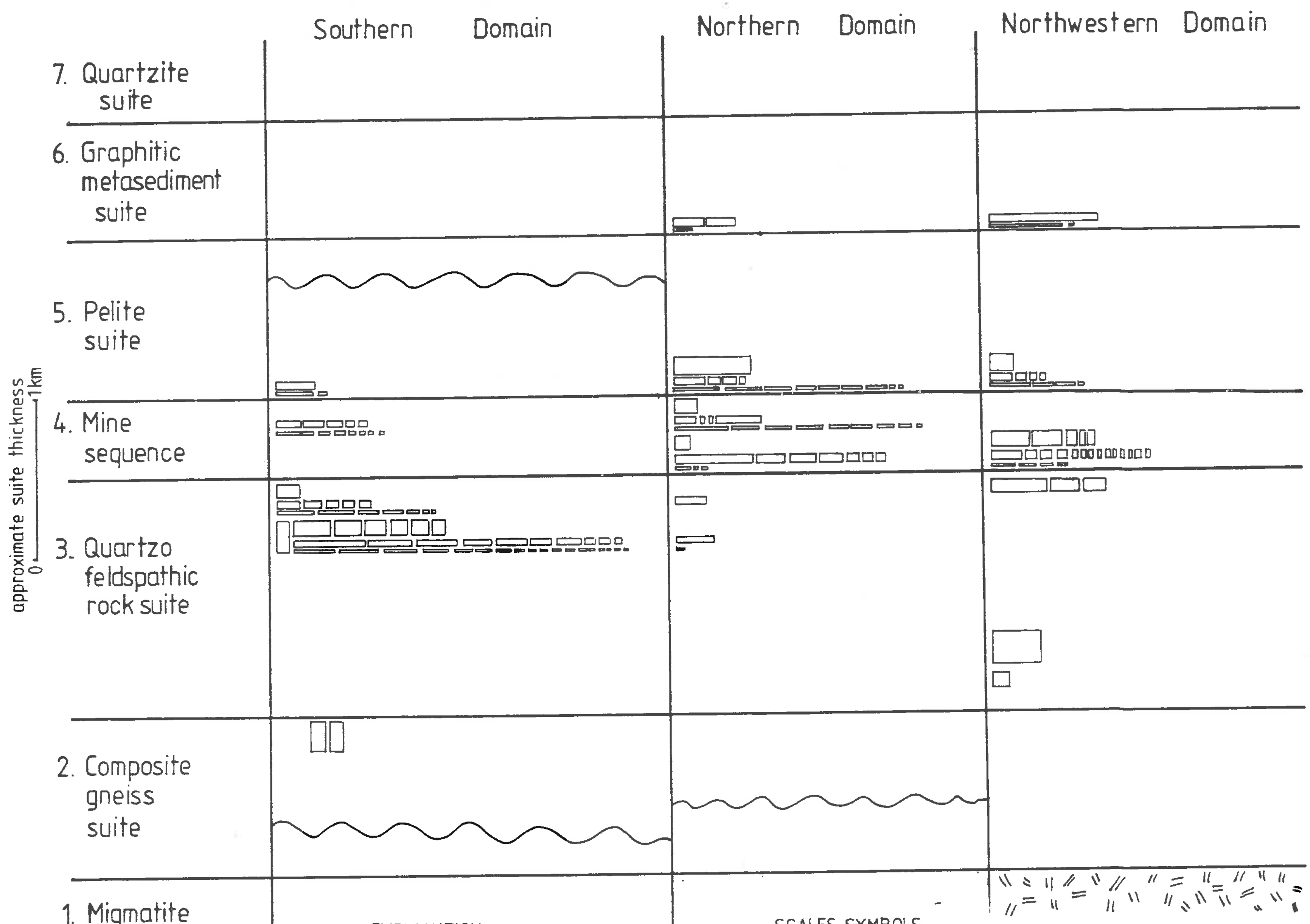
Magnetic horizons are distinctly zoned through the stratigraphy. The linear antiformal core of the Diamond Jubilee structure consists of highly magnetic suite 1 rocks. McIntyre (1979) has inferred from airborne and ground magnetics that this core plunges to the north and that the overlying suite 2 composite gneisses are completely non magnetic. Along the eastern edge of this structure narrow tracts of suite 3 and suite 4 are associated with a strong magnetic anomaly. The Diamond Jubilee and Mt. Robe structures are both bounded to the south by a very abrupt and possibly unconformable lithological change. The mapping by Stevens in this area suggests that this very straight feature is not a fault although the magnetics indicate that the rocks to the north terminate very rapidly at this boundary, i.e. they do not persist to the south.

In the Mt. Robe structure a generally magnetic core of suite 3 is surrounded by a non magnetic and extremely amphibolite rich sequence of suite 4 rocks. Magnetite in the suite 3 rocks occurs in discontinuous schistose horizons within interpreted acid metavolcanics (McIntyre, 1979) and these generate irregular aeromagnetic patterns from which individual horizons are not easily discernable.

This aeromagnetic anomaly pattern persists in the Eldee Structures (G6) where narrow outcrop of suite 3 and suite 4 rocks coincide with a zone of moderately high and noisy magnetic response. Although the more magnetic parts of the Eldee Structures lie in suite 3 the area as a whole appears magnetic and it is difficult to isolate sources from individual outcrops of the metamorphic suites. This noisy magnetic area is bounded to the south by the Mayflower Zone where a much less intense and more regular magnetic pattern is observed. In the East Eldee Structure, horizons can be recognized here from suites 4 and 3 with an extremely weak horizon evident in interpreted suite 2 rocks.

The Ettlewood structure (H6) to the south contains a prominent magnetic horizon in suite 3 and one in suite 4. This structure 'closes' at the southern margin of the Mayflower Zone.

Between the Mt. Franks and Apollyon Valley shears Stevens has mapped the Lakes Creek Structure (J6) as a dome like form exposing suite 3 rocks fringed by a broad amphibolite rich sequence lying in suite 4. These suite 3 and suite 4 rocks cannot be separated on the basis of magnetic signature. The whole structure is charcterised by a broad rise in magnetic intensity with several strong NS peaks superimposed. This magnetic feature persists to the north of the mapped structure where it broadens indicating a probable northerly subsurface extention. At the eastern and western margins of this structure, prominent linear anomalies coincide with mapped suite 4 rocks.




EXPLANATION

Magnetic anomalies are symbolized by rectangles depicting amplitude (vertically) and strike length (horizontally). The stratigraphic positions have been estimated by comparing the aeromagnetic contour maps (see map 3) with the Stratigraphic Interpretation map (see map 5). This was done using 1:100,000 scale plans.

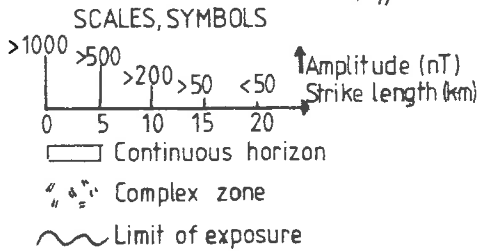



Figure 5.10 Magnetic stratigraphy of the Southern, Northern and Northwestern Domains.

The Lakes Creek structure is terminated to the south by a complex zone of retrogression in part related to the Apollyon Valley shear.

The metasediments of suites 5, 6 and 7 which are well represented in the Northwestern Domain do no generate any strong magnetic anomalies. The persistent suite 5 magnetic horizon present in the Central and Northern and Southern Domains is very poorly developed here.

Apart from this the stratigraphic distribution of magnetic horizons closely follows that of the Central Block.

## 5.6 Generalized Magnetic Stratigraphy

Comparisons of the aeromagnetic map with the detailed geological interpretations in separate areas yield a coherent pattern of distribution of magnetic horizons within geologically interpreted stratigraphy.

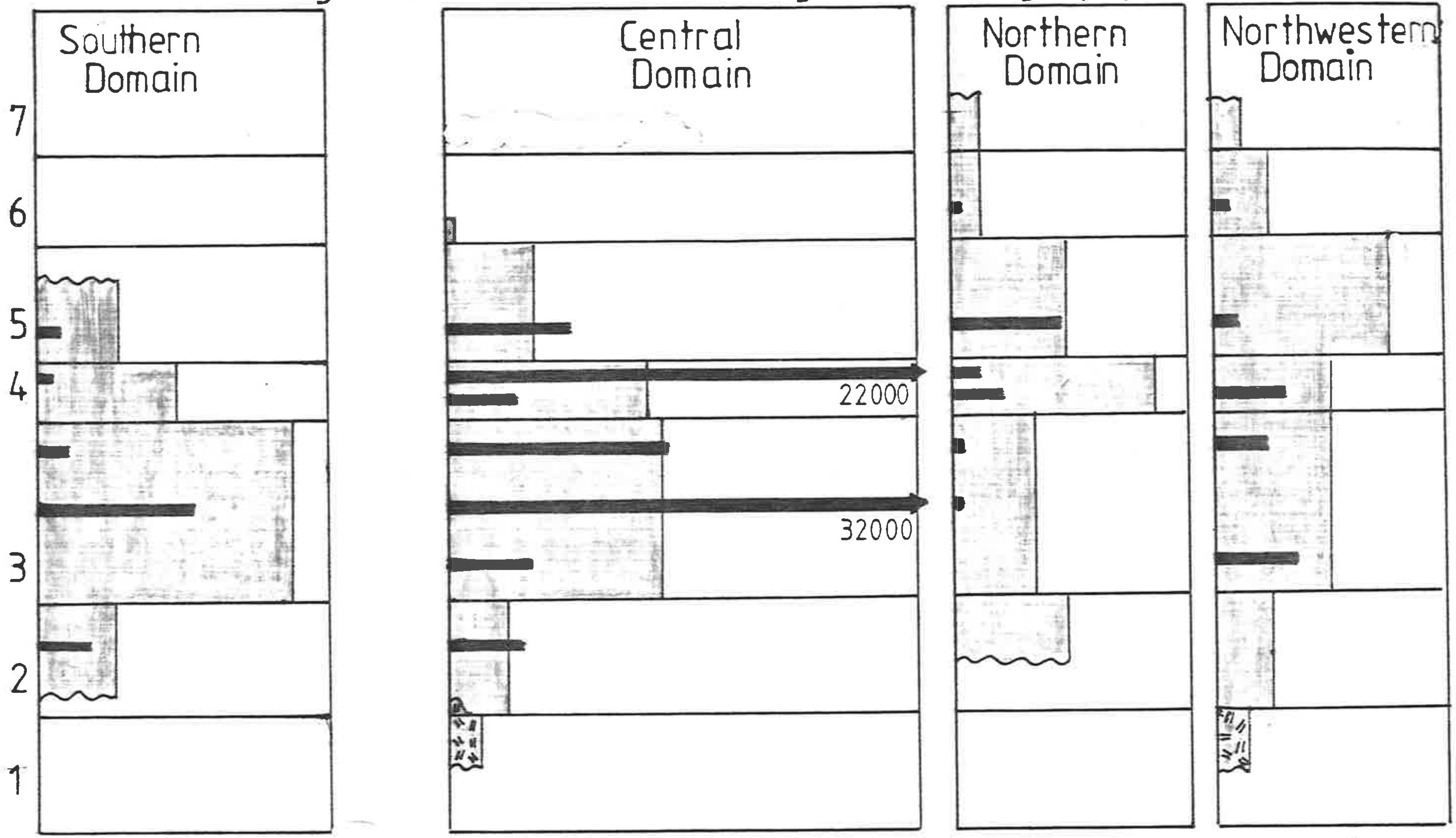
While the magnetite content, inferred from the intensity of anomalies varies considerably between the various magnetic subdivisions of the Broken Hill Block, the stratigraphic positions of magnetic horizons appear to follow the same pattern throughout the Block. The only exception is the metamorphic suite 2 which, as mapped, is, magnetically, quite heterogeneous.

Suite 1 is the only metamorphic suite which is magnetic everywhere it is mapped in the area.

Suites 6 and 7 may contain some very weakly magnetic horizons, but they do not generate any well defined magnetic anomalies.

While most of the lithologies of suites 3 to 5 are commonly non magnetic, they contain the magnetite rich horizons which appear to lie in a narrow stratigraphic interval from upper suite 3 to lower suite 5.

## Figure 5.11 Generalized Magnetic Stratigraphy




Explanation: The abundance of magnetite at each stratigraphic level is indicated by a bar whose length is proportional to the sum of the products of strike length × amplitude of anomalies at that level. The shading indicates the proportion of suites within each domain.

0 5 10 15 20 25%

0 5000 10000 nT-km

Fig. 5.11 shows the magnetic stratigraphy observed in the various subdivisions of the BHZ. From this diagram it is suggested that there are three main stratigraphic intervals in the Broken Hill Block which contain magnetic horizons. The lowest interval includes suite 1 and possibly parts of suite 2. Most of the major persistent horizons observed in the BHZ lie in suite 4 and upper suite 3. This interval also includes most of the Broken Hill type mineralization and the related chemical sediments (Barnes, 1979, Fig. 1) suggesting a relationship between the developments of magnetite and mineralization in the rocks. This relationship has been studied by Stanton (1976) and is discussed in the next section.

The highest stratigraphic level where magnetite is present in significant amounts is in the lower parts of suite 5.

While these results are generalized and certainly require detailed study to refine the stratigraphic positions of horizons within suites and to establish the lateral continuity of horizons, the simple pattern which has emerged from this study suggests that magnetic horizons may serve to clarify stratigraphic boundaries in areas where either outcrop is poor or where definition of suite boundaries cannot be easily made on the basis of rock type associations.

If this is to be attempted much better definition of magnetic horizons is required than that which can be obtained from the aeromagnetic contour map - regardless of the scale at which it is presented (see Chapter 6).

## 5.7 Significance of Domains

The spatial zoning of strong magnetic anomalies which has been used as the basis for subdivision of the BHZ is not a subtle feature. The differences in magnetic characteristics of the Domains are profound and the boundaries between them well defined. It seems surprising then that the Domains do not readily correlate with any recognized geological subdivisions. The same basic stratigraphy prevails throughout the BHZ and although there are local differences in rock type associations characterizing the suites and local difficulties in defining suite boundaries, the overall stratigraphic interpretation is confidently presented.

McIntyre's conclusion, developed from studies in four representative areas, that magnetic horizons are confined by stratigraphic intervals rather than being controlled by rock type appears to have wide application in the BHZ because the distribution of magnetic horizons through the stratigraphic sequence shows a remarkably consistent pattern in both highly magnetic and weakly magnetic areas.

The magnetic "Domains", in the simplest sense, represent a zoning in the abundance of magnetite through an otherwise uniform stratigrpahic sequence.

There are three events in the geological history of the Broken Hill region which could possibly have produced this observed zoning in magnetite abundance.

1. Deposition

   The relative abundance of magnetite in the Central and Northwestern blocks may reflect depositional or possibly diagenetic environments which favoured the development of magnetite.

2. Prograde Metamorphism

   Rocks with essentially the same 'magnetite producing capability' may have been subjected to different prograde metamorphic temperatures and pressures. More magnetite might be expected to develop in the higher prograde metamorphic areas.

3. Retrograde Metamophism

The relative deficiency of magnetite in the Northern and Southern Domains may be related to the destruction of magnetite which can occur during retrogression.

The Northern and Southern blocks would then be areas which have been much more severely retrogressed than the Central and Northwestern Blocks if this is the cause.

Prograde Metamorphism

The prograde metamorphic zones of Phillips (1977) and the earlier, more approximate zones of Binns (1964), show some correlation with the magnetic subdivisions. The Central Domain lies almost entirely within Phillips' granulite zone while the Northern and Northwestern Domains lie in lower grade zones (Fig. 5.12). The Northern Domain includes rocks of the three lower grades but there is no relationship apparent here between anomaly amplitudes and metamorphic grade.

The Northwestern Domain conspicuously coincides with the area of lowest grade (Phillips' Sillimanite-Muscovite and Andalusite Zones).

The Southern Domain lies within the Granulite zone and although Phillips' investigations do not cover the Oakdale area, Stroud (1976) regards this area as being "granulite facies".

The existence of strong magnetic anomalies in the Northwestern Domain which lies in the lowest metamorphic grade area, and the absence of strong anomalies in the Southern Block which is in the granulite zone, are evidence contrary to the interpretation of the magnetic zoning as a result primarily of prograde metamorphism. However, an association between metamorphic zone boundaries and magnetic domain boundaries is apparent in the northern part

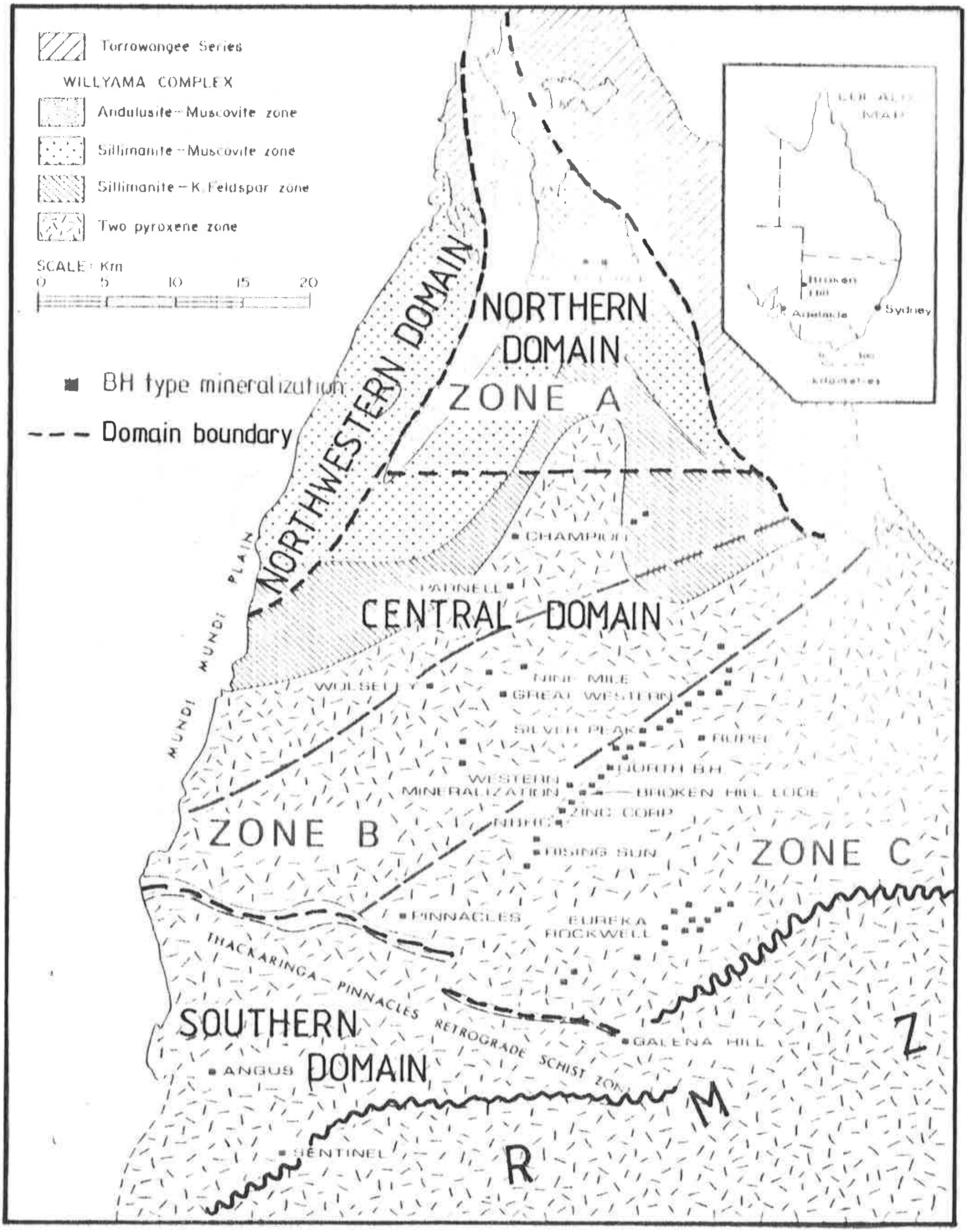



Figure 5.12 BHZ Domains compared with Binns' and Phillips' metamorphic zones

of the BHZ. The Mayflower Zone marks the northern limit of the granulite zone and the Apollyon Valley shear, apart from constituting a major structural boundary, marks the eastern limit of the Northwestern Domain and also bounds the lowest grade metamorphic zone.

Although the magnetic zoning may not be caused only by prograde metamorphism a link between the two is suggested by the associations between magnetic and metamorphic boundaries in the northern part of the Broken Hill Domain.

Retrograde Metamorphism

There is very little detailed information available on the distribution of retrogression in the Broken Hill Block. In view of the fact that retrograde metamorphism is regarded by geologists as a nuisance which camouflages prograde mineralogies it is perhaps not surprising that it has received little attention in the literature. Referring to Binns' prograde metamorphic zones, Both and Rutland (1976) state:

> "Retrograde metamorphism is particularly widespread in the northern part of the Willyama Block (i.e. within zone A area). In the southern part (zones B and C) retrogression is most conspicuous in association with distinct planar zones referred to in the literature as "shear zones", "crush zones", "faults" and, more recently "retrograde schist zones". ....... There is also widespread, but very patchy retrogression outside the retrograde schist zones."

In the Thackaringa area Willis (1979) refers to "pervasive retrograde metamorphism, particularly in schist zones" while further south in the Oakdale area, Stroud (1976b) has observed "very extensive retrograde metamorphism.

Within the Central Domain, Bradley (1979), Brown (1979) and Stroud (1979a) all refer to retrograde metamorphism as being widespread.

The fact that strong magnetic anomalies occur in the areas where retrogression appears to be most widespread effectively rules out the possibility of this being a major influence on the magnetic zoning.

Depositional Environment

Since the processes of metamorphism can be discounted as the principal cause of the zoning of magnetite rich rocks within the BHZ it would appear that the zoning was established prior to metamorphism and, if this is the case, then the Domains defined on the basis of magnetite abundance most probably represent areas of different depositional environment.

It is noteworthy that Stanton (1976) has suggested that metamorphic facies may stem significantly from sedimentary facies.

He states:-

> "The distribution of rocks of particular (metamorphic) facies and consequent 'isograds' at Broken Hill may well be a subtle consequence of patterns of clay sedimentation as defined by variations in original clay mineralogy, and this principle may well be of wide application."

This could explain the relationships between magnetic block boundaries and metamorphic grade boundaries observed in the north of the BHZ. However, it should be stated that Stanton's ideas on the deformation and metamorphism of the BH Block differ widely from those of most other workers (see Chapter 2).

McIntyre (1980) has reviewed the processes which control magnetite development in metasediments. He states "The development of magnetite in metasediments is primarily controlled by:-

(a) bulk composition and

(b) the oxidation state ($Fe^{3+}/(Fe^{3+}+Fe^{2+})$ ratio) of the original sediment

As these two factors are often unaffected by metamorphism, the capacity for magnetite development is chiefly inherited from the original sediment. The metamorphic process is like photographic development - certain variations in a sediment sequence may be magnetically "visible" by the metamorphic process."

and further:

> "Where bulk composition is fairly uniform throughout a sedimentary sequence, variations in the $Fe^3/(Fe^3 + Fe^2)$ ratio of the original sediment will determine the stratigraphic magnetic patterns developed in the metasediment. The $Fe^3/(Fe^3 + Fe^2)$ ratio is a function of the oxidizing potential of the sedimentary and diagenetic environments."

If the observed magnetic "Domains" are to be attributed to changes in sedimentary or diagenetic environments then the nature of the boundaries between these Domains must be examined.

Two of the three boundaries are now manifest as prominent shear zones (Thackaringa-Pinnacles and Apollyon Valley). Although the shear zones in the BH Block are generally regarded as late stage (i.e. post F3) features, Glen et al (1977) suggest that they may have been active during the third folding episode.

The Mayflower Zone does not correlate with any single geological feature but it is a zone of 'attenuation' of many major structures. Both the Stephens Creek and Mt. Vulcan antiforms are interpreted to close to the north in the vicinity of the Mayflower Zone as are the East Eldee and Ettlewood structures which are actually separated by the Mayflower Zone in the Northwestern Domain. While in the Allendale Antiform, the continuity of rock units across the Zone is firmly established (Bradley et al, 1979). ENE trending faults such as the Holder fault occur 'en echelon' across the Mayflower Zone in a similar fashion to the segments of the Stephens Creek fault. Perhaps the most significant geological feature associated with the Mayflower Zone is the change in regional strike from NNE to NNW which occurs at the northern margin of the Zone. There is, therefore, substantial evidence to support the contention that the Mayflower Zone is a zone of significant geological as well as geophysical change.

The abruptness and linearity of the Domain boundaries is difficult to reconcile with the proposition that they represent changes in sedimentary environment. The dramatic folding episodes, particularly F1 and F2, would be expected to have deformed any original geometrically simple boundary between different environments.

If the domain boundaries are to be interpreted as such they must be regarded as features which have not only controlled depositional environment but have also exerted a strong influence on the subsequent deformational events. There is evidence both on the local scale and the very regional scale which supports the concept of 'recurring influence' or 'reactivation' of primary tectonic features in the Broken Hill Block.

On the local scale, Laing et al (1978) have shown that the British and De Bavay shears coincide with culminations in the F1 fold pattern which cannot be attributed to F2 or younger 'refolding' of the F1 lineations. This indicates that these shears, now manifest at least in part as faults in the BH mine area were present in some form during the first deformation.

On the regional scale it is evident that the structural controls in force during the deformation of the Willyama Complex have been active through the subsequent geological history of surrounding younger provinces. The close reltionship between structural features in Willyama, Adelaidean and Palaeozoic rocks is seen northwest of BH where all of these features trend NNW and to the south and southwest where they trend NE (for a detailed account of these relationships and the regional tectonics of the Willyama Complex the reader is referred to Glen et al, 1977). Within the BH Block this change in geological trend direction occurs across the Mayflower Zone.

Similarly, the Thackaringa-Pinnacles and Apollyon Valley shears also represent structural boundaries. The Southern Domain and particularly the Northwestern Domain are characterized by small scale dome and basin like structures in marked contrast to the long linear structures which dominate the Central and Northern Domains.

Rutland (pers comm, 1979) has suggested that the Mayflower Zone and the Thackaringa-Pinnacles shear may represent boundaries separating an originally more positive structural zone (the Central Domain) from more negative zones (Southern and Northern Domains), since this broad structural form is observed in the present day relationship between the positive Broken Hill Block and the more negative Adelaidean areas to the NE and SW (see Glen et al, 1977).

The proposition that the magnetic Blocks within the BHZ represent different depositional environments and the accompanying requirement that the Block boundaries have been tectonic boundaries active during the deposition and deformation of the Willyama Complex, is broadly compatible with the interpreted structural history of the region. The testing of this proposal requires detailed stratigraphic comparisons between the Domains and a detailed examination of the Domain boundaries both of which are beyond the scope of this thesis.

Hence, despite the lack of direct substantiating evidence the interpretation of the Domains as areas of different depositional environment appears to be the most consistent with the available geological data.

## 5.8 Nature of Environments

The nature of any change in depositional environment with a relatively uniform sequence can only be firmly established by detailed geological studies. However, considering that a broad scale and generalized comparison of aeromagnetic data with interpretative geology has suggested that such changes occur, it is possible to use these data to give some indication of the type of environmental variation which may be involved.

Clearly the 'magnetic' interval from upper suite 3 to lower suite 5 is much richer in magnetite in the Central Domain than in either the Northern or Southern Domains. The Northwestern Domain, although it lacks a strong horizon in suite 5 has a magnetite abundance more in keeping with the Central Domain than that of the Northern or Southern Domains.

The origins of the magnetite rich metasediments and the 'iron formations' (mainly BIF and QM) in the Broken Hill Block have been discussed by McIntyre (1979) and Stanton (1976) respectively.

In reference to the prominent magnetic horizons investigated by himself, McIntyre states:-

> "These magnetite bearing markers are generally similar to surrounding rocks except that they include minor lenses of rocks of unusual composition, viz. quartz-magnetite, sillimanite magnetite or banded iron formation. These unusual rock types are inferred to be chemical precipitates. The lower concentrations of magnetite distributed throughout the marker horizons may be of similar origin, and may have been diluted by mixing with sedimentary detritus."

Stanton's study was concerned largely with the relationships between BIF, QM and stratiform mineralization in the BH district. He concludes:-

> The similarity yet distinctiveness between the two iron-rich units (BIF and QM) ....... may be due to their having two quite distinct volcanic affiliations - the QM with an earlier Keratophyric phase, and the BIF with a later calc-alkaline, rhyodacitic phase. The Broken Hill orebody and its related smaller analogues appear to represent and episode of intense hydrothermal emmission during rhyodactic volcanism and the BIF a later, dying phase of this activity."

The greater abundance of magnetite in the metasediments of the Central and Northwestern Domains implies a greater abundance of these iron rich chemical precipitates within these Domains. The mapping presented by Stevens et al suggests that this is certainly the case in the Central but not necessarily in the Northwestern Domain.

The Central Domain contains nearly all of the major developments of BIF, QM and the related rocks. The abundance of these appears to decrease at the Northern and Southern Domain boundaries. One striking example of a 'lensing' out of one of these units is seen in the geological map of the Southern Cross-Brewery Well Area (Fig. 5.13). Here a thin unit described as "fine grained, granular garnet and quartz (+ magnetite ± iron sulphide rock)" lying in probable suite 3 rocks is continuous in the Champion Mine area but loses continuity to the north and dies out within the Mayflower Zone. While this unit does not have a strong magnetic response it is genetically very closely related to the BIF and QM and this can be cited as direct evidence of change in geological conditions from the Central to the Northern Domain.

There appears to be no major developments of BIF or QM in the Northern Domain. This, however, also appears to be the case in the Northwestern Domain where McIntyre (1979) has found that magnetic anomalies associated with suite 3 rocks in the Mt. Robe Structure stem from probable metamorphosed acid volcanics. The suggestion that the prominent magnetic anomalies in suites 3 and 4 of the Northwestern Domain may

## STRATIGRAPHIC COLUMN FOR BEDDED METASEDIMENTS AND COMPOSITE GNEISS

| | SUITE |
|---|---|
| *Metasediments — psammitic and psammopelitic — psammites are fine grained, feldspathic* | 7 |
| *Metasediments — graphite-bearing pelitic; minor calc-silicate rock* | 6 |
| *Metasediments — mainly pelitic to psammopelitic, more psammitic towards the top* | 5 |
| *Metasediments — variable, commonly interbedded psammitic/pelitic; minor composite gneiss. Includes minor amphibolite and leucocratic quartzo-feldspathic rock* | 4 |
| *Composite gneiss — mainly psammitic to psammopelitic metasedimentary type with pegmatitic segregations. Includes numerous amphibolite bodies, minor leucocratic quartzo-feldspathic rocks, very minor calc-silicate rocks.* | 3 / 2 |

## REFERENCE TO OTHER ROCK TYPES, INTERBEDDED WITH THE METASEDIMENTS AND COMPOSITE GNEISS.

| | |
|---|---|
| *Quartz-feldspar-biotite-garnet gneiss, medium to fine grained ("Potosi" type)* | 4 |
| *Amphibolite plus one or more of the following:-- (a) quartz-feldspar-biotite-garnet gneiss. (b) quartz-gahnite rock. (c) leucocratic quartzo-feldspathic rock. Also includes pelitic/psammopelitic or pelitic/psammitic metasediments* | 4 |
| *Unit containing variable amounts of amphibolite, leucocratic quartzo-feldspathic rock and metasediments of various types.* | 4/3 |
| *Leucocratic quartzo-feldspathic rock — intermixed pegmatite, leucocratic granitic rock, and leucocratic gneissic rock. Includes minor metasediments of various types.* | 4/3 |
| *Quartz-albite rocks — leucocratic, saccharoidal textured, generally well layered.* | 3 |
| *Quartz-feldspar-biotite gneiss — coarse to medium grained, some phases contain augen.* | 3 |
| *Fine-grained, granular garnet + quartz (± magnetite ± iron sulphide rock).* | |

## INTRUSIVE ROCKS AND RETROGRADE SCHIST

*Post-folding granitic intrusives.*

*Retrograde micaceous schist zone*

*Sedimentary younging directions — observed from sedimentary structures or inferred from stratigraphic interpretation.*

Interpreted from geology by G. Bradley, I. Willis, K. Cordwell, I. Williams, J. Stroud, G. Corbett, J. Thomson and B. Stevens.

Legend for fig. 5.13

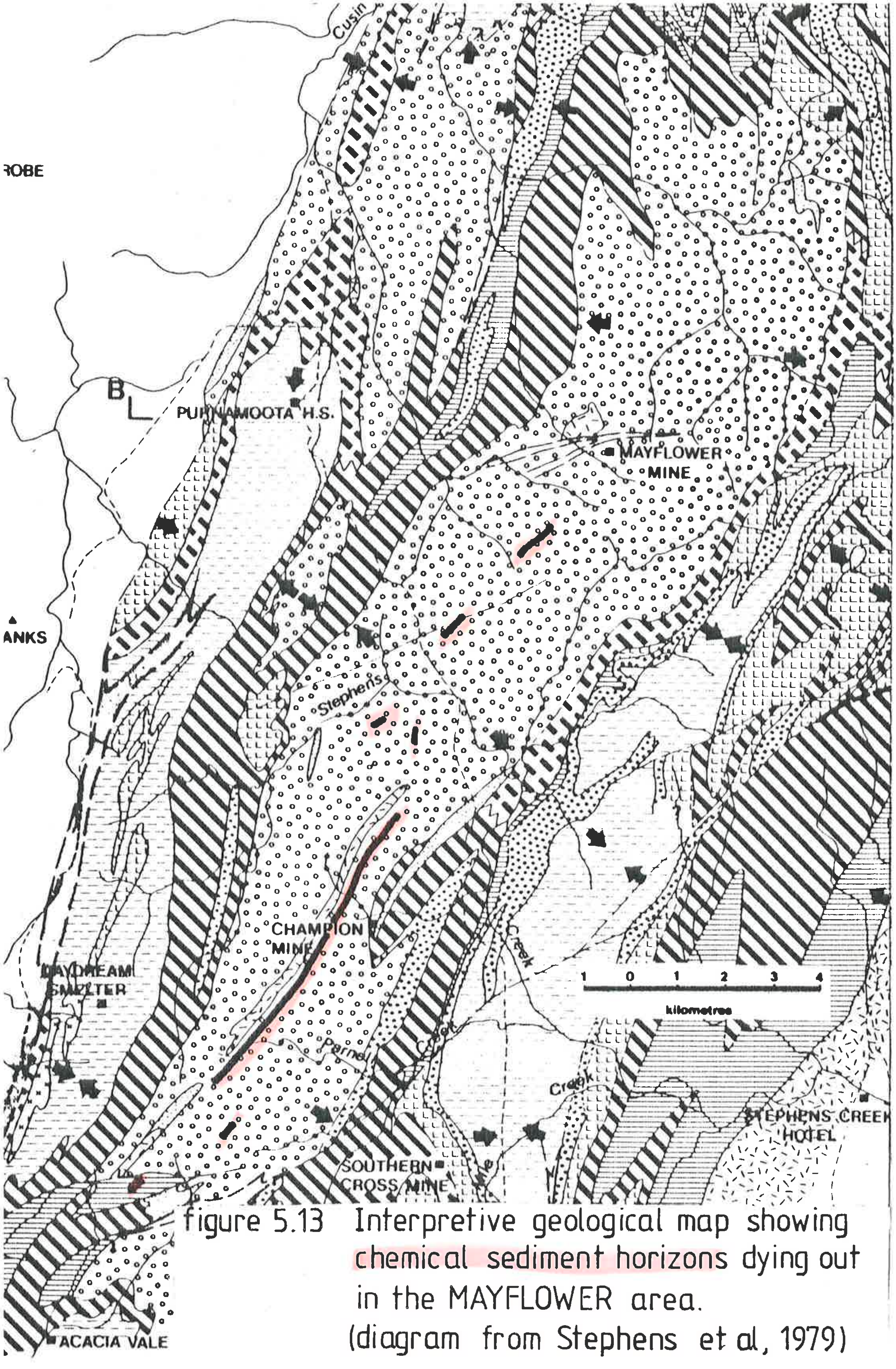



figure 5.13 Interpretive geological map showing chemical sediment horizons dying out in the MAYFLOWER area.
(diagram from Stephens et al, 1979)

be largely due to magnetite in acid volcanics and not due to magnetite in metasediments, provides a simple explanation of the presence of magnetic anomalies and the absence of BIF and QM. It also suggests that the depositional environment in the NW Domain differs markedly from the east of the BH Block.

In the Southern Domain one major quartz magnetite is present (the Sentinel) in suite 3 but no other developments of BIF and QM have been mapped.

Lode Horizons

Since Stanton has shown that the BIF and, to a lesser extent, the QM, are stratigraphically related to the stratiform mineralization at BH, it would appear that the Central Block, being the area by far the most abundant in both BIF and QM, should be more likely to contain such mineralization than the other Blocks.

Barnes (1979) has produced a map of BH lode and related rocks (Fig. 5.14) which includes the BIF, QM and other chemical precipitates. The relationship between this distribution and the magnetic domains is very strong. The Central Domain is outstanding as the area of greatest concentration of "lode Horizon" and the Thackaringa-Pinnacles shear defines a clear break south of which lode horizon is much more sparsely distributed.

The Northern Domain which contains fewer and much weaker magnetic anomalies than the Central Block shows the same trends in development of Lode Horizon.

The Northwestern Domain is particularly poor in lode horizon so that the presence of strong magnetic anomalies in the suite 3-suite 5 interval here does not herald strong development of "lode horizon" as it does in the Central Domain. As mentioned, this may be due to the magnetite being largely in metavolcanics in the NW Domain whereas it is primarily contained in metasediments in the Central Domain.

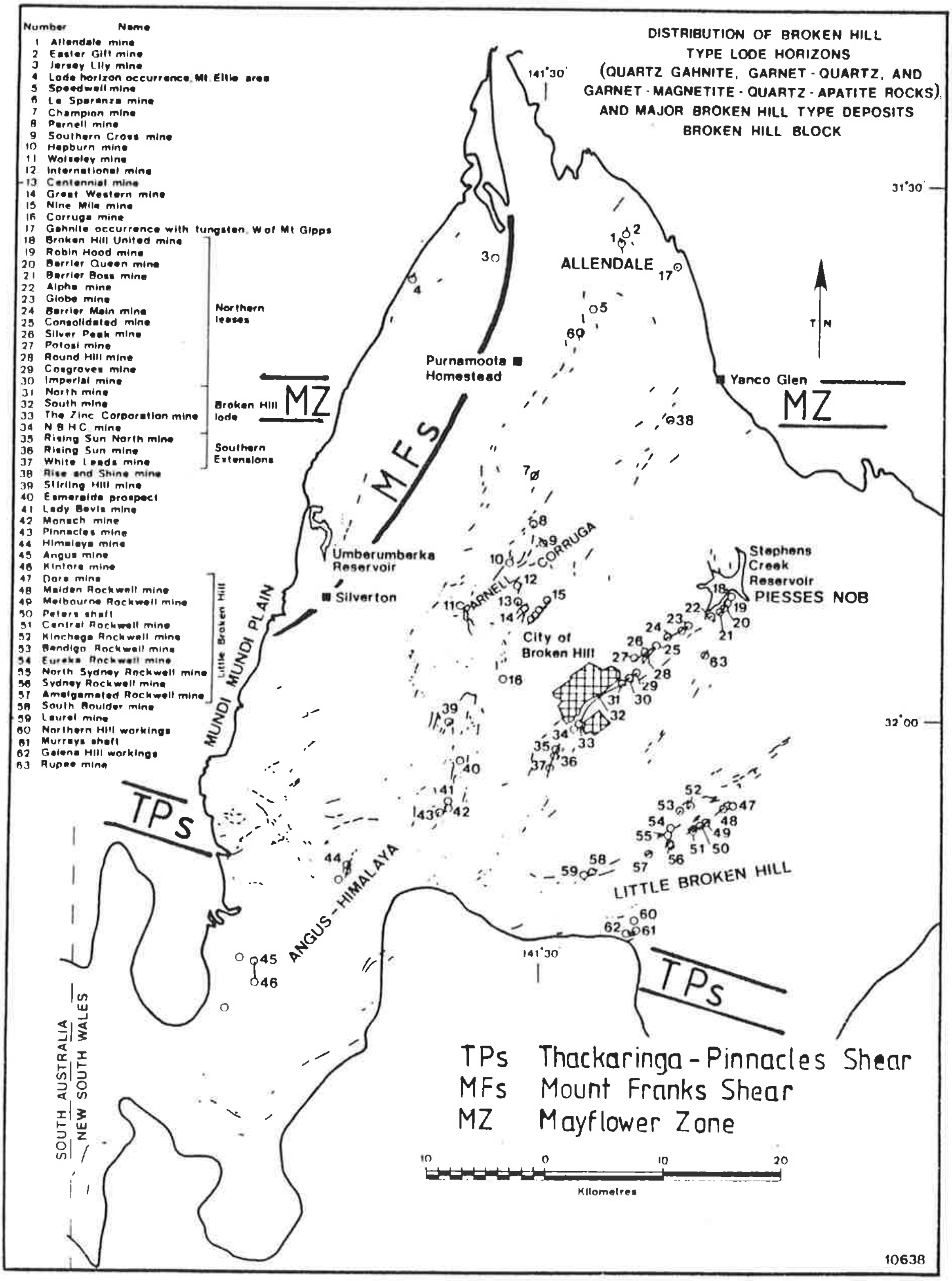



figure 5.14 Distribution of lode horizon and related rocks (from Barnes, 1979).

BHZ magnetic domain boundaries superimposed

## 5.9 Summary

Within the BHZ a systematic distribution of magnetic horizons is observed both in a spatial and stratigraphic sense. The lowest part of the stratigraphy, suite 1 is quite strongly magnetic wherever it is observed, while the upper metasedimentary suites appear everywhere to be either very weakly or non magnetic. Nearly all of the major magnetic horizons outside of suite 1 lie in a narrow stratigraphic inteval from around the middle of suite 3 to the lower part of suite 5. The horizon(s) within suite 5 appear distinct from the suite 4 and suite 3 horizons which are seen as one magnetite rich interval which in different localities may include horizons in suite 3 or suite 4 or in both suites. This latter broad horizon spanning suite 3 and suite 4 appears to correlate with a period of intense acid volanic activity during which all of the Broken Hill Type mineralization in the region was 'deposited'.

Apart from this stratigraphic zoning of magnetic horizons which persists throughout the BHZ there are four spatial subdivisions of the BHZ which display quite different concentrations of magnetite, particularly within the suite 3-suite 4 stratigraphic interval. These magnetic 'Domains' are interpreted as effects of different depositional environments and their boundaries are regarded as primary basement features which have influenced both deposition and subsequent deformation of the Willyama Complex.

Of prime importance is the Central Domain which apparently constituted an environment highly favourable for the development of chemically precipated iron formations and the related stratiform lode rocks. The Northern and Southern Domains are by comparison, much poorer in magnetite bearing rocks and lode horizon.

The Northwestern Domain possibly derives its magnetic character largely from acid volcanic rocks in contrast to the Central Domain which is dominated by metasedimentary magnetic horizons. The possible implications of this interpretation are discussed in Chapter 8.

# 6 STRUCTURAL INFORMATION FROM THE AEROMAGNETIC DATA

The linear magnetic anomalies in the Broken Hill magnetic zone have been interpreted as stratigraphic markers and therefore probably contain valuable structural information. While this information would primarily be concerned with the lateral continuity of individual horizons, defining strike directions, fold closures, etc., dips of horizons may also be obtainable from the aeromagnetic profiles. This chapter examines the degree of continuity apparent in some of the main magnetic horizons within the Central Domain and explores the possibility of extracting useful dip information from the aeromagnetic profiles. The Parnell-Stirling Vale area and Razorback areas were chosen for this study because they contain continuous magnetic horizons which are associated with large geological structures and are therefore more consistent with the scale of investigation in this thesis than some of the more localized structures containing magnetic horizons. This area was also considered suitable because the aeromagnetic data was available in digital form, allowing flexibility in data presentation which greatly streamlined the interpretation process. The detailed surveys to the south and east of BH were not digitally recorded.

It is stressed that the aim of the analysis in this section is not to produce detailed structural interpretations of the areas but rather to extract all of the valid structural information contained in the magnetic anomalies and to present it in a form readily useable by the interpreter of structural geology.

Clearly, the available aeromagnetic data can only hope to resolve gross structural trends but in areas such as Broken Hill where structural complexity on the scale of a few metres (or less) tends to mask the broad scale structural pattern, such 'coarse' magnetic data provides a useful overall picture.

The "Magnetic Horizon Maps" produced are therefore not structural maps in the strict sense but represent the structural information contained in the aeromagnetic data.

## 6.1 Resolution of the BMR (1975) Detailed Survey

This survey (No. 3, Fig. 3.1, Table 3.1) was flown at a nominal height of 100 metres, sampling total magnetic intensity 5 times per second. This sampling interval, in terms of distance, averages around 11 metres and is certainly adequate to resolve sources 100 metres below the detector. However, to reduce the volume of data at the processing stage, the BMR averaged every 5 samples to produce a working data base with 1 second (c. 55 metre) sampling interval, and all data published by BMR was based on this averaged data set (Wyatt, 1979).

Prior to gridding and contouring the data was further "desampled" by extracting data samples at 3 second intervals (c. 165 metres) from the 'averaged' 1 second data set. This was considered appropriate to the line spacing (300 m) and the scale of presentation of the contour maps.

For practical presentation purposes and for generalized interpretation (as presented in Chapters 4 and 5) the BMR's processing procedures are entirely adequate. However, for detailed interpretation, particularly computer modelling, the loss of detail from the original data set was considered undesirable and consequently the original data, in the form of edited field tapes was obtained from BMR.

Figure 6.1 illustrates the effects of the desampling and averaging processes applied by BMR to the the original data. The line is from the Razorback area. The 0.2 second data clearly indicates two distinct magnetic sources while the 1 second data gives no real suggestion of the minor source on the eastern (right hand) side. The 3 second samples, on which gridding and contouring of survey 3 was based, give a reasonable estimate of the position and amplitude of the "anomaly" but otherwise the feature is poorly resolved.

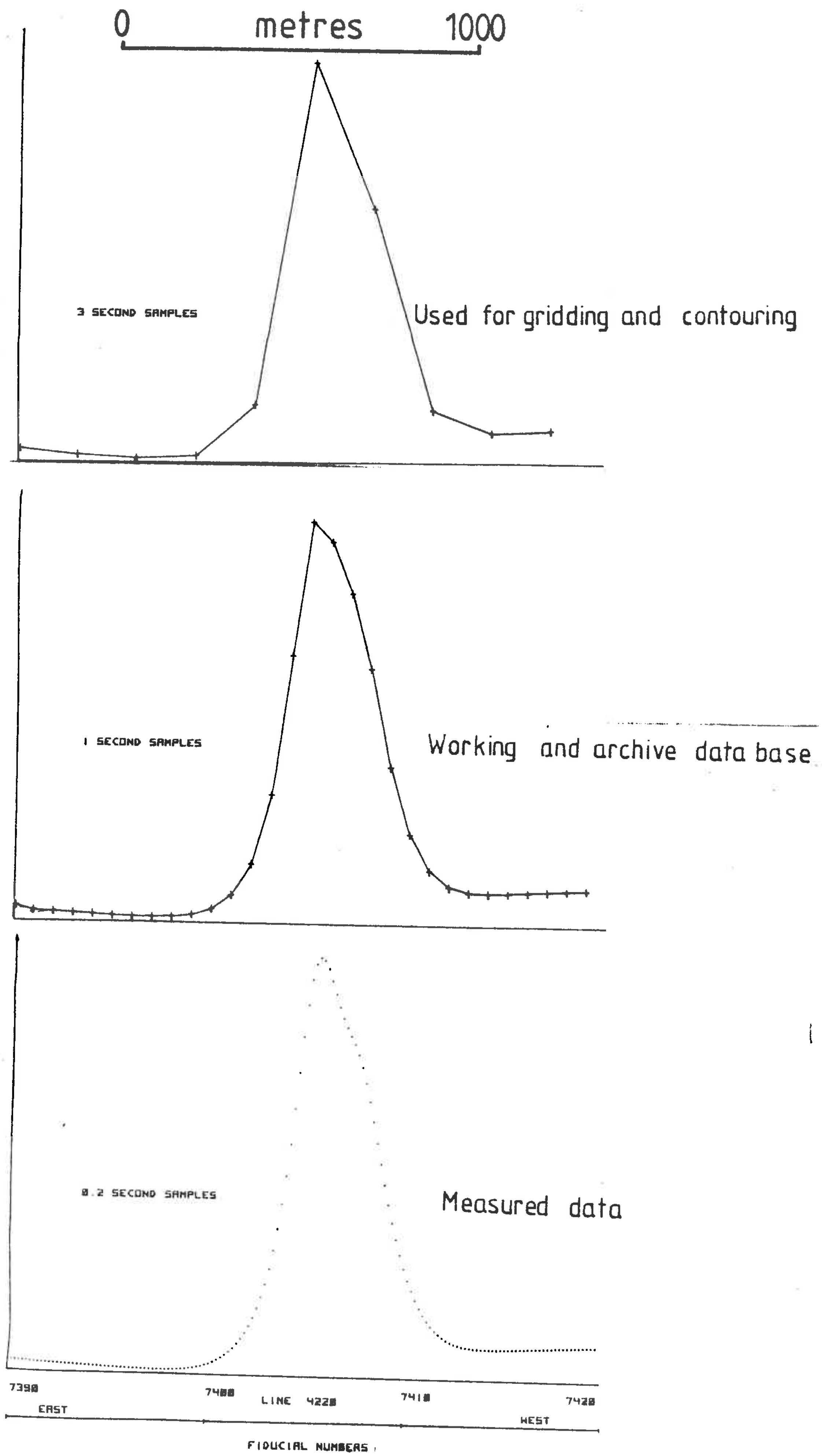



figure 6.1 Comparison of BMR magnetic data sampling intervals

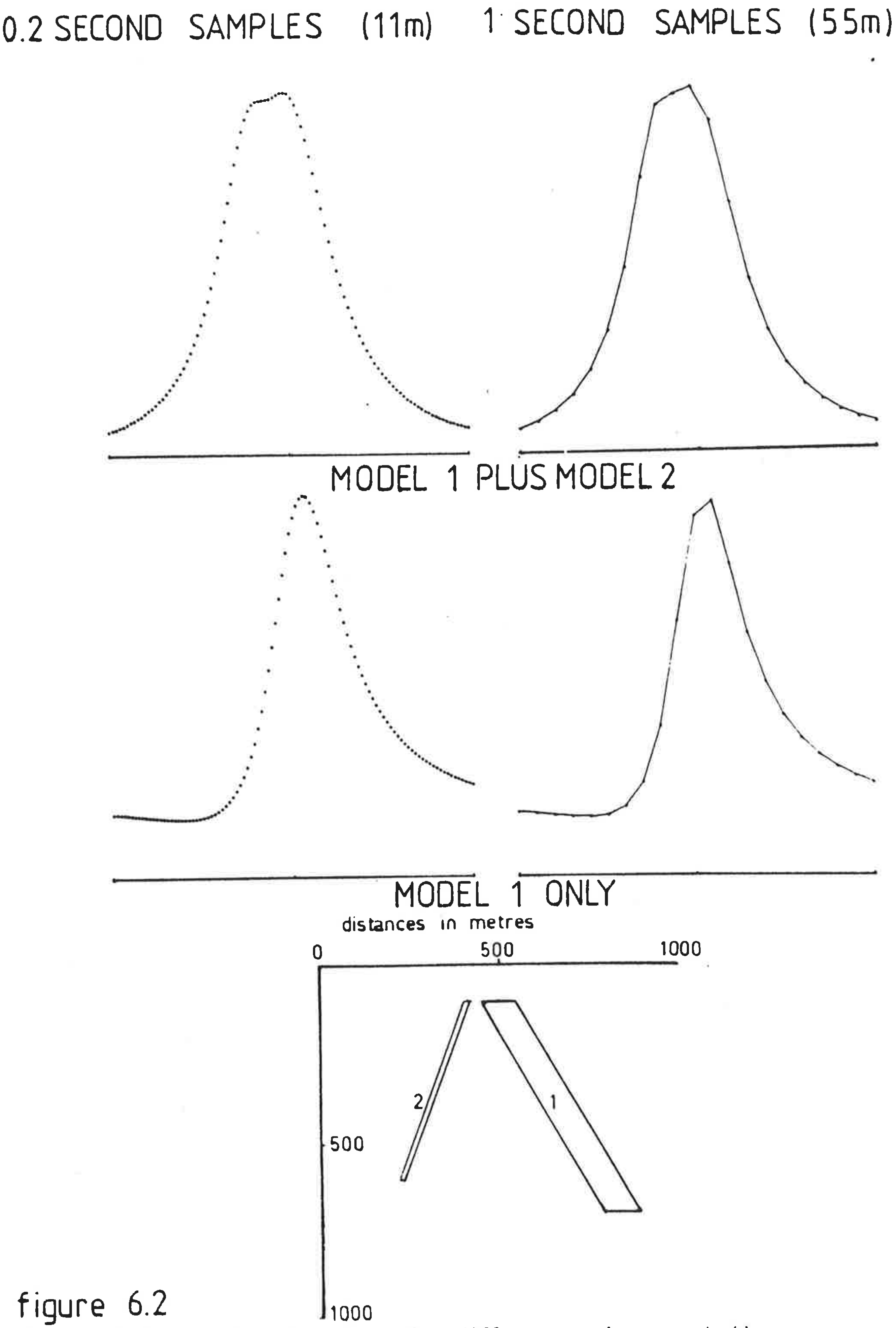



figure 6.2
Computed models showing the difference in resolution between 0.2 and 1 second sampling

A brief model study was conducted in order to test whether or not the 0.2 second samples could resolve two steeply dipping, closely spaced bodies. Fig. 6.2 shows two bodies separated by 25 metres with centres 100 m apart, dipping in opposite direction (profile in magnetic E-W). The two sources are in fact resolved in the 0.2 second data but not (visually) in the 1 second data. No attempt was made to quantify the differences in resolution of the two data sets - Figs. 6.1 and 6.2 were deemed to provide sufficient evidence, both measured and computed, of improved resolution to warrant processing the field tapes.

## 6.2 Magnetic Horizon Mapping Procedure

Flight path maps of the area studied were produced at a scale of 1:25,000, since the aeromagnetic contour maps were produced at this scale and it is also a scale commonly used in regional geological mapping.

Profiles of the original field data were then plotted at approximately the same scale (scaling of the magnetic data was based on time and not distance). Individual magnetic sources were then visually identified from peaks or inflexions in the profile data and manually located using the fiducial numbers.

The central position of each source was defined as the fiducial number at the peak or inflexion. Approximate maximum widths were estimated as the distance betweeen the maximum gradients on either side of the peak. Where this was not possible due to closely spaced sources, the widths were taken to be equal to the flying height (c. 100 metres) since this is the minimum width which can be confidently resolved from aeromagnetic data (see Koulomzine et al, 1970, Fig. 6). Fig. 6.3 shows an example of sources selected along a typical flight line in the Parnell area.

With the positions of sources established along the flight lines, correlation of "horizons" across lines was attempted using the following criteria:-

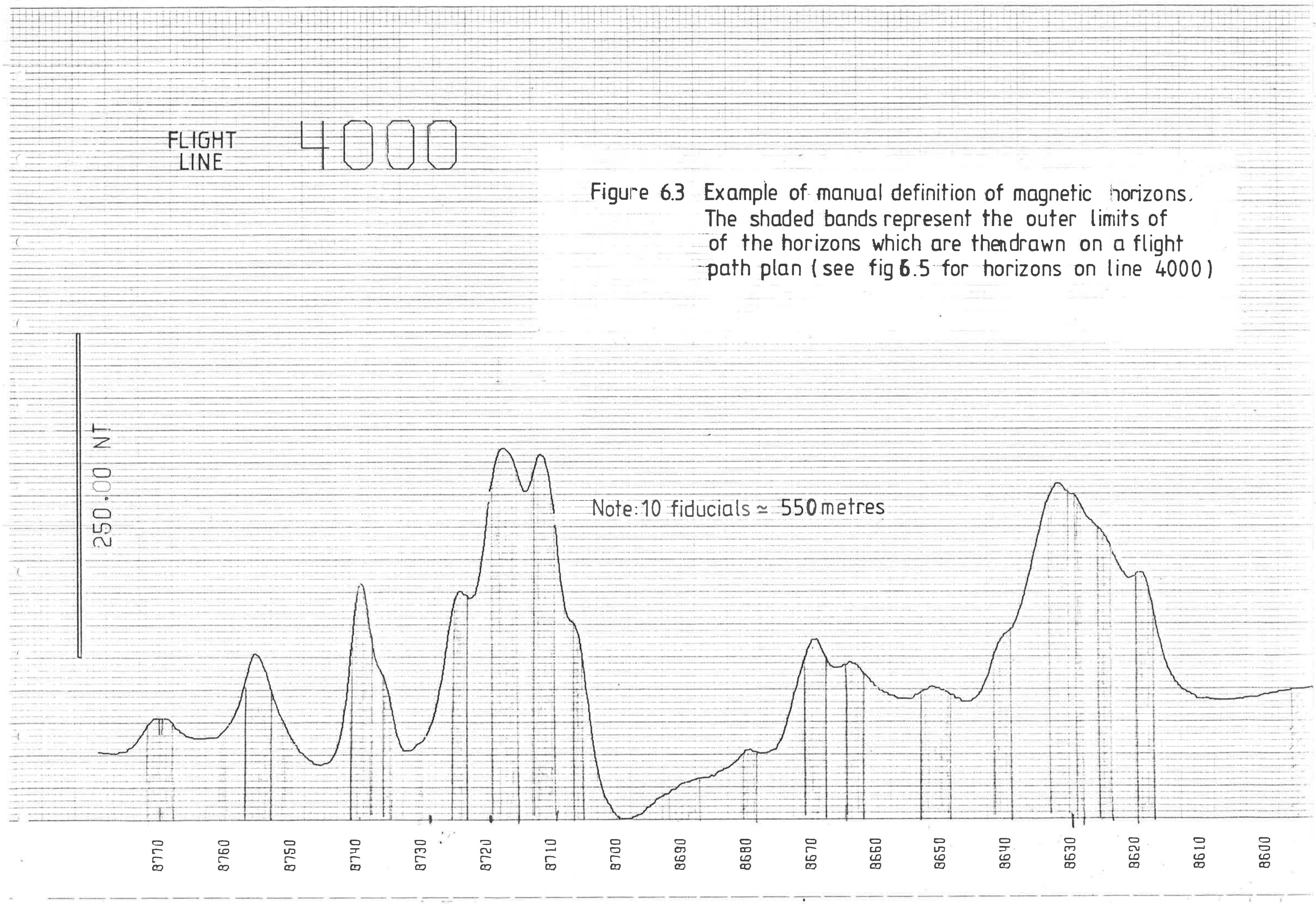



Figure 6.3 Example of manual definition of magnetic horizons. The shaded bands represent the outer limits of of the horizons which are then drawn on a flight path plan (see fig 6.5 for horizons on line 4000)

1. Strike trends from correlations on previous lines
2. Anomaly shapes
3. Along line associations between groups of anomalies
4. Anomaly amplitudes

This magnetic horizon mapping procedure is a simple and well established interpretation technique, its main disadvantage is that it is very laborious. Recent efforts to automate this procedure rely heavily on signal enhancement filters which map the inflexion points in the magnetic profiles as "sources". In particular second derivative filters have been applied by Stewart and Boyd (1977) and McIntyre (1979 and 1981) to map linear magnetic horizons automatically from the digitally recorded data. While these authors have demonstrated the effectiveness of this method, the correlation of 2nd derivative peaks across lines in complex magnetic areas is, in the opinion of the writer, subject to greater uncertainty than the across line correlation of the measured magnetic field. The main reason for this is that second derivative procedure very strongly discriminates against anomaly shape, an important criterion available for correlating the measuring field.

However, the results obtained by McIntyre are quite impressive; particularly considering his use of the 1 second sampled data to obtain his second derivative maps. The advantages of his technique are that it rapidly, objectively and precisely (in true position) displays the fine detail in a large amount of data. While the loss in resolution (due to the coarser sampling) and the presentation of filtered rather than measured data may make correlation of anomalies across lines subject to greater uncertainty, it must be conceded that McIntyre's technique would be appropriate is most situations owing to its "automation".

Considering the aim of the work presented here was to extract the maximum amount of structural information from the data, including dip information from computer modelling, the "manual" approach was regarded as preferable.

A comparison between the two techniques is presented in Figs. 6.5 and 6.6

## 6.3 Modelling Procedures

Examination of the raw magnetic profiles in the two areas chosen for study revealed that around 50% were conducive to simple, single body modelling. Due to time constraints, modelling was restricted to the more persistent horizons although many of the smaller, less continuous horizons could equally well have been modelled.

Modelling was carried out on a desktop computer with an accompanying plotter using straightforward but flexible programs written by the author (Appendix 3). Prior to modelling, depths and dips of anomaly sources were estimated. Depths were calculated using the "straight slope" method while dips were estimated visually by comparison with type curves constructed for the magnetic latitude of Broken Hill (e.g. Fig. 6.4). Subsequent modelling of these anomalies generally produced dips within 20 degrees of the initial estimates. The simpler, "single source" anomalies typically required 4 or 5 "iterations" to produce a satisfactory match between observed and computed curves. More complex anomalies showing evidence of interfering sources occasionally required more than 10 iterations (Each iteration involved about 5 minutes work).

### Usefulness of Modelling Parameters

Of the parameters deduced from modelling results, the dips were most likely to be useful in the "structural" sense.

In most cases the anomaly sources were found to be within 50 metres of the surface so that the magnetic horizons could be inferred to exist in outcropping or subcropping formations. The widths and susceptibilities resulting from modelling are most probably generalized values which actually represent an internally heterogeneous "envelope"

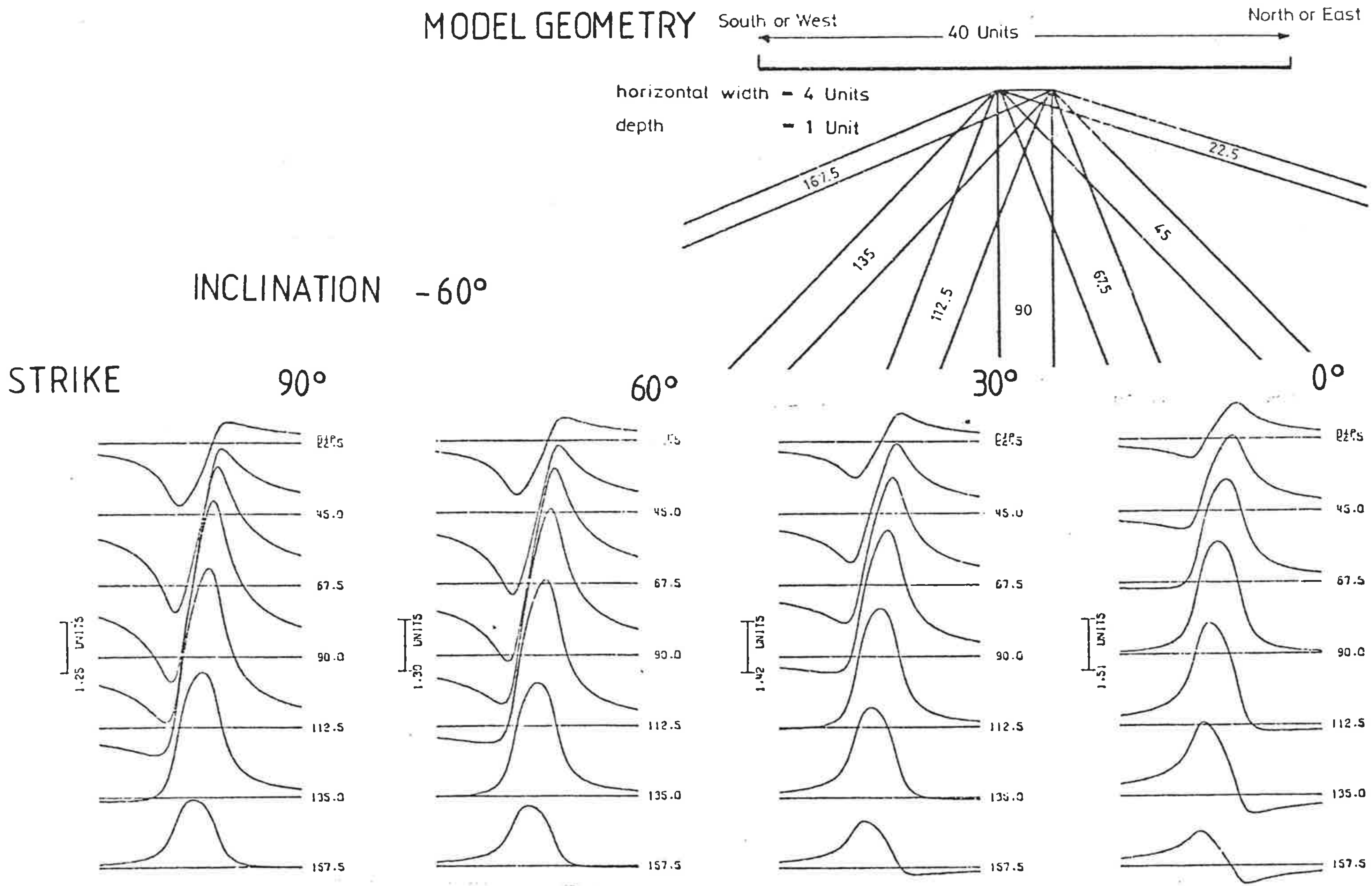



figure 6.4 Dyke models used to estimate dips on linear magnetic anomalies

containing many magnetite rich lenses (see McIntyre, 1979). Susceptibility values are therefore unlikely to be representative of measured susceptibiities.

The calculated dips are interpreted to represent the dips of the magnetite rich envelopes and thereby give a measure of the regional dip of these inferred stratigraphic markers.

Validity of Dip Information

Regardless of the quality of the match between computed and observed data, dips inferred from modelling may be considerably different from the true dips of the magnetite horizons. The most likely cause of this error is an incorrect assumption regarding the direction of magnetization within the source. In all of the models the direction of magnetic polarization has been assumed parallel to the earths ambient field. Limited susceptibility and remanent magnetism studies by Wood (1972) and Everle (1973) suggest that remanent magnetism is rarely significant in the Willyama rocks so that the above assumption is likely to be valid in the majority of cases.

Bearing in mind the sedimentary nature of most of the magnetic horizons in question, and the subsequent metamorphism, both prograde and retrograde, it is considered unlikely that a systematic remanent component is present. A possible exception to this may be the massive quartz magnetite rock which occurs throughout the Central Domain and is clearly the most magnetic rock type in the Willyama sequence, producing anomalies of up to 4000 nT. Demagnetization effects may also be present in the QM's. While a systematic study of magnetic properties of the magnetite rich horizons would be highly desirable, it would effectively be a major study in itself and was considered to be outside the scope of this thesis.

An empirical test of the validty of the dip information provided by magnetic modelling was possible due to the availability of field measured dips either coinciding with or very close to the interpreted position of some of the magnetic horizons.

Recent mapping by Laing (pers comm, 1979) shows that the major "suite 4" anomaly (PE) on the western margin of the Stephens Creek antiform is associated with sources which dip to the northwest at around 75-80 degrees, the dips being generally shallower in the north. The models deduced for this anomaly (see section 6.6) consistently show dips to the NW of between 50 and 85 degrees with a mean of around 70 degrees and a noticeable trend for dips to become shallower in the north.

In addition the Razorback quartz magnetite horizons are depicted on Map 1 as dipping at 85 degrees to the east and the dips resulting from modelling of these horizonsm are in close agreement with this figure, ranging fom 70 to 99 degrees.

In the light of the comparisons the dip data inferred from modelling these magnetic horizons may be regarded as reliable to within about $\pm$10 degrees and therefore certainly constitute ueful structural information.

The following sections present the main features of the magnetic horizons in the two areas studied. Some general comments are made on possible structures outlined by these horizons but it is suggested that the geological interpretation of these magnetic horizon maps is the province of the geologist mapping the particular area. Without geological control these maps, if used without due consideration to their limitations, may be misleading.

The main limitation is, of course, that these maps show only magnetic rocks units. In areas where thse are sparse, structural information from magnetic maps will be correspondingly sparse.

The line spacing and flying height also place limitations on the amount of detail obtainable from the magnetics. McIntyre (1979) has suggested that in particular "problem" areas in the Willyama Complex, line spacings of 100 metres with detector height of 30 m would be feasible and would resolve complex structures. It is apparent from McIntyre's work and the maps presented here that the 300 metre line spacing and 100 flying height make the magnetic horizon maps most appropriate to medium scale (1:25,000 to 1:50,000) geological interpretation.

## 6.4 The Parnell-Stirling Vale area

North of the Stephens Creek fault, between the Apollyon Valley Shear and the Stephens Creek antiform is a zone of very striking continuity in the magnetic horizons. Five particularly strong magnetic anomalies (PA-PE, Fig. 6.5) have been modelled in this area and all except one show very consistent dips. The major structures interpreted by Stevens et al in this area are the Allendale antiform and the Parnell synform.

The Allendale antiform is defined largely by outward stratigraphic younging at the boundaries of the very broad composite gneiss unit (see Stevens et al, p. 104). in a zone of upward facing structures. Although symmetry about this proposed structure is usually well developed in terms of the suites, the strong magnetic horizons which border the antiform are not necessarily correlable. The major anomaly on the western side of the antiform (Anomaly PB) shows remarkable continuity and is a relatively broad horizon which appears to be entirely contained within suite 3. Ground investigations in the north of this anomaly zone by McIntyre (1979) show the sources to be in metasediments. Anomaly PC lies on the eastern side of antiform and appears more closely related to a Potosi gneiss unit, which lies in suite 4, than to the adjacent suite 3 rocks. However both in PB and PC horizons lie close to the suite 3/suite 4 boundary and may therefore be correlated in a broad sense as part of the "magnetite rich

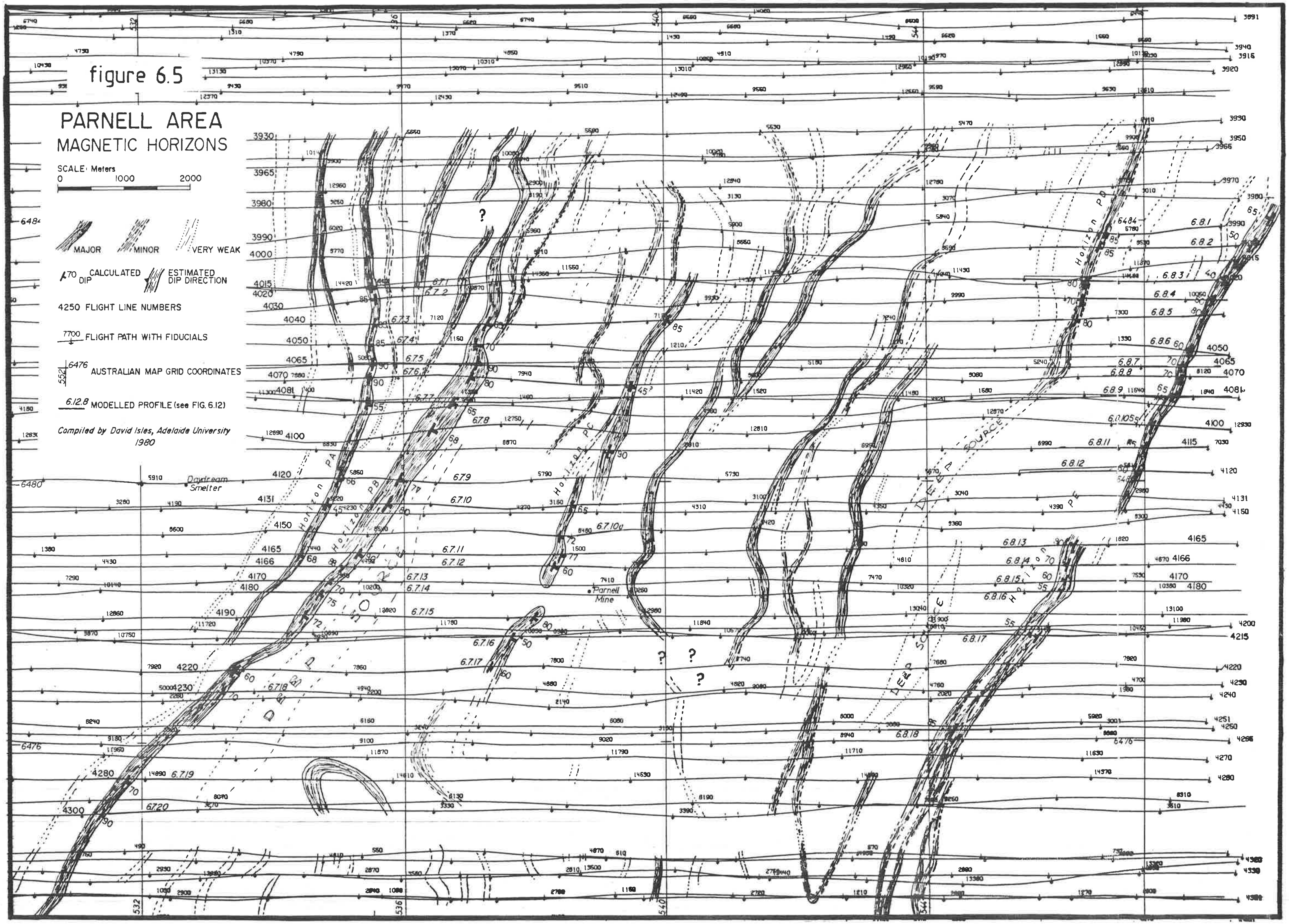


figure 6.5
PARNELL AREA
MAGNETIC HORIZONS
SCALE: Meters
0 1000 2000
MAJOR
MINOR
VERY WEAK
70 DIP CALCULATED
ESTIMATED DIP DIRECTION
4250 FLIGHT LINE NUMBERS
7700 FLIGHT PATH WITH FIDUCIALS
6476 552 AUSTRALIAN MAP GRID COORDINATES
6.12.8 MODELLED PROFILE (see FIG. 6.12)
Compiled by David Isles, Adelaide University
1980
Daydream Smelter
Parnell Mine
Horizon PA
Horizon PB
Horizon PC
Horizon PD
Horizon PE
DEEP SOURCE

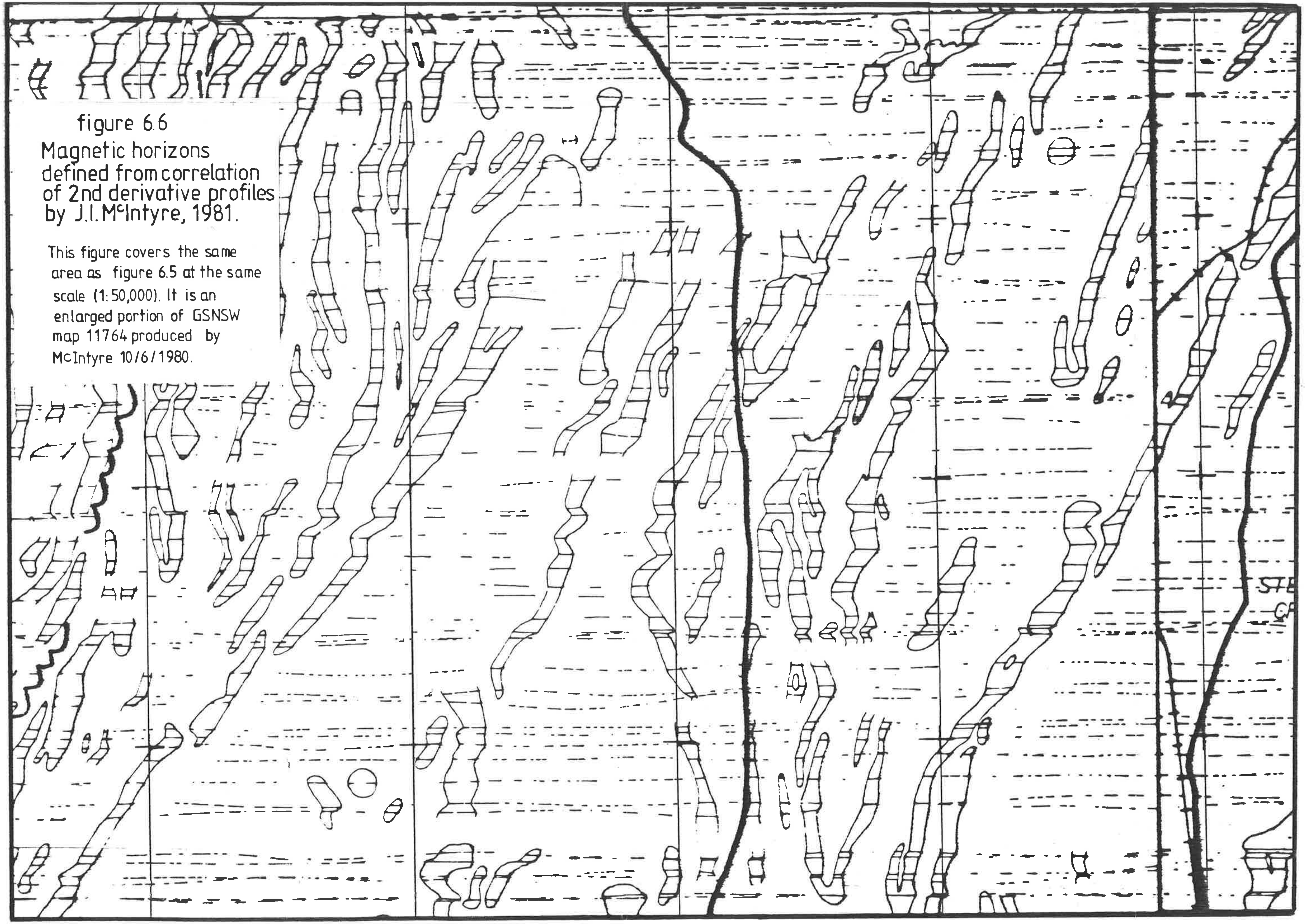


figure 6.6
Magnetic horizons defined from correlation of 2nd derivative profiles by J.I. McIntyre, 1981.

This figure covers the same area as figure 6.5 at the same scale (1: 50,000). It is an enlarged portion of GSNSW map 11764 produced by McIntyre 10/6/1980.

interval" found in this stratigraphic position throughout the BHZ. Modelling of these horizons in both cases indicates a steep dip (around 70 degrees) to the east. A deep (400-500 metres) magnetic source is evident immediately to the east of PB (Fig. 6.5) over a strike distance of around 15 km. This may be due to a structural repetition of the PB horizon or may even represent an underlying magnetic core in the Allendale antiform.

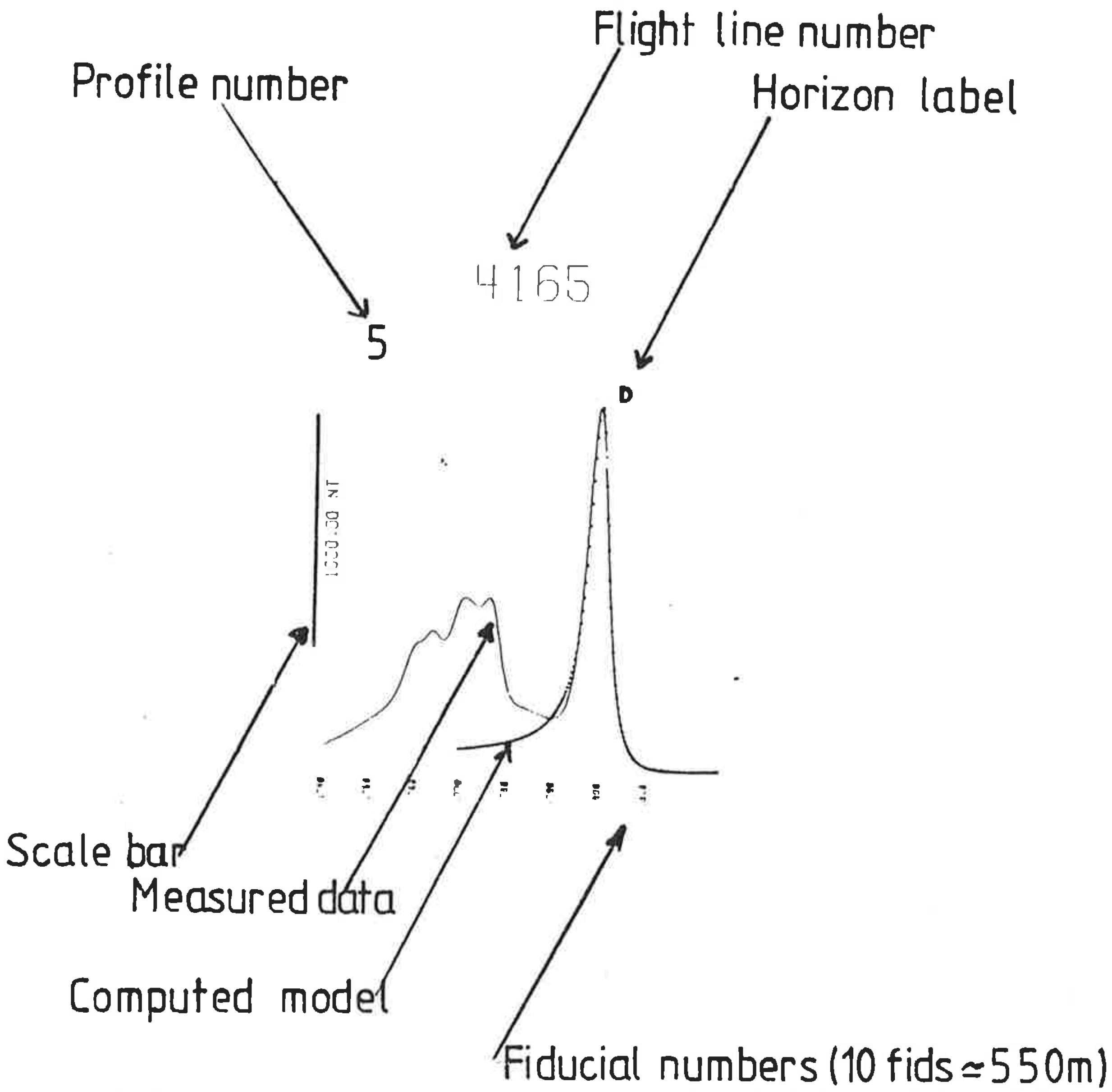
To the west of PB a diverging pattern of magnetic horizons is apparent in an area where the structure is not well known. The anomaly PA correlates precisely with a mapped Potosi gneiss unit and the magnetic models indicate that this unit dips to the east at roughly the same angle as the PB horizon. Although this unit has been interpreted by McIntyre (1979) to die out to the south, there is some suggestion that it may continue as an intermittently magnetic horizon along most of the strike length of PB. The magnetic modelling results from anomalies PA, PB and PC are presented in Fig. 6.7 and Table 6.1

The Parnell synform is characterized by a set of magnetic horizons which show positive indications of closure to the south. The axis of this structure appears to be well mapped out by the closures of the magnetic horizons and there is some indication of refolding of these horizons.

East of the Parnell synform the mapping of Stevens et al and Majoribanks et al suggest structural complexity. This is reflected in the disjointed nature of the magnetic horizons, and no coherent pattern is evident. Horizons such as PD show little or no evidence of fold closures. Modelling on anomaly PD yields dips partly to the east and partly to the west, which may indicate structural complexity.

The anomaly PE extends along strike for a distance of around 15 km, between the Stephens Creek fault and the Mayflower Zone. Investigations by McIntyre (1979) in the north of this anomaly show that it lies in suite 4 close to

# KEY TO FIGURES 6.7,6.8,6.9 & 6.12




note : model parameters are detailed in tables 6.1 – 6.4

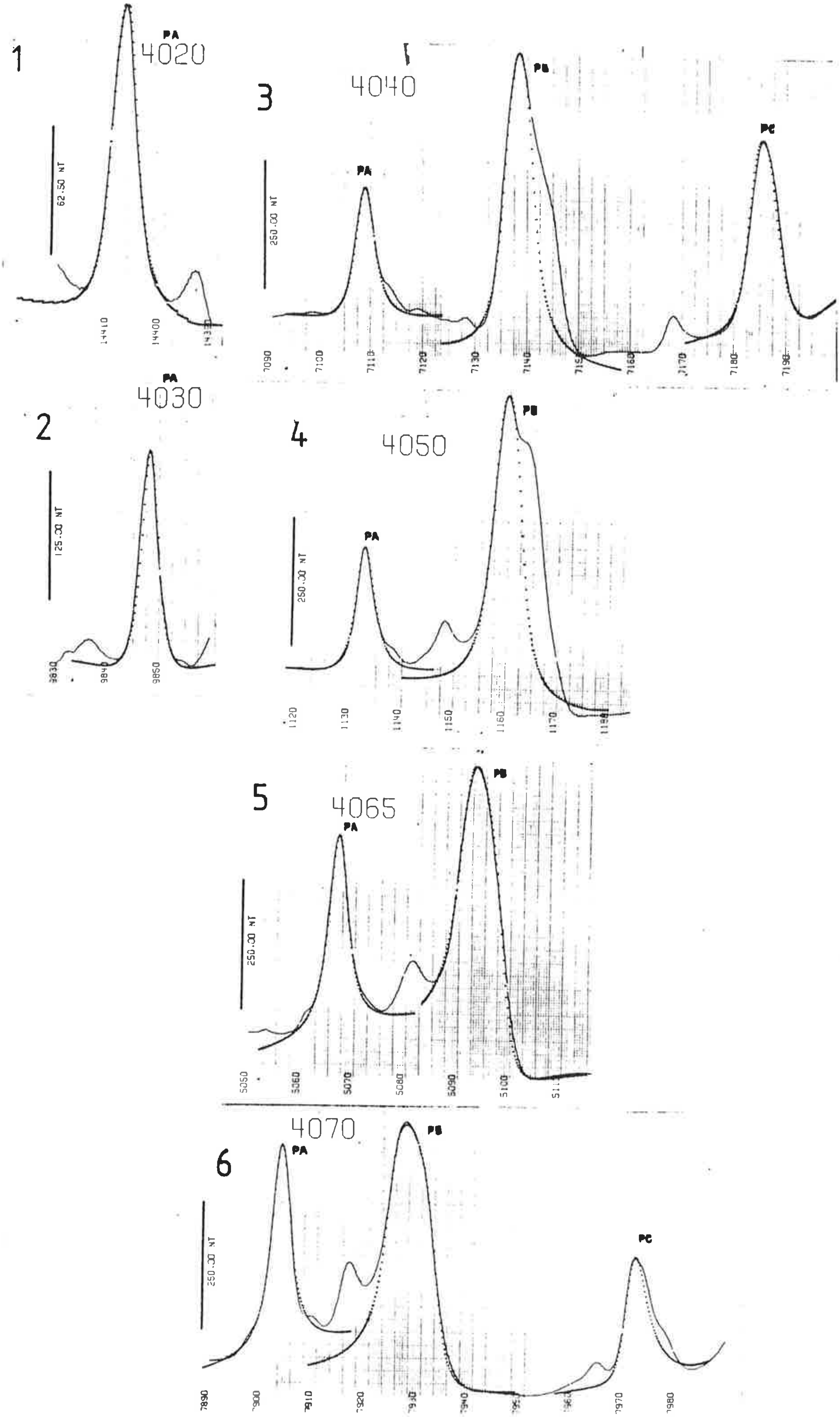



figure 6.7a Modelled magnetic profiles 1–6, PARNELL area

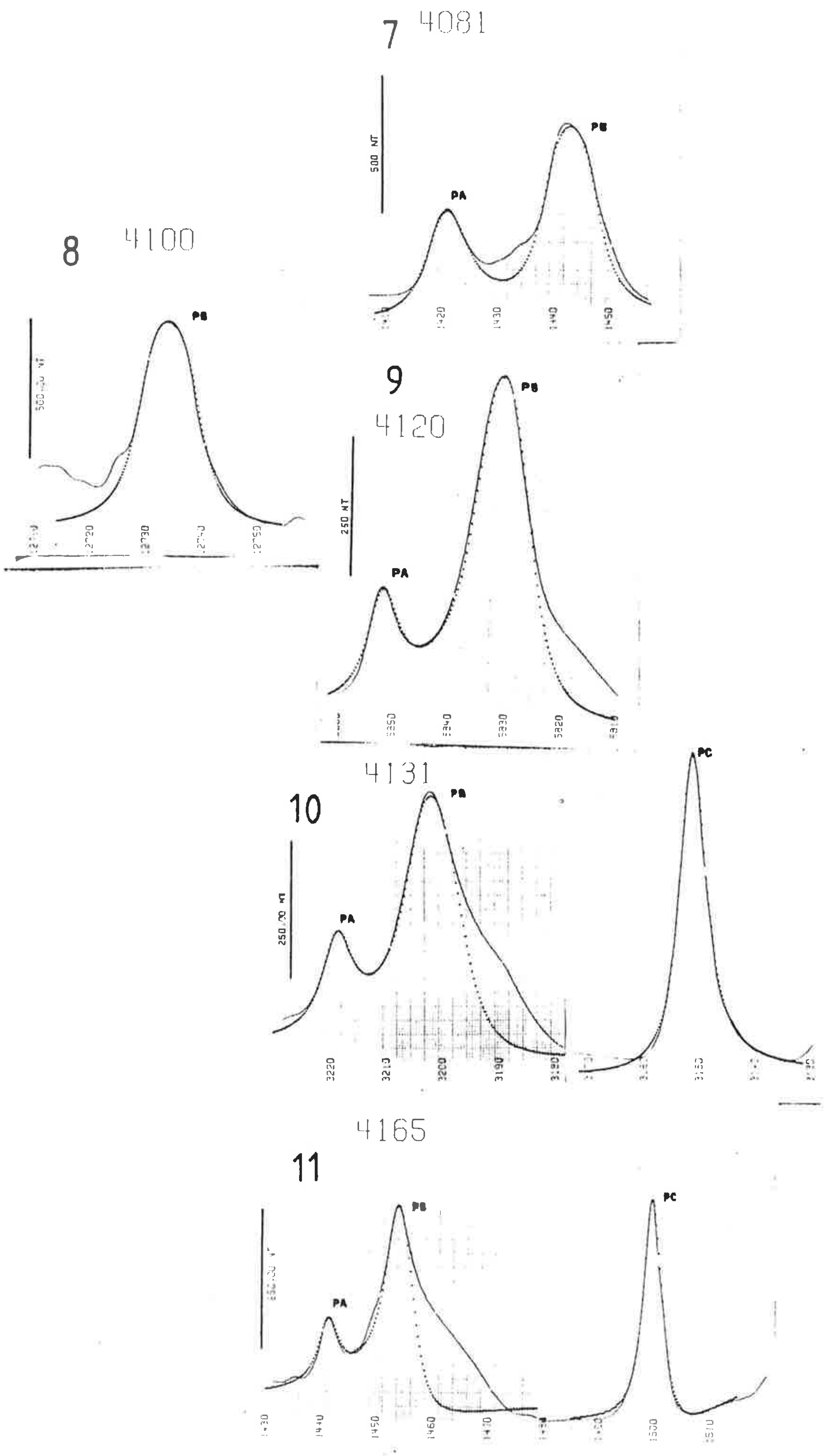



figure 6.7b Modelled magnetic profiles 7 — 11, PARNELL area

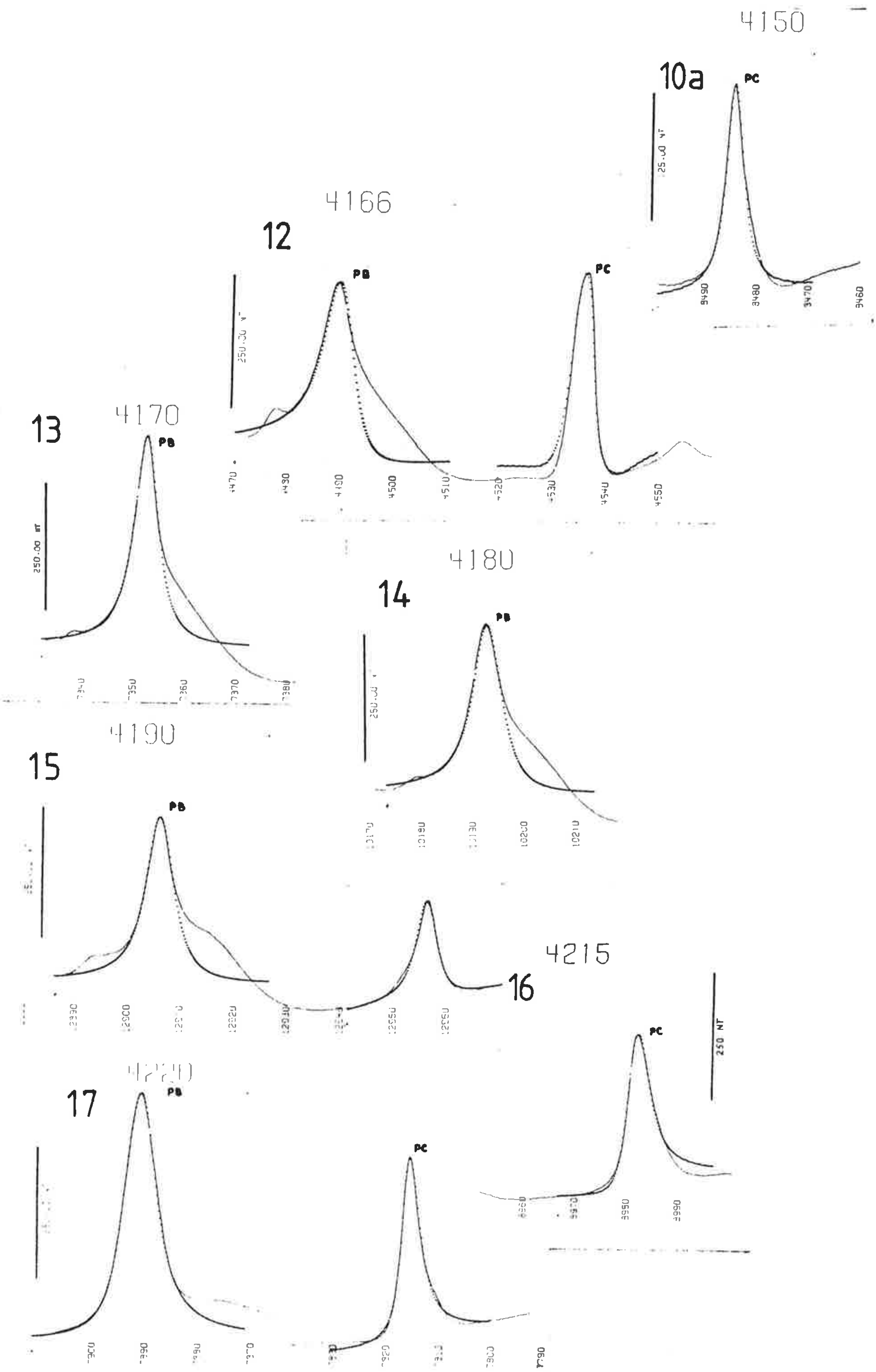



figure 6.7c Modelled magnetic profiles 12 – 17, PARNELL area

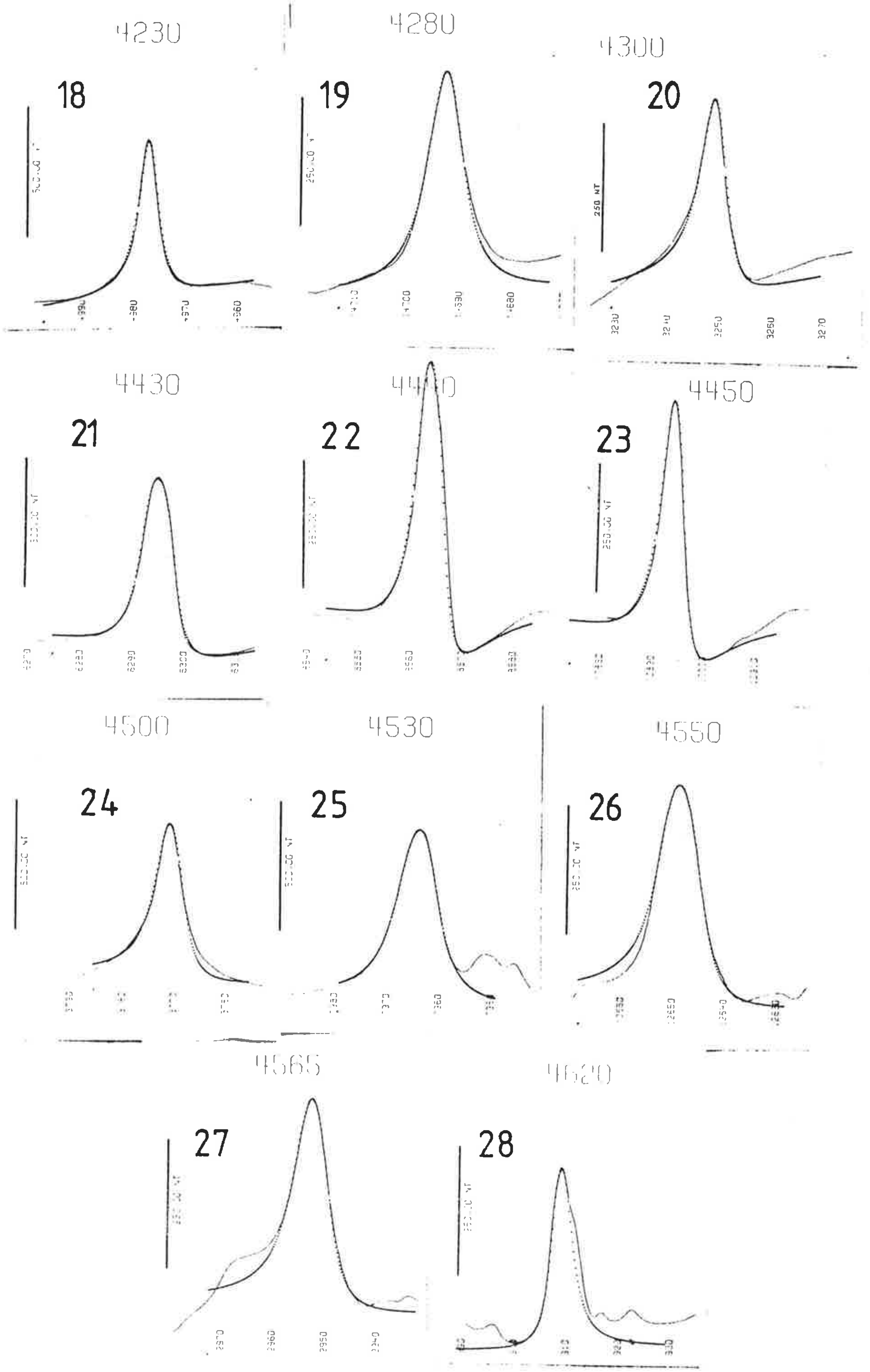



figure 6.7d Modelled magnetic profiles 18 — 28, horizon PB

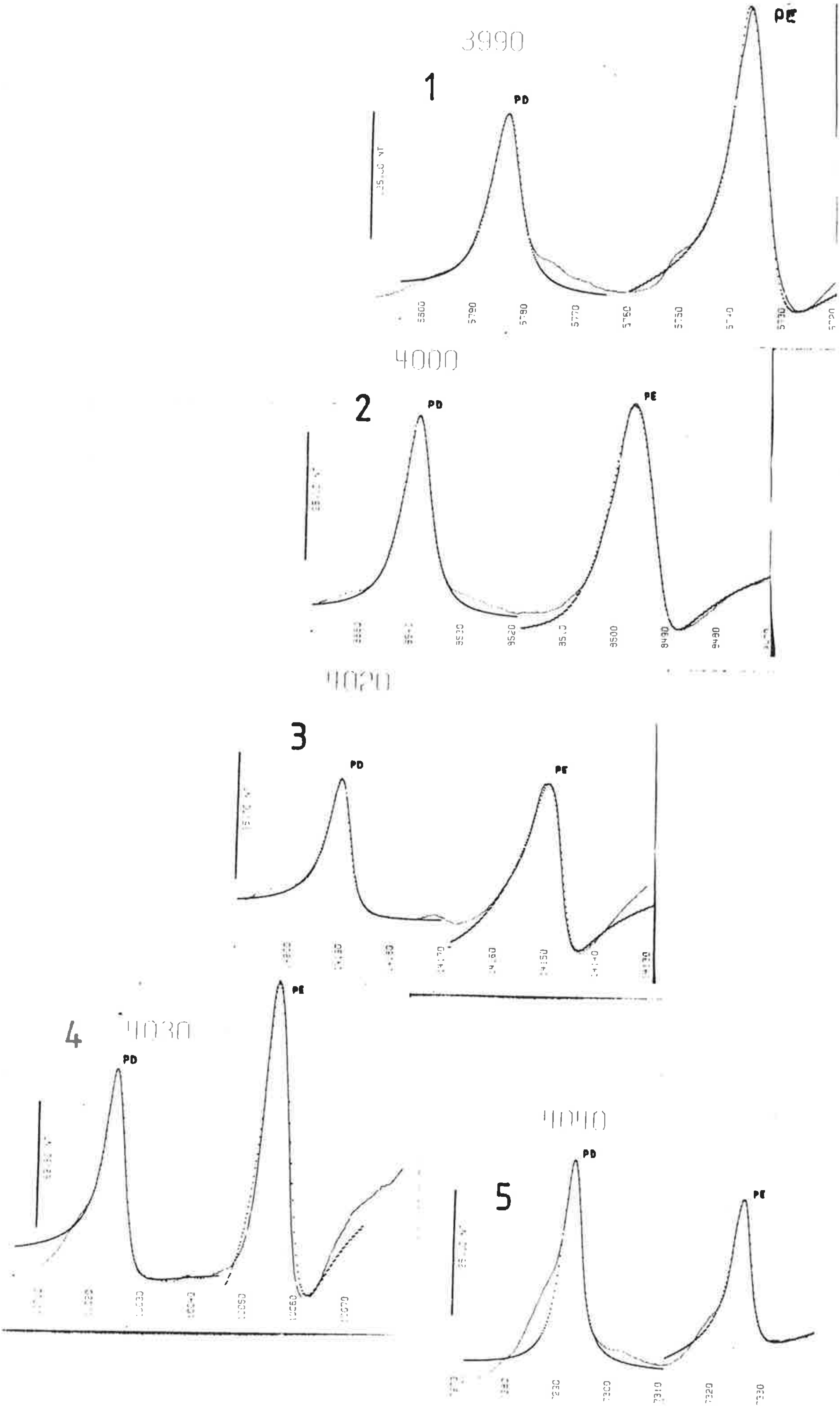



figure 6.8a Modelled magnetic profiles 1—5, PARNELL (east)

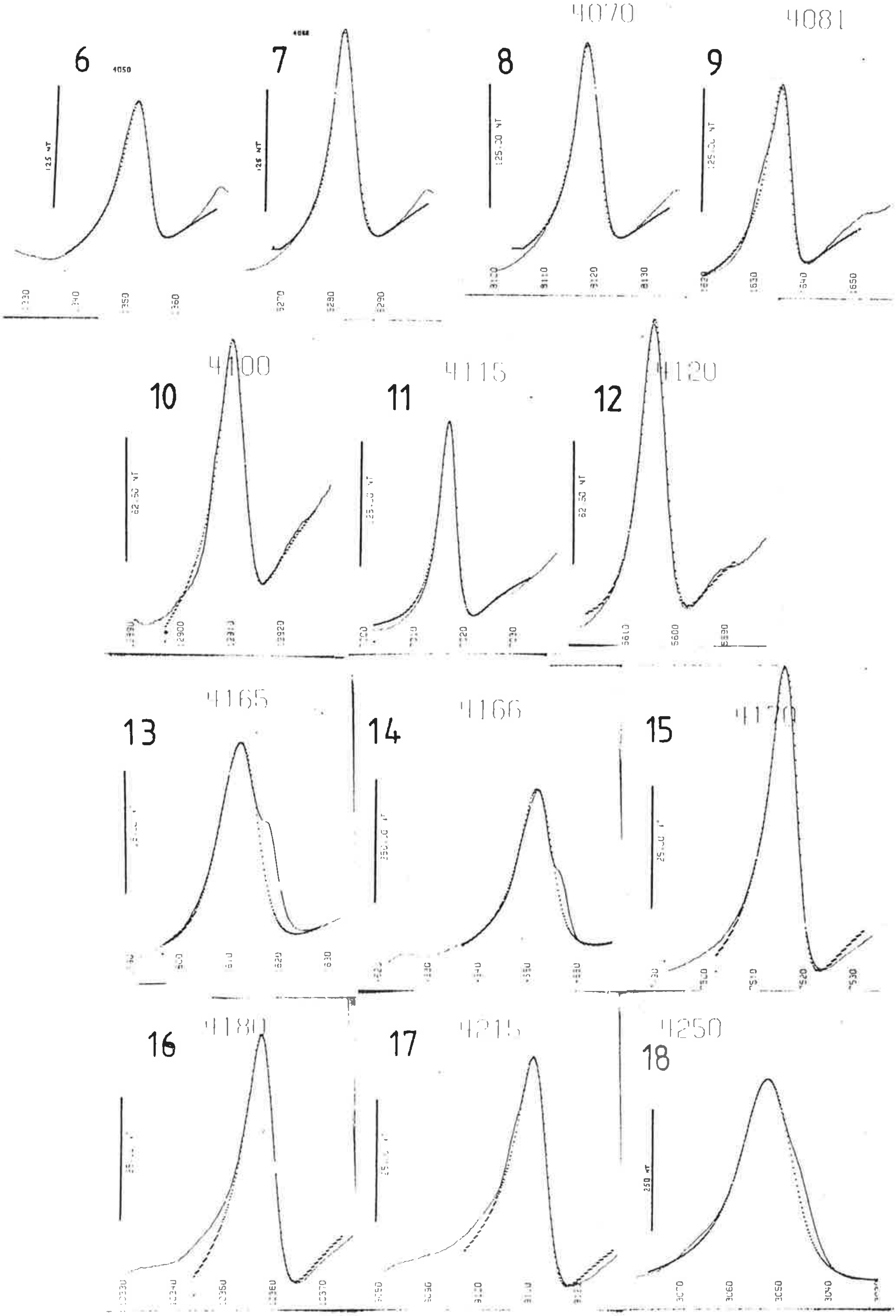



figure 6.8b Modelled magnetic profiles 6—18, horizon PE

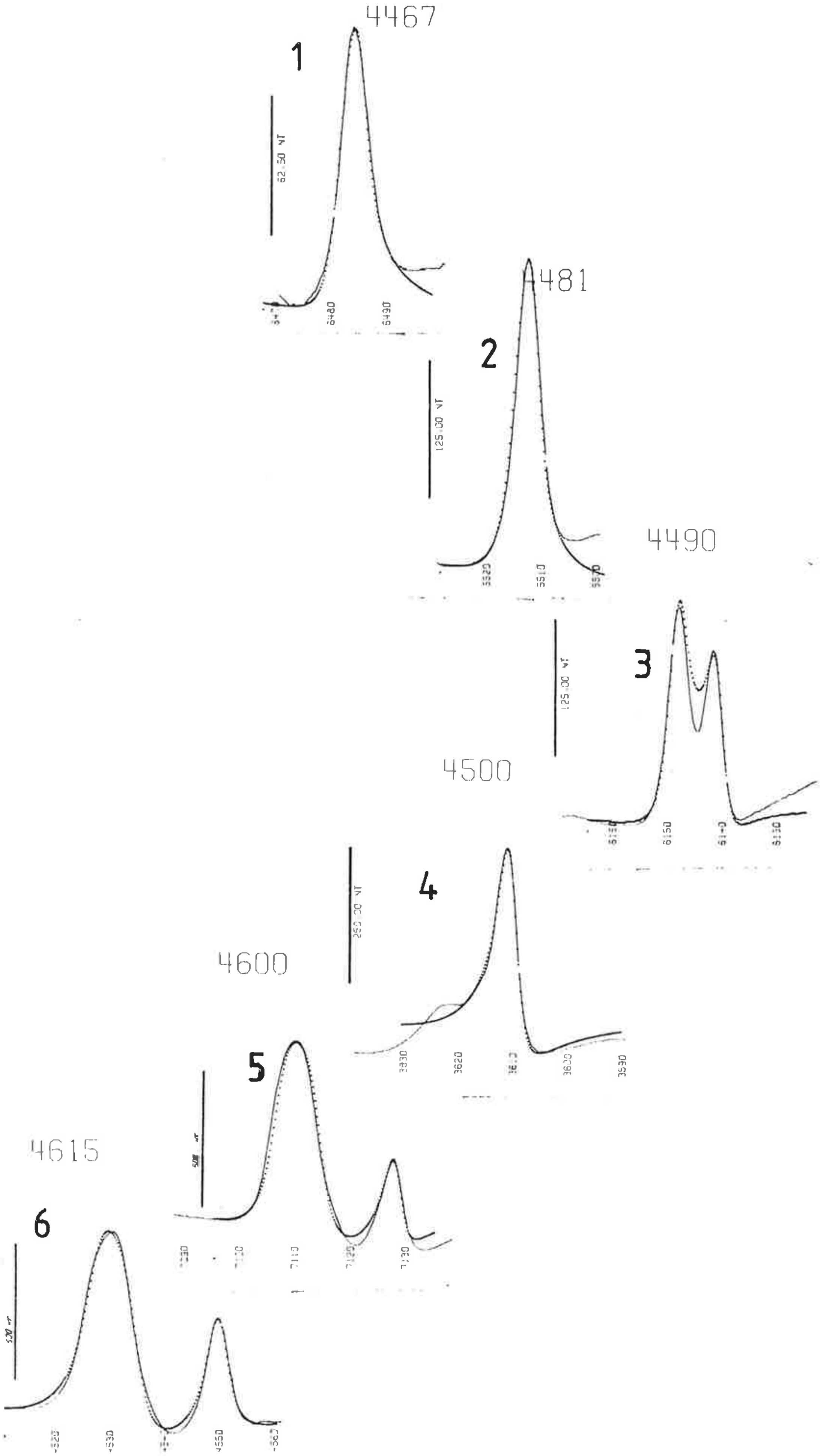



figure 6.9 Modelled magnetic profiles, STIRLING VALE SYNFORM

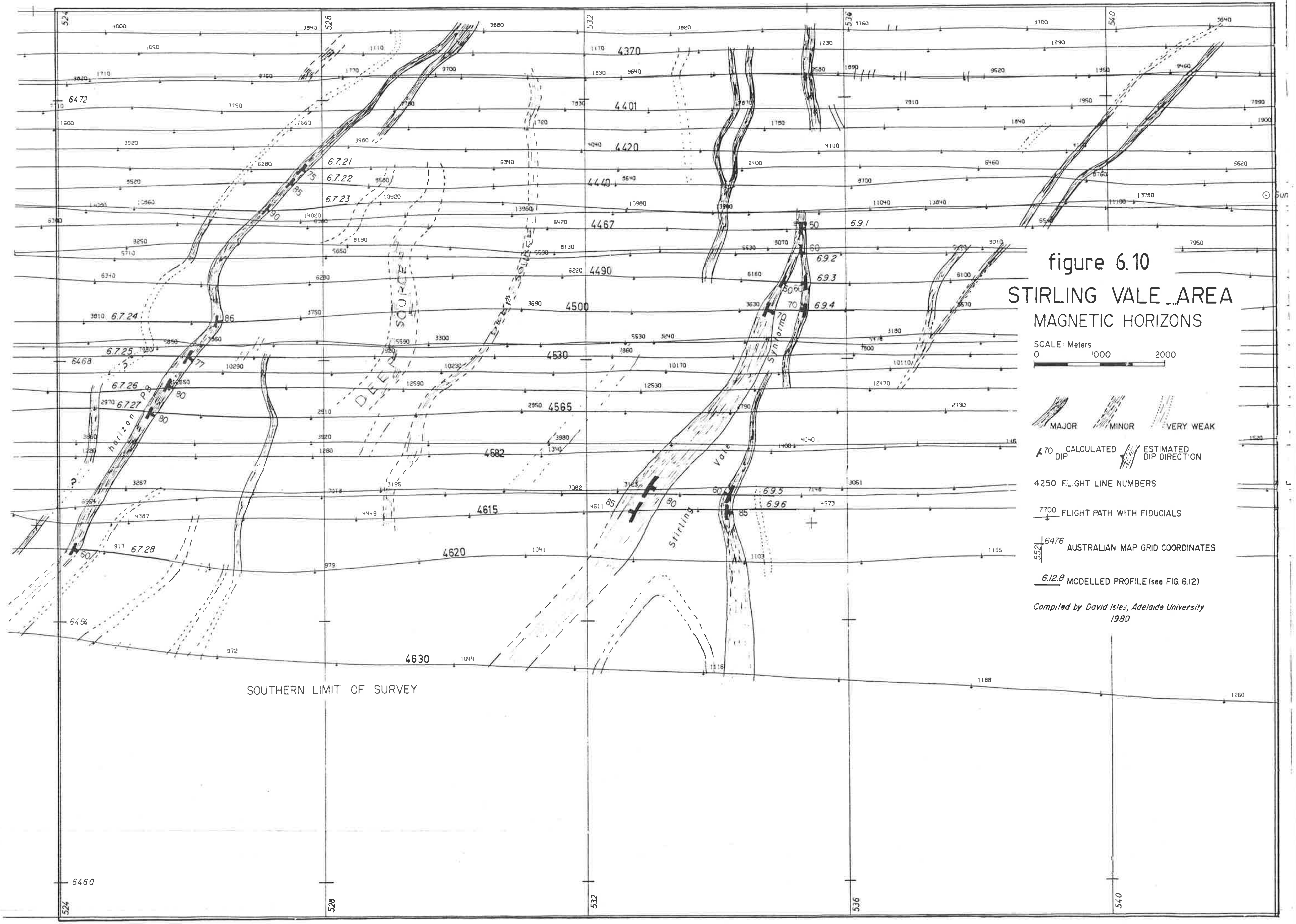


figure 6.10
STIRLING VALE AREA
MAGNETIC HORIZONS
SCALE: Meters
0
1000
2000
MAJOR
MINOR
VERY WEAK
70 DIP
CALCULATED
ESTIMATED DIP DIRECTION
4250 FLIGHT LINE NUMBERS
7700 FLIGHT PATH WITH FIDUCIALS
552 6476 AUSTRALIAN MAP GRID COORDINATES
6.12.8 MODELLED PROFILE (see FIG. 6.12)
Compiled by David Isles, Adelaide University
1980
SOUTHERN LIMIT OF SURVEY
DEEP SOURCE
DEEP SOURCE
Stirling Vale Synform
horizon P8
4370
4401
4420
4440
4467
4490
4500
4530
4565
4582
4615
4620
4630
6472
6468
6464
6460
524
528
532
536
540
6.7.21
6.7.22
6.7.23
6.7.24
6.7.25
6.7.26
6.7.27
6.7.28
6.9.1
6.9.2
6.9.3
6.9.4
6.9.5
6.9.6

a Potosi gneiss unit which is non magnetic. The magnetic horizons here lie exclusively in metasediments. Apart from its striking continuity, modelling of anomaly PE yields a very consistent dip to the west of around 70 degrees. Although the dips are variable (50-80 degrees) they appear to be more shallow in the north. This compares very favourably with the dips observed by Laing (pers. comm.) in the field. The models for anomalies PD and PE are presented in Figure 6.8 and Table 6.2

The continuity of this feature is broken at flight line 4150, south of which it broadens and subdivides a number of branches. The dips calculated, are the same as in the northern section supporting the contention that both sections are part of the same stratigraphic horizon. The dips on the anomaly PE are consistent with its mapped structural position on the western limb of the north plunging Stephens Creek antiform.

In the vicinity of the Stephens Creek fault both the structure and the distribution of magnetic horizons are complex. Map 5 shows the interpreted dislocation of many magnetic anomalies across the fault.

In the Stirling Vale area south of the Stephens Creek fault (Fig. 6.10) only the anomaly PB is readily "modelable". Significantly it yields the same range of dips as the northern section and is therefore inferred to be stratigraphically and structurally the same as the northern section despite the presence of the Stephens Creek fault. A weak horizon is intermittently present around 500 metres west of the PB horizon and this may be a lateral equivalent of the PA horizon found to be associated with a Potosi gneiss unit to the north.

East of anomaly PB wide tracts of suite 4 rocks are mapped (Map 2) but the structure is poorly understood. Distinctive magnetic horizons are absent in the area between PB and the Stirling Vale synform although some continuity in broad groups of horizons can be inferred.

The Stirling Vale Synform is outlined by a broad suite 4 horizon which is very conspicuous on the western side but is narrower and less continuous on the eastern side. A few estimates of dips have been obtained from modelling and these generally show the synformal nature of the structure (Fig. 6.9, Table 6.3). Attempts to model the synform as a whole using two depth limited dyke models (Fig. 6.10, Line 4600 and 4615) produced reasonable fits to the observed data but showed no consistency in dip direction. The shape of the model anomalies was found to be greatly modified by limiting the bottom depth and therefore it is likely that, despite the "quality" of the match between the observed and computed data, the model is inadequate and the dips are probably unreliable.

## 6.5 The Razorback Area

The Razorback area (Fig. 6.11) is mapped as a relatively open synform (Stroud, 1979a). It is characterized by narrow quartz-magnetite horizons, which are inferred to grade laterally into magnetite rich metasediments (see Chapter 5). Where the quartz magnetites outcrop they dip very steeply, the Razorback itself (Horizon D, Fig. 6.11) having a measured dip of 85 degrees to the east (Map 1).

Simple magnetic models (Fig. 6.12, Table 6.4) are in agreement with this figure showing dips to the east of between 70 and 87 degrees with a mean of around 81 degrees. The assumption of induced magnetization in the models appears to be justified on this basis despite the extremely high apparent susceptibility (around 0.05 cgs).

Four main magnetic horizons have been identified in this area, but the relationships between these horizons are not clear. The Razorback (D) appears separate from horizons A, B and C which show some evidence of fold closure and may represent one continuous, but tightly folded horizon. While the magnetic anomaly associated with horizons A and B is a composite feature (see Fig. 6.12) the rather broad gradient on the western side of horizon A strongly suggests

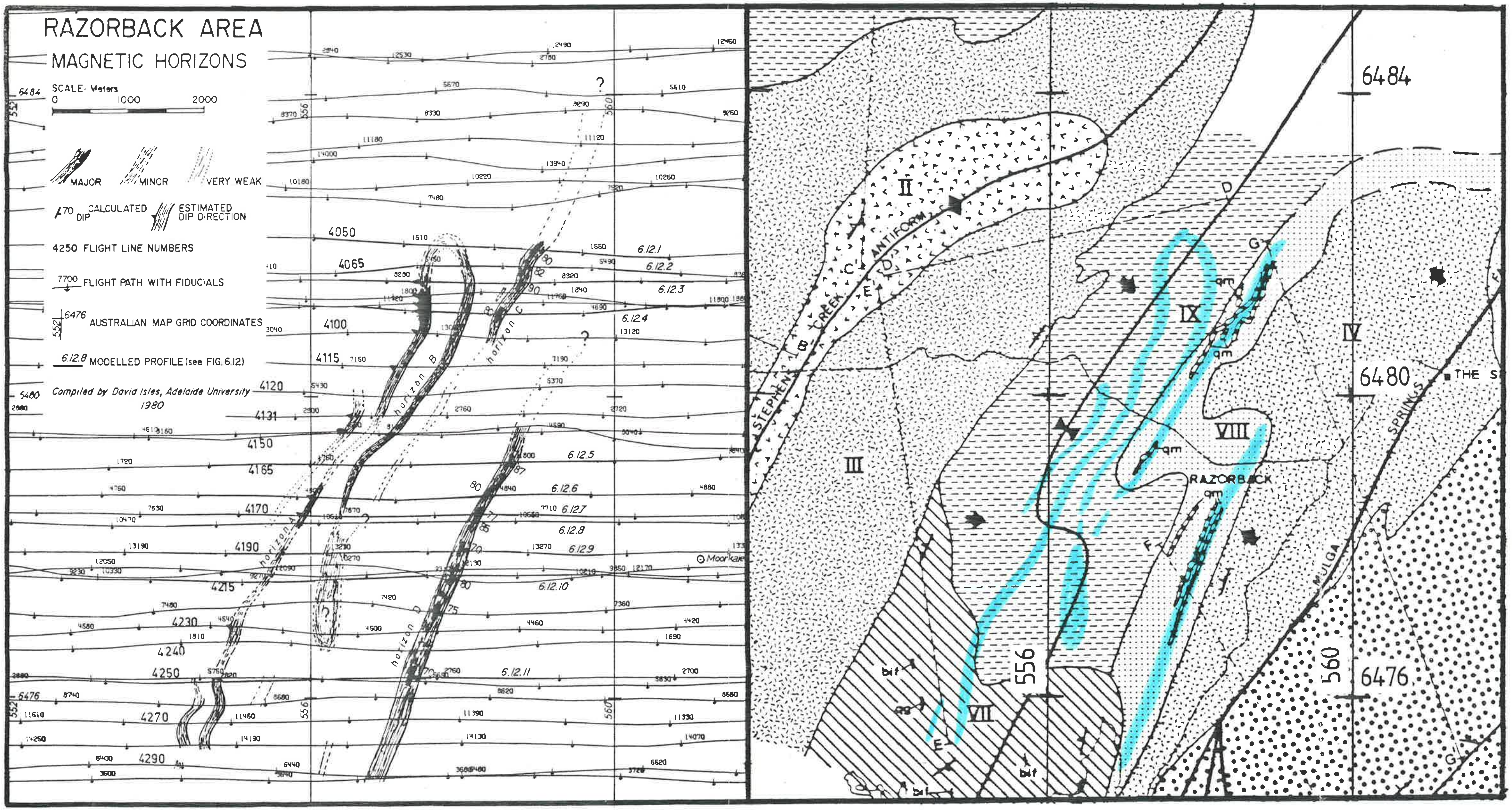


figure 6.11 RAZORBACK area- magnetic horizons and interpretive geological map. Geology from Stroud (1979a).

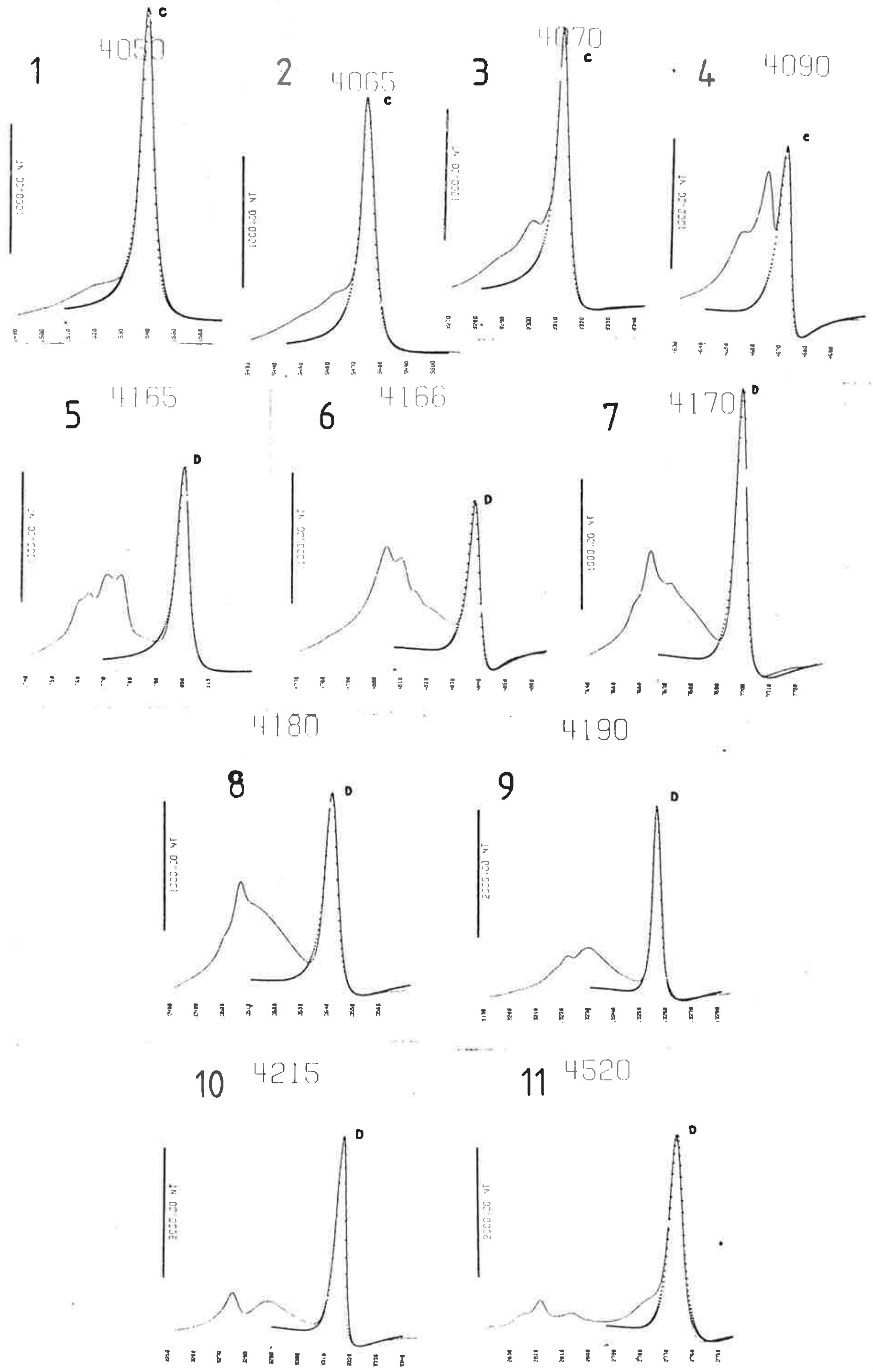



figure 6.12 Modelled magnetic profiles, RAZORBACK area

a shallow dip to the west. This is consistent with Stroud's interpretation (Fig. 6.11) of these horizons lying on the eastern limb of a broad synform, but the internal complexity suggested from the magnetics is not evident in Stroud's mapping. The geological interpretation shown in Figure 6.11 infers that there are three separate parallel quartz-magnetites within a suite 4 unit which shows little regional structural complexity.

Comparisons between this geology and the traced magnetic horizons suggest that a reinterpretation of the mapped geological information (the area in question has about 30% outcrop) using the magnetics would be invaluable.

## 6.6 General Comments

It has been shown that careful manual correlation of anomalies across flight lines and some simple modelling can greatly extend the amount of useful geological information obtained from an aeromagnetic survey. In particular, the limited amount of modelling attempted suggests that reliable dip information can be obtained where anomalies are sufficiently isolated from neighbouring sources. Comparing the magnetic interpretations from the contour map (Map 5) and from McIntyre's second-derivative map (Fig. 6.6) to those from the more detailed analysis presented in this chapter, it is apparent that each is appropriate to a particular scale of investigation. The 1:100,000 scale contour interpretation provides a solid but generalized view of the region as a whole and allows rapid visual comparison of widely spaced areas. As McIntyre (1979) has pointed out, however, the contour map is of limited value at the more detailed scales (say 1:25,000) because fine detail is lost and therefore comparisons with detailed geological mapping ar rather vague.

McIntyre's (1981) second derivative approach greatly improves the resolution of magnetic data and is amenable to presentation at both regional and detailed scales. A minor drawback with this technique is that in some cases it is easier to visually correlate measured magnetic intensity profiles across lines than the second derivative profiles because the loss of the shape characteristics.

The detailed "manual" approach adopted in this chapter is only appropriate for small areas because it is labour intensive. However, in the context of mineral exploration where, in the State of N.S.W., a typical exploration licence is 16 km x 16 km, the extra effort involved in manual interpretation is certainly warranted. Indeed, it is the writer's contention that this approach is essential to gain the maximum amount of information from a detailed magnetic survey. While in the theory, this laborious process could be automated with the use of "anomaly picking algorithms" and refined inversion procedures, the writer knows of no case histories where these have been successfully applied to give information of equivalent detail to that derived manually.

For future exploration in the Broken Hill area, the interpretation method used here could be readily applied over most of the Broken Hill Block. The two areas studied in this chapter were selected because they contained the most (visually) prominent anomalies. Clearly, throughout the BHZ, magnetic stratigraphic horizons are sufficiently abundant to provide useful structural information through aeromagnetic data. In the less complex areas, which include most of the northern and central Domains, the available BMR data with 300 line spacing and 100 m altitude is considered adequate. In other areas, particularly in the Southern Domain where magnetic horizons are far more "curvilinear", a small line spacing and lower altitude would be necessary to give worthwhile results.

TABLES OF MAGNETIC ANOMALY MODELLING RESULTS

EXPLANATION

LINE NUMBERS,FIDUCIALS are those used in the flight path maps. Fiducials listed are at the centre point (x=0) of the model.

LINES were flown E-W. Dips are measured relative to the more easterly end of the profiles.

DISTANCES have been corrected for the "off line" angle between flight direction and modelling direction(i.e. perpendicular to strike). All distances are in metres.

SUSCEPTIBILITIES quoted are in the unrationalized cgs system (SI=4*pi*cgs).

REGIONAL correction has been added to the computed profile rather than subtracted from thee observed data because this was found to give more flexibility in modelling. The regional gradients quoted are in nT/fiducial measured positive relative to East.

MODEL parameters are sketched opposite. note the depths are measured from the detector which was flown at a nominal height of 100 metres.

QUALITY OF FIT G-Good F-Fair P-Poor

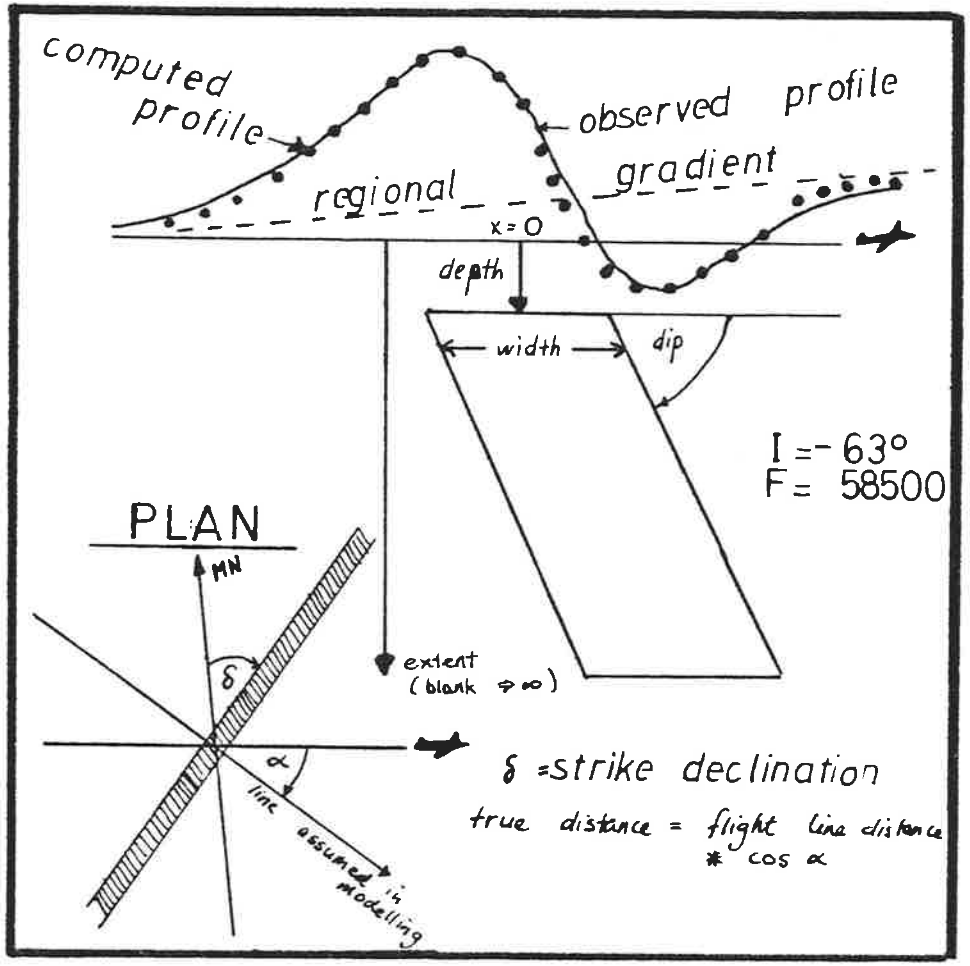


TABLE 6.1

MAGNETIC ANOMALY MODELLING RESULTS
PARNELL AREA

ANOMALY PA

| LINE | FID | REGIONAL | DEPTH | EXT | WIDTH | DIP | SUS | QUALITY |
|---|---|---|---|---|---|---|---|---|
| | | | METRES | | | | CGS | OF FIT |
| 4020 | 14407 | -20/40 | 102 | | 203 | 85 | .0014 | F |
| 4030 | 9849 | | 108 | 600 | 108 | 95 | .0028 | F |
| 4040 | 7108 | | 115 | 863 | 115 | 85 | .0032 | F |
| 4050 | 1133 | | 117 | 875 | 117 | 85 | .0031 | F |
| 4065 | 5067 | 75/30 | 112 | | 112 | 90 | .0045 | G |
| 4070 | 7904 | 75/30 | 117 | | 117 | 90 | .0047 | F |
| 4081 | 1422 | | 223 | | 223 | 55 | .0051 | P |
| 4120 | 5850 | | 150 | | 125 | 66 | .0028 | F |
| 4131 | 3222 | | 165 | | 138 | 65 | .0024 | F |
| 4165 | 1442 | | 135 | | 135 | 68 | .0013 | P |

ANOMALY PB

| LINE | FID | REGIONAL | DEPTH | EXT | WIDTH | DIP | SUS | QUALITY OF FIT |
|---|---|---|---|---|---|---|---|---|
| 4040 | 7138 | -50/40 | 106 | | 264 | 65 | .0038 | P |
| 4050 | 1160 | -50/40 | 101 | | 253 | 70 | .0036 | P |
| 4065 | 5096 | | 107 | | 429 | 90 | .0026 | G |
| 4070 | 7930 | | 107 | | 483 | 80 | .0023 | F |
| 4081 | 1444 | | 152 | | 455 | 65 | .0039 | F |
| 4100 | 12733 | | 160 | | 534 | 68 | .0041 | F |
| 4120 | 5830 | | 172 | | 344 | 77 | .0042 | F |
| 4131 | 3201 | | 200 | | 399 | 80 | .0031 | P |
| 4165 | 1465 | | 153 | | 183 | 90 | .0035 | P |
| 4166 | 4491 | | 184 | | 184 | 92 | .0038 | P |
| 4170 | 7351 | | 153 | | 153 | 70 | .0049 | P |
| 4180 | 10193 | | 172 | | 172 | 75 | .0039 | P |
| 4190 | 12906 | | 166 | | 184 | 72 | .0034 | P |
| 4220 | 7891 | | 129 | | 172 | 60 | .0047 | G |
| 4230 | 4977 | 100/30 | 76 | | 76 | 70 | .0071 | G |
| 4280 | 14694 | 60/40 | 186 | | 212 | 70 | .0043 | G |
| 4300 | 3246 | 120/40 | 121 | | 145 | 90 | .0036 | F |
| 4430 | 6294 | | 87 | 784 | 262 | 75 | .0038 | G |
| 4440 | 8564 | | 91 | 545 | 227 | 85 | .0035 | G |
| 4450 | 10894 | | 90 | 537 | 170 | 90 | .0037 | G |
| 4500 | 3771 | | 138 | | 220 | 85 | .0047 | F |
| 4530 | 7964 | | 187 | | 220 | 77 | .0051 | F |
| 4550 | 12649 | | 155 | | 340 | 80 | .0027 | G |
| 4565 | 2953 | | 150 | | 256 | 80 | .0031 | F |
| 4620 | 909 | | 106 | | 177 | 60 | .0030 | F |

ANOMALY PC

| LINE | FID | REGIONAL | DEPTH | EXT | WIDTH | DIP | SUS | QUALITY OF FIT |
|---|---|---|---|---|---|---|---|---|
| 4040 | 7185 | 110/30 | 115 | 548 | 280 | 85 | .0027 | F |
| 4070 | 7972 | 80/30 | 137 | 493 | 219 | 45 | .0028 | P |
| 4115 | 6895 | 50/30 | 188 | | 283 | 90 | .0021 | F |
| 4131 | 3152 | | 123 | | 148 | 65 | .0062 | F |
| 4150 | 8484 | 15/30 | 82 | | 82 | 72 | .0024 | F |
| 4165 | 1500 | 55/30 | 118 | 723 | 132 | 77 | .0046 | F |
| 4166 | 4534 | 55/30 | 118 | 460 | 243 | 60 | .0034 | F |
| 4190 | 12956 | 60/30 | 112 | | 160 | 80 | .0016 | F |
| 4215 | 8981 | 25/30 | 104 | | 192 | 50 | .0028 | F |
| 4220 | 7816 | 40/20 | 78 | | 87 | 60 | .0042 | F |

## TABLE 6.2

### MAGNETIC ANOMALY MODELLING RESULTS
### PARNELL AREA

ANOMALY PD

| LINE | FID | REGIONAL | DEPTH (METRES) | EXT (METRES) | WIDTH (METRES) | DIP | SUS CGS | QUALITY OF FIT |
|---|---|---|---|---|---|---|---|---|
| 3990 | 5784 | | 148 | | 172 | 85 | .0018 | F |
| 4000 | 8538 | | 140 | | 165 | 85 | .0020 | F |
| 4020 | 14190 | | 116 | | 97 | 100 | .0018 | G |
| 4030 | 10025 | | 116 | | 134 | 110 | .0014 | G |
| 4040 | 7292 | 20/40 | 117 | | 140 | 80 | .0021 | P |
| ANOMALY PE | | | | | | | | |
| 3990 | 5735 | 65/50 | 125 | | 208 | 115 | .0025 | F |
| 4000 | 8495 | 60/50 | 155 | 580 | 363 | 130 | .0020 | G |
| 4020 | 14148 | 55/50 | 115 | 599 | 230 | 140 | .0017 | P |
| 4030 | 10057 | 50/30 | 140 | 559 | 140 | 130 | .0027 | F |
| 4040 | 7326 | 40/30 | 107 | | 123 | 100 | .0016 | G |
| 4050 | 1352 | 60/30 | 143 | 857 | 171 | 120 | .0018 | G |
| 4065 | 5283 | 60/30 | 107 | 804 | 160 | 110 | .0020 | G |
| 4070 | 8119 | 60/30 | 113 | 804 | 177 | 110 | .0019 | G |
| 4081 | 1635 | 60/30 | 98 | 719 | 169 | 115 | .0016 | F |
| 4100 | 12912 | 70/30 | 127 | 811 | 203 | 125 | .0014 | G |
| 4115 | 7017 | 50/30 | 107 | 564 | 107 | 115 | .0027 | G |
| 4120 | 5604 | 30/30 | 124 | 460 | 124 | 120 | .0023 | G |
| 4165 | 1612 | 50/40 | 220 | 1014 | 358 | 100 | .0019 | P |
| 4166 | 4652 | 50/40 | 179 | | 298 | 100 | .0027 | F |
| 4170 | 17517 | 35/30 | 153 | 1040 | 263 | 120 | .0028 | G |
| 4180 | 10358 | 40/30 | 155 | 1115 | 266 | 125 | .0023 | G |
| 4215 | 9112 | 40/30 | 143 | | 276 | 125 | .0019 | F |
| 4250 | 3053 | 50/50 | 298 | | 477 | 95 | .0034 | F |

## TABLE 6.3

### MAGNETIC ANOMALY MODELLING RESULTS
### STIRLING VALE AREA

| LINE | FID | REGIONAL | DEPTH (METRES) | EXT (METRES) | WIDTH (METRES) | DIP | SUS CGS | QUALITY OF FIT |
|---|---|---|---|---|---|---|---|---|
| 4467 | 6482 | | 125 | 1250 | 250 | 50 | .0011 | G |
| 4481 | 5513 | | 101 | 1170 | 203 | 60 | .0022 | G |
| 4490 | 6142 | | 99 | | 137 | 50 | .0021 | F |
| 4490 | 6149 | | 99 | 550 | 99 | 120 | .0019 | F |
| 4500 | 3611 | | 98 | 790 | 88 | 110 | .0052 | G |
| 4600 | 7110 | | 115 | 734 | 420 | 80 | .0040 | G |
| 4600 | 7128 | | 94 | 420 | 94 | 120 | .0045 | G |
| 4615 | 4529 | | 145 | 1050 | 440 | 95 | .0043 | G |
| 4615 | 4550 | | 119 | 1050 | 104 | 85 | .0059 | G |

## TABLE 6.4

### MAGNETIC ANOMALY MODELLING RESULTS
### RAZORBACK AREA

ANOMALY C

| LINE | FID | REGIONAL | DEPTH (METRES) | EXT (METRES) | WIDTH (METRES) | DIP | SUS CGS | QUALITY OF FIT |
|---|---|---|---|---|---|---|---|---|
| 4050 | 1539 | | 144 | | 53 | 80 | .069 | G |
| 4065 | 5477 | | 152 | | 54 | 82 | .059 | G |
| 4070 | 8311 | | 122 | | 51 | 92 | .055 | G |
| 4090 | 4671 | | 133 | 800 | 53 | 108 | .044 | G |
| ANOMALY D | | | | | | | | |
| 4165 | 1800 | | 153 | | 61 | 87 | .040 | G |
| 4166 | 4839 | | 153 | 700 | 59 | 100 | .040 | F |
| 4170 | 7699 | | 138 | 1080 | 60 | 77 | .057 | G |
| 4180 | 10540 | | 165 | 1300 | 59 | 85 | .057 | G |
| 4190 | 13257 | | 102 | 840 | 102 | 70 | .037 | F |
| 4215 | 9316 | | 80 | 850 | 160 | 80 | .022 | F |
| 4250 | 2768 | | 193 | | 173 | 70 | .044 | F |

# 7 GRAVITY DATA AND THE REGIONAL GEOLOGICAL INTERPRETATION

The purpose of this chapter is to study the regional gravity variations in relation to the magnetic interpretation developed in the preceeding chapters. The distribution of gravity data in the study area is sparse (see chapter 3) and its interpretation is limited to the broad scale. Geological features with dimensions less than a few tens of square kilometres are unlikely to be represented in the gravity map, regardless of their density contrast. In terms of this thesis, the gravity data has been used to compliment the aeromagnetic interpretation by assisting in the delineation of the major geophysical subdivisions within the study area. However, as might be expected, the gravity data shows the Broken Hill region in a different light to that of the aeromagnetics because its emphasis is on the gross density properties of the upper 5 to 10 kilometers of the crust, whereas the aeromagnetics emphasise the specific susceptibility variations in the top one or two km. This is almost wholly a consequence of the different intensitites of sampling of the two data sets rather than any inherent difference in the nature of the gravity and magnetic potential fields. Indeed, the very detailed gravity data collected by CRAE in the Broken Hill mine district shows variations on a scale which can be directly correlated with magnetic horizons. In general, however, it is not feasible to collect gravity data with comparable sample spacing to aeromagnetics.

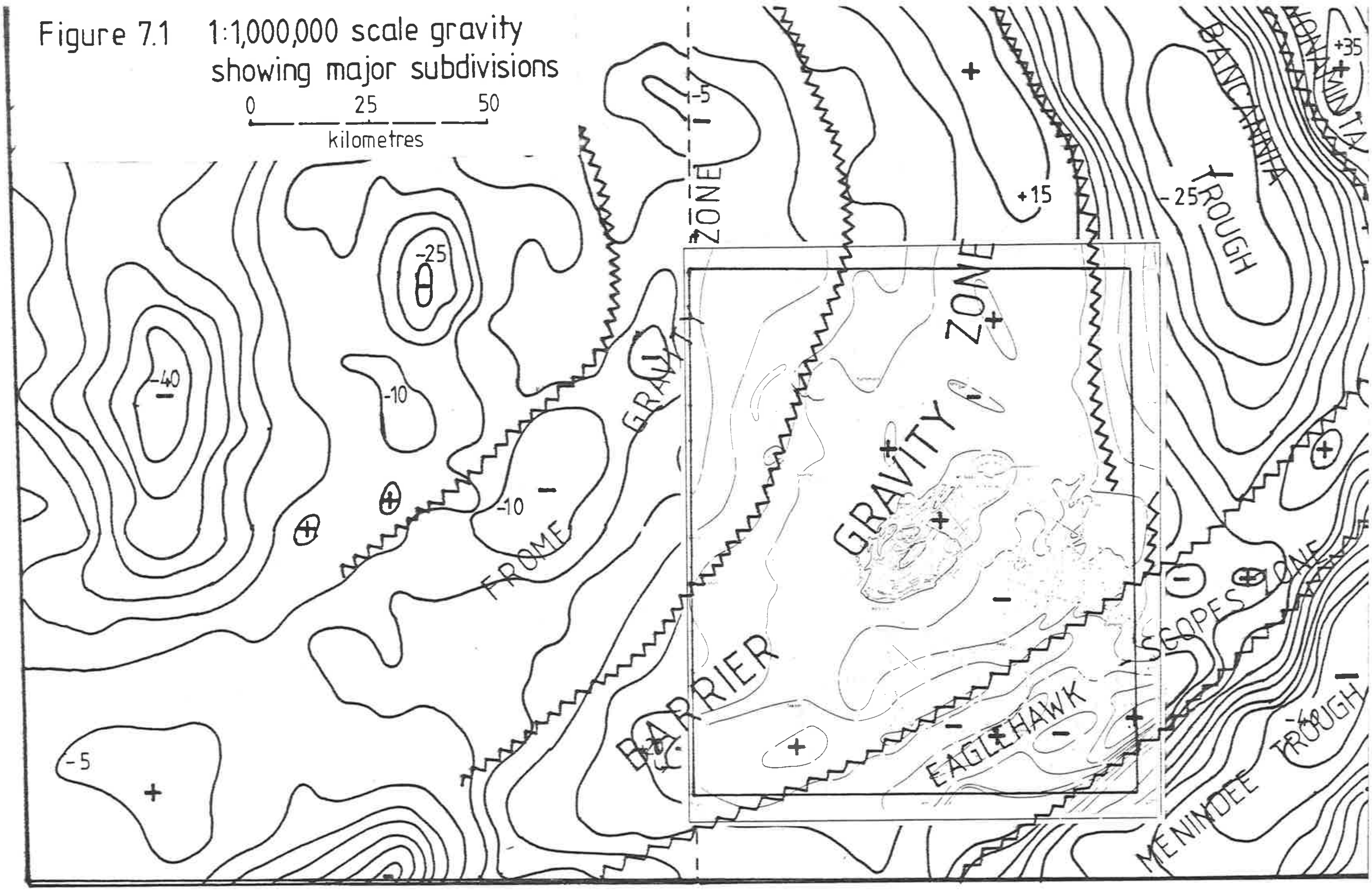
## 7.1 Major Gravity Subdivisions

Figure 7.1, a 1:1,000,000 gravity composite of the study area and its surrounds shows six major subdivisions. These are, in a broad sense, compatible with the gravity variations "anticipated" from the surface geology.

### 7.1.1 The Barrier Gravity Zone

The BGZ includes outcrop areas of both Willyama Complex and Adelaidean rocks and largely coincides with the topographic

Figure 7.1 1:1,000,000 scale gravity showing major subdivisions



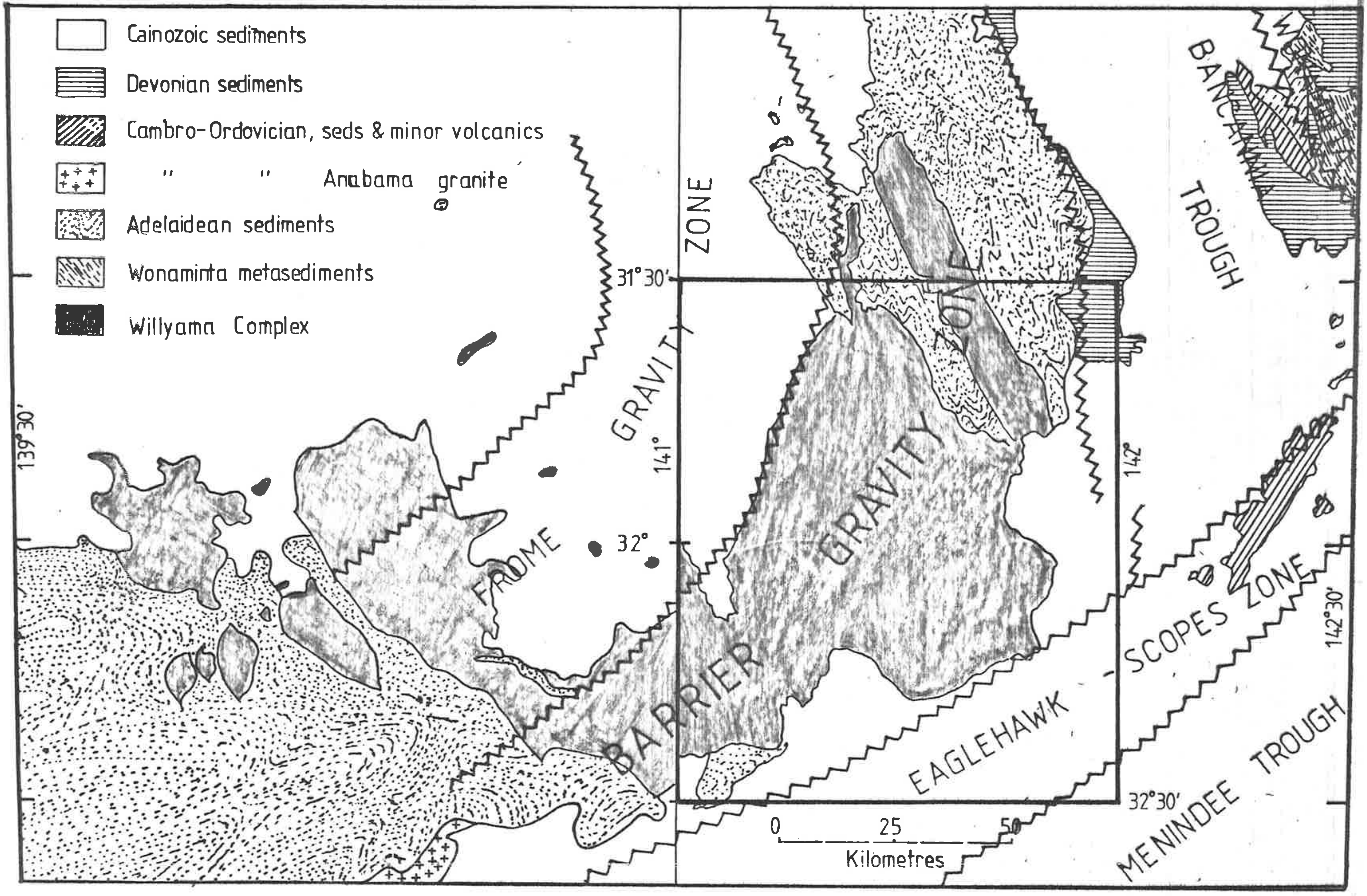
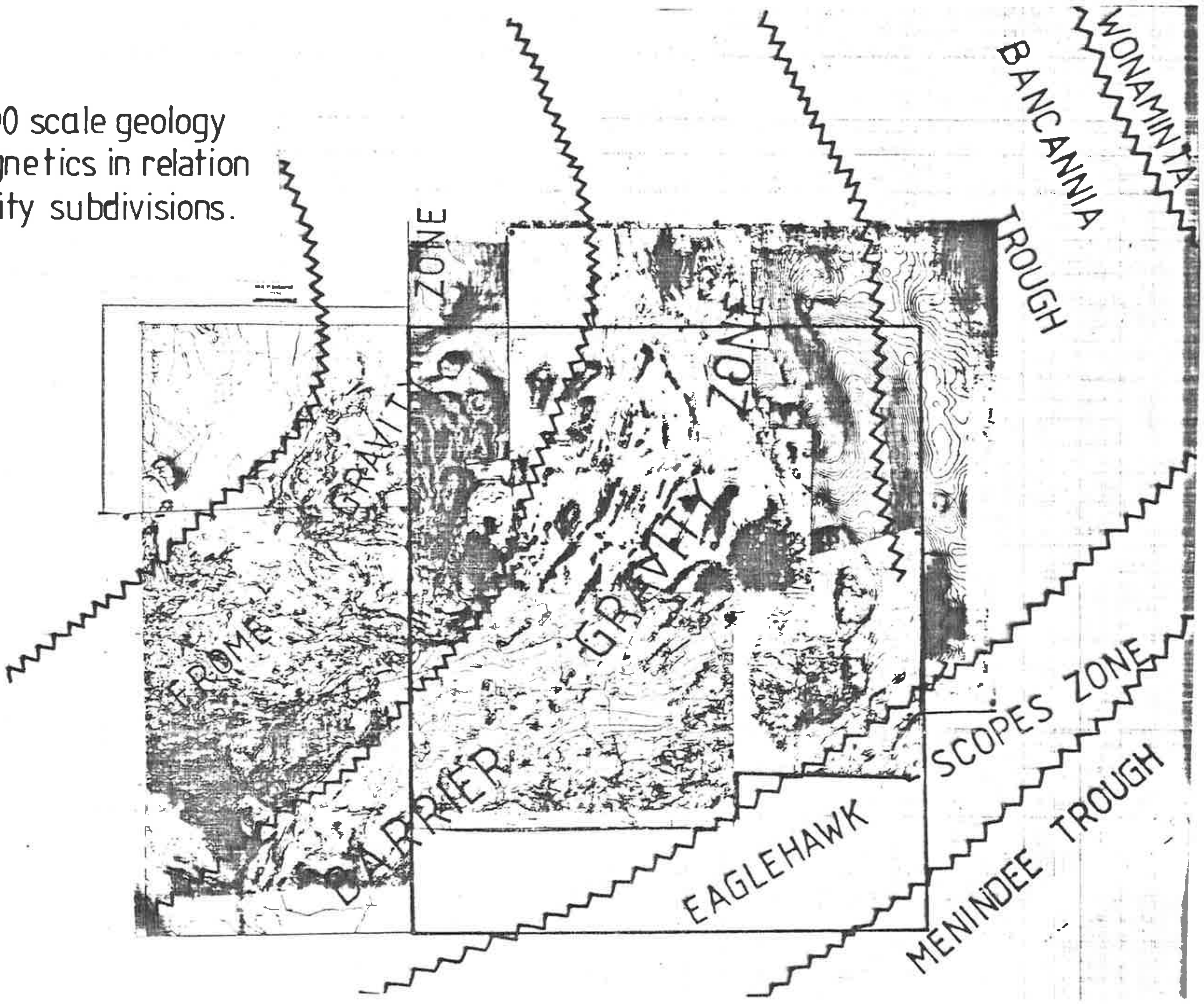



Figure 7.2 1:1,000,000 scale geology and magnetics in relation to gravity subdivisions.



high belt known as the Barrier Ranges. It is an area of generally higher gravity values than those areas adjacent to it and this is consistent with the geological fact that the Willyama and Adelaidean form a massif around which younger, largely sedimentary provinces have developed.

### 7.1.2 The Frome Gravity Zone

The Frome Gravity Zone is defined as the area of lower gravity values immediately west of BARRIER ZONE. It is likely that the prime cause of this westward decrease in gravity is the thickening of sedimentary cover of the "Frome Embayment Region" (Thomson, 1976). The boundary between the BARRIER and FROME regions is, in part, the Mundi Mundi Fault. Drilling by North Broken Hill Pty. Ltd. (Leigh, 1981) shows that in this area the thickness of Cainozoic sediment is around 200 metres and has an associated drop in gravity of around 5 milligals with respect to the Willyama outcrop areas. Figure 4.4 shows the gravity profiles and drill results of NBH and Figure 4.3, the earlier data collected by the author in order to estimate the cover thickness west of the fault. Companion of the gravity and magnetic profiles shown in Maps 6 and 7 suggests that the more magnetic basement material (of the "PHZ") has an associated negative gravity effect.

Consideration of the profile data of Maps 6 and 7 and the composite comparison maps of Figure 7.2. suggests that the PHZ and the Frome Gravity Zone are largely coincident and occupy a considerable proportion of the outcropping Olary Block.

Together the gravity and magnetic provide a strong case for regarding the Broken Hill Block and the Olary Block as distinctly different entities. The boundary between the Olary Block and the Broken Hill Block is then conveniently and quite precisely defined by the PHZ/BHZ magnetic zone boundary.

The Frome Gravity Zone is therefore due in part to the lower density, highly magnetic Willyama rocks of the Olary Block and partly to a westward thickening of younger sediments over the Willyama rocks.

7.1.3 The Bancannia and Menindee Troughs

The Bancannia and Menindee Troughs are filled with clastic sediments of Devonian and younger age and, as might be expected, show marked gravity lows. They occur to the NE and SE of the Broken Hill Block respectively and follow the structural trend directions of the northern and southern parts of the Willyama Complex respectively.

7.1.4 The Scopes-Eaglehawk Zone

The Scopes Range, although exposing relatively young (Ordovician) sedimentary rocks, has an associated gravity high which trends NE forming a ridge between the Bancannia and Menindee troughs. This Scopes Range gravity high has associated magnetic anomalies which extend to within the Eaglehawk Magnetic Zone. The EHZ is characterized by high amplitude variations in gravity with strong NE trending linear highs and lows. Since there is no distinct break between the Scopes and Eaglehawk areas they are here classified as one (gravity) zone. The initial interpretation of this gravity zone as being due to Willyama or older rocks directly beneath Cainozoic Cover (Isles, 1979) has since been shown to be incorrect with younger basic and intermediate volcanics within a sedimentary sequence, of probable post Adelaidean - pre Delamarian age, being intersected in mineral exploration drill holes by Mobil (1980) and BHP (1982). However, considering the partly sedimentary nature of the "Eaglehawk Sequence", the thickness of unconsolidated cover overlying it and its proximity to the vast mass deficiency of the Menidee Trough, it seems unusual that the Bouguer gravity values within the Eaglehawk Zone are generally higher than those on the exposed Broken Hill Zone (see Map 7). An attempt to resolve this problem by computer modelling is presented in Section 7.3.

### 7.1.5 The Wonaminta Ridge

A similar interpretation problem is presented by the Wonaminta Gravity Ridge which coincides with the Wonaminta Block (Fig. 2.1). Geologically, the Wonaminta Block is mapped as post-Willyama, pre-Adelaidean low grade metasediments and as such would not be expected to have an extremely high bulk denisty. The Wonaminta Block, being flanked by Devonian Sediments of demonstrably low density, would be expected to have an associated relative gravity high. However the Bouguer gravity values on the Wonaminta Gravity Ridge are significantly higher than on the Broken Hill Block, peaking at around 35 milligals compared to around 22 mgals in the BHB. This points to the existence of a body of high density material beneath the Wonaminta Block whose effect is not generally apparent beneath the Broken Hill and Euriowie Blocks.

## 7.2 Gravity Subdivisions of the Barrier Gravity Zone

All of the outcropping Broken Hill Block lies within the "Barrier Gravity Zone" and hence the more detailed gravity variations within the BGZ are of prime interest.

### 7.2.1 Williyama - Adelaidean Contrasts

Density determinations by Tucker (1973) on the Adelaidean rocks (mainly in S.A.) suggest that they should show only minor contrasts with the Willyama complex.

In particular the lower density suites in the Broken Hill Block have been inferred (Chapter 3) to have bulk densitites around 2.7 g/cc, roughly equivalent to density of the Adelaidean metasediments inferred by Tucker. The presence of higher grade and amphibolite rich metamorphic rocks within the Willyama suggest that it should have slightly higher gravity values than the Adelaidean rocks. This is evident within the study area as shown in Map 6. In the NE of the area Bouguer gravity values on outcropping Adelaidean areas are, in some cases higher than on Willyama

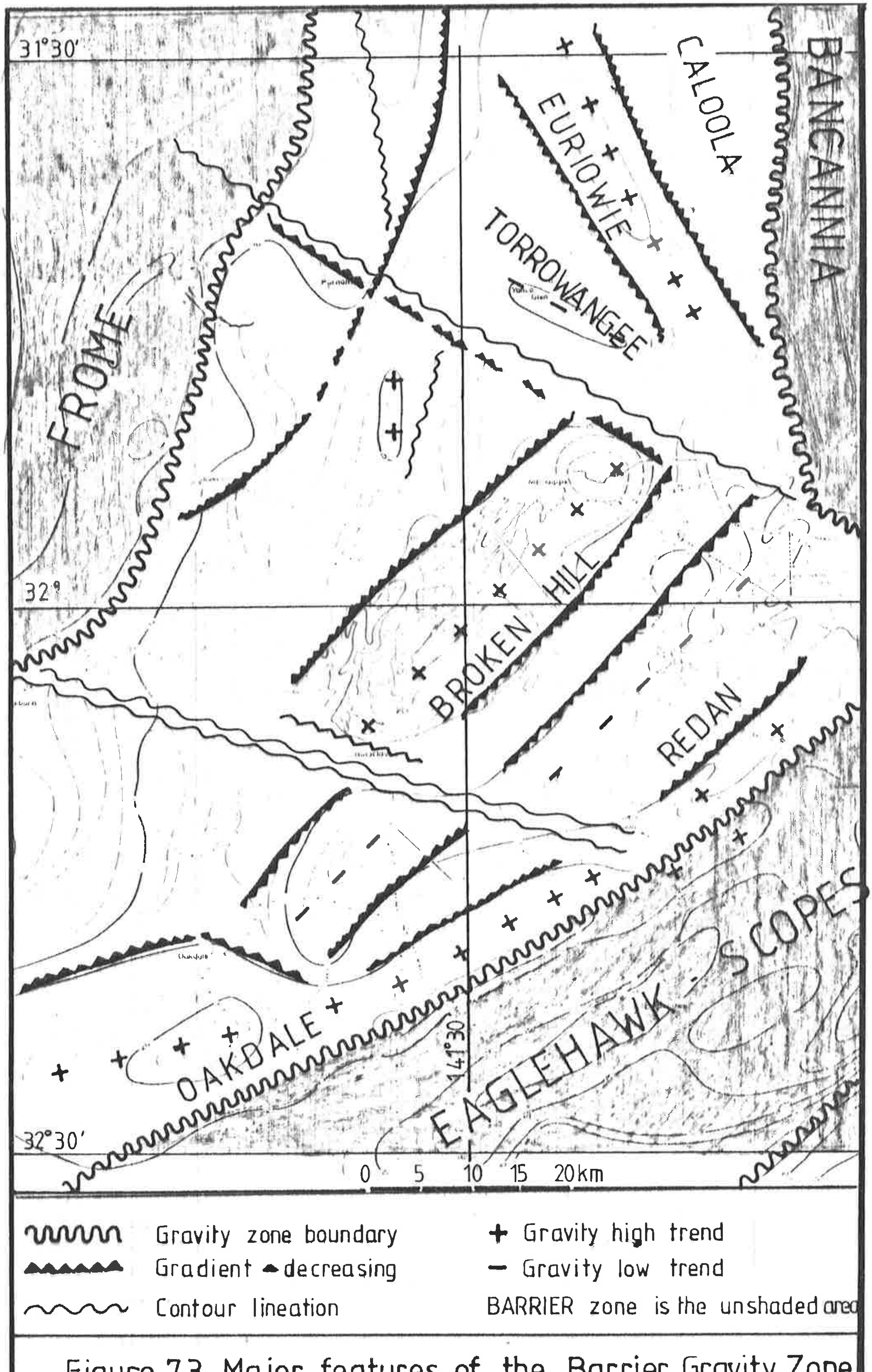



Figure 7.3 Major features of the Barrier Gravity Zone

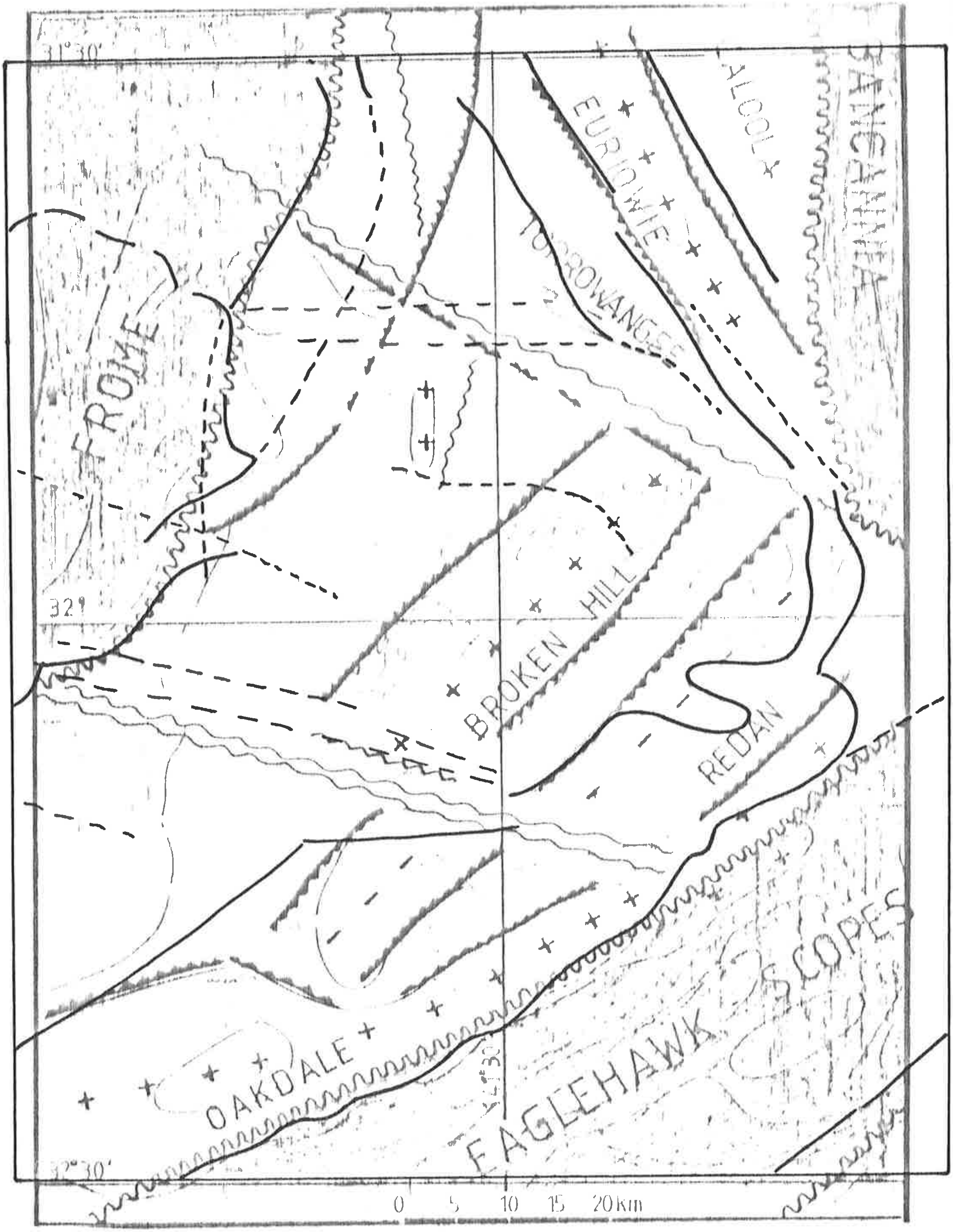



Figure 7.4 Magnetic boundaries of fig 4.1 superimposed on gravity boundaries of fig 7.3.

outcrop areas but the profiles suggest this more likely to be a "regional" effect due to an unexposed high density source.

### 7.2.2 Correlations with Magnetic Subdivisions

The Torrowangee magnetic Zone comprising Adelaidean sediments concides with a quite well defined gravity low, while the adjacent Euriowie Magnetic Zone has an associated linear gravity high (Figs. 7.3, 7.4).

The most striking correlation between the magnetic and gravity subdivisions within the Broken Hill Block is the close spatial relationship between highly magnetic rocks of the Redan and Peak Hill magnetic zones and strong gravity lows. The profiles of Maps 6 and 7 illustrate this clearly. The rocks of the RMZ are, like the PHZ, are therefore significantly different in density, as well as magnetization, to the Broken Hill Zone Willyama rocks. It would appear likely then that the two rock provinces are quite distinct geologically. The implications of this are discussed in Chapter 8.

The Mundi Mundi magnetic zone is non descript in its gravity response, suggesting that the non magnetic material which abuts the PHZ rocks at relatively shallow depths (around 200 metres) beneath the Mundi Mundi plain is of similar density to the PHZ. Either the Adelaidean or the upper sedimentary Willyama suites would fit into this category. Drill holes by North Broken Hill (Leigh, 1981) suggest that the former is more likely although their hole MMP2 (Fig 4.4) is interpreted to have intersected Willyama rocks. An interpretation of this is shown in the profiles of Map 6.

Within the Broken Hill magnetic Zone, the interpreted magnetic domains appear to have some expression in the gravity field. The Apollyon Valley - Mt. Franks schist zone system which separates the Northwestern Domain from the Northern and Central Domians is related to a linear zone of higher gravity gradient, decreasing to the west (Map 6).

The Mayflower (magnetic) Zone which trends EW, separating the Northern and Central Domains is a zone of northward decrease in gravity, but the gravity lineation along which this decrease occurs is inclined NW rather than EW (Fig. 7.3, 7.4).

Similarly the Thackaringa-Pinnacles shear, the bounding structure between the Southern and Central Domains shows a general decrease in gravity southward. In this case the gravity and magnetic trends are more closely related spatially.

The Central Domain remains therefore as the areas of highest gravity values within the BHZ. Within the BHZ two areas have Bouguer values exceeding 15 milligals. The weaker closure of the two, in the Parnell area, may well be related to the outcropping thick synformal sequence of suite 4 and suite 5 rocks.

The larger feature, the "Broken Hill Gravity High", is much more difficult to explain, despite the fact that it is the area where data is most abundant!

### 7.2.3 The Broken Hill Gravity High

The Broken Hill Gravity High is here defined as the area immediately east of Broken Hill enclosed by the 15 milligal Bonguer Gravity contour. The profiles 4460 (Map 6) and 1280 (Map 7) show how the high relates to the other areas on the BHZ.

As shown in Figure 3.5, the highest gravity values in the Broken Hill Block would be expected to be associated with thick sequences of suites 4 and 5. Reference to the Geological Maps of the area (see Map 2, Fig. 5.2) shows clearly that the area of the BH gravity high in fact is dominated by the lower density suites 2 and 3.

<u>Within</u> the BH gravity high there is excellent agreement between mapped geology and the local scale gravity

variations evident from CRAE's detailed data. The Hanging Wall Synform and the Broken Hill Synform, both comprising suite 3 quartzo feldspathic gneisses coincide with well defined gravity lows while the areas of suite 4 and 5 rocks are associated with higher gravity values. In particular, the Rupee Antiform which is mapped as a tightly doubled thickness of Mine Sequence rocks (Bradley 1979) produces a prominent linear gravity high (see Pecanek (1975), Wood (1972), and Jenke (1972) for discussion of gravity models in this area). This agreement between observed and theoretical gravity (based on mapped geology and density studies) suggests that the densitites assigned to the rock suites (Figure 3.5) are broadly valid.

If this is the case, the observed geology on the broad scale would infer that the area contained within the BH gravity high should in fact show generally lower gravity values than its surrounds, particularly to the west. To illustrate this, the geological section shown in Figure 2.6(b) has been converted into a density model and its gravity response computed. The resulting values, at 1 km intervals have been subtracted from the observed gravity along the same traverse (Figure 7.5). While small modifications to the density model could certainly produce a better match on the local scale the fact is that on area dominated by relatively low density rocks produces a relative gravity high.

The residual anomaly should therefore be due to sources not included in the subtracted density model. This leads directly to the conclusion that there exists an unexposed high density rock formation beneath the "Broken Hill Gravity High". The nature and signficance of this formation is not known but its position with respect to the Broken Hill ore body raises the question of a possible link between the two. However it is outside of the scope of this thesis to speculate on relationships between gravity anomalies and the metallogeny of the Broken Hill orebody. To investigate this possible relationship, a detailed study of the density and gravity variations, extending to outside

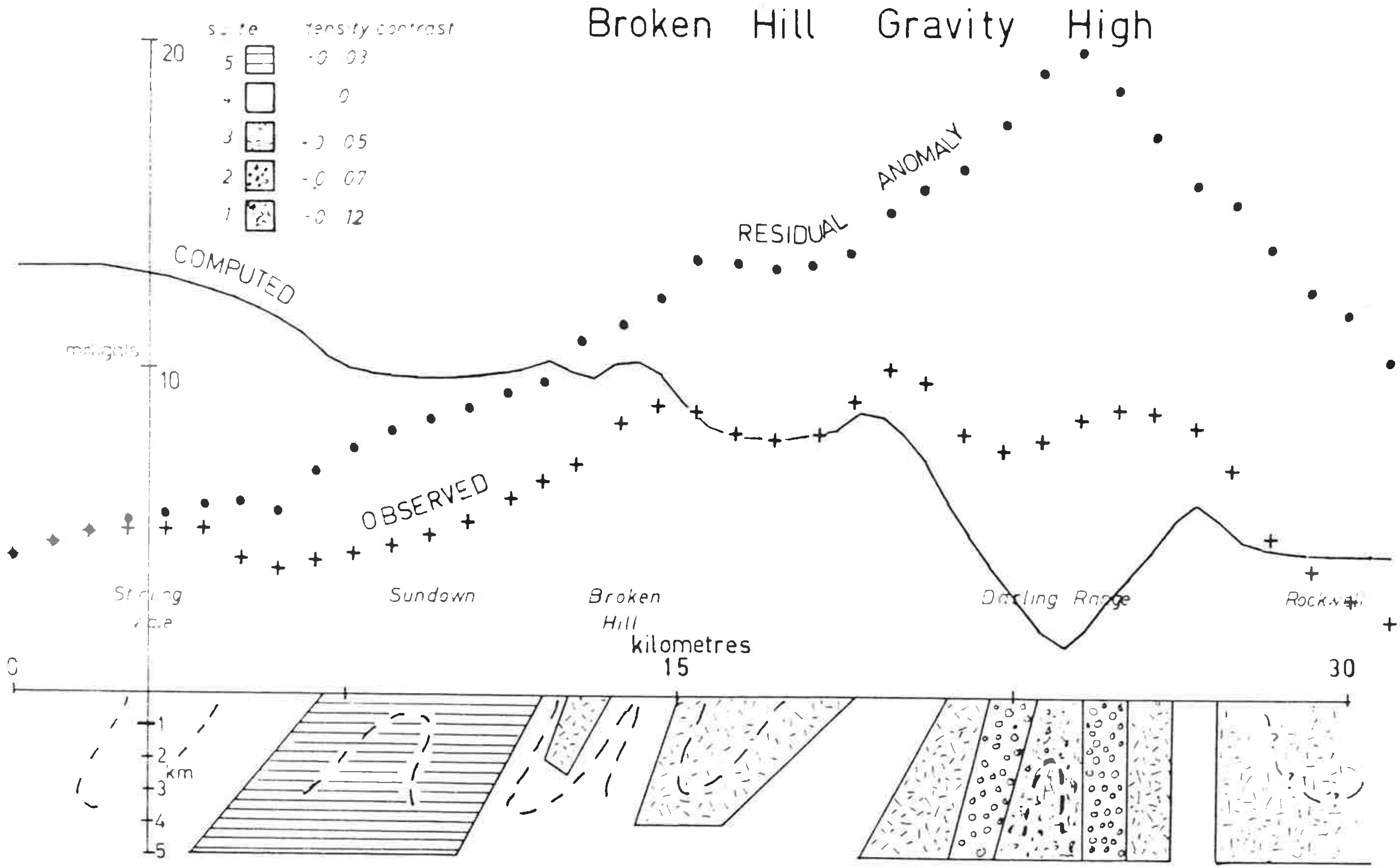



Figure 7.5 Measured and computed gravity profile across the Broken Hill gravity high.

the Broken Hill Gravity High, would be of great value. Much of the basic data necessary for this study already exists in the form of CRAE's detailed gravity and wealth of drill core accessible at Broken Hill.

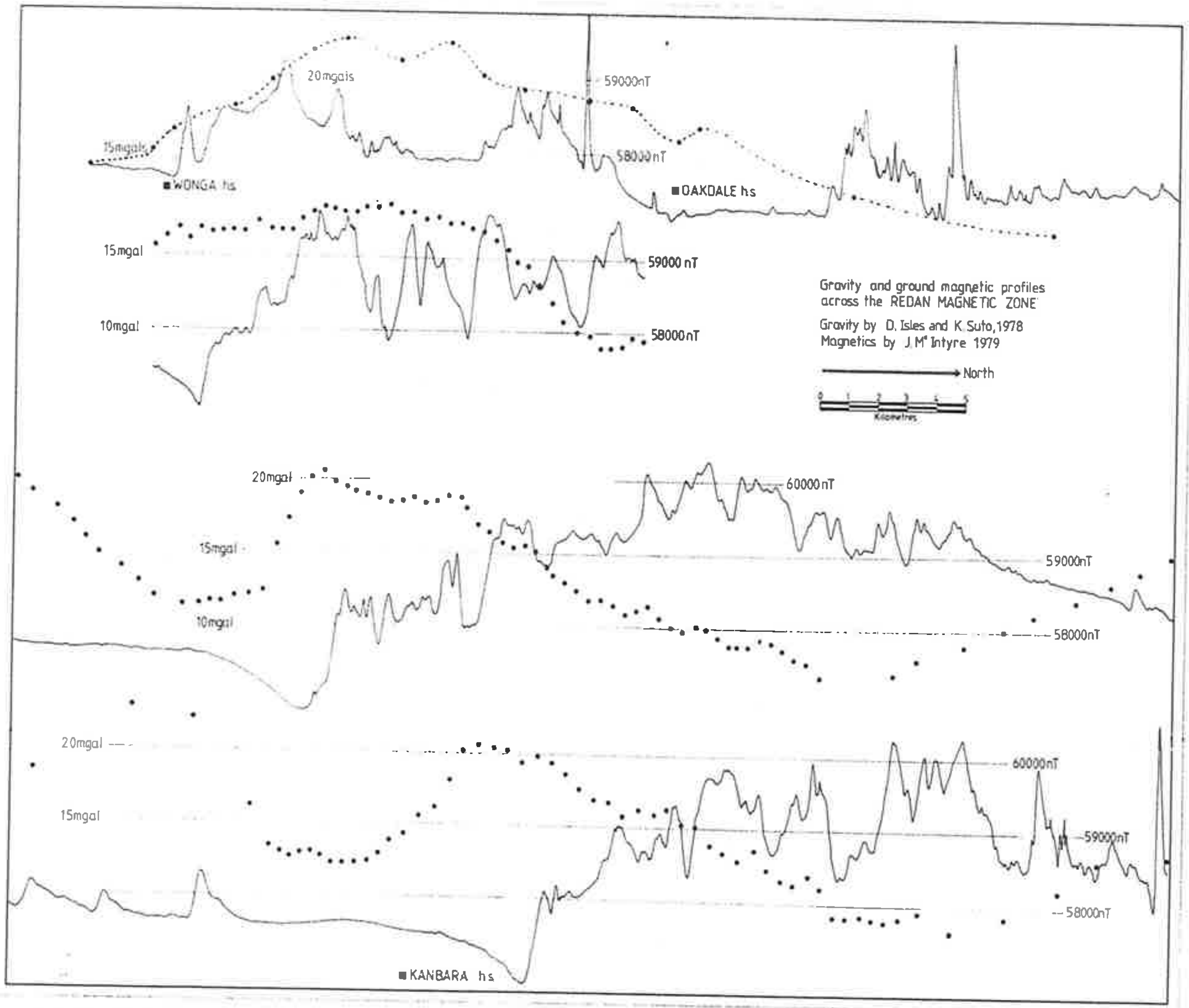
### 7.2.4 Post Willyama Intrusions

Post Willyama basic intrusions are common in the southern part of the Broken Hill Block and four of these have an expression in the gravity map. The pyroxenite plug 7 km NW of Silverton and 190 metres beneath the Mundi Mundi plain was traversed by one of the authors regional gravity traverses and produced a 5 milligal anomaly, while the northern part of the Little Broken Hill Gabbro (Stevens et al. 1982) is covered by the CRAE detailed data where it shows a 2 milligal anomaly. Smaller bodies are evident in the regional data south and east of Broken Hill.

## 7.3 The Oakdale - Eaglehawk Area

The linear gravity highs and lows trending ENE in the south of the study area are a most striking feature of the Gravity Map (Map 4). The "Oakdale - Eaglehawk area" includes the Redan Magnetic Zone and all of the area SE of the Redan fault. The only outcrop in the area is either within the RMZ or in the far SW where Adelaidean sediments, including the Hawson's Knob iron formation are exposed. The east of the area is obscurred by unconsolidated Cainozoic sediment. In order to resolve some of the uncertainties in the positions of geophysical features gravity traverses were conducted by the author in conjunction with J.I. McIntyre of the NSW Geological Survey who measured ground magnetics along the same traverses using a vehicle borne magnetometer. The data shown in Figure 7.6 compliments the more generalized profiles shown in Map 7.

### 7.3.1 The Redan Magnetic Zone



20mgals
59000nT
15mgals
58000nT
WONGA hs
OAKDALE hs
15mgal
59000 nT
10mgal
58000nT
Gravity and ground magnetic profiles across the REDAN MAGNETIC ZONE
Gravity by D. Isles and K. Suto, 1978
Magnetics by J. McIntyre 1979
North
Kilometres
20mgal
60000nT
15mgal
59000nT
10mgal
58000nT
20mgal
60000nT
15mgal
59000nT
58000nT
KANBARA hs


Figure 7.6

Figure 7.7 Coloured aeromagnetic map – Broken Hill south

While the RMZ is an area of very complex magnetic variations as evident in Figure 7.6 and Figure 7.7, when viewed in the light of the variations in gravity, two features become apparent.

1) There is a zone of lower "background" intensity, around 5 kilometres wide, extending along the SE margin of the zone. In the profiles of Figure 7.6 it is apparent as a change in background level of around 1500 nT while in Figure 7.7 it is seen as a distinct zone of "cooler" colours. There is no apparent change in the nature of the shallowest magnetic sources, since the amplitudes and depths of individual peaks remain essentially the same. No systematic changes are evident in the few rock exposures (Corbett pers. comm.). This area of reduced background intensity coincides with a strong rise in gravity values.

2) In the Oakdale area magnetic contour trends in the RMZ change abruptly from NE to a circular pattern rimming a magnetically flat area. This magnetically flat area coincides with the peak in the gravity values and the gravity contours follow the same circular trend as the magnetic contours. The few outcrops within the flat magnetic areas have been mapped by Stroud (1979) as Suite 2 composite gneisses.

Because of the poor exposure and deep weathering in the Oakdale-Eaglehawk area, it does not lend itself to detailed density and magnetization measurements on rock samples. The Redan Gneiss samples provided by G. Corbett of the NSW Geological Survey showed little variation in density (Table 3.4) and hence there is no evidence to suggest a rise in gravity within the RMZ. The magnetic profiles of Figure 7.6 themselves suggest that there is no signficant change in the magnetization of the Redan Gneiss.

The most straightforward interpretation of this data is to infer the presence of a high density, relatively non magnetic formation beneath the Redan Gneiss.

### 7.3.2 The Redan Fault

The Redan fault exhibits a remarkably uniform magnetic profile over a distance of more than 70 kilometres. its trace in plan is overall relatively straight but closely spaced aeromagnetic data (BHP, 1982) shows it to be sinuous in detail.

The computer models of Figure 4.8 show the magnetic feature to be explained by a steeply dipping boundary with a depth to bottom at at least 4 kilometres. Models computed with depths to bottom of less than 4 km simply do not fit the data. The dip inferred from modeling is, in most cases to the SE but this assumes that the magnetic material(i.e. the Redan Gneiss) is, when considered as a whole, inductively magnetized. Since the area has been subjected to regional high grade metamorphism it is possbile that a block the size of the RMZ could have attained and retained a uniform remanent magnetic component. At the time of writing North Broken Hill Pty. Ltd. were undertaking systematic magnetization measurements on Redan Gneiss through D. Clarke at the CSIRO Mineral Physics laboratory in Sydney. The writer had no access to this data, so the dips quoted on the models of the Redan Fault must be regarded as being conditional on the results of Clarke's study.

The gravity profiles across the Redan Fault shows it to be commonly associated with a northward decrease in gravity. This, however, could be interpreted as a regional effect and when all profiles are considered it can be stated that there is no uniform gravity feature coinciding with the Redan Fault. However in a gross sense the gravity values associated with the RMZ are lower than those associated with the Eaglehawk Magnetic Zone (EHZ) implying that the material beneath the cover of the EHZ has a net positive density contrast compared to the material beneath the RMZ.

### 7.3.3 The Eaglehawk Magnetic Zone

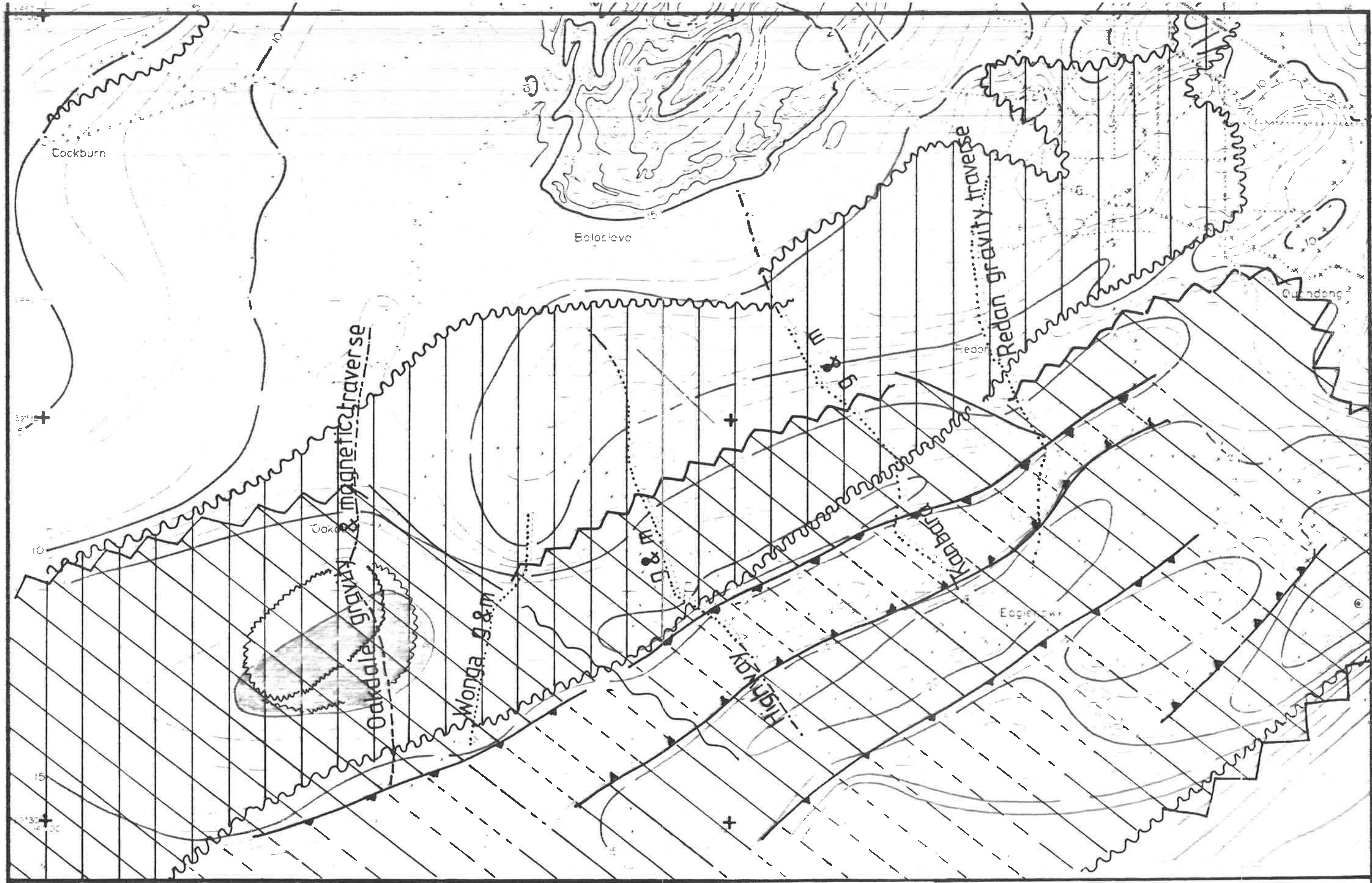
The similarity in magnetic style between the EHZ and the BHZ lead two mineral exploration companies (BHP, 1982 and

Mobil, 1980) to drill exploratory holes within the EHZ. Both holes were located on gravity highs because the shallowest magnetic anomalies are associated with the higher gravity (see maps 4 and 5). The hole in the Willeila area (U18) intersected a steeply dipping sequence of basic volcanics and clastic sediments at 80 metres and was still in this sequence at 400 metres. The hole in the Eaglehawk area entered a sequence of dominantly Andesitic volcanics with minor sediments, also steeply dipping at 100 metres. The age of these rocks is uncertain but the fold patterns evident from the magnetics are consistent with the main Broken Hill deformations and the Delamerian orogeny (Cambro-Ordovician) suggesting that they are at least Cambrian in age.

The existence of basic igneous rocks beneath the EHZ suggests a possible source for the high gravity values present, but no information is available on the bulk density of rocks intersected. The gravity lows can be readily explained in terms of younger (probably Palaeozoic) depressions which may have developed at the same time as the Menindee Trough.

Depths to magnetic sources within the gravity lows range from 400 to 600 metres whereas the depths on the higher gravity areas range between 80 and 300 metres (see Map 5). These inferred depressions are bounded by very steep gravity gradients the gravity lows themselves being in the order of 12 milligals.

There remains, however, a major interpretation problem in the RMZ/EHZ geology and gravity. The root of the problem is that the gravity high, inferred in section 7.3.1 to be caused by a dense formation beneath the Redan Gneiss, in fact crosses the Redan Fault near "Kanbara" and actually lies within the EHZ southeast of "Redan" (see Figure 7.8). If the younger depressions are ignored, the southern part of the RMZ and EHZ in fact could be interpreted as one large, generally EW trending high.




Unexposed high density formation

Redan Magnetic Zone

Palaeozoic (?) graben 400 - 700m deep

Dome (?) structure (see map7)

SCALE 1:250,000
0 10 20 km

Discontinuity in gravity trend

Lineation

Ground profile, see figures 7.6 & 7.9

Figure 7.8 Gravity & magnetic interpretation
Broken Hill South

It would appear that the high density formation beneath the Redan Gneiss also exsits at some depth beneath the volcano-sedimentary sequence of the EHZ.

### 7.3.4 Models

Simple two dimensional models were computed to investigate this hypothesis. While the "final" models (Fig. 7.9) agree reasonably well with the observed profiles, the shape of the computed curve was found to be extremely sensitive to the density constrasts chosen for the overlying unconsolidated sediments. These contrasts were much greater than the 0.1 glcc chosen for the basement contrast.

An attempt was made to constrain the model using the magnetic data but no single geometric shape could be found to simulataneously match the gravity and magnetic data. In the absence of any useful data on the density and magnetization of the formations involved it was considered that recourse to more complex forms of modelling would not provide a solution to the interpretation problem.

While the gravity models are not definitive, they do show that the form of interpretation envisaged by the writer is not inconsistent with the observed data.

### 7.3.5 Discussion

The more local scale gravity variations in the study area are readily correlable with known geological and or magnetic provinces. The larger scale features, in particular, the regional gravity highs are much more difficult to explain in terms of ourcropping rocks. There is really no alternative but to imply the existence of "unexposed high density formations" knowing that there is insufficient data available (both density data and gravity measurements) to allow one to usefully interpret these highs.

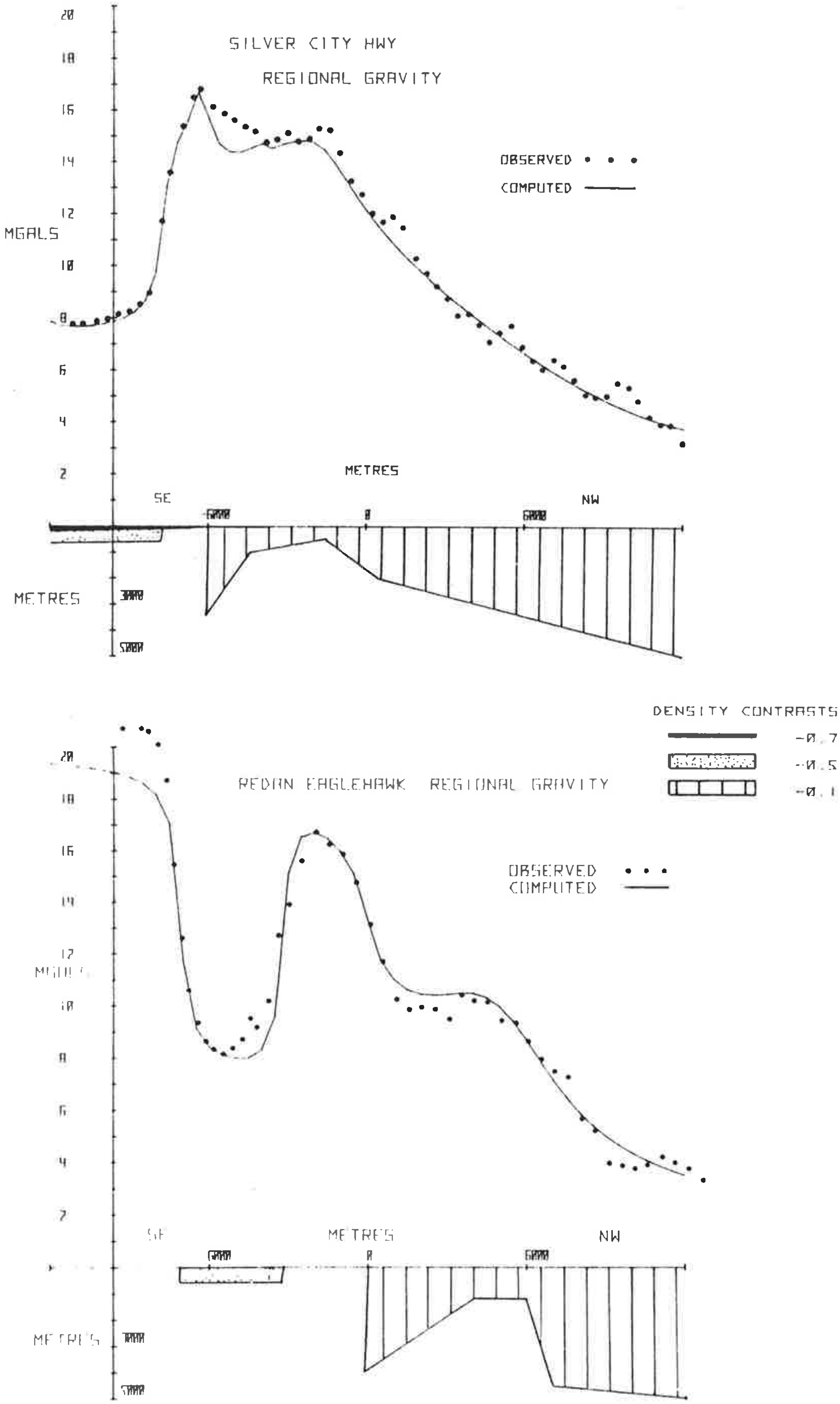



Figure 7.9 Gravity models in the Redan-Eaglehawk area.

This problem is not pecuuliar to Broken Hill. Unexplained, unexposed gravity highs bound Proterozoic provinces such as the King Leopold Mobile Zone in the south Kimberleys, the Mount Isa Block and the Eyre Penisula (BMR, 1976b). Models, such as those developed by Rumph (1976) on the Mt. Isa Block give a useful starting point for elucidating the crustal structure of these provinces. A great deal more interpretive work along these lines is required if the teconic history of our continent is to be understood.

# 8 CONCLUDING DISCUSSION

A composite interpretation of the aeromagnetic and gravity data on the Broken Hill Block is presented in Map 5. The greater part of the Block coincides with an area of relatively uniform magnetic response (the BHZ) which has been divided into four magnetic domains. The domains are defined on the basis of the abdundance of magnetite with the narrow stratigraphic intervals to which the magnetic horizons in the BHZ are largely confined. The relative abundances of magnetite are attributed to conditions prevailing in the depositional environment, and the conditions which favoured magnetite development appear to have also favoured the development of the Broken Hill type mineralization. On this basis, the Central Domain is seen as the area most likely to contain Broken Hill type mineralization.

PHZ and RMZ

To the west and SE of the BHZ very different magnetic provinces exist. Both the PHZ and the RMZ are highly magnetic in an overall sense and this characteristic led Glen et al. (1977) to correlate the two areas which they suggested might represent a "reworked older basement complex".

The work undertaken in this thesis certainly supports the correlation of the two areas. Both the PHZ and the RMZ cover large areas and are clearly very strongly magnetic. Both areas are associated with gravity lows and modelling of both gravity and magnetic data suggests that both zones of highly magnetic, low density material extend to depths of at least 4 km. Limited outcrop reveals that both zones are characteristically dominated by quartzo feldspathic rocks, in contrast to the BHZ which contains considerably higher proportions of pelitic and basic rocks.

The differences between the PHZ and RMZ are relatively minor. In detail the PHZ and RMZ show distinctly different magnetic characteristics. The PHZ is dominated by large areas of low (but very variable) magnetic anomalies with narrow, sinuous highs. Conversely, the RMZ lies at a much higher magnetic intensity level and has a much higher proportion of relative magnetic highs. The differences are apparent in Figures 7.7 and Map 7.

While this may signify differences in the magnetic character of the original rocks, it may also be an effect of metamorphism. The rocks in the RMZ have been subjected to different metamorphic conditions than the Peak Hill rocks and it is possible that magnetite development has been more widespread in the RMZ. It is also possible that remanent magnetism, present in one of the zones, could account for the dissimilarity in magnetic character. Mutton and Shaw (1979) have observed aeromagnetic zoning due to remanent magnetism in Proterozoic granulites in the Arunta complex in the Northern Territory. The differences in the magnetism of the PHZ and RMZ do not preclude their correlation.

Returning to Figures 4.1 and 7.2 it can be seen that the PHZ is best classified with the Olary Block, on the basis of aeromagnetic and gravity response and hence the PHZ/BHZ magnetic boundary represents a logical boundary between the Broken Hill Block and the Olary Block.

Stratigraphic Position of Magnetic Complexes

The suggestion that these complex magnetic zones represent a reworked older basement is also compatible with the geophysical observations. In particular, magnetic modelling indicates that the RMZ rocks dip relatively shallowly beneath BHZ rocks in the Balaclava and Farmcote areas (Fig. 4.6). Both the RMZ and PHZ repeatedly correlate with inferred basal units. In the Peak Hill (L3) and Umberumberka (L4) areas, the exposed PHZ is geologically mapped as the lowest part of the stratigraphic sequence. The Peak Hill rocks are classified by Willis as suite 1, while Stevens groups the Umberumberka rocks into one "complex zone" of quartzo- felspathic rocks which is apparently difficult to correlate with other parts of the Broken Hill sequence.

The simplest interpretation of the magnetic complexes appears to be as correlatives of the lowest magnetic interval found in Broken Hill Block stratigraphy, which includes suite 1 and possibly parts of suite 2 (Figure 8.1). This is termed the Basal Magnetic Complex in preference to basement because a degree of parallelism is apparent between the trends these rocks and the higher parts of the stratigraphic sequence. This is evident in outcrop in the Peak Hill and Oakdale areas while in the RMZ fold trends discernable from the aeromagnetics are very similar in style to those in the BHZ. In the Rockwell-Farmcote area particularly, the boundary between the BHZ and RMZ is smoothly folded and magnetic trends on either side of the boundary run parallel to it.

If the correlation of the PHZ, RMZ and Suite 1 rocks in the BHZ is valid, the Basal Magnetic Complex covers a vast area compared to the higher stratigraphic units and so is probably best regarded as a separate entity from the main Broken Hill Sequence.

The main objection to this interpretation comes from recent mapping in the Redan area (Corbett, pers. comm.) which indicates very strong associations between the Redan Gneisses and the Suite 3 BHZ rocks. The suggestion that the Redan Gneisses could simply be the suite 3 rocks which have developed more magnetite through higher metamorphic temperatures is apparently feasible on petrological grounds (McIntyre, 1981). Under this interpretation, however, two important geophysical observations remain unexplained.

1. The boundary between the BHZ and the RMZ is extremely abrupt. It seems likely that a "metamorphic temperature boundary would be relatively gradational.

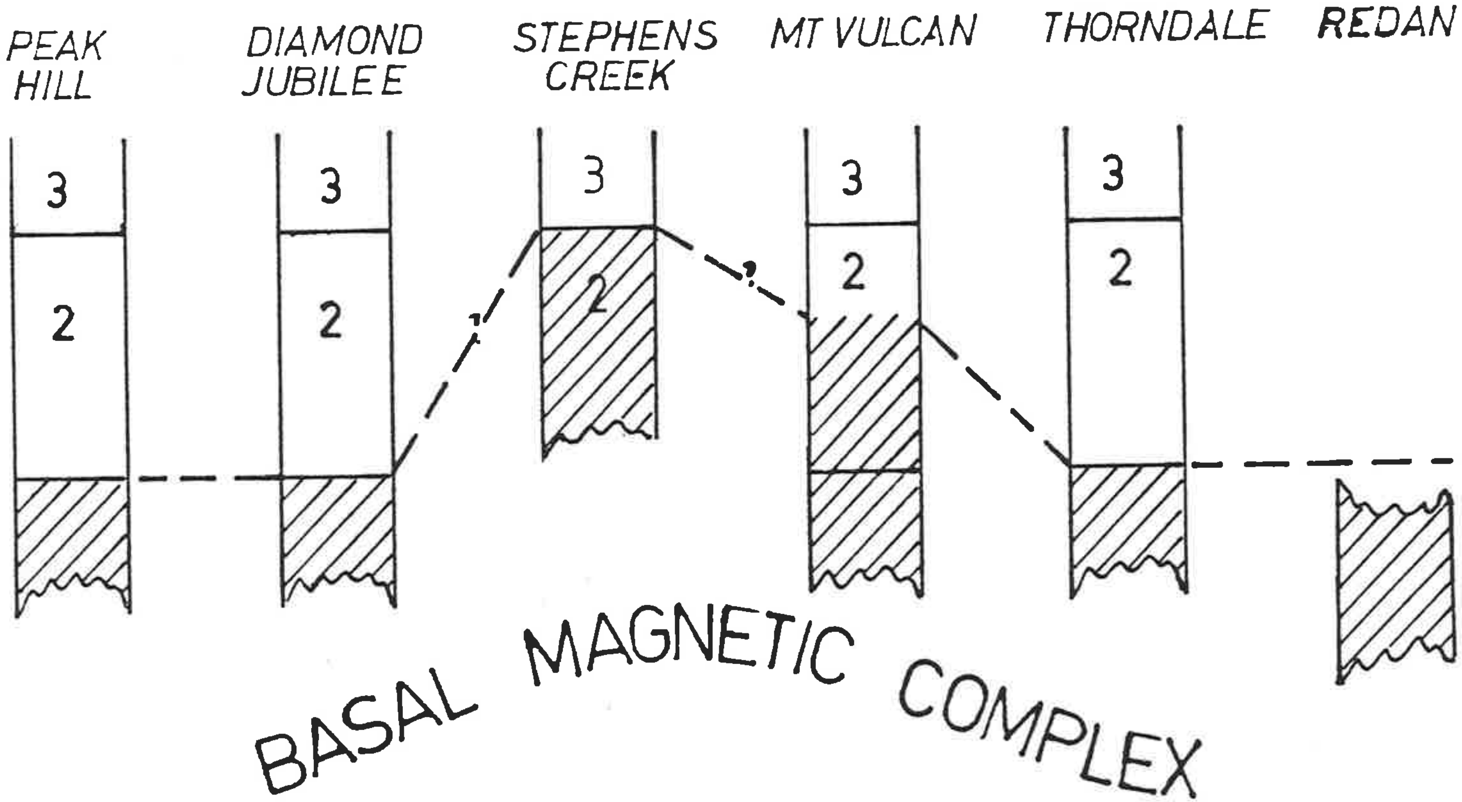



Figure 8.1 Relationship between the Basal magnetic complex and the metamorphic suites of Stevens et al.

2. The gravity low associated the RMZ suggests that it almost exclusively comprises low density rocks which persist to depths of around 5 km over most of the RMZ. Such large volumes of Suite 3 are not observed in the BHZ, where the true thickness of Suite 3 does not greatly exceed 1500 m.

Bearing in mind the difficulties cited by Stevens et al in differentiating suites 1, 2 and 3 from one area to another it seems reasonable to suggest that quartzo feldspathic gneisses (which typify Suite 3) may also occur in large amounts lower down in the stratigraphic succession.

Gravity Highs

A rigorous study of the nature of the "unexplained" gravity highs at Broken Hill itself and to the east and south of Broken Hill is beyond the scope of this thesis. Knowing that present day continental margins are rimmed by gravity highs (Karner and Watts, 1982) and given the post Willyama Tectonic history of Western NSW (Scheibner, 1976) it is very tempting to suggest that the highs are associated in some way with an ancient continental margin.

However, without a great deal more gravity and density information and many hours of interpretation this must remain pure speculation. A study of this nature into the cause of these gravity highs is highly recommended as an avenue for further academic research. In particular, the existance of one of these highs in close proximity to the Broken Hill orebody may have implications for mineral exploration in the Broken Hill and other areas.

Concluding Remarks

The study undertaken has revealed profound geophysical subdivisions many of which have not been recognised as geological subdivisions. The significance of the geophysical interpretation in terms of its contribution to the understanding the geology and the metallogenesis of the Broken Hill Block will be tested with time.

It is suggested that a reappraisal of the current geological interpretation in the light of the geophysical observations should be carried out.

It is stressed that the interpretation presented here represents a starting point for further geophysical and geological interpretation, a framework on which a more comprehensive understanding can be developed. When the hundreds of man years spent in the study of the geology of Broken Hill are compared to the 15 or so geophysical man years spread between the writer, McIntyre, Pecanek, Wood, Jenke and Tucker it can be readily seen that there is ample room for further fruitful and innovative geophysical work. In terms of the aims of the study, the development of a comprehensive regional scale interpretation has been accomplished and it is hoped that this provides stimulus for further analysis and interpretation of Broken Hill data. In particular, mineral exploration groups who will, as time passes, increasingly rely on an understanding of regional tectonics for their successes should find that studies, such as this one provide them with a rapid insight into the gross structure of an area.

Whether nor not the ideas and "mechanical" interpretation procedures employed here are appropriate to other metamorphic terrains remains to be seen. However, if this work stimulates a similar study on the Mt. Isa Block, the Eyre Peninsula, the Tennant Creek Block or the Nabberu Basin, all of which have geophysical data of similar quality to Broken Hill, practically uninterpreted, it will have achieved perhaps its most important aim.

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## APPENDIX I - AQUISITION AND COMPILATION OF GRAVITY DATA

### I - SURVEY PROCEDURE

#### Levelling

The greater part of the gravity work was planned as semi detailed coverage at spacings of 500-1000 metres. Traverses were conducted by vehicle along easily negotiable tracks and fence lines to provide speed of operation and to facilitate position fixing.

Levelling along the vehicle traverses was carried out with "Baromec" digital microbarometers using the "single base" configuration (Hamilton et al., 1957). In most cases, traverses could be carried out between two points of known height, since major roads, railways and trig points with height control are quite plentyful in the study area. Where height control was not available at both ends of a traverse, spot heights from preliminary 1:50,000 topographic maps were used to check tne barometric heights.

The accuracy of the barometric heights was tested by running a traverse in the Adelaide Hills reading the barometers at bench marks with known heights. Table A-1 shows the results of these traverses and demonstrates that, given height control at both ends of the traverse an uncertainty of less than ± 2 metres can be expected. Without this control however the uncertainty may vary from around ± 5 metres in mild weather, to more than ± 10 metres in adverse weather conditions.

Detailed traverses with stations spaced at 200 metres or less were carried out on foot and were optically levelled. Most of these stations were surveyed with a "Sokkisha" automatic level on single runs with an uncertainty on each station of less than ± 5 cm. A "Wild" self reducing tachaeometer (kindly loaned by S.A.I.T.) was used in some of the more severe terrain. The uncertainty on these heights ranged from ± 50 cm on steeper slopes to less than ± 5 cm on gentle slopes.

TABLE A-1

BAROMETRIC LEVELLING TESTS

Stoneyfell to Mt. Lofty via Greenhill Road

| Date / Weather | | 30/9/77 fine | | 30/9/77 fine | | 4/2/76 hot | | 28/1/76 humid | | 28/1/76 unsettled | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bench Mark | Height metres | Differences | | | | | | | | | |
| | | raw | adj | raw | adj | raw | adj | raw | adj | raw | adj |
| 7996 | 181.7 | +0.8 | 0 | * | * | * | * | * | * | -15.6 | 0 |
| 7995 | 266.5 | -1.0 | -1.7 | -1.3 | -1.4 | +1.2 | -0.6 | +1.5 | +0.6 | -13.3 | -0.2 |
| 3/810 | 327.7 | +1.3 | +0.7 | -0.6 | -0.8 | +3.0 | +2.1 | +3.7 | +1.9 | -10.9 | 0 |
| 7994 | 440.9 | +1.8 | +1.3 | +1.0 | +0.8 | +3.2 | +1.4 | +3.7 | +1.0 | -8.6 | +0.5 |
| 11/810 | 497.1 | +0.6 | +0.3 | +0.4 | +0.7 | +2.2 | -0.2 | +4.2 | +1.6 | -6.2 | +0.1 |
| 7993 | 593.4 | +1.4 | +1.2 | -0.2 | -0.5 | +5.7 | +2.7 | +5.7 | +1.2 | -3.9 | +0.5 |
| 6610 | 685.3 | -0.5 | -0.6 | +3.1 | +2.7 | +4.4 | +0.8 | +6.7 | +1.3 | -0.4 | +1.8 |
| 15/810 | 711.1 | * | * | +0.4 | 0 | +4.1 | 0 | +6.5 | 0 | * | * |

Note: raw differences are as calculated assuming no control
adjusted differences assume end station has a known height
* denotes base station location

Gravity Meters

About 70% of the stations were established using a Lascoste and Romberg (Model G37) gravity meter. The drift rate of this instrument was generally less than 0.003 milligals/hour so that reoccupation of the base station was only required every 2 or 3 hours. The reading accuracy of the Lacoste and Romberg meter is ± 0.001 milligals.

A Worden (model 368) meter was used for the remainder of the readings. This meter is of the "prospector" type and has a very narrow (80 mgals) reading range. With a drift rate of up to 0.1 milligals/hour, very frequent drift checks were necessary and were usually effected at least every hour. The Worden's reading accuracy is ± 0.02.

Despite the shortcomings of the Worden meter, very good agreement between the two meters was observed in the field. Ties between pre-existing BMR gravity stations were in agreement to within ± 0.04 milligals.

II - POSITIONING

While occasional recourse to air photographs was necessary to locate station along the detailed traverses the preliminary 1:50,000 topographic maps (compiled by the NSW Lands Department) were generally sufficient to locate stations with an accuracy of 100 metres.

Precision of Bouguer Gravity Values

1. Optically Levelled Stations

| | |
|---|---|
| observed gravity adjusted for drift | - ± 0.05 mgal |
| height error - 5 cm, density 2.67 | - ± 0.01 mgal |
| position error - 100 cm at 32 degrees | - ± 0.07 mgal |

Total precision ± 0.008

2. Barometric Stations

gravity and positioning uncertainty as above
height errors - ± 2 m, density 2.67 - ± 0.4 mgals

Total Precision ± 0.41

## APPENDIX II - COMPILATION OF THE BOUGUER GRAVITY MAPS

Observed gravity, Australian map grid coordinates (digitized from topographic maps) and station heights (datum - AHD) were digitized and Bouguer Anomaly values computed using the Standard International Gravity Formula (1930) and Bouguer /elevation correction formula (Dobrin, (1976).

The computer program designed for this task converted the input grid coordinates to geographic coordinates and output the raw data in the format used by BMR. The program then drew a specified base map and plotted the stations within the area of the map, annotated with their Bouguer values. The maps plotted corresponded to the Standard 1:50,000 topographic series sheets used for positioning.

Contouring was carried out by hand on these 1:50,000 sheets and the contoured sheets were photographically reduced to the compilation scale (1:126,720). A base map with station locations was drawn at this scale by the computer and the reduced contoured segments were manually draughted onto this base. The map was reproduced photographically at 1:100,000, 1:250,000, 1:500,000 and 1:1,000,000 scales.

The principal facts of the gravity data, excluding the NGH Pty. Ltd. and CRAE company data, are presented on a microfiche card in Appendix V.

# APPENDIX III - MAGNETIC DATA

The data for surveys 1 and 4 (Table 3.1) was available in analogue form only. Occasional recourse to microfilmed profiles was made in some areas south of Broken Hill.

Surveys 2 and 3 and to a lesser degree 6 were made available in the form of magnetic tapes by the BMR shortly after the data was published. Software for reading and processing the data tapes was developed by the author with assistance from the Adelaide University Computing Centre Staff.

Survey 5 consisted only of isolated hand drawn profiles.

# APPENDIX IV - MAGNETIC DATA PROCESSING AND MODELLING

## I - FLIGHT PATH MAPS

The program written to prepare the flight path maps (maps 6, 7 and 8) is a FORTRAN program which uses the University's CYBER 173 processor linked on line with a Calcomp drum plotter. The program reads the coordinates of each position fix from magnetic tape and draws the map consisting of the specified flight paths, fiducial marks and geographic reference points with appropriate labels. The program code and a sample run were stored under the name "PALINT" on "GEOPHYSICS LIBRARY" which is available through the Department of Economic Geology at Adelaide University.

## II - PROFILES

Copies of the original aircraft tapes from the BMR survey 3 (Figure 3.1) were transcribed onto tapes in a form convenient for reading on the CYBER 173. The program written for this purpose and a description are stored under the name AIRTAPE on the GEOPHYSICS LIBRARY.

The CYBER tapes were used to plot aeromagnetic profiles using a program called "MAGIC" (also documented on (GEOPHYSICS LIBRARY). The program MAGIC draws the profile segments (specified by line and fidicial numbers) using fiducial intervals for distance scaling and selects a scaling factor for the magnetic values based on the maximum anomaly amplitude.

## III - MODELLING PROGRAMS

Most of the magnetic modelling carried out in this work used a simple program called MAGMATCHER which was written in BASIC language for a Hewlett-Packard desk top computer (Model 9830A), with a small flat bed plotter (Model 9862A). The program computes the total magnetic field of the following bodies:

DYKE (ref. Reford and Sumner, 1964)
Depth Limited DYKE (as above)
STEP (ref. Grant and West, 1965)
SPHERE (equations derived by author)
Infinite vertical PRISM (Bhattaeharyya, 1964)
Limited vertical PRISM (As above).

The desired amplitude of the model curve is input and the apparent susceptibility of the body is computed to match this amplitude. The effects of several bodies can be accumulated to form a composite model profile.

The gravity and magnetic models for 2-D bodies of arbitarary shape were calculated using the "Talwani" method with programs written for the HP 9830.

The gravity program (GRAVE) was written by the author using the equations of Talwani et al. (1959) and the magnetic program was modified and converted from a FORTRAN program written by Dr. L. Thomas, Melbourne University, after Heirtzler, Peters, Talwani and Zurfluch (1962).

These programs use a similar amplitude matching and body accumulating routine to that of MAGMATCHER.

The Hewlett-Packard programs reside on cassette tapes and lists are available through the Department of Economic Geology at Adelaide University.

## APPENDIX V - PRINCIPAL FACTS FOR GRAVITY STATIONS- BROKEN HILL REGION