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INTERPRETATION OF AEROMAGNETIC DATA OF THE OLARY PROVINCE, SOUTH AUSTRALIA AND THE DEVELOPMENT OF INTERPRETATION METHODS

by

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To my late father

Isaiah Ukaigwe Olekanma

Plate 1

False Colour Landsat Image of the Olary Province, South Australia. Scale 1:400,000 Note a variety of geological structures and alluvial cover. Digitally processed by courtesy of the South Australia Lands Department.

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SUMMARY

This research reported in this thesis is an attempt to extend the scope of magnetic interpretation by thinking of the magnetic map as containing a record of past geological processes as well as being a key to the present geometry of the magnetic rock units which is the standard approach to interpretation. The first form of interpretation because it involves a time factor is regarded as dynamic interpretation and the second kind is a static interpretation.

The ideas about dynamic interpretation are put into practice using good quality aeromagnetic data and the published geological reports and maps from an area of Middle and Upper Proterozoic schists, quartzites, gneisses and igneous intrusions from an area in the southern part of Olary which is about 100 kilometers west of Broken Hill. At the same time a standard static interpretation is carried out.

The static interpretation displays clearly the value of magnetic surveys as a tool in geological mapping. The Adelaidean and the Willyama rocks are clearly distinguished on the magnetic contour map. Magnetic bands which are conformable with this layering can be followed in both the Adelaidean and Willyama rock groups and used to extend the geology in areas of poor outcrops, and to identify folds and faults. Profiles were produced from the magnetic tape record of the survey data and suitable anomalies analysed to find the dips and strikes of the rocks. The magnetic contour map is used to identify the pattern of lineaments in the area and these are related to structures recorded by geologists on the ground. Most of the copper deposits in the Willyama schists and quartzites show a clear relation to magnetic features and to the lineaments.

The dynamic interpretation was applied to three features in the area, the development of magnetization in the major sheer zones which provides a record of part of the thermal history of the area, the relationship of magnetic anomalies to carbonaceous horizons in the Willyama rocks which provides information about the depositional environment, and the development of the magnetic properties of the cooling tonalite pluton. As the work progressed it became clear that full development of the dynamic interpretation required geological and geophysical data which was not available and whose collection seemed to be beyond the scope of the research which was initially intended to be a team effort.

In order to analyse the magnetic anomalies a straight forward and unsophisticated interpretation procedure was developed for use on the Cyber 173. The method is simple to use and does not require major computing facilities.

This thesis contains no material which has been accepted for an award of any other degree or diploma in any University nor, to the best of my knowledge and belief, does it contain any material previously published or written by another person, except where due reference is made in the text.

N.F. UKAIGWE

The author consents to the thesis being made available for photocopying and loan if accepted for the award of the degree.

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CHAPTER 1

INTRODUCTION

1.1 Philosophy of Interpretation

Interpretation is the key which unlocks the chest of valuable information contained in an aeromagnetic survey. An interpreter translates the physical values of magnetic field strength into a model of the geology. Interpretation is a link between the magnetic survey and the future actions which will be taken to develop the natural resources of the country. Often it is a weak link and one of the aims of this thesis is to stengthen it.

Interpretation of magnetic surveys, like a translation from one language into another, involves a number of activities which must be used in the right sequence if the right result is to be obtained. For example, the translation of a geological text from Russian into English requires not only proper handling of the words and the syntax, but also an understanding of the geological ideas and the problems to which they are being applied; that is, the philosophy of geology must be understood. If interpretation of the aeromagnetic data is to be made more effective there is a need to examine and understand the current ideas and opinions about interpretation; for it is the ideas, opinions and motives which determine what kind of interpretation and how much interpretation is done. It is in this sense that the term philosophy of interpretation is used.

Philosophy is concerned with how people think about things and problems and the opinions they hold about these problems. This section is about how people think about magnetic surveys and the interpretation of magnetic surveys and comes at the beginning because what is thought about a problem can affect the solution. The classic example is that of the geocentric astronomy of Ptolomy which held back the proper understanding of the movement of the planets for seventeen hundred years. This example shows why it is important to think about the aim of an interpretation as a general problem as distinct from the aim of an interpretation as a particular magnetic survey. This will be done by considering a number of aspects of interpretation.

The first step in understanding interpretation is to consider a standard plan of interpretation of an aeromagnetic survey which may be described as follows. Interpretation of magnetic data is the process which transforms a series of observations of the earth's magnetic field strength into meaningful geological information. The magnetic results are usually presented as a series of contour maps but recently magnetic field strength maps have been presented as grey scale images using procedures developed for the display of landsat data. The interpretation of these maps is usually done in four main stages which are repeated many times to improve and refine the results. These stages are as follows:

1. Study the geology and define the problems.
2. Analyse the magnetic profiles and contours to establish the shape and magnetic properties of the bodies which cause the magnetic anomalies.
3. Use the control provided by the geological observations and theories to relate the shapes of the anomalous bodies to the known geology.
4. Produce a synthesis of the geological and geophysical data using all the available information which will include other geophysical data, geochemistry, photogeology and landsat data etc.

It is often the middle two stages only which are regarded as interpretation of magnetic data; this and a number of other misconceptions of the scope of interpretation are responsible for the less than satisfactory outcome of many airborne geophysical surveys.

These misconceptions are of two kinds; firstly, what should be done about magnetic surveys and secondly, what should come from magnetic surveys. Misconceptions of the first kind are concerned with the management of the problems; misconceptions of the second kind are concerned with what is possible and includes expectations. Some people expect too much of the wrong things from interpretation, others expect too little. In order to understand this a number of topics relating to surveys and interpretation will be given in the following paragraphs.

Aeromagnetic surveys are favourably regarded. It is obvious that people in positions of authority in many countries think that magnetic surveys, and particularly airborne magnetic surveys, are important. The extensive regional magnetic surveys costing many millions of dollars carried out by Government agencies in every continent and the great number of detailed surveys carried out by mining companies and Government groups in the search for ores are proof of this. They all expect to get some return from the aeromagnetic surveys and there is a long list of mineral discoveries which have followed from aeromagnetic surveys.

It is less obvious to the same people in authority that the magnetic maps produced from these surveys need to be interpreted and regularly re-interpreted if the fullest value is to be obtained from them. The interpretation should be done in a systematic way by people who understand the special problems involved. Instead it is often undertaken by geologists who know no physics or by physicists who know no geology. What is needed is a team approach in which interpretation is performed by a partnership of both geologists and geophysicists. Interpretation is often seen as something which is done at the end of a survey to help the geologist sort out the more mathematical problems involved. Interpretation in practice requires a long term effort and commitment which should start at the planning stage of the survey and continue with regular input into the geological study with minor reviews being carried out as new geological data or problems emerge. From time to time the whole interpretation needs to be reviewed as does any geological program. This is best done by a team which includes both geologists and geophysicists and might also include mathematicians and economists as well.

A further management problem concerns techniques used in exploration and interpretation. The Canadian Geological Survey (Hood, 1980) gathered together a most valuable series of papers on mineral exploration and, in the discussion of the wider problems, noted the aim is always to increase the capacity of the combination of prospecting methods. This may be achieved by:

1. Developing new and improving existing methods and techniques.
2. Making field methods and instruments more sensitive.
3. Reducing the effect of or eliminating obscure events.
4. Improving the existing and developing new methods of presentation and interpretation of data by making wider use of mathematical models and electronic computers. It is a surprising fact that although the authors in this book often reiterate the necessity for geological interpretation of geophysical data there are few works addressed to the important requirement of increasing the geological effectiveness of magnetic exploration operations to obtain solutions which will yield the optimum satisfaction of both geological and geophysical observations. The few works that do exist lead one to expect something better but over the years there has been a gradual increase in the gap between the theory and practice of interpretation.

This last point draws attention to the problem of the procedure by which the geophysicist obtains the information about the anomalous bodies which is called analysis. The shortcomings have already been referred to in the paragraph above, i.e., the lack of effective use of the numerous sophisticated methods of analysis of magnetic anomalies which is offered in the literature and the preference shown by many interpreters for the simple methods which were developed thirty years ago. It seems that these methods are still used because they are more convenient to apply or because the refinements in analysis offered by the computer methods do not provide sufficient additional information to justify the additional time and effort spent on them.

The method of analysis used in this thesis was designed by the author so that it was simple to use and was not overbearing on computer time. In organisations where computer methods are being used effectively it appears to be the result of close and extended cooperation between geophysicists and computer specialists. The problem is a practical one but the solution depends on how management sees the whole problem.

There is a completely different kind of problem involved in communicating the results of an interpretation. The information obtained from a magnetic survey looks very much like geological information but there are some important differences. Firstly, there is the scale. Geologists make most of their observations on rock outcrops whose extent rarely exceeds a few metres while geophysicists studying airborne magnetic data are normally dealing with bodies which have a dimension of at least 20 metres and are often dealing with bodies which are more than 100 metres across, so minor variations which are important to geologists may not be evident to geophysicists. Secondly, the properties used by geologists and geophysicists to distinguish the rock units are different and may not be easily reconciled, so it is important that both geologists and geophysicists should understand the differences in order to make the most of the information.

One final and very important point remains to be made. Most users of magnetic data do not expect the correct things from interpretation. They are not asking the right questions. At present many interpreters do not seem to make the most of the information available; they analyse the shape of the magnetic anomalies to reveal the geometry and the magnetic properties of the anomalous bodies, but this is only a static picture of the present geology. There is a real opportunity to take interpretation a stage further than the analysis of magnetic anomalies and the integration of the results into the geological framework (which is effectively a static process and use of the magnetic data) in order to understand better the actual processes which have occurred in the development of the geological evolution of the area, (which is a more dynamic approach to interpretation).

Iron oxides, by virtue of their magnetic and non-magnetic state, provide a record of past temperature and pressure conditions and this record makes the magnetic method probably the most valuable of the geophysical methods for unravelling past processes. This last topic is one which has been given the most thought and attention in this research although it is only seen as part of the thesis. This is so because any interpretation which is concerned with processes must consider them as part of a much wider study which puts them properly in context, and that context is provided, in part, by the more standard type of interpretation.

These thoughts were developed in the course of the research. Many of them were recognised early in the project but were not resolved until toward the end of the work. They were found because the author was trying to solve real problems. Had they been understood earlier the work would have been tackled in a very different way. The fact that so very little has been written about this important subject is an indication of its inherent difficulty.

1.1.1 PLAN OF RESEARCH

It is easier to look back on what should have been done after the work is completed than it is to look forward at the start to see what should be done. This research project started as a "static" interpretation in which the geometry of the anomalous magnetic bodies would be established using more efficient computer techniques and related to the geology in order to produce a better geological map of the conventional kind. The chosen area was adjacent to Broken Hll where Dr. David Isles was completing a thesis on the interpretation of the magnetic and gravity data so that the research was initially seen as developing interpretation, using, to some extent, the experience gained in the previous work as a starting point for interpretation in a less well known area. The theory of approaching an interpretation in this way may be sound, but in practice, Dr Isles' thesis was not completed until the present work was itself almost finished so that Dr Isles' work provided less of a starting point than hoped for.

For this reason magnetic interpretation is usually done better if it is done:

(1) As part of a larger undertaking;
(2) For a purpose and leads into further work; and
(3) In parallel with geological studies and there is frequent communication between the geophysicists and the geologists.

It had been intended that there would be cooperation with geologists of the South Australian Department of Mines and Energy who were mapping the area but priorities in the Department changed and the geologists either left or were given other projects to work on so that the desired cooperation did not occur.

In the meantime as the interpretation progressed without the sufficient information, new and more fundamental problems began to be recognised, specifically the importance of a dynamic approach to interpretation and the need for a better matching of analytical techniques using computers in relation to the requirements of practical interpretation. These were developed as a more important contribution to the study of interpretation than the more straightforward study of the Olary Region. All this work was done with a further factor in mind. Much practical interpretation remains to be done in situations where resources are limited and the ideas, methods and techniques used in the thesis are intended to be appropriate for such conditions.

In the course of explaining to the reader the aims of interpretation it is also necessary to be aware of the importance of the way the interpretation is carried out, for the modern sophisticated processing and presentation of the data will affect what information can be obtained from the data (c.f. Part B of Chapter 3 and Appendix A). This thesis is about interpretation carried out with limited resources because there is still a lot of interpretation to be done under such conditions and it is important that it should be done better than it is at present.

While an interpreter may feel that the philosophy of interpretation is almost exclusively his domain he must not forget that decision makers also have their philosophies. The main reason for taking up this particular research problem was the recognition that while airborne magnetic surveys provide an exceedingly important source of information about the geological resources of a country, the magnetic maps need to be interpreted properly if the data is to be of use. The need for effective interpretation is great in developing countries such as Australia or Nigeria. The way to achieve this is by making sure that both the administration with the overall responsibility for commissioning the survey and the geologist who will use the result understand what can be and is being done about the data.

1.2 Dynamic Interpretation of Aeromagnetic Data: The Olary Province

This thesis describes the method and results of the interpretation of regional airborne magnetic data from the Olary Province, South Australia (fig 1.1). The aims (by reference to this actual example) are to achieve a deeper interaction of existing geological theory with magnetic interpretation and to demonstrate how this can actually be used. This is what is meant by dynamic Interpretation and it contrasts with static interpretation which is made with the finite geometry of the rocks. Basically, this will involve not only an understanding of the standard approach but also an ability to integrate this new approach with the standard approach.

Any interpretation should start with full knowledge of the geology of the area in question as far as it is known; and the critical role of the geological information in establishing the basic models makes it essential to understand the geology of the Olary Province. A review of the geology of the Olary Province is dealt with in Chapter 2. Attention has been given only to those parts of the geology which are deemed to contribute to the study. The magnetic responses of the Adelaidean metasediments, the granitic plutons and the schists have made possible utilization of the aeromagnetic data in developing geologic theories.

After studying the basic geology the next step in any interpretation is to look at a wider area (Appendix B) as big features seen on this scale of interpretation may be valuable for the more detailed interpretation. The major faults recognised outside the study area across the Olary Province are for example the Norwest Fault (see for example fig B.3), the Thackaringa-Pinnacle Fault of Thomson (1969) and the Redan Fault of Hills (1953); (c.f. Isles, 1983) which can reasonably be expected to occur inside the studied area.

Regional variations and their mode of formation and metamorphism may regulate the occurrence of magnetism in rocks and consequently have essential influence on the interpretation of aeromagnetic maps. From the geological angle the anomaly distribution for the different rock types as well as their regional variations are of interest; and the analysis of some of the individual anomalies formed the basic approach in this thesis. It became apparent from this approach that it may not

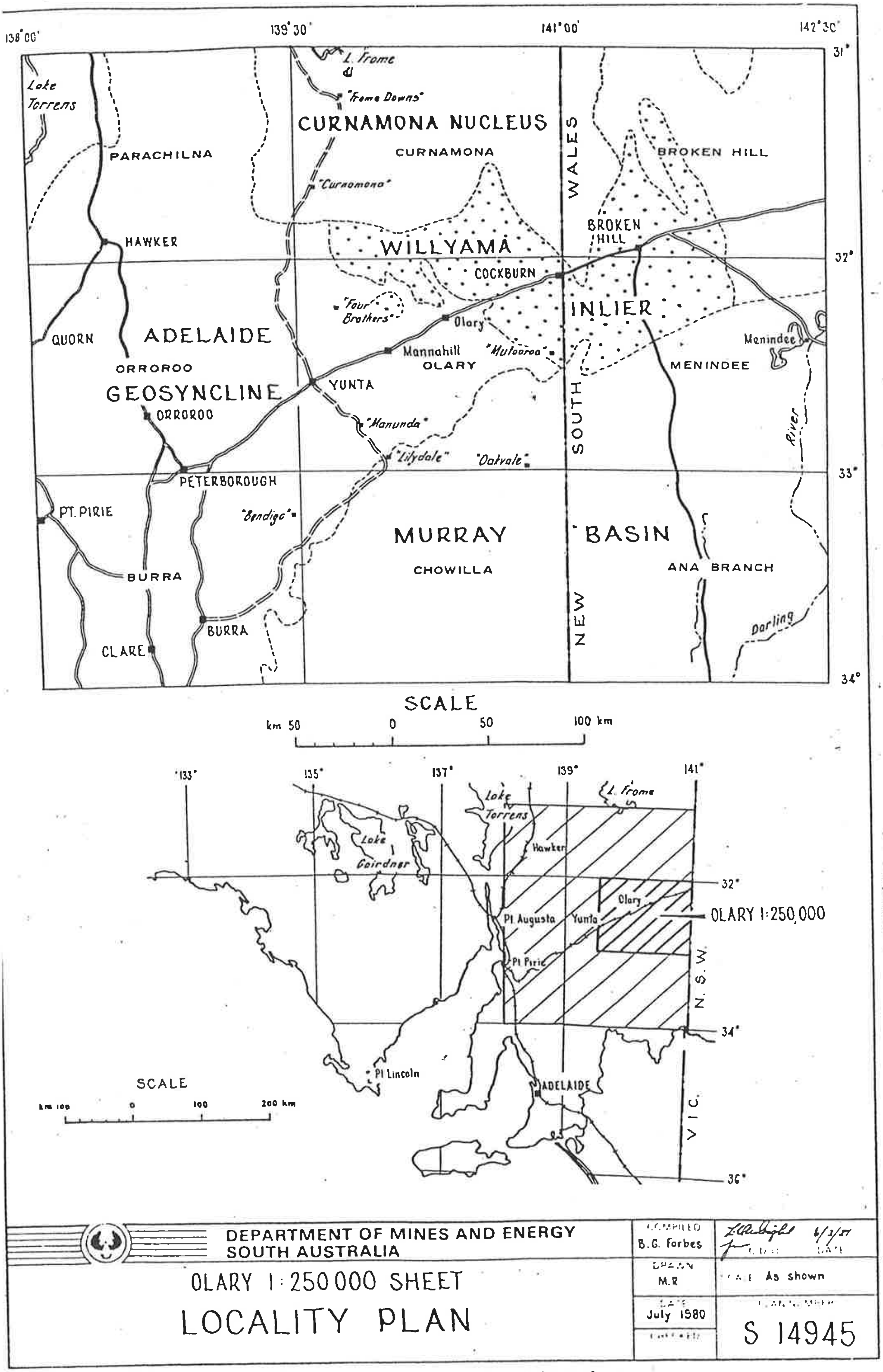


Figure 1.1 General geological and geographical situation of the study area.

be desirable in future to concentrate only on simple classical solutions to airborne anomalies like:

1. The morphology of the field and its relationship to geological information.
2. Comparison of graphs of cross-sections.
3. Visual solutions of many important problems.

The quantity, type and concentration of magnetic minerals are the main parameters that control the intensity of magnetization among rock bodies. The relative importance of magnetite is that it is more stongly magnetic than pyrrhotite or ilmenite; and it is more wide spread and generally occurs in greater concentration in the more common rock types. Magnetite occurs as an accessory mineral and is not included in the classification of different rock types. In the Olary Province the most important magnetic mineral is magnetite, pyrrhotite being extremely rare (Tucker, 1983, p. 97). It becomes obvious that the responses depend chiefly on the magnetite content of the rocks. A problem therefore has to be solved as to how to relate the magnetite content of rocks recorded in the aeromagnetic data and the actual geologically mapped rock types. A starting point that was found to bear on the geological interpretation of the aeromagnetic data in this thesis was to explore:

1. Why a rock type on the average has more magnetite than the other; and
2. To show that it may be petrologically significant that in some of the rocks both magnetite-bearing and magnetite-free variants are to be found.

This leads to a third step; a clarification of what we think about interpretation (Chapter 3). These are essentially considerations of a static interpretation. The new improvement in interpretation developed and demonstrated in this thesis forms a new tool in the interpretation of magnetic surveys under conditions of "meagre" geological information as obtained in the Olary Province, South Australia. The new improvements seek answers to the following questions:

1. What sequence do we operate in such situations; and

2. By what general considerations are we guided in the qualitative and quantitative interpretations.

The answers to these questions sought to explain both the context of geological interpretation and the importance of the magnetic prospecting method as a geophysical mapping tool and has been referred to as a dynamic approach to interpretation.

Ideas of interpretation are as important as new techniques of interpretation. In the past 15 years graphical methods were used to analyse magnetic anomalies. Significant improvements have been made in the use of computers for interpreting magnetic data. In addition to working out type curves and nomograms, important progress has been made in inversion techniques. By this process the computer defines a physical model that best fits the observed magnetic data, rather than generating theoretical anomalies which have to be matched and adjusted by a process of trial and error. A form of inversion referred to as a ridge regression has been developed and used extensively in this thesis (Appendix C; and 3.6.2). It is simple to use. The process is quite straightforward, flexible and effective. It is easy to interpret and to relate the results to geology. It shows that there is no need to spend time and money to produce complex programs whose use and need are limited. Indeed complex programs make geologic interpretation of the results very difficult. "We cannot teach a computer to make geological interpretations; until that day, geophysical results must be assessed through the skilled eye and brain of the human interpreter." (Anstey, 1973, p. 408).

Step five deals with the geological/geophysical hypothesis treated in Chapter 3. Three examples are selected from the regional geophysical data to show the application and limitations of the dynamic approach to aeromagnetic interpretation for geological mapping, and in particular, to economic mineral assessment. The first examines the effect of inverted geothermal gradient, metasomatic fluid and plastic deformational process in shear zones to explain the observed magnetic characteristics within the MacDonald and Outalpa Shear Zones (Corridors). The second deals with the relationship of the carbon/pyrite/pyrrhotite ratios in carbonaceous schists and the magnetic variations within the schist fractions which shed light on the depositional conditions. The third employs fractional crystallization, and partial pressures of oxygen during crystallization which is related to the depths of crystallization to explain the differing magnetic responses of the igneous intrusions of the same composition.

Having developed the ideas and techniques of interpretation, step six details the matching of the geology and the magnetic data. Chapter 4 reviews the magnetic features of the Adelaidean and the Willyama basement rocks. The Adelaidean rocks show relatively simple featuers and outline geologic structures which are presented in the Chapter. In contrast the complex high metamorphic Willyama basement rocks are not simple to talk about briefly and they are treated in Chapter 5. Chapters 6 and 7 are concerned with some special features of the interpretation. Chapter 6 deals with the experimental studies on the determination of trends and direction statistics in a form that incorporates field mapping geological elements. The basis for the geological interpretation of these magnetic trends derives from knowledge of similar trends in both the Broken Hill, lying immediately to the northeast of the Olary Province (Stewart and Boyd, 1983) and the Australian major structural trends (O'Droscoll, 1981a and b; 1982). Correlations and integration of interpretations with other geophysical methods, like gravity, serve to improve the quality of the magnetic interpretation. The gravity data for the Olary Province is spaced at 7km and the anomalies are small and poorly defined compared with magnetics. Chapter 7 therefore discusses possible uses of the gravity had more suitable data been available. Not much contribution came from the gravity data towards the dynamic approach of interpretation.

It is necessary to point out that it has been assumed that the accuracy and density of mapping is good enough to warrant the correlation of the geology and the aeromagnetic data. In Chapters 4, 5 and 6 emphasis has been given on viewing the maps on a variety of scales.

Further development of the interpretation in step seven is the application of the magnetic interpretation to resource assessment which is presented in Chapter 8; while the final step is the conclusion that is presented in Chapter 9. This Chapter reviews the success of the dynamic approach to interpretation and notes that the lack of the intended geologic input from the geological mapping planned by the South Australian Department of Mines and Energy, and the unavailability of Dr Isles' work at the time this project was completed did not really make it a success.

It is concluded that whatever is new is at first unfamiliar, so it may well take time for others to get used to the dynamic approach to geological interpretation. A long journey begins with one step and this thesis takes that all important first step.

1.3 Practice of Interpretation

Aeromagnetic surveys are flown to provide information about the geology. All theories about interpretation must eventually be tested by applying them to real data. This introduction to the thesis concludes with reviewing ideas and concepts involved in carrying out an interpretation.

The interpretation of aeromagnetic data in geological terms is the objective and end-product of airborne surveys. Deducing geologic significance from an aggregate of many minor observations not only tests the ingenuity of the interpreter, but also tests his depth of understanding of geological and physical principles. This aspect of interpretation is not realised by many interpreters because they confuse it with mathematical methods or theory of interpretation. The practice of interpretation requires both discussion of the philosophy of interpretation and cautions against erroneous conclusions. Part of the solution of any problem resides in a clear statement of that problem. The problem of aeromagnetic interpretation must be stated in two broad categories; strategic basic research and exploration problems. Insofar as our objectives are defined, the interpreter should start with basic concepts of the geology which are fundemental in realisation of the defined objectives. It is quite easy for the mathematician to be carried away with his calculations and to lose contact with the geological problems on hand. The purpose of this thesis, which is specifically directed to the interpreter, is to show, with some examples, how certain new considerations and techniques may be of assistance to him in solving some of his real problems. Solutions of his problems have lagged behind other areas of development in aeromagnetic survey studies and the publications indicate that this is so.

The resolution of both geological and geophysical maps depend on the density of the information. The appearance of a contour map is critically dependent upon the flight spacing of the survey, the data being progressively degraded by wider spacing. The combination of line spacing and angle between flight line and strike directions of the rocks will determine the size of structures that can be identified; and this may have a critical effect on the usefulness of the interpretation. If an important structure cannot be resolved, the problem will not be solved, and it may not even be possible to correlate the magnetic map with known geology. The geologist and the geophysicist, by working together as a team, can extract the maximum amount of information from the data being used at the limits of resolution.

Good data of appropriate quality is by itself not enough. The interpreter needs time, space, materials and adequate technical support in the form of computing facilities. Ideas about interpretation develop slowly; although once they are produced, they appear to be obvious. The production of the data in different forms (total field, derivative maps, colour and grey scales) will each reveal new features. These maps are nowadays provided by a computer which is also required for the analysis of the individual anomalies. Without this support, geophysical interpretation work is at a serious disadvantage.

The data used to construct a geological map depends on the availability of outcrops. Abundant detail may be available in small isolated areas and there may be larger areas where there is no data at all. As a result any geological map constructed from the data is often ambiguous. Occasionally, additional information may be obtained from drill holes and trenches in an area of no outcrops but there will still be large gaps in the record of geological facts. Geological and geophysical interpreters, who are often working at the limits of resolution of their data, will achieve better results if they support each other by working as members of a team.

In the industrialised countries, the interpreters benefit from support in the form of available geological control, and other relevant photogeology, landsat and geochemical information. In Australia, the search for mineral deposits that can be mined commercially has been an important activity for decades and is largely responsible for the establishment of acceptable geological concepts and a particularly detailed and abundant data base in centres of mining activity like the Broken Hill district. In addition, much of the country has been covered by aeromagnetic surveys flown by the Bureau for Mineral Resources (BMR) at 1 mile flight spacings (Appendix A), which are valuable for regional geological studies. Surveys with flight lines at 400m intervals or less have been carried out by various mineral exploration companies in areas of interest. The density of background knowledge provided by this work is of great help to the interpreter in trying to interpret the result in a specific survey. Ready availability of computing facilities for the analysis of these data allows a better match of the models to the observed anomalies, and reasonable cooperation between geologists and the geophysicists result in better use of both the geological and geophysical data. There are however some shortcomings in the Australian scene: Systematic studies of the magnetic properties of rocks are almost non-existent and this seriously hampers the interpreter's correlation of the magnetic bodies with the geology described in the various geological publications. By way of comparison with Finland and some of the Eastern Block countries, Australia does not possess enough information on petrophysics.

In developing countries in West Africa, like Nigeria, the recent search for mineral deposits that can be mined commercially has not been a particularly important activity, and as a result there exists a limited amount of geological control and little work is being done in developing new geological concepts relevant to the interpreter. In these countries aeromagnetic surveys have resulted from cooperation with the United Nations Special Fund. In Nigeria, where petroleum exploration is an important activity, the sedimentary basins have been reasonably covered and good geologic control and concepts exist. Regional aeromagnetic surveys are available in a number of the other West African countries, but the data is not always readily available. In Nigeria most of the surveys have been flown with a flight line spacing of 2km which limits the resolution of the geological structures which can be recognised. Cooperation between geologists and geophysicists is less evident in the publication of results than it is in Australia. In Nigeria, Government agencies, such as the geological survey have yet to address the problem of integration of the interpretation of the magnetic maps with the geological maps and other information.

Common though to both the industrialised and developing countries is the lack of petrophysical data; the situation is more serious in the latter, but less excusable in the former.

In conclusion, whilst advances have been made in both the digital acquisition, processing and interpretative scheme of the aeromagnetic data, it appears that the interpretative scheme has not gone forward as rapidly as the capability for acquiring field data. It is the considered opinion here, that we should look forward to continued modification of the magnetic exploration operations, particularly in the direction of increasing their optimum geological effectiveness.

CHAPTER 2

THE GEOLOGY OF THE OLARY PROVINCE

2.1 Introduction

A fairly detailed summary of the geology is regarded as a necessary background for aeromagnetic interpretation and discussion of such a complex region as that of the Olary Province. In the following descriptions the main emphasis will be on the Early Proterozoic Willyama Complex rocks and structures and the Upper Proterozoic Adelaidean cover rocks. The description relies upon existing literature.

The Province is part of the Willyama Complex which extends southeast of the Broken Hill in New South Wales, west for 200 kms to Mount Victoria in South Australia (fig 1.1). It lies in the northeastern portion of the State at longitudes 139°55' - 140°30' and latitudes 32°S and 32°17'S and covers Bulloo and Outalpa 1:50,000 scale sheets (figs 2.1 and 2.3).

The Olary Province has for years been recognised as a water divide between the Murray Basin to the south and the Lake Frome Basin to the north. Typical arid region erosion, with short but violent precipitation accompanied by sharp changes and wide ranges of daily and seasonal temperatures and equinoxial strong winds are generally shown by the low relief of the few exposed bedrocks which are either bare or covered at intervals by a thin veneer of residual soil (Plate 1). This offers no opportunity of direct observation of the deeper structures of the Province. The geologic terms used in this thesis are consistent with those of the South Australian Department of Mines and Energy.

2.1.1 Regional Geologic Setting of Willyama Complex

The Olary Province is part of the Willyama Block (Glen et al., 1977; Rutland et al., 1981; Flint and Parker, 1982) which has undergone a varied and complex tectonic evolution. Detailed geological studies in the area of this study have only been made in the last decade covering the Old Boolcoomata (Wiltshire, 1975), Whey Whey River (Berry, 1973; Flint, 1974; Berry et al., 1978), MacDonald Corridor (Pitt, 1971a), Wiperaminga (Parker, 1972; Robertson, 1972) and Weekeroo areas

(Talbot, 1967). The remainder of the area has had little investigation since the regional studies by Mawson (1912) and Campana and King (1958) which covered all the area described in this work as the Olary Province, and Whittle (1949) for the Old Boolcoomata area. A regional map by Forbes and Pitt (S.A. Department for Mines & Energy) is in preparation, while a review of the entire region is contained in the publications of Glen et al. (1977) and Rutland et al. (1981). A diagram showing the distribution of geological investigations relevant to this study is given in fig. 2.1.

Two major subdivisions of the Pre-Cambrian rocks have been recognised. The basement rocks comprise of regionally metamorphosed complex which is more or less continuous with, and which is correlated with, the Willyama Complex of the Broken Hill and Barrier Ranges area. These rocks are overlain unconformably by a younger sequence, less than 1,100 m.y., of comparatively little metamorphosed sedimentary succession which is part of the Adelaidean system of the Adelaide Geosyncline (Thomson, 1969).

The Lower Proterozoic Willyama Complex consists of metasedimentary and meta-igneous schists, gneisses, granitoids, amphibolites and minor pegmatites, calc-silicate rocks, quartzites and banded ironstones. It outcrops as a series of blocks, each with the eastern boundary unconformably overlain by Upper Proterozoic Adelaidean system sediments and its western margin in faulted contact with the Adelaidean sediments. The Adelaidean succession is composed of siltstones and interbedded quartzites with tillite and conglomerate beds and minor dolomite lenses.

Unlike the Adelaidean system, the Willyama Complex is not divided into a widely accepted framework of rock units, nor is it well supported by isotopic age determinations (Thomson, 1969). A Lower Proterozoic Age, i.e., exceeding 1,800 m.y., is assigned to the original sediments from which the Complex was derived (Thomson, 1974; Glen et al., 1977).

The basement complex has been deformed at least twice prior to the deposition of younger, Adelaidean sediments. High-grade metamorphism with associated pegmatites and a lower grade of regional metamorphism appears to have been imposed in the second phase of deformation. Both the younger Adelaidean sediments and the underlying Willyama Complex were deformed in a later Palaeozoic orogeny and metamorphosed to the biotite grade.

Quarternary alluvial deposits and local continental deposits of the Cainozoic Age are present over most of the Province and in some places conceal the older rocks.

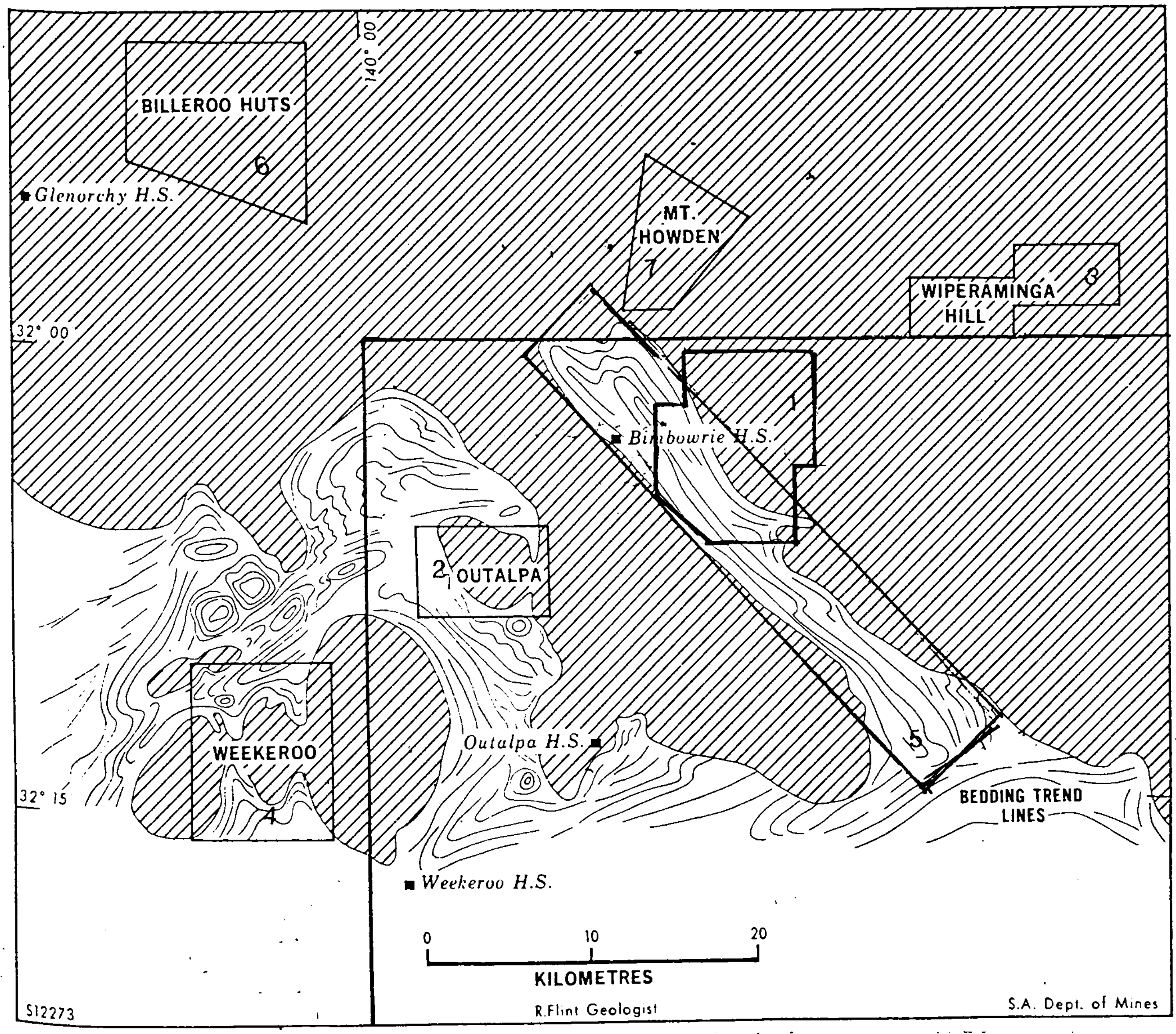


Figure 2.1 Areas of geological investigation relevant to the study area (1) Wiltshire 1975, (2) Berry 1973; Berry et al. 1978, (3) Parker 1972; Robertson 1972, (4) Talbot 1967, (5) Pitt 1971a and (6) Waterhouse 1970.

2.2 Stratigraphy

The rocks of the Willyama Block are thoroughly deformed. Thus, both unconformable relations and stratigraphic continuity are difficult to demonstrate, and the amount of section locally eliminated or repeated is not easily determined. Furthermore, the definition of regional sequence is considerably subjective, and is complicated by block-to-block correlations, in addition to both metamorphic and original sedimentary facies changes. Nevertheless, efforts have been made to clear up the sequence of the strata and their regional relations.

The division within the stratigraphy introduced by Thomson (1969), and revised by Glen et al. (1977) and Rutland et al. (1981), will be adhered to in this thesis for the Lower Proterozoic rock units, while the Late Proterozoic Adelaidean system stratigraphy used is that by Forbes and Pitt (1980) which has been reproduced in fig. 2.2.

2.3 The Willyama Basement Rocks

As the Willyama Complex has never previously been mapped as a system of formal units, a new system of symbols has been employed. Of importance in the structure of the system adopted is that a particular unit representing a certain stratigraphy level may be either schistose, gneissic or even migmatitic, depending on the degree of metamorphism. Hence, correlation was accomplished by reference to thorough-going marker horizons such as calc-silicates or iron formations.

The three main metastratigraphic sequences are represented in a triple column form (see fig. 2.2) which correlations are clearly indicated. The system of symbols employed is based on a sequence of schist units, designated pws_1 to pws_5. In gneissic form they are known as pwg_1 to pwg_5 respectively. A less confident correlation with the units in migmatitic areas is reflected in use of broader units (pwc) with rare marker horizons indicating the local statigraphic level.

Other symbols (pwm, x, z, l, i) define gneissic or migmatoid units which have an unknown or no stratigraphic significance. Granitoid units which have undergone metamophism during the Olarian orogeny are prefixed pw, while those which are essentially late to post tectonic are shown as py. The same logic is applied to basic intrusives pB.

2.3.1 Quartzo Feldspathic Gneisses

As used here, its correlatives are the earlier defined leucogneiss, migmatitic schist and granitoid gneiss of Talbot (1967), and migmatites and granite gneisses of Campana and King (1958). They outcrop over large areas in the cores of major antiformal structures which dominate the south central outcrops of the Willyama Complex in the map area (fig. 2.3). They consist of alternating quartzo-feldspathic and biotite schist bands which range in thickness from 10cm to 10m. The quartzo-feldspathic rocks range in composition from quartz rich to feldspar rich, but biotite and some muscovite are also present.

Migmatites overlie the quartzo-feldspathic gneissic unit having a gradational contact with it. The migmatites are overlain sharply by granitic gneisses which in turn are overlain by more migmatites. The granite gneisses have as their important constituents quartz and plagioclase with small amounts of biotite and muscovite.

2.3.2 Layered Gneisses

A layered gneiss unit apparently overlies the migmatites. It is in contrast with the poorly layered nature of the previous unit. Macroscopic layering of about 120-130m thick is clearly visible (Wiltshire, 1975, p. 21). They have their correlatives with the layered gneisses of Talbot (1967) and Outalpa quartzites of Campana and King (1958). The major difference of the layered gneisses from the underlying units is that they contain one to three thin, sublaterally persistent iron formations which display a +/- sulphide +/- magnetite +/- hematite +/- baryte +/- quartz +/- albite mineralogy. Whitten (1966) noted that amphibolites are also present adjacent to the banded iron formations. Magnetite in concentrated layers of 1mm to 2mm thick is not uncommon. The iron formation's most massive and iron-rich parts consist of quartz, magnetite and hematite, with lesser actinolite and/or hornblende. They pass into actinolite-quartzite-magnetite-bearing schists, phyllites and quartzites. Their occurrences have been noted at Doughboy Hill, Outalpa Station and Dome Rock.

2.3.3 Knotted Alumino-Silicate and/or Muscovite Schists

This group is equivalent to the mica schists of Talbot (1967) and the "Ethiunda Calc-Silicate Group" of Campana and King (1958) and contain ubiquitous tourmaline and garnet. Of the alumino-silicate minerals fibrolitic sillimanite is the most common but it overprints earlier kyanite and andalusite, although the andalusite is often retrogressed to muscovite +/- corrundum +/- pyrite. Chiastolite is developed locally in an upper carbonaceous member.

Calc-silicate and calc-albitic marker beds are present at the top and base of this schist unit and their graduation from the gneissic unit to the schist unit.

Metamorphosed calcareous sediments occur widely, although not abundantly, throughout the area. They are mainly fine-grained, banded rocks consisting of calcium silicate minerals and epidote quartzites, but there are pure marbles at Weekeroo and also coarse pyroxene-plagioclase rocks resembling diorites, fine grained silicate bearing cherts, breccias and banded amphibolite.

Magnetite-bearing quartzites containing 15% iron oxide occur as major associations with calc-silicate rocks. The origin of such rock is not clear.

The schists are the most abundant outcropping rocks of the Willyama Complex. They crop out well, forming low hills which are elongated parallel to schistosity.

2.3.4 Interlayered Schist and Quartzites

This unit was previously referred to as Bedded Mica Schist (Talbot, 1967) and Weekeroo Schist (Campana and King, 1958). It is a low-grade sequence of fine grained, well-bedded metasediments which is quartzitic at the base, and which show a well preserved cross-bedded ripple structure (Talbot, 1967, p. 50 and Plate 1, fig. 2). Talbot suggested there might be an unconformity at the base of this schist/quartzite unit.

2.4 Origin of the Rocks

All the rocks of the region are highly metamorphic, and even their bulk compositions have locally been modified. As far as can be judged by their present appearance and geologic relations, Glen et al. (1977) and Rutland et al. (1981) have suggested that the Willyama Complex rocks, along with apparent equivalents in the Gawler Craton, are characterised by relatively shallow water sedimentation on an older Archaean crust. However, they suggest that an increase in thickness and prominence of schists in the Olary and Broken Hill areas represent a change from a more proximal to more distal environment from west to east. The similarity of the lower part of the sequence with its banded iron formations and amphibolite sills according to Glen et al. (1977) invites analogy with the Middleback subgroup of the Gawler Craton.

This has recently found support from the work of Pitt (1981) in the Kalabity area. According to him the general aspect of the original Willyama Complex deposits should be considered to be one of low energy, shallow water, clastic, chemical and pyroclastic sedimentation. Early deposition of argillites and arenites occurred in a broad shallow basin that was followed by precipitation of iron oxide (hydroxide), silica, evaporites and sodium silicates in lenticular bodies. Metamorphism of such deposits produced the iron formations and their equivalents in the layered gneisses that are recorded today.

Subsequent shallow basinal deposition of clastics, with minor evaporite-derived albitic components, was followed by a major complex phase of argillite, impure carbonate and evaporite deposition. Contemporaneous extrusive igneous activity probably contributed a volcaniclastic component; and variation of facies of the resultant sediments, particularly across major structures, would indicate a complex basin and sub-basin palaeogeography. Metamorphism of these sediments produced the knotted alumino-silicate and muscovite schist sequence.

Finally, siltstone and mudstones were deposited and their variation in thickness may be related to original basinal topography. Within the siltstone unit syngenetic sulphates and rare carbonates are formed. Also, organic rich argillites are deposited under a low-energy regime. These siltstones were metamorphosed to an upper schist unit.

It has been speculated (Forbes and Pitt, 1980) that the albite, calc-silicate and iron-formation rocks formed within the lagoons or small, restricted basins, under an evaporative and possibly volcanogenic influence. These features, particularly the association of evaporites and alkaline volcanics, evoke models of modern continental rift-zone tectonics, alkaline igneous activity and related sedimentation.

A rift-zone model has also been invoked by Stevens et al. (1980) in explaining an analagous depositional environment for the Broken Hill Block. According to them Proterozoic intracratonic mobile belts (eg, Namaqua Belt, Southern Africa) and Archaean volcanic provinces may be analagous in terms of magmatism, deformation history and metamorphic grade. They suggest that a model involving rifting within an island arc-trench system as the most feasible, drawing a possible analogue with the Green Tuff region of Japan. This is a zone within the Japanese island arc system which subsided under tensional stress, forming a shallow marine environment in a volcanic rift (possibly an incipient inter-arc basin) (see Sato et al., 1974). In this place the typical island arc andesitic volcanism (Monzen Stage) was followed by sedimentation with accompanying acid and basic volcanism leading to Kuroko-type stratiform base metal deposits. The Green Tuff region is characterised by high geothermal gradients and low pressure metamorphism.

There are no indications of an Archaean basement to the succession in the Willyama Block, and preliminary estimates give it a thickness of 4,000-6,000 metres (Rutland et al., 1981).

2.5 Igneous Rocks

Igneous rocks of various lithologies and ages occupy a substantial portion of the Willyama Block. Some are metamorphosed whereas others are not, but it is not clear in some instances whether a given rock is the metamorphosed equivalent of a certain igneous phase or whether one is pre-metamorphic and the other post-metamorphic (Spry, 1977).

Granites are abundant, the largest being the Boolcoomata adamellite which is a massive batholith containing patches of migmatite (fig. 2.4). Tonalites occur in the south-western and southern portions of the map area (figs. 2.3 and 2.4), (eg, Walparuta, Outalpa Springs, Ameroo and Yerki Hills); and granodioritic granites occur at Doughboy Hill and Peryhumucky and Nine-Mile Gate areas.

Antro granite in the north-western corner of the map area (figs. 2.3 and 2.4) is regarded as part of the same body as Triangle Hill granite on the Kalabity map sheet, but separated by movement on the MacDonald fault. Both granites are of adamellite composition, with a highly distinctive component of large, partly aligned, tabular, albite-mantled, microcline phenocrysts. Tonalite gneisses at Walparuta and Spring Bore are also believed to be related but in this case are thought to have been separated by the Outalpa fault.

Dating of the massive, non-foliated granitoids such as the Binberrie granite give ages of 1,450-1,550 m.y. Unfoliated to poorly foliated granitoids are regarded as late tectonic, while the concordant gneissic granitoids which occur widely in the area are regarded as of an earlier (unspecified) syntectonic origin.

Pegmatites are widespread. They are commonly parallel to the foliation and vary in thickness from a few centimetres to over 100 metres. Their distribution shows a high degree of correlation with certain stratigraphic units being most abundant within the basement schists, layered gneisses and migmatites. They could be related to metamorphic phases rather than late-tectonic granite intrusion. Zoning is common in all types (eg, tourmaline in Alconie Hill), and a variety of radioactive minerals comprise the accessory mineralogy (Campana and King, 1958).

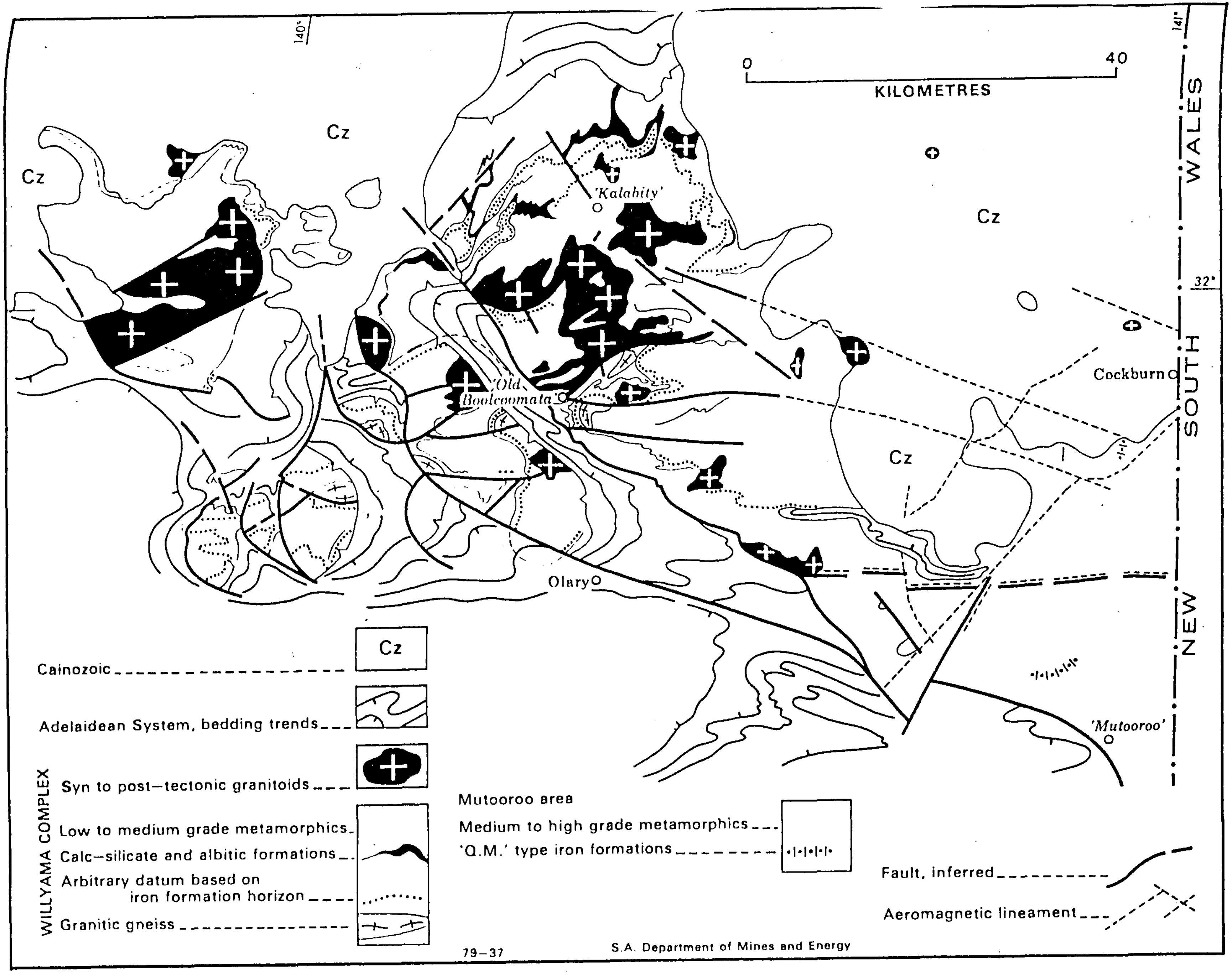


Figure 2.4 Major fault patterns and location of granitoids in the Olary Province (after Rutland et al., 1981).

Amphibolites are quite common in the Willyama Complex. They occur as both concordant and discordant bodies in the Boolcoomata, Outalpa and Weekeroo-Walparuta areas. Although metamorphosed, they do not have a well pronounced foliation and relict igneous textures are common; it seems clear, therefore, that they represent altered basic igneous rocks. Some structural features are suggestive of volcanic origin (Jones et al., 1962).

Doleritic amphibolite dykes occur in a number of places in both schists and granite gneisses, but their outcrop is generally poor. They are composed predominantly of albitic plagioclase with lesser actinolite (replacing original igneous pyroxene), opaque oxides (up to 10%), epidote, and a trace of sphene and apatite. Quartz is absent. Depending on the degree of metamorphism the albite laths can define a relict ophitic (doleritic) texture which may be visible in hand specimen.

The dykes are post-tectonic and are considered to have been intruded prior to Adelaidean sedimentation.

2.6 Late Pre-Cambrian (Adelaidean)

Thomson (1969) grouped the Adelaidean system sediments into four major lithostratigraphic units: the Wilpena Group, the Umberatana Group, the Burra Group and the Callana Beds, in order of increasing age. The relation between lithostratigraphic and chronostratigraphic names are shown in fig. 2.2. The following outline of stratigraphy is drawn from reviews of Thomson (1969), Talbot (1967), Campana and King (1958), Pitt (1971) and Forbes and Pitt (1980).

In the Olary Province two sequences are represented, a lower group believed to be the equivalent of the Burra Group (Torrensian) and an upper group which is correlated with the Umberatana Group of Sturtian Age. In the map area they outcrop mainly along the MacDonald Corridor, the Outalpa Corridor and to the west near Weekeroo and Outalpa homesteads.

2.6.1 The Burra Group

Sedimentary rocks of the Burra Group lie unconformably upon the Willyama Complex. The Burra Group is characterised by a basal sandstone-conglomerate member with maximum thickness of about 15m. This is overlain by an argillite-carbonate succession. In the lower part of the sequence, bands of dolomite marble are common. Wiltshire (1975) has estimated the thickness to be 230m in the MacDonald Corridor.

Subdivision of the Burra Group is based in lithologic correlation with the Burra Group on Orroroo (Brunks, 1971) and elsewhere. Sandstones with black, hematitic laminations similar to Rhynie Sandstone or lower Aldgate Sandstone occur in sequence east of Weekeroo and the Outalpa Hills. Skillogalee dolomite occurs west of Outalpa where a complete but condensed Burra Group sequence is exposed. A consistent north-easterly thinning of the Burra Group sequence is observed in the map area, particularly in the western Olary and Kalabity areas.

In the Adelaide Geosyncline this group is considered to have been deposited in fluviatile deltaic and shallow marine environments, controlled by contemporaneous movements of basement faults (Thomson et al., 1976; and Rutland et al., 1981).

2.6.2 The Umberatana Group

The Umberatana Group consists of mixed glacial and shallow marine sediments of Yudnamutana sub-group, Pualco Tillite, Benda Siltstone below and the shallow-water, non-glacial Wilypera Formation. The early glacial unit Pualco Tillite (which is possibly equivalent to the Bolla Bollana Formation of the Arkaroola region) and the Benda Siltstone are absent over a great part of the Adelaide Geosyncline.

Within the MacDonald and Outalpa Corridors in the map area, the basal glacial unit consists of arkose and quartzitic horizons and massive tillites interbedded with siltstones, shales and sandstones. This glacial sequence grades upwards and laterally into a thick, glacial marine sequence of argillites with occasional tillites. Braemar Iron Formation or "ironstone" forms a ferruginous facies of this Pualco Tillite and the conformably overlying Benda Siltstone representing local deposition of iron oxides (Whitten, 1970; Miriam, 1962).

Benda Siltstone comprises a thick laminated pile of siltstones and shales. No tillites or erratics have been found in the sequence. This in turn is overlain unconformably by the Wilypera Formation, which has a thick basal quartzite overlain by siltstones. Wiltshire (1975) has suggested that the thickness of the Umberatana Group ranges from 150m to 2,000m along the MacDonald Corridor, while the thinning in most places is attributed to erosional breaks (Pitt, 1971a).

The presence of the Braemar Iron Formation within the Umberatana Group will undoubtedly render it the most magnetic sedimentary group in the Olary area. The magnetic effect of the other sedimentary rocks is much smaller because of lack of magnetic minerals.

2.7 Cover Rocks

Tertiary rocks have only been penetrated in the subsurface of the Murray and Frome Basins south and north, respectively, of the Olary Block in a search for sedimentary uranium deposits by Tricentrol Aust. Limited, Sedimentary Uranium NL and Mines Administration Pty. Ltd. (Bryan, 1971 and 1972; Jarre, 1972; Middleton, 1975). The oldest tertiary rocks are fossiliferous marine marls and clays, of early Miocene Age (Lindsay and Harris, 1973; Cooper, 1978) and these are overlain by sand possibly of Pliocene Age. Burn (1980) has inferred an unconformity below the sand. In the south-eastern Oakvale area, the sand varies from a partly silicified, white, kaolinitic, fine grained sandstone, to that of a reddish, ferruginous, micaceous, laminated medium grained sandstone (Callen, 1969).

In the Olary Province wide areas of Pleistocene calcrete occur at or close to the present day topography; for example, near Olary Creek where they cement old higher-level gravel sheets which resemble Telford Gravel and which are possibly equivalent to part of Millyera Formation (Callen and Tedford, 1976). The calcretes vary from hard massive sheets to soft nodular sheets and are often draped over weathered basement.

Pleistocene, reddish alluvial clay rich gravels, in-fill many of the valleys in the Olary Province and are commonly exposed in creek banks. They are correlated with Pooraka Formation (Firman, 1969) and are possibly equivalent to Eurinilla and Coonarbine Formation of Callen and Tedford (1976). These gravels are younger than both the Telford Gravel and the hard Pleistocene calcretes.

In the south-east, over the Murray Basin, there are reddish east-trending sand ridges (Woorinen Formation) which appear to be transitional to Pooraka Formation.

Callabonna clay occasionally occurs as a thin, reddish clay layer above the Pooraka Formation throughout the Olary Province and Holocene light brownish alluvial silt, sometimes laminated, ripple sometimes up to 1m thick and may often be seen above reddish Pleistocene clay at the top of creek banks. This silt appears to form the basis for clay flats adjacent to some main creeks. Other Holocene deposits are gravel and sand of drainage channels; younger drifts and veneers of silt, clay, salt and gypsum of clay pans are seen in areas of poor drainage.

2.8 Geological Structures

There have been various structural interpretations made in the past (Sprigg, 1954; Campana and King, 1958; Talbot, 1962 and 1967; Wiltshire, 1975, Glen et al., 1977; Berry et al., 1978; and Rutland et al., 1981). In brief, the Olary Province is framed by a northwest trending set of shears, typified by the MacDonald Shear Zone, and the northeast trending Anabama-Redan lineament (see figs. 2.3 and 2.4, and Flint and Parker, 1982). All the northwest trending shears show reverse faulting or steep overthrusting of basement over Adelaidean from the east during the late Proterozoic and early Palaeozoic. There are several fold sets recognised in the basement, but major fold axes have an overall northeast trend (Glen et al., 1977) reflecting the major structures of the gneisses. The structures described in this section were formed during the early to middle Proterozoic Olarian Orogeny and the later Phanerozoic Orogeny.

2.8.1 Olarian Orogeny (1,700 m.y.)

Polyphase folding, deep-seated ductile faults, high metamorphic grade with migmatization and paucity of outcrops render the structural analysis of the Olary Province especially difficult. Nevertheless, the geological structure of the area pre-dating the Adelaidean unconformity is similar to that in other high grade metamorphic areas of the Broken Hill region and Gawler Craton (as described by Glen et al (1977) and Rutland et al. (1981)). The structures occurring near Outalpa Springs of the mapped area have been unravelled by Berry et al. (1978) and that within the Boolcoomata area by Wiltshire (1975). Recent regional geological mapping by Forbes and Pitt (1980) has revealed that conclusions made from the detailed structural study of the Outalpa Springs area (Berry et al., 1978) are applicable to most of the South Australian Willyama Complex, maybe with the exception of the Mutooroo area where lack of data and poor outcrops has precluded any serious structural study.

Small-scale folds are the most easily classified structural elements of the Olary Province, and have been subdivided into systems on the basis of style, associated fabric elements and age relationships. Mineral lineations, schistosities and other structures that are genetically related to folds are discussed in terms of this relationship.

Three deformational episodes have affected the Willyama Complex rocks in the Olary Province prior to Adelaidean sedimentation. The first folding phase, D_1 produced the earliest structural features observed in the area. Evidence of its existence is rare; however, mesoscopic isoclinal D_1 folds that affect compositional layering and exhibit a strong, pervasive, axial planar schistosity have been observed at Outalpa Springs in the schist, granodiorite and migmatite zones. This fold phase may be associated with the amphibolite facies metamorphism observed in other areas of the Willyama Complex (Talbot, 1967; Rutland et al., 1981) and may be correlated with the early isoclinal recumbent folding which over-turned the sequence at Broken Hill. If D_1 was once an extensive feature of the Willyama Complex, evidence for its presence has been almost completely destroyed by the later metamorphic and structural events. It may actually represent several independent folding phases, but further subdivision is not possible because of the rarity of these structures.

The presence of the D_1 fold phase is also suggested by interference patterns produced during D_2 folding in the quartzites within bedded schists west of Old Boolcoomata near Hudson's Hut (Wiltshire, 1975, p. 53). An early fold phase (D_1) is also present in the Weekeroo area and near Wiperaminga Hill (Parker, 1972).

The second recognisable folding event D_2 produced fold styles which vary from open to tight and inclined to upright. Closures have generally been removed by faulting or post Willyama erosion, and only parallel limbs are preserved. Their recognition however is vital to interpreting a correct stratigraphy. D_2 folds are generally hard to identify where no overprinting criteria are available and their axes showed diffuse orientation. However, several have been mapped in Outalpa Spring and Old Boolcoomata areas. The D_2 folds exhibit crenulation cleavage within the pelitic units indicating a steep dip with strike varying from 090° to 180° but concentrating at 120°. Metamorphic assemblages associated with this folding event (Flint, 1980) indicate a relatively high metamorphic grade though somewhat lower than D_1. In consequence, retrogression of D_1 assemblages probably began during this phase. The D_2 deformation was coeval with the widespread emplacement of pegmatites (Glen et al., 1977, p. 135).

During the third deformation the fabrics produced by both D_2 and D_1 were refolded. This folding event produced many of the major structural features of the region as presently mapped. They trend roughly east-northeast and vary from tight to moderately open upright folds.

Like D_1 and D_2 structures, macroscopic D_3 folds are generally hard to identify because distinctive marker beds are rare. However, several have been mapped in Walparuta, Outalpa Spring and Mulga areas.

The one at Outalpa Spring shows an eastward plunge (Berry et al., 1978). The Ameroo Hill and Mount Mulga synforms were formed during D_3.

The D_3 mesoscopic fabric elements include a strong crenulation and crenulation cleavage in pelitic rocks, and reflect continued retrogressive greenschist facies metamorphic conditions. Shear zones (MacDonald and Outalpa Shears) and numerous large granite and pegmatite bodies were emplaced during D_3 (Glen et al., 1977, p. 135).

2.8.2 Upper Proterozoic Structures

The Late Proterozoic grand unconformity truncates the third generation fold structures clearly separating pre and post-cover fold structures. The Adelaidean rocks are strongly folded and, for example, near Doughboy Well, Burra Group sediments occupy a tight northward plunging syncline.

Two deformation episodes have affected both the Willyama Complex rocks and the Adelaidean cover rocks and have been attributed to the Delamarian Orogeny. The regional D_4 deformation identified in the Willyama Complex rocks is correlated with the first deformation phase recognised in the Adelaidean rocks. In the latter, this deformation produced a schistosity which is axial planar to tight synclines in the basal sequence. Mesoscopic fabric elements have also been recognised within the Umberatana Group and open macroscopic folding has been inferred from the bedding relationships.

In the Willyama Complex D_4 crenulations were produced with NNE striking axial surfaces. Folding was largely controlled by basement cover interaction and D_4 mesoscopic structures apparently became rare in the basement rocks further from their contact with the Adelaidean. Metamorphic mineral assemblages (biotite, chlorite and actinolite) are indicative of biotite zone greenschist facies.

The latest phase of deformation affecting the basement and cover rocks is identified as D_5 in the Willyama Complex rocks. It was a penetrative deformation related to easterly trending crenulations and gentle macroscopic folds within the Willyama Complex metasediments. The similarity of trends for D_3 and D_5 folds led Wiltshire (1975) to erroneously conclude that the Mount Mulga D_3 synform (actually an overturned anticline) was produced by D_5 folding during the Delamerian orogenic phase. In fact, the Mount Mulga synform and the Walparute antiform are examples of coaxial D_3 and D_5 structures with Adelaidean and Willyama rocks separated by a D_5 fold, fault and unconformity respectively (Forbes and Pitt, 1980).

The regionally more significant D_5 deformation was associated with the peak of metamorphic conditions (upper greenschist facies) for cover rocks; and generally had a more homogenous effect on both basement and cover rocks.

2.8.3 Faults

The Willyama Complex in South Australia is composed of a number of semi-isolated partly fault-bound blocks, many of which are further broken up by north-west and east-west shears. Much of the faulting certainly took place during the folding of the Willyama Complex metasedimentary rocks, but faults of both syn-Adelaidean and post-Adelaidean sedimentation also occur.

The largest most prominent fault in the map area runs from MacDonald Hill to Bimbowrie Station and beyond (Flint and Parker, 1982), and it defines the northeast margin of a narrow corridor of Adelaidean system sediments. The sediments strike northwest, almost at right angles with the general structural trend of the basement. Sprigg (1954) interpreted the fault structure in the basement, the major one of which has been named the "MacDonald Fault" and is interpreted as pre-Adelaidean (Wiltshire, 1975). Parallel to this runs another deeper axial depression which is developed in the continguous area between Walter-Outalpa fault. This is also delineated in the Tectonic map of South Australia (Flint and Parker, 1982). Faults in the same direction were also formed south of the MacDonald fault in the southwest boundary with the Adelaidean geosyncline sediments. The dip of the faults are steep and the northern side is probably block tilted upwards.

In the Broken Hill region a flexture-like fault zone strikes east southeast (Thackaringa-Pinnacles Shear). Thomson (1969) extended it into the Olary Sub-domain where it appears to be a late-stage feature, disrupting early structures and having possible dextral sense of movement (Andrews, 1922; Glen et al., 1977).

A fault system trending north-easterly similar to Globe-Vauxhall, Apollyon Valley, Mount Franks and Mundi-Mundi Faults of the Broken Hill Sub-domain have also been inferred for the Olary Sub-domain (Glen et al., 1977, p. 136); for example, in the district around Whey Whey River and Old Boolcoomata. Wiltshire (1975, p. 62) reports faults E-W and N-S strikes cutting gneissic rocks which form the core of the easterly plunging synform. These faults are verticle and one of them has a strike slip component of 400 metres. A dolerite dyke striking NW in Whey Whey River is interpreted as an intrusion into a fault (Berry et al., 1978). In the central margin this fault displaces the margin of the granodiorite by at least several tens of metres.

2.8.4 Metamorphism

Three metamorphic events have previously been recognised (Talbot, 1967; Cobb and Morris, 1970; Parker, 1972; Wiltshire, 1975):

(a) an early high grade regional metamorphism;
(b) a later, medium to high grade, may be locally retrograde metamorphism; and
(c) a post-Adelaidean system metamorphism.

Recent studies by Spry (1977) and Berry et al. (1978) have suggested that there might have been four metamorphic episodes in the Olary Province. Petrographic studies (Spry, 1977; Flint, 1980) further suggest that these metamorpic phases may be directly correlated with deformation phases D_1, D_2, D_3 and D_4/D_5 as discussed in 2.7.1.

In schists of appropriate composition early formed mineral assemblages include andalusite (Chiastolite), sillimanite, rare kyanite, and garnet. The sillimonite bearing assemblages are associated with granite intrusions and migmatization, as is wollastonite indicating relatively high temperatures and moderate to low pressure. The dimensional orientation of certain minerals in these assemblages has a geometric relationship with the D_1 mesoscopic folds, ie, axial planar (Spry, 1977, p. 6 and Berry et al., 1978, p. 45) suggesting that this amphibolite facies metamorphism (Berry et al., 1978; Talbot, 1967) may be related to D_1.

Overprinting the amphibolite facies fabric is a later low amphibolite to greenschist facies metamorphism indicated by the growth of post-tectonic muscovite (Spry, 1977). This muscovite growth has been related to the D_2 structural event. Petrographic and structural studies by Flint (1980) has indicated that retrogression of earlier high grade metamorphic mineralogy was initiated at this stage. Evidence for continued retrogressive greenschist facies conditions is found in an irregularly distributed regional event consisting of the production of retrograde sericitization (associated with D_3) followed by growth of post-tectonic chlorotoid (Spry, 1977). The D_3 sericitization is most pronounced in the retrograde shear zones (Glen et al., 1977).

The assemblages defined by biotite, chlorite and actinolite which are listed by Winkler (1967) as biotite zone greenschist facies conditions are found in Adelaidean system metamorphic rocks. Its effect on the older crystalline rocks has not been studied although its imprint is known to be reflected on continued retrogression of aluminous minerals.

Regionally, Thomson (1974, fig. 3) has divided the Olary Province into zones of lower amphibolite grade and upper, sillimanite bearing amphibolite facies grade (fig. 1 and Table 1 in Spry, 1977) which may be equivalent to zone B and C of Binns (1963, 1964) in the Broken Hill area. However, Forbes and Pitt (1980, p. 6) have stated that isograds of the early D_1 prograde "Olarian" metamorphism are not well defined, and that Zones A, B and C of Binns (1963, 1964) are not easily recognised. However, they suggest that the grade drops from upper amphibolite to granulite facies in the south eastern areas of the South Australian Willyama Complex to lower amphibolite facies in the norther areas on Kalabity (Curnamona).

The absolute age of the amphibolite facies metamorphic event is not entirely conclusive. This early high grade metamorphism has been correlated with the D_1 granulite to amphibolite facies event of the Broken Hill area where a Proterozoic Rb/Sr metamorphic age of 1,700 m.y. was recorded by Shaw (1968) and Pidgeon (1962). Cooper (1972) using Crocker Well U-pb isotope data, has related Uranium mineralization to this 1,700 m.y. event. Geochronology of the South Australian Willyama Complex by Webb (Amdel project 1/1/140) has not been successful, due in part to the effects of later retrogression phases (discussed above) and the problem of selecting suitable rock types.

Geochronological data on granitoids in the Olary area (Flint and Webb, 1979) indicates a sample age of 1,500 m.y. which is equivalent to the age obtained for the Mundi Mundi granite from the Broken Hill area (Thomson, 1974). Forbes and Pitt (1980) have suggested that this thermal event overprinted earlier ages in the Olary region. A poorly defined grouping of 1,050-1,200 m.y. dates have also been obtained and Thomson (1980) has speculated that it may reflect some limited influence of the Musgravian Orogenic Phase.

Finally, a geochronological age of 500 m.y. (Thomson, 1969) is correlated with the final metamorphic age and falls within the Delamarian Orogeny. Rutland et al. (1981) concluded that the final development of a stable craton in the Willyama area took place ca. 490 m.y.

2.9 Economic Geology

The Pre-Cambrian rocks of the Olary Province contain many types of ore deposits, industrial minerals and rocks which have given rise to mining operations. Reviews on these mineralisations have been published by Campana and King (1958); Blissett (1975) and Pitt (1978). The most important mines and quarries in the region include:

(1) Mount Mulga Mine from which a total of 13,253 tonnes of oil drilling barite has been mined since 1962. The present rates stands at 1,500 tonnes per year;

(2) Pegmatites found within the Willyama Complex are potential sources of potash and soda feldspar, with beryl and mica as minor accessories, fluorite have been worked near "Plumbago" and "Mutooroo" and apatite near "Old Boolcoomata". White rock deposit, Raven Hill deposit, White Lady deposit and Maggie Mines have been mined to produce 18,507 tonnes of feldspar (1932-1979);

(3) Copper and barite occur at Walparuta (west-northwest of Outalpa); Perryhumucky and Maroo, Lady in White and Lady Louise mine near Ameroo Hill and at Mount Mulga (southeast of Old Boolcoomata). This stratigraphic level, below the schists of Ameroo Hill, may approximate the mine sequence in Broken Hill Sub-domain where huge lead zinc and silver deposits have been mined for over a century;

(4) Some iron formationss have been prospected as possible sources of iron ore. Small quantities of sillimanite, andalusite (chiastolite) and kyanite have been mined in the past. Small deposits of apatite near Old Boolcoomata have been worked in the past;

(5) Elsewhere in the region Davidite, a complex iron-uranium titanite, was mined a Radium Hill from 1954 to 1961, when 954,000 tonnes of ore averaging 1.2kg U_3O_8 per tonne was produced. Davidite was associated with steep shears in gneiss and amphibolite of the Willyama Complex. Davidite also occurs in Mount Victoria, Spring Hill, and Mindamereeka prospects and low grade uranium occurs at Crooker Well as absite (Uranium-Thorium titanite) with adamellite and pegmatite;

(6) Approximately 6,000 tonnes of high-grade, secondary copper ore, including chalcocite, cuprite and copper carbonates were

obtained from Mutooroo Mine between 1887 to 1908. This deposit was associated with shear zones in an amphibolite body;

(7) Stratiform cobaltiferous copper deposits and barite also occur in association with bedded iron formation and calc-silicate rocks of the Willyama Complex. At Ethiudna Mines, sheelite and galena occur with chalcopyrite and other minerals;

(8) Sedimentary martite and magnetite within the Yudnamutana subgroup (Braemar ironstone facies) were investigated at Razorback Ridge (Whitten, 1970). Reserves of over 120 million tonnes averaging 26% iron were proved but were considered uneconomic;

(9) Gold associated with quartz veins have been mined in Olary (King Bluff) (1887) in Wilyerpa Formation. The gold and copper deposits of the Luxemburg and Queen Bee Mines are associated with east trending quartz veins and amphibolite bodies. A total of 5,300 grams of gold are recorded for the period from about 1887 to 1915.

CHAPTER 3

INTERPRETATION OF MAGNETIC ANOMALIES

PART A: AEROMAGNETIC ANOMALIES AND GEOLOGICAL PROCESSES
PART B: PROCEDURE AND ANALYSIS OF ANOMALIES

3.1 Introduction

In Part A of this Chapter three special geologic problems are considered:

(1) The structural and petrologic conditions that can affect magnetic anomalies observed within the shear zones;

(2) The environment of deposition and the magnetic mineral compositions in carbonaceous schists; and

(3) Physiochemical environments that affect magnetic minerals in intrusive rocks.

Automatic analysis of magnetic anomalies has become very important in easing the drudgery of tackling large volumes of data. The speed with which data can be processed allows more time to the geophysicist or geologist for interpretation. In addition, the computer offers new techniques in finding the more subtle anomalies and those masked by complex geology. An iterative scheme developed for use in this thesis and the qualitative interpretation method used in this study will be discussed in Part B of this Chapter.

The ideal interpreter is one who has training in both geology and geophysics. He is aware of what processes the data has undergone from acquisition of data to its presentation and understands the mathematical and physical principles of interpretation of the geophysical data. His geological experience helps him to assimilate the mass of data, much of it conflicting, and recognise alternative plausible geological picture. It is rare to find in the same person the requisite knowledge and experience in both geology and geophysics; often the alternative is to have a geophysicist-geologist team working in close operation.

As aeromagnetic surveys are usually carried out to help geological mapping it is rare that the correctness or incorrectness of many aspects of an interpretation can be ascertained, because the actual geology is rarely even known in adequate detail. We accept as right any geophysical result which seems to us to be "geologically plausible", but that corner-stone of "geological plausibility" is in itself weak. It has never been formalised or expressed rigorously or quantified. The test of good interpretation is consistency. An interpretion must be consistent with all the geophysical data and all that is known about the area, including gravity, landsat, photogeology and surface geology; it must also be consistent with geology and physical concepts.

3.1.1 Some Views of Aeromagnetic Interpretation

Writing for the 75th Anniversary Volume of the Society of Exploration Geologists, Wright (1981, p. 836-7) stated that a complete interpretation requires both geophysical and geological considerations. The goal of a geophysicist is to turn a magnetic map into one or more geologically reasonable subsurface models showing depths, lateral boundaries and magnetic susceptibility contrasts of the various bodies detected. The geologist then takes this information and makes the most reasonable geologic interpretation in terms of distribution of rock types.

Emerson (1979, p. 4) expects the interpreter to be intimately involved in all stages of a magnetic interpretation which should be more than just the highlighting of anomalous areas and determination of depth and width of source bodies, before passing the problem on to other explorationists.

Boyd (1967; 1969) considers that the most important step in interpretation is the understanding of the geological problem and that the airborne magnetic survey is one of several tools used to solve it. He suggests that interpretation progresses as follows:

(1) Establish the geological character and tectonic style of the area;
(2) Define the aims of the interpretation and find out what geology may be expected;
(3) Work out the shape, attitude and apparent magnetic susceptibility of the magnetic bodies;
(4) Correlate geometrical patterns of the magnetic bodies with the geological observations and theories and with the magnetic properties and rocks from the area;
(5) Test the magnetic interpretation by field observations; and
(6) Repeat the cycle.

In this thesis the interpretational procedure used goes beyond these conventional methods above and it seeks to extract the "possibilities" rather than the "most probable" from the aeromagnetic data used.

3.1.2 Petrophysics and Interpretation

All anomalies are derived from magnetic susceptibility and remanence of the rocks. Magnetite has by far the highest magnetic susceptibility of the most common accessory magnetic minerals which include ilmenite, pyrrhotite and specular hematite and is usually the most important. As rocks are classified on the basis of their silica content by geologists, it is necessary to derive a relationship between magnetite content and the accepted classification, as shown below in Part A of this Chapter.

To gain an even better understanding of the relationship between geology and aeromagnetic pattern trends and intensities, more detailed knowledge is necessary in relation to:

(a) geological field relationships of magnetic rocks;
(b) depositional environments, (see Stevens et al., 1980; Forbes and Pitt, 1980), as reflected by oxidation ratios and other factors; and
(c) possible metamorphic reactions which affect composition of magnetite, and hence the bulk composition of the rocks.

The concepts related to these factors have been treated below in Part A and they form the basis on which the related anomalies have been interpreted in Chapters 4 and 5.

PART A

AEROMAGNETIC ANOMALIES AND GEOLOGICAL PROCESSES

3.2 The MacDonald/Outalpa Shear Zones: Geological/Geophysical Hypothesis

The two major fault areas of the Olary Province are the MacDonald fault which runs from MacDonald Hill to Brimbowrie Hill Station and beyond, and the Outalpa fault which is developed between Walter-Outalpa Mine and Outalpa Hill. These two faults are regarded as shear zones and geological structural studies have been undertaken in the Adelaidean rocks within these shear zones by Berry (1973); Berry et al. (1978); and Wiltshire (1975). They are prominent features on the magnetic map fig. 4.2 (Chapter 4) and profiles 9160, 9130 and 9390 in fig. 4.9. Analysis of the magnetic characteristics in Chapter 4 led to the development in this Chapter of the geological hypothesis which helps to explain the high magnetic low and positive anomalies within these shear zones.

3.2.1 Geological Explanation

Detailed studies of shear zones in the Lewisian Complex of northwest Scotland by Beach (1976, p. 586-601) showed:

(1) that there were differences in total iron content and variation in the oxidation state of sheared and undeformed samples;

(2) that Fe_2O_3 and FeO attained equilibrium in response to local oxidation conditions (presumably during metamorphism);

(3) that PH_2O was very low during this metamorphism with water certainly mobile on a regional scale when oxidation of the rocks occurred; and

(4) the Fe_2O_3/FeO ratio in shear zones reflects an equilibrium between fluid common to the shear zones and the solid phase in the rock. The temperature, pressure, and composition of this fluid determine the Fe_2O_3/FeO ratio attained in the rock when at equilibrium by oxidation and by depletion or enrichment in the shear zones of either Fe^{3+} and Fe^{2+}.

Attainment of constant Fe_2O_3/FeO ratio within shear zones suggests that equilibrium exists between the rock in the shear zones and fluid phases with a uniform (buffered) Fe^{3+}/Fe^{2+} ratios and lower FeO content than their undeformed equivalents. This Fe^{3+}/Fe^{2+} is also independent of ${}^{a}O^{H}$-) concentration and varies with temperature (Beach, 1976, fig. 10, p. 593). Heimlich (1974) records a similar variation in Fe content in shear zones cutting across amphibolites in the Bighorn Mountain, Wyoming.

Fluids in rocks may move by either grain boundary diffusion or by hydraulic fracturing. It has been suggested that fluid transported along shear zones was accompanied by the mechanism of hydraulic fracturing (Beach, 1976)and that this process causes much of the cataclastic deformation in the zones.

The thermal consequence of metasomatism along shear zones is rapid transfer of heat that results from the movement of large quantities of water. Bailey (1970) has considered the thermal evolution of a volume of water separated from its source region somewhere in the lower crust and points out that after upward transfers, water would be at a temperature above that of its surroundings. Beach (1976) shows isotherms on pressure enthropy and pressure enthalpy graphs for water (c.f. his fig. 11): and also three different geothermal gradients and concludes that both isentropic (slow reversible expansion) and isenthalpic (rapid irreversible expansion) transfers of water upwards through the crust result in water attaining geothermal gradient. In the case of isenthalpic expansion, the temperature of water itself actually rose. He observed that isenthalpic expansion was a property common to all imperfect gases at pressure above the Joule-Thomson inversion (c.f. Denbigh, 1968, p. 120). The maximum pressure on the Joule-Thomson inversion curve for water is about 0.42Pa at about 900°C (Beach, 1976, fig. 11b, p. 597).

Conditions of temperature and pressure reported for the Adelaidean rocks in the Olary Province are 400°C and 0.42Pa and a geothermal gradient of 27°C/km. (Wiltshire, 1975, p. 107; Rutland et al., 1981; and Berry et al., 1978).

Whichever type of expansion occurs geologically, it is inevitable that large volumes of water flowing along shear zones will attain significantly higher temperatures than surrounding rocks only a few kilometres above the fluid source region.

In the Olary Province, the metasomatic activity is not well understood. Spry (1977, p. 6) thinks that the production of muscovite during the second deformational episode could imply large additions of potash and water. Wiltshire (1975, p. 98) and Cobb and Morris (1970) think albite-rich rocks have formed from sodium metasomatism and they predate the second period of deformation which suggests that these albite-rich rocks may have been metasomatized by sodium rich solutions migrating away from granite during the first metamorphic episode, but in the Broken Hill Block albite-rich bedded rocks are thought to be either as a result of sodium rich volcanics or as analcime altered tuffs or sediments or evaporites. Whittle (1949) has also made reference to metsomatism while discussing the Boolcoomata adamellite.

3.2.2 Some Physical relationships between the processes in Shear Zones (a Discussion)

In 3.2.1 it was suggested that metasomatic water accompanying metamorphism in the MacDonald and Outalpa shear zones may have been derived from granites, adamellites, and amphibolites (Cobb and Morris, 1970; Spry, 1977; Wiltshire, 1975), outcropping at Boolcoomata, Walparata, Whey Whey River area, Nine Mile Gate etc. Le Grand (1958, p. 178) has shown that granites yield a soft slightly acidic water that is low in dissolved mineral constituents. Also it was noteworthy that the rather unusual thermal gradient of 37°C/km has been suggested for the Willyama Block rocks and 27°C/km for the Adelaidean rocks (Wiltshire, 1975; Rutland et al., 1978;).

Strain softening and grain size reduction were discussed in Berry et al., (197)8; Flint, (1974); Berry, (1973); and Talbot, (1967). If this were so, the water might have been released during re-crystallization of the rock and subsequently flowed away by focusing in the shear zones. This implies that fluid started from the granites at perhaps a high temperature of about 800°C with fO_2 probably similar to that of biotite-quartz-magnetite. The fluid then moved to a region of about 600°C with fO_2 buffered by hematite-magnetite (Whitten, 1970). Metasomatism that results from this type of situation according to Beach and Fyfe (1972) gives rise to oxidation, and is a general feature of metamorphic rocks. Magnetite content could be thought of as being dependent on the Fe_2O_3 and FeO percentages in a rock and their mutual relations. The author considers the hypothesis here that the thermal history of the magnetite might be a factor in interpreting the magnetization characteristics observed over these shear zones.

Water moving down a thermal gradient will tend to reduce rocks, while water moving up a thermal gradient will tend to oxidise rocks. Elder (1965) and Johnson and Meril (1972) have suggested that water content probably plays an important role in oxidation in nature.

However, they suggested that the oxidation product depended on the water content of the initial material (c.f. Le Grand, 1958).

In all cases, oxidation produces a decrease in the total remanent magnetism. Such drop in NRM intensities are reflected in a corresponding drop in the magnetic anomalies and corrlates well with oxidation (Irving, 1970). Polarities of these anomalies appear to be preserved during this oxidation because chemical remanent magnetization (CRM) produced by oxidation is small (Johnson and Merill, 1972)(c.f. Balsley and Fahey, 1952; and Balsley and Buddington, 1954).

In the present discussion it is considered that the water moved from the granites upwards. Such fluid would cause oxidation and would be capable of leaching out silica.

3.3 Carbonaceous Schists

The following discussion deals with the magnetic characteristics of carbonaceous schists. Special attention is paid to the variation of pyrite/pyorhotite ratios and carbon content of carbonaceous schists. The hypothesis is compared with those obtaining from contemporaneous and younger through to recent carbonaceous formations, about the origin of which more information is available, and this was used to shed light on the depositional conditions of the Proterozoic carbonaceous schists in the Willyama Block.

It is well established that carbonaceous schists give rise to a strong electrical, electromagnetic and magnetic anomalies in metamorphosed Pre-Cambrian terrain. They are frequently met with in Finland, and they have been studied by Marmo (1960), Peltola (1960 and 1968) and Kukkonen et al. (1985). These workers agree that carbonaceous schists, particularly the graphite bearing schists, are well shown in aeormagnetic maps in which the magnetic anomalies due to them curve around the gneissic granites.

They consider that the carbonaceous schists generally originated as metamorphosed products of sapropelic sediments deposited in anaerobic marine sedimentary environments; and that the typical feature is the presence of iron sulphates. They note that in certain areas pyrrhotite predominate and in other parts pyrite may be almost the sole sulphide present. They conclude that as a result of differences in the types of the associated iron the ratio of sulphide to graphite varies, so that every intergrade is found between pure sulphide schists without graphite and graphite schists containing only traces of iron sulphide. Marmo (1960, p. 19) contends the fact that the magnetic anomaly characteristics are related to the fact that the schists are rich in pyrrhotite.

In India at Vagarjunaijarin, according to Murty et al. (1962) the organic carbon content of Pre-Cambrian graphite bearing schists has direct relationship to the content of sulphur and ferrous iron.

In the Broken Hill Block, Steven et al. (1980, p. 29) have commented on the carbonaceous schists and their environment of deposition, particularly their suites 6 and 7 may have been deposited in shallow environment in which algae flourished. Forbes and Pitt (1980) have reached similar conclusions for the Olary Province. Steven et al. 1980) have also established a workable stratigraphy, and using this Isles (1983) has interpreted the magnetic features observed over carbonaceous schists as reflecting the environment of deposition.

Outcrops of magnetic horizons are scarse because they weather easily. Abrupt ending of outcrops has been associated with the "ghost" stratigraphy of Stevens (1978). McIntyre (1978) suggested that these schistose magnetic horizons are probably of stratigraphic layers and the abrupt terminations are due to partial melting and mobilization. On the other hand, Isles (1983) concluded that the graphitic schists may in part be very weakly magnetic but they do not generate any defined magnetic horizons.

As shown on the geology map (fig. 2.3) the schists, where they outcrop, occur in the immediate vicinity of locally exposed gneisses and granites of the Willyama basement rocks and are closely associated with minor quartzites (Wiltshire, 1975).

Although knowledge of the graphite content of the schists is incomplete, enough is known to recognise that there are interesting magnetic features of the carbonaceous schists (Chapter 5). Towards the Kalabity unit to the north of the Olary Province there are abundant chiastolite schists, whereas the Boolcoomata unit contains sillimanite and andalusite in rocks of similar composition (Spry, 1977, p. 19). In addition, chiastolite rarely occurs further south in the Outalpa and Boolcoomata units where its place is taken by andalusite. Spry compared the metapelites of Boolcoomata, Outalpa, Crocker Well and Weekeroo-Walparuta units with those of the northern part of the Broken Hill region (Zone A of Binns, 1964), and concluded from chemical analysis by Joplin (1963) that the schists of the two regions are similar in composition.

In the Olary Province, the schists show varying magnetic responses (5.2-5.4). The graphite bearing Ameroo schists (pws4) are magnetic while the mica plagioclase schists (pws) are slightly magnetic. Whittle (1949, p. 294) refers to migration of elements within the schists encountered by him in the Old Boolcoomata area which suggests that there was migration of elements from one schist fraction to another during the period of strong metamorphism. If this is so, it could be that in schists submitted to strong metamorphism sulphide content increased at the same time as the carbon content, and as also observed by Gernik et al. (1975, p. 97-98) in USSR this increase is accompanied by a similiar increase in the concentration of anorthite in plagioclase and a corresponding decrease in the quantity of micas. This observation agrees with the petrological description of the mica plagioclase schists in the Olary Province by Spry (1977).

3.3.1 Carbonaceous Rocks and the Environment of Deposition

The composition of carbonaceous schists is related to primary sedimentation. Studies on recent carbonaceous sediments have revealed that under marine conditions with sulphate available more sulphides are formed than in fresh water bearing basins of similar environments. This conclusion is supported according to Keith and Bystro (1959) and Degens et al (1957), by sulphur analysis of marine and fresh water shales of Pennsylvania Age as well as modern fresh water and marine muds from Oahu in Hawaii.

Strakhov (1960), reported in Peltola (1968), found that in highly reducing marine environments of exunic sediments on the Black Sea, sulphides are formed in amounts comparable to those of carbon. He also stated that the irregular distribution of pyrite parallels the distribution of organic carbon, both of which increase markedly in the centre of the basin.

Earlier, Strakhov et al. (1959) developed quantitative geochemical methods to determine the conditions for the formation of sedimentary strata to determine the conditions of their formation. According to them, in the rocks of marine origin, the ratio of pyrite iron to residual organic carbon fluctuates between 0.2 to 2.0 but in the majority of cases it is between 0.2 and 0.9. In rocks of continental origin these ratios are 0.03 and 0.06 and in lagoonal between 0.06 and 0.2. The ratio of pyrite iron to residual organic carbon in rocks formed in the same environment varies from region to region, but there is usually a sharp increase in the ratio in the transition from continental to marine rocks, eg, the coal basins of the USSR (Strakhov et al., 1959).

The magnetic response of the schists in the Olary Province varies from high to moderate amplitude anomalies (Chapter 5); if shallow marine environment (Steven et al., 1980; Forbes and Pitt, 1980) of deposition is accepted, it is likely that the ratio of pyrite iron to the residual organic carbon varies from region to region.

In the Olary Province the metamorphic grade decreases towards Kalabity in the north (Forbes and Pitt, 1980) where Spry (1977, p. 19 and pp. 51-52) shows that graphitic rocks are common; and the magnetic record in this area shows moderate to low amplitude anomalies for these schists. This is consistent with the variation of graphite in the schists.

It could be that as the ratio of sulphide to graphite varied, that every integrade is found between pure sulphide schists without graphite in parts of the Boolcoomata, Weekeroo-Walparuta, and Outalpa units and graphite schists containing traces of iron sulphide towards the Kalabity unit.

3.4 Hypothesis for Magnetic Anomalies Due to Granitic Pluton

The purpose of this section is to discuss the hypothesis that could be used to explain reasons for the occurrence of magnetic and non-magnetic granitic types and consider implications for the Olary Province.

Field studies of granitic rocks show a long and complex history of emplacement, involving compositional variations and even mixtures of genetic types (eg, Pitcher, 1975; 1978). Chappell and White (1974; 1976) in the Lachlan zone of Eastern Australia recognise a group of early metamorphically harmonious plutons composed largely of S-type (containing ilmenite) granites which probably originated by melting of metasediments and a later group of metamorphically disharmonious I-type (containing magnetite) plutons derived by remelting deep seated material. Further accounts of the relationship between magmatism, tectonism and crustal site and metamorphic associations are found in Miyashiro (1961; 1967) and Zwart (1967; 1969).

A number of granitic rocks which are exposed in the Olary Province (figs. 2.3 and 2.4) were emplaced during the dying phase of the Olarian orogeny (Glen et al., 1977, p. 139) about 1,520 m.y. (Thomson, 1974, p. 5). The magnetic anomalies caused by the granitic bodies vary in intensity (figs. 4.1, 4.2 and 4.9, flight lines 9130, 9160 and 9390). This has been described in Chapter 5. The following account explains the differences in the magnetic properties of four of these bodies.

3.4.1 Fractional Crystallization and Magnetization of Rocks

Plant et al. (1980, p. B202), working in Scotland, have demonstrated that deeply eroded tonalite intrusions show no magnetic anomalies and they (1980, p. B206) have suggested that the differences in magnetic properties of similar intrusions can be related to the degree of fractionation of similar tonalite parent magma or to different degree of partial melting of source rocks. These differences are emphasized by fractional crystallization during ascent which is responsible for the geochemical variations within individual pluton (Pankhurst, 1979).

If this view is accepted, Beck (1966, p. D115) has suggested a probable fractionation trend in which the melt is progressively enriched with iron as well as water and other volatiles that may account for the magnetization of such rocks. Cooling proceeds from the outside of the body but density causes residual liquid to accumulate substantially above the centre (c.f. Hess, 1960, p. 187-190). Further, Beck suggested that the concentration of volatile material causes progressive oxidation, which in turn causes the ratio of ferric to total iron to increase by as much as six-fold. Primary Fe-Ti oxide begins to form early and continue to form throughout much of the cycle. The magnetic minerals which crystalize early thus are low in iron, especially ferric iron, and hence contain little Fe-oxide. To this he adds that the magnetic oxides may contain comparatively large amounts of cation "impurities" and thus have low values of saturation magnetization. Later crystallization show magnetic minerals that contain higher quantity of Fe-oxides.

This may explain why high magnetic relatively felsic material accumulates near the top of bodies and penetrates the overlying country rock producing a magnetic halo (Beck, 1966). The following comparison made with magnetic granitoids are presented below.

3.4.2 The Chemical Properties of Some Magnetic Granitoids

In the Adironadack Area, New York, Balsley and Buddington (1958) found that the magnetic anomalies could be explained by variations in the iron-titanium oxide minerals and the lithology of the rocks. They concluded that the positive magnetic anomalies over granites and gneisses depend on the ratio of magnetite and to iron-titanium oxides which in turn depend on the degree of oxidation of the iron.

McGarth (1970) used data obtained by Martin (1966) to explain the observed magnetic intensity variations within Pokiok and Charlotte batholiths in New Brunswick in terms of multiple intrusions or partial metasomatism.

In this section the results of the chemical analysis of some magnetic granites around the Boolcoomata adamellite are discussed and related to the magnetic properties of the rocks. This work could have been a complete study on its own.

TABLE 3.1

Oxide Content of Magnetic Granitoids Plotted in Fig. 3.1

Silica SiO_2	Sodium Oxide Na_2O	Pegression Values
74.82	4.41	4.40
73.13	3.84	3.85
72.23	3.89	3.55
74.03	4.06	4.14
73.23	3.49	2.88
71.84	3.23	3.42
72.60	4.30	3.67
73.30	3.71	4.03
72.73	3.74	3.71

Silica SiO_2	Magnesium Oxide MgO	Regression Values
74.2	0.22	0.22
73.14	0.35	0.31
72.24	0.47	0.36
74.04	0.28	0.26
72.23	0.25	0.31
71.84	0.42	0.39
72.60	0.20	0.34
73.70	0.26	0.28
72.73	0.36	0.34

Table 3.1 Coninued

Silica S_1O_2	Fe_2O_3: $FeO + Fe_2O_3$	Regression Values
74.82	0.58	0.30
73.14	0.64	0.52
72.24	0.53	0.64
74.04	0.54	0.40
73.23	0.63	0.51
73.23	0.63	0.51
71.84	0.50	0.69
72.60	0.30	0.59
73.70	0.65	0.45
72.73	0.31	0.58

Silica S_1O_2	Titanium Oxide	Regression Values
74.82	0.11	0.79
73.14	0.18	0.16
72.24	0.22	0.21
74.04	0.14	0.12
73.23	0.16	0.16
71.84	0.23	0.23
72.60	0.13	0.19
73.70	0.07	0.14
72.73	0.23	0.18

Table 3.1 Continued

Silica SiO_2	Calcium Oxide CaO	Regression Values
74.82	0.39	0.39
73.14	0.49	0.43
72.24	0.40	0.45
74.04	0.39	0.41
73.23	0.48	0.43
71.84	0.46	0.46
72.60	0.38	0.44
73.70	0.36	0.42
72.73	0.52	0.44

Silica SiO_2	Potassium Oxide K_2O	Regression Values
74.82	3.96	3.83
73.14	4.66	4.76
72.24	4.83	5.27
74.04	4.42	4.26
73.23	5.01	4.71
71.84	6.21	5.49
72.60	4.36	5.07
73.70	4.50	4.45
72.73	4.89	4.99

Table 3.1 Continued

Silica SiO_2	Ferrous Oxide FeO	Regression Values
74.82	0.45	0.49
73.14	0.55	0.69
72.24	0.85	0.80
74.04	0.60	0.59
73.23	0.55	0.68
71.84	0.75	0.65
72.60	0.78	0.76
73.70	0.60	0.62
72.73	1.10	0.74

Silica SiO_2	Ferric Oxide Fe_2O_3	Regression Values
74.82	0.63	0.87
73.14	0.96	0.75
72.24	0.86	0.69
74.04	0.70	0.82
73.23	0.95	0.76
71.84	0.75	0.66
72.60	0.34	0.72
73.70	1.10	0.79
72.73	0.50	0.72

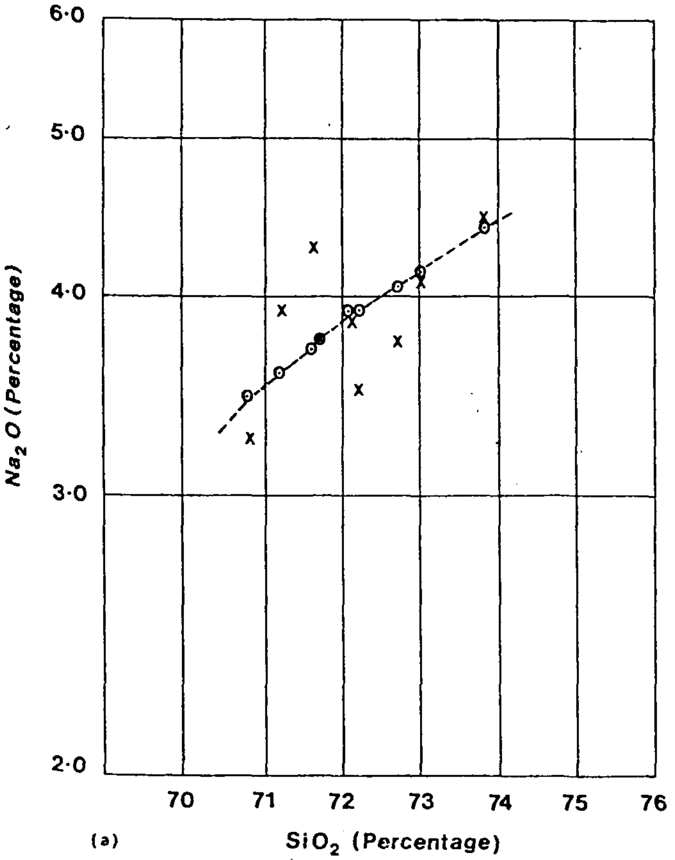
Table 3.1 Continued

Silica SiO_2	$FeO + Fe_2O_3$	Regression Values
74.82	1.08	1.28
73.14	1.51	1.44
72.24	1.61	1.52
74.04	1.30	1.35
73.23	1.50	1.43
71.84	1.50	1.56
72.60	1.12	1.49
73.70	1.70	1.38
72.73	1.60	1.48

TABLE 3.2

Correlation Coefficients Between the Contents of Certain Oxides and Silica of Granitoids

Oxides	Correlation Coefficient of Magnetic Granitoids
CaO	0.380
Na_2O	0.760
NgO	0.520
K_2O	0.760
FeO	0.510
Fe_2O_3	0.250
TiO_2	0.770
Fe_2O_3: $(FeO + Fe_2O_3)$	0.860
$(FeO + Fe_2O_3)$	0.370



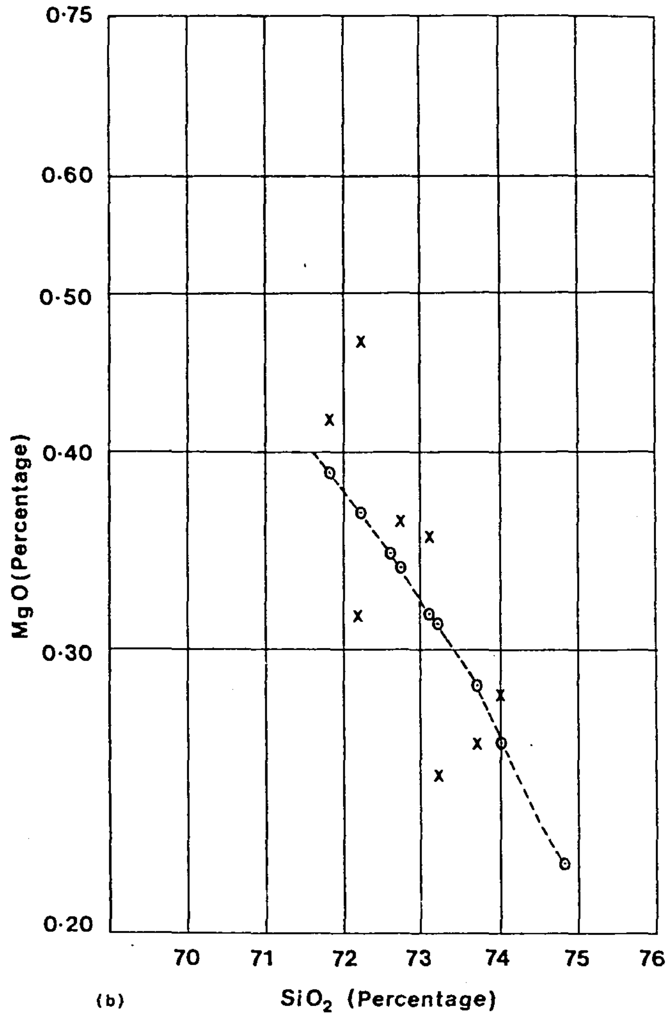
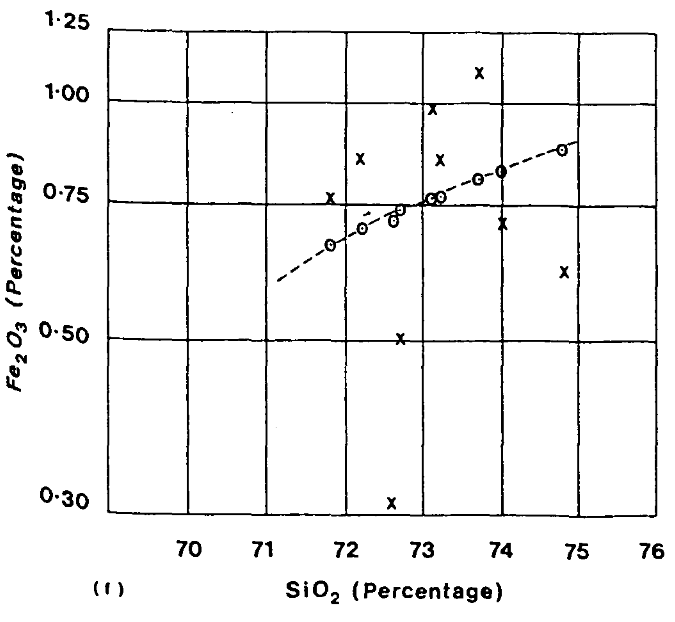
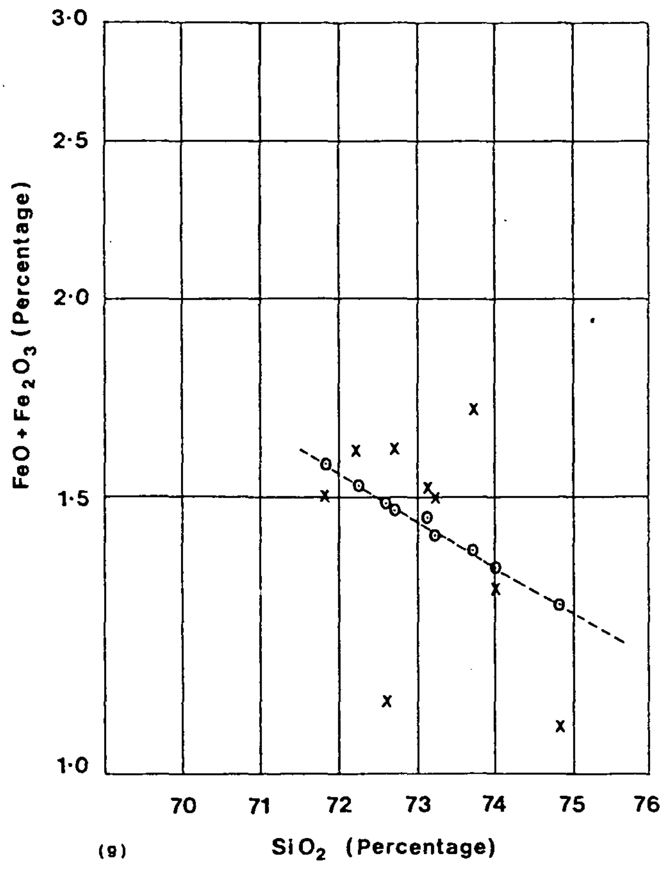
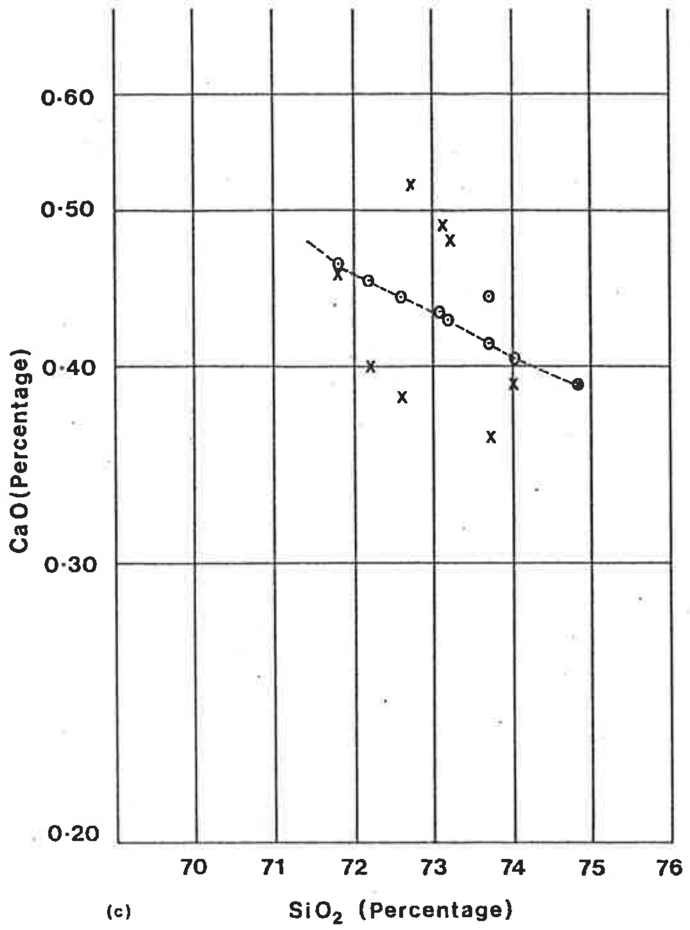
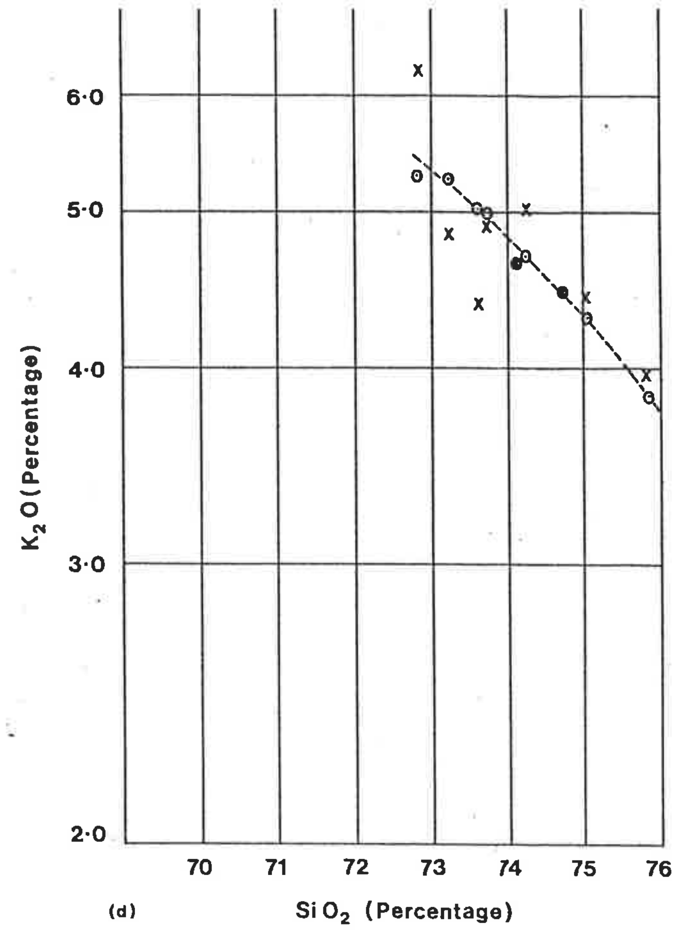


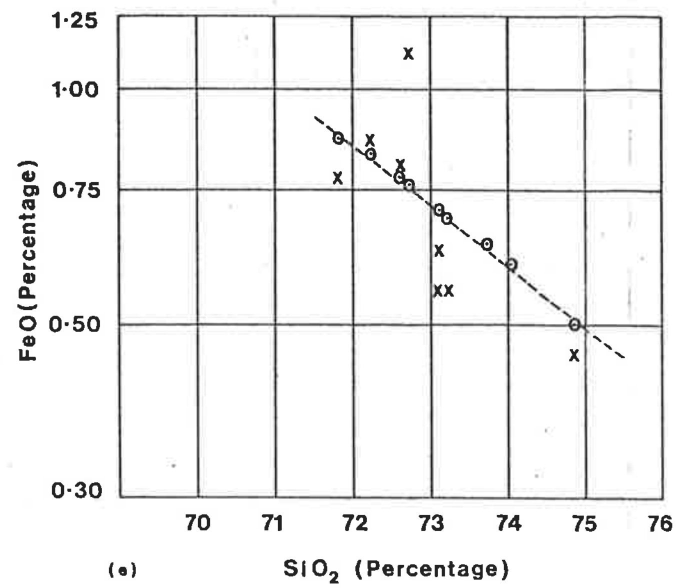
Figure 3.1 Contents of Na_2O(a), MgO(b), CaO(c), K_2O(d), FeO(e), Fe_2O_3(f), FeO+Fe_2O_3(g), Fe_2O_3/FeO+Fe_2O_3(h), T_1O_2(i) in Granitoid rocks as a function of S_1O_2 content.

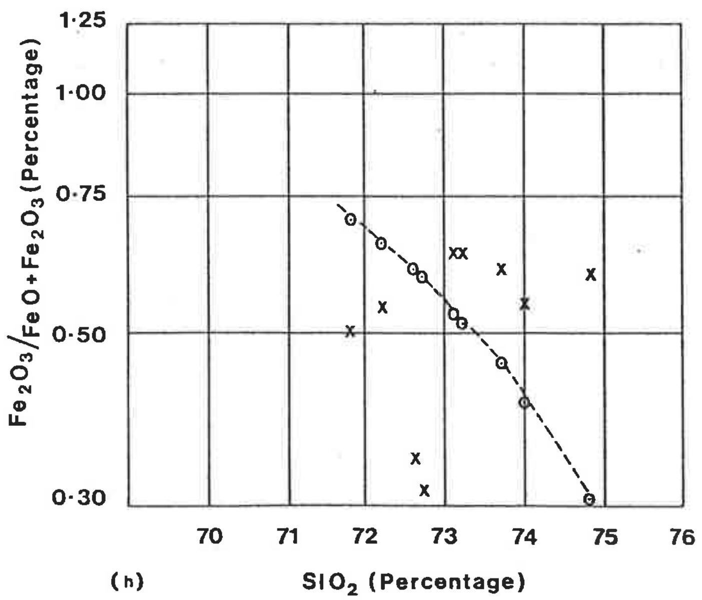


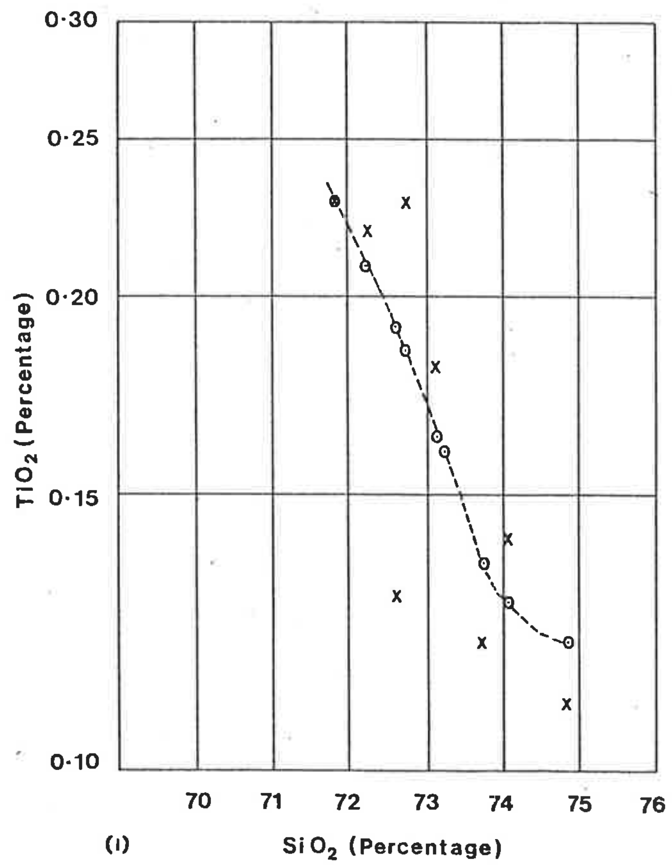












LEGEND:
x Original Data
o Regression Line

Fig. 3.1: CONTENTS OF Na_2O(a), MgO(b), CaO(c), K_2O(d), FeO(e), Fe_2O_3(f), FeO+Fe_2O_3(g), Fe_2O_3/FeO+Fe_2O_3(h), TiO_2(i) IN GRANITOID ROCKS AS FUNCTION OF SiO_2 CONTENT.

The chemical analysis (see Table 3.1) of some of these magnetic rocks which were carried out by Spry (1977; Table 15) were used to relate magnetic responses and the composition of the granite. The regression values obtained using the method outlined in Johnston (1972, p. 14-18) were plotted using a logarithmic scale (fig. 3.1). The oxide of sodium, potassium, calcium, magnesium, ferric iron, ferrous iron and titanium have been plotted against SiO_2 (fig. 3.1). Soda and potash, which crystalize as feldspars congregate in a narrow cluster of points showing greater (in comparison to other oxides in the figure) correlation with silica (see also Table 3.2) and are probably independent of the degree of magnetization of granitoids. Magnesia and lime show moderate to low correlation and a diverse grouping of the clusters of points (fig. 3.1) and there is a lack of coincidence of the mean regression line. This could characterise the non-dependence of the magnetization of this type of rock on the silicate portion of the rock (see Percherskiy, 1967, p. 1970).

Iron occurs in silicates, particularly biotite and hornblende, and in oxides, mainly in magnetite, ilmenite and hematite. FeO is perhaps the principal component in the dark minerals, and together FeO and Fe_2O_3 in the iron oxides. Fe_2O_3 unlike FeO shows no clear correlation with silica (Table 3.2). Reduction in the correlation coefficient of 0.260 shown in the table between two of them could indicate that Fe_2O_3 is much more dispersed in the silicate than FeO, as an isomorphous mixture and forms iron oxides-magnetite, and hematite, the crystallization of the latter depending to a small extent on the basicity of the rock, (because hematite is stable under oxidising conditions), but more on other factors, particularly oxidation potential causing the variation of the plotted points. The total iron content FeO and Fe_2O_3 confirms this speculation as its correlation coefficient is also low (Table 3.2). The apparent disparity of the individual correlations of FeO and Fe_2O_3 could not be attributed primarily to variations in total iron content in the source magma, but to the distribution between ferric and ferrous forms as determined by the oxidation regimes in the magma. This factor depends however, on the thermodynamic environment of crystallization, which in turn is related to the tectonic environment of emplacement.

If oxidation of the ferrous iron has taken place, it will be reflected in the ratio of Fe_2O_3: (FeO + Fe_2O_3) (Jaeger and Joplin, 1954, p. 9; McIntrye, 1980) which is also plotted against silica in fig. 3.1. There is a fairly high correlation coefficient of 0.860. One possible explanation for this could be that the Fe_2O_3 is concentrated in the iron oxides and this ratio remains constant in them, instead of being dispersed as an isomorphous mixture in either (biotite or hornblende etc) and hence does not form a discrete mineral. The mean of the ratio Fe_2O_3: (FeO + Fe_2O_3) decreases rapidly with increasing silica (SiO_2) from the different rock outcrops (fig. 3.1). It ranges from 1.56-1.28. Since the ratio is indicative of the oxidation state of ferrous iron (Jaeger and Joplin, 1954, p. 9; McIntyre, 1980) it could then reflect the variation in oxidation potential of the different rocks.

The correlation coefficient for TiO_2 with silica is nearly the same as the FeO; and is considerably higher than Fe_2O_3; Fe_2O_3: (FeO + Fe_2O_3) and total iron (FeO + Fe_2O_3), (Table 3.2). As TiO_2 oxides are generally more soluble in hematite than in magnetite, percent of TiO_2 in the hematite increases rapidly. However, in the physiochemical environment of oxidation of iron biotite, the only oxides are rutilohematite rutile (Balsley and Buddington, 1958). So in this instance following Jaeger and Joplin (1954) and Pecherskiy (1967, p. 1970-1973) it is suggested that the TiO_2 varied with silica as the temperature at which the rocks were formed, and that FeO, Fe_2O_3 and TiO_2 form a series of mineral assemblages that are in part dependent upon the intensity of oxidation which is in part dependent upon the composition of the system and temperature and pressure at which the minerals form. This suggestion implies that titanium is concentrated in the silicates particularly in biotite, and not in magnetite and therefore is not significant in the magnetization of these rocks (opp. cit.)

Oxygen content is different in rocks formed in different depths. Among the rock component elements, iron is most sensative to differences in oxygen content (partial pressure) in the surrounding medium. Depending on the condition of this medium iron can either assume a ferrous or ferric form. Consequently, Balsley and Buddington (1958), have suggested that depending upon the degree of oxidation, the iron, even where its total quantity is nearly the same in the different granites, may be present in one as femaghastingsite with magnetite predominant over ferric ilmenite and the rock has a positive magnetic anomaly, and in the other is more iron rich hornblende (ferrohastingsite) with ferrous ilmenite predominant over magnetite and a negative anomaly is observed.

This suggests that magnetic anomalies observed on these granitoids reflect the influence of oxidation. Thus, crystallization of oxides of iron-titanium spinels intermediate in composition between magnetite-ulvospinel and hematite-ilmentie might have occurred.

As the oxidation progressed, the spinel phases became involved in an increase in the number of vacanies in cation lattic sites which in turn seemed to have effect on the magnetite properties (c.f. Kastura and Kushiro, 1961).

This, of course, is speculative. More geochemical and chemical data are needed to substantiate the claim. Magnetic susceptibility measurements have not been employed in this experiment; for the reasons offered later in this Chapter, viz, measurements of magnetic susceptibiity and remanent magnetization are often carried out on a relatively small number of intrusions and, as a rule, those available are unrepresentative because the diverse assemblages of rocks making up the outcrop may not be sampled. The magnetic field on the other hand gives a picture analogous to statistical averages of the magnetization of the intrusion.

3.5 Concluding Remarks

In conclusion, it can be stated that the discussion on the geological/geophysical hypothesis of rocks and their subsequent application in Chapters 4 and 5 to geologic problems will undoubtedly be of great value to helping unravel some of the problems of interpretation of geophysical data. The cases cited here are but a few cases of similar applications which are only as representative of the type of problems that can be tackled. Many other problems can be tackled as a more complete picture of the geological principles and informations are built up.

Magnetite content of metamorphic rocks is affected not only by their original composition and manner of formation but by the type of metamorphism to which they are submitted. The magnetite content can only either increase or decrease during metamorphism. According to some authors, the magnetite in rocks may become unstable during regional metamorphism. It is probable that the P,T, fH_2O, FO_2 prevailing during metamorphism are the critial factors influencing the stability of magnetite.

Many of the rock types of the Olary Province have undergone regional metamorphism. Originally they were sedimentogenic, or volcanogenic and some even palingenetic, so that the condition of metamorphism probably also had a great significance for the occurrence of magnetite.

PART B

PROCEDURE AND ANALYSIS OF ANOMALIES

3.6 Four Dimensional Modelling

Although the interpretation of aeormagnetic survey has become highly specialised using various computer techniques, their main aim has been in determination of depth to basement beneath the sedimentary cover. This is what is commonly done in petroleum exploration where one is attempting to map sedimentary basins. As a consequence the high cost of computer processing will not be a serious draw back. In mineral exploration one may wish to obtain other geometrical estimates like width, location and more especially, contrasts in addition to the depth of determination.

It should be stressed, however, that not too much reliance should be placed on purely mathematical interpretations, however complex and involved the computer program. Geophysical interpretation can never be completely automated and a good interpretation will always depend on the interpreter having good understanding of the geology of the area and a full grasp of the applications and limitations of the mathematical techniques being used.

This view has been aptly expressed by Harbaugh and Merriam (1966) in the following extract **".... while computers are not necessarily labour saving devices in geology, they can be regarded as 'intelligence amplifiers' which have great potential in extending an individual's thought processes."**

The advantage of using computers to solve these problems lie in the speed of computation, the accuracy that can be obtained and the flexibility of models that can be treated compared with graphical ("direct") techniques. It is safe to say that in the 1960's and early 1970's many of the models of obvious significance in computer implementation were not employed because of lack of available facilities. However, at about the time computer application became an accepted thing in geophysical modelling, emphasis in interpretation of aeromagnetic data shifted towards the "indirect" approach to interpretation.

3.6.1 Computer Methods of Aeromagnetic Interpretation

Automatic interpretation analysis is becoming very important in easing the drudgery of tackling large volumes of data (3.6). Most of these operate along profiles, and they use the computer to locate and analyse individual anomalies. These include:

(a) Computer-depth profiling techniques in which the depth estimates are made along digitized magnetic profiles using a single geometry or multi-geometry causative bodies (Johnson, 1969; McGarth and Hood, 1970; Hartman et al., 1973; O'Brien, 1972; Nandy, 1971; Rao et al., 1973; Won, 1981; Jain, 1976; Kitty, 1983; and Ku and Sharp, 1983). The interpreter must relate the profile to a contour map, decide which models are valid and which should be discarded or modified, and proceed to a final synthesis over the whole area. In this the computer has not replaced the interpreter, and particular care must be taken to choose the right parameters in setting up the processing of a particular set of data, and allow for the strike direction of the magnetic body.

(b) The next method is the computer curve fitting technique in which a three dimensional geometrical model is derived by an optimization technique. In this the best fit anomaly is calculated to fit a set of gridded data in a horizontal plane. This is more difficult to achieve. McGarth and Hood (1973) have developed a method, and Bhattacharyya (1978) has reviewed the topic. Teskey (1978), in Reford (1980), may have developed the most successful routine to date. A form of inversion referred to as magnetic susceptibility mapping has been developed (Paterson, 1974). By this, the magnetic data, digitized and gridded at an appropriate interval, is used to calculate the susceptibility of an equal number of vertical prisms whose upper edges form the ground surface.

(c) Another technique which has been developed in recent years is the interactive computer graphics technique which utilizes a curve fitting method. In this case the interpreter may communicate interactively with the computer through a cathode ray tube display and a light pencil to modify the interpretation (see Ogawa and Tsu, 1976).

In their lucid account on computer application in geophysics, Spector and Parker (1979, p. 535) summarised the major obstacles in the application of the various "indirect" procedures described above. According to them the obstacles are described as follows:

(a) the data must be carefully edited in advance;
(b) there is a problem in defining background or regional levels;
(c) two-dimensional causative bodies are often assumed (and may not be appropriate);
(d) a very high degree of manual interaction is often required to synthesize the results into plausible geology; and
(e) the high cost of computer processing versus manual or graphical methods must be considered.

Most of these points will be commented on in Section 3.6.2 while discussing the iterative scheme used in this thesis.

3.6.2 Calculation Method Used in this Research Project

In this thesis an iterative optimization procedure is developed which enables a relatively unskilled interpreter to obtain a geologic picture from aeromagnetic data. The form of rock bodies which give local deviations from the regional magnetic field has been calculated using a method akin to the curve-fitting technique of the iterative scheme and its mathematical background is described in Appendix C.

It was simple to use. Magnetic data of interest was read into the computer or transferred from the appropriate data file and initial values were automatically determined there from using the classical or direct method (a feature adapted from Won, 1981). Routine ZXSS from the University of Adelaide's Computing Centre IMSL Library was then used. Five parameters were determined, viz, susceptibility, dip, depth, width, and the centre of the causative body. The determination of "zero level" (Appendix A) was deliberately left as a point at which the interpreter interacted with the process, because the interpretation of magnetic anomalies depended considerably on the zero level selected (see also Parasnis, 1966, p. 36; Rao and Babu, 1980, p. 1004; Powell, 1967; and Koulomizine et al., 1970).

Initially, a zero "zero level" was used, depending on the difference between the calculated and the observed values, then the interpreter decided on the value of the "zero level". With experience, a degree of proficiency was attained in fixing the zero level. This method has been used and tested by geologists who found that it gave results which proved to be of valuable help in interpreting aeromagnetic maps.

3.6.3 Method of Magnetic Interpretation Used in This Area

The interpretation of the magnetic map is a variable process, involving the correlation of information from different kinds of sources, and building from this a picture based on the magnetic results, but controlled and checked by the geological and other geophysical data.

The procedure in this thesis started with the small scale 1:250,000 and 1:100,000 (c.f. Appendix A) aeromagnetic map because, until the pattern of big anomalies is understood or at least observed, it is difficult to pick out and attach significance to the smaller, but often as important, features above them.

The interpretation fell into the following stages:

(1) An unbiased study was made of the pattern of the anomalies on the magnetic map. At this stage only the minimum amount of geological knowledge was used. The grouping of anomalies was considered quite independently of the geological division so that this might be regarded as an almost purely physical division into magnetic zones or units.

(2) This large pattern of the magnetic areas (eg, Zone A Chapter 4) and the non-magnetic areas (eg, Zone E Chapter 4) was then compared with the geological map and was found to correspond fairly closely with it.

(3) After this comparison of the large features had been made, the anomaly pattern was studied again, this time with more attention being paid to the geological evidence; the main boundaries and the main faults, suggested by the magnetic map, were picked out and a closer correlation made with the geological map.

In all these stages, the emphasis was on the pattern of the anomalies and, although no analysis of the individual anomalies was attempted, it was necessary to know the nature of the anomalies produced by different shaped bodies.

(4) The process of interpretation then progressed to the stage of examining individual anomalies and the following matters were considered:

(a) The magnetic interpretation and the known geology were compared and where there were discrepancies, both were examined in an attempt to find out the causes of the differences;

(b) The boundaries of various small magnetic bodies were marked out and related, when possible to the structural pattern of the area;

(c) Detailed correlation between the geological and the magnetic maps was then attempted. In this stage individual anomalies were analysed and use was made of the iterative scheme developed in this thesis (Appendix C, and 3.6.2).

(5) In this last stage there was a continual attempt to build up a consistent geological picture and to compare the results within the context of the geological/geophysical hypothesis in 3.2 - 3.5.

Although the physical part of the magnetic interpretation concerns the examination of the shape and pattern of the magnetic anomalies, much of the interpretation is closely related to geological thinking and it is important to know as much about the geology as possible.

Indeed, one of the most difficult problems facing the interpreter of a magnetic survey is to understand the geology and grasp the root of the geological problems which have to be solved. Only by doing this can the interpreter make the most of the results available and be sure of contributing as much as possible to the solution of the geological problems.

An adequate geological knowledge of the area concerned can also help as the anomalies can be most usefully expressed in terms which the geologists can understand and use. Often no final choice can be made but the interpretation indicated the likely corresponding geological features which simplifies the follow up work of the geologist. The decision as to the significance of the anomalies and inferred structures was made easier both by understanding the geological information required and by using the outcrop information available (figs. 2.3 and 2.2).

Sometimes an awkward geophysical problem may have been solved already by the geologists (fig. 2.4; and Rutland et al., 1981) or may be solved easily when the geology in the adjacent areas is known (Steven et al., 1980; Isles, 1983; Tucker, 1975; 1983; McIntyre and Wyatt, 1978).

Anomalies were analysed to determine the depth of the magnetic basement of the Adelaidean metasediments in Zone E using the horizontal slope distance method (H.S.D.), Peter's method, and Sokolov's method, which are published in the literature. A correction was made for the anomalies when strike is not at right angles to the flight line direction and all the values are integrated in the tie line idealized profile section shown in figure 4.9.

A method developed by Linsser (1971) was used for these profiles. The method starts with the definition of the simplified model which could be a two-dimensional infinite body or step model. The theoretical magnetic effect of the model is determined with a set of initial parameter estimates obtained from the observed magnetic field values, and then compared with the observed magnetic field values by optimized least square methods. Bosum, reported in Linsser (1971, p. 181) has shown that the method yields good results if applied to mapping of shallow bodies which is the case with Adelaidean system sediments. In addition, he demonstrates that it can be used successfully along profiles where rocks with higher magnetic susceptibility have irregular dip due, for example, to folding as encountered in the Adelaidean system sediments.

3.6.4 Nature and Origin of Magnetic Anomalies

In the absence of drilling or other geophysical data to offer control on the limitations that could be attached to the causes of observed anomalies, general considerations of geologic reasonableness often form a necessary alternative. This can often be derived in the case of magnetic methods from factors that affect rock magnetism.

Four factors which have been widely accepted as affecting rock magnetization are:

(1) Mineral composition and size;
(b) geologic history;
(c) disintegration; and
(d) concentration.

(1) Mineral Composition and Size:

Magnetization depends not on the total iron present but on the type and quantity of magnetic mineral present. The magnetite content chiefly determines the magnetization of rock formations. Fine-grained powders have lesser susceptibility than powder of coarse grain, but may have greater remanent magnetization.

(2) Geologic History:

The thermal and mechanical events which occur in connection with igneous intrusions, regional metamorphism, tectonic movements, machanical and chemical concetrations - distintegration and lightning are likely to affect the magnetic properties of the rock. (c.f. Heiland, 1946; Grant and West, 1965). Coercive force, remanent magnetization and susceptibility are individually dependent on temperature. A correct analysis of thermal relations is difficult since the same ferromagnetic body may not exist after changes in temperature and another body may have been formed with a different structure and chemical properties. The intensity of magnetization decreases first slowly and then more rapidly with temperature until a critical "Curie Point" is reached.

When a magnetic rock is heated to the Curie Point and then cooled, its magnetism reappears at a much lower temperature. This is known as "temperature hysterisis magnetization" and occurs particularly in pyrrholite (Heiland, 1946).

(3) and (4) Disintegration and Concentration:

Disintegration and concentration of rocks is effective both chemically and mechanically. Since the trivalent iron is more paramagnetic than the bivalent iron, rock magnetism is much reduced when magnetite disintegrates to limonite or hematite. Conversely, on contact and dynamic metamorphic processes, the iron in sedimentaries and other rocks are transformed from the bivalent into the trivalent form, so that concentrations of magnetic minerals are found near intrusive bodies. The mechanical effect of disintegration is to break up the magnetic particles and produces a more fine-grained material, and secondly, increases the spacing of particles and path reluctance. Both result in a decrease of magnetization and increase of the remanent effect of fine-grained material. Concentration of magnetic material has the opposite effect of disintegration.

Structural forces may change the position of magnetic bodies in the course of their geologic history (Chapters 4 and 5). When they have acquired remanent magnetization, their overturning may produce abnormal apparent polarization (Chapter 4).

3.7 Remanent Magnetization and Susceptibility Measurements

The presence of remanent magnetism, often in a direction different to that of magnetism induced by the present earth's field, complicates magnetic interpretation. Where it is present, body dip and magnetization directions become inseperable unless one of them is known (Sutton and Mumme, 1954; Powell, 1963; and Green, 1960). In consequence, predictions of the general aspect of magnetic bodies show that dip and susceptibility contrasts are at variance with the actual dip and susceptibility contrasts. This is because remanent magnetization can give rise to very strong anomalies many times greater than those that can be explained by induced magnetism and can be in different directions to that of the earth's field.

If the shape of the magnetic body is known it is often possible to calculate the remanent magnetization required to produce the observed anomaly.

The presence of remanent magnetization makes the standard curves (fig. A.2) adapted from Roux (calculated for induced magnetization) inapplicable to the body forms for which they were computed and so it is important to establish whether remanent magnetization is present.

This was done by using these standard curves; thus, if an observed anomaly on any profile cannot be matched against any of the standard curves then it is most probably produced by a body with remanent magnetization or is not a dyke or sheet. Similarly, remanent magnetization was suspected if the body suggested by the model curves was inconsistent with reliable geolgical controls.

There are several ways in which rocks may acquire remanent magnetization. Most rocks could easily remagnetize as a result of deep burial in the earth's crust, since under such conditions the temperature might stay at consierably high values for long periods. This causes reorientation of magnetic grains as a result of pressure which is evidently very likely to have occurred in old rocks of Pre-Cambrian age. Other causes, or a combination of causes, are:

(a) Chemical formation or crystallization in the magnetic field; and
(b) Magnetic grains tending to be oriented in the direction of the magnetic field during sedimentation.

The subject of remanent magnetization of rocks and its application in the interpretation of magnetic anomalies has been extensively treated in geophysical literature (see for example, Girdler and Peter, 1960; Books, 1962; Gaucher, 1965; and Strangway, 1965).

The remanent magnetization and susceptibility were not determined. In the Olary Province bedrock is often covered by a thin layer of Quarternary soil (Campana and King, 1958). The bedrock is exposed here and there and the frequency of outcrops varies considerably from one area to the other (c.f. Plate 1). Thus geological observations and susceptibility measurements cannot be carried out at regular intervals. It is seldom possible to employ expensive excavation or drilling in areas covered by soil (see Tucker, 1975).

For the above reasons, the geographical distribution of the rock samples from the area will be statistically unsatisfactory. A sample cannot be considered either a systematic sample or a true random sample of the investigated area. In this case it is difficult to estimate the representativeness and accuracy of the results objectively.

Geologic bodies are usually magnetically very inhomogeneous. Even in the most homogeneous rocks the relative dispersion of susceptibility of rocks exists (see for example, Puranen et al., 1968). In other words, there is not much to be gained from high accuracy in measurements on individual samples. Rather, an abundant and representative series of samples should be taken from the geological body to be investigated. Furthermore, Pullaiah et al. (1975) have concluded from their experiments that probably very little, if any, remanent magnetization can survive into amphibolite facies metamorphism. They arrived at this conclusion as a reasonable compromise between theory and experiment, taking into account the chemical changes that are likely to occur. In addition, they suggested that any remanent magnetization that does survive is bound to be only a small fraction of primary remanent magnetization that was carried by grains with exceptionally high blocking temperature. In addition, Isles (1983) and Tucker (1983) have reported that from the susceptibility and remanent magnetization measurements in nearby Broken Hill it is safe to regard the effect of remanence of Willyama type rocks as negligible.

However, Tucker (1983) has shown that hand held susceptibility meters (Geoinstrument JR8) could be used on surface exposures in the Broken Hill area to obtain fairly good measurements of the magnetic susceptibility of the rocks of the Willyama Complex. According to him the weathering has not significantly altered the rock susceptibility at the surface. It is to be noted, however, that during weathering, there is production of maghematite; development of secondary low oxidation magnetic phase and a reduction of primary magnetite domain size. All these contribute to reduce the susceptibility values measured (Ellwood, 1981).

There is no doubt that the confidence level generated by these observations arose from their comparison with similar measurements obtained from their fresh rock samples from drill cores and cuttings which, according to Tucker (1983), are abundant in the area as a result of increased exploration activity.

These fresh rock samples and drill cutting are not readily available in the Olary Province to encourage any good statistical comparisons.

At the outset of this project it was hoped that the author would benefit from both the geological mapping by the South Australian Department of Mines and Energy (SADME) and the exploratory drill holes planned for the area by ESSO Australia Limited. Unfortunately, these two projects were stopped because of the economic reversals experienced by the company and the resignation of the Project Geologist, Mr G. Pith, from SADME.

The situation did not improve until this project had been completed. Even then, the company was not particularly very keen to give out information when their exploration program was still under way.

It is nevertheless of interest to know the susceptibility of the rocks within an area being surveyed, if only to recognise the difference in magnetic intensities and how they would then relate to the specific rock types.

The relevance of thermal enhancement, below the Curie point, of viscous magnetization and magnetic susceptibility has been discussed differently by Dunlop (1974) and Pullaiah et al. (1975). According to Dunlop enhancement of susceptibility might be restricted to a small temperature range near the Curie point, for multi-domain grains. Viscous build-up of magnetization occurs even for small temperature increases, with the rate of enhancement increasing with temperature (Pullaiah et al., 1975). On a large scale, a general increase in heat flow values across a region, with corresponding increase in regional vertical temperature gradients in the crust (allowing for heat production), might produce a "magnetic-thermal enhancement" effect on crustal structure. For a given type of magnetic grain structure, the peak of thermal enhancement would occur at shallower depths for larger vertical temperature gradients in the earth.

Although it is speculative at the present, certain structures may experience a maxiumum magneto-thermal enhancement in the crustal temperature conditions associated with the Willyama Complex rocks and produce intense magnetic field anomalies. Glen et al. (1977) have noted that the Province was characterised by a high geothermal gradient and concluded that a general correlation existed between metamorphic grade and height in the structural succession (see also Rutland et al, (1981). Wiltshire (1975) had earlier reported the unusually high temperature gradient associated with the Willyama rocks in the Olary Province. According to his estimates a value of 37°/km formed a reasonable value of the Willyama block rocks, while 27°/km characterised metamorphic grade observable within the Adelaidean type sediment.

CHAPTER 4
MAGNETIC INTERPRETATION - PART ONE

4.1 Preliminary Interpretation

Aeromagnetic surveys carried out over the Willyama rocks in New South Wales (adjacent to the area now being described) show that they are either strongly magnetic or have distinctive linear magnetic horizons. By way of contrast, the Adelaide sediments of the Adelaide Geosyncline are mainly non-magnetic although there are a number of magnetic horizons in the western portion of the Geosyncline and a few very strong anomalies occur over low-grade iron formations.

The aeromagnetic contour map, fig. 4.2, can be divided into zones of similar magnetic character and texture (fig. 4.1) as follows:

ZONE A: An area of linear high amplitude anomalies which are located along structures referred to as the MacDonald and the Outalpa Corridors (or shear zones). The anomalies extend northwest beyond the area of no outcrop in the vicinity of Whey Whey River area; their trend is mostly northwest.

ZONE B: This zone is made up of linear broad anomalies whose trend is predominantly northeast.

ZONE C: This zone has moderate amplitude circular anomalies bounded by linear contours in a sinous region of low magnetic values along the Bimbowrie-Doughboy area and part of Whey Whey River area; it includes some anomalies with a northeast trend.

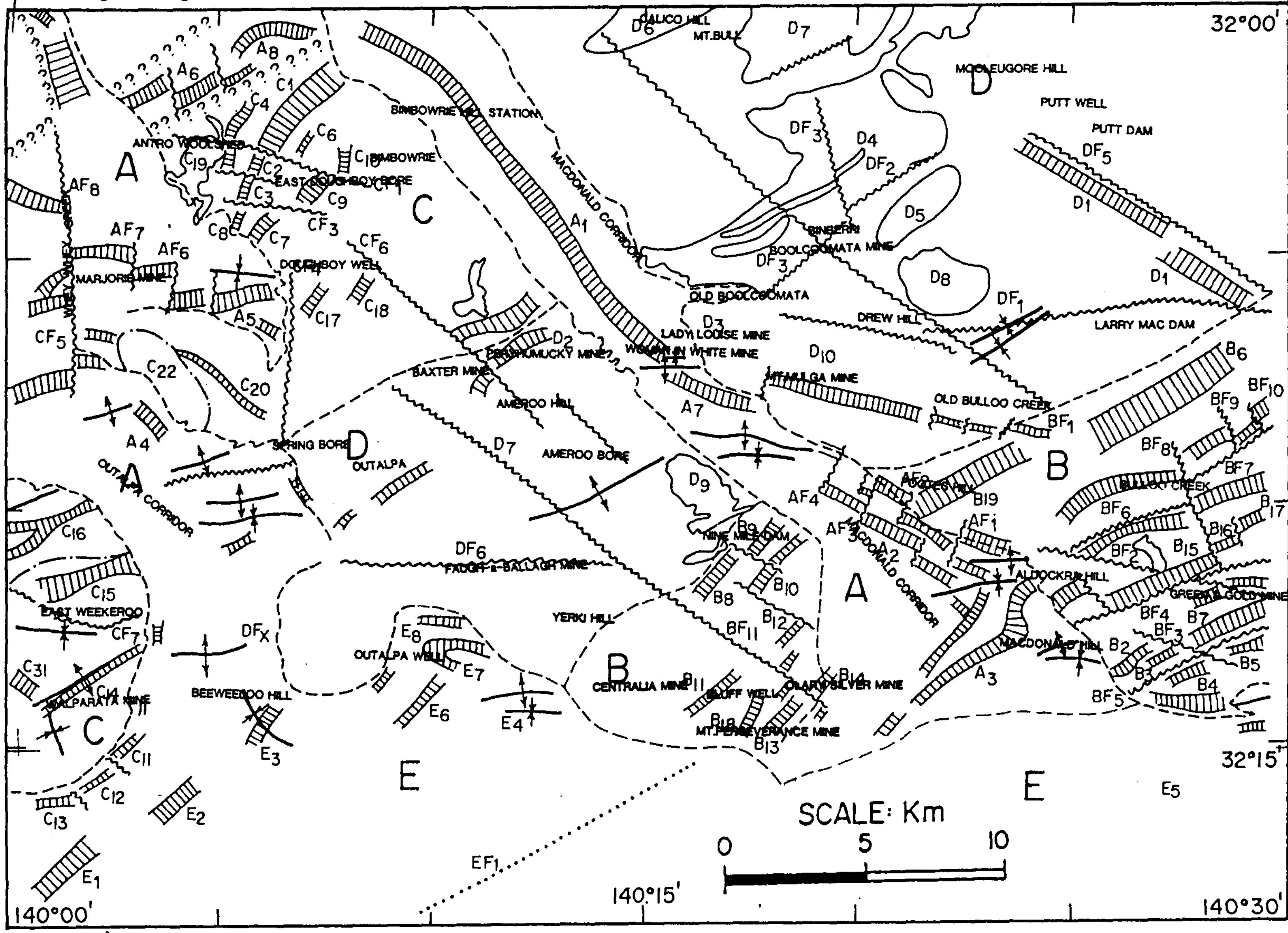
ZONE D: This zone is marked by moderate to low amplitude complex shaped anomalies covering Ameroo-Old Boolcoomata areas.

ZONE E: Is an area of low amplitude broad anomalies in the southern edge of the map area.

These Zones clearly correspond to the broad geological division of the area. Zones A and E correspond to the Adelaidean metasediments whiles Zones B, C and D relate to the Willyama basement rocks. The lowest and the highest intensity anomalies recorded during the survey occur over the Adelaidean sediments. The MacDonald and the Outalpa Corridor group (Zone A) contrast sharply with the low gradient southern

OLARY PROVINCE – Aeromagnetic Interpretation
Hologeological Map

Fig. 4.1



Interpreted magnetic horizon

Major zone boundaries

Geological and Interpreted fault trends

Outline of granites and pegmatites

? Inferred magnetic boundaries

Fold axis

Synclinal axis

Linear structure

see also 1:50,000 map at the pocket.

Figure 4.2 The aeromagnetic map of the Olary Province (photo reduced version of the 1:50,000 contour map).

edge of the map area (Zone E). These will be discussed in this Chapter as they present different lithology and structure from the generally magnetic high grade metamorphic basement rocks (Zones B, C and D) which are treated in Chapter 5. The Willyama basement covers a large portion of the study area.

It is possible to relate some of the anomaly groups with rock divisions which have been mapped by geologists, as well as to extrapolate geologically to areas in which rock exposures are too few to correlate directly. The Adelaidean sediments were found to have three magnetic horizons, viz:

(1) The Burra Group.
(2) The Umberatana Group (Braemar iron formation).
(3) The Wilyerpa Formation.

While the Willyama basement rocks are more difficult to describe about briefly, it can be said that most rock types are magnetic although the iron formation is different and not continuous.

This Chapter sets out to discuss the results of the application of the method described in 3.6.3 in Zone E to outline structure, distribution of magnetic horizons and the determination of depth to magnetic basement. In addition to discussing the structure and distribution of the magnetic units in Zone A, special ideas about interpretation will be touched upon.

4.1.1 ZONE E - Magnetic Anomaly Pattern

One of the striking features on the magnetic contour map (fig. 4.2) is the Zone E area to the south of the survey area which has long wavelength anomalies with open rounded contours recorded over sequences of thick non-magnetic sediments that overlie deep magnetic basement. Zone E correlates very well with outcrop of mainly Adelaidean rocks that have accumulated within the Adelaide Geosyncline.

A series of magnetic anomaly profiles of north-south aeromagnetic flight tie lines (c.f. fig. 4.9) have been prepared to investigate the magnetic anomaly pattern of this Zone. The southern part of the magnetic profiles are almost flat and slope gently southwards. Only a few small anomalies, eg, flight tie line 9160 ($A_{1.0}$ - $A_{6.0}$); 9130 ($A_{0.0}$ - $B_{0.0}$ and $C_{5.5}$ - $C_{7.0}$); 9170 ($A_{1.0}$ - $A_{7.0}$); 9260 ($A_{0.0}$ - $A_{7.5}$); and 9330 ($A_{3.0}$ - $A_{7.0}$) superimposed on the gently sloping regional magnetic gradient were recorded in this area. The amplitude of these anomalies vary between 50 gammas and 120 gammas.

The flatter parts of the profile occur over Adelaidean sediments. The small sharp anomalies are produced by magnetic horizons in the basal conglomerates and silty grey siltstones of the Burra Group. It is probably the siltstones within this Group that are responsible for these anomalies but there is no outcrop to check it (c.f. Tucker, 1983, p. 97).

There are four approximately oval shaped anomalies along the southern limit of the Willyama Block (figs. 4.1 and 4.2) with amplitudes of 300 gammas to 900 gammas which strike parallel to the basement margins; eg, see E_3 figs 4.1 and 4.9, 9170 ($B_{2.5}$ - $B_{6.0}$); Centralia Mine E_4, 9240 ($A_{0.0}$ - $A_{7.0}$); and Outalpa Well E_7 and E_8 (fig. 4.1). Anomalies E_1 and E_2 are probably due to lenses within the underlying Burra Group rocks. Two other anomalies on flight line 9330 ($B_{0.0}$ - $B_{3.5}$, fig. 4.9) are attributed to Wilyerpa Formation basal quartzites or siltstones which have been folded.

The asymmetrical shaped E_2 and E_3 (fig. 4.1) magnetic anomalies were interpreted using the two dimensional model of the iterative scheme (3.6.2, Appendix C) see figure 4.3 and Table 5.1. In the case of E_3 the magnetic contour outline is "apple" shaped (figs 4.2 and 4.1) and covers a synclinal structure of Burra Group rocks.

An ill-defined trend is provided by some contour chevroning. This shows a northeast trend EF_1 (fig. 4.1). The cause of the anomaly is not known but it cuts across the strike of the geological strata and is probably due to a dyke. It is shallow because of the sharpness of the contours. Other magnetic anomaly features of similar trend have been mapped in Zone A, A_3 (fig. 4.1) and B_{13}, B_{14}, and B_6 in Zone B (figs 4.1 and 5.1).

4.1.2 Depth Determination in Zone E

A number of long wavelength anomalies which can be related to the underlying magnetic basement can be seen on the north-south flight tie line profiles across the map area. Depth estimates made using the standard methods (maximum slope, Peter's method, Sokolov's method and half slope method, 3.6.3) are listed in Table 4.1.

The depth indicates that the magnetic basement slopes westwards towards Weekeroo area. The magnitude of the broad anomalies and the depth at which they are produced suggest the possibility that they represent topography of the magnetic basement. Because the Adelaidean system sediments and the Cainozoic cover are virtually non-magnetic the sources of the magnetic anomalies are interpreted to be the Willyama type basement within the Zone E magnetic pattern and indicates a depth

TABLE 4.1

DEPTH ESTIMATES (KM BELOW FLIGHT LEVEL)

Tie Line Profile Number	Location of The Anomaly on the Flight Data Record (Northings)	Methods Used and Depth Values Obtained		
		Horizontal Slope Distance	Peter's Method	Sokolov's Method
9090	6431420-6434928	1.0	0.8	0.5
9100	6413479-6415934	0.7	0.6	0.6
9100	6438422-6440453	0.5	0.3	0.2
9110	6412545-6416025	1.1	0.6	0.3
9110	6438545-6440531	0.7	0.3	0.2
9120	6440240-6449705	0.6	0.7	0.3
9130	6436948-644039	1.3	1.2	?
9140	6420112-6423136	0.8	0.7	0.3
9140	6424673-6426605	0.5	0.3	0.2
9151	6412732-6415205	0.8	0.6	0.4
9160	6416436-6419933	1.3	0.6	0.5
9160	6436911-6438411	0.8	?	?
9170	6412426-6416423	1.9	?	?
9180	6438045-6439563	0.5	0.3	0.2
9240	6413810-6418880	1.9	1.4	?
9310	6415738-6419287	1.2	0.6	0.3
9310	6424703-6426731	1.0	0.8	0.4
9360	6418839-6423302	1.2	0.7	0.6
9441	6412843-6418844	1.9	1.3	1.1
9451	6412229-6418225	1.6	1.3	0.8
9461	6412323-6417501	1.5	1.1	0.8
9472	6412339-6416820	1.6	1.3	0.8
9480	6412310-6417844	1.7	1.6	0.9
9491	6412010-6416034	1.3	0.9	0.6

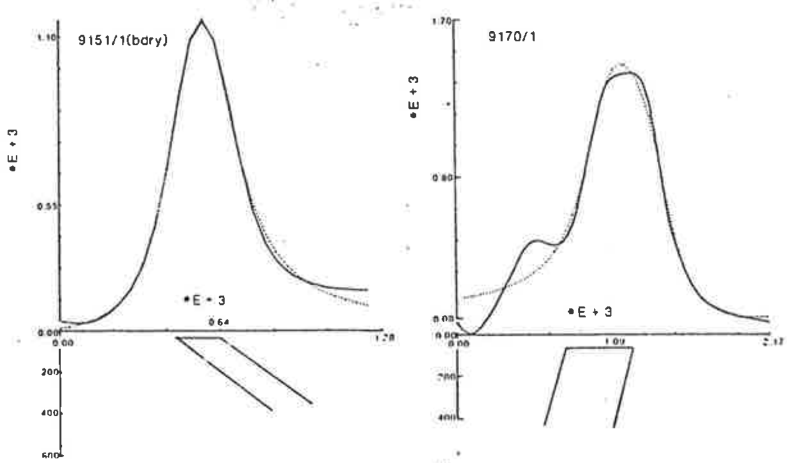


Figure 4.3 Two-dimensional magnetic modelling of the anomalies in Zone E. Solid lines are observed fields; dotted lines are calculated fields.

of about 1.8 kilometers. The distribution of depth suggests that the basement may form a broad synclinal fold here.

4.2 ZONE A - Magnetic Anomaly Pattern

Strong, well-defined magnetic anomalies are centred over the MacDonald and Outalpa Corridors. The crest of these anomalies exceed 2500 gammas in several places and nearly everywhere reaches 2000 gammas. Together with the complimentary "low" the anomalies have a relief of nearly 5000 gammas.

Within the MacDonald Corridor the anomalies can be traced from the Bimbowrie Hill Station southeastwards to the Aldockra Hill Station where they turn sharply southwestwards. The magnetic anomaly is essentially one anomaly with several superimposed highs and lows. The linearity of the anomaly is best shown in the Bimbowrie to Old Boolcoomata Hill Station areas.

Within the Outalpa Corridor near the Spring Bore area the anomaly appears erratic in both trend and intensity.

The magnetic features are made up of:

(1) A northwest trending positive and negative pattern A_1 (fig. 4.1) which dominates the map; towards the southeast, separate areas of high anomalies form broken bands A_2. Contrasting strike directions exist between A_1 and A_2 on the one hand and the northeast trending A_3 in the southeast near Aldockra Hill.

(2) Other high amplitude anomalies are A_4 whose bands are not as sharp and conspicuous as are found in the MacDonald Corridor or in the Whey Whey River area A_5.

(3) Furthermore, there exists a uniform magnetic gradient pattern immediately adjoining these high frequency anomaly patterns (forming a visual effect of the high gradient patterns).

On figure 4.9 examples of the anomalies taken from the original digital data, viz: flight tie lines 9160 ($A_{9.0}$ - $B_{4.0}$ and $C_{1.5}$ - $C_{5.0}$); 9130 ($C_{5.5}$ - $C_{7.5}$) and 9330 ($A_{8.0}$ - $B_{5.0}$ and $D_{3.0}$ - $E_{0.0}$) confirm that the anomaly is a major multi-peak anomaly consisting of an alternating positive and negative peaks.

4.2.1 Sources of the Zone A Magnetic Pattern

In the MacDonald and Outalpa Corridors the geologic sub-division are as follows:

(1) Cainozoic Cover;

(2) Wilyerpa Formation;

(3) Umberatana Group; and

(4) Burra Group (figs. 2.2 and 2.3).

The magnetic anomaly pattern delineates in precise detail the distribution of the glacial and interglacial Umberatana Group rocks containing the Braemar iron formation and the structures in which it was involved. The anomalies fall into two groups: those caused by the magnetic strata of the Braemar iron formation and those produced by the Umberatana Group structures. As can be seen from the magnetic map pattern, a well defined overturned fold A_3 which on the geology map can be seen to be overturned and is shown by the dips calculated from the magnetic anomalies to be overturned (figs. 2.3 and 4.2) is present in the southeastern part of the map area around Aldockra Hill. Inspection of the map (figs. 4.1 and 4.2) show that the northeast trend is observed sub-parallel to trends in Zone B (5.2 and 5.3) and in Zone E (4.1.1). Irregularities in the course of the crest of the anomalies reflect the mapped folds within the MacDonald Corridor (Fig. 2.3, and Wiltshire, 1975, fig. 4.34b).

Within the Outalpa Corridor the anomaly pattern faithfully depicts the structure in the Spring Bore Well area, and outlines the anticline and syncline (shown on fig. 4.1 as fold axes, see also fig. 2.3) in the Umberatana Group rocks (Berry et al., 1978).

The discontinuous nature of the magnetic anomalies are partly because of facies changes (Forbes and Pitt, 1980, Dunn et al., 1971; and Whitten, 1970) and partly because of faulting AF_1 - AF_4 (fig 4.1 and Pitt, 1971a) and partly because of oxidation of the magnetite as discussed by Whitten (1970) and Miriam (1962).

The elongated shape of the anomalies suggest the trace of a dipping sheet-like mass. As the profile is steeper on its southern side the dip is to the north (assuming induced magnetization). The amplitudes are high probably because of the increase in the modal iron oxide in the Upper part of the Umberatana Group rocks (c.f. Lindsley et al., 1966, p. 584) and secondly, increase in the dip of the horizons as you go up the stratrigraphic height. The width and spacing of the anomalies vary as well as the amplitude suggesting the sources are closer together and irregular and shallow.

4.2.2 The Magnetic Model Analysis in Zone A

The main concern of this study is the geologic meaning of the observed magnetic anomalies, and in 4.2.1 a qualitative correlation was demonstrated between the magnetic anomalies and the rocks observed on the surface. This section will consider quantitative aspects.

To investigate the structures of the Adelaidean rocks within the Corridors, two-dimensional modelling has been prepared along the north-south flight tie line profiles until the computed effect of the model matches reasonably well with the observed magnetic anomaly profiles. The computed and the observed magnetic anomaly profiles together with the geologic model are presented in figures 4.4, 4.5, 4.6 and 4.7, and the values of the calculated susceptibilities, depths, widths, and locations are summarized in Table 5.1. Although numerous anomalies appear on the aeromagnetic profile, only a few of them are suitable for interpretation. For an anomaly to be used, the anomaly must be magnetically "clean" in the sense that the effect of the neighbouring anomaly is negligibly small.

The anomalies show that a series of shallow magnetic sheets dipping at angles of approximately 80°N, 50°N, 60°N, 30°N and 15°N, and having susceptibilities of 0.013cgu, 0.003cgu, 0.006cgu, 0.022cgu, and 0.02cgu respectively, satisfy the observed anomaly profile (see also 4.2.1 and Lindsley et al., 1966, p. 548). These dip values are consistent with geologically recorded dip values and demonstrate that the results obtained are consistent with geological observation, and the magnetization may be due to induced magnetization and no remanence along bedding.

The profiles in figure 4.5 (A_1 and A_2 figure 4.1; Table 5.1) are muted in comparison with the above values from the Outalpa Corridor. The magnetic horizons dip at angles 60°N, 30°N, 60°N, 30°N, 60°N and 90°N. A good agreement with those recorded on the geology maps of the area by Pitt (1971a) and Wiltshire (1975) is again observed. Their effective susceptibilities are 0.015cgu, 0.009cgu, 0.030cgu, 0.054cgu, 0.016cgu, 0.033cgu, and 0.022cgu respectively. This shows the same order of magnitude but different from those recorded on the anomalies across the Outalpa Corridor.

Other modelled anomalies belong to the Adelaidean sediments in the Whey Whey River area. (A_5, figure 4.1). The figures obtained (fig. 4.6, Table 5.1) are in the same order but with shallow dipping horizons. In the vicinity of the Aldockra Hill, the northwest trending magnetic rock A_2 (fig. 4.1) dip northwards at angles estimated from the magnetic data (fig. 4.7; Table 5.1) at ($B_{1.5}$ - $B_{2.5}$ figure 4.9, 9390 tie line) 60° and ($B_{2.5}$ - $B_{3.0}$) 60°. After the turn to the northeast trend A_3 (fig. 4.1) they dip southeast at estimated angles of 65° ($A_{9.0}$ - $A_{9.8}$ figure 4.9; 9390 flight tie line) 65°; ($A_{9.8}$ - $B_{0.8}$) 50°

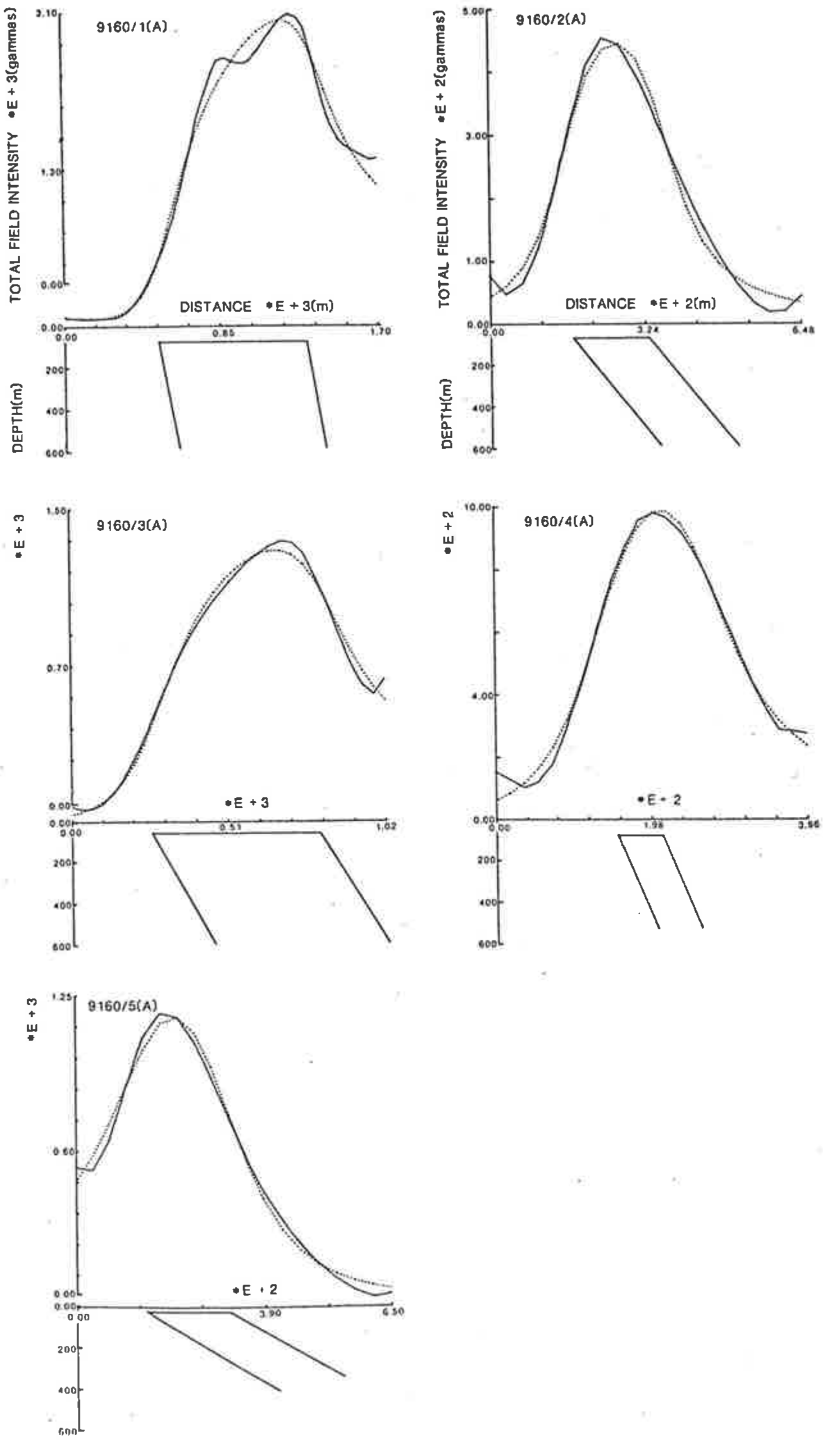


Figure 4.4 Two-dimensional magnetic modelling of the Outalpa Corridor magnetic highs. Solid lines are observed fields; dotted lines are calculated fields.

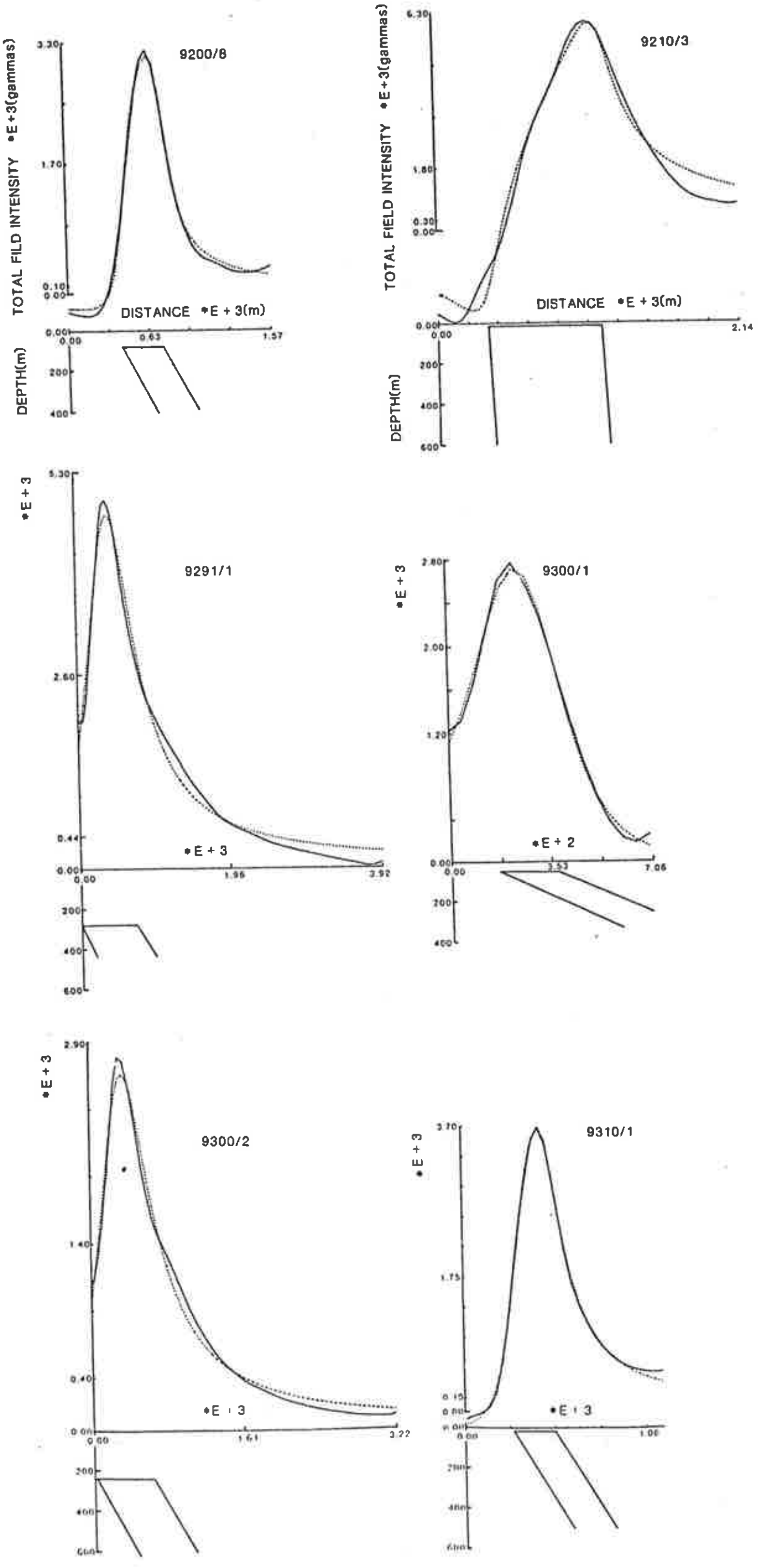


Figure 4.5 Two-dimensional magnetic modelling of the MacDonald Corridor magnetic highs.

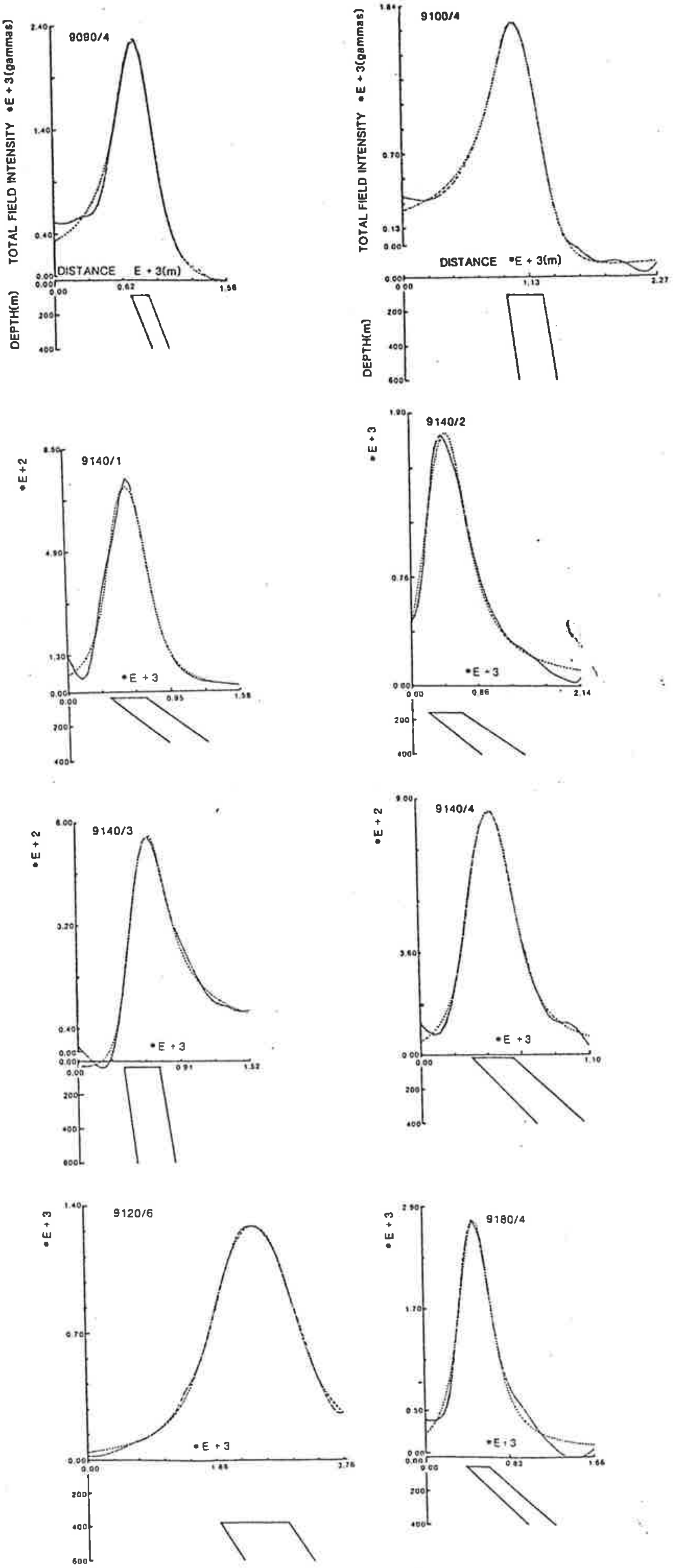


Figure 4.6 Two-dimensional magnetic modelling of other areas of Upper Ptoterozoic Adelaidian metasediment cover rocks' magnetic anomaly.

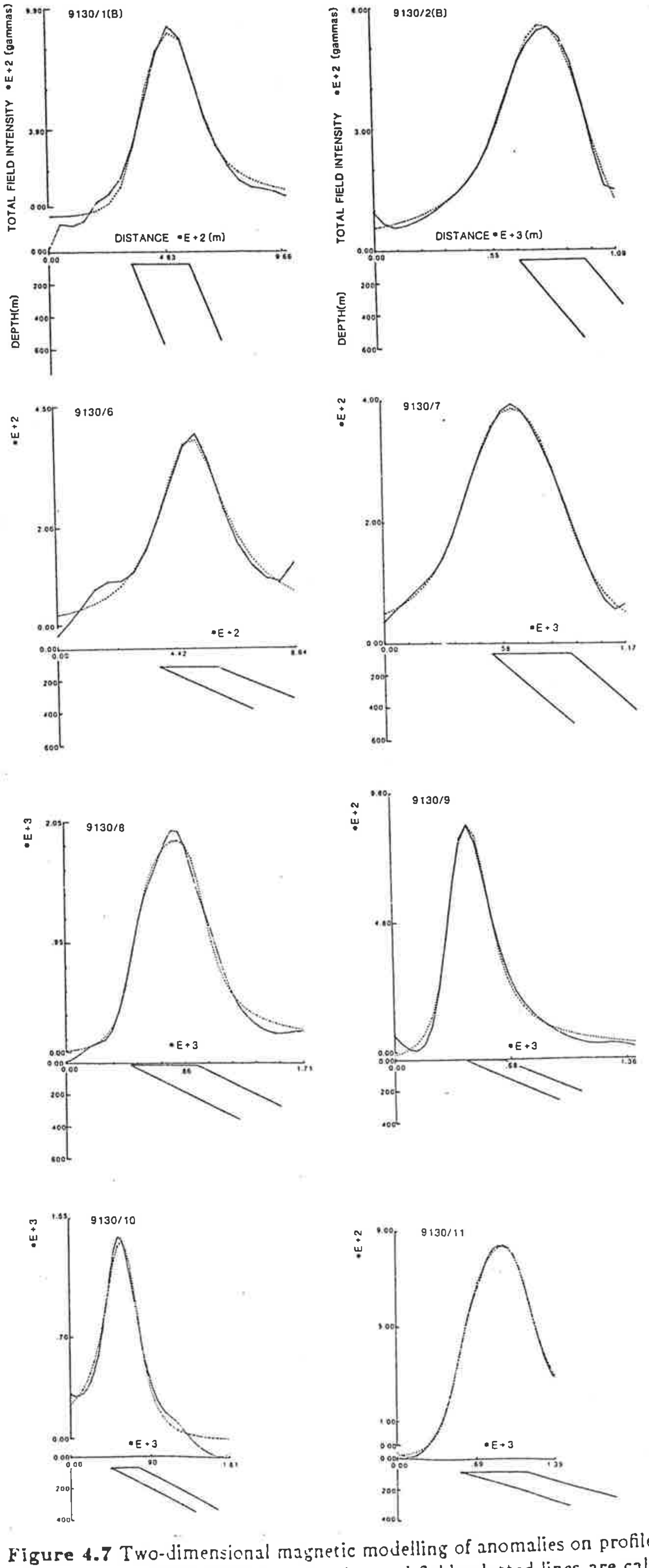


Figure 4.7 Two-dimensional magnetic modelling of anomalies on profiles 9160, 9130, 9240, 9330, 9320 and 9390. Solid lines are observed fields; dotted lines are calculated fields.

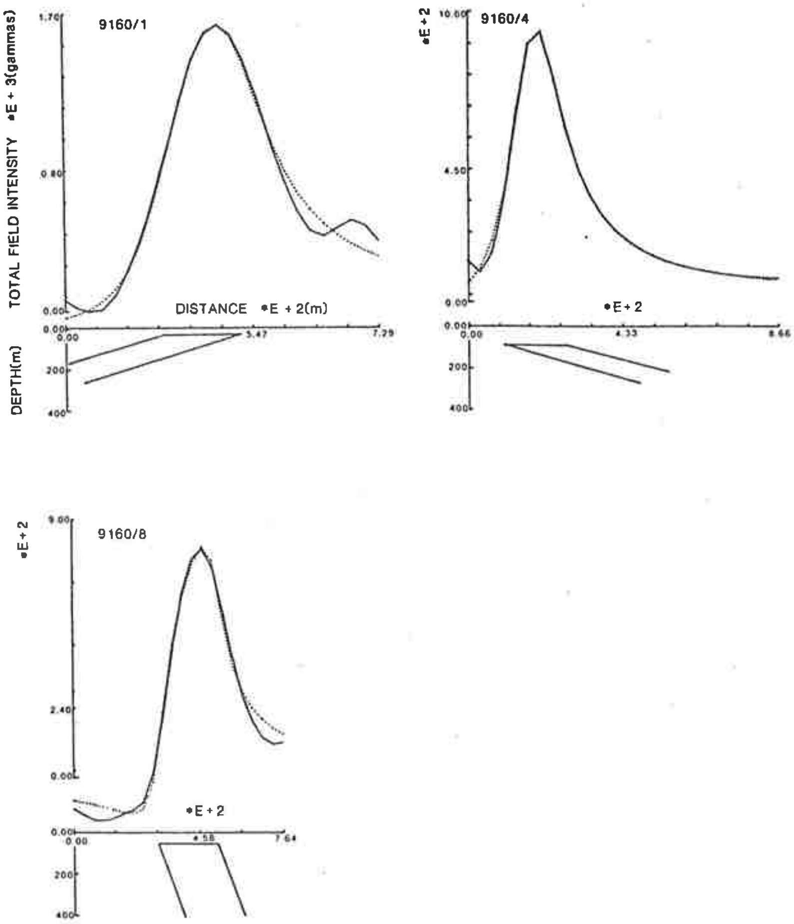


Figure 4.7 Two-dimensional magnetic modelling of anomalies on profiles 9160, 9130, 9240, 9330, 9320 and 9390. Solid lines are observed fields; dotted lines are calculated fields.

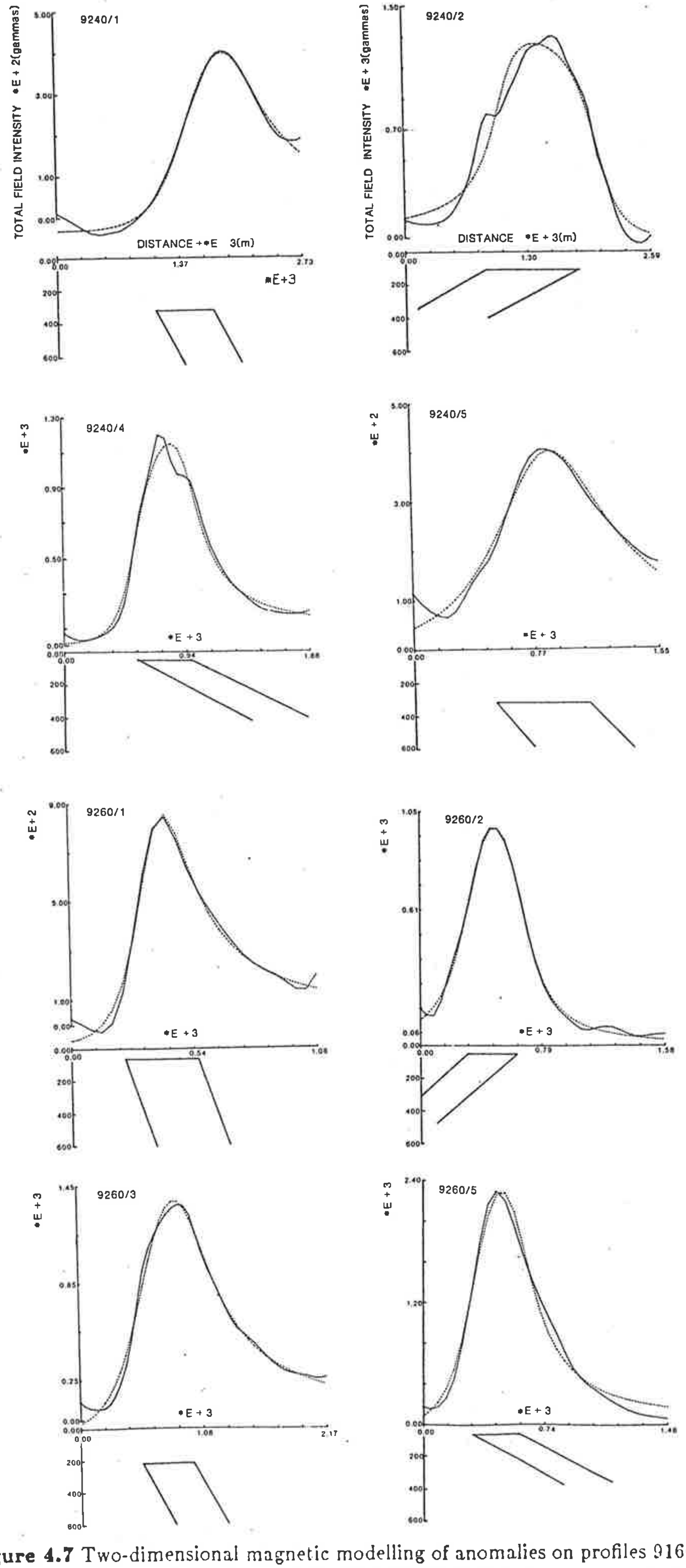


Figure 4.7 Two-dimensional magnetic modelling of anomalies on profiles 9160, 9130, 9240, 9330, 9320 and 9390, Solid lines are observed fields; dotted lines are calculated fields.

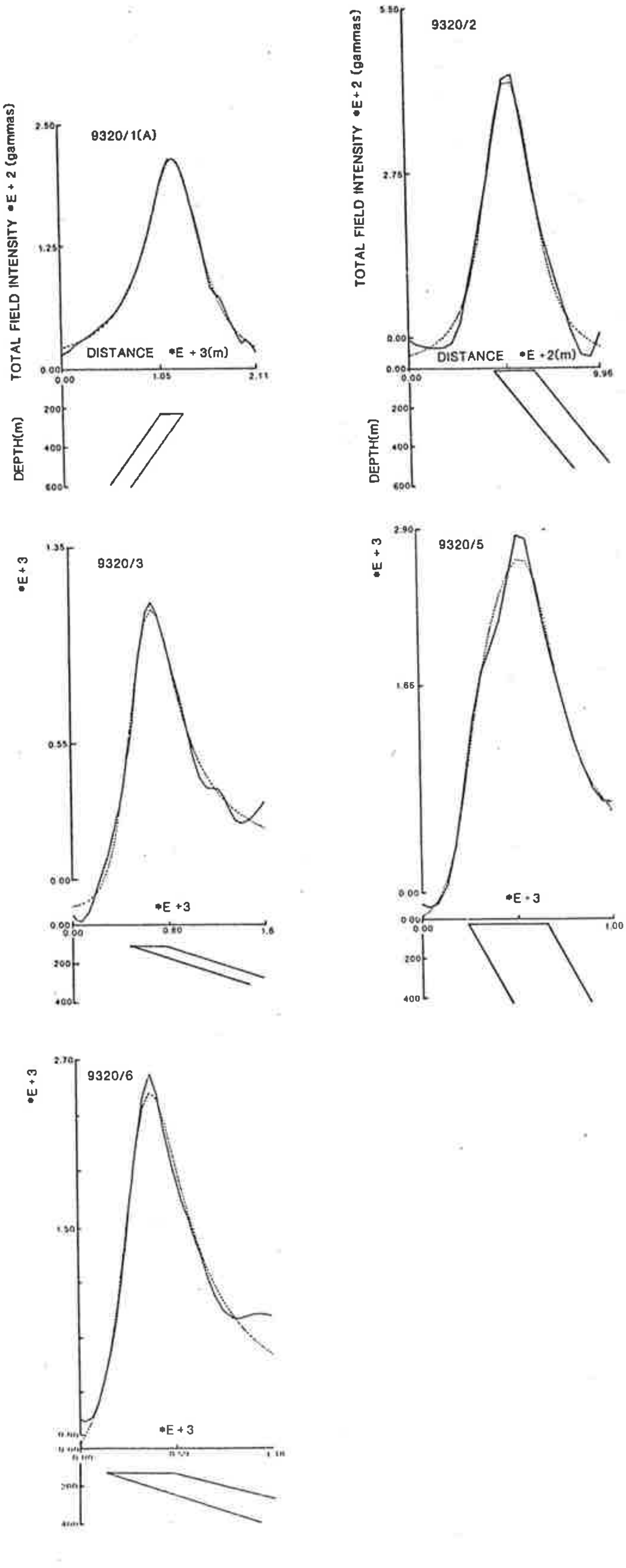


Figure 4.7 Two-dimensional magnetic modelling of anomalies on profiles 9160, 9130, 9240, 9330, 9320 and 9390, Solid lines are observed fields; dotted lines are calculated fields.

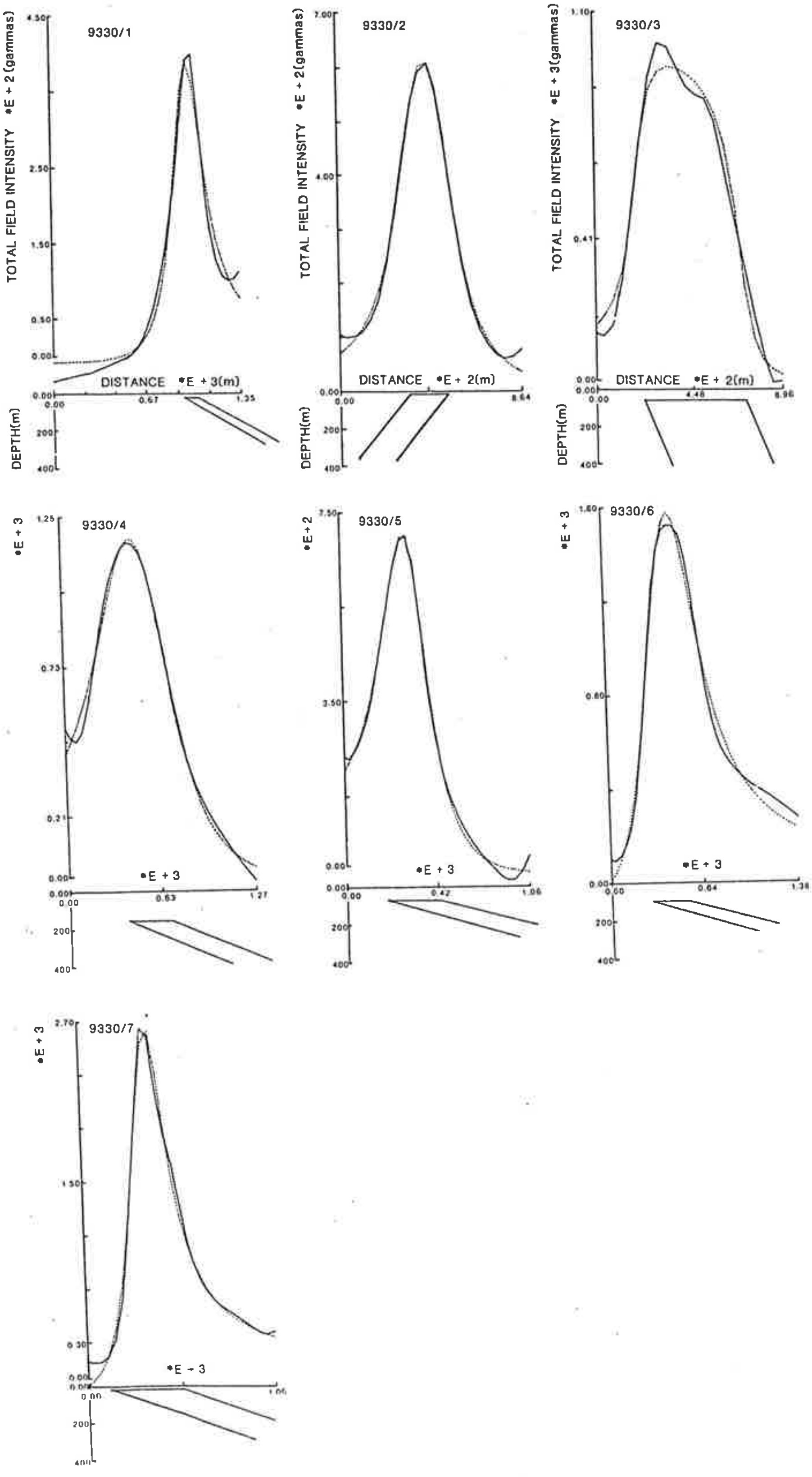


Figure 4.7 Two-dimensional magnetic modelling of anomalies on profiles 9160, 9130, 9240, 9330, 9320 and 9390, Solid lines are observed fields; dotted lines are calculated fields.

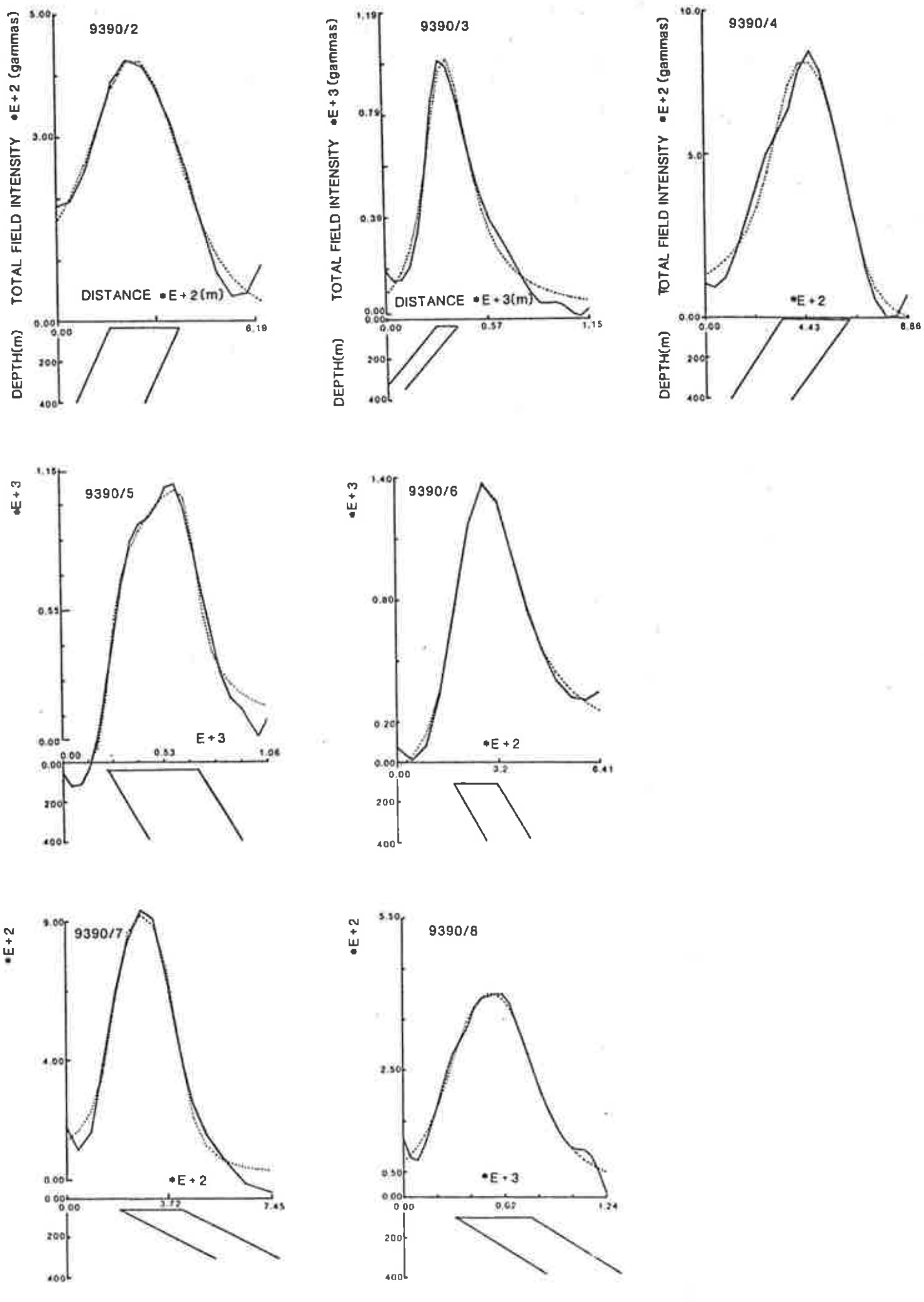


Figure 4.7 Two-dimensional magnetic modelling of anomalies on profiles 9160, 9130, 9240, 9330, 9320 and 9390, Solid lines are observed fields; dotted lines are calculated fields.

and $(B_{0.8} - B_{1.5})$ 55°. An overturned fold structure has been geologically mapped here (fig. 2.3; Forbes and Pitt, 1980).

Finally, it seems that although the major magnetic anomalies along the MacDonald and Outalpa Corridors coincide with shear zones in which the basement was involved, the magnetic anomaly patterns are in general caused by contrasts in magnetization within the Adelaidean rocks rather than by displacements at the surface of the basement. In fact the resulting shear zones outlined the main masses of rocks that have the contrasting magnetization (c.f. Dunn et al., 1971). As stated from the calculation there is sub-surface evidence for steep dips.

4.3 The Magnetic Low

The large anomaly on the Braemar iron formation in the Umberatana Group is of special interest because of the size of the rocks, unusual shape and moderately large amplitude of the anomalies. The large positive anomalies and the adjacent negative anomalies are of equal amplitude which is unusual in this area. The low is always located to the south of the high values (see figs. 4.1, 4.2, 4.8, 4.9, tie lines 9160, 9130, 9170 and 9330). Both the positive and negative anomalies are located over the 300m thick iron formationn (Wiltshire, 1975) which occurs in the Umberatana glacial and interglacial sediments. The rocks occurring below the negative anomalies apparently differ in no way in the structure and composition from the similar rocks of the area with the positive anomaly.

Geological observations on the Umberatana Group rocks indicate that they show open macroscopic folding (Berry et al., 1978, p. 47) in the Outalpa Corridor, while Wiltshire (1975), considers the section in the MacDonald Corridor to be a half syncline with steep dips, cut close to the fold axis by the northwest striking MacDonald fault (see fig. 4.9).

In order to understand the relationship of the geology and magnetic anomalies, it is desirable to consider the magnetic properties of the rocks. Bath (1962) has shown that for metamorphosed Pre-Cambrian iron-formations that the direction of the dominant magnetization is along the layers and remanent magnetization is more important than the induced magnetization (see also Hinze et al, 1982). He has used this as a basis for explaining aeromagnetic anomalies in the Biwabik iron formation. Outcrop samples are not considered to be representative of iron formations because according to Bath (1962) the vector sum of the individual samples will not account for the negative anomalies produced by iron formations. Very large numbers of outcrops and drill hole samples will be needed to be representative of iron formations, and azimuth variations in the directions of remanent magnetization from sample to sample is not unlikely. To add to the above complications, samples from the outcrops of magnetic anomaly lows of iron formations could show values of inclination that tend to be more along than across the bedding in addition to showing a wide scatter (Bath, 1962; Jahren, 1963). King and Zeitz (1971, p. 2198; fig. 7) tackled a similar problem in Central United States (Mid Continent Gravity High) where they modelled a reversely magnetized synclinal structure produced by lava flows by using the cross-section of the flows calculated from the gravity profile and approximating a continuous change in dip by varying the inclination of the remanent magnetization across the synclinal structure in a number of small increments. The resulting computed profile was not satisfactory as it did not show anomalies related to more local structures such as troughs and basins on the top of the synclinal structure.

Therefore not much will be expected in the form of obtaining a good match on the negative anomaly observed in this area. As a preliminary guide to the interpretation, the magnetic low produced by the iron formation (fig. 4.8) was computed for selected models. The sediments were assumed to be uniformly magnetized by induction in the direction of the earth's present field which normally seems to be the case in this area. The computed effects for a dipping dyke and a step model are shown in figure 4.8. The most successful model for the dyke indicates a body about 240m deep, and 410m thick with assumed susceptibility contrast of 0.162cgu and dips at 10°N. A better fit was obtained with a second model a step with a dip of 83°N and depth to the top of 110m and a vertical thickness of 800m, and a susceptibility contrast of 0.020cgu.

As the dip of the sediments is known to be 70° the first model with a dip of 10°N would need to be explained by a low dipping thrust plane cutting across the high angle horizons in a form of a sole fault. This seems an unlikely explanation. The second model could be explained as a fold starting with steep dips near the surface and continuing to the northeast where it is cut off by the MacDonald fault. It could also show some folding on the flat section of the magnetic model.

An attempt was made to reproduce the shape of the anomaly using the inclination of the remanent magnetization vector directed along the bedding plane of a dipping dyke model (Bath, 1962), and varying the intensity of the remanent field vector. The resulting computed anomaly

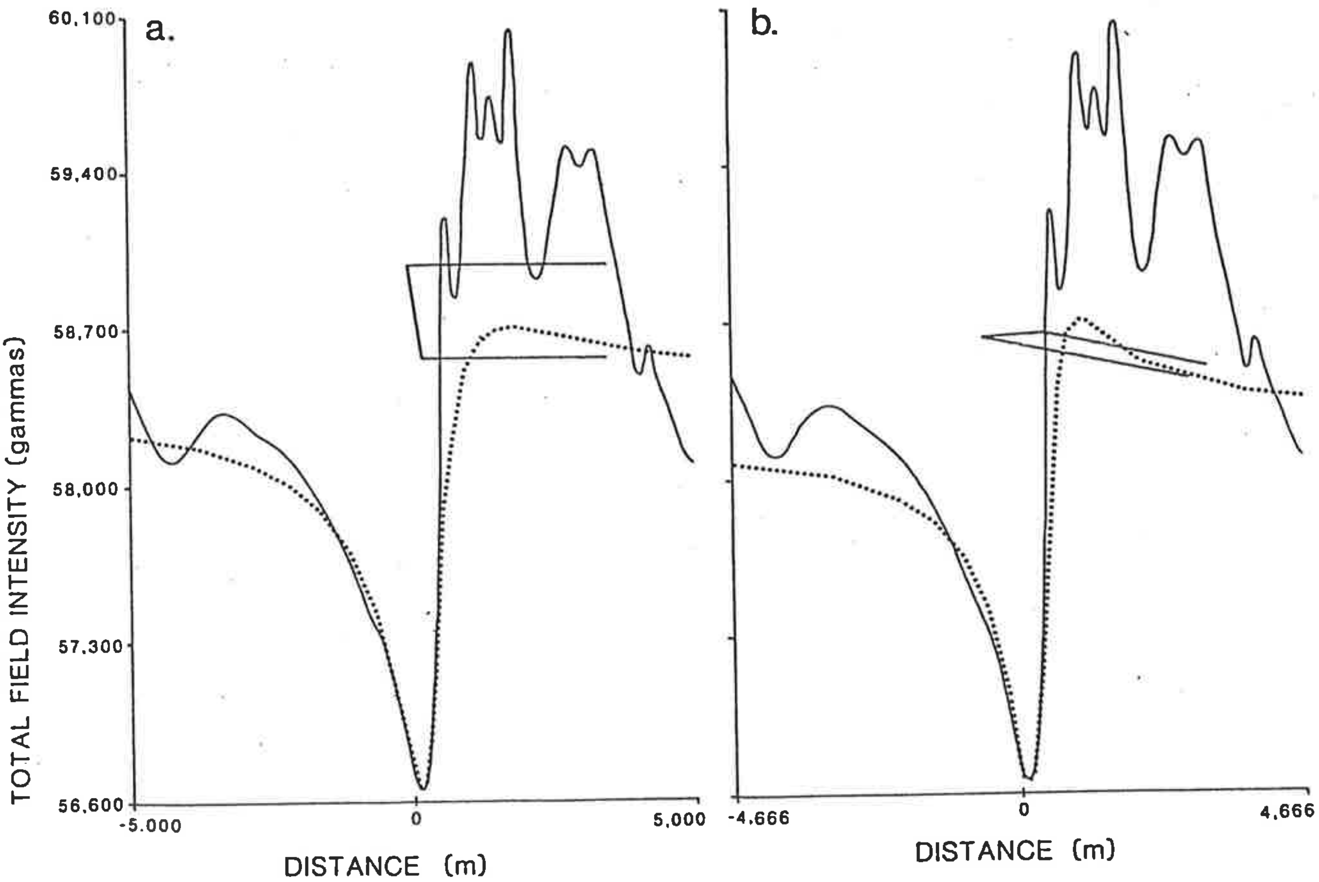


Figure 4.8 Two-dimensional and step-models of the magnetic anomaly low along tie-line 9140. Solid lines are observed fields; dotted lines are calculated fields.

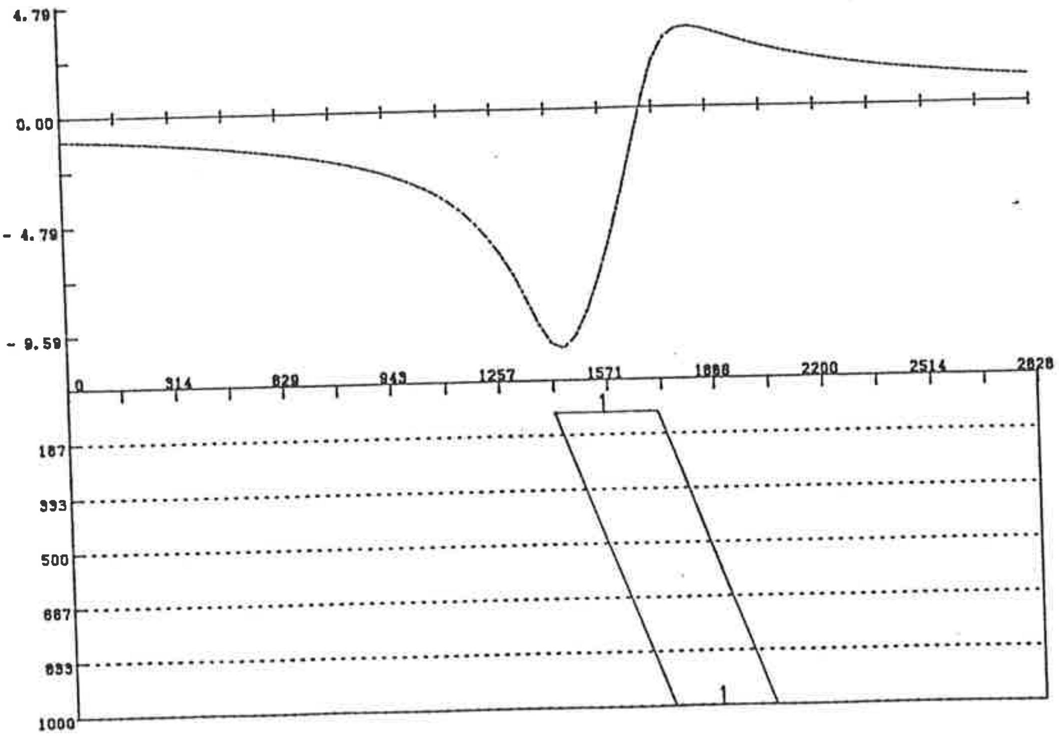


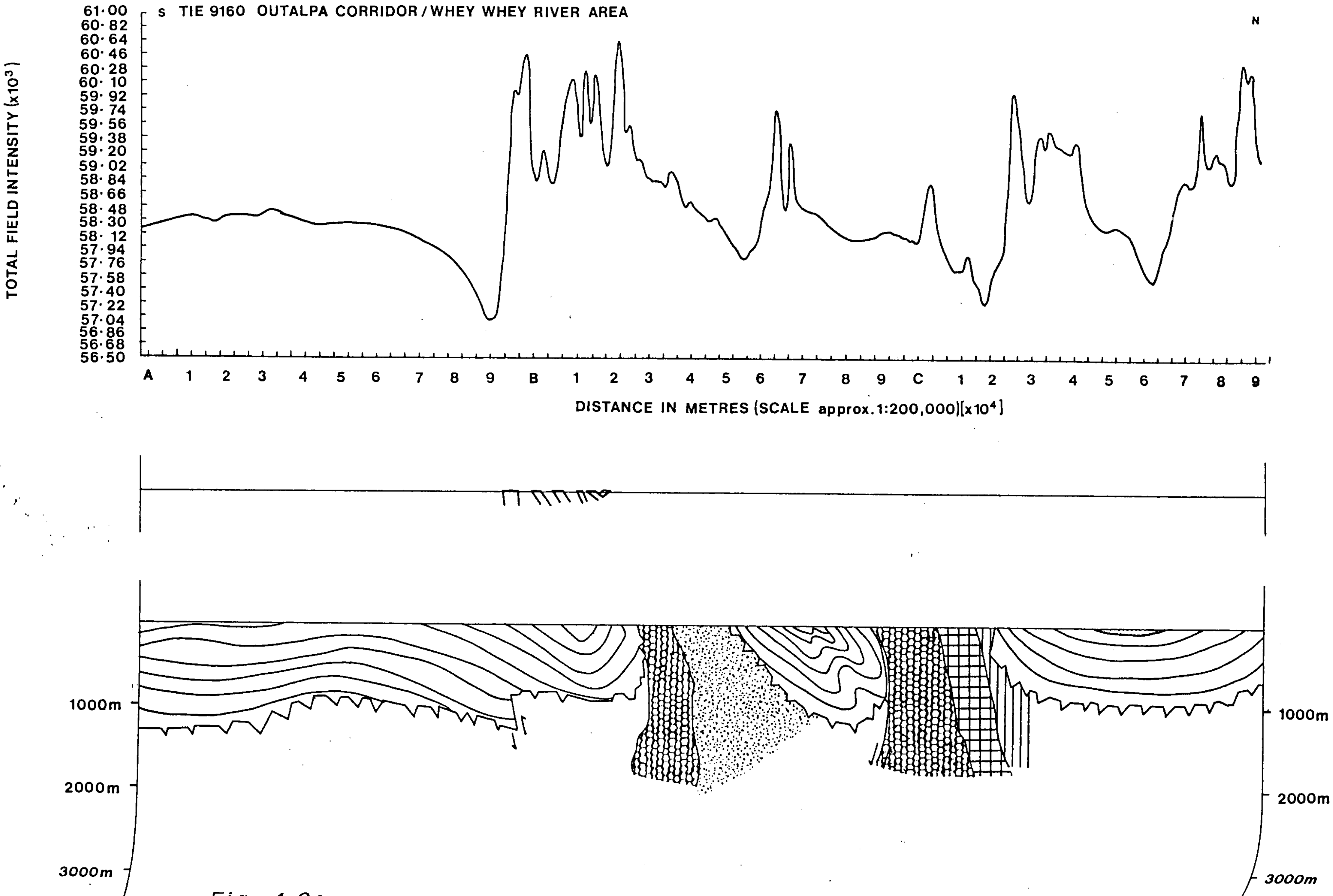
Figure 4.8c. Theoretical two-dimensional anomaly calculated for banded iron-formation with the remanence direction along the bedding plane dipping at 70°; angle between the geographic north and the x-axis is 140°; inclination of the Earth's magnetic field 60s; susceptibility is 10^{-2} units; remanent field intensity = 500 gammas and the Earth's field is 5800 gammas.

profile figure 4.8c shows the marginal low on the southern limb of the magnetic units within the Corridor. Because the remanent vector dips in the direction of the bedding plane and in a direction different from the ambient field, it produces a negative rather than a positive anomaly over the Braemar iron formation. The unit here should be stratigraphically lower than the other horizons producing positive magnetic anomalies which are cut along the fold axis by the northwest trending Outalpa fault. The feature here is a special characteristic of the Braemar iron formation within the Corridor and has not been noticed anywhere in the Province or in the Broken Hill District.

The thickness of the Adelaidean sediments on the MacDonald Corridor deduced from the aeromagnetic data using the method described by Bulina (1964), is about 1km and consistent with the model above. The displacement on the MacDonald fault is found by adding the thickness of the non-magnetic Burra Group to the depth obtained and the sum gives a displacement of 1.8km which is less than the 3km estimate by Wilsthire (1975). The geologically indicated depth may not have taken into consideration the complex fold and the postulated thrust relationships within the Corridor.

Qhf Qh	Quarternary Sediments.
Ꝑuw Ꝑye Ꝑyp$_{1-3}$ Ꝑb$_{1-3}$	Adelaidean System Sediments.
β_1	Discordant metadolerite type.
β_2	Amphibolite.
Ꝑγ_{1-4}	Undifferentiated granitoid bodies. Ademallitic to slightly granodioritic intrusives. Tonalite gneiss.
Ꝑws$_3$	Interlayered quartz - Muscovite schist.
Ꝑws$_4$	Pelitic quartz - Muscovite schist.
Ꝑws$_5$	Interlayered schist.
Ꝑws	Undifferentiated quartz-mica-plagioclase schist.
Ꝑwg$_3$	Layered quartz - plagioclase - biotite gneiss.
Ꝑwg$_5$	Layered psammitic - pelitic gneiss.
Ꝑwg	Massive homogenous tonalite gneiss.
Ꝑwf	Massive feldspar rich mica gneiss.
Ꝑwq	Massive to layered quartz - plagioclase "magnetic" quartzite.
Ꝑwc	Undifferentiated Complex gneiss.
	Migmatites(Non-sequence gneiss units.)
Ꝑwl l=m,x,z	Layered migmatitic biotite gneiss.

Fig. 4.9: AEROMAGNETIC AND IDEALIZED GEOLOGIC PROFILES - OLARY PROVINCE.



S TIE 9160 OUTALPA CORRIDOR / WHEY WHEY RIVER AREA
N
TOTAL FIELD INTENSITY (x10³)
61·00
60·82
60·64
60·46
60·28
60·10
59·92
59·74
59·56
59·38
59·20
59·02
58·84
58·66
58·48
58·30
58·12
57·94
57·76
57·58
57·40
57·22
57·04
56·86
56·68
56·50
A 1 2 3 4 5 6 7 8 9 B 1 2 3 4 5 6 7 8 9 C 1 2 3 4 5 6 7 8 9
DISTANCE IN METRES (SCALE approx. 1:200,000) [x10⁴]
1000m
2000m
3000m
1000m
2000m
3000m

Fig. 4.9a

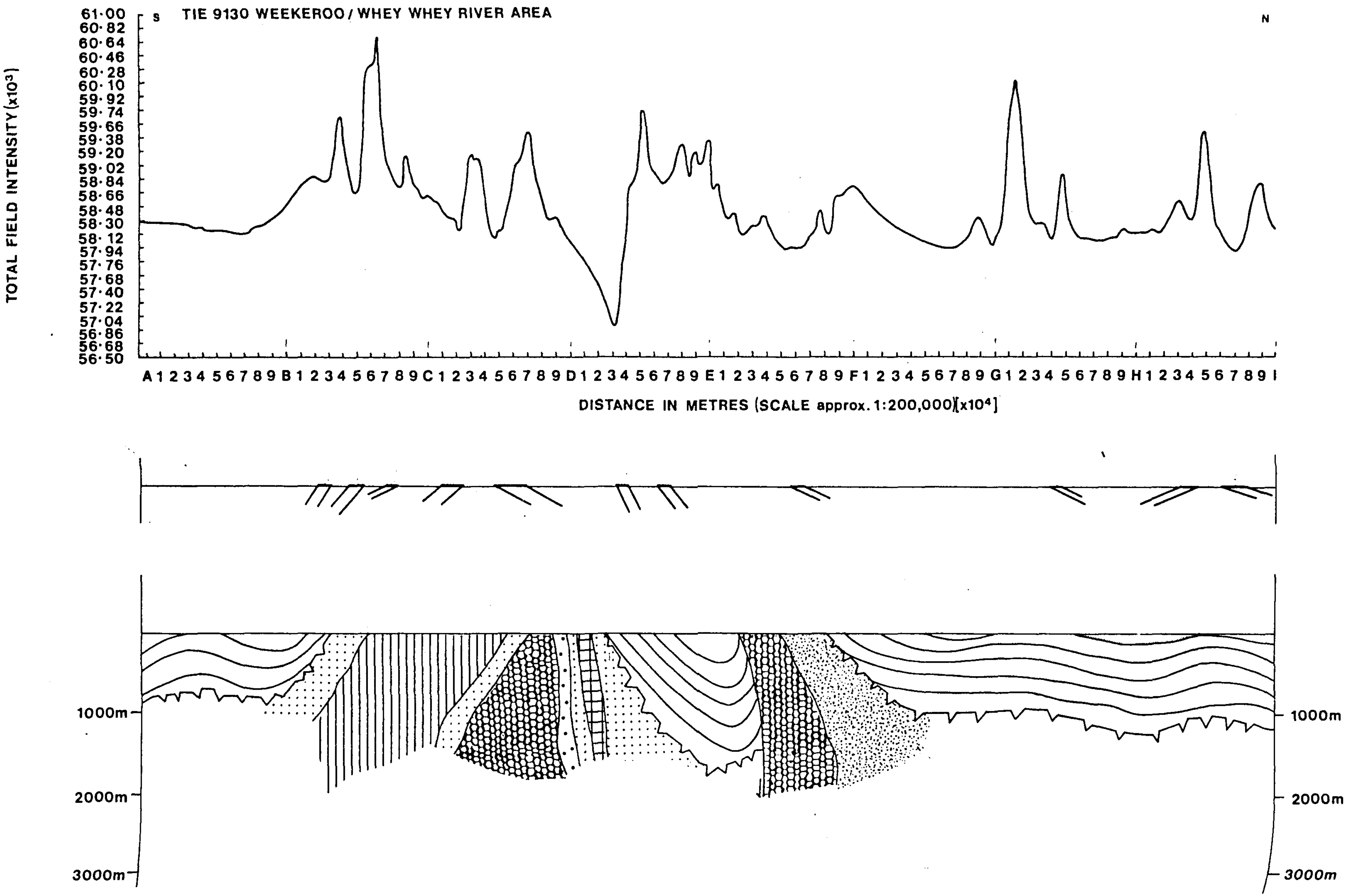
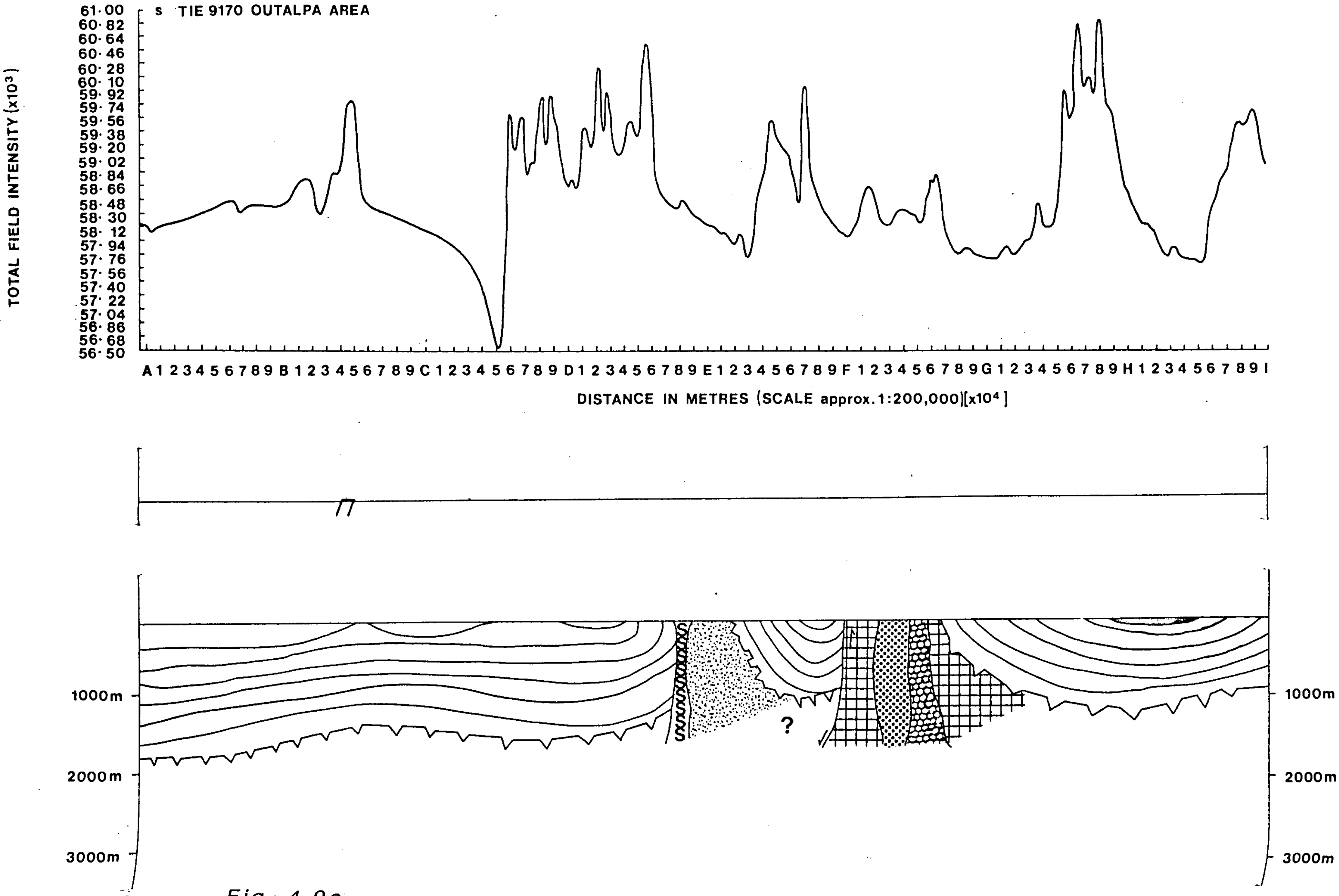

TIE 9130 WEEKEROO / WHEY WHEY RIVER AREA
S
N
TOTAL FIELD INTENSITY (x10³)
61·00
60·82
60·64
60·46
60·28
60·10
59·92
59·74
59·66
59·38
59·20
59·02
58·84
58·66
58·48
58·30
58·12
57·94
57·76
57·68
57·40
57·22
57·04
56·86
56·68
56·50
A 1 2 3 4 5 6 7 8 9 B 1 2 3 4 5 6 7 8 9 C 1 2 3 4 5 6 7 8 9 D 1 2 3 4 5 6 7 8 9 E 1 2 3 4 5 6 7 8 9 F 1 2 3 4 5 6 7 8 9 G 1 2 3 4 5 6 7 8 9 H 1 2 3 4 5 6 7 8 9 I
DISTANCE IN METRES (SCALE approx. 1:200,000) [x10⁴]
1000m
2000m
3000m
1000m
2000m
3000m

Fig. 4.9b



S TIE 9170 OUTALPA AREA
TOTAL FIELD INTENSITY (x10³)
61·00
60·82
60·64
60·46
60·28
60·10
59·92
59·74
59·56
59·38
59·20
59·02
58·84
58·66
58·48
58·30
58·12
57·94
57·76
57·56
57·40
57·22
57·04
56·86
56·68
56·50
A 1 2 3 4 5 6 7 8 9 B 1 2 3 4 5 6 7 8 9 C 1 2 3 4 5 6 7 8 9 D 1 2 3 4 5 6 7 8 9 E 1 2 3 4 5 6 7 8 9 F 1 2 3 4 5 6 7 8 9 G 1 2 3 4 5 6 7 8 9 H 1 2 3 4 5 6 7 8 9 I
DISTANCE IN METRES (SCALE approx. 1:200,000)[x10⁴]
?
1000m
2000m
3000m

Fig. 4.9c

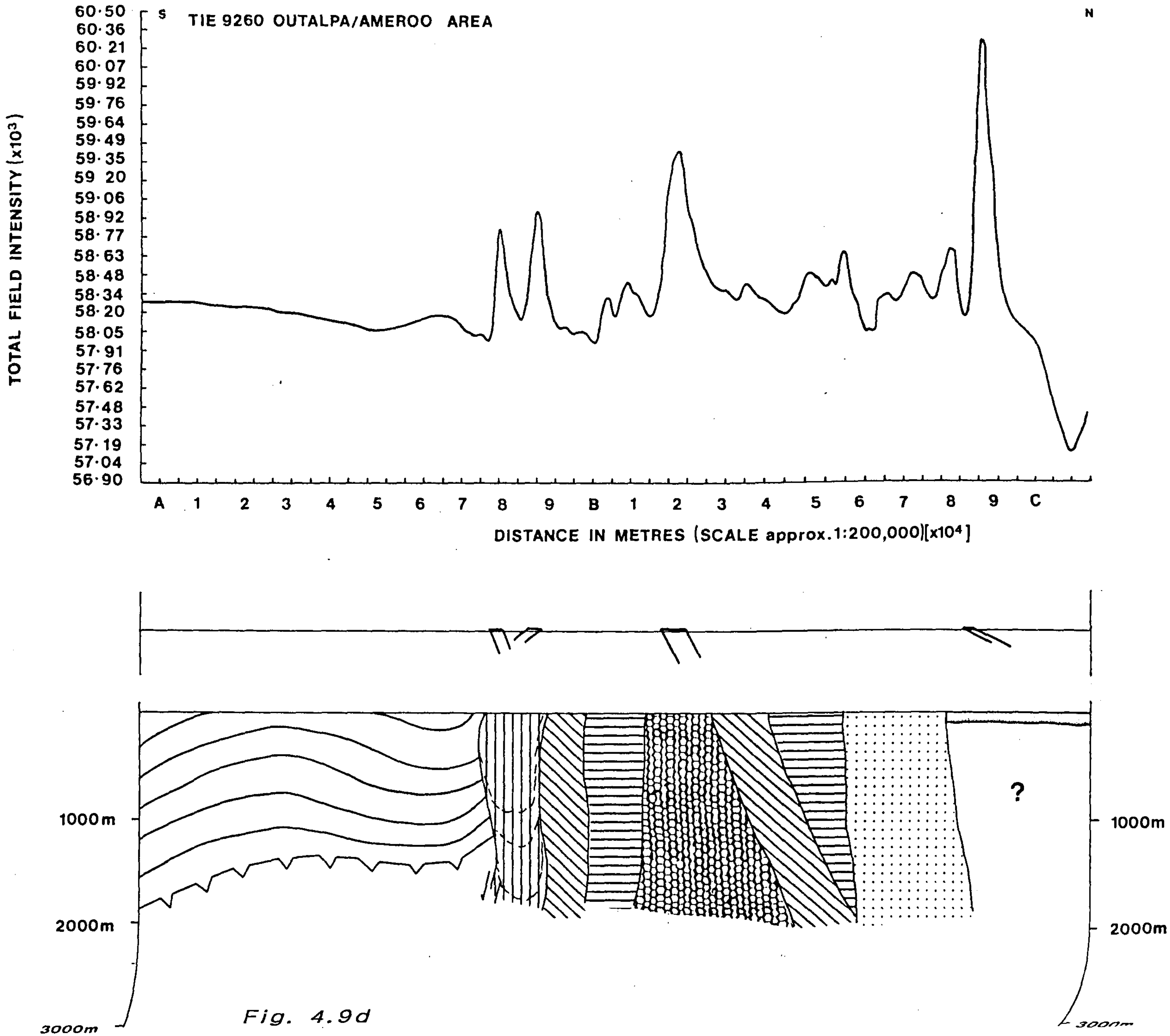
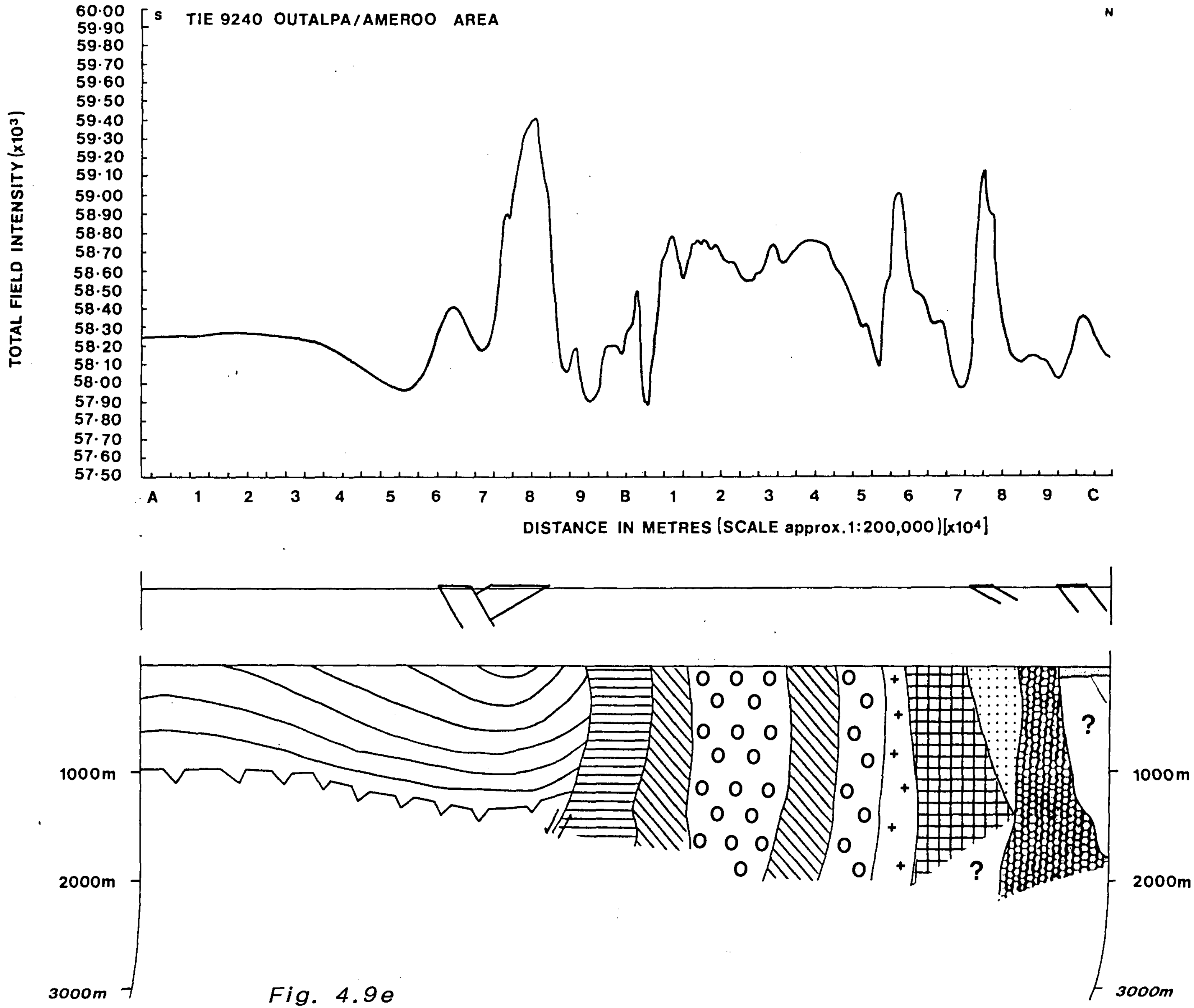
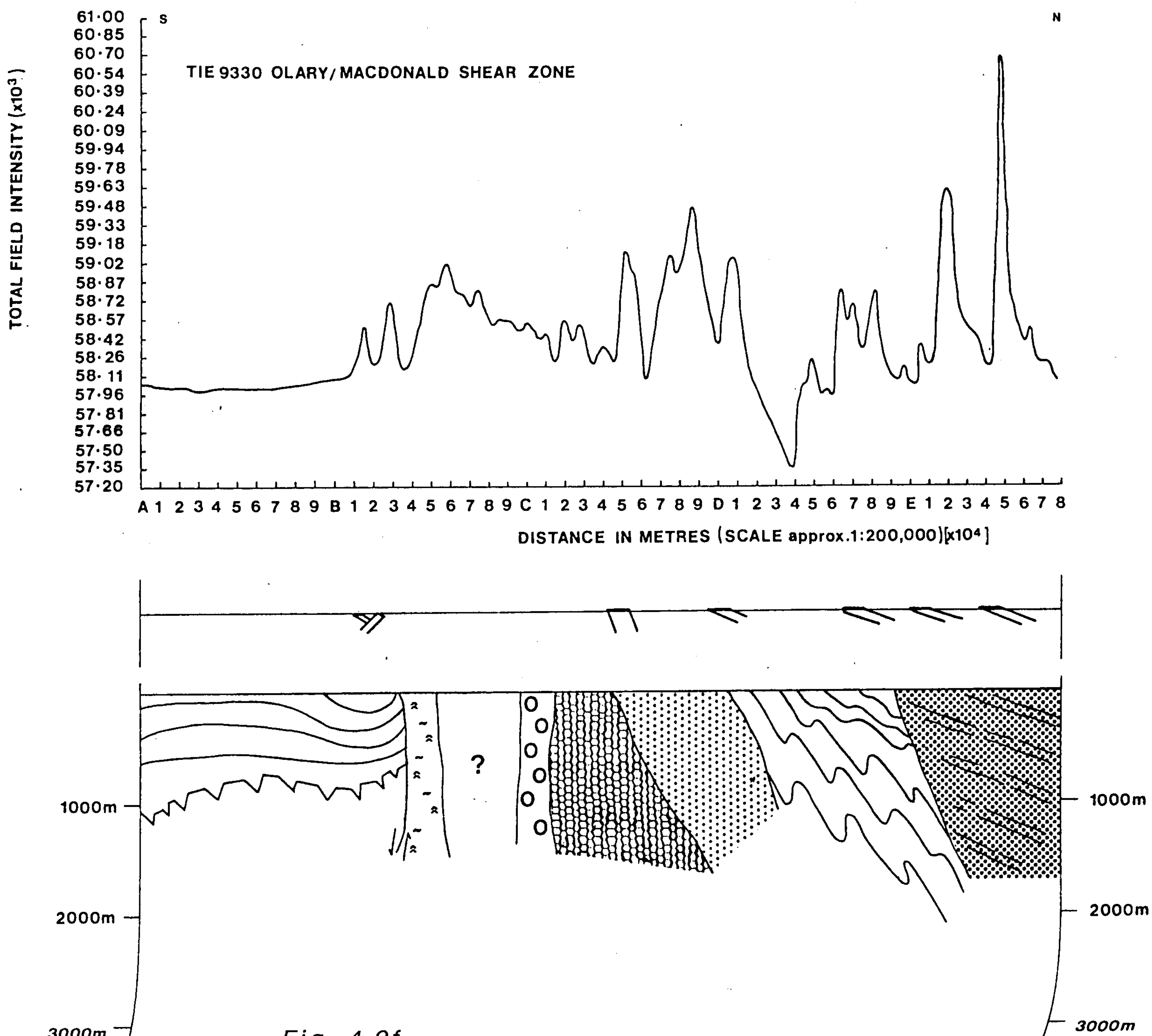

TIE 9260 OUTALPA/AMEROO AREA
S
N
TOTAL FIELD INTENSITY (x10³)
60·50
60·36
60·21
60·07
59·92
59·76
59·64
59·49
59·35
59 20
59·06
58·92
58·77
58·63
58·48
58·34
58·20
58·05
57·91
57·76
57·62
57·48
57·33
57·19
57·04
56·90
A 1 2 3 4 5 6 7 8 9 B 1 2 3 4 5 6 7 8 9 C
DISTANCE IN METRES (SCALE approx.1:200,000)[x10⁴]
?
1000m
2000m
3000m
1000m
2000m
3000m

Fig. 4.9d



S
TIE 9240 OUTALPA/AMEROO AREA
N
TOTAL FIELD INTENSITY (x10³)
60·00
59·90
59·80
59·70
59·60
59·50
59·40
59·30
59·20
59·10
59·00
58·90
58·80
58·70
58·60
58·50
58·40
58·30
58·20
58·10
58·00
57·90
57·80
57·70
57·60
57·50
A 1 2 3 4 5 6 7 8 9 B 1 2 3 4 5 6 7 8 9 C
DISTANCE IN METRES (SCALE approx. 1:200,000) [x10⁴]
1000m
2000m
3000m
?

Fig. 4.9e



TIE 9330 OLARY/MACDONALD SHEAR ZONE
S
N
TOTAL FIELD INTENSITY (x10³)
61·00
60·85
60·70
60·54
60·39
60·24
60·09
59·94
59·78
59·63
59·48
59·33
59·18
59·02
58·87
58·72
58·57
58·42
58·26
58·11
57·96
57·81
57·66
57·50
57·35
57·20
A 1 2 3 4 5 6 7 8 9 B 1 2 3 4 5 6 7 8 9 C 1 2 3 4 5 6 7 8 9 D 1 2 3 4 5 6 7 8 9 E 1 2 3 4 5 6 7 8
DISTANCE IN METRES (SCALE approx.1:200,000)[x10⁴]
?
1000m
2000m
3000m

Fig. 4.9f

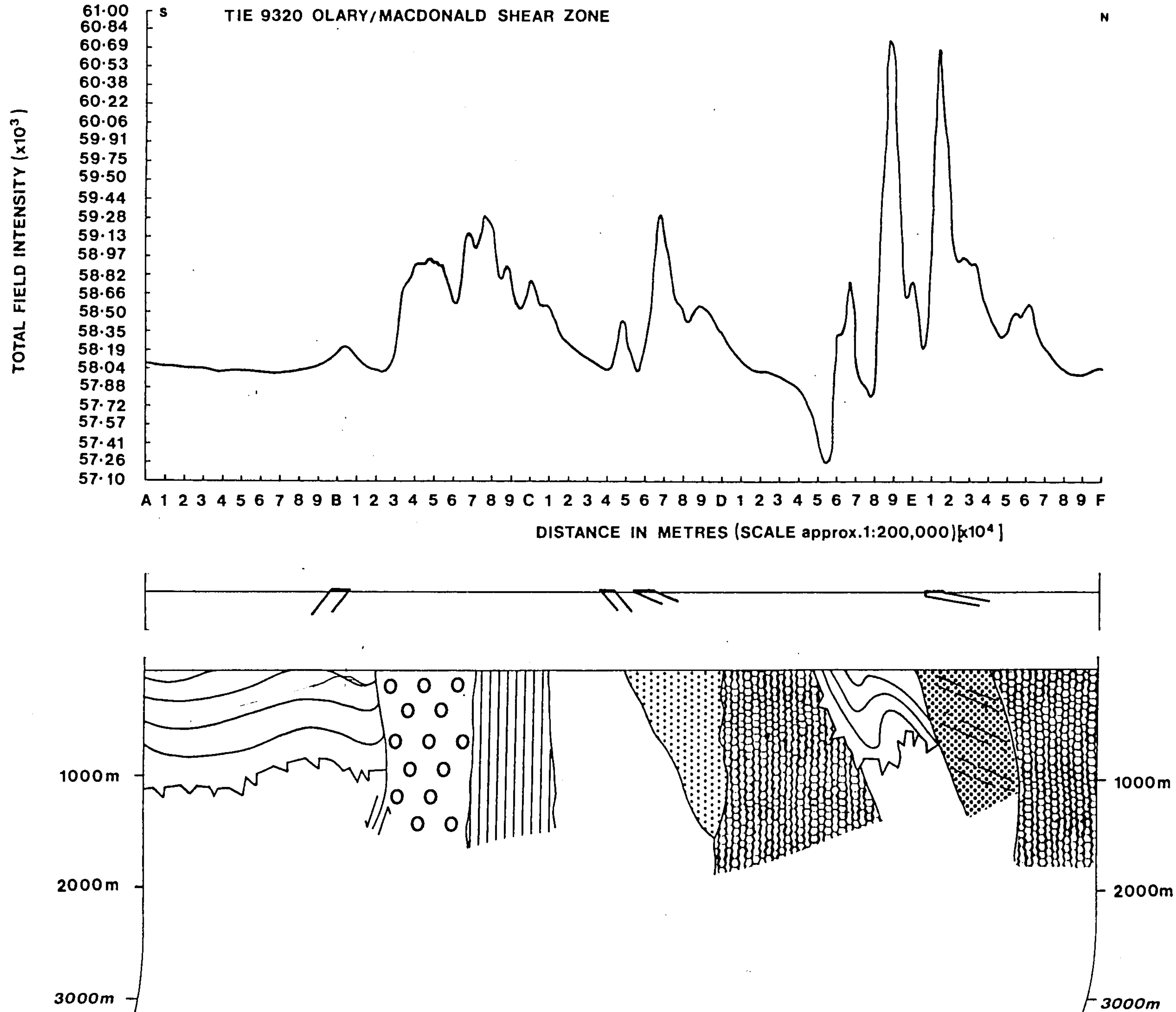

S
TIE 9320 OLARY/MACDONALD SHEAR ZONE
N
TOTAL FIELD INTENSITY (x10³)
61·00
60·84
60·69
60·53
60·38
60·22
60·06
59·91
59·75
59·50
59·44
59·28
59·13
58·97
58·82
58·66
58·50
58·35
58·19
58·04
57·88
57·72
57·57
57·41
57·26
57·10
A 1 2 3 4 5 6 7 8 9 B 1 2 3 4 5 6 7 8 9 C 1 2 3 4 5 6 7 8 9 D 1 2 3 4 5 6 7 8 9 E 1 2 3 4 5 6 7 8 9 F
DISTANCE IN METRES (SCALE approx.1:200,000)[x10⁴]
1000m
2000m
3000m
1000m
2000m
3000m

Fig. 4.9g

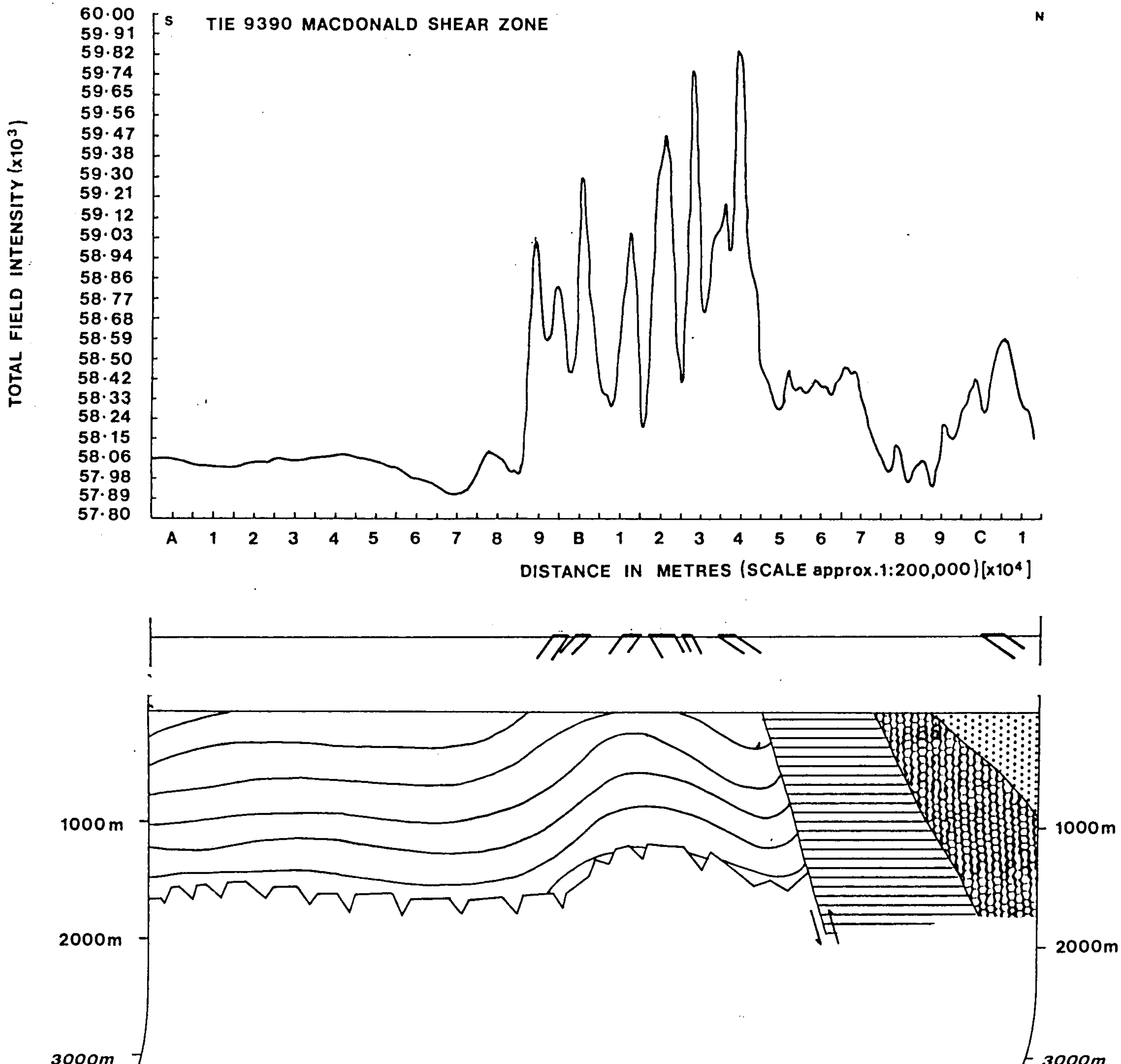

TIE 9390 MACDONALD SHEAR ZONE
S
N
TOTAL FIELD INTENSITY (x10³)
60·00
59·91
59·82
59·74
59·65
59·56
59·47
59·38
59·30
59·21
59·12
59·03
58·94
58·86
58·77
58·68
58·59
58·50
58·42
58·33
58·24
58·15
58·06
57·98
57·89
57·80
A 1 2 3 4 5 6 7 8 9 B 1 2 3 4 5 6 7 8 9 C 1
DISTANCE IN METRES (SCALE approx.1:200,000)[x10⁴]
1000m
2000m
3000m
1000m
2000m
3000m

Fig. 4.9h

CHAPTER 5

MAGNETIC INTERPRETATION - PART TWO

5.1 Introduction

The previous Chapter has shown that the many geophysical anomalies in the MacDonald and the Outalpa Corridors and the southern limit of the survey area can be related to geologic structures and lithologies that are already known or inferred from geologic mapping. Some anomalies extend into the basement part of the Olary Province and can provide clues to the rock types and structures that underlie the Proterozoic basement rocks of the Willyama block.

The following discussion of the geological significance of the anomalies is based primarily on the comparison of the observed anomalies with the known geology illustrated in figs 2.3 and 2.4 and the stratigraphic column fig. 2.2, and the magnetic effect of approximately idealized bodies calculated by the methods outlined in 3.6 and Appendix C on the one hand and the geological/geophysical hypothesis in 3.2. For the purposes of this discussion the magnetic anomalies have been marked on fig. 4.1 and the significant anomalies selected for individual consideration have been labelled in fig. 5.1.

5.1.1 Main Features of the Magnetic Map

Three magnetic zones B, C and D, clearly correspond to the Willyama basement rocks. Zone B stretches from Centralia Mine in the south across the MacDonald Corridor to Aldockra Hill and Larry Mac Dam in the northeast. It consists of moderate wavelength magnetic anomalies of limited strike extent. A separate group of an unusual anomaly highs and lows bounded by steep magnetic gradients form one of the most prominent features. They trend east-northeast and northeast as if they are running into each other. This may be due to complexity of the structure underlying the magnetic anomalies. The magnetic rocks in this area occur among massive layered quartzites and pelitic quartz-muscovite schists. Outcrops in this area are scarce and are relatively small.

Zone C includes the Whey Whey River, Bimbowrie and Spring Bore Well areas to the northwest and the east Weekeroo area to the southwest of the survey area (fig. 4.1). The group shows a few northeast

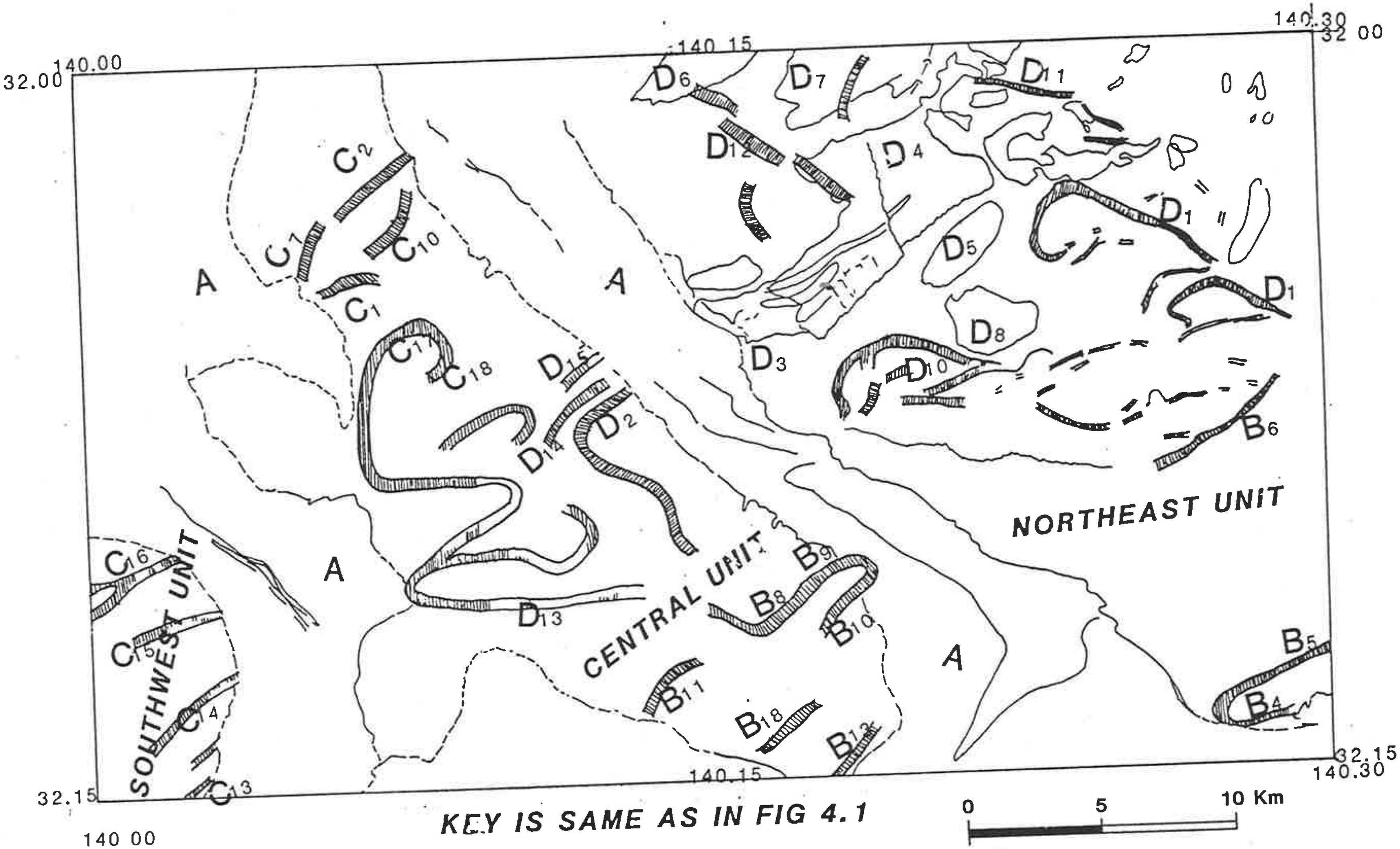


Figure 5.1 Magnetic anomalies discussed in Chapter 5. They are the same anomalies as are found in figure 4.1.

trending anomalies which vary in amplitude from 400 gammas to 1,200 gammas. These anomalies are related to the few outcropping amphibolites found in the zone. The anomaly amplitude in this zone is small in comparison with zones B and D. The similarity of the rock types and strata in the East Weekeroo-Bimbowrie areas divided by the Outalpa Corridor of zone A into two blocks is indicated by the magnetic map. The area is underlain by schists, gneisses, granites and tonalite gneiss.

Zone D anomaly group extends from Drew Hill and Old Boolcoomata southwestwards to Ameroo and Outalpa Hills. It is much wider and much more complex than zones B and C. The trends of the magnetic anomalies does not always correspond to the observed strike of the underlying rocks. Tucker (1983) refers to this as the "complex" type of anomaly. Campana and King (1958), and Thomson (1969, 1974) refer to a regional fold in this area but there is no evidence for this from the magnetic map. The very variable magnetic field assumes some consistency near Ameroo where trends are roughly northeast. The magnetic anomalies are due to gneisses, schists, quartzites, granites, minor iron formations and calc-silicate rocks.

Two features should be noted on this map: Firstly, there appears to be a decrease in the intensity of the magnetic anomalies from the southeast to northwest (ie, from zone B northwest through to zone D and zone C), so that the changes from one type of anomaly group to the other is not abrupt. This could be interpreted as the thinning of the magnetic rocks within the metamorphic sequence to the northwest, a lateral change in rock types or the effect of a change in the style of the regionally postulated northeast trending fold and its consequent magnetic response. Secondly, there is abrupt change in the intensity of the anomalies which run northwesterly along the MacDonald and Outalpa Corridors (figs. 4.1 and 4.2).

In order to simplify the presentation of the interpretation, the discussion that follows will treat three major units which are separated by the Adelaidean rocks: The northeastern unit is northeast of the MacDonald fault, the central unit lies between the MacDonald and Outalpa Corridors, and the southwestern unit which covers the east Weekeroo area. Then in each of these units the interpretation is arranged as follows: The magnetic properties of the metamorphosed metasedimentary rock bands and an account of the analysis of the magnetic anomalies will be first discussed and the magnetic properties of the igneous rocks and the structural features within the unit follow in that order. Finally, the rock groups and structures in the separate geographical unit will be related to each other.

5.2 Northeast Unit

From the geologic bedrock map fig. 2.3 compiled by the geologists of the South Australian Department of Mines and Energy, the description of the rock unit makes it clear that some of them can be expected to be strongly magnetic. These rock units include pelitic quartz-muscovite schist (Ameroo schist)(Pws_4), massive to layered quartz plagioclase magnetite quartzite (Pwq), massive to thickly layered feldspar mica gneiss (Pwf) and amphibolites (PB), and they provide a basis for the magnetic lithostratigraphy in the Olary Province (2.2 and 2.3). Some of the rock sequences have not been differentiated into distinct units and this is in an area where the aeromagnetic data will be providing new information.

From the magnetic map it can be seen that the high amplitude magnetic anomalies originate from the associated massive to layered often reddish quartz plagioclase magnetite "quartzite". These bands of narrow anomalies occupy the large area between D_{10} (around Drew Hill) to D_1, B_6 and B_4 (figs. 4.1and 5.1) to the south of the Green and Gold areas. The continuity of these magnetic bands is a useful confirmation of the continuity of some divisions of the rocks in this area. The prominent anomaly B_6 is a newly discovered feature that is interpreted due to magnetite quartzite (Pwq), D_1 anomaly is markedly irregular in magnitude and course. It is slightly displaced along its strike and its elongated length suggests a trace of dipping sheet-like anomaly. The results of the magnetic analysis of the anomalies B_6 and D_1 (figs 5.2 and 5.3) are listed in Table 5.1.

The acidic granitic rocks D_4, D_5 and D_7 (fig 4.1) are weakly magnetic and not well defined on the magnetic map, although in a few places the boundary coincides with magnetic features. The Calico Hill granite D_6 which is magnetic is different from the other granites (fig. 4.1). The magnetic anomalies could be due to a greatly increased number of basic inclusions or magnetic metasediments within the granite, a different phase of intrusion, or to a different type of granite altogether. There is a band of rocks D_{12} (fig. 5.1) about 3km here which has a greater range of magnetic susceptibility than the granite in this area. The anomalous rock appears to be adjacent to a marker horizon mapped within the undifferentiated complex gneiss and resemble D_{11}, 15km to the east (fig. 5.1).

The combination of aeromagnetic contour map, dips of magnetic analysis and the existing geological facts provides much information about the structures and indicates a series of folds which involve the

TABLE 5.1

MAGNETIC PARAMETERS FROM MAGNETIC MODELLING DISCUSSED IN CHAPTERS 4, 5 AND 8

Flight Line Number	Anomaly Location On Flight Record (Northings)	Parameters Estimated				
		Susceptibility (CGS Units)	Dip (Degrees)	Depth Below Surface (M)	Width (M)	Centre (M)
9160/1A	6425515-6427214	0.013	80°N	70	810	950
9160/2A	6427145-6427796	0.003	50°N	70	160	260
9160/3A	6427693-6428712	0.006	60°N	50	560	540
9160/4A	6428638-6429069	0.022	60°N	90	50	190
9160/5A	6428998-6429648	0.020	30°N	30	180	230
9200/8	6447669-6449236	0.015	60°N	90	310	580
9210/3	6444232-6446367	0.022	90°N	10	810	770
9291/1	6433651-6437571	0.030	60°N	280	790	360
9300/1	6432634-6436507	0.016	60°N	240	620	300
9310/1	6420070-6420898	0.009	31°N	50	200	460
9090/4	6440790-6442350	0.032	60°N	90	160	790
9100/4	6441323-6443590	0.014	82°N	110	320	1110
9140/1	6436374-6437953	0.007	34°N	40	330	570
9140/2	6443302-6445442	0.025	31°N	160	400	410
9140/3	6446324-6447923	0.004	81°N	30	290	560
9140/4	6451396-6452498	0.007	40°N	20	270	460
9120/6	6440074-6443834	0.010	48°N	360	1120	2440
9180/4	6448230-6449889	0.03	38°N	50	240	500
9451/2	6430254-6432426	0.04	20°N	130	760	830
9430/4	6439200-6441189	0.005	61°N	190	640	670
9441/5	6438377-6440244	0.006	40°N	240	550	1190
9420/2	6440195-6441231	0.003	37°N	210	500	640
9451/3	6437979-6439835	0.008	25°N	210	660	830
9461/4	6436317-6437716	0.024	10°N	50	410	960
9310/4	6434891-6434940	0.003	46°N	50	470	590
9340/4	6430435-6431351	0.011	41°N	20	190	330
9350/1	6420576-6423027	0.007	88°N	50	320	920
9380/3	6421462-6422991	0.006	84°S	20	280	480
9380/3	6425586-6426513	0.011	40°S	40	300	360

Table 5.1 Continued

Flight Line Number	Anomaly Location On Flight Record (Northings)	Parameters Estimated				
		Suscept-ibility (CGS Units)	Dip (Degrees)	Depth Below Surface (M)	Width (M)	Centre (M)
9380/4	6426427-6427648	0.023	74°S	130	220	360
9441/1	6426482-6427680	0.003	26°S	100	260	520
9441/2	6427554-6429834	0.004	82°S	220	620	1500
9480/1	6421747-6423001	0.003	80°S	80	870	980
9480/3	6427762-6429397	0.003	43°S	60	700	810
9151/1 (bdry)	6416890-6418116	0.015	34°N	30	150	500
9170/1	6418825-6420997	0.008	78°S	70	480	1220
9160/1	6429573-6430758	0.042	15°S	30	220	400
9160/4	6435938-6436804	0.025	20°N	90	130	180
9160/8	6450148-6450912	0.003	70°N	50	210	410
9130/1B	6429727-6430715	0.005	66°N	80	230	480
9130/2B	6430810-6431904	0.005	50°N	50	320	820
9130/6	6424893-6427003	0.05	25°N	120	210	470
9130/7	6441407-6442669	0.003	40°N	70	430	650
9130/8	6442573-6444284	0.018	25°N	20	510	730
9130/9	6444562-6445966	0.013	22°N	10	210	430
9130/10	6449502-6451310	0.023	20°N	80	280	620
9130/11	6451085-6452474	0.014	70°N	80	600	830
9260/1	6421247-6422323	0.004	40°N	50	300	370
9260/2	6422185-6427367	0.009	60°N	50	320	480
9260/3	6425529-6427697	0.012	30°N	220	480	750
9260/5	6433735-6435641	0.034	60°N	60	280	440
9240/1	6418589-6421322	0.003	25°S	320	640	1670
9240/2	6421001-6423593	0.012	25°N	110	1050	1540
9240/3	6433797-6435672	0.013	50°N	50	370	750
9240/5	6436401-6437948	0.015	30°N	340	150	820
9330/1	6418586-6417380	0.016	45°S	30	70	970
9330/2	6418465-6419343	0.007	66°N	20	180	430
9330/3	6424724-6425620	0.004	66°N	60	490	460
9330/4	6427347-6428594	0.032	20°N	160	300	520
9330/5	6431161-6432214	0.016	13°N	70	320	400

Table 5.1 Continued

Flight Line Number	Anomaly Location On Flight Record (Northings)	Parameters Estimated				
		Suscept-ibility (CGS Units)	Dip (Degrees)	Depth Below Surface (M)	Width (M)	Centre (M)
9330/6	6432711-6433840	0.06	10°N	130	470	380
9380/7	6434459-6435520	0.26	20°N	30	190	320
9320/1A	6416426-6418638	0.004	50°N	240	230	1210
9320/2	6423330-6425330	0.004	50°N	10	220	540
9320/3	6425186-6426762	0.04	20°N	100	270	590
9320/5	6431333-6432339	0.013	60°N	30	420	450
9320/6	6432711-6433884	0.11	10°N	130	470	390
9390/2	6422064-6422703	0.004	65°S	40	220	280
9390/3	6422566-6423716	0.017	50°S	40	120	340
9390/4	6423624-6424570	0.005	55°S	10	300	490
9390/5	6424370-6425434	0.004	60°N	50	460	460
9390/6	6425342-6425983	0.012	60°N	100	140	250
9390/7	6426469-6427889	0.008	30°N	60	230	300
9390/8	6432846-6434092	0.004	30°N	100	470	540
9120/1 (bdry)	6417231-6418686	0.010	50°S	90	540	930
9120/2 (bdry)	6418604-6419629	0.005	70°S	60	280	290
9130/1	6418835-6420128	0.005	60°S	120	540	720
9130/2	86419974-6421685	0.009	50°S	60	670	580
9130/3	6421588-6422491	0.008	25°S	40	190	270
9130/4	6423682-6425045	0.007	40°S	10	710	580
9130/5	6435962-6436845	0.001	25°N	50	850	820
9350/2	6435051-6435881	0.0012	38°N	90	180	380
9360/2	6435436-6436225	0.006	41°N	30	190	280
9370/2	6430767-6431902	0.009	30°N	60	280	610
9280/1	6433517-6437681	0.030	82°N	60	760	1080
9260/4	6432842-6433831	0.005	90°N	80	230	640
9180/1	6427797-6429798	0.08	60°N	70	470	910
9110/1	6427034-6428646	0.003	60°N	60	210	710
9120/2	6427843-6429424	0.011	42°N	20	130	540
9170/4	6437547-6439110	0.005	40°N	60	560	850
9170/5	6441758-6440234	0.007	34°N	20	570	700
9180/3	6441235-6444130	0.013	41°N	150	620	480

NOTE: Parameters for depth, width and centre have been rounded off

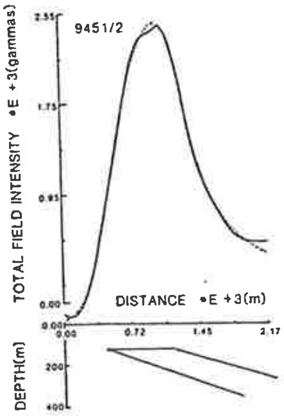


Figure 5.2 Two-dimensional magnetic modelling of anomaly B_6 in Zone B discussed in 5.2. Solid lines are observed fields; dotted lines are calculated fields.

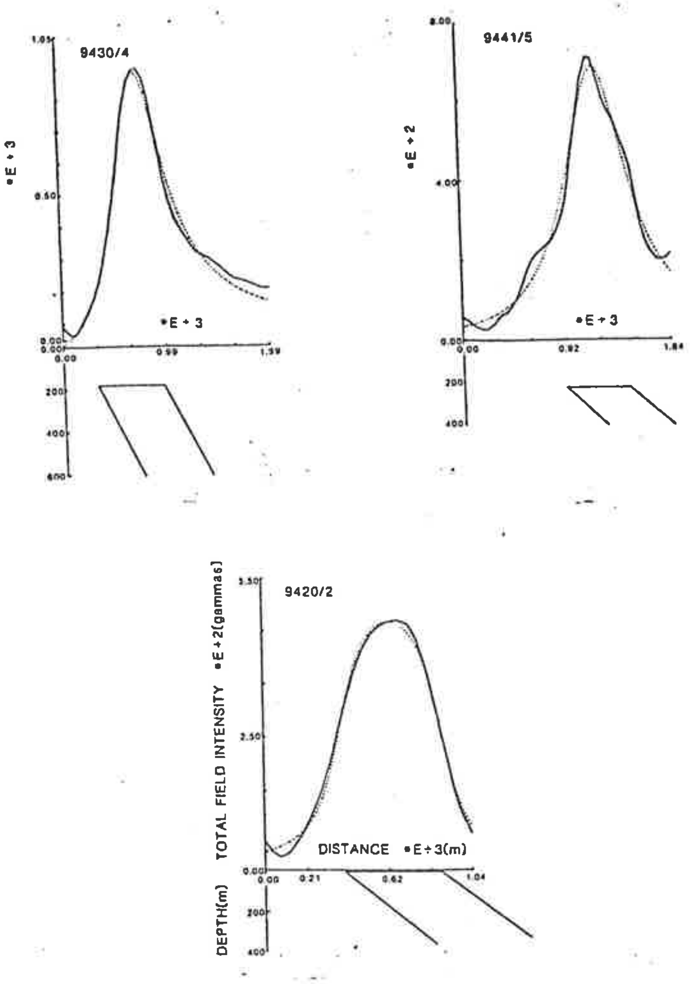


Figure 5.3 Two-dimensional magnetic modelling of anomaly D_1 in Zone D discussed in 5.2.

area bounded by the anomalies D_3 to B_6 and D_1 to D_{10} (fig. 5.1) and confirms:

(a) The synclinal axis mapped near Bulloo Well and Bore, by Wiltshire (1975; fig. 4.34) and Forbes and Pitt (1980) (c.f. figs 2.3 and 5.1);

(b) The Mount Mulga synform of Wiltshire (1975) (which according to Forbes and Pitt, (1980) is an overturned anticline, 2.8.1) marked D_{10} (figs 5.1 and 4.2). Modelled anomalies of the surrounding quartzite on tie-line profile 9320 $E_{1.5}$ - $E_{4.0}$ (figs 4.7, 4.9 and 5.4) showed an average dip of 20°. Recorded geology dips range from 20° to 35°NE.

The curvilinear anomaly trend defines several fold structures in an area of poor outcrop (fig. 5.1). B_4 (fig. 4.1) in the Green and Gold area to the southeast may also be part of an east-northeast trending fold. It is suggested that the localized thickening of magnetite quartzites or remanent magnetization is responsible for the values in the amplitude of the anomalies. These folds are not shown on the geology map (fig. 2.3).

Although there is some doubt about the amount of movement of the big northwest striking MacDonald fault forming the boundary of the Willyama basement and the Adelaidean sediments and its effect on the basement rocks, there is no doubt on the magnetic map about its existence or position. There is evidence on this magnetic map for a less prominent fault which runs from D_{10} to D_1 (fig. 4.1) which is probably the continuation of the fault which forms the northern boundary of the Mount Mulga quartzites and passes around Drew Hill. A fault of considerable importance probably runs from the Old Boolcoomata Hill BF_1 (fig. 4.1) to the south of B_6 and even beyond, causing an abrupt end to anomaly B_6. This fault shows up on tie-line profile 9320 $E_{0.0}$ - $E_{1.5}$ (fig. 4.9) as a magnetic low. In addition, there are a number of minor faults which trend east-northeast, northeast east-west and northwest (fig. 4.1).

The strong anomaly B_7 (figs 4.1, 4.2 and 2.3) is unusual. No outcrops were found near it which could provide the magnetic susceptibility high enough to account for the anomaly. The strike of the anomaly is parallel to the Adelaidean rocks underlying the anomaly A_3 (fig. 4.1). It is a possibility that they belong to the same group of rocks. If the MacDonald fault did prove to be a thrust plane this meagre evidence suggests that the Adelaidean sediments Braemar iron

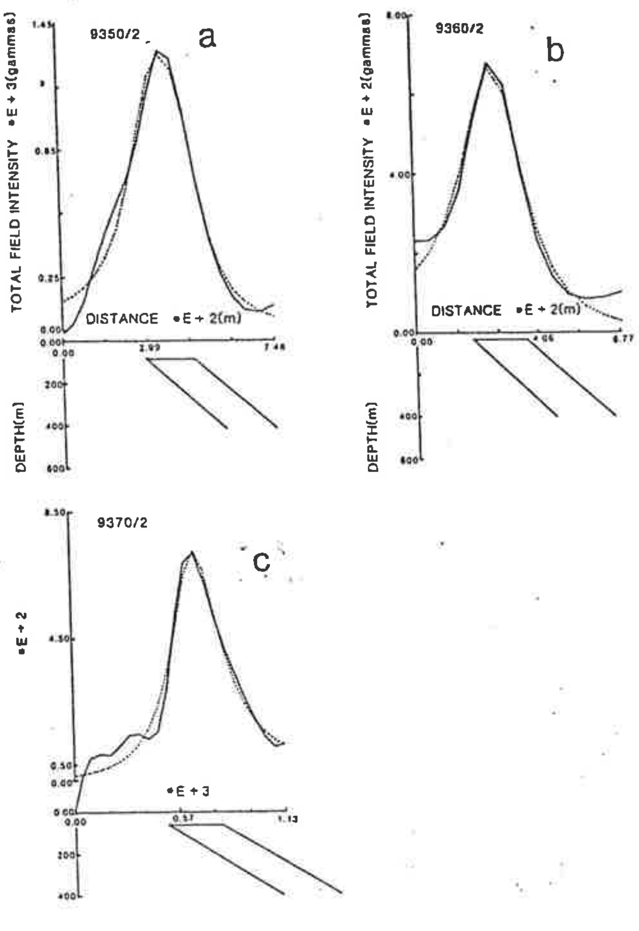


Figure 5.4 Two-dimensional magnetic modelling of some of the anomalies around the Mount Mulga Fold structure.

formation might be associated with the magnetic source of the anomaly B_7. If this were so it implies folding of the MacDonald fault plane. This suggestion at the moment is highly speculative.

In the Northeast unit, the magnetic results define linear magnetic trends D_{11} and D_{12} (figs 5.1, 4.2 and 2.3) which are related to magnetite in the Ameroo schist and the D_{11} anomaly coincides with it, while D_{12} is due to epidote quartzite in the undifferentiated complex gneiss.

5.3 Central Unit

The massive layered feldspar mica gneiss, layered psammitic pelitic muscovite schist which are magnetic in the northeast unit are magnetic here too. The weak magnetic characteristics of the area around Spring Bore were taken as percluding the presence of significant magnetite quartzite or gneiss therein. Tonalite gneiss, Pwy_3, interlayered schist and quartzite, Pws_5, and layered migmatitic biotite gneiss (Pwm) are mapped in this area.

From the magnetic contour map it is clear that many of the bigger anomalies in the southeast corner of the Central Unit, B_9-B_{14} and B_{18} (figs. 4.1 and 5.1) are similar to the anomalies on quartzites and schists in the Northeast Unit. A strong east-west striking positive anomaly (D_{13}, fig. 5.1) follows quartz plagioclase quartzite (Pwq) which continues irregularly to quartz plagioclase leucogneiss (Pwi) in which magnetite or other magnetic mineral has been found. This anomaly seems to extend to the next band of magnetic rock which runs from around Spring Bore Well area to Doughboy Hill C_{17} and C_{18} (fig. 4.1) where it is underlain by massive layered feldspar mica gneiss (Pwf). Both large anomalies may be due to some rock group (fig 5.1). Two strong anomaly features D_2 (fig. 4.1) located around Ameroo Hill and Peryhumcky Mine correlate with pelitic quartz muscovite schist (Pws_4) and layered psammitic pelitic gneiss (pwg_5). The divisions of the anomalies are vague. A strong positive anomaly (D_{15}, fig. 5.1) trending northeast and parallel to the D_2 anomaly is on strike with an outcrop of pelitic quartz muscovite schist (Pws_4) near Baxter prospect. Anomalies C_7 and D_9 in the northwest relate to the pelitic quartz muscovite schist mapped around there, while C_{10} (fig. 4.1) relate to the calc-silicate rock.

Analysis of these anomalies are summarised in Table 5.1 and are shown in figs 5.5 and 4.7. (See also, tie-line 9260, $B_{6.5}$-$B_{8.5}$; $B_{8.5}$-$C_{0.0}$ fig. 4.9; 9240, $B_{5.9}$-$B_{7.0}$; 9330, $C_{4.5}$-$D_{3.0}$ and 9320, $C_{5.5}$-$C_{8.0}$).

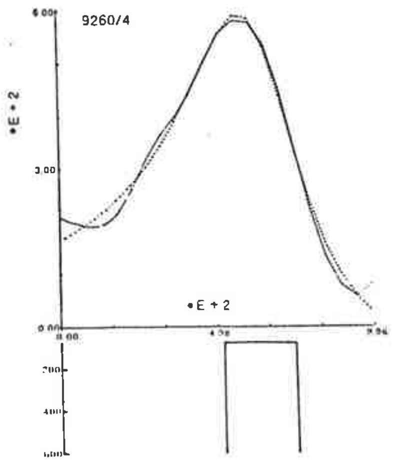


Figure 5.5 Two-dimensional magnetic modelling of anomaly D_2 in Zone D around the Ameroo Hill area.

All acidic igneous intrusions are non-magnetic as is shown by the flat magnetic field over them C_{19}, C_{22} and D_9 (fig. 4.1). D_9 (9320, $D_{3.0}$-$D_{5.0}$, fig. 4.9) reflects non-magnetic granite intrusion which interrupts the northwest trending anomalies at the southern edge of the MacDonald Corridor (figs. 4.1 and 4.2). The node-like anomalies bounded by straight contour lines C_1-C_4 and C_8 (figs. 4.1 and 4.2) which strike northeast parallel to the foliation trends on the undifferentiated schist are due to the Doughboy amphibolites. The results of the analysis of this Doughboy amphibolite anomaly is given in fig. 5.6.

The structure within the magnetic group is complex. More will have to be known about the geology before full interpretation can be made. The regional fold inferred by Campana and King (1958) and Thomson (1969, 1974) within this unit is not discernable on the magnetic map. The double curve towards the southwest on the magnetic map (figs. 4.1 and 5.1) could be related to folding with the same axial direction.

Two major faults, the Doughboy fault CF_4 (fig. 4.1) and the Faugh-a-Ballagh fault DF_6 are obscured by anomalies resulting from magnetic susceptibility contrasts between rock units (see for example 9260, $B_{1.5}$-$B_{3.0}$, 9240, $B_{0.8}$-$B_{1.0}$, fig. 4.9). Although anomalies due to dykes are not prominent they illustrate some unusual features rather well. A dyke which strikes northwest C_{20} (fig 4.1) is seen in the Spring Bore area of the Unit. It appears to accommodate itself to inhomogenities in the interlayered schists but passes with simpler paths through the tonalite gneiss and the migmatitic biotite gneiss to the southwest. Berry et al. (1978) suggests that it has intruded into a fault and has been folded with it. The results of a magnetic analysis are shown in fig. 5.7 and Table 5.1.

5.4 Southwest Unit (East Weekeroo)

Most of the rock types in this Unit have been met in the other Units and apart from C_{16} and C_{15} they are not strongly magnetic. The normally magnetic schists (Pws_4) and mica gneiss (Pwf) do not stand out clearly as in the other Units except towards the southern edge C_{11}-C_{13} (fig. 4.1).

Anomaly C_{16} follows the outline of the amphibolite mapped here. A single positive anomaly C_{15} is located on the tonalite gneiss (figs. 4.1, 4.2 and 2.3 and tie-line 9130, $C_{2.5}$-$C_{6.5}$ fig. 4.9) in contrast to the tonalite gneiss C_{22} in the Central Unit which is not magnetic.

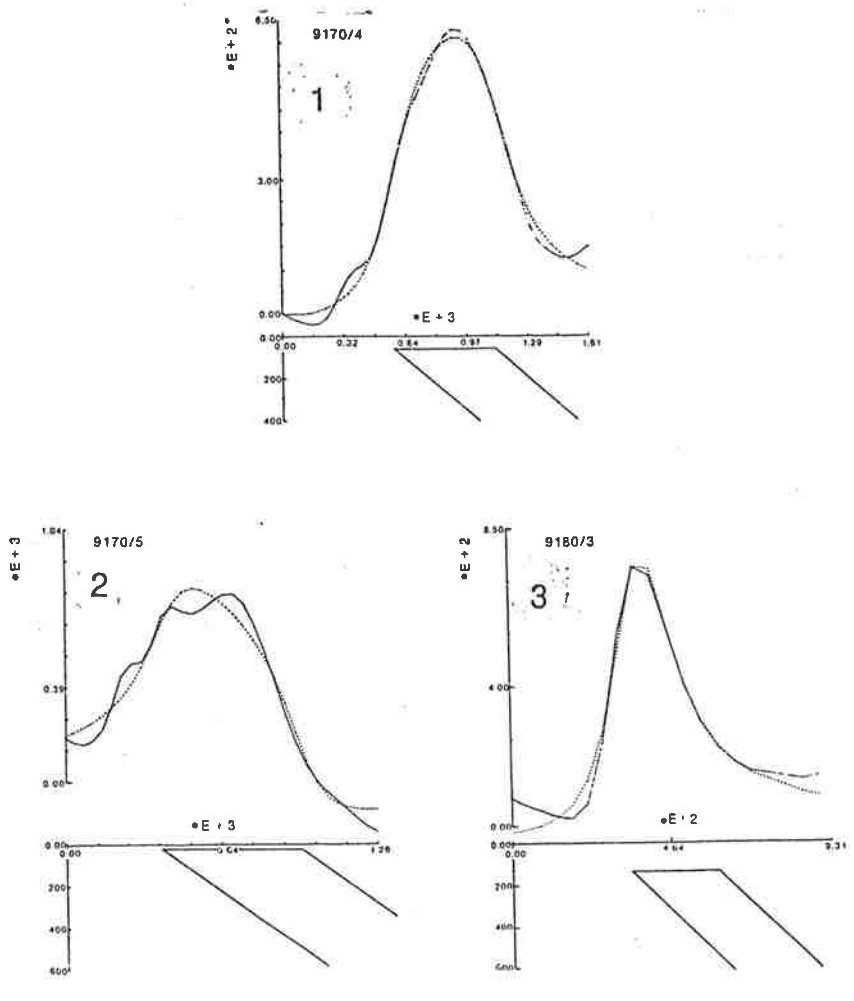


Figure 5.6 Two-dimensional magnetic modelling of the anomalies over the Doughboy amphibolites.

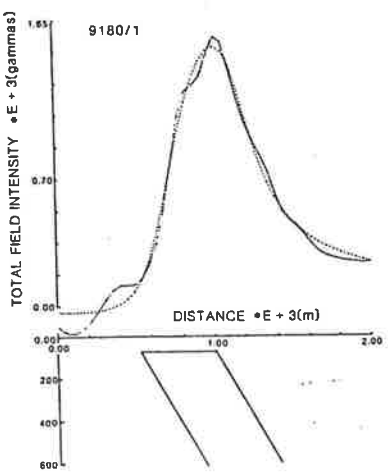


Figure 5.7 Two-dimensional magnetic modelling of the anomaly over the dolerite dyke discussed in 5.3.

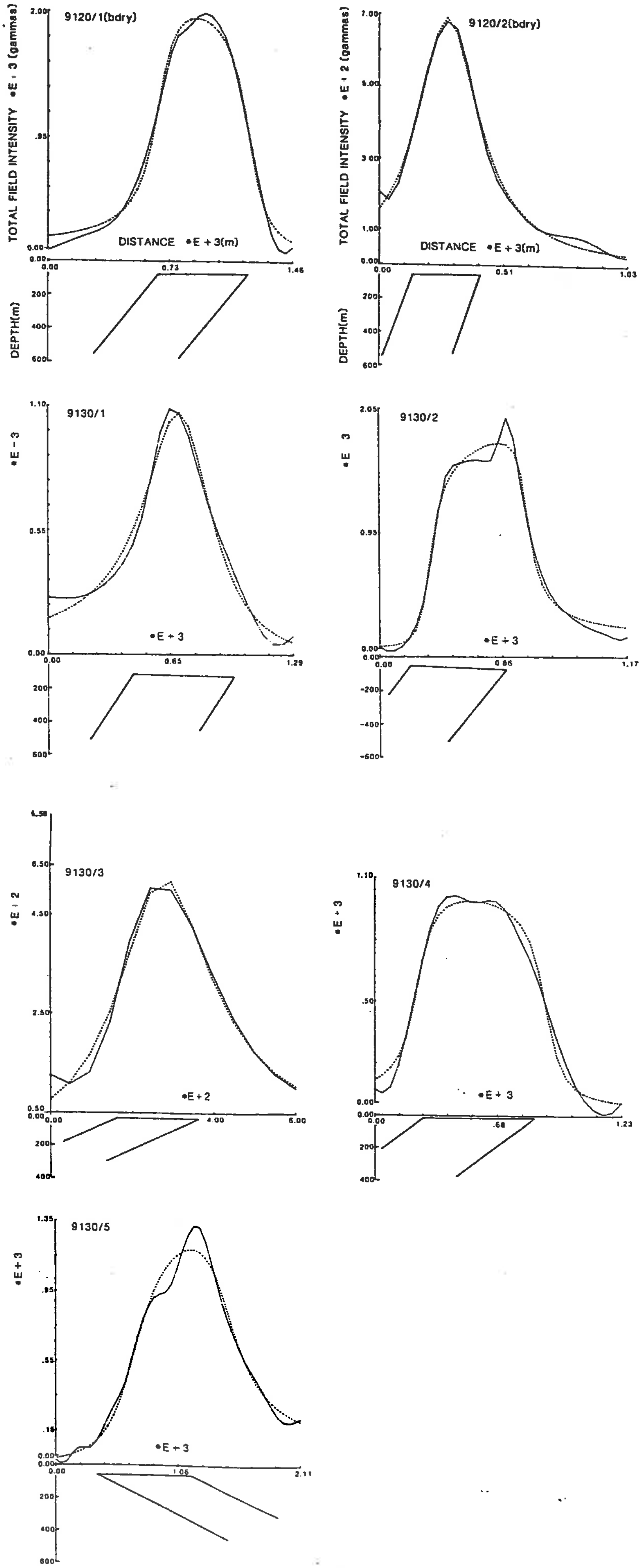


Figure 5.8 Two-dimensional magnetic modelling of the anomalies over the Weekeroo inlier (5.4).

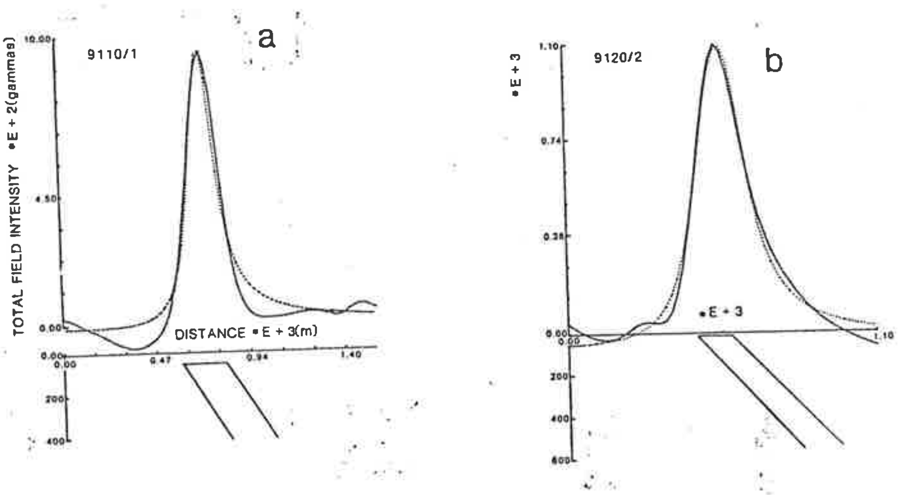


Figure 5.9 Two-dimensional magnetic modelling of the Weekeroo amphibolite.

Estimates of dips assuming induced magnetization have been listed in Table 5.1 and the computed profiles are presented as figs. 5.8 and 5.9.

The fold associated with C_{14} (fig. 4.1) is more easily recognised from the geology than it is on the magnetic map. The effect of faults on this Unit is not obvious on the magnetic map.

5.5 The Basement/Adelaidean Contact

The Willyama basement anomaly group is bounded on the southern part by the Zone E magnetic contact shown on figs. 4.1 and 4.2 which separates it from the low gradient magnetic pattern over the Adelaidean sediments within the Adelaide Geosyncline. The contact is manifested by a steepening in the gradient (fig. 4.9) and/or a change in character at the northern edge of the low gradient contact over Zone E. The change in magnetic character is not necessarily accompanied by a large increase in the amplitude of the anomalies because some of the rocks on the Willyama side are weakly magnetic. The distinctness of the anomaly implies that the contact dips steeply, but the direction of the dip cannot be determined. It can be recognised on tie-line profile 9260 (fig. 4.9) where it is obscured by the covering of the Wilyerpa formation fold anomaly ($A_{7.0}$-$A_{9.0}$), on the tie-line 9330 ($B_{5.0}$-$C_{4.5}$) and 9320 and 9240. It is not recognizable on profile tie-line 9160 and 9170 where the magnetically smooth area south of the Beeweeloo Hill area merges with the low gradient magnetic pattern near the Outalpa Corridor. The contact is seen again on tie-line profile 9390. The contact follows the arcuate trend of the Willyama basement tectonic elements in the southern part of the survey area and is oblique to trends in the basement. Where it is overlain by the Cainozoic sedimentary rocks in the Whey Whey River area the magnetic expression is subdued.

CHAPTER 6

Aeromagnetic Lineament Study in the Olary Province, South Australia

6.1 Introduction

The concept of lineaments within the earth's crust has direct and far-reaching implications for all fields of geolgy, and in particular, those that are concerned with the fundamental structures of the earth and with the origin and distribution of mineral deposits. This Chapter attempts, through aeromagnetic lineaments, to demonstrate how to correlate the locally mapped structural features in the Olary Province (Berry, 1973; Wilsthire, 1975) to the mega-structures that have been recognised by O'Driscoll (1981a and b, 1982) and Harrington et al. (1982). O'Driscoll (1982) has shown that South Australia and in particular its central part, the Adelaide Geosyncline, is covered by a network of sets of intersecting shear-net systems which have contributed to the evolution of the geosyncline; and he has related them to the concentration of copper deposits within the State.

Brock (1957) has remarked that "Lineaments are facts whatever these facts may mean"; and he stated that "we would not presume to be prescient on the matter, but would point out as any elementary treatise on logic will show that there are different senses of facts." However, there are instances when geologists go into the field to look at specific places for the cause of a specific lineament or linear features as revealed by air photos, geophysical data and/or imagery of various types and in many or even most cases they find the sought-for evidence, thus tying the "elusive" linear features to hard previously unknown geological facts (Gay, 1974).

Limitations on structural interpretation of the Olary Province arising from lack of outcrops in some regions and uncertainty in the stratigraphy, and difficulties in determining the age of some folds (Wiltshire, 1975, p. 63) make it suitable for magnetic lineament analysis. Thomson (1974, fig. 2) and Rutland et al. (1981, fig. 5.3, p. 312) have referred to some of the aeromagnetic lineaments in this area as faults (fig. 2.4).

6.1.1 Scale of Lineament Analysis

Controversy as to the reality of a lineament has rested on the scale; and to accommodate those who think in scales other than field scales, the analysis of the aeromagnetic lineaments in this Chapter has been undertaken on a scale of 1:50,000. As Bucher (1955) remarked, "over smaller restricted areas, where there exists adequate control, then the lengths of lineaments become more trustworthy; when such are extended over hundreds, even thousands of kilometres, one feels inclined to state as axiomatic that the farther a lineament is proposed, the weaker the substantiation."

One works up the table of Scales to tie with continental or world patterns and down the table to field observations. Any pattern of lineaments comprise a number of sets of different directions vying with each other for prominence. One must not expect any lineament on any scale to be conspicously marked throughout its length on a field map. Every lineament has its appropriate scale; it is nonetheless real being visible on one scale and "intermediate" on another (Brock, 1961, p. 273). When such synthesis and analysis meet in a global view the two are complementary. If the global view can be attained a step at a time, the detailed observations may be reconcilable with the fundamental fracture pattern of the crust. It is the global view that gives lineaments a fundamental meaning related to the fragmentation of the crust itself.

6.1.2 Linear Features on Geophysical Maps

Geophysical and geological lineaments are determined from intrinsic characteristics, some of which, however, may be modified by external agencies. Geophysical lineaments need to be distinguished on the basis of what geophysical paramenters are used - gravitational, seismic, magnetic, etc. Nor must we lose sight of a possible conflict between lineaments based on geophysical factors and those based on geological evidence; and if reconciliation is not possible, this should be made clear.

Aeromagnetic maps are often indicators of regional features. Krutihovskaya et al. (1973) have shown that magnetic anomalies reveal surface folds as well as deep folding and faulting. Applying this principle in Finland, Mikkola and Vuorela (1974) have compiled lineament maps for their entire country. Emerson (1976) has considered tectonic history as reflected by magnetic character and has proceeded to use the idea to distinguish two different tectonic provinces in Western Australia. Correlations such as these have also been made for the Churchill/Superior boundary in Canada by Kornik and MacLaren (1966); for the huge area in the USSR by Simenenko, (1969) and for the Liberian Archean/Eburnean Proterozoic/Pan-African Phanerozoic age

Province contacts by Behrendt and Wotorson (1971). Stress directions within the western Upper Peninsula of Michigan have also been inferred from the analysis of magnetic trends. (Meshref and Hinze, 1970).

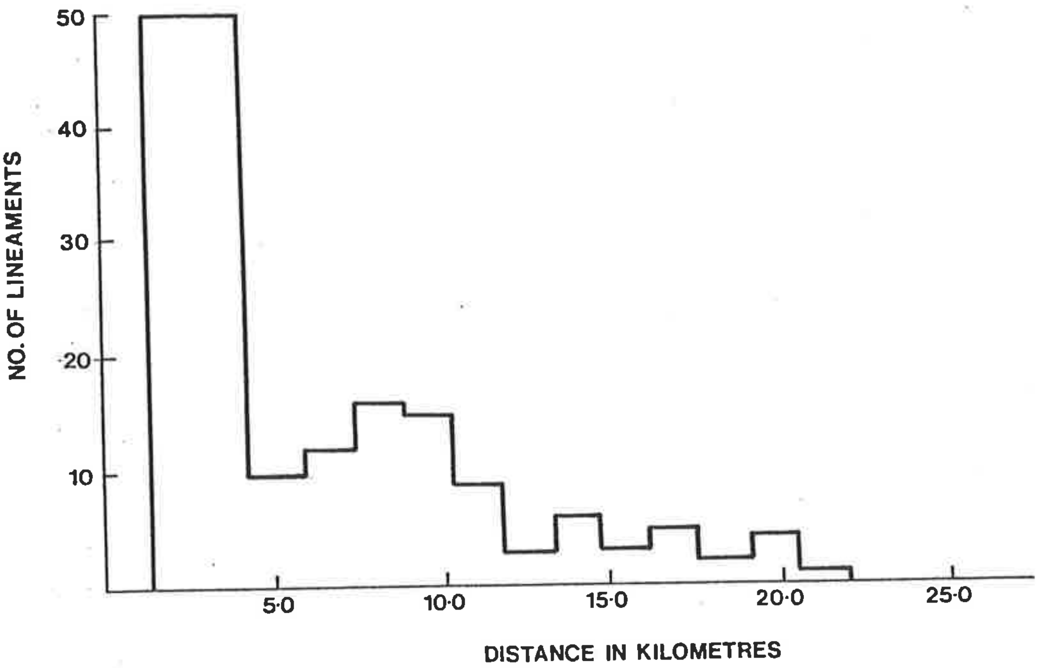
Other workers like Hepworth (1965) and Stockwell (1968) have employed aeromagnetic trends, gneissic structures, bedding and photogeology trends for their structural interpretation of basement tectonics.

In more recent times aeromagnetic lineament are studied by specially processed data like derivative maps (Stewart and Boyd, 1983). These methods presuppose that there are no compilation errors in the original gridded data. Levelling errors are enhanced by the derivative methods which decreases coherency of data as well as increasing difficulties in contouring of the data into map form (Holroyd, 1974; McGarth, 1976). In addition, on derivative maps many features with considerable aerial continuity tend to be broken up into smaller circular anomalies which are difficult to relate to one another (Hood et al., 1974). One-dimensional derivative filters tend to emphasise those features which strike at high angles across the flight lines and discriminate against those features which are sub-parallel to the flight-lines. Where survey specifications are different as is the case with the Olary Province, upward or downward continuations are needed to bring the data into the same perspective (c.f. Isles, 1983).

6.1.3 Method of Study

Gay (1971, p. 413) defined an aeromagnetic lineament as a disruption in the contours, that is, as a part of the pattern against which other anomalies terminate. The recognition of faults and fault patterns in the Olary Province was primarily based on the study of the aeromagnetic lineaments. Persistent lows and highs and their sudden terminations and displacements have been used as the basic criteria for the lineaments. Other aeromagnetic lineaments used corresponded to elongated magnetic contours, gradient changes and persistent chevroning and kinks. As the flight line spacing is 300m anything shorter than 200m was discarded. Figure 6.1 is a histogram of lineament lengths versus frequency which highlights the above mentioned bias attributed to the inability of the author to identify short linear elements on the aeromagnetic contour map as lineaments of probably structural origin.

Coloured aeromagnetic contour maps at a scale of 1:100,000 and black and white aeromagnetic contour map at a scale of 1:50,000 were used to find and interpret the lineaments. Lineaments observed on the maps were drawn on an anomaly. The process was repeated four times on



6.1: HISTOGRAM SHOWING LINEAMENT LENGTH VERSUS FREQUENCY.

four different overlays. Any corresponding lineaments on any three of the overlays were accepted as a valid lineament. The locations, directions, continuities, and lengths of the lineaments were recorded by measuring the directions of each lineament as an azimuth, clockwise from the north. A lineament that changes its azimuth by more than 5 degrees along its length was broken into shorter ones. Their location within a 2km square grid was recorded. The number of lineaments in each 10 degress of azimuth and their frequency characteristics were calculated using a Rosnet (Williams, 1980). In order to analyse the structural significance of the lineaments the lineament map was compared with the geology map (fig. 2.3).

6.2 Distribution of Lineaments

The total length of the lineaments measured from the lineament map (fig. 6.2) gives an average lineament density of 0.76km/km^2 for the whole area. For determining the aerial variations in the lineament density, the lineament map was gridded in 2km squares. In fig. 6.3 the most pronounced high lineament density areas (>1.5km/km^2) stand out as units or islands surrounded by a low (<0.75km/km^2) and an intermediate (0.75-1.5km/km^2) densities.

The intermediate density areas seem to trend approximately towards the northwest. The areas of high and intermediate densities are referred to as high density lineament zones. These zones in most places seem to outline the low density area as will be shown from the following discussion.

Parallel sets of shorter or individual long lineaments sets believed to determine trends of fracture zones have been marked in fig. 6.2. Individual lineaments greater than 5km are believed to emphasise some of the lineament forming sets of this kind, and they have been marked in fig. 6.2 with the letters A-A....I-I.

The most prominent high density zones occur in the northwestern, southeastern and central portions of the Olary Province and these adhere to the lineament sets marked D-D (50-70), I-I (30-40), A-A (65-80), B-B (50-65), and C-C (30-50). The curvilinear features displayed by the high density units in these areas are due to the intersections of G-G (290-230) and E-E (310-330) with the above sets.

The southern portion of the Province is a uniformly low lineament density area. This area is mainly housed within the Adelaidean Geosyncline which borders the southern portion of the Willyama Block. Locally the area is marked by uniform gradients (Chapter 4; and Tucker, 1975). The contour interval may have contributed to the observed magnetic picture.

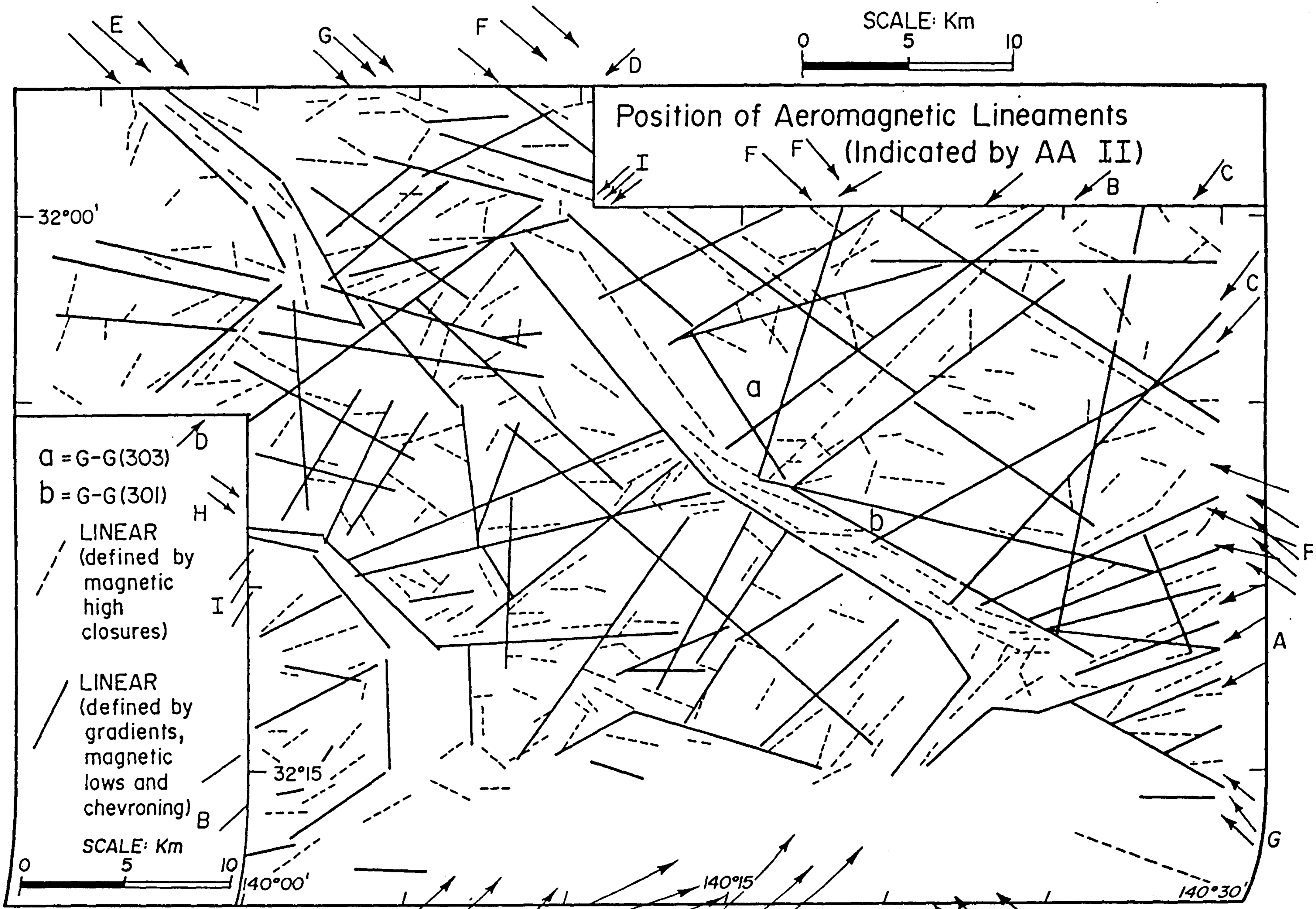

SCALE: Km
0 5 10
Position of Aeromagnetic Lineaments
(Indicated by AA II)
32°00'
32°15
140°00'
140°15
140°30'
a
b
A
B
C
D
E
F
G
H
I
a = G-G(303)
b = G-G(301)
LINEAR (defined by magnetic high closures)
LINEAR (defined by gradients, magnetic lows and chevroning)
SCALE: Km
0 5 10

Fig. 6.2

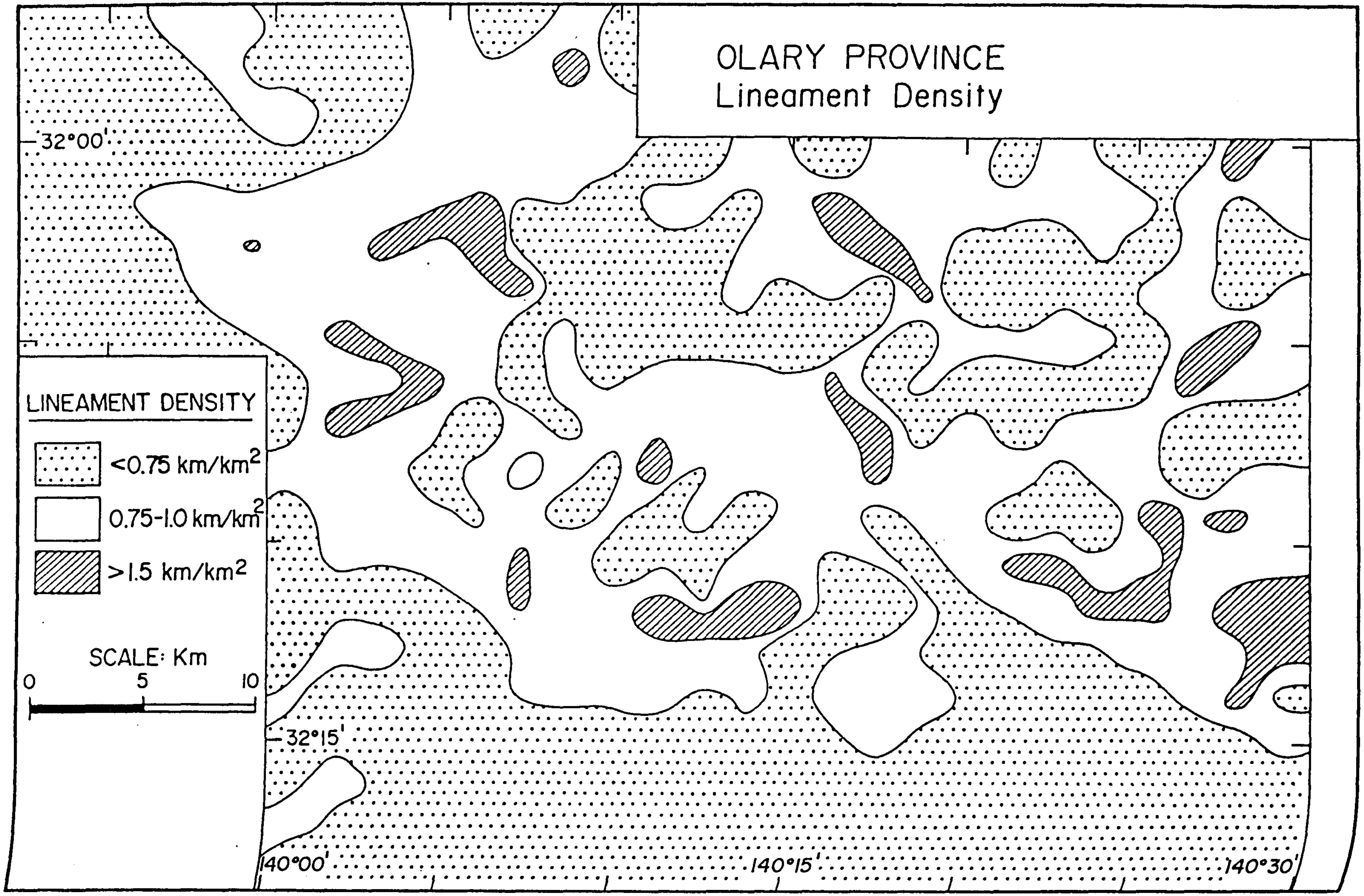

OLARY PROVINCE
Lineament Density
32°00'
32°15'
140°00'
140°15'
140°30'
LINEAMENT DENSITY
<0.75 km/km2
0.75-1.0 km/km2
>1.5 km/km2
SCALE: Km
0
5
10

Fig. 6.3

6.2.1 Observed Patterns

Figs 6.4, 6.5 and 6.6 represent relative azimuthal distribution of the lineament shown in fig 6.2. The diagrams are based on a frequency of the lineaments at each interval of 10 degrees. The following observations were made from the visual comparisons of the histograms:

(1) The most strongly developed directions for both long and short lineaments is the general northwest trend, centred at N300-310E. The trend is better developed in the longer lineaments than the short lineaments. It is due mainly to lineament sets E-E, F-F and G-G. These sets run across the entire Province following a northwestern direction.

(2) The second most prominent direction is at N50-70E. This trend is most pronounced in the long lineaments (fig. 6.5) than the short lineaments (fig. 6.6). It is composed mainly by the northeast striking lineament sets B-B, C-C, D-D and I-I which define the northwestern and southeastern boundaries.

(3) N310-330E is one of the best developed directions among the long lineaments (fig. 6.6). Set H-H also belongs to this group and resides on the southwestern portion of the Province.

(4) N30-40E is a high well defined peak for the long lineaments (fig. 6.5) and is clearly outlined on the total lineaments (fig. 6.4) and on the short lineaments (fig. 6.6);

(5) A consistent E-W trend is shown by short lineaments and on the total lineaments; and

(6) A N-S trend is the last important direction. It is one of the moderately high peaks of the histogram of long lineaments (fig. 6.5) but is a very weak peak when short lineaments are only considered (fig. 6.6).

6.2.2 Relationship of Lineaments to Plutonic Rocks and Migmatites

When fig. 6.2 is compared with the geology map in fig. 2.3 it can be observed that the distribution of the metamorphosed basic igneous rocks encountered around the Doughboy and Weekeroo areas, 1415·34 Kms.

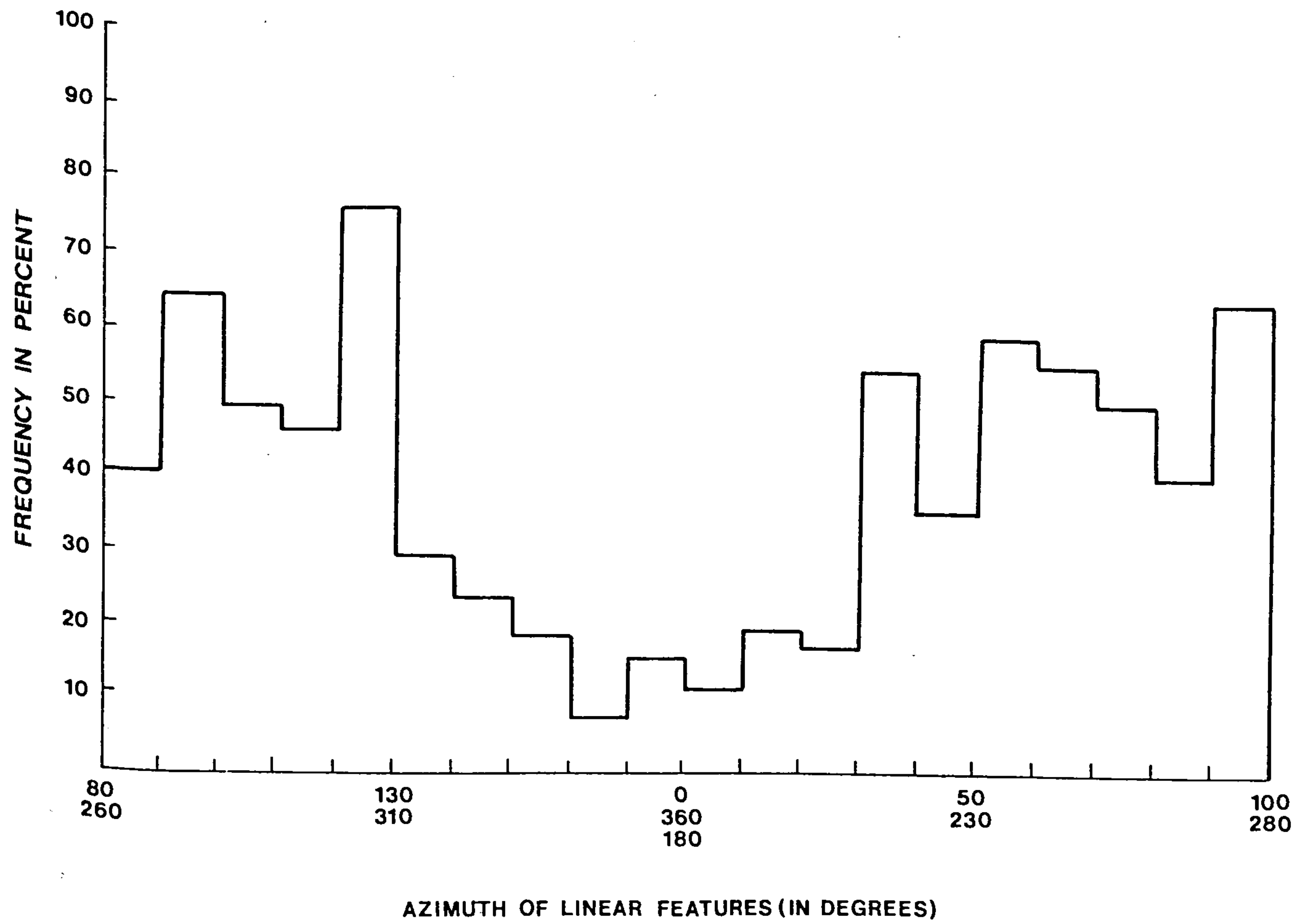


Fig. 6.4: FREQUENCY PLOT OF TOTAL LINEAMENTS.

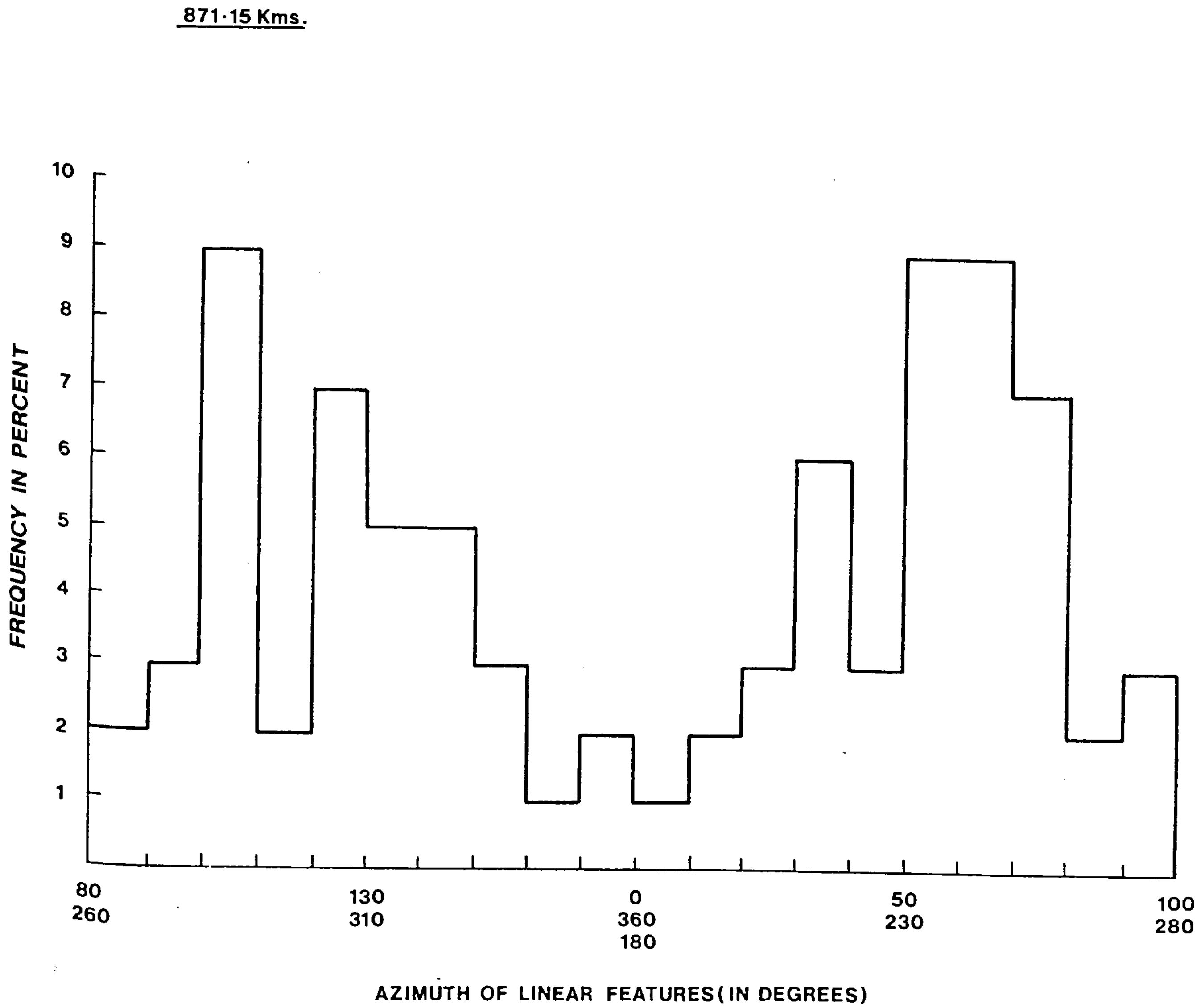


Fig. 6.5: FREQUENCY PLOT OF LINEAMENTS GREATER THAN 5Kms.

580·19 Kms.

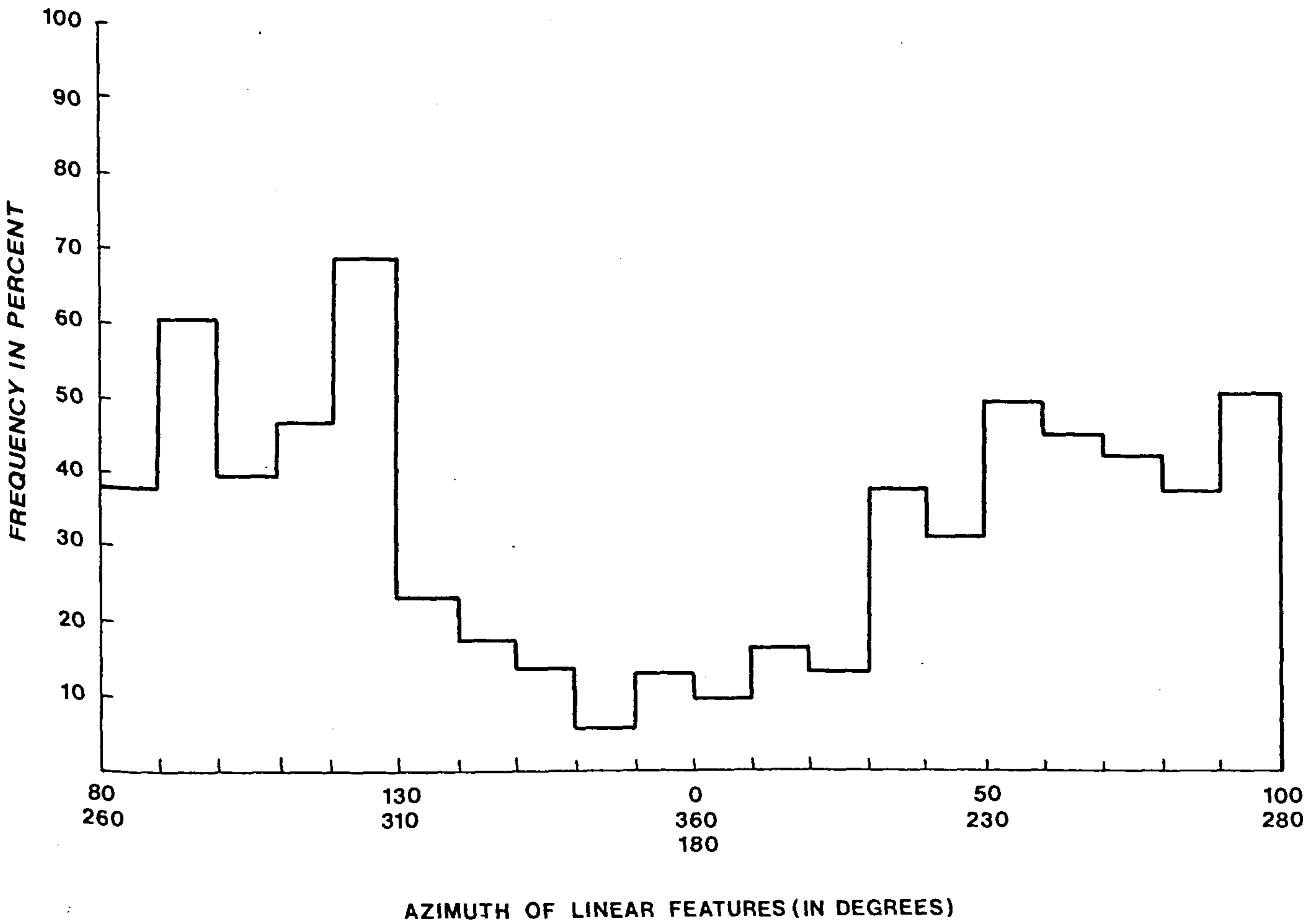


Fig. 6.6: FREQUENCY PLOT OF LINEAMENT LESS THAN 5 Kms.

appears to coincide with the lineament sets I-I (30-32) and E-E (311-314). In one case, the elongation of an individual body coincides with I-I (30). When the distribution of these basic rocks is compared with the lineament density map (fig. 6.3) its occurrence appears to be situated in the high-intermediate lineament density units.

The distribution of the albite rich foliated granitoids seems to be partly connected with the lineament sets. For example, the granodioritic gneiss west of Meningie Well appears to correlate with the sets F-F (294-306) and is elongated along B-B (52). In addition, the semi-concordant adamellite at Mount Mulga - Drew Hill coincides with B-B (52-57) and lies close to F-F (284).

The sets I-I (30-32) and H-H (315-321) coinciding with the Outalpa fault are the places where the concordant to partly intrusive tonalite gneiss occur. These foliated granitoid appear to be situated mainly in the intermediate lineament density units.

Acid intrusives occurring as undifferentiated granitoid bodies of granitic to granodioritic composition are frequent in sets C-C (42-60), B-B (58-74), F-F (294-306) and A-A (20-76). They show no preferred lineament density unit for their occurrence. The Calico Hill granite occurs on sets B-B (65) and F-F (306). A satisfactory division of granite to granodiorite rocks D_4, D_5 and D_7, fig. 4.1, does not exist. Wiltshire (1975, p. 95) related their occurrence at Boolcoomata to an intrusive, crystallized from a magma which was formed by the melting of the metamorphic rocks. Their further correlation with the lineament sets is premature. They occur mainly within the edges of the intermediate lineament density units. The migmatitic gneisses are developed within intermediate to low lineament density units on sets B-B' (51-76) and E-E (311-314), A-A (65-76), E-E (310-311) and G-G (299-325). Wiltshire (1975, p. 94) has suggested either an Eskola (1948) "mantle gneiss dome" origin for the migmatites and their nearby granite gneisses or an anatectic partial melt origin.

6.3 Relationship of Lineaments to Foliation, Lineation and Small Folds in Berry and Wiltshire Areas

The relationship between the lineaments and certain Proterozoic structures such as foliation, and small folds, are investigated in this Section using the geology data from Berry (1973) and Wiltshire (1975) shown in fig. 2.1 In this connection, foliation and lineation refer to the parallel linear orientation of minerals and mineral aggregates respectively (Turner and Weiss, 1963, p. 97; Ragan, 1973, p. 104; Wiltshire, 1975, p. 51). Lineation is associated with foliation and the linear feature is parallel to the plane of cleavage or schistosity (Billings, 1972). The fold axes were measured from small folds visible in single outcrops (Wiltshire, 1975; p. 53).

Geophysical considerations for this type of analysis have been encouraged from the general assumptions made by most geophysicists: that the long axes of magnetic anomalies is parallel to the lineation, gneissosity or foliation in the rocks which caused the anomaly (MacLaren and Charbonneau, 1968, p. 58; Krukihovskaya et al., 1973; Hood, 1972, p. 145; Hepworth, 1965).

When fig. 6.2 is compared with the geology map of the area mapped by Wiltshire (1975) in fig. 2.3 and the lineament density map in fig. 6.3, it is seen that the area is spanned to the north by the northeast striking lineament sets F-F (290-310) and G-G (290-330) to the south. The lineament set B-B (50-65) strikes northeast. Individual lineaments G-G (301) and G-G (303) (c.f. fig. 6.2) belonging to the northwest striking lineament set G-G coincide with the southern edge of the MacDonald Corridor (Pitt, 1971a).

The linear elements corresponding to crenulations show plunges of 30° and 50° in the plane of foliation whose maxima strike at 85°, 275° and 280°, and they dip at angles of 80° towards 175° and 88° towards 190° (Wiltshire, 1975, p. 66 and fig. 4.34). These correspond to the general directions of the lineaments G-G (290-330), F-F (290-310) and B-B (50-65) that span the area.

Measurements on the Boolcoomata adamellite D_4 (fig. 4.1) taken on trace of foliations on the surface by Wiltshire (1975, fig. 4.34) show the maxima striking 290°, 320° and 330° which are parallel to F-F. Poles of foliation around second generation folds of cover rocks show that strikes of 300° and 320° are also present. The three major lineament density units are found in this area.

The area mapped by Berry (1973) is covered by intermediate high magnetic lineament density units, where lineament sets I-I (30-40), E-E (310-330) and H-H (315-321) intersect. All the patterns of the structural linear and planar elements charaterizing the area are presented in Berry (1973, fig. 4). Berry mentions that the Lower Proterozoic metasediments contain penetrative foliations which are parallel to compositional layering (c.f. Berry et al., 1978). These foliations show prominant strikes of 20°, 60° and 90°. Slight maxima of foliation striking 40°, 80° and 330° are also present showing an easterly plunge. Fig. 4 in Berry (1973) shows strong linear element concentrations with an easterly plunge with foliation planes dipping 50°-60°. Other linear elements show weak distribution plunging between

40°-60° and striking 60° and 330°. Moderate plunges in places striking 70° are revealed in the Upper Proterozoic units. In the main, however, these linear elements are largely in the plane of the northeast foliations and have variable plunges.

The structural geology maps (fig. 4.34a in Wiltshire, 1975 and figs. 6 and 7 in Berry, 1973) by the author show that the dominant foliations are steep and on the average strike northeast and northwest parallel to the respective lineaments I-I and E-E in Berry (1973) and G-G and B-B in Wiltshire (1975). In each, the linear elements are in the plane of foliation and plunge steeply, 40°-88°.

Two patterns of steep foliation striking north-northeast are common in the areas. Wiltshire (1975) shows additional strong foliation striking northwest and dipping between 56°-84°. East-west striking foliations are occasionally present dipping from 31°-80°.

The directions given in the above paragraphs are derived partly from the structural geology map and partly from their accompanying stereonet plots. Detailed interpretation has not been considered as they are covered by these authors. However, several important aspects emerge, namely:

(1) Lineaments occur in narrow zones, in which foliations tend to strike parallel to them;

(2) A pattern of the linear structural elements around the magnetic lineaments seems to exist, characterized by deviations from the patterns between the lineaments (see for example, Berry, 1973, fig. 6); and

(3) Within the Lower Proterozoic rocks in the Old Boolcoomata area of Wiltshire (1975) and around Doughboy and Whey Whey River area of Berry (1973), a possible generalization can be made that the linear elements and their coinciding lineaments are characterized by similar foliation, lineation and minor folding that deviate from other corresponding ones in these areas.

From the foregoing, there is both direct and indirect evidence that the lineament sets and areas of high density lineaments represent surface structural expressions. Hepworth et al. (1967) who examined the structure of part of Uganda, drew attention in that area to the fact that the tectonic domain is characterized by such predominant lineation trends.

6.4 Relationship of Lineaments to Other Structures

The 1451.34km of lineaments shown in fig. 6.2 were used to compile the rose diagram (Williams, 1980), cartesian histogram (Gay, 1974), and a statistical table (Matyukhin et al., 1980) (see Table 6.1, figs 6.7a and b; 6.8a and b; and 6.9a and b). From all these, it is clear that:

(a) Two predominating overall lineament orientations are in the range N30-75E and N280-319E, centred on N35+/-5E, N60+/-5E, N284+/-5E and N305+/-5E;

(b) Most of the large lineaments (>5km) fall into the range N50-75E;

(c) In addition, a considerable proportion of the lineaments have orientations N75-100E centred on N75+/-5E and N95+/-5E;

(d) The directions N15E and N140E form additional structural elements;

(e) The results of the statistical processing of established lineament directions (fig. 6.7b, 6.8b, 6.9b and Table 6.1) show that the predominance of the northwestern directions over the northern directions is not so substantial, which suggests the significant role played by the northeastern trends in the structural plan of the Province;

(f) Lineaments trending approximately 90 degrees apart, namely:

N35E and N305E; N15E and N75E; and N146E and N56E are obvious from the histograms.

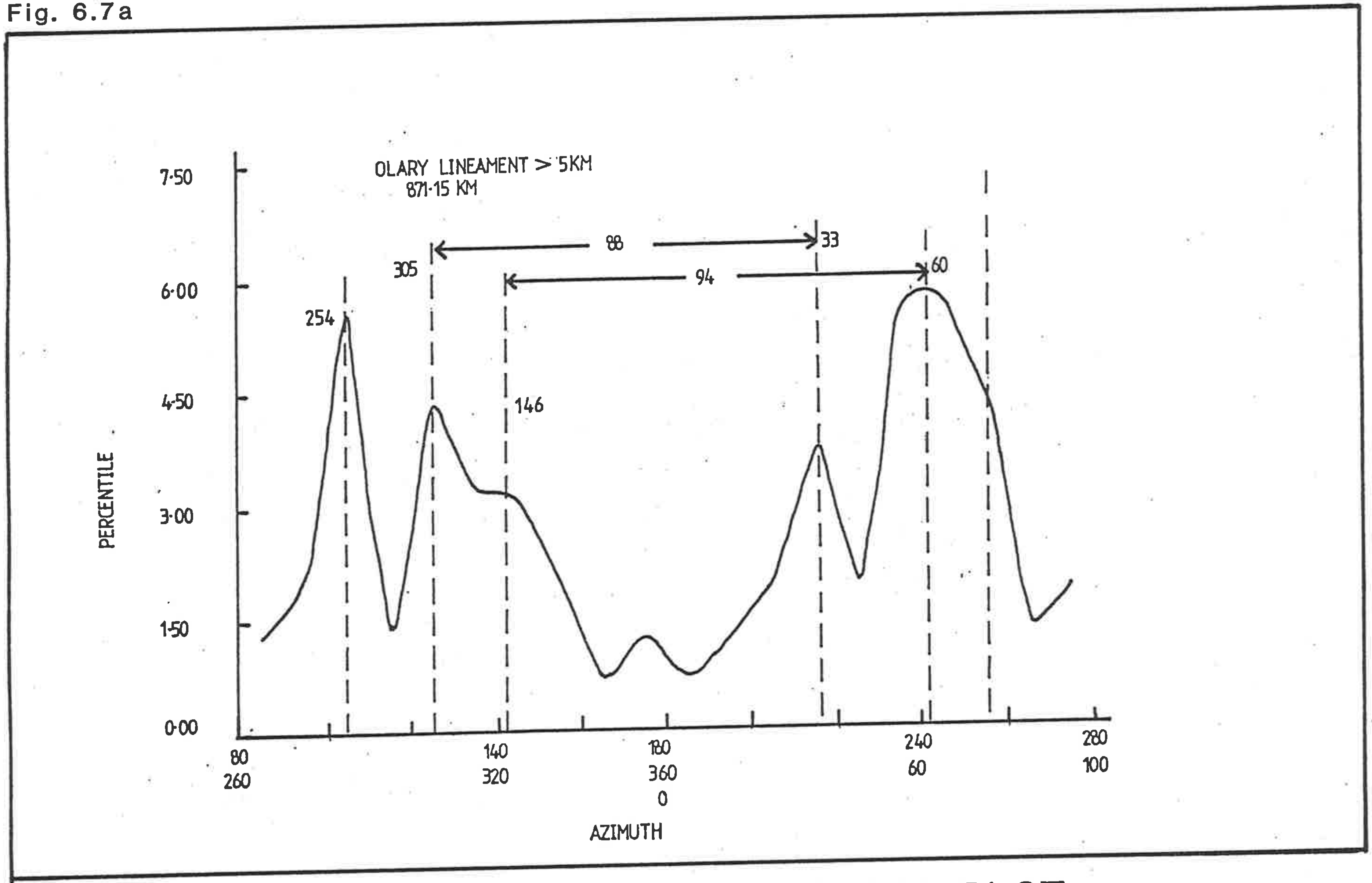
At Broken Hill Katz (1976, Table 1 and fig. 3) has recognised four prominent trends viz: northeast, east-west, northwest and west-northwest, and noted that they also coincided with trends from Landsat -1 imagery, airphotos together with compilation from published geological and geophysical maps. In the Olary Province of the present study, Katz's west-northwest direction is poorly represented as a magnetic lineament trend, but the northeast and northwest directions are closely similar to the orthogonal lineament directions in (f) above.

Earlier, King and Thomson (1953) grouped the major faults of the Willyama Complex into three types, namely:

(1) Northeast lineament set (ie, Mundi Mundi type);

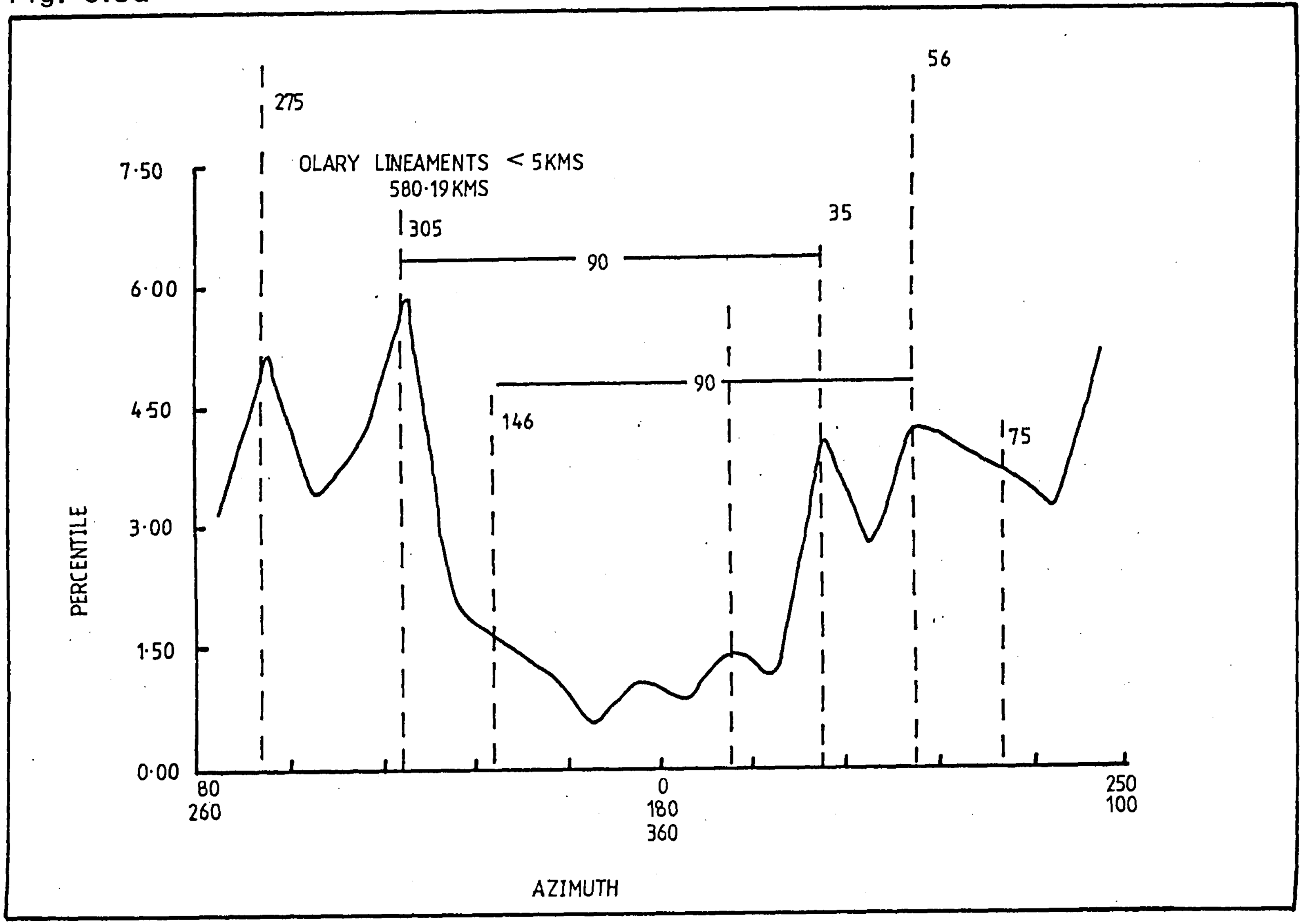
(2) East-west lineament (the Thackaringa type); and

Fig. 6.7a



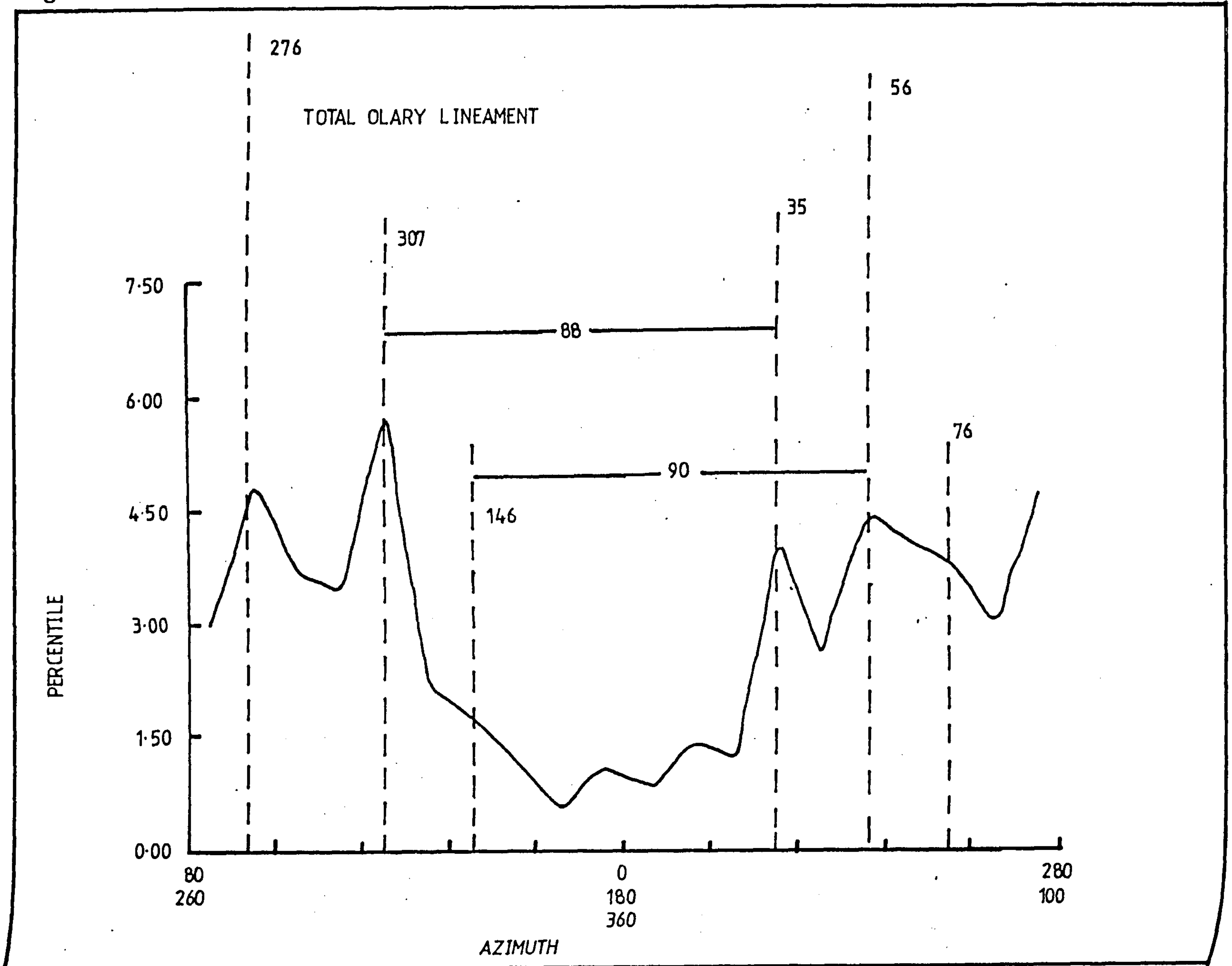
CARTESIAN FREQUENCY PLOT

Fig. 6.8a



CARTESIAN FREQUENCY PLOT

Fig. 6.9a



CARTESIAN FREQUENCY PLOT

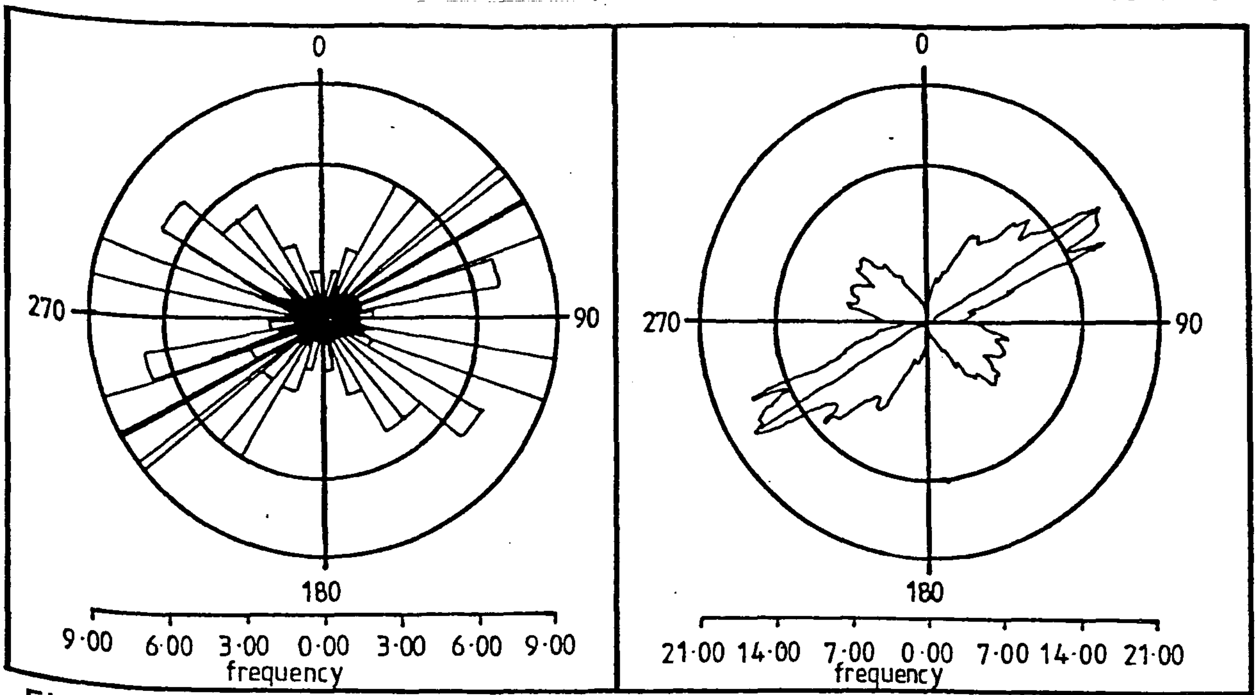


Fig. 6.7b OLARY LINEAMENT FOR DISTANCE GREATER THAN 5Km

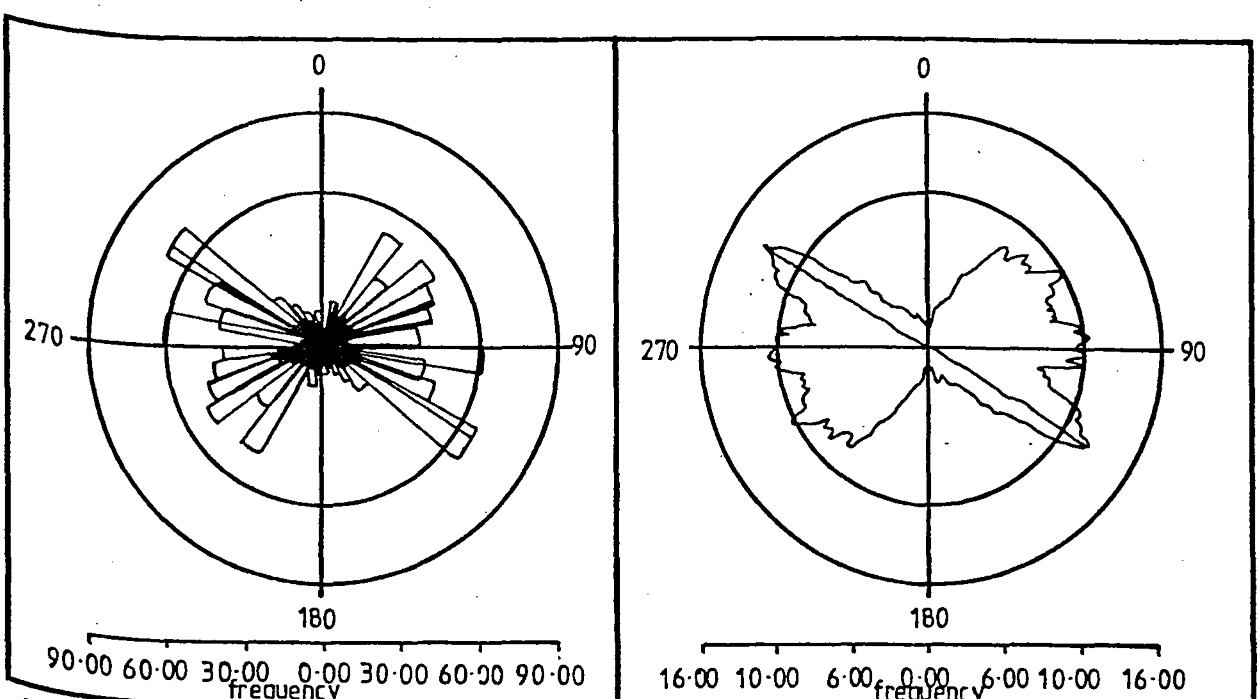


Fig. 6.8b OLARY LINEAMENT FOR LESS THAN 5Km

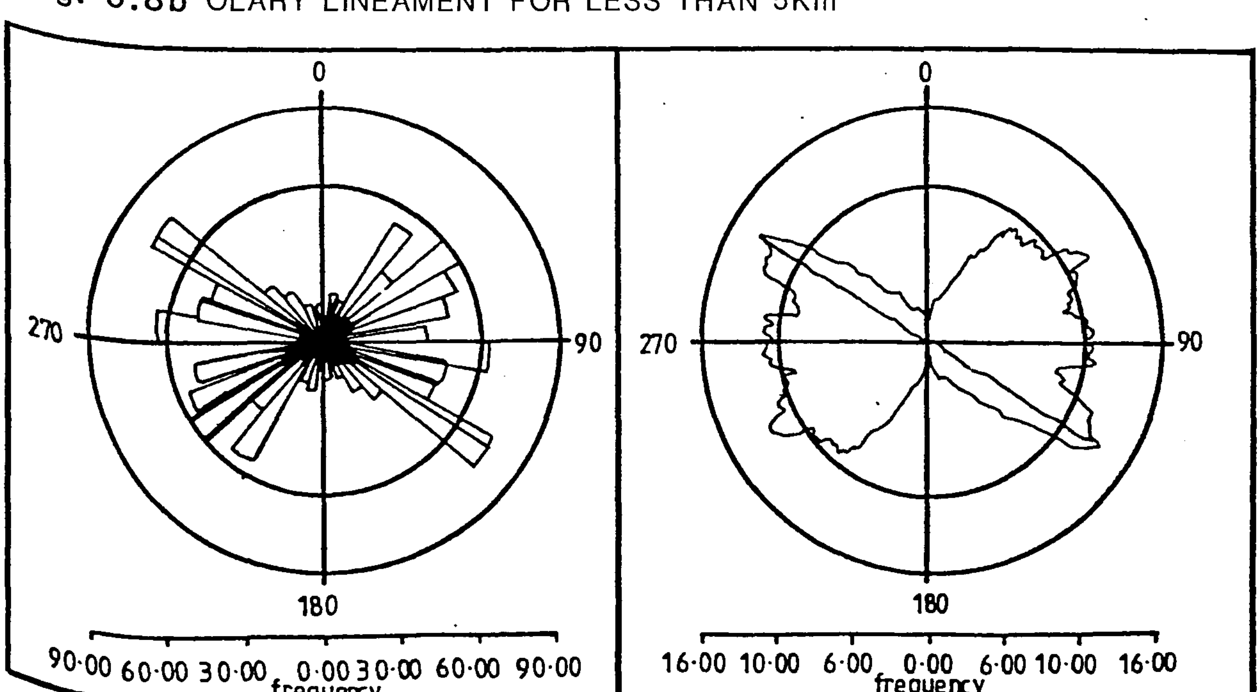


Fig. 6.9b OLARY LINEAMENT PLOT

TABLE 6.1

STATISTICAL PROCESSING OF LINEAMENT DIRECTIONS

	Lineaments > 5 km				
	NE NW	0-30 270-300	30-60 300-330	60-90 330-360	TOTAL
Percentiles	NE NW	4 9	11 11	11 4	25 24
Weight of Directions %	NE NW	15 37	42 46	42 17	
	All Lineaments				
Percentiles	NE NW	4 12	11 10	11 3	26 25
Weight of Directions %	NE NW	15 48	42 40	42 12	
	Lineaments < 5 km				
Percentiles	NE NW	3 13	11 9	11 3	25 25
Weight of Directions %	NE NW	12 52	44 36	44 12	

(3) Northwest lineament (the Debavay type).

The east-west trend is weakly represented, and this is due to the east-west flight-line traverses used during the survey of this area which acts as a filter that discriminates against east-west anomalies. The northeast and northwest trends are similar to the Broken Hill and Roxby Downs lineament sets of O'Driscoll and Keenihan (1980); Harrington et al. (1982) (c.f. Stewart and Boyd, 1983). Glen et al. (1977, p. 143) have noted that within the main part of the Broken Hill sub-domain of the Willyama Complex the northeast trending Shears are most prominent. In addition, Firman (1974, fig. 4) has demonstrated a predominant northeast and northwest trends on airphotos for the whole of South Australia. The system also conforms with the suggested world-wide foliation and fault trends of the Pre-Cambrian shields proposed by Badgley (1965, p. 498), and also the northeast trends conform to his Proterozoic orogenic trends for Australia (see ibid p. 397, fig. 11.32). A similar northeast trend for preferred strikes of folded zones has been suggested for Australia and the whole world by Beloussov and Dimitriyeva (1981, p. 1365 and 1384, figs. 2 and 3a).

Some intrusive bodies are elonaged parallel to lineament sets, for example I-I (30) and B-B (62) lineament sets. This may indicate that they are surface manifestations of deep faults which were active during the Pre-Cambrian time. If indeed the suggested "mantled gneiss dome" of the Boolcoomata adamellite is true (Wiltshire, 1975), their mode of occurrence could be connected with lineament tectonics.

Dispersion exists on the rose diagram for both the total lineaments and the lineaments less than 5km (figs. 6.7a and 6.8a). This may be related to the heterogeniety in the rock structure or characteristic arising as a result of local variations in the structural response of differing rock materials developed or a combination of structural responses due to successive non-uniform tectonic episodes (c.f. Lathram and Albert, 1974, p. 22). If this is so, it could be related to the swing in the Olarian and Adelaidean fold trends from meridianal through northeast southwest to east-northeast west-northwest, as one progressed from north to south in the Willyama Complex (Glen et al., 1977, p. 143). The abundance of lineaments less than 5km (fig 6.8a) may further suggest that they constitute a "tectonic noise" which must be filtered out in order to achieve a regionally significant concept. As a result three orthogonal pair sets have been abstracted from the Cartesian histograms (figs. 6.7b, 6.8b and 6.9b) and the result is shown in figure 6.10.

6.4.1 Major Lineament Trends in the Olary Province

By way of comparison, when fig. 6.10 is compared with fig. 6.3 (the lineament density map) it is observed that the lineament density units seem to convey some structural meaning. The zone of the high and intermediate density units may be fractured as revealed by the criss-crossing patterns located within these areas. The criss-crossing pattern of the deformations may belong to a country-wide structural pattern (see O'Driscoll and Keenigan, 1980). In the Broken Hill District up to 150km northeast of the Olary Province, Stewart and Boyd (1983, p. 19, fig. 8) have demonstrated the presence of what may be regional discontinuities in the basement. The main features (as shown in figs. 6.3 and 6.10) are:

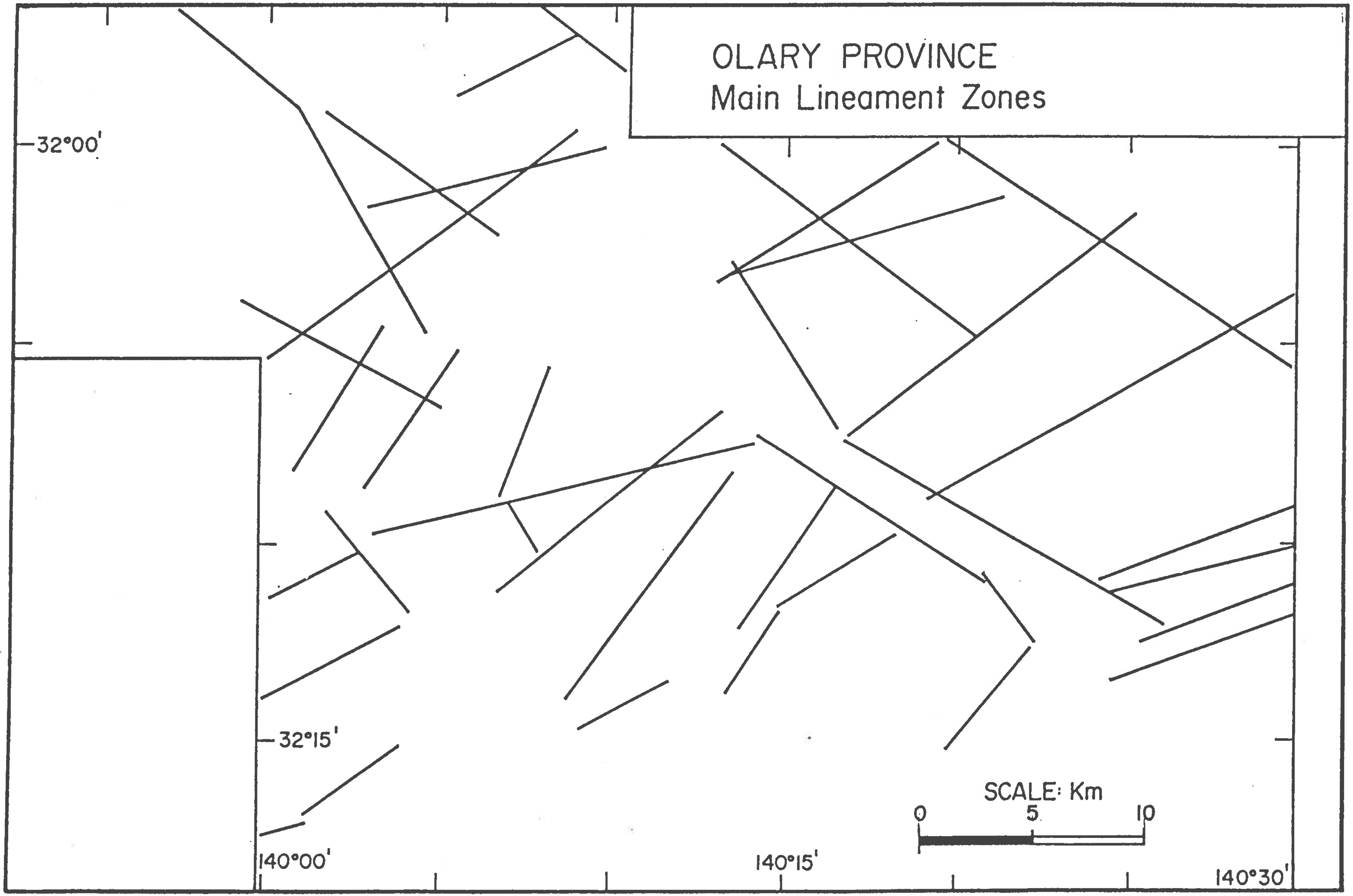
(a) Numerous lineament systems split the Olary Province into different polygonal blocks;

(b) Lineaments with northeast strike constitute a belt in the northwestern portion around the Whey Whey River area, and lineaments of east-northeast strike define another belt around the MacDonald Hill and Bulloo Creek area; other lineaments of similar strike exist in the south-west and central portions of the mapped area;

(c) Across the map area, a wide northwest lineament belt occurs and intersects the northeast trending lineament belts, in the Ameroo, Boolcoomata and Whey Whey River area. This trend coincides with the zone of the MacDonald fault system extending between the MacDonald Hill to the southeast and Bimbowrie to the northwest for approximately 35km. Southwestwards in the vicinity of the Outalpa fault, slight curvature displayed by these two lineaments is assumed to be related to the reported thrust faulting; other northwesterly trending lineament systems exist in the northeast portion of the map area; and

(d) Some granitic and other rocks are found along some of the lineament zones which add to the prominence of the block structure of the Province.

In the Olary Province, the Willyama Complex shows predominantly northeast trending folds with variations towards the east-northeast around Drew Hill and Bulloo Creek (Thomson, 1969, 1974; fig. 4; Tectonic Map of South Australia; Flint and Parker, 1982). The northeast and northwest directions in particular has been mentioned by Katz (1976) as contributory to the initiation of the Adelaide Geosyncline.



OLARY PROVINCE
Main Lineament Zones
32°00'
32°15'
140°00'
140°15'
140°30'
SCALE: Km
0
5
10

CHAPTER 7
Reconnaissance Gravity Data in the Olary Province

7.1 Scale of Gravity Survey and Problems of Their Interpretation

The size of geological units recognised increases with decreasing scale of survey. Structures must be separated from each other by a distance of more than their depth before their anomalies can be told apart on a gravity data (Romberg, 1958, p. 687).

The Bureau of Mineral Resources (BMR) gravity survey in the Olary Province was done at 7km data intervals. In addition, Pecaneck (1975), McIntyre and Wyatt (1978), Isles (1983) and Tucker (1983) show that the densities of rocks of the Willyama Block and the Adelaidean system sediments do not vary much so that surveys with closer station spacing are needed in the Olary Province to portray the subtle features that have been observed on the magnetic map. The scale of survey, as it is at present (fig. 7.1), is most suitable for regional geological and crustal studies.

Information on the crustal structure at depth such as will satisfy the requirement of such studies can be obtained from deep seismic sounding data. But the Olary Province has thus far not been studied by this method so that it has only been possible to use highly schematic constructions based on considerations of the gravity data. In consequence, not much contribution from the gravity data to the detailed magnetic interpretations will be expected.

Measurements recorded on fig.7.1 were reduced to complete Bouguer gravity anomalies using an average density of 2.67gm/cm^3 for rocks above sea level (Anfiloff et al., 1976; and Gerdes, 1975). The data was then presented on a 1:250,000 scale Bouguer anomaly contour map at a contour interval of 2mgals. The area covered corresponds with the magnetic field map shown on fig. 4.2 and the Curnamona area to the north and the Oakvale area to the south.

7.1.1 Fractures from the Gravity Method

Geophysical methods are best suited for ascertaining structures and specifying vertical and horizontal displacements of blocks. The criteria used are gravity and magnetic steps (Cordell and Grauch, 1983; Linsser, 1967, p. 500), change of the character of isoanomaly lines on opposite sides of the structure, and local linear magnetic and gravity anomalies along these structural zones.

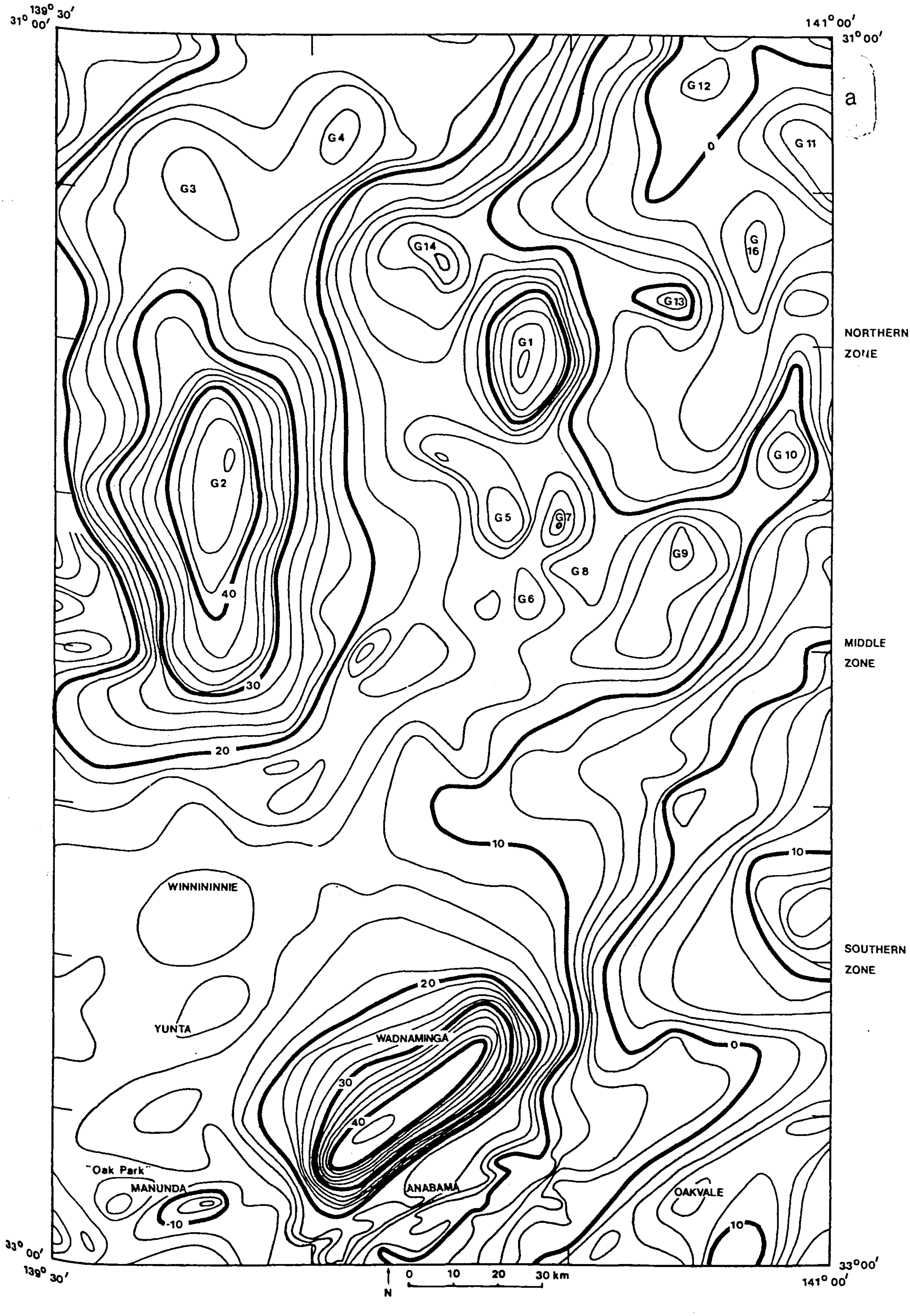


Fig. 7.1 BOUGUER GRAVITY MAP OF OLARY AND CURNAMONA, SOUTH AUSTRALIA. Density : 2·67gm / cm³. S.A.D.M.E., 1975.

The vertical density displacement boundary across an entire crust of say 35km with a density contrast of $0.01m/cm^3$ say, results in a gravity step with an amplitude of 14.7mgals (Tyapkin, 1980, p. 936). Thus, wherever there is a relative displacement in the earth's crust even if further erosion of the upthrown block occurs gravity anomalies of the step type occurs. The characteristic feature of this type of anomalies is the consistency of their strike and their lateral extent.

The gravity difference (A) between the upper and lower asymptotes of the gravity effects reminiscent of these structural charateristics can be calculated (Sherrif, 1978, p. 27, fig. 3.5). The difference is related to the thickness, h of the anomalous mass and the anomalous density P by the relationship $A = 0.04191ph$ metre gm/cm^3. The value obtained by this operation is analogous to the "E" (effect) of Linsser (1967, p. 500). The problem, however, is that not all structures are characterized by the gravity steps.

7.1.2 Main Features of the Method Used.

The determination of the main tectonic directions consisted of three steps. First, the gravity difference between the lower and upper asymptotes were determined, then the difference was related to anomalous mass and density, and in the third step, a line was drawn at each calculation point perpendicular to the fault direction and the position of the maximum slope was marked. This procedure was executed for all the north-south and east-west gravity profiles. At each point an element of the fault in the direction of the fault was drawn. The procedure was repeated for all calculation points. The various fault elements almost formed continuous lines indicating the fault system in the area under consideration.

The clarity of the tectonic map was achieved by giving symbols of the size corresponding to the throw of the individual fault. The symbol size used is proportional to the value of the "E" (effect) factor (Linsser, 1967). The scale factor was governed by the smallest and extreme values of "E" in the study area. If two symbols obtained from two different calculation points almost coincided, the mapping area was simplified by drawing only one symbol between the two. In such cases, the size symbol was the mean value of the two "E" values.

7.1.3 Results

Figure 7.2 summarises the results obtained from the Bouguer anomalies in the Olary Province. The following observations seemed immediately apparent:

(a) Some faults which belonged to the same trend showed opposite directions of density contrast along strike; and

(b) The amounts of displacements varied both within and between faults.

The zones of steeper gravitational gradients were then interpreted as boundaries of basement block and these were joined to produce (fig. 7.2). One reason for doubting the fracture may be their close spacing which may be the result of superposition of one system upon another. To rule out doubts, it is proposed to compare the result of the study from the gravity data with those from the magnetic lineament studies.

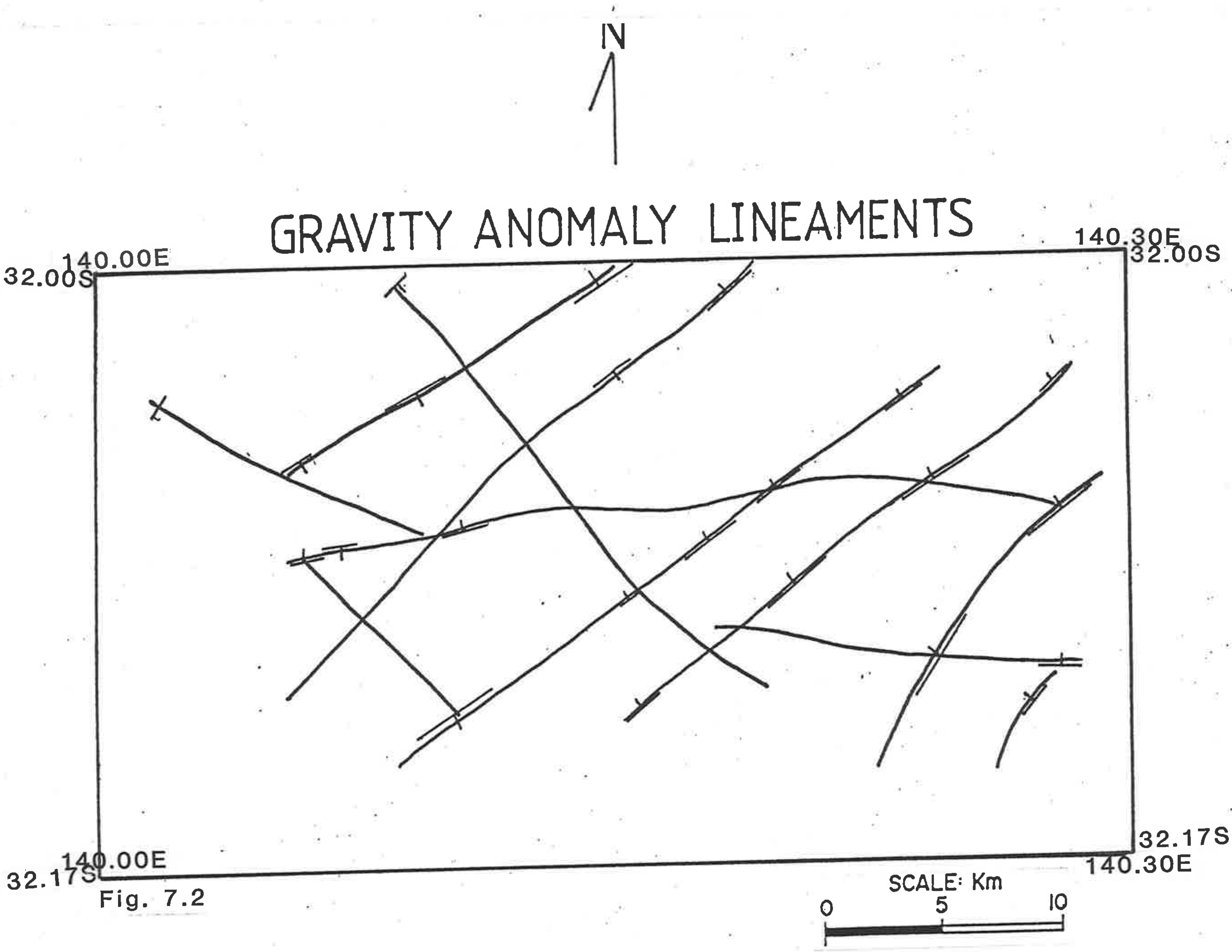
In the gravity field, the MacDonald fault appears fragmentary and as such, not clearly manifested in fig. 7.2. This applies also to the Outalpa fault which does not span all its length in the gravity map. Recall that the Adelaidean sediments which fill these sutures show no appreciable density contrast with the Willyama basement rocks. A roughly east-west trending feature extending for a long distance is conspicuous in figure 7.2. This is not clearly manifested in the magnetic field and is lacking in fig. 6.10.

In conclusion, an unbiased use of gravity data provides objective criteria for investigation of structural tectonics, but consequent use of both gravity and magnetic methods might give more valuable results.

7.2 Possible Correlation of Gravity and Magnetic Data for Optimum Geological Interpretation

A particularly weak link in this type of interpretation is the low denisty of the available gravity stations. It becomes ever more obvious that an understanding of the geologic conditions from the gravity data of the Province furnishes a clue to the information on the composition and structure of the Olary Province and will provide valuable support for the magnetic interpretation. Only by means of a comprehensive study can one obtain a reliable knowledge of the deeper geology of the Province.

Unlike magnetic maps, gravity maps can and usually do contain anomalies having their sources over a wide range of depths from near surface to very deep within the basement rocks. This means that before quantitative analysis of gravity anomalies and accurate relation of such anomalies to geological disturbances can be carried out, it is first necessary to isolate or separate out the anomaly itself from the


N
GRAVITY ANOMALY LINEAMENTS
140.00E
32.00S
140.30E
32.00S
32.17S
140.30E
140.00E
32.17S
SCALE: Km
0
5
10
Fig. 7.2

background. The separation of these anomalies into long wavelength and short wavelength anomalies, in spite of all its short-comings, independently aids the interpretation of the relatively shallow and deep structures.

Further, any interpretation of the short wavelength anomalies (which are presumably due to density contrasts at or near the surface) will undoubtedly place constraints on the intrusive bodies.

The geometrical properties of the fractures, viz the depth of formation, their extent along strike and width of the zones of external manifestations, would be better revealed by the long wavelength anomalies. These three parameters are inter-related by laws governing deformations in the earth's crust. None of this detailed work however was possible because of the absence of close spaced gravity station.

CHAPTER 8
GEOPHYSICAL CHARACTERISTICS FOR ORE EXPLORATION, AND THE SEARCH TARGET MODEL AND PHILOSOPHY IN THE OLARY PROVINCE

8.1 Introduction

The interpretation of the aeromagnetic map in geological terms can be used to identify targets for mineral exploration. Iron ores are the only economic deposits that commonly produce magnetic anomalies large enough to be detectable from the air. For other minerals, as in the case of the Olary Province, it is necessary to study the aeromagnetic contour maps over known deposits and to characterise that deposit in terms of its association with geological features that may be distinguished on the aeromagnetic map, eg, igneous intrusions, a particular fault direction or with the intersection of faults and/or intrusions.

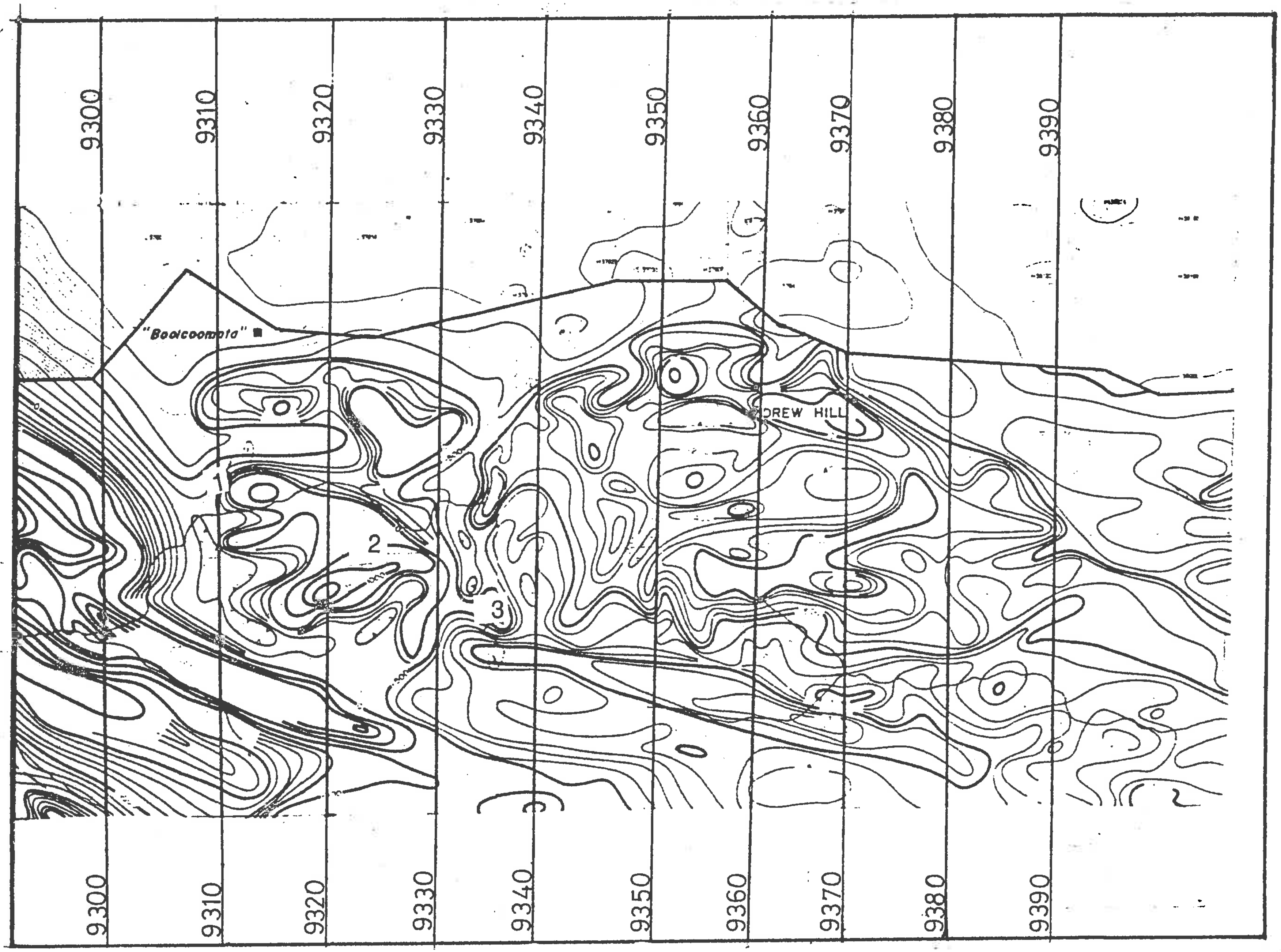
8.2 Geophysics and Geology of Copper Ore in the Olary Province

(Woman in White, Lady Louise, Old Boolcoomata (Raven Hill) and Mount Mulga Mines).

This group of deposits is located in the Old Boolcoomata schist zone. The general strikes in the Lady Louise and Woman in White Mines are east-west and east-northeast respectively. The geology of the area has been described by Campana and King (1958), and Wiltshire (1975), while the geophysics has been described in 5.2.

The cupriferous deposits are chiefly represented by weak and sporadic sulphide replacements along bedding plane and joint openings. In the Woman in White Mine just 2.8km south-southwest of Old Boolcoomata Homestead the productive workings consist of a deep open-cut in albite schist on the normal limb of an anticlinal drag fold. These carry low-grade disseminations of chalcopyrite and gold, and secondary copper minerals, covellite, chalcanthite, tenorite, malchite, azurite and native copper. At about 2.4km to the northeast of the Mine, copper stained rocks are interbedded with some schistose rocks, and have been prospected by small open-cut. The aeromagnetic contour map (fig. 8.1) shows that the areas of mine location are defined by the 500 gamma contour, and it can be seen that an irregular shaped feature encloses the deposits between tie lines 9310-9340. A zero contour line encloses the deposits at Lady Louise and the Woman in White Mines.

Figure 8.1 Aeromagnetic contour map of 1) Lady Louise, 2) Woman-in-White, and 3) Mount Mulga mine areas (photo reduced from the 1:50,000 scale contour maps).



The anomaly as defined by the contour lines indicates that nearly any traverse across the area will show several magnetic crests, commonly three. The width of the anomaly is 2.75km (northwest) and the peak value of the zone extends for 1.9km. The width and the appearance of several crests suggests either several magnetic beds or more probably one magnetic bed repeated by folding which is consistent with the close-folded nature of the structure disclosed by detailed structural mapping of the area by Wiltshire (1975). The anomaly directly north of the above feature, but south of Boolcoomata, is sub-parallel to the east-west axis of the mapped fold structure in this place.

The magnetic anomaly in the east, between tie lines 9340 and 9390 (D_{10},figs 4.1, 4.2 and 5.1) is more complex and less easy to interpret. The somewhat "spotty" anomalies outlining the central complex feature is closely related to schists and quartzites surrounding to overturned folded core of the older migmatites and granite gneisses of Wiltshire (1975) (c.f. 5.2).

Another magnetic feature of interest includes BF_1 (fig. 4.1) which lies in the southern part of the complex anomaly pattern (D_{10}, fig. 4.1). BF_1 is expressed here by roughly east-northeast trending anomaly feature between tie lines 9330 and 9380. This structure appears in profile on a number of lines as a negative feature (5.2) with distinctive positive to the north side. One other prominent feature is the magnetic low at the southwestern end, (along tie line 9310) which trend northwest. It is considered to be a complementary low to the anomaly features between tie lines 9310 and 9330.

Estimates made on the anomalies on tie line 9320 are tabulated on Table 5.1 and the results are shown in figure 4.7.

8.2.1 Putt Well and Lady Mary Mines

The Putt Well Mine described by Campana and King (1958) is situated sixteen kilometers northeast of Old Boolcoomata Hill Station.

The main copper values were found at the southern end of the open cuts. The metasediments are intersected by a narrow pegmatite carrying scattered disseminations of pyrite, chalcopyrite, bornite and traces of molybolenitc, the leaching of which has led to the formation of secondary concentrations of copper carbonate in a biotite gneiss footwall. The main types of ore are malachite and very low gold values in joint planes.

The aeromagnetic data is shown in fig. 8.2. The anomaly in the area of overlap between the two surveys (Appendix A) is clearly due to

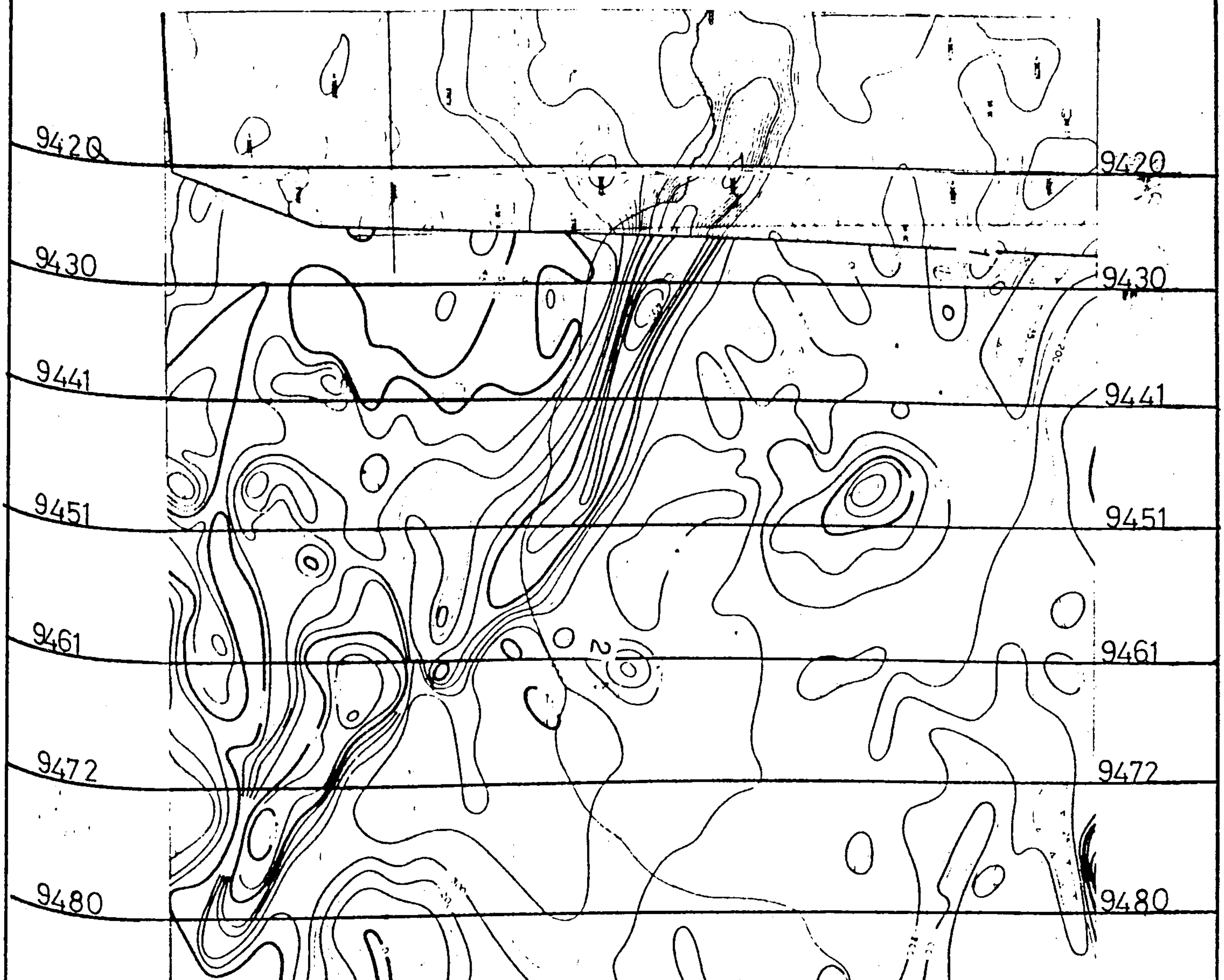


Figure 8.2 Aeromagnetic contour map of 1) Putt Well, and 2) Lady Mary Mine areas (photo reduced from the 1:50,000 scale contour maps).

the rocks surrounding the Putt Well deposit. Where the anomaly is located over quartz muscovite schist (Pws_4) it follows the east-west strike. This relation is best shown on Survey D on the west side of 9430. The airborne anomalies are not suitable for analysis within this area.

The Lady Mary Mine (and the associated quartzite (Pwq) and calc-silicates) is characterized by an ovoid-shaped anomaly. The principal anomaly is about 300 gammas in amplitude and falls along tie line 9461. Another obvious feature of the magnetic map here is the magnetic anomaly intersected by tie line 9451 which lies between the above deposits. It is bigger than the anomaly at the Lady Mary Mine but it shares similar texture. The anomaly is almost elliptical in shape with its long axis trending northwest. The long axis is 2km while the short axis is 1.25km. Low gradient features and some magnetic lows surround the anomaly, of which one of the lows lies between it and Lady Mary Mine anomaly between 9451 and 9461. Similar rocks types as found in Lady Mary Mine underlie the anomaly. All these anomalies are near D_1 (fig. 4.1) that has been discussed in 5.2.

8.2.2 The Green and Gold Mine

The Green and Gold Mine deposit, (see aeromagnetic map fig. 8.3), is located in the area of no outcrop. It is situated 2.4km northeast of the MacDonald Hill Siding. Schists (Pws_4), quartzites (Pwq) and migmatite (Pwc) have been mapped around it.

A shallow open-cut has been sunk on a vein containing magnetite, chalcopyrite and malachite of up to 3m wide intersects a thick body of ironstone. On the southwest face of the workings, the vein is narrow and carries visible flakes of gold (Campana and King, 1958).

The amplitude of the anomaly on tie line 9472 is 600 gammas. It is flanked on the north by a 100 gamma low that trends northeasterly. The presence of banded ironstones and magnetite contained in the vein is therefore the most likely cause of the anomaly. The complex high amplitude anomalies correlate with the quartzites and the migmatites (see 5.2).

Computations on the anomaly within the deposit area on tie line 9472 is shown in fig. 8.3b and results obtained are summarized on Table 8.1.

8.2.3 Peryhumuck and Ameroo Mines

The Peryhumuck Mine is 6.4km southwest of Old Boolcoomata Hill Station. Three large pot holes sunk there revealed a malachite stained

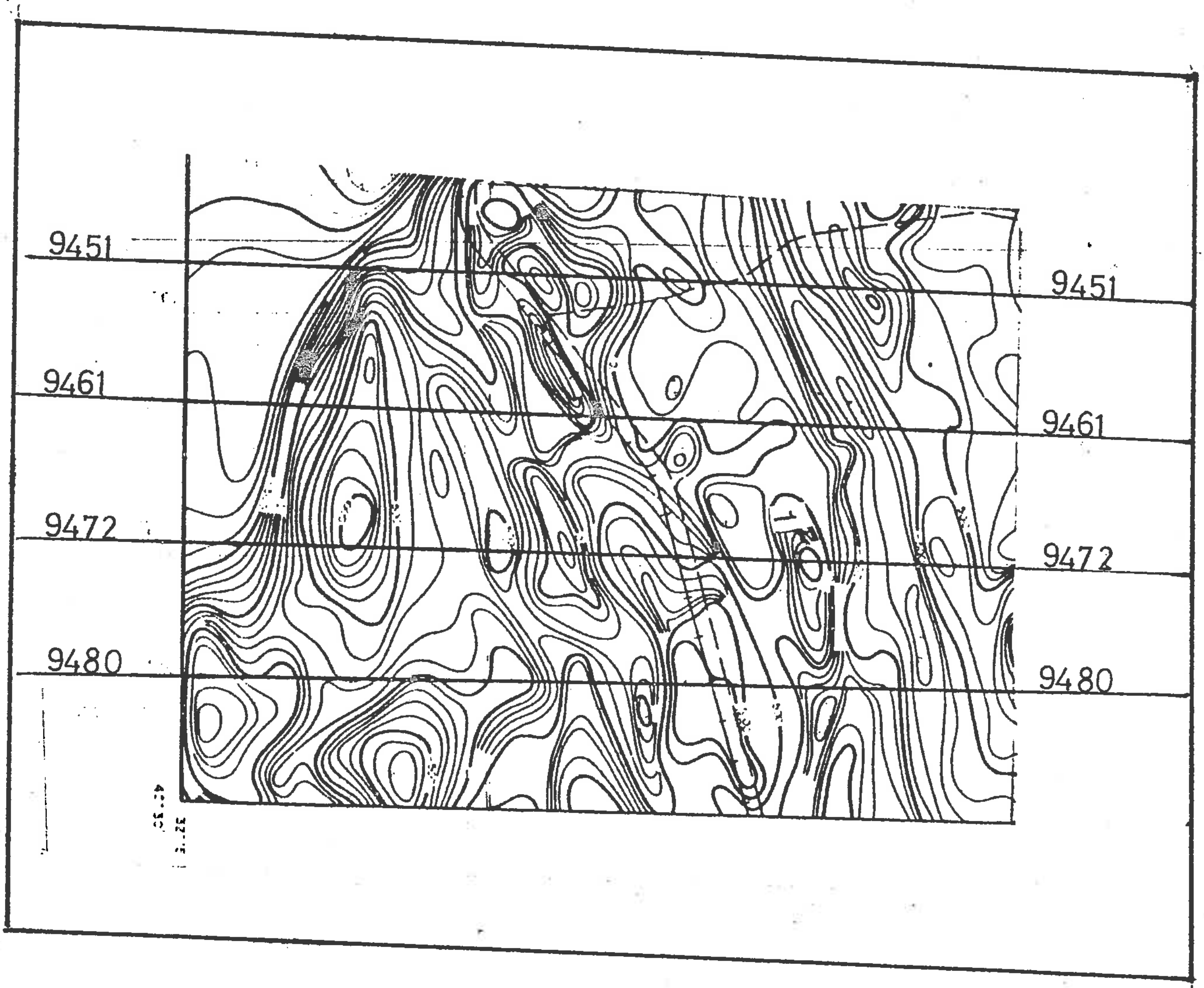


Figure 8.3a Aeromagnetic contour map of the Green and Gold Mine area (photo reduced from the 1:50,000 scale contour map).

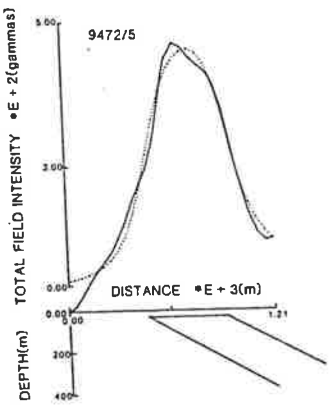


Figure 8.3b Two dimensional magnetic modelling of the magnetic anomaly around the Green and Gold Copper deposit.

TABLE 8.1

MAGNETIC PARAMETERS FROM MAGNETIC MODELLING

DISCUSSED IN CHAPTER 8

Flight Line Number	Anomaly Location on Flight Record (Northlings)	Parameters Estimated				
		Suscept-ibility (CGS Units)	Dip (Degrees)	Depth Below Surface (M)	Width (M)	Centre (M)
9472/5	6426246-6427453	0.004	28°N	30	470	700
9340/1	6421649-6423055	0.004	50°N	120	500	460
9340/2	6422824-6424197	0.003	62°N	100	330	610

NOTE: Parameters for depth, width and centre have been rounded off layer of magnetite-pyrite-actinolite rock in an ironstone bed. Chalcocite was observed in samples from the pot holes as an interstitial filling between magnetite and pyrite.

Another deposit lies southwest of this near Ameroo Hill. Small test holes in malachite stained amphibolite and cupriferous schists have been found there. D_2 isoclinal fold occur between Bimbowrie Hill Station and Ameroo Hill. Closures of these folds have generally been removed by faulting or post Willyama erosion and only parallel limbs are preserved (Forbes and Pitt, 1980).

Outcrops in the general vicinity are scarce but mapped geology around the area indicates that schists (Pws_4), layered gneisses (Pwg_5) form the main bedrock geology. Some banded ironstones and migmatites are also recorded on the geology map (fig. 2.3).

The largest total intensity (figure 8.4) anomaly is the elongated high amplitude (>1000 gammas) anomaly situated at some 500m northwest of these deposits and striking northeast. Northwest of this feature between tie line 9240 and 9260 is another high amplitude anomaly of similar trend (5.3). An almost ovoid-shaped anomaly node is located between 9250 and 9260 on this anomaly. Drilling around Ameroo shows that amphibolite is stained by malachite. As there is no outcrop in this area, the anomaly is probably due to both amphibolite and schist.

Results obtained from quantitative analysis on tie line 9260 are shown on figure 4.7 and Table 5.1.

Areas of markedly irregular contours and low magnetic intensity are present just south of these high amplitude anomalies (5.3).

8.2.4 Mount Bull Mine

According to Campana and King (1958), the Mount Bull Mine is located 9.6km north of Old Boolcoomata Homestead. A deep shaft and two open excavations were sunk on low grade impregnations of chrysocolla in quartzite, on the footwall of a massive banded hematite body forming the pinnacle of Pimpena Hill. On the surface evidence it would appear that no saleable ore was produced.

The principal rock in the Mount Bull area is massive layered gneiss (Pwc) with some mapped iron formation. Granodioritic rock of Calico Hill D_6 is in faulted contact with this unit around the Mine.

The aeromagnetic contour map illustrated in figure 8.5 shows that only a small circular anomaly high could be related to this deposit. A uniform magnetic gradient contour pattern characterized the outcrop with distinct discrete magnetic lows surrounding the high on

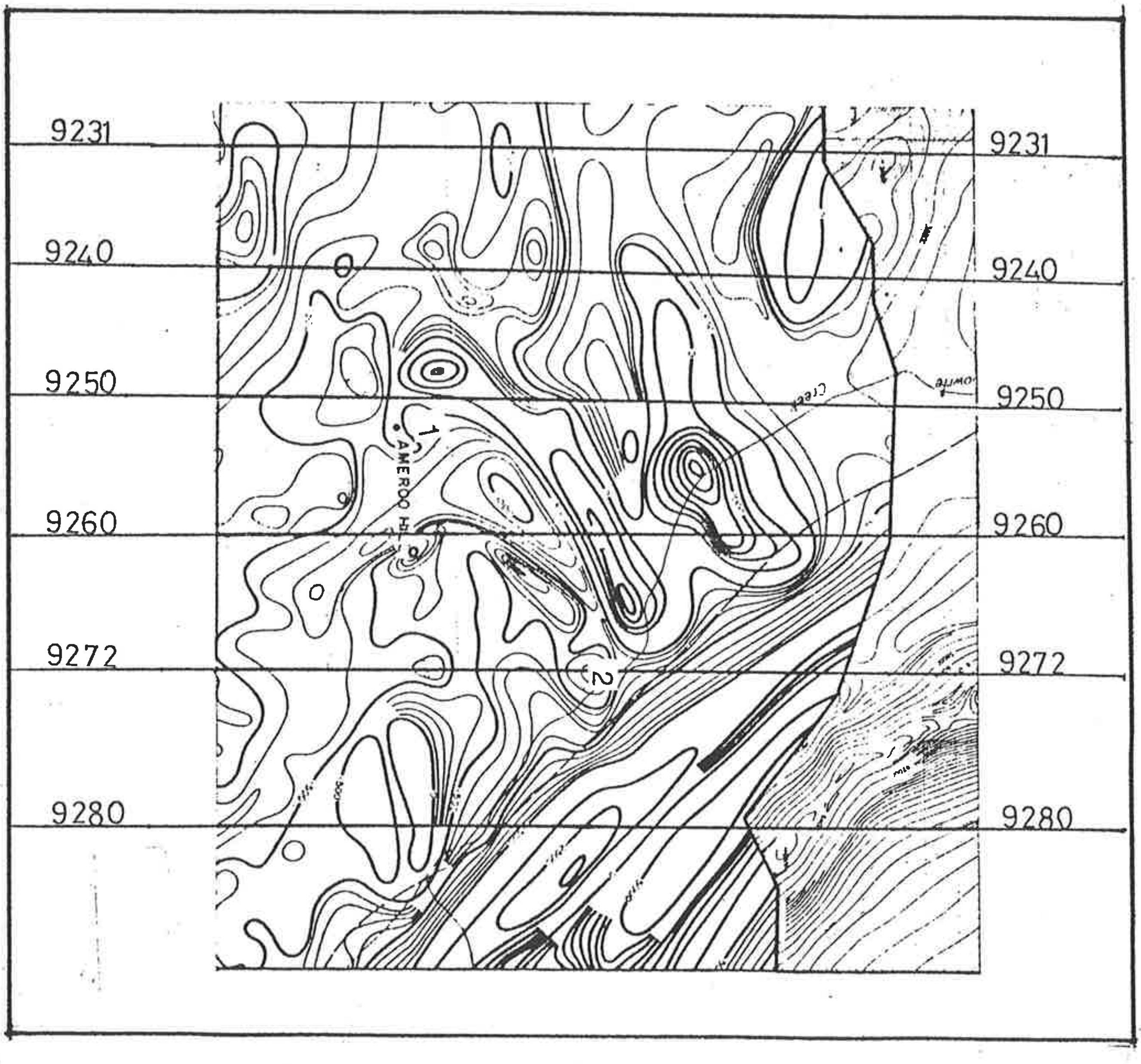


Figure 8.4 Aeromagnetic contour map of 1) Ameroo, 2) Peryhumuck mine areas (photo-reduced from the 1:50,000 scale contour map).

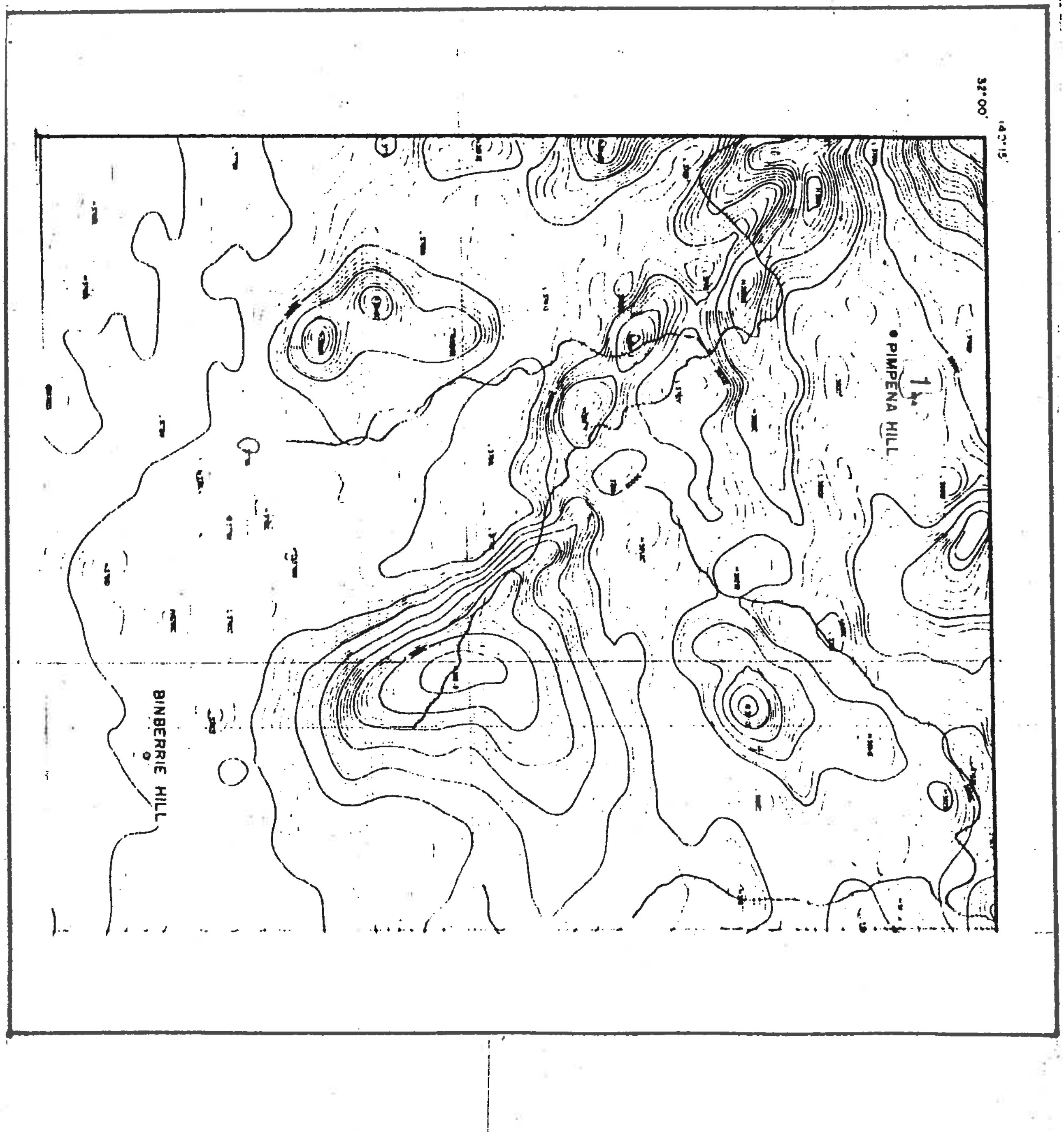


Figure 8.5 Aeromagnetic contour map of Mount Bull Mine area (photo reduced from the 1:50,000 scale contour map).

Pimpena Hill. Southwestwards, a clear anomaly pattern D_{12} (fig. 5.1)(5.2) could be seen trending northwest. South of this D_{12} is another set of three connected ovoid-shaped anomaly highs and they are on strike with a similar anomaly to the northwest. Probably these anomalies are due to variations in the concentrations of magnetite associated with the hematite body encountered in the Mount Bull Mine area (Campana and King, 1958).

8.2.5 The Olary Silver Mine, Centralia and Peseverance Mines

Small copper showings have been opened up around the isolated outcrops containing small banded iron formations. The mapped outcrops around these deposits range from migmatite (Pwc) through to massive to layered quartz plagioclase magnetite "quartzite" (Pwq) and feldspar rich mica gneiss (Pwf) to pelitic quartz muscovite schist (Pws_4).

The magnetic relief in the area is about 600 gammas. In general, although the isoanomaly contours are widely spaced and irregular over much of the area, the magnetic anomalies over these deposits are well defined and clearly related to the schists and quartzites (5.3). The prevailing northeast trend of the magnetic contours in the area between tie line 9300 to 9350 probably reflects the strike of the strata in the area (5.3). Near the Centralia Mine of the same section, (tie lines 9272 - 9291) the contours trend north-northeast, and the area north of these mines show a northwesterly trend (between 9291 - 9310). The trend of the anomaly contours throughout the area is consistent with the observed strike of the underlying beds (5.1.1 and 5.3).

The Olary Silver Mine anomaly in the area is along tie line 9350 where the linear anomaly with a peak value of about 500 gammas can be traced for 2.5km. A magnetite quartzite (Pwq) and feldspar rich mica gneiss (Pwf) assemblage cause the anomaly and is well displayed in the drill data as a banded iron formation. About 500m south, a similarly trending anomaly (tie line 9330 - 9340) is underlain by pelitic quartz muscovite schist (Pws_4). The amplitude of the anomaly is 350 gammas.

West of this (9320 - 9330), a 2.25km long anomaly forms the major anomaly of a group of northeast trending anomaly nodes extending northwards between tie line 9330 and 9340. This anomaly occurs over schists (Pws_4) and together with the anomaly between tie lines 9330 and 9340 (at the southern tip) lie over the area of Peseverance Mine. Some calc-silicate rocks are also mapped around the schist.

Locally the massive to thickly layered feldspar rich mica gneiss (Pwf) contains enough magnetite to cause a moderate anomaly as between

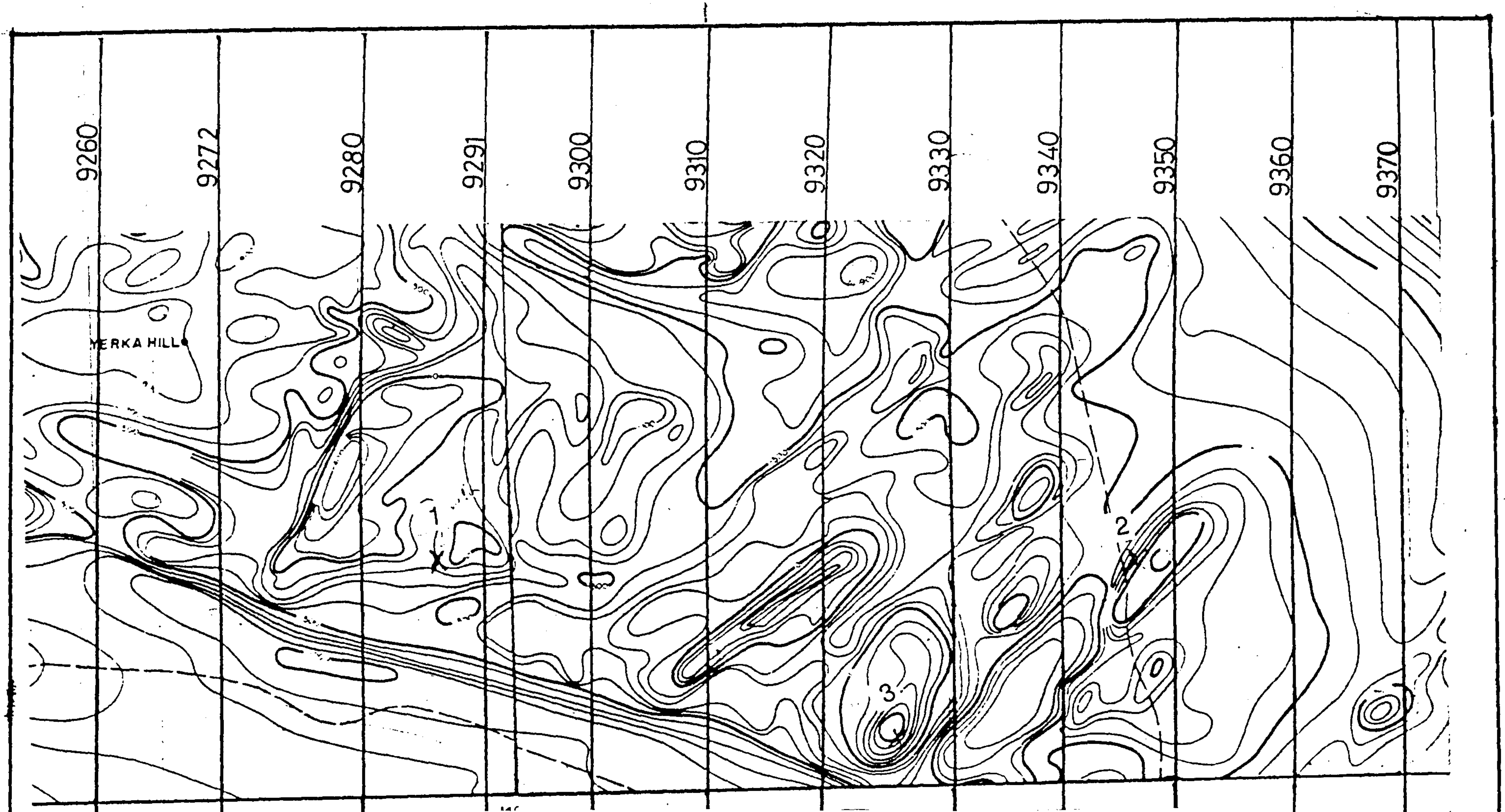
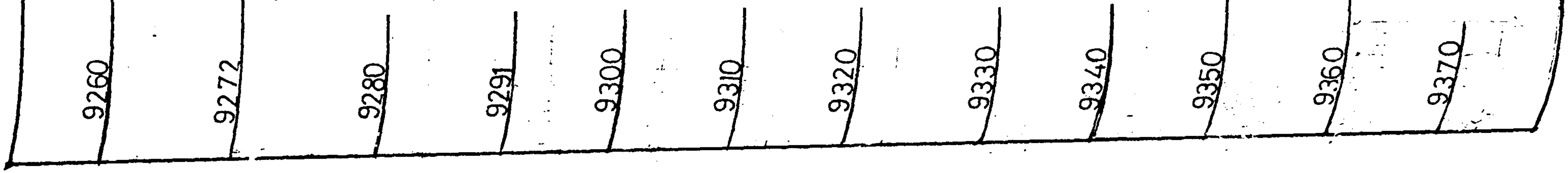


Figure 8.6 Aeromagnetic contour map of 1) Centralia, 2) Mary and 3) Perseverance mine areas (photo reduced from the 1:50,000 scale contour map).



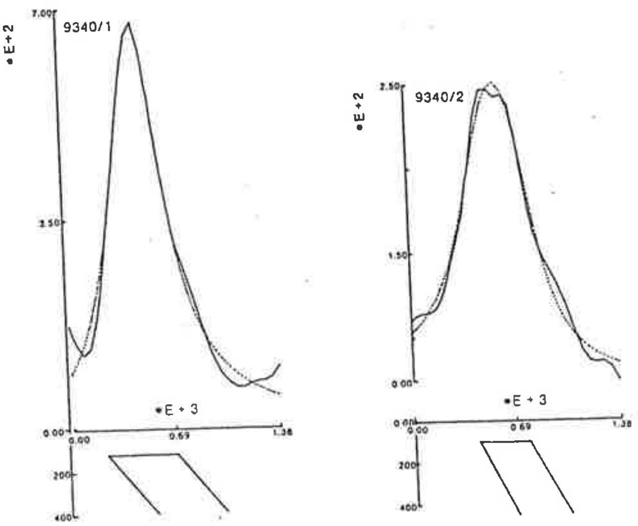


Figure 8.6b Two-dimensional magnetic modelling of the anomaly around Centralia Mine area.

tie lines 9272 - 9291 around the Centralia Mine. A northwest trending discordant hornblende-albite metadolerite dyke cuts across the outcrop (fig. 2.3). While the anomaly outlined by the 100 gamma contour with steep gradients correlates with the gneiss (Pwf), a lopsided narrow end anomaly near 9291 correlates with the Centralia Mine. Irregular anomaly contours wind their way through the migmatoid rocks and continue through into areas of no outcrops.

Calculations made on small anomalies to the north between tie line 9330 and 9340 are summarized in Table 8.1 while the profile is shown in figure 8.6b. Estimates made on tie line 9350 anomaly is presented in Table 5.1.

8.2.6 The Marjorie and Doughboy Mines

The copper bearing deposit shown on the aeromagnetic map figure 8.7 produces moderate to weak amplitude magnetic patterns. Copper sulphides are disseminated in highly cleaved Adelaidean slates in the Marjorie Mine. A few scattered outcrops of the Umberatana metasediments have been recorded on the geology map around this area (fig. 2.3; Forbes and Pitt, 1980). Anomalous copper contents have been reported in the interglacial units of the Umberatana Group (0.7 b.y.) (Rowlands, 1974; Rayner and Rowlands, 1980, p. 147).

The magnetic anomaly caused by the Umberatana type rocks in the Marjorie Mine is discontinuous presumably because of faulting (fig. 4.1).

Several kilometers to the east of the Marjorie Mine, near tie line 9180, another deposit - the Doughboy deposit - is located over the massive feldspar rich mica gneiss (Pwf). This deposit shows a moderate anomaly gradient and on 9190 just 1.5km towards the northeast the enclosing 500 gamma contour line includes few amplitude anomalies. (C_{17} and C_{18} fig. 4.1, 5.3). These anomalies are bean-shaped.

8.2.7 Walparuta Mine

A low grade copper deposit in quartzite host rock has been worked in 1956 at Walparuta near Weekeroo. This deposit is located at the contact between an outcropping tonalite gneiss and massive quartz feldspar rich mica gneiss (Pwf) containing some ironstones.

The magnetic anomaly around this place is presented as figure 8.8 and has been discussed in detail in 5.4. The magnetic anomaly located over the Mine workings could in part be correlated with the banded iron formation. The bordering schist (Pws_5) outlines a synclinal axis around the deposit.

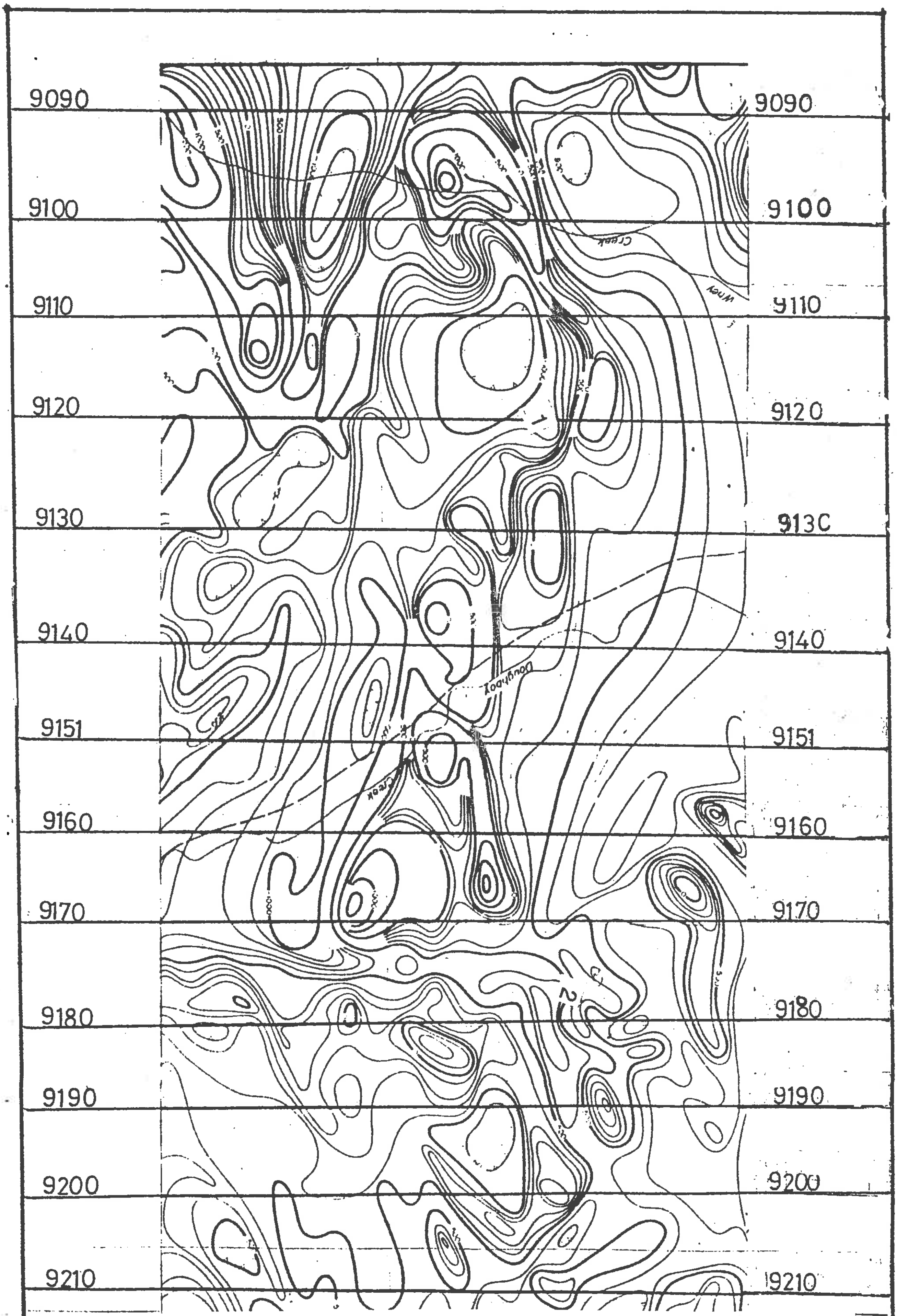


Figure 8.7 Aeromagnetic contour map of 1) Marjorie and 2) Doughboy mine areas (photo reduced from the 1:50,000 scale contour map).

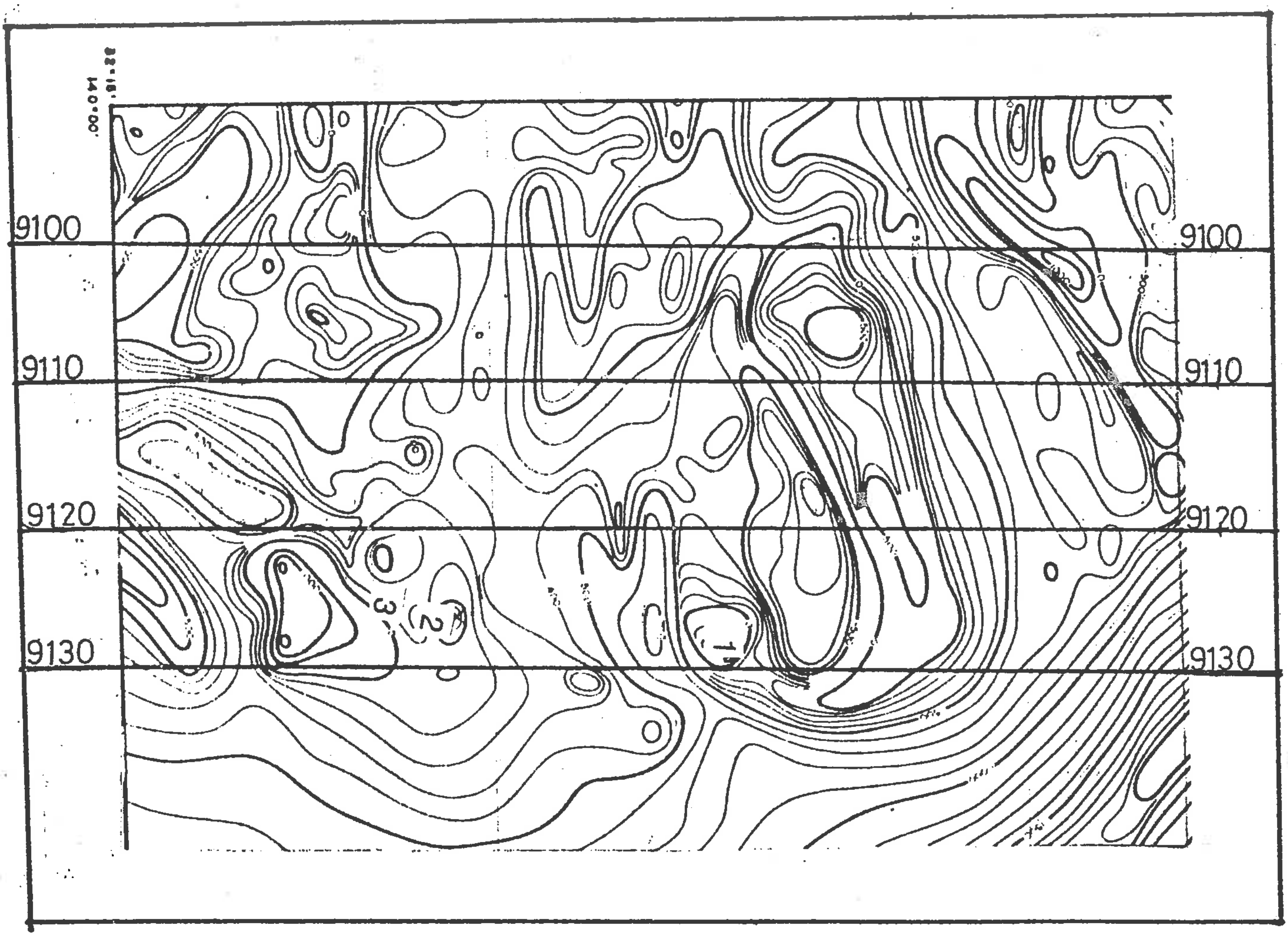


Figure 8.8 Aeromagnetic contour map of Walparuta copper baryte mine area (photo reduced from the 1:50,000 scale contour map).

8.2.8 Discussion

In these examples the relationship between copper mineralizations and aeromagnetic anomalies is clearly defined. The mineral occurrences are characterized by moderate to high positive magnetic anomalies. Amplitude values range from 300 gammas to 850 gammas and their strike extent range from 0.05km to 2.2km. The anomaly shapes range from linear, and ovoid to circular. Occasionally elliptical and bean-shaped anomalies are observed.

Some conclusions on the reasons for this relationship can be drawn from the analysis of both the geologic and the aeromagnetic data. The characteristics of the positive magnetic anomalies are:

(1) The presence of metamorphosed pelitic, psammopelitic, psammitic and impure calcerous rocks and minor basic intrusives;

(2) Folding of ore zone with host rocks, confinement of ores to the pelites or semi-pelitic rocks, stratabound and locally even stratiform nature of the ore bodies;

(3) Absence of spatial and temporal relationships with granitic rocks of the region; and

(4) Probable relationship of copper showings to migmatitic gneiss (ie, Mount Bull area).

Whilst recognizing that the magnetite quartzites (Pwq) do not always constitute the major ore bearing horizons, their association with mineralization and their geophysical response make them important in any search for copper deposits in the Olary Province. The magnetite quartzites act as marker horizons and given other favourable parameters (like faults) it remains a valid approach to assign high priorities to these horizons (5.2 and 5.3).

It is beyond the scope of this thesis to argue the origin of the deposits. However, the metallogeny of the Broken Hill district has been most recently reviewed, analysed and classified by Barnes (1980), who refers to the main literature of Campana and King (1958) for the Olary Province. Barnes discusses the ore deposits by type and reviews the main genetic concepts. He stresses the stratigraphic relationships of these deposits and noticed that they are related to the environment of deposition and are mainly stratiform and stratabound types.

Because it is not possible to discriminate between the geophysical anomalies caused by the copper mineralization and the anomalies caused by the pelitic, semi-pelitic and other rocks, the aeromagnetic data in this case is utilized in the so-called indirect exploration (Ketola, 1979; 1982). It is important to realise that the distinction between "direct" and "indirect" is not inherent in the method used, but in the question asked of the method (Cooper and Davidson, 1979).

8.3 Mineralization and Major Geophysical Lineaments in the Olary Province

Ore deposits are geochemical anomalies that depend for their genesis on a source or sources for the elements and one or more geologic processes or features to concentrate these elements into bodies of sufficient size and grade to become economically extracted (Guild, 1983, p. 16).

In many parts of the world many ore deposits have been recognised (or thought to have been recognised) by the use of the lineament techniques. In such circumstances it has been suggested that the lineaments controlled the distribution of the ore deposits. However, a number of ore deposits seem to have very weak connection with the lineaments (Zuffardi, 1978).

In Australia, the problem of association of known ore deposits with major lineament trends has been studied by O'Driscoll (1974; 1981 a and b; and 1982), O'Driscoll and Keenihan (1980); Findlay (1982); and Hills (1953). To determine whether such correlations exist, the known copper mineralizations in the Olary Province (8.2-8.2.7) are studied to determine the relation of the mineral deposits and the aeromagnetic and gravity lineaments (Chapters 6 and 7).

8.3.1 Major Lineaments and Spatial Distribution of Copper Mineralization

For the purposes of this study lineaments include mapped faults and all well-defined alignment of geophysical features that are too pronounced to be fortuitious. Four main groups of lineaments have been detected (figs. 6.10 and 7.2):

(1) NW-SE to NNW-SSE;
(2) NNE-SSW to NE-SW;
(3) E-W and ENE-WSW; and
(4) N-S.

The mineralization known in the Olary Province is mainly related to the schists (Pws_4), gneisses (Pwf), magnetite quartzites (Pwq) and amphibolites (P_B). The positions of the copper mineral occurrences have been plotted on the geology map (fig. 2.3). By superimposing the lineament map figure 6.10 on figure 2.3, the following relationships between the lineaments and the mineral occurrences can be seen:

(1) Several of the occurrences seem to be situated directly on the intersection of the lineaments, that is, on the line symbolizing these zones. Lady Louise and Woman in White B-B(52) and G-G(201 and 327); Ameroo and Peryhumuck B-B(330) and I-I(51); Marjorie Mine E-E(300) and I-I(32); Lady Mary Mine C-C(42) and F-F(302); Mount Mulga Mine B-B(52) and G-G(301); and Putt Well and B-B(52); see figure 6.2;

(2) Green and Gold lies 500m from A-A(70) and Walparuta Mine lies 250m from E-E(62);

(3) Other mines lie further from the lineaments, eg, Doughboy Mine 2km from I-I(20) and 2.25km from I-I(32); Olary Silver Mine 2.25km from B-B(59); Faugh-a-Ballagh Mine 1.25km from B-B(35). When these distances are compared with the tens of kilometers of the respective lineament zones, and with spaces between the zones, it seems obvious that these occurrences are related to the lineament zones; and

(4) Old Tietz Dam mineral occurrence cannot be related to any lineament.

Of the 15 deposits, seven or 47% correlate with lineaments while six or 40% are situated in the vicinity of the lineaments. Altogether fourteen or 93% of the occurrences seem to have some correlation with the lineaments and 7% do not.

By way of comparison, the lineament density map (figure 6.3) was superimposed on the geology map figure 2.3. The most favourable locations are areas of intermediate density, nine or 60%, namely Putt Well, Woman in White, Ameroo, Peryhumuck, Marjorie, Walparuta, Olary Silver, Faugh-a-Ballagh, and Mount Mulga Mines. On the other hand, four or 27% are located within low density areas, viz, Doughboy, Lady Mary, Centralia and Old Tietz Dam Mines; while two or 13% are located in areas of high density, eg, Lady Louise and the Green and Gold Mines.

From the spatial distribution of the copper ore occurrence it is easy to conclude that most of them are in close association with the major lineaments in the Olary Province and are preferentially located at or near the intersection of the different lineament patterns. The most favourable locations are:

(1) Areas where the NNE-SSW and the NE-SW lineaments intersect the lineaments with other trends;

(2) Areas where the NW-SE lineaments intersect the NE-SW trends; and

(3) Areas where the E-W lineaments intersect other patterns, especially the NE-SE ones.

Such structures possibly determined the scale of mineralization instead of its type. These results are tentative. Their significance from the standpoint of prospecting for copper requires more study.

CHAPTER 9

CONCLUSIONS

It was stated in the Introduction that it is an especially surprising fact that although the authors of the "Geophysics and Geochemistry in the Search for Metallic Ores" (Hood, 1979) often reiterate the necessity for the geological interpretation of geophysical data, there are very few works addressed to the most important requirement of increasing the geological effectiveness of magnetic exploration operations to obtain solutions which would yield the optimum satisfaction of both geological and geophysical observations. Those existing in the literature lead us to expect something better. Over the years, there has been a gradual increase in the gap between the theory and the practice of interpretation. The purpose of this thesis was something about this gap.

As this was the situation in 1979, 33 years after the first commercial surveys were flown with fluxgate magnetometers, it is clear that a problem of such long standing is not likely to be an easy one to solve; and in this thesis the author would expect to be able to take the solution only a short distance down a new track. The problems tackled in this thesis are twofold, they are in part philosophical insofar as they are concerned with how one thinks about the problem and what one understands the problem to be; and they are partly practical in that they have been also concerned with what one actually does about the problem.

The procedure followed in this research has been to tackle an actual area in which the theories have been tried out. There were really three separate parts to the work which are as follows:

(1) A standard interpretation of the magnetic map was carried out; and this established the static geometry of the magnetic bodies;

(2) A dynamic interpretation was adopted which led to an understanding of the geological processes which have affected the magnetic rocks from deposition to final metamorphism; and

(3) Observations were made and analysis was done of the procedures used in interpretation, and this was followed by an examination of the difficulties encountered.

It is necessary to carry out a standard type of interpretation before any progress could be made in the use of the information contained in the magnetic map. This consisted of recognising the main magnetic units, associating these units with known geology, estimating dips of bodies, and boundaries and recognising other structures some of which may not be evident to the geologist; and where it was appropriate, mineral deposits had to be related to the features identified on the magnetic maps. All this work was done and is included in this thesis.

The magnetic maps have been carefully matched with the known geology and the magnetic responses of the different rock units have been classified so that any geologist who undertakes work in this area will be able to start from the base provided in this thesis. Details of the interpretation can be found in Chapters 4 and 5.

The major conclusions of the study are:

(1) By analogy with the strikingly magnetic profiles observed over the Braemar iron formation within the Adelaidean metasediments, the magnetite quartzites (Pwq) and the Ameroo schists (Pws_4) within the Willyama metasediments, additional areas of similar outcrops can be postulated for areas of poor outcrops - as for example, Whey Whey River area and the Putt Well and Larry Mac Dam areas;

(2) The magnetic data suggests the continuity of the metasediments D_{11}, B_6 and D_1, which was not indicated on the geology map;

(3) The magnetic map indicates that numerous structures could be identified, for example, open folds A_3 and the structure EF_1 are known, but B_6 and D_1 were not known from the geology mapping and possibly are related to A_3. Tight folds were difficult to identify because of lack of resolutions, while many faults like the MacDonald, Outalpa and Doughboy faults could be recognised;

(4) The lineament analysis results showed that the major lineament directions influenced the lithological and structural picture of the area investigated. The structural picture indicates that

the lineament directions NW-SE, NE-SW, E-W and N-S are important; and

(5) Attempts were made to demonstrate the feasibility of aeromagnetic method in the indirect exploration of the known copper deposits in the graphite bearing schist environment; and the documentation of the empirical relationships of the magnetic field of known mineral occurrences is of permanent value to mineral exploration operations in the area.

In the dynamic interpretation, which is regarded as the principal original contribution of the thesis, emphasis has been given to the importance of viewing the observed magnetic anomalies from the physio-chemical and tectonic conditions that affect the accessory magnetite content of the rocks. Metamorphism is a complex relationship between the rock composition, pressure and temperature conditions of any given area. The strength of the optimum interpretation is that the geophysicist and the geologist can both understand aspects of the geological environment in which they are both working; and the object is to convert magnetic data into geological information at a satisfactory level of precision. Much depends on the interpreter being able to formulate meaningful questions which relate to the geological environment and which in some way can be answered by changes in the physical and chemical properties of magnetite. Objective application of this capability will perpetuate expertise in advancing understanding of the geology of an area and improve geological momentum for future geological mapping. Looking at the work in hindsight, Olary was not ideal for this purpose. There was too little control; and the integrated account of the geology was not as up-to-date as needed. Enough was known to indicate what could be done to make clear what kinds of difficulties are encountered when a problem of this magnitude is tackled.

It is perhaps inevitable that any research which has the development of method as one of its principal aims should end with a statement on what are the prerequisites for a satisfactory interpretation. While some of them would seem very obvious they appear to relate to common problems and are therefore worth listing:

(1) The magnetic data should be recorded on magnetic tape which should be both accessible to the researcher and be easily read from the tape. This is often not the case in Australia. Delays

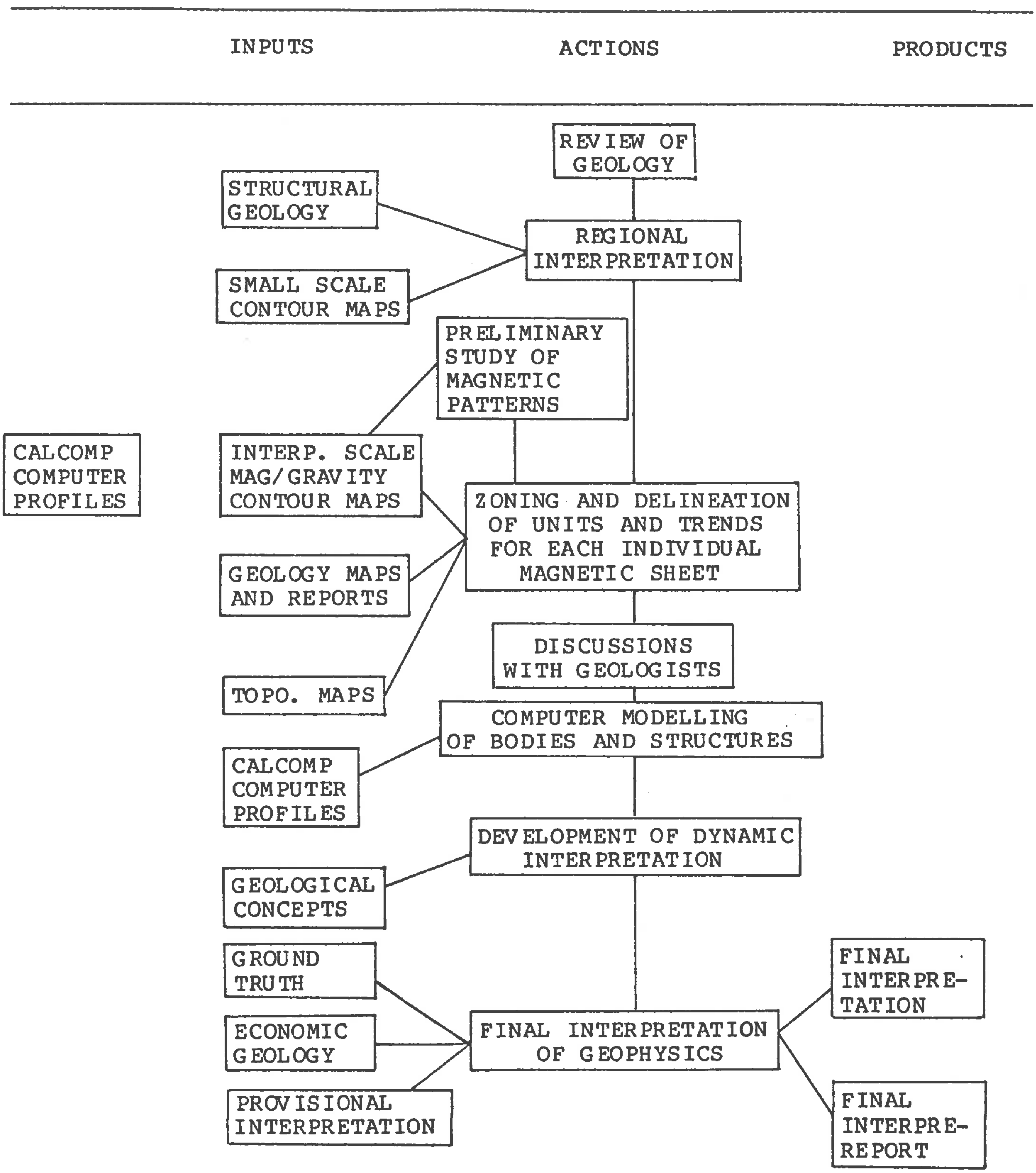
in availability of data appear trivial but they can be a source of major irritation and can seriously interrupt the rhythm of interpretation;

(2) The position of the magnetic data must be known beyond dispute. This was not so in the Olary data used. In this case the client for whom the data was obtained was unaware of this until the data was studied here;

(3) The quality of the interpretation may be seriously compromised by the resolution of the data. The flying height, flight line spacing and direction, frequency of data sampling and the noise level, all limit the size and character of the structures which can be identified by the survey;

(4) Wherever possible the work should be undertaken by a team which includes both a geologist and a geophysicist so that ideas may be exchanged and developed as the work progresses. It is very properly said that "no man can serve two masters" and this is particularly true in interpretation of magnetic data which is to provide an optimum result. The interaction between the geologist and the geophysicist is an important component. This was in fact a significant problem in the present study. When it commenced it was expected that staff from the South Australian Department of Mines and Energy would be actively mapping in the area but due to changes in the Department's plans this was not so. As a result the exchange of ideas was less effective than anticipated;

Many of the problems in Nigeria are not unlike those encountered in Olary Province. There are very large areas of poorly exposed metamorphic rock which may contain information about mineral resources important for the development of the country. Nigeria would seem to be an ideal area in which aeromagnetic interpretation could play an important part in speeding up the production of geological mapping and in reducing the cost of work in the field. Problems in interpretation can be anticipated because of the wide spacing of the flight lines over parts of the country. Such wide spacing will reduce the resolution of the moderate-sized features which may be very important in applying the interpretation to the exploration for economic mineral. A program of sampling and petrophysical measurements should be planned to support the magnetic interpretation which should be fully integrated into a current geological mapping program for which the geophysicist and geologist both share responsibility.



<u>**INTERPRETATION FLOW DIAGRAM (see 3.6.3)**</u>

APPENDIX A

DIGITAL AEROMAGNETIC DATA QUALITY, PROCESSING AND PRESENTATION

A.1 Introduction

Aeromagnetic survey provides magnetic data which is cheap and can be employed by geophysicists and geologists in a variety of ways including mineral exploration. This method maps the distribution of magnetic minerals, generally magnetite, and as such can be used in any application where knowledge of the distribution might help.

One of the most useful applications of magnetic data is to facilitate geological mapping. Outcrop geology can be extended under soil, vegetation or alluvial cover by observing the correlation between magnetic response and geology (Boyd, 1967; Wright, 1981). These applications have been so revealingly brought out in many cases during the last 30 years that practically all developed and developing countries have embarked on organised programs to cover their territories with aeromagnetic surveys.

During the 1970's aeromagnetic surveys saw the development of digital compilation systems which are now of universal application throughout the industry. This Appendix gives a summary of the acquisition and processing of the available aeromagnetic data over the Olary Province and discusses some of the procedures employed for positioning of the aeromagnetic anomalies, as it is important to understand problems which come from data collection.

A.1.1 Aeromagnetic Surveys in Australia

Australia was one of the earliest countries along with Canada, USSR and Finland that realised the promise offered by airborne geophysics. Almost all of the Australian continent was covered by major surveys in the period between 1955 and 1985. Regional surveys were made by Government agencies like the Bureau of Mineral Resources (BMR), the South Australian Department of Mines and Energy (SADME), and more recently the New South Wales and the Northern Territory Department of Mines. A great many detailed surveys have been flown by petroleum and mineral exploration companies. These regional surveys have been produced at 1:250,000 scale and consolidated into 1.1 million scale contour maps which cover the entire continent. Some results have also been produced at 1:100,000 scale.

In South Australia a systematic aerogeophysical mapping of the whole State was carried out in the years 1955-1977. The results of the aeromagnetic surveys are summarized on maps drawn to scales of 1:250,000, 1:100,000 and 1:2,000,000. The interval between the isoanomaly curves shown on the original total intensity maps from which the aeromagnetic map of South Australia was compiled varies between 10-200 gammas.

Advances made in computer processing, machine plotting, in addition to cost and popularity of these methods, encouraged the South Australian Department of Mines and Energy to specify that all the airborne geophysical surveys carried out for the SADME be collected digitally and they should be processed by computer.

A.2 The Aeromagnetic Data of the Olary Province

The aeromagnetic surveys of the Olary Province are shown as shaded in figure A.1. These surveys, covering about 1,800 square kilometers, were made concurrently with airborne radioactivity. Together they are known as Survey E 1977 and Survey D 1972.

A.2.1 Survey E 1977

This survey was carried out by Geoex Pty. Ltd. for the South Australian Department of Mines and Energy. The aeroplane carrying the survey equipment was flown at a height of 115 meters, with sensor clearance of 100m along east-west lines with north-south tie lines. Traverses were spaced at 300m apart for the east-west line, and at 1.2km for the north-south tie lines. The flight height was recorded by a Vinten 16mm ground tracking camera and the elevation was continuously recorded by a Bonzer MK 10 Altimeter. Magnetic measurements were made by the Geometrics G806 Proton precission Magnetometer using towed bird configuration with a 37m cable from a Cessna 185E aircraft. Data for Dinurnal correction was recorded with a Geometrics G806 Proton Magnetometer with Geoex film digital recorder and crystal clock. Geoex adopted the value of 57870 gammas at the Dinurnal base at the Broken Hill Airport for the adjustments. Readings were made at 0.8 second intervals at a nominal aircraft speed of 100 knots producing values at intervals of 41 meters. The datum for the total magnetic intensity contours is the International Geomagnetic reference field 1976.

A.2.2 Survey D 1972

This survey was carried out by Aero Services (Aust) Pty. Ltd., for ESSO Australia Ltd. It was made on a north-south traverse at

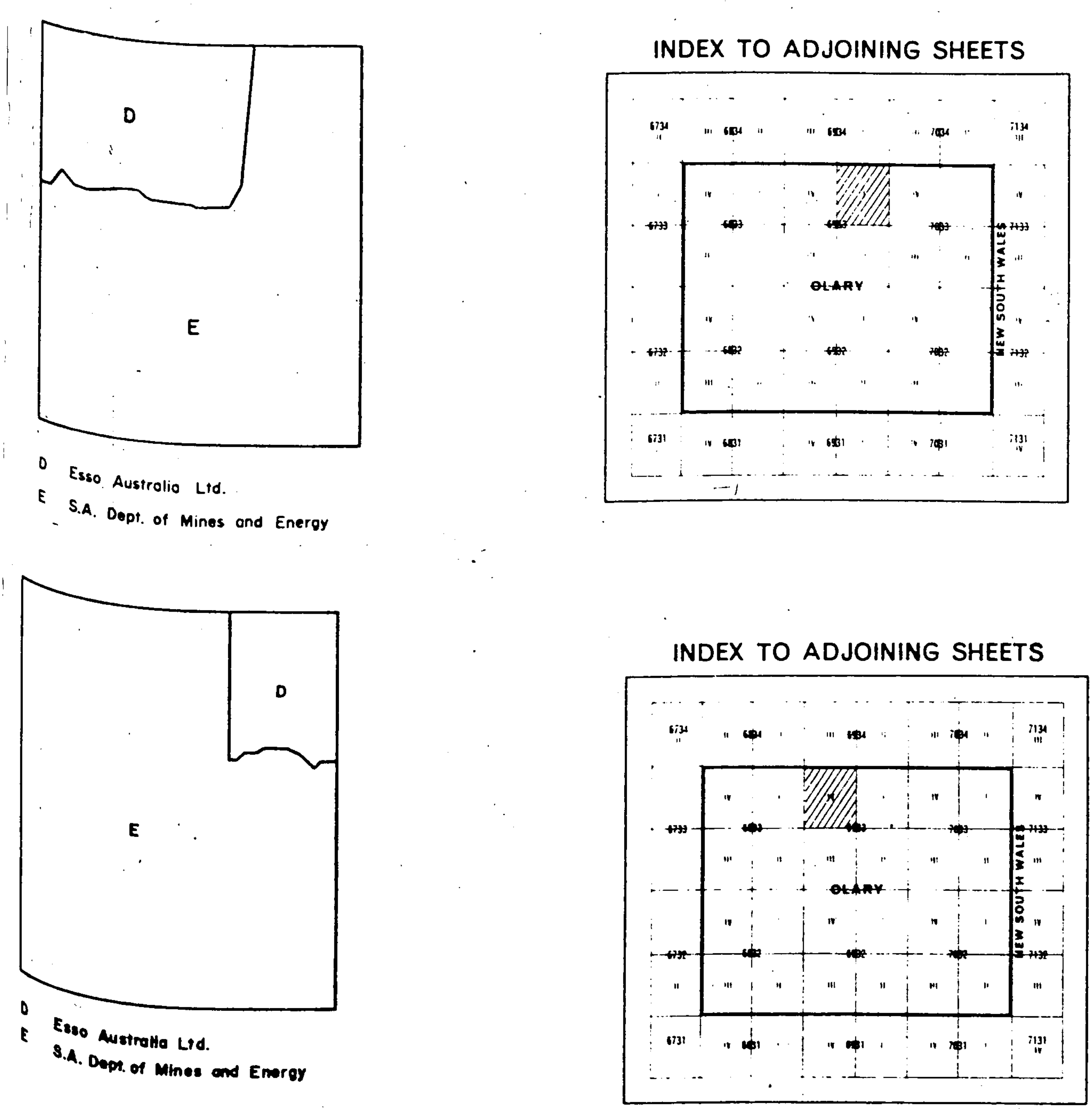


Figure A.1 Index of aeromagnetic surveys in the Olary Province.

intervals of 250m apart, at an altitude of 60m ground clearance, except locally where topography required a higher terrain clearance. Total intensity magnetic data along the traverses were obtained from a Proton magnetometer. The survey was flown using mosaics compiled from uncontrolled aerial photographs. The scale is approximate only.

The two surveys extend north from latitude 32°, the easternmost line being longitude 140°30', the western-most line longitude 139°55' and the southern-most line latitude 32°17'. They have been compiled and published as total intensity magnetic contour maps at a contour interval of 100 gammas for the South Australian Department of Mines and Energy (SADME). Digitally recorded magnetic tapes were also available.

A.2.3 The Magnetic Tape Data

Digital compilation techniques produce more objective results and permit greater versatility in the data operations. The object of digital recording is to supplement rather than replace the analog recordings. In this thesis the presentation of the data is not a sophisticated operation, but simply a reproduction of the analog records at different horizontal and vertical scales.

Acquisition sequence of in-flight data and therefore the order of the data on the magnetic tape is determined by logistical and economic considerations. Lines are not all flown in the same direction nor in "strict geographical order" across the survey area.

The sequence of digitization of recorded flight path data is governed by practical considerations. Unless the map area of the survey of the recovery scale is small enough to fit into the digitizing table, the flight lines must be digitized, map sheet by map sheet. A line which exists on the in-flight data tape as a continuous unbroken sequence of record will exist on the digitized flight path data tape as a series of map sheet size segments separated by segments of other lines. To bring the two data sets together requires a complex sort-merge process in a computer. This immediately introduces hardware problems related to tape compatibility and differences in techniques used by the individual companies in processing their data.

An additional problem arises from the lack of a universal format on which such data is stored in files on magnetic tapes. These discrepancies take a lot of time to overcome; and this discourages many interpreters from availing themselves of the original data. They take the data from the contour maps and this in itself constitutes a filtering process. The subject of digital acquisition of data has been intensely reviewed by Hood (1972, 1973, 1976 and 1979), Steinland (1970) and Richards and Walraven (1975).

The digital magnetic data is gridded for the machine contouring process; this facilitates the production of a variety of derived and processed maps to any scale or map projection for use in the subsequent interpretation of the aeromagnetic data.

A.2.3.1 The Processing of Magnetic Tape Data of the Olary Province

The University of Adelaide's computing facility was used in this study. Access to the University's Cyber 173 Computer was made through a terminal housed in the Department of Economic Geology. Software was developed by the author to implement automatic transcription of in-flight data, first as a computer print out and then the production of analog profile records on the scale of the available geology map. Briefly, the computer programs comprise:

(a) A FOTRAN IV program adapted from Dr G. Staker's routines for accessing Landsat data from magnetic tapes. This program reads any specified block lines of data from a 9-track ASCII tape and prints on a CDC 6-bit display. Two processing options exist:

  (i) IOP - either the record in each flight line is printed in which case IOP is not equal to zero (IOP.NE.O). This option is useful for obtaining a summary of the whole tape; or

  (ii) Selected flight line is written onto a file which can then be printed out on a line printer in which case IOP is equal to zero (IOP.EQ.O). However, it is advisable to use option (i) above, first to determine how many blocks of data to skip and the number of blocks to read in option (ii). Adjoining flight lines on either side of the required traverses were often read to build up a complete profile record. A compass routine (subroutine) to unpack two 60-bit words into 6-bit bytes (right justified) in fifteen words formed an important feature of the FOTRAN program. This returns bytes in a fifteen element array which has to be declared a "common" block statement - this improved the efficiency of the processing program.

To use the program a VSN control statement (see University of Adelaide Computing Centre Local Publication No. 503/1978) was set up with two input cards containing:

(i) the number of blocks to skip (NSKP), the number of blocks to read (NBLK) and the input option (IOP);

(ii) the format in which the data is to be read (eg, 49R1).

It was found useful to retain this format throughout the whole process.

(b) The computing centre's FORM-data manipulation utility. (see Cyber's Users' Guide Soft Ware Facility 1979, p. 65). The FORM (File Organisation Using Record Manager) commands were used to reformat the data. FORM can read records in any format, select, reformat, sequence and otherwise manipulate the records. It was especially useful for data or programs received from other installations. Almost all the functions performed by FORM can be performed by FOTRAN programs, but writing FORM directives is easier.

This was used to extract the column of magnetic readings from the profile record against their corresponding eastings or northings. This provided a structure in which they could be plotted as analog records;

(c) A FOTRAN IV program for plotting the profile data, at the Computing Centre's Calcomp plotter at any chosen scale. It was the practice to provide the profile data on the same scale as the contour maps;

(d) The Computing Centre's PAGE Command (University of Adelaide Cyber Users' Guide to Soft Ware Facilities, 1979, p. 145). The command was used to display on the screen selected positions of the file containing the profile data. The file must be associated with the users terminal as a local file, that is, the local file name must be included in the output from the FILES Command. In addition, the file must be an ordinary text file. Windows of data containing any anomaly of interest were extracted by the above method. Other information, such as the model name, number of data points, station spacing, field intensity, field inclination, and zero level, were added to it to make up a data file for input into the iterative optimization scheme used for the quantitative interpretation (Chapter 3).

A.2.4 Methods of Positioning Anomalies

Before any interpretations are begun, it is prudent to inspect the analog records and to mark anomalies of interest on the aeromagnetic maps. This allows the interpreter to develop a "feel" for the data and at the same time to cross-check the compilation and any corrections which may have been applied.

Geologic and aeromagnetic maps at scales of 1:50,000 were used for this purpose. There were slight discrepancies in the alignment of the geology and the aeromagnetic maps at 1:50,000 scale; in the form of a mismatch on the overlay of aeromagnetic map on the geology map. Estimates made from the two maps showed that the aeromagnetic map is about 350m east-west smaller than the geology map and about 50m north-south smaller than the geology map. This was resolved in most of the cases by comparing the profile plot in the following way. An anomaly that can be confidently correlated on both the contour map and the profile plot on the same scale is confirmed on the geology map to come from a particular rock type (eg, Zone A anomaly on the MacDonald Corridor). The anomalies on both the profile plot and the aeromagnetic contour map are aligned and then correlated to the underlying geology. Other anomalies took their reference correlation from this position. This is not good but was forced on the author because no more accurate method was available.

A.2.4.1 Isolation of Aeromagnetic Anomalies

The aeromagnetic maps consist of a complex array of overlapping anomalies which are derived from a multitude of geological sources, creating difficulty in resolving anomalies due to an individual source. Anomalies with moderate to large amplitudes and slopes indicative of magnetic sources were selected from the flight path records. The

International Geomagnetic Reference Field (IGRF) value published for the continent of Australia (Finlayson, 1973) was subtracted from all the anomalies of the magnetic sources as a zero value. The remainder of the values above and below this zero value at the selected anomaly intervals were accepted as the anomaly values for that location. This IGRF value also served as the regional anomaly for the survey area (see for example Richard and Walraven, 1975, p. 256; and Krutikhovskaya and Pashkevich, 1979).

A.3 Determination of the Anomaly Zero Line

The anomaly zero line is not to be confused with the 57870 gammas used by Geoex Pty. Ltd. as datum zero when data was processed at the acquisition stage (A.2.1). That datum zero was an arbitrary choice made for convenience of plotting the data, and was influenced by the overall magnetic background of the survey area.

The true zero for the specific anomaly will be above or below the datum zero or may be coincident with it. Where the latter is the case, the area beyond the anomaly is magnetically flat. It is necessary to establish the anomaly zero (or true zero) before an interpretation can be attempted. The manner adopted for obtaining the anomaly zero in this study for the dyke model has been devised by Werner (1953) and is shown in figure A.3.

This method is particularly useful when the minimum of the anomaly is not clearly defined and when there is a doubt about the position of the zero line. Described briefly:

(1) Draw three coordinate AA, BB, CC (fig. A.3) parallel to each other and together parallel to the abscissa and at any arbitary positions on the coordinates;

(2) Project the centre of coordinates marked by circle vertically up or down onto adjacent coordinates (points J, K, H and M in fig. A.3);

(3) The lines through JK and LM meet at O;

(4) O is above the centre of the dyke; and

(5) The zero line passes through O. The anomaly centre is the surface position of the centre of the anomaly source.

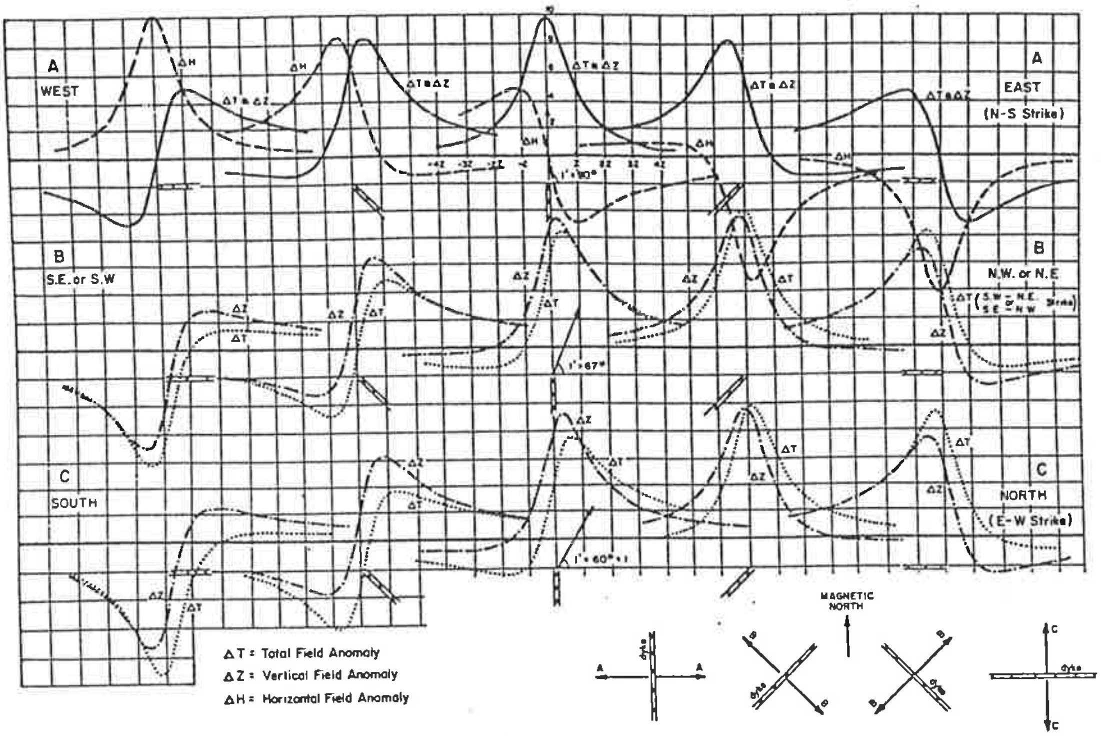


Figure A.2 Magnetic anomaly across a thin dyke in the Southern Hemisphere at a magnetic inclination of 60° (after Roux, 1980). Note how the anomaly changes with a) dip of the thing dyke, and b) strike direction of the dyke.

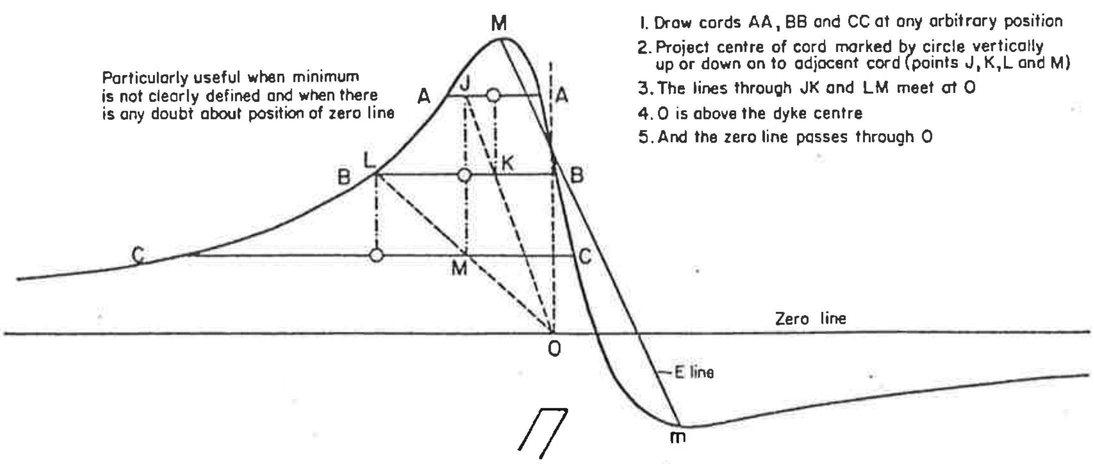


Figure A.3 Establishing the zero, the zeroline position and center (after Werner, 1953).

A.3.1 Effect of Line Spacing on Interpretation

For any airborne geophysical survey the flight line interval is one of the most important parameters that govern the degree of detail that can be recognised by the data. The interval chosen for the regional survey of the Olary Province is necessarily a compromise between cost and required detail.

Closer line spacing leads to an increase in resolution of detail and consequently location of small magnetic dipolar anomalies and helps to define their detail structural settings. The regionally spaced flight line specifications define major crustal fracture patterns, but could not resolve the small magnetic dipolar targets.

The combination of the width of individual geologic features, line spacing and the angle between the flight line and strike directions will have a greater effect on the detail that can be interpreted from the resultant maps and the degree to which this may correlate with known geology. Flight line spacing should be determined by the nature of the expected anomalies (c.f. Agocs, 1955).

Generally the total cost of a survey is inversely proportional to the line spacing; halving the line spacing doubles the total cost. This critical relation has led many exploration groups to determine flight line spacing by the funds available and the area to be covered.

APPENDIX B

THE MAIN REGIONAL GEOPHYSICAL CHARACTERISTICS OF SOUTH AUSTRALIA AND PART OF NEW SOUTH WALES

B.1 General Remarks

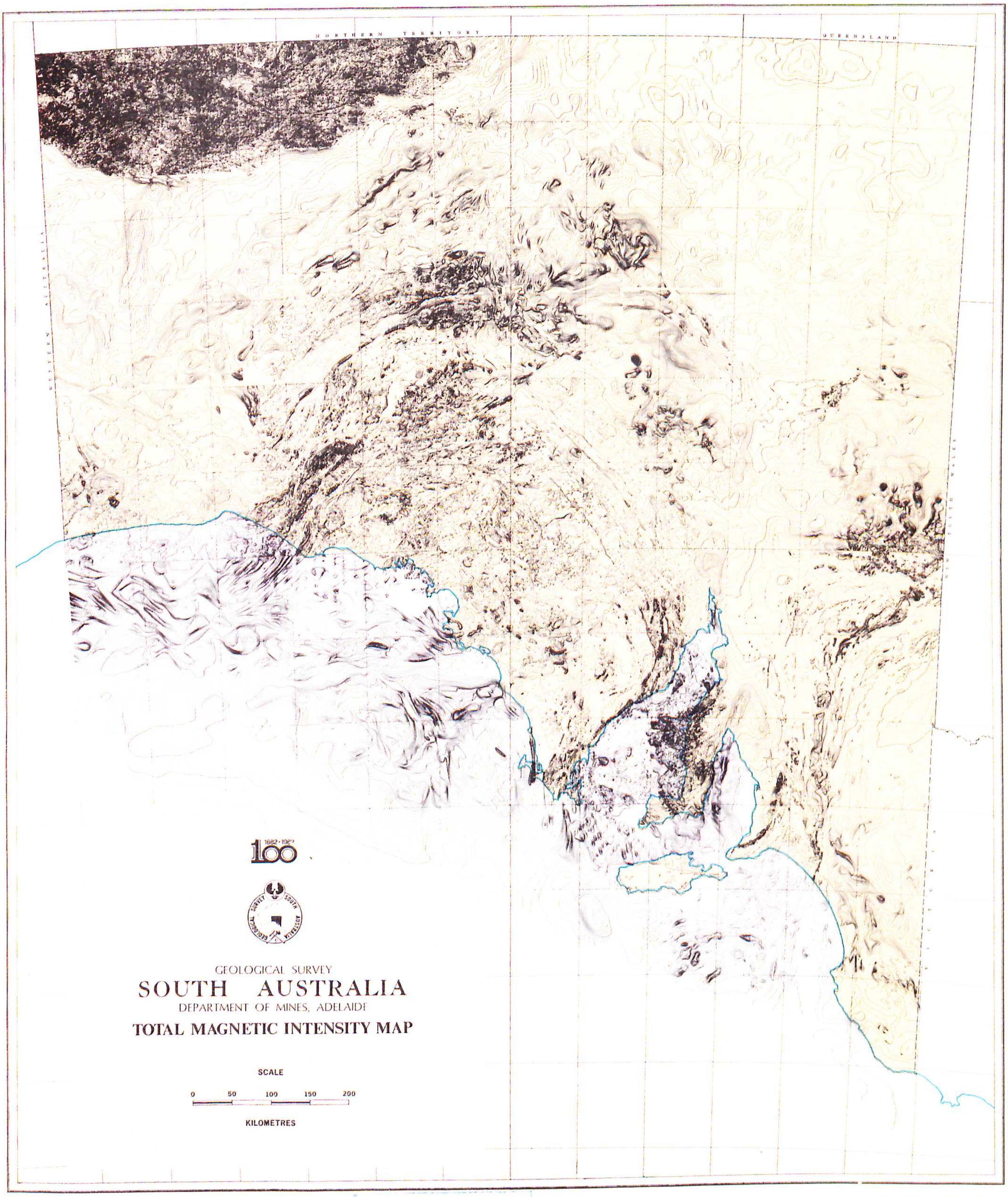
A detailed geophysical interpretation of the total intensity aeromagnetic map (fig B.1) prepared for the South Australian Department of Mines and Energy (SADME) is beyond the scope of this thesis. Attention will only be directed to the salient features on the map that will be necessary for the detailed interpretation of the Olary Province presented in Chapters 4-8. The main features of the geology of South Australia for this type of interpretation is shown in fig B.2 which summarizes the work of the SADME, and that described in the literature. The pre-existing body of the geological knowledge varies from area to area in both detail and type of information available, and the following account compares this with the regional geophysical results.

B.2 Types of Magnetic Field of the Basement Complex of South Australia

It is highly desirable to begin the interpretation by considering the major features of the State as shown on the magnetic map, and this can be done easily using the 1:2 million regional aeromagnetic map of South Australia (fig. B.1). The internal structure and composition of the basement complexes are reflected clearly on maps of the magnetic anomalies and show the regional context in which the Olary structures occur.

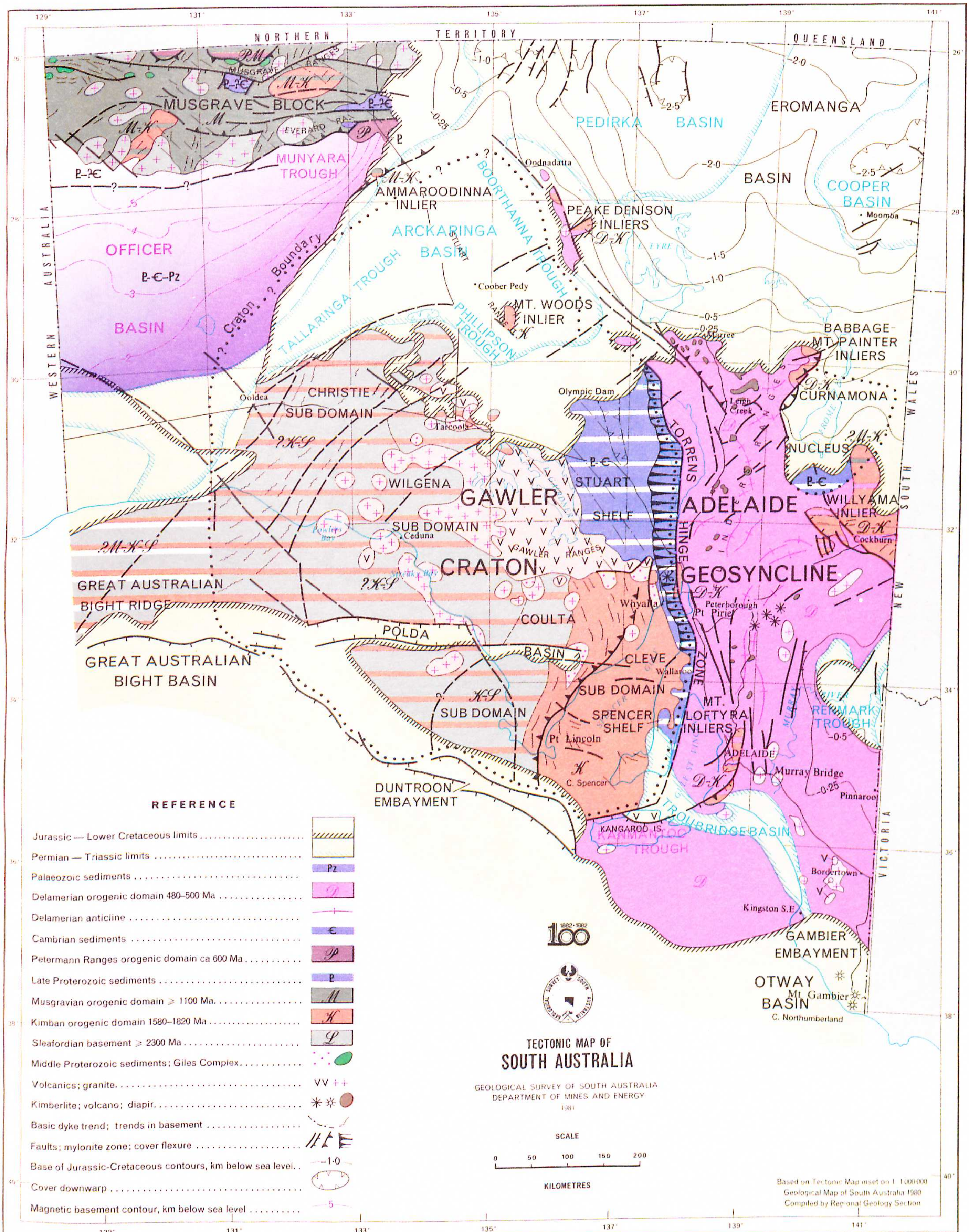
Several distinct patterns and/or lineations can be distinguished from the magnetic data shown in fig. B.1. The most striking of these are the zones of complex anomaly patterns A_1 -A_6 (fig. B.3). These areas are made up mainly by Archaean/Proterozoic gneisses. Each area is marked by high intensity but different magnetic field structure.

A_4 and A_5 form one of the most striking traverse Pre-Cambrian structural features of the State. The extension of A_5 can be seen in areas to the north and it also crosses the adjoining regions to the west. A_6 forms a major basement feature within the continental shelf and trends to the northwest. A_1, A_2 and A_3 have an overall northwest trend expressing probably a bigger regional feature. The magnetic



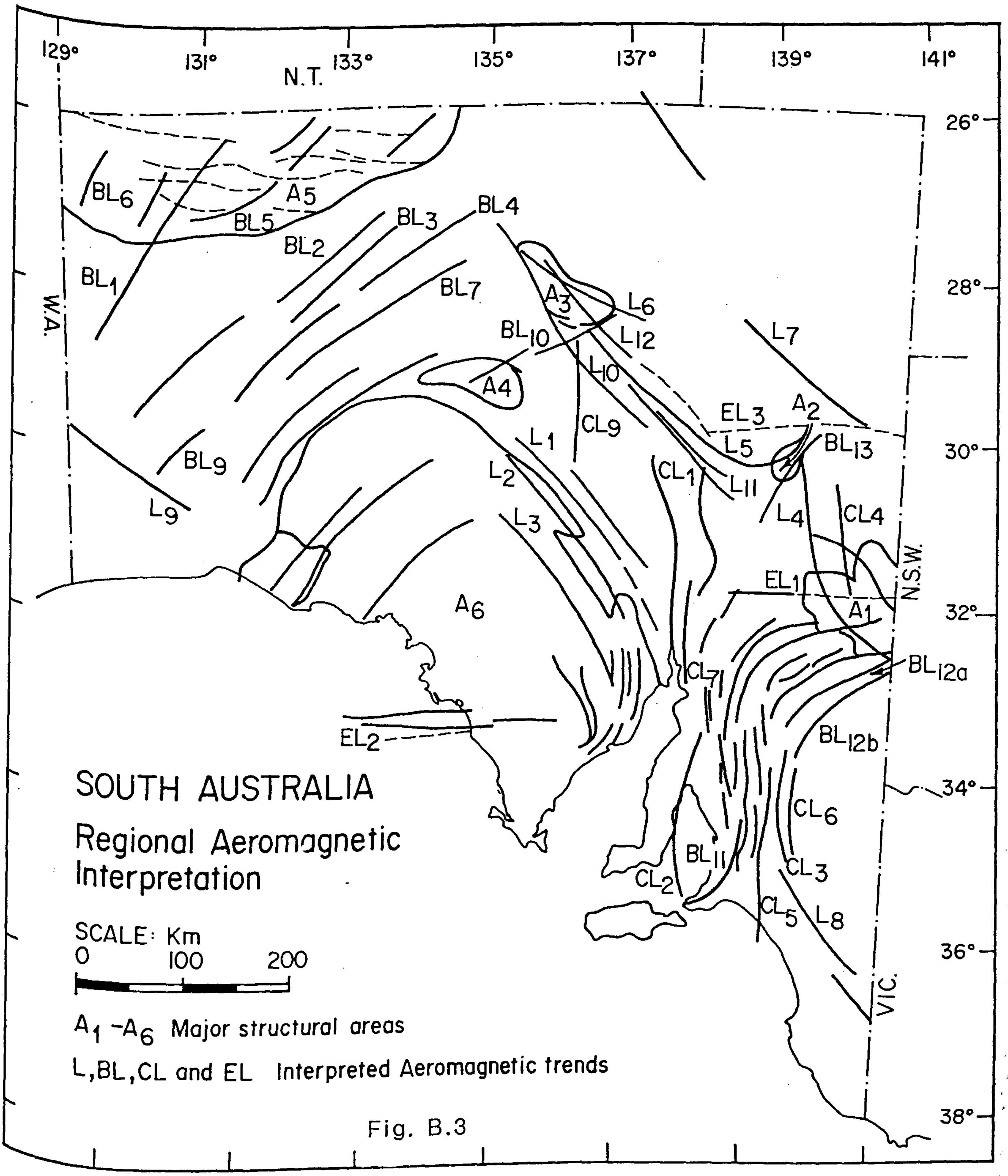
D.J.Woolman, Government Printer.

Figure B.1



NORTHERN TERRITORY
QUEENSLAND
WESTERN AUSTRALIA
NEW SOUTH WALES
VICTORIA
MUSGRAVE BLOCK
MUSGRAVE RANGES
EVERARD RA.
MUNYARA TROUGH
OFFICER BASIN
Craton ? Boundary
TALLARINGA TROUGH
AMMAROODINNA INLIER
ARCKARINGA BASIN
BOORTHANNA TROUGH
PEDIRKA BASIN
EROMANGA BASIN
COOPER BASIN
Moomba
Oodnadatta
PEAKE DENISON INLIERS
Coober Pedy
MT. WOODS INLIER
PHILLIPSON TROUGH
BABBAGE-MT. PAINTER INLIERS
CURNAMONA NUCLEUS
Olympic Dam
Ooldea
CHRISTIE SUB DOMAIN
Tarcoola
WILGENA SUB DOMAIN
GAWLER CRATON
Ceduna
GAWLER RANGES
STUART SHELF
TORRENS HINGE ZONE
ADELAIDE GEOSYNCLINE
WILLYAMA INLIER
Cockburn
Leigh Creek
Peterborough
Pt Pirie
Whyalla
GREAT AUSTRALIAN BIGHT RIDGE
GREAT AUSTRALIAN BIGHT BASIN
POLDA BASIN
COULTA SUB DOMAIN
CLEVE SUB DOMAIN
Wallaroo
SPENCER SHELF
Pt Lincoln
C. Spencer
MT. LOFTY RA. INLIERS
ADELAIDE
Murray Bridge
RENMARK TROUGH
Pinnaroo
DUNTROON EMBAYMENT
KANGAROO IS.
KANMANTOO TROUGH
TROUBRIDGE BASIN
Bordertown
Kingston S.E.
GAMBIER EMBAYMENT
OTWAY BASIN
Mt Gambier
C. Northumberland
REFERENCE
Jurassic — Lower Cretaceous limits
Permian — Triassic limits
Palaeozoic sediments
Delamerian orogenic domain 480–500 Ma
Delamerian anticline
Cambrian sediments
Petermann Ranges orogenic domain ca 600 Ma
Late Proterozoic sediments
Musgravian orogenic domain ≥ 1100 Ma
Kimban orogenic domain 1580–1820 Ma
Sleafordian basement ≥ 2300 Ma
Middle Proterozoic sediments; Giles Complex
Volcanics; granite
Kimberlite; volcano; diapir
Basic dyke trend; trends in basement
Faults; mylonite zone; cover flexure
Base of Jurassic-Cretaceous contours, km below sea level
Cover downwarp
Magnetic basement contour, km below sea level
1882-1982 100
TECTONIC MAP OF SOUTH AUSTRALIA
GEOLOGICAL SURVEY OF SOUTH AUSTRALIA
DEPARTMENT OF MINES AND ENERGY
1981
SCALE
0 50 100 150 200
KILOMETRES
Based on Tectonic Map inset on 1:1000000
Geological Map of South Australia 1980
Compiled by Regional Geology Section

Figure B.2



129°
131°
133°
135°
137°
139°
141°
N.T.
26°
28°
30°
32°
34°
36°
38°
W.A.
N.S.W.
VIC.
BL6
BL5
BL2
BL1
BL3
BL4
BL7
BL10
BL9
BL13
BL12a
BL12b
BL11
A5
A3
A4
A2
A1
A6
L6
L12
L10
L7
L1
L2
L3
L5
L11
L4
L9
L8
CL9
CL1
CL4
CL7
CL6
CL3
CL2
CL5
EL3
EL1
EL2
SOUTH AUSTRALIA
Regional Aeromagnetic Interpretation
SCALE: Km
0 100 200
A_1 - A_6 Major structural areas
L, BL, CL and EL Interpreted Aeromagnetic trends

Fig. B.3

patterns of these zones are attributed to the metasedimentary and metavolcanic rocks.

B.2.1 Northwest Trending Linear Magnetic Features

L_1, L_2, L_3 and L_4 are northwest trending linear magnetic features that are delineated by a series of magnetic gradients or approximately discernable magnetic patterns which stand out in marked contrast to uniform, smooth, or at least appreciably flattened, magnetic features on the northeastern flank of the Gawler Craton (A_6). The magnetic features L_1, L_2 and L_3 probably represent mafic rocks forming the dykes reported by Webb and Woyzbun (1967), while L_4 is due to iron formations within the Adelaidean sediments. The next of the postulated northwest structures are in the vicinity of Peak Denison inlier and Lake Eyre areas and are marked by uniform magnetic gradients L_{11} and L_6 (fig. B.3) which are correlated to the Norwest and Lake Eyre faults respectively (fig. B.2). Other prominent magnetic trends L_{10} and L_{12} exist in this region and they correlate with those shown on figure B.2 over Cretaceous sediments. A suggestion of yet another of such features is shown as L_7. Irregular, smooth, long wavelength anomalies of the Warburton Basin are apparently terminated along this feature across Lake Blanch and Lake Gregory. The magnetic feature L_8 in the southeast of the State suggests the prolongation of the Pathway Ridge (fig. B.2) and marks a major northwesterly swing in trend of the northern margin of deep Mesozoic Tertiary Otway Basin (Wopfner, in Parkin, 1969, p. 61). L_9 comprises of elongated anomalies which cross the southwestern part of South Australia within the Nullarbor Plain and across into Denman Basin.

Thomson (1970) speculated that the northwest structural features in South Australia were probably established in Archean times.

B.2.2 Northeast Trending Linear Magnetic Features

The system BL_5 and BL_6 found over non-magnetic Officer basin cut across the transverse trends found over the Musgrave Block (A_5); and together with BL_1 - BL_4 are probably caused by the crystalline basement which shallows under the Eucla Basin (Peers and Trendal, 1968). Striking alignment of these features with the limits of the sub-outcrops of the Mount Isa-Cloncurry and George Town Pre-Cambrian basement inliers in Queensland (which can be seen on the 1:1 million magnetic and gravity map of Australia) has led Thomson (1970) to suggest the existence of a major transcontinental feature outlined by this northeast trend. BL_7 - BL_{10} at the northwestern edge of the

Gawler Craton (A_6) are characterised by strong magnetic features distributed over a background of both regional high and low anomaly features (fig. B.1). Some of the anomalies extend into Mount Wood inlier (A_4) and even beyond.

Other northeast trending anomalies are BL_{11}, BL_{12} and BL_{13} (fig. B.3). BL_{12} a and b represent the locations of the Anabama and the Redan faults at the southern edge of the Willyama Block (A_1), while BL_{13} marks the outline of the inlier within Mount Painter Block (A_2), and is believed by Wopfner (1969a) to continue into the Warburton Basin. However, the magnetic picture within the basin is irregular long wavelength anomalies and this trend can not be traced easily.

B.2.3 North-South Trending Magnetic Features

The linear anomaly feature CL_1 is related to the Torrens Hinge Zone while CL_2 is correlated to the Ardrossan fault within the St. Vincent Gulf. Towards the southeast of the State the magnetic feature CL_3 (fig. B.3) is correlated to the total effect of the north-south striking Palmer fault, the granites, and the diorites (fig. B.2). The granites and the diorites also underlie the magnetic features L_8 and BL_{12a} in (B.3.1 and B.3.2). A north-south feature CL_4 probably extends to the Olary area from the Frome Embayment to Mount Painter. It is marked by a node like anomaly feature. This feature together with the associated granites (Coats and Blissett, 1970) is on strike with the western limits of the Anabama Granite.

B.2.4 East-West Trending Magnetic Features

East-west feature EL_1 expressed by a combination of anomaly gradient and strong aligned magnetic features is believed by Thomson (1970) to flank a promontory of the Willyama basement block and extend west from the Olary region. This is also correlated to aligned diapiric structures within the Adelaide Geosyncline (Coats and Blissett, 1970). Other major features of the east-west trend include the Polda Basin (Wopfner, 1969a) which is expressed on the magnetic data as a featureless magnetic pattern that is borded on its northern flank by a sharp magnetic gradient EL_2, while EL_3 may mark the east-west feature which separates Mount Painter into two parts (Coats and Blissett, 1970). East-west features are also found within the Musgrave Block (A_5).

B.3 Regional Gravity Fields of South Australia

The gravity contour map fig. B.4 shows a complex pattern of anomalies which compliments the aeromagnetic pattern and focuses upon aerially extensive crystalline sources causing anomalies that have amplitudes of 10mgals or more.

A most prominent gravity lineament stretches northwest across the Australian continent and is shown by major pattern discontinuities. O'Driscoll (1982) has called this gravity feature "lineament NO.3". The lineament coincides with L_5, L_6, L_{10}, L_{11} and L_{12} (figures B.3 and B.4) magnetic features and the Muloorina Ridge. It forms part of the Muloorina Ridge gravity unit of Fraser (1976) which is an important feature of the Australia wide gravity map.

A broad regional gravity minimum (Wellman, 1976) and Milton and Parker (1973) strikes northeast between the Nullabor Plain and the southern edge of the Musgrave Ranges. It attains a maximum amplitude of 150mgals, and correlates with the magnetic features recognised in the area as BL_1, BL_2, BL_4, BL_7 and BL_9 (figs. B.3, B.4 and B.2.2). One of the more significant features of the gravity map (fig B.4) is the Barrier regional gravity Ridge of Fraser (1976) which is a prominent linear gravity high that follows the eastern edge of the Adelaide Geosyncline, and lies just south of the Olary region. The northern unit of this gravity anomaly lies more within the Broken Hill region and the southeastern portion of the Olary sub-domain. Gerdes (1973) has proposed from available geophysical and geological data within this northern unit, that rocks of the Willyama inlier continue into this area in the sub-surface and have there been thrust to the west over the metamorphics of the Kanmantoo Group and the Adelaidean rocks. According to geologic data (fig. B.2) there are granites and diorites which underlie these anomalies. Magnetic anomalies BL_{12} a and b could be traced to coincide with the anomalies and together they may give better indication of the location of the Anabama-Redan faults in this area of thick overburden.

The negative anomaly of 30mgals amplitude to the west of this northern unit is due to the Anabama granite, and gravity studies by Tucker (1975) confirm that the granite has a southern vertical contact, a 70° north dipping contact and extends to 20km below the surface.

Towards the south this positive gravity ridge changes strike and coincides with the north-south magnetic features CL_3, CL_5 and CL_6 (figs. B.4 and B.3). Within this southern unit the anomaly amplitude is not as pronounced as in the northern unit. The strong linearity of the anomalies here which is more pronounced on the outer parts of the

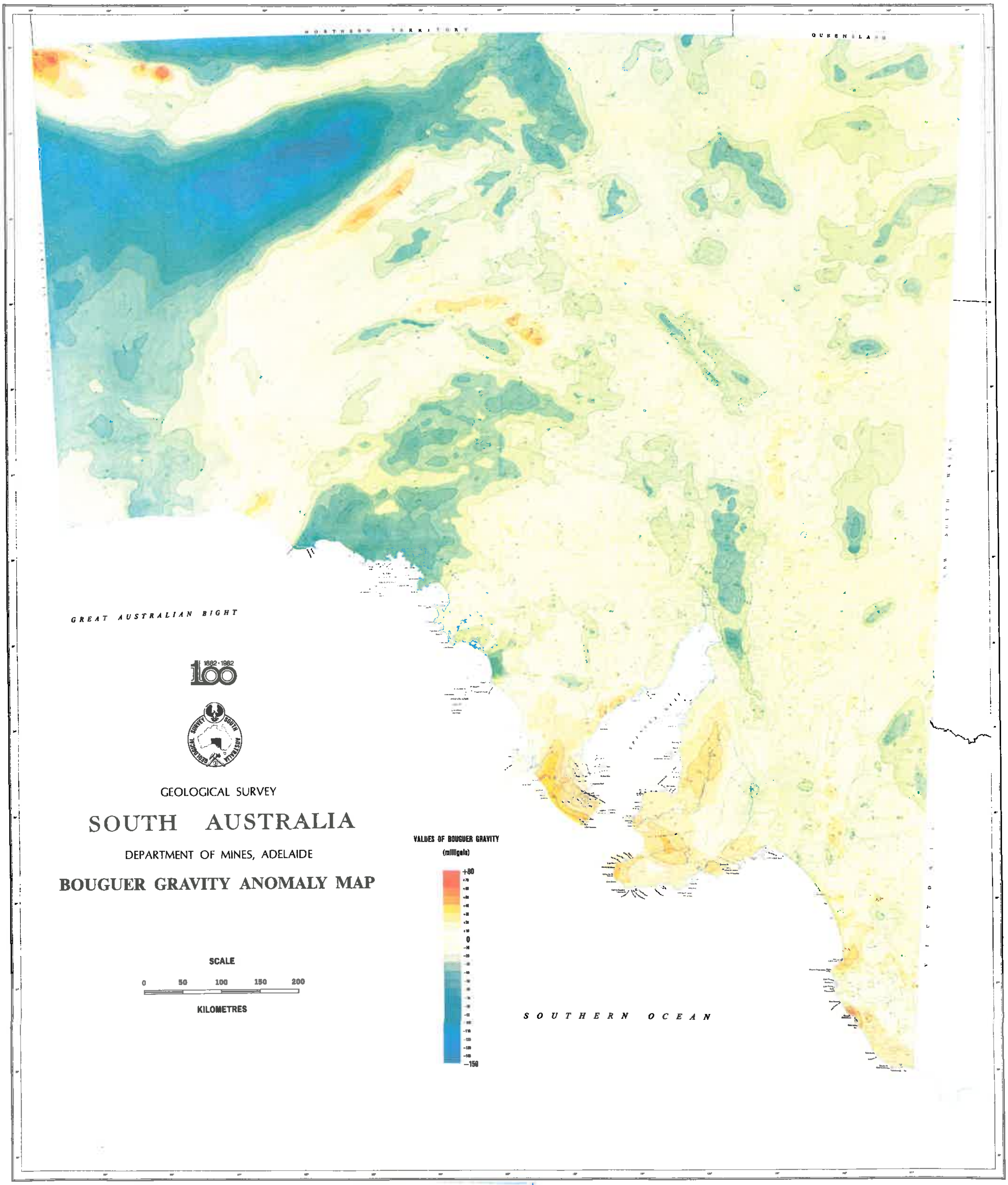

NORTHERN TERRITORY
QUEENSLAND
GREAT AUSTRALIAN BIGHT
1882-1982
100
GEOLOGICAL SURVEY
SOUTH AUSTRALIA
DEPARTMENT OF MINES, ADELAIDE
BOUGUER GRAVITY ANOMALY MAP
SCALE
0 50 100 150 200
KILOMETRES
VALUES OF BOUGUER GRAVITY
(milligals)
+80
0
-150
SOUTHERN OCEAN
D.J.Woolman, Government Printer.

Figure B.4

anomalies closely resemble the pattern over the northern unit and impies a similar overall structure.

The anomalous area with steep gradients of gravity directed towards Lake Torrens parallels the Torrens Hinge Zone which incorporates an area of Tertiary Graben Belt that extends from Lake Torrens to St. Vincent Gulf (Thomson, 1970). The aeromagnetic map (fig. B.1) shows a magnetic anomaly feature CL_1 (fig. B.3) that correlates with the location of the steep gravity gradient.

East-west gravity features are found in the area of Musgrave Block and they correlate with the east-west structures marked on fig. B.3 from the magnetic map (fig. B.1).

B.4 Summary

A study of the State wide map is helpful because some of the structures seen on small scale maps are better understood from their large scale counterparts. Some of these large structures L_4, L_5, L_6, L_7, L_{10}, L_{11}, L_{12}, BL_{13}, EL_1, EL_3 and CL_4 (fig. B.3) run across or near the Olary Province and are related to elements of the interpretation which furnish information on the Pre-Cambrian rocks and their relationship to the overlying metasedimentary rocks.

The principal trends which are NW, NE, NS and EW reflect trends in the geologically complex basement. Most of the complex anomalies are of shallow origin and indicate small comparatively shallow concentrations of magnetic material.

The trends on the Australian scale magnetic, heat flow, gravity and topographic data agree with the NW, NE, NS and EW structural trends only in a general way.

AUTOMATIC INTERPRETATION OF MAGNETIC PROFILES

C.1.1 Introduction

In this appendix we describe an algorithm for determining the parameters of a dipping dyke from observations of the total magnetic field at stations along a survey line. The algorithm consists of two parts:

(i) a forward model, which predicts the anomaly caused by a dyke with parameters;

(ii) an optimization algorithm which attempts to reduce the difference between the predicted and observed anomalies by adjusting the parameters of the dyke.

We have restricted attention to a two-dimensional model in which the dyke has infinite length and depth extent, but finite width, and for the optimization algorithm we chose a modified Levenberg-Marquardt algorithm called ZXSSQ, available on the IMSL library. The combination of the two seems to be both fast and fairly stable.

A detailed approach to interpretation of magnetic survey data is curve matching. This has been thoroughly discussed by Gay (1963) and its automatic counterpart, curve fitting, has been the subject of many papers recently (Johnson, 1969; Al-Chalabi, 1970; Hjelt, 1973; and Rao et al., 1973).

Won (1981) has developed an interpretation program similar to ours, except that he used a Gauss-Newton algorithm for the optimization rather than the Levenberg-Marquardt algorithm. When all the model parameters are well determined, both algorithms perform similarly, but in the presence of poorly determined parameters or noise on the data, the Levenberg-Marquardt algorithm is superior.

C.1.2 The Dyke Model Fig. C.1

We assume that:

(1) the dyke is dipping at an angle d ;

(2) the dyke has infinite lenght and infinite depth, but finite width B ;

(3) the susceptibility k of the dyke is sufficiently small that demagnetization can be neglected.

In the mathematical formulation of the model, we adopt the following conventions.

(1) The co-ordinate system will be left handed, with positive z pointing downwards.

(2) For any vector $\underline{V}$, we will let Iv and Av denote the polar angles which fix the direction of $\underline{V}$, as shown in Fig. C.2. Thus Iv is the inclination of $\underline{V}$ to the horizontal and Av is the angle between the horizontal projection of V and the positive x-axis.

We demand that

$$\frac{-\Pi}{2} \leqslant Iv \leqslant \frac{\Pi}{2}$$

$$-\Pi \leqslant Av \leqslant \Pi$$

(3) Let $\underline{V}'$ denote the projection of $\underline{V}$ into the xz plane, and we introduce angles $I'v$ and $A'v$ as shown in Fig. C.3. $I'v$ is the inclination of $\underline{V}'$ to the horizontal, and $A'v$ is the angle between $\underline{V}$ and $\underline{V}'$. An elementary calculation gives

$$\tan I'v = \tan Iv / \cos Av$$

$$\cos A'v = \sqrt{1-\sin^2 Av \cos^2 Iv}$$

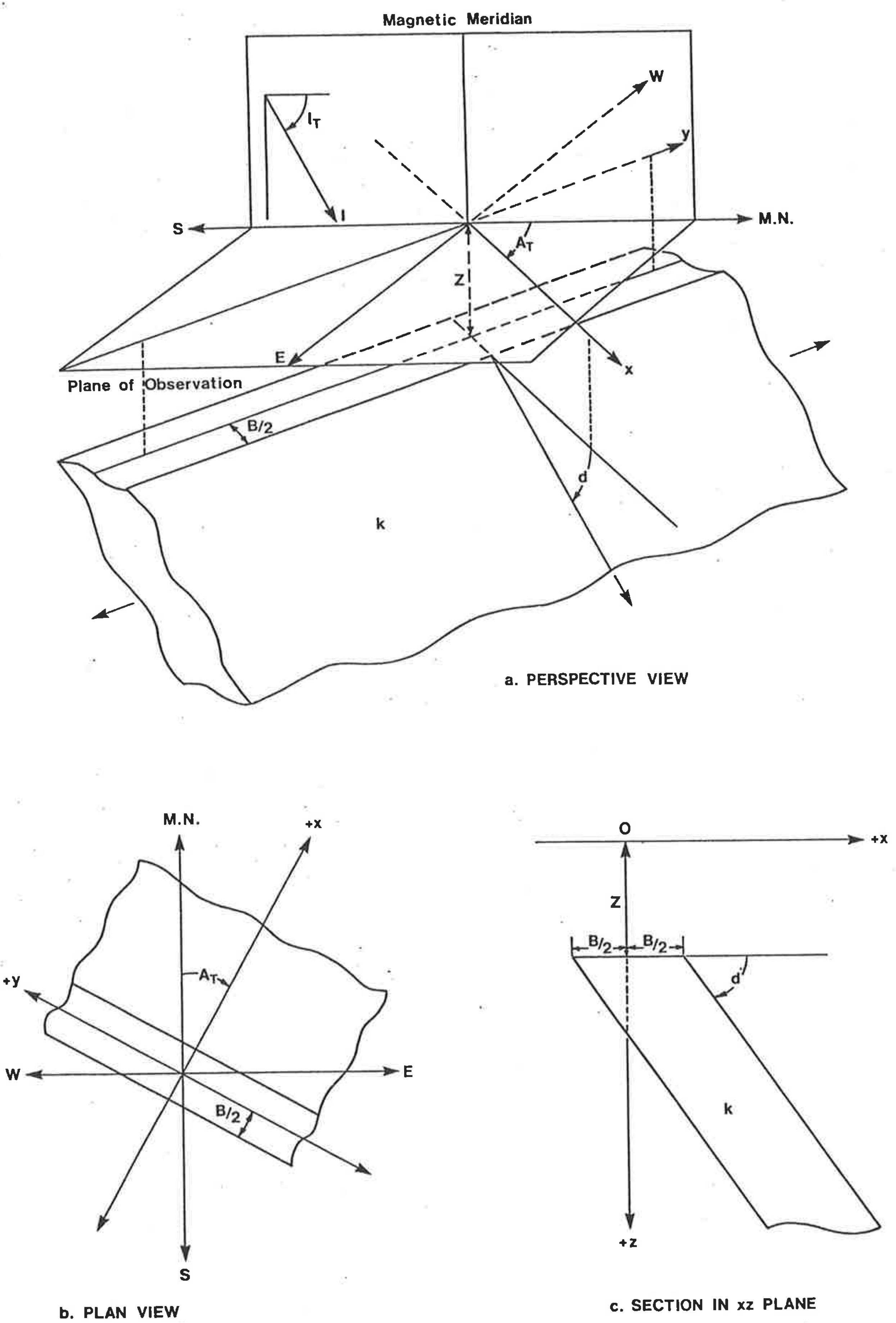


Fig. C.1

COORDINATE SYSTEM AND PARAMETERS OF THE DYKE MODEL.

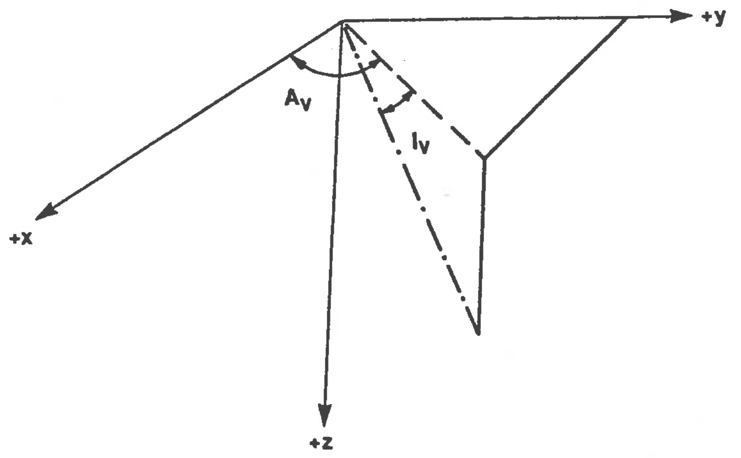


Fig. C.2: POLAR ANGLES OF VECTOR $\underline{v}$.

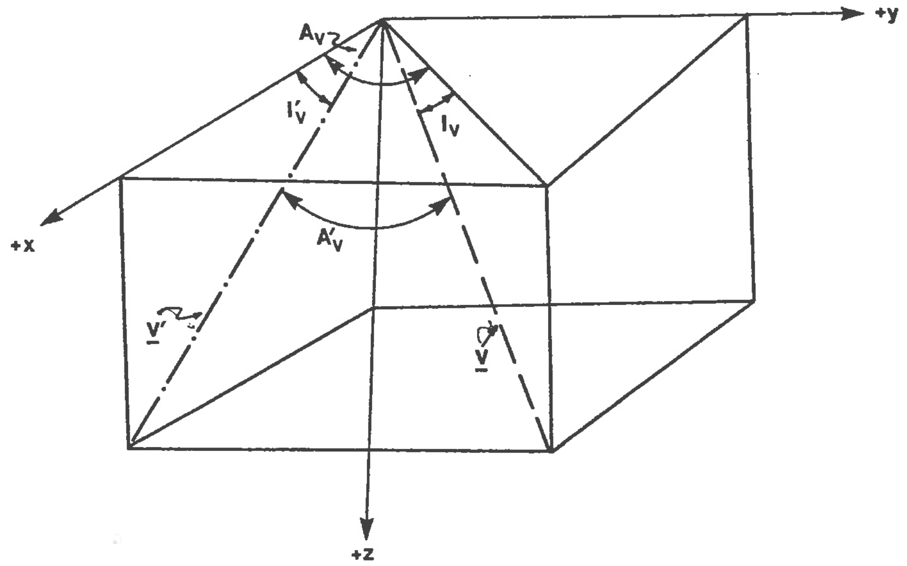


Fig. C.3: PROJECTION OF VECTOR $\underline{v}$ INTO THE xz PLANE.

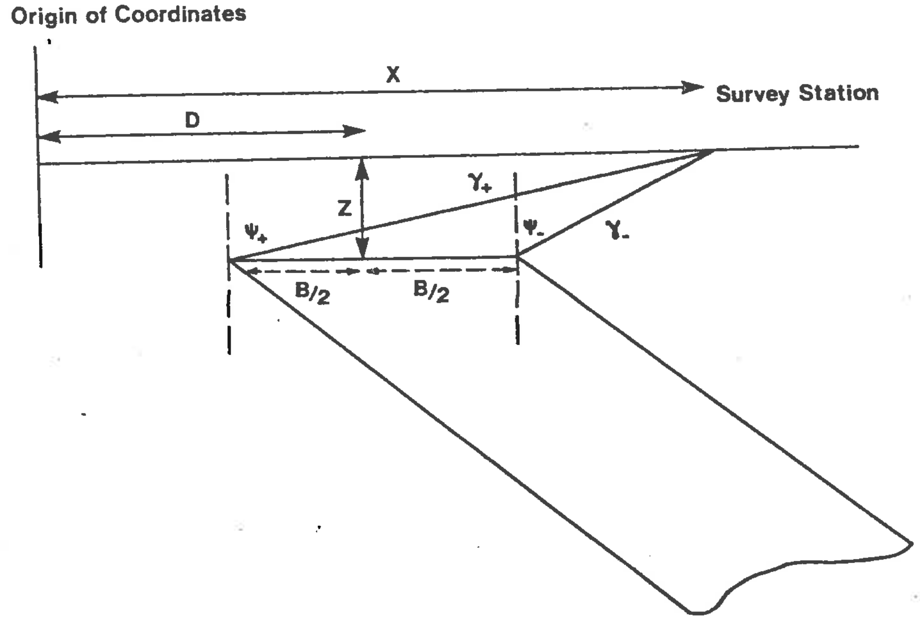


Fig. C.4: DEFINITIONS OF $\psi_\pm, \gamma_\pm$.

We denote the ambient magnetic field of the earth by I, the magnetization of the dyke by $\underline{M}$, and the direction of observation of the anomaly by U.

With these notations, the anomaly is

$$\Phi = C\ (\Lambda + - \Lambda -)$$

where

$$C = 2M\mathrm{Cos}A'm\mathrm{Cos}A'u\sin d,$$

$$\Lambda + = \Psi\mathrm{Cos}Q + \log r\pm\mathrm{Sin}Q,$$

$$Q = I't + I'u - d - \pi/2$$

and $\Psi\pm$ and $r\pm$ are the angles and radii shown in Fig. C.3.

It is easy to show that

$$\Psi\pm = \arctan\frac{(X - D + B/2)}{Z} \qquad \text{C.1}$$

$$r\pm = \sqrt{Z^2 + (X - D \pm B/2)^2}$$

We demand that the principal branch of the arctangent function be chosen in (C.1) so that

$$-\pi/2 < \Psi\pm < \pi/2$$

The amplitude factor C in the expression for the anomaly arises as follows:

(1) Only the component of the magnetization in the plane normal to strike contributes to the anomaly. Therefore, the anomaly measured in the plane is proportional to $M\mathrm{Cos}A'_m$.

(ii) If we measure the anomaly in some direction other than the plane normal to strike, we measure only a component of anomaly proportional to $M\mathrm{Cos}A'_m\mathrm{Cos}A'_u$.

It is worth nothing that the factor C governs the magnitude of the anomaly, but does not affect its shape.

The second factor $(\Lambda + - \Lambda -)$, controls the change in the anomaly with the observed position. Notice that the coefficient of CosQ in $(\Lambda + - \Lambda -)$ is even function of $(X - D)$, whereas the coefficient of SinQ is an odd function, so the angle Q controls the degree of symmetry of the anomaly.

The derivation of the expression for the anomaly can be found in Gay (1963), Reford (1964), Koulomzine et al. (1970).

Note the following special cases:

(i) Induced magnetization, without remanence

In this case,

$\underline{M} = kI$

where k is the susceptibility of the dyke. Consequently,

$A_m = A_t$, $I_m = I_t$

(ii) Vertical field measurements

$Iu = I'u = \pi/2$

(iii) Horizontal field measurements

$Iu = Iu' = 0$

(iv) Total field mesurements

$Iu = I_t$, $Au = A_t$

In all the modelling described in this thesis, we have assumed induced magnetization without remanence and total field measurements.

Finally, we collect the parameters which describe the dyke into a five component vector $\underline{\alpha}$ as follows:

k = magnetic susceptibility = α_1,

d = angle of dip = α_2,

Z = depth to top of dyke = α_3,

B = thickness of dyke = α_4,

D = horizontal location of centre of dyke = α_5.

C.2.1 Formulation of the Inverse Problem

Suppose that the observed total tield anomalies at stations $X_1, X_2, X_3, \ldots\ldots, X_m$ are $\Phi_1, \Phi_2, \Phi_3, \ldots\ldots, \Phi_m$. Let

$$F_i\,(\underline{\alpha}) = \Phi\,(x_i, \underline{\alpha}), - \Phi_i \qquad \text{C.2}$$

denote the residual, or difference between the observed anomaly and the predicted anomaly computed from the dyke model with parameter $\underline{\alpha}$. We seek the parameter of $\underline{\alpha}^*$ which minimizes the cost function

$$F(\underline{\alpha}) = \sum_{i=1}^{m} Fi(\underline{\alpha})^2 \qquad \text{C.3}$$

We anticipate that any algorithm for computing $\underline{\alpha}^*$ will be iterative and will proceed from an initial guess $\underline{\alpha_0}$ to a <u>local</u> minimum $\underline{\alpha}^*$. Which local minimum of F that is found will depend upon the initial guess, so it is very important that $\underline{\alpha_0}$ be as close to the correct values as possible. In other words, every effort must be made to fix a reasonable $\underline{\alpha_0}$ from the available geological or other geophysical information. The strategy we have chosen for determining $\underline{\alpha_0}$ is described in a later section.

C.2.2 Choice of Optimization Algorithm

A strategy common to many optimization algorithms is to approximate the cost function F by a quadratic function $F^{\#}$ in a neighbourhood of the current point, $\underline{\alpha_\beta}$. Thus,

$$F^{\#}(\underline{\alpha}) = \frac{1}{2}\,(\underline{\alpha} - \underline{\alpha_\beta})^T\, G_k\, (\underline{\alpha} - \underline{\alpha_k}) + $$
$$+ (\underline{\alpha} - \underline{\alpha_k})^T\, g_k + f\,(\underline{\alpha_k}),$$

where $(g_k)_i = \frac{\partial F}{\partial \alpha_i} (\underline{\alpha}_k)$

and $(G_k)_{ij} = \frac{-\partial^2 F}{\partial \alpha_i \; \partial \alpha_j} (\underline{\alpha}_k)$

are the gradients vector and Hessian matrix of F, respectively. For example, the Newton-Raphson algorithm takes a step $\underline{\delta}_k$ from the current point $\underline{\alpha}_k$ in the direction of the minimum $F^{\#}$ (provided that G_k is positive definite!).

Thus,

$$G_k \underline{\delta}_k = -g_k \qquad \text{C.4}$$

Because the cost of computing G_k^{-1} is usually excessive, a number of variations have been developed in which G_k^{-1} is replaced by a positive definite approximation. Perhaps the simplest is the Gauss-Newton algorithm which is arrived at as follows. Let J denote the $n \times n$ Jacobian matrix

$$(J_k)_{ji} = \frac{\partial F_j}{\partial \alpha_i} (\underline{\alpha}_k)$$

then $\underline{g}_k = 2 J_k^T \underline{F}_k$

and $(G_k)_{ij} = 2(J_k^T J_k)_{ij} + 2 \sum_{\ell=1}^{m} F_\ell \frac{\partial}{\partial \alpha_j} A_{\ell i}$

Provided that the residuals are small, it can be argued that the second term is small and so

$$G_k \simeq 2 J^T J.$$

With the approximation, equation C.4 for the step $\underline{\delta}_k$ reduces to

$$J_k^T J_k \underline{\delta}_k = - J_k^T \underline{F}_k \qquad \text{C.5}$$

Convergence of the Gauss-Newton algorithm is guaranteed if the condition number $J_k^T J_k$ is uniformly bounded away from zero. However, Powell (1970b) has demonstrated that convergence to a non-stationary point can occur.

It was the Gauss-Newton algorithm that Won (1981) used for automatic interpretation of magnetic survey data.

The major difficulty with the Gauss-Newton algorithm is that the matrix $J_k^T J_k$ will become very poorly conditioned whenever any of the parameters of the model is poorly determined. Once the condition is bad, errors or noise in the data can lead to large errors in the step $\underline{\delta}_k$, and consequently the algorithm will fail. Levenberg (1944) and Marquardt (1963) suggested a modification to the Gauss-Newton algorithm as follows: replace equation C.5 for the step by

$$(J_k^T J_k + \nu_k I)\underline{\delta}_k = - J_k^T \underline{F}_k \qquad \text{C.6}$$

where the parameter ν_k is to be chosen at each step to stabilize the inverse of $(J_k^T J_k + \nu_k I)$. Many different algorithms of the type have been suggested: some control the iteration using ν_k directly; others control using the spectral radius ν_k and choose ν_k so that $\|\underline{F}_k\|_2 = r_k$, employing an inner iteration (More, 1978; Jupp and Vozoff, 1975).

It is clear that the Levenberg-Marquadt algorithm for minimizing a sum of squares of m non-linear functions of n variables is an iterative application of the technique known as "ridge regression", which has been used successfully on many linear least square problems. Inman (1975) and Hoversten et al. (1982) testify to the suitability of ridge regression for a variety of geophysical problems.

We have settled for a modified Levenberg-Marquardt algorithm which eliminates the need for explicit derivatives. The algorithm is the IMSL routine ZXSSQ which uses the iteration,

$$\underline{x}_{k+1} = \underline{x}_k - \left[J_k^T J_k + \nu_k D_k\right]^{-1} J_k^T F_k ,$$

where: (i) J_k is the Jacobian matrix at $\underline{x}_k$ evaluated by finite differences;

(ii) D_k is the diagonal matrix equal to the diagonal of

$J_k^T J_k$;

(iii) ν_k is the Marquardt parameter at the k^{th} iteration.

The precise strategy for determining ν_k at each iteration is described in the IMSL documentation.

It is worth remarking that we also tried the IMSL routine ZXMIN , which required only the value of F and not the values of the individual residuals $F_1, F_2, F_3, \ldots\ldots, F_m$. As might be expected, ZXMIN was slower and less stable because it had less information at its disposal.

C.2.2.1 The Initial Guess, $\underline{\alpha}_0$

An iterative procedure performs well when the starting values $\underline{\alpha}_0$ of the iteration is close to $\underline{\alpha}^*$.

We determine the physical parameters of the body such as width, depth of burial, attitude, and susceptibility contrasts from the unique characteristics of the anomalous magnetic profile, such as the ratio of the shapes of the two flanks of the anomaly, the location of the points of half maximum slope and the distance and intensity difference between the maximum values of the anomaly curve.

Corrections were made to the estimated width value for dip, especially when the dyke is thick or when the direction of magnetization and dip differ greatly (Hjelt, 1973, p. 247). Corrections to depth were derived from the formula given by McGarth and Hood (1970, p. 836); while the horizontal position α_5 of the dyke we tied to the position of the anomaly maximum through Hjelt's (1973, p. 248) correction factor.

C.2.2.2 Flow Diagram

<u>Magnetic Data Input</u>

Number of stations	NSTN
Station positions	X(1),X(2),...,X (NSTN)
Anomaly values	VAL(1),...,VAL (NSTN)
Inclinations of the earth's magnetic field	AINC
Magnitude of the earth's field	FIELD
Strike	STRIKE
Station spacing	DELX

<u>Optimization Control Data</u>

Number of significant figures	NSIG
Tolerance on sum of squares	EPS
Tolerance on the norm of gradient	DELTA

↓

<u>Subroutine Start</u>

Computes $\underline{\alpha}_0$

<u>Subroutine ZXSSQ</u>

Terminate iteration if

(1) $\underline{\alpha}_{k+1}$ and $\underline{\alpha}_k$ agree to NSIG significant figure;

(2) $|SSQ_{k+1} - SSQ_k| \leqslant EPS$

(3) $\|g_k\|_2 \leqslant DELTA$

$\xrightarrow{\underline{\alpha}_k}$ <u>Subroutine fun</u>

Computes

$\longleftarrow$ $Fi(\underline{\alpha}_k)$

↓

<u>Data Output</u>

VAL(k) , X(k) , $\Phi\ (x_k, \underline{\alpha}^*)$ and

VAL(k) $- \Phi\ (x_k , \underline{\alpha}^*)$, $\underline{\alpha}_k^*$.

The program calls subroutine START to compute the initial guess $\underline{\alpha}_0$. Subroutine ZXSSQ requires a subroutine, called FUNC, to compute residuals $\underline{F}_k$ at the current point $\underline{\alpha}_k$. Provision is made to plot the observed and calculated values against the station locations.

2.2.3 Test Example

The program was tested on the theoretical profile of Won (1981, p. 212, Table 1). The data and program (Won's) used were sent by Won (1981, personal communication). The values obtained from the two programs are shown on Table C.1 and Fig. C.5. A very good agreement was observed between the two methods. Examination of the residuals returned by the two methods showed that the method described in this thesis was superior to Won's. In addition, Won's program failed to produce satisfactory fits with many of the observed field data.

Equally good fits were recorded by Cohen (1983, in preparation) and Staker (1982, personal communication) for their respective field problems using the method. The reason may be that the method works very well in practice. It is probably robust and behaves similarly to modified Gauss-Newton algorithms which it is intended to emulate. Convergence was achieved in a relatively shorter computer time than that returned by Won's program.

Hoversten et al. (1982) have also reported good results from the method on resistivity data. In their comparison with other least squares methods they found that the algorithm proved to require fewest number of forward problem evaluations to reach a desired fit.

TABLE C.1

COMPARISON OF WON'S GAUSS' METHOD AND THE AUTOMATIC INTERPRETATION USED IN THIS METHOD

Method		Parameters Estimated				
		Suscept-ibility (CGS Units)	Dip (Degrees)	Depth Below Surface (M)	Width (M)	Centre (M)
Won (1981)	Initial	0.002	70.62	4.68	20.00	44.38
	Final	0.00193	69.97	5.01	20.01	50.01
This Thesis	Initial	0.0045	80.60	5.31	22.50	49.98
	Final	0.0019	70.05	5.01	20.01	50.01

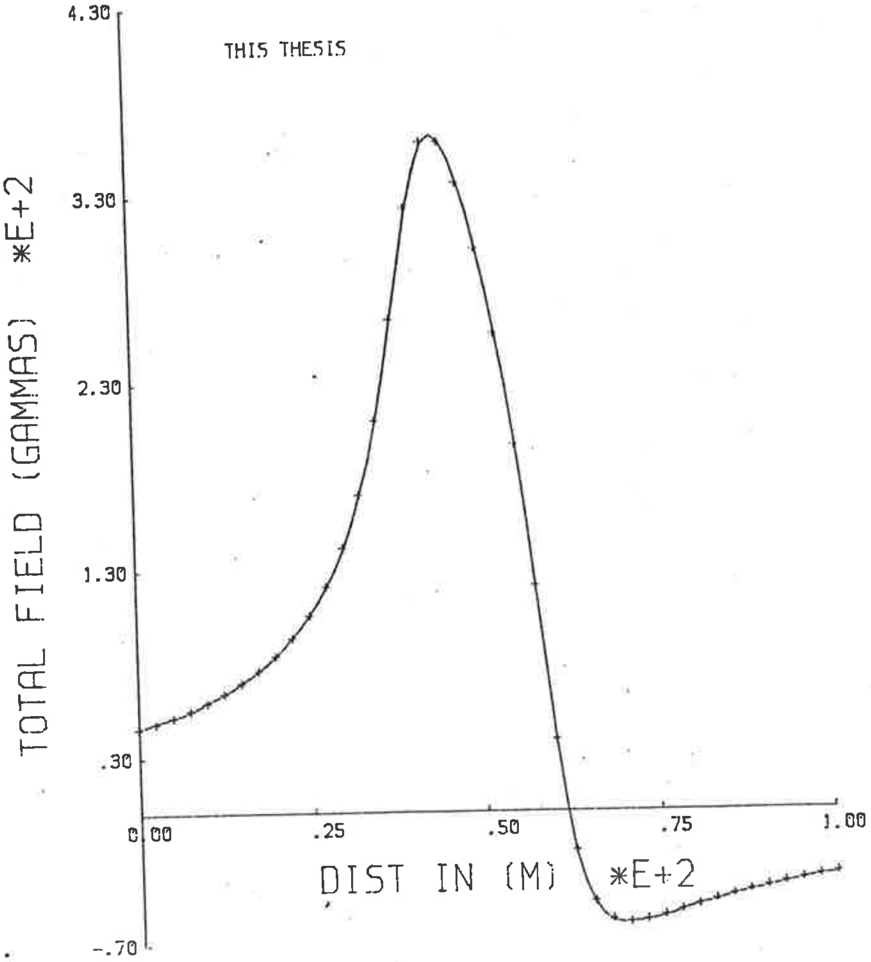
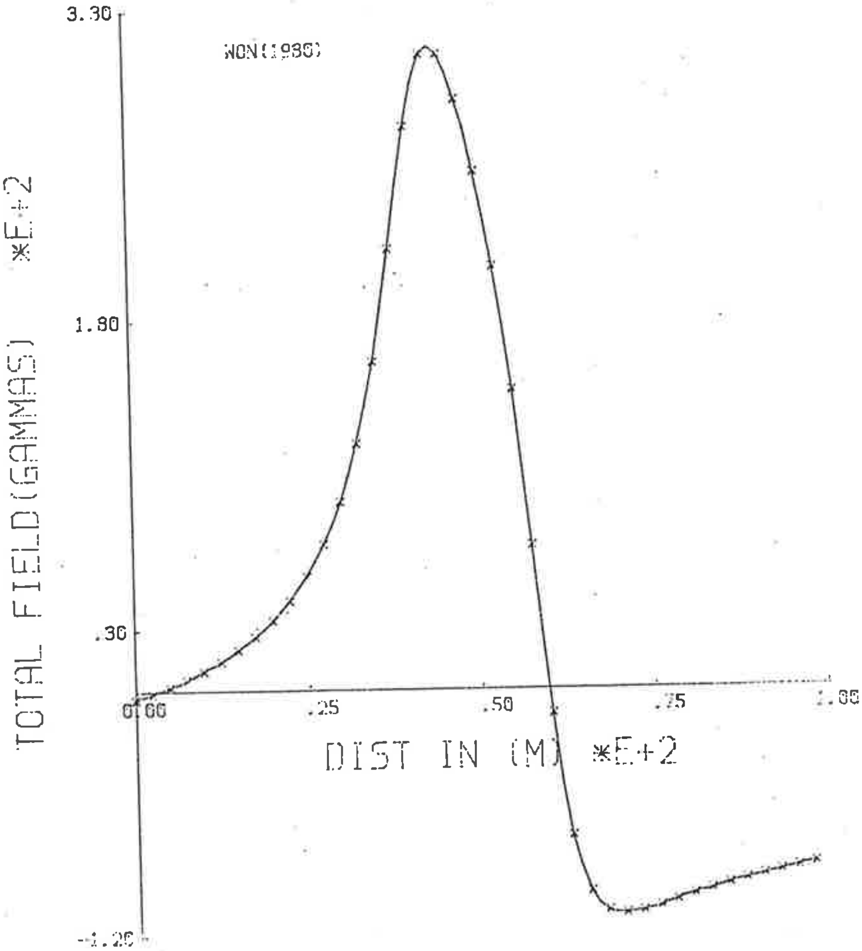


Figure C.5 Comparison of the application of Gauss's method and the automatic method of interpretation used in this thesis.



BIBLIOGRAPHY

AGOCS, W.B., (1955) Line spacing effect and determination of optimum spacing, illustrated by Mamora, Ontario magnetic anomaly, Can. Min. Metall. Bulletin, Vol. 58, pp. 397-400.

AL-CHALABI, M., (1970) Interpretation of two-dimensional magnetic profiles by non-linear optimization, Bolletino di Geophysica Teorica ed Applicata, Vol. 12, pp. 3-20.

ALLINGHAM, J.W., (1966) Aeromagnetic anomalies in Bonne Terre area of the South Missouri Mining District, Mining Geophysics, Vol. 1, pp. 36-53, SEG. Tulsa.

ANSTEY, N.A., (1973) How do we know we are right? Geoph. Prospect, Vol. 21, pp. 407-411.

ANFILOFF, W., BARLOW, B.C., MURRAY, A.S., DENHAM, D., and SANFORD, S., (1976) Compilation and production of the 1976 gravity map of Australia, Bull. Bur. Min. Resources, pp. 273-276.

BAARDA, F.D., (1968) Bancannia South No. 1 Completion report for Planet Exploration Company Pty. Ltd. (unpublished) Geol. Surv. New South Wales file G.S. Well Completion Report, 129.

BABCOCK, E.A., (1974a) A statistical analysis of Photolineaments and Joints, Terrain parameters and lineament density near Leithbridge, Alberta in Hodgson, R.H., Gay, S.P. and Benjamin, J. (eds.) Internationaal Symposium on New Basement Tectonics, Utah Geol. Association, pp. 437-448.

BABCOCK, E.A. and SHELDON, L.G., (1976) Structural significance of lineaments visible on Aerial photos of the Athabasca Oil Shields area near Port MacKay, Alberta, Bull. Canadian Petroleum Geology, Vol. 24, No. 3, pp. 457-470.

BADGLEY, P.C., (1965) Structural and Tectonic Principles, Harper and Row, New York, 1965.

BAILEY, D.K., (1970) Volatile flux, heat-focusing and the generation of magma, in Mechanisms of igneous intrusion (ed.) Newall and Last, Geol. Journal Special Issue, Vol. 2, pp 177-186.

BALSLEY, J.R. and BUDDINGTON, A.F., (1954) Correlation of reverse remanent magnetism and negative anomalies with certain minerals, Journ. Geomag. and Geoelect., Vol. 6, pp. 176-181.

BALSLEY, J.R. and FAHEY, J., (1952) Titanferous hematite and ilmenohematite correlated with inverse polarization in rocks of the northwest Adirondacks, N.Y. Amer. Geoph. Union, Vol. 33, p. 320.

BALSLEY, J.R. and BUDDINGTON, A.F. (1958) Iron-titanium oxide minerals,; Rocks and Aeromagnetic Anomalies of the Adirondack Area, New York, Econ. Geol., Vol. 53, No. 7, pp. 777-805.

BALSLEY, J. and BUDDINGTON, A.F., (1960) Magnetic Susceptibility Anisotropy and fabric of some Adirondack Granites and Orthogenesis, American Journal of Science, Bradley Volume, Vol. 258A, pp. 6-20.

BARNES, R.G., (1980) Types of mineralization of the Broken Hill Block and their relationship to stratigraphy, in A Guide to the Stratigraphy and Mineralization of the Broken Hill Block, New South Wales: New South Wales Geol. Survey Record, Vol. 20(1), pp. 33-70.

BATH, G.D., (1962) Magnetic anomalies and magnetizations of Biwabik iron formation Mesabi area, Geophysics, Vol. 27, pp. 627-650.

BATTERHAM, P.M., BULLOCK, S.J. and HOPGOOD, D.N., (1983) Tanzania: integrated interpretation of aeromagnetic and radiometric maps for mineral exploration, Trans. Instn. Min. Metall. (Section B. Applied Earth Sciences), Vol. 92, pp. B88-B92.

BEACH, A. and FYFE, W.S., (1972) Fluid transport and Shear Zones at Scourie, Sutherland: evidence of overthrusting, Contributions, Mineralogy and Petrology, 36, pp. 175-180.

BEACH, A., (1976) The interrelations of fluid transport, deformation, geochemistry and heat flow in early Proterozoic shear zones in the Lewisian Complex, Phil. Trans. Roy. Soc. London, A280, pp. 569-604.

BEAN, R.J., (1966) A rapid graphical solution for the aeromagnetic anomaly of two-dimensional tabular body, Geophysics, Vol. 31, pp. 963-970.

BECK, M.E. (Jnr.) (1966) The effect of magmatic differentiation on the magnetic properties of diabase sheets of Southern Pennsylvania, U.S. Geol. Survey Professional Paper, 550-D, pp. D109-D116.

BEHRENDT, J.C. and WOTORSON, S.C., (1971) An aeromagnetic and aeroradioactivity survey of Liberia, West Africa, Geophysics, Vol. 36, pp. 590-604.

BELOUSSOV, V.V., (1962) Basic Principles of Geotectonics, McGraw Hill.

BELOUSSOV, V.V., (1965) The Crust and Upper Mantle of Continents, Inter. Geol. Review, Vol. 23, No. 12, pp. 1361-1366.

BERRY, R.F., (1973) Geology of the Doughboy Creek Area, Outalpa Station, Olary Province, South Australia, unpublished B.Sc. (Hons.) thesis, Flinders University of South Australia.

BERRY, R.F., FLINT, R.B. and GRADY, A.E., (1978) Deformation history of the Outalpa Area and its Application to the Olary Province, South Australia, Trans. of the Roy. Society of South Australia, Vol. 102, Pt. 2, pp. 43-54.

BHATTACHARYYA, B.K. (1978) Computer modelling in gravity and magnetic interpretation, Geophysics, Vol. 43, pp. 912-929.

BILLINGS, M.P., (1972) Structural Geology (3rd edition), Prentice-Hall, Englewood Cliffs, N.J., 1972.

BINNS, R.A., (1963) Some observations on metamorphism of Broken Hill, Proc. Aust. Inst. Metall., Vol. 207, pp. 239-261.

BINNS, R.A., (1964) Zones of progressive regional metamorphism in the Willyama Complex, Broken Hill District, New South Wales, Journ. Geol. Soc. Austr., Vol. 11, No. 2, pp. 283-330.

BINNS, R.A., (1965) Petrographic evidence relating to movement on the Thackaringa-Pinnacles Fault, Broken Hill District, Proc. Aust. Inst. Min. Metall., Vol. 214, pp. 95-101.

BOSUM, W., (1968) Ein automatisches Verfahren zur Interpretation magnetischer Anomalien nach der Methode der kleinsten Quadrate, Geophys. Prospect., Vol. 16, pp. 109-126.

BOYD, D., (1967) The contribution of airborne magnetic survey to geological mapping, Canadian Gentennial Conference on Mining and Groundwater Geophysics, Niagara.

BOYD, D., (1979) Geophysics for Geologists, Australian Mineral Foundation Incorporated Workshop Course 115/79, Adelaide, March, 1979.

BROCK, B.B., (1957) World patterns and lineaments, Trans. Geol. Soc., South Africa, Vol. 60, pp. 127-160.

BROCK, B.B., (1961) Discussion in Mitchell-Thome Raoul, C. (1961) Lineaments and Vincula, Trans. Geol. Soc. of South Africa, Vol. 64, pp. 257-278.

BULINA, L.V., (1964) Application of Aerial magnetic survey in the studies of deep-lying structures in the Siberian platform, Int. Geol. Rev., Vol. 4, No. 11, pp. 1263-1266.

BURNS, S.D., (1980) Summary report EL 470 Sturt Vale, for Mines Administration Pty. Ltd. - Teton Exploration Drilling Co. Pty. Ltd., South Australia, Department of Mines, South Australia Open File Report Envelope 3527 (unpublished).

BYRAN, R., (1971) Exploration report SML 282 (Lilydale) carried out by Mines Administration Pty. Ltd. 1.4.69 - 31.3.71. Department of Mines, South Australia Open File Report Envelope 1428 (unpublished).

BYRAN, R., (1972) Final report SML 416 (post mark) for Mines Administration Pty. Ltd., South Australia, Department of Mines Open File Report Envelope 1403 (unpublished).

CALLEN, R.A., (1969) Preliminary notes on the Oakvale 1:63360 sheet, South Australia, Department of Mines, South Australia Report 69/1 (unpublished).

CALLEN, R.A. and TEDFORD, R.H., (1976) New Late Cainozoic rock units and depositional environments, Lake Frome area, South Australia, Trans. Roy. Soc. South Australia, Vol. 100, pp. 125-167.

CAMPANA, B. and KING, D., (1958) Regional geology and mineral resources of the Olary Province, Geol. Survey of South Australia, Bull. 34.

CHAPELL, B.W. and WHITE, A.J.R., (1974) Two contrasting granite types: Pacific Geology, Vol. 8, pp. 173-174.

CHAPELL, B.W. and WHITE, A.J.R., (1976) Plutonic rocks of the Lachlan Mobile Zone: 25th International Geol. Congress Sydney, Excursion Guide No. 13C.

CLEGG, J.A., ALMOND, M., and STUBBS, P.H.S., (1954a) The remanent magnetism of some sedimentary rocks in Britain: Philo. Mag. Ser. 7, Vol. 45, pp. 583-598.

COATS, R.P. and BLISSET, A.H., (1970) Regional and economic geology of the Mount Painter Province, Bull. Geol. Surv. South Australia, Vol. 43.

COBB, M.A. and MORRIS, B.J., (1970) The Weekeroo Amphibolite, Olary Province, South Australia, unpublished B.Sc. (Hons.) thesis, University of Adelaide.

COMPSTON, W. and ARRIENS, P.A., (1968) The Precambrian Geochronology of Australia, Canadian Journ. of Earth Sciences, Vol. 5, pp. 561-683.

COOPE, J.A. and DAVIDSON, M.J., (1979) Some aspects of integrated exploration in Geophysics and Geochemistry in the Search for Metallic Ores, Geol. Survey Can. Econ. Geol. Report 31, pp. 575-592.

COOPER, B.J., (1978) Palaeontological examination of samples from Borings along the northern margin of Murray Basin, South Australia, Department of Mines, South Australia Report 78/82 (unpublished).

COOPER, J.A., (1975) Isotopic datings of the basement cover boundaries within the Adelaide Geosyncline (abstract), Geological Society of Australia, First Geological Convention on Proterozoic Geology.

CORDELL, L. and GRAUCH, V.J.S., (1983) Mapping basement magnetization zones from Aeromagnetic Data in the San Juan Basin, New Mexico, Abstract, Geophysics, Vol. 48, No. 4.

DEGENS, E.T., WILLIAMS, E.G. and KEITH, M.L., (1957) Environmental studies of Carboniferous sediments Pt. 1: Geochemical criteria for differentiating marine and fresh-water shales, Bull. Amer. Assoc. Petrol. Geol., Vol. 41, pp. 2427-2455.

DOELL, R. and COX, A., (1967) Magnetization of Rocks: Mining Geophysics, Vol. II, SEG, Tulsa, pp. 446-453.

DUNLOP, D.J., (1971) Magnetic properties of fine particle hematite, Annals de Geophysique, Vol. 23, pp. 269-293.

DUNLOP, D.J., (1974) Thermal enhancement of magnetic susceptibility, Journ. Geoph., Vol. 40, pp. 439-452.

ELDER, T., (1965) Particle size effect in oxidation of natural magnetite, Journ. Appl. Physics, Vol. 36, pp. 1012-1013.

ELLWOOD, B.B., (1981) Weathering effects on magnetic properties of the Milledgeville granite, Georgia: Earth and Planet Sci. Letters, Vol. 55, p. 311-316.

EMERSON, D.W., (1973) A geophysical study of the eastern margin of the Yilgarn Block, Western Australia, Ph.D. thesis, University of Sydney (unpublished).

EMERSON, D., (1976) Magnetic anomaly trends in the Yilgarn Block, Western Australia, Bull. Aust. Soc. Expl. Geophy., Vol. 7, No. 3, pp. 96-102.

EMERSON, D.W., (1978) The regional geology and gross structure of the Cundeelee area, Western Australia, Geoexpl., Vol. 16, pp. 235-250.

EMERSON, D.W., (ed.), (1979) Proceedings from Applied Magnetic Interpretation Symposium, Bull. Aust. Soc. Expl. Geophys, Vol. 10.

EMERSON, D.W., (1979) Comments on Applied Magnetics in Mineral Exploration, Bull. Aust. Soc. Expl. Geophy., Vol. 10, No. 1, pp. 3-5.

ESCHER, A., JACK, S. and WATTERSON, J., (1974) Tectonics of the North Atlantic Proterozoic Dyke Swarm, Phill. Trans. Roy. Soc. London, A280, pp. 529-540.

EVERLE, V.A., (1973) Susceptibility studies of some amphibolites from the Broken Hill region, New South Wales, B.Sc. (Hons.) thesis, University of Adelaide, (unpublished).

FIELD, D. and ELLIOTT, R.B., (1974) The chemistry of gabbro/amphibolite transitions in South Norway II Trace elements, Contr. Mineral Petrology, Vol. 47, pp. 63-73.

FINDLAY, D., (1982) Necking, a structural control in the location of ore deposits, Global Tectonics and Metallogeny, Vol. 1, No. 4, pp. 304-324.

FINLAYSON, D.M., (1973) Isomagnetic maps of the Australian Region for Epoch, 1970.0 BMR Report 159.

FIRMAN, J.B., (1969) The Quaternary Period in Parkin, L.W. (ed.) Handbook of South Australian Geology, Geol. Surv. South Australia, pp. 204-233.

FIRMAN, J.B., (1974) Structural Lineaments in South Australia, Trans. Roy. Soc. South Australia, Vol. 98, No. 3, pp. 153-171.

FLINT, D.J. and WEBB, A.W., (1979) Geochronological investigations of the Willyama Complex, South Australia, Department of Mines, South Australia, Report 79/136 (unpublished).

FLINT, D.J., (1980) Petrographic descriptions of Willyama Complex rocks and Umberatana Group metasediments, Southern Outalpa Inlier, Olary Province, South Australia, Department of Mines and Energy Report 80/43 (unpublished).

FLINT, D.J. and PARKER, J., (1982) Tectonic Map of South Australia, <u>Department of Mines, South Australia</u>.

FLINT, R.B., (1974) A petrological and structural study of a portion of the Olary Province east of Whey Whey Creek, South Australia, B.Sc. (Hons.) thesis, Flinders University of South Australia (unpublished).

FORBES, B.G. and COOPER, R.S., (1976) The Pualco Tillite of the Olary Region of South Australia, Quat. Geol. Notes, <u>Geol. Surv. South Australia</u>, No. 60, pp. 1-5.

FORBES, B.G. and PITT, G.M., (1980) Geology of the Olary region, Geol. Surv. South Aust. Department of Mines Report 80/151 (unpublished).

FORBES, B.G., (1982) Minor Changes in stratigraphic nomenclature, Adelaide System, Late Proterozoic, Quart. Geol. Notes, <u>Geol. Surv. South Australia</u>, No. 79, pp. 7-16.

FRASER, A., (1976) Gravity Provinces and their Nomenclature, <u>Bull. Bur. Min. Resources</u>, Vol. 1, No. 4, pp. 350-352.

GAY, S.P. (Jnr.) (1963) Standard curves for the Interpretation of magnetic anomalies over long tabular bodies, <u>Geophysics</u>, Vol. 28, No. 2, pp. 161-200.

GAY, S.P. (Jnr.) (1971) Morphological study of geophysical maps by viewing in three dimensions, <u>Geophysics</u>, Vol. 36, No. 2, pp. 396-414.

GAY, S.P. (Jnr.) (1974) Proceedings of the First Internationaal Conference on New Basement Tectonics, 1974, <u>Utah Geol. Assoc. Publ. No. 5</u>, p. 4.

GAY, S.P. (Jnr.) (1974) Aeromagnetic lineament study of covered Precambrian basement, southeastern Missouri, in Hodgon, R.A., Gay, P.S., Benjamin, J.Y. (eds.) Proceedings of the First International Conference on the New Basement Tectonics, <u>Geol. Survey, Utah</u>, pp. 183-191.

GAY, S.P. (Jnr.) (1974) Short Notes, Standardization of Azimuthal Presentations, Geol. Survey, pp. 499-500.

GERDES, R.A., (1973a) Anabama fault project Part A: Regional geophysical interpretation of the Southern half of Olary and the Northern half of Chowilla 1:250,000 acres, South Australian Department of Mines Report 73/75.

GERDES, R.A., (1975) Bouquer Anomaly Map of Olary and Curnamona, Geol. Surv. South Australia.

GERDES, R., (1982) Personal communication, Department of Mines and Energy, South Australia.

GERDES, R.A., (1982) The Interpreted Depths to Magnetic Basement Map of South Australia, Quarterly Geol. Notes Geol. Survey of South Australia, No. 83.

GERNIK, V.V., KLUSHIN, I.G. and RIVOSH, L.A., (1975) Relationships between metamorphism and Geophysical properties of the crust in Northern Karelia, Dolkady Akad. Nauk SSSR 226, pp. 95-98.

GLEN, R.A., LAING, W.P., PARKER, A.J., and RUTLAND, R.W.R., (1977) Tectonic relationships between the Proterozoic Gawler and Willyama Orogenic Domains, Australia, Journ. Geol. Soc. Australia, Vol. 24, No. 3, pp 125-150.

GRAHAM, J.W., (1949) The stability and significance of magnetism in sedimentary rocks: Journ. Geoph. Research, Vol. 54, p. 131-167.

GRAHAM, J.W., (1954) Magnetic susceptibility anisotropy an unexploited petrofabric element (Abstract), Bull. Geol. Soc. America, Vol. 65, pp. 1257-1258.

GRAHAM, J.W., BUDDINGTON, A.F. and BALSLEY, J.R., (1957) Stress induced magnetization in some rocks with analyzed magnetic minerals, Journ. Geoph. Research, Vol. 62, pp. 465-474.

GRANT, F.S. and WEST, G.F., (1965) Interpretation theory in applied geophysics, McGraw-Hill.

GREEN, R., (1960) Remanent magnetization and the interpretation of magnetic anomalies, Geophys. Prospect., Vol. 8, pp. 98-110.

GUILD, P.W., (1983) Tectonics and Metallogenic Provinces, Adv. Space Res., Vol. 3, No. 2, pp. 9-16.

HARBAUGH, J.W. and MERRIAM, D.E., (1968) Computer Applications in Stratigraphic Analysis, John Willie, New York

HARRINGTON, H.J., BURNS, K.L. and THOMSON, B.R., (1973) Gambier - Beaconsfield and Gambier - Sorell fracture zones and the movement of plates in the Australia-Antarctic-New Zealand region, Nature, Phys. Sci., Vol 245, pp. 109-112.

HARRINGTON, H.J., SIMPSON, C.J. and MOORE, R.F., (1982) Analysis of continental structures using digital terrain model (DTM) of Australia, BMR Journal of Geology and Geophysics, Vol. 7, No. 1, pp. 68-72.

HEILAND, C.A., (1946) Geophysical Exploration, New York, Prentice Hall Inc.

HEIMLICH, R.A., (1974) Retrograde metamorphism of amphibolites, Bighorn Mountains, Wyoming, Geol. Society of America Bull., Vol. 85, pp. 1449-1454.

HENKEL, H. and GUZMAN, M., (1977) Magnetic features of fracture zones, Geoexpl., Vol. 15, No. 3, pp. 173-182.

HEPWORTH, J.V., (1967) The photogeological recognition of ancient orogenic belts in Africa, Quart. Journ. Geol. Soc. London, Vol. 123, pp. 253-292.

HEPWORTH, J.V. and KENNERKY, J.B., (1970) Photogeology and structure of the Mozambique orogenic front near Kolo, north-east Tanzania, Quart. Journ. Geol. Soc. London, Vol. 125, pp. 447-479.

HESS, H.H., (1960) Stillwater igneous complex, Montana, Geol. Soc. America, Mem. 8.

HILLS, E.S., (1953) The tectonic setting of Australia ore deposits in Edwards, A.B. (Ed.) Geology of Australian Ore Deposits 1, 41-61 (5th Empire Mining and Metallurgical Congress, Melbourne).

HJELT, S.E., (1973) Experiences with automatic magnetic interpretation using the thick plate model, Geophys. Prospect., Vol. 21, pp. 243-265.

HODGSON, R.A., (1974) Proceedings of the First International Conference on New Basement Tectonics, 1974, Utah Geol. Assoc. Publ. No. 5, p. 3.

HOLROYD, M.T., (1974) The aeromagnetic data automatic mapping (ADAM) system in Geol. Surv. Canada Paper 74-60, pp. 71-76.

HOOD, P.J., (1964) The Konigsberger Ratio and the Dipping Dyke Equation, Geophys. Prosp., Vol. 12, No. 4, pp. 441-456.

HOOD, P.J., (1969) Magnetic Methods in Prospecting in Canada in Laing, A.H. (Ed.) Economic Geology Report No 7 pp. 134-146.

HOOD, P.J., (1972) The application of aeromagnetic survey data to geological mapping programs (Abstract), 24th Internationaal Geological Congress Section 9, pp. 75.

HOOD, P.J., (1979) Geophysics and geochemistry in the search for metallic ores, Geol. Survey of Canada, Economic Geol. Report 31.

HOOD, P.J., HOLROYD, M.T. and McGRATH, P.H., (1979) Magnetic methods applied to base metal exploration in Geophysics and Geochemistry in Search for metallic ores, Geol. Survey of Canada, Economic Geology Report 31, pp. 77-104.

HOOD, P.J., McGRATH, P.H., and KORNICK, L.J., (1974) Evaluation of Derived Vertical Gradient Results in the Timmins area, Ontario: Geol. Sur. Can. Paper 75-1, Part A, pp. 111-115.

HOVERSTEN, G.M., DEY, A. and MORRISON, H.F., (1982) Comparison of five least-squares inversion techniques in Resistivity sounding, Geophsycial Prospecting, Vol. 30, pp. 688-715.

INMAN, J.R., (1975) Resistivity inversion with ridge regression, Geophysics, 40, pp. 798-819.

IRVING, E., (1970) The mid-Atlantic ridge at 45°14': Oxidation and magnetic properties of basalts, Review and discussion, Can. Journal of Earth Sciences, Vol. 7, pp. 1528-1538.

ISLES, D.J., (1983) A regional geophysical study of the Broken Hill block, New South Wales, Australia, Ph.D. thesis, Adelaide University (unpublished).

JAEGER, J.C. and JOPLIN, G., (1955) Rock magnetism and the differentiation of dolerite sill, Journal Geol. Soc. Australia, Vol. 2, pp. 1-19.

JAHREN, C.E., (1963) Magnetic susceptibility of bedded iron formations, Geophysics, Vol. 28, No. 5, pp. 756-766.

JAHREN, C.E., (1965) Magnetization of Keweenawan Rocks near Duluth, Minnesota, Geophysics, Vol. 30, No. 5, pp. 858-874.

JAIN, S., (1976) An automatic method of direct interpretation of magnetic profiles, Geophysics, Vol. 41, pp. 531-541.

JAKOSKY, J.J., (1950) Exploration Geophysics, Second Edition, Trija Publishing Company, California.

JARRE, G.A., (1972) Final Report SML 555 (Brady's Dam) (for Mines Administration Pty. Ltd.) South Aust. Dept. Mines and Energy Open File Envelope 1644 (unpublished).

JOHNSTON, J., (1972) Econometric Methods, 2nd Edition, McGraw Hill Co. New York.

JOHNSON, H.P. and MERRILL, R.T., (1972) Magnetic and Mineralogical Changes Associated with low-temperature oxidation of magnetite, Journal of Geophysical Research, Vol. 77, No. 2, pp. 334-341.

JOHNSON, W.W., (1969) A least squares method of interpreting magnetic anomalies caused by two-dimensional structures, Geophysics, Vol. 34, No. 1, pp. 65-74.

JONES, J.B., TALBOT, J.L. and McBRIAR, E.M., (1962) A suite of volcanic rock with spilitic affinities from the Archaean of South Australia, Aust. Journ. Science, Vol. 24, No. 8, p. 356.

JOPLIN, G.A., (1963) Chemical analyses of Australian rocks, Part 1: Igneous and Metamorphic, Bull. Bureau of Min. Resources, Vol. 65.

JUPP, D.L.B. and VOZOFF, K., (1975) Stable iterative methods for the inversion of geophysical data, Geoph. Journ. of Roy. Astro. Soc., Vol. 42, pp. 952-976.

KATUSURA, T. and KUSHIRO, I., (1961) Titanomaghemite and igneous rocks, American Mineralogist, Vol. 46, pp. 134-145.

KATZ, M.B., (1976) Lineament Tectonics of the Willyama Block and its relationship to the Adelaide Aulocogene, Journ. Geol. Soc. Australia, Vol. 23, Pt. 3, pp. 275-285.

KEITH, M.L. and BYSTROM, A.M., (1959) Comparative analysis of marine and fresh-water shales, Penn. State Univ., Mineral Inds. Expt. Stat. Bull. (Mineral Conservation Series).

KETOLA, M., AHOKAS, T., LIIMATAINEN, M. and KASKI, T., (1975) Some case histories of the interpretation of magnetic and gravimetric anomalies of two- and three-dimensional models, Geoexpl., Vol. 13, pp. 137-169.

KETOLA, M., (1979) On the application for geophysics in the indirect exploration for Copper sulphide ores in Finland, in Geophysics and Geochemistry in the Search for Metallic ore, Hood, P.J. (Ed.), Geol. Surv. Can. Economic Geol. Report 31, pp. 665-684.

KETOLA, M., (1982) On the application of geophysics and geology to exploration for nickel - copper ore deposits in Finland, Report of Investigation No. 53, Geol. Surv. Finland.

KHAN, M.A., (1962) The anisotropy of magnetic susceptibility of some igneous and metamorphic rocks: Jour. Geoph. Research, Vol. 67, No. 7, pp. 2873-2885.

KILTY, K.T., (1983) Werner deconvolution of profile potential field data, Geophysics, Vol. 48, No. 2, pp. 234-237.

KING, E.R. and ZEITZ, I., (1972) Aeromagnetic study of the mid-continent gravity high of Central United States, Bull. Geol. Soc. America, Vol. 82, No. 8, pp. 2187-2208.

KING, H.F. and THOMSON, B.P., (1953) The geology of the Broken Hill District, in Geology of Australian ore deposits, 5th Empire Min. Metall. Congress 1, pp. 533-577.

KORNIK, L.J. and MacLAREN, A.S., (1966) Aeromagnetic study of the Chruchill-Superior boundary in Northern Manitoba, Canadian Journal of Earth Science, Vol. 3, No. 4, pp. 547-557.

KOULOMZINE, T., LAMONTAGNE, Y. and NADEAU, A., (1970) New methods for the direct interpretation of magnetic anomalies caused by inclined dykes of infinite length, Geophysics, Vol. 35, No. 5, pp. 812-830.

KRUTIKHOVSKAYA, Z.A., PASHKEVICH, I.K. and SIMONENKO, T.N., (1973) Magnetic anomalies of Precambrian Sheilds and some problems of their geological interpretation, Canadian Journal of Earth Sciences, Vol. 10, pp. 629-636.

KRUTIKHOVSKAYA, Z.A. and PASHKEVICH, I.K., (1979) Long-wavelength magnetic anomalies as a source of information about deep crustal structure, Journ. Geophys., Vol. 46, pp. 301-317.

KRUTIKHOVSKAYA, Z.A., SILINA, I.M., BONDAREVA, N.M. and PODOLYANKO, S.M. (1979) Relation of magnetic properties of the rocks of the Ukrainian Shield to their Composition and metamorphism, Canadian Journal of Earth Science, Vol. 16, No. 5, pp. 984-991.

KU, G.C. and SHARP, I.A., (1983) Werner deconvolution for automated magnetic interpretation and its refinement using Marquardt's inverse modelling, Geophysics, Vol. 48, No. 6, pp. 754-774.

KUKKONEN, I., SARAPAA, O. and HEINO, T., (1985) Black schists, their origin composition and occurrence: Geol. Surv. Finland, Report of Invest. No. 69, pp. 70-84.

LATHRAM, E.H. and ALBERT, N.R., (1974) Significance of Space Image Linears in Alaska, in Hodgson, R.A., Gay, S.P., and Benjamin, J.T. (Eds.) Proceedings of the First International Conference on the New Basement Tectonics, Geol. Survey Utah, pp. 11-26.

LE GRAND, H.E., (1958) Chemical Characteristics of water in the igneous and metamorphic rocks of North Carolina: Econ. Geol. Vol. 53, pp. 178-189.

LEVERBERG, K., (1944) A method for the solution of certain non-linear problems in least squares, Quarterly of Applied Mathematics, 2, pp. 164-168.

LIDIAK, E.G., (1974) Magnetic characteristics of some Precambrian basement rocks, Journal of Geophysics, Vol. 40, pp. 549-564.

LINDSAY, J.M. and HARRIS, W.K., (1973) Miocene marine transgressions on Mutooroo, Olary at the northern margin of the Murray Basin, South Aust. Dept. of Mines Report 779, (EL 63) (unpublished).

LINSSER, H., (1967) Investigation of tectonics by gravity detailing, Geoph. Prosp., Vol. 17, No. 3, pp. 480-515.

LINSSER, H., (1968) Transformation of magnetometric data into tectonic maps by digital template analysis, Geoph. Prospect., Vol. 16, No. 2, pp. 179-207.

LINSSER, H., (1971) Mapping of Tectonics of Sediments by Airborne Magnetics, Geoph. Prosp., Vol. 19, No. 2, pp. 243-252.

LINDSLEY, D.H., ANDREASEN, G.E. and BALSLEY, J.R., (1966) Magnetic properties of rocks and minerals, in Clark Sydney. P(Ed.) Handbook of Physical constants. Geol Soc. Am. Memoir 97, pp. 456-464.

MacLAREN, A.S. and CHARBONNEAU, B.W. (1968) Characteristics of the Magnetic Data over major subdivisions of the Canadian Shield, Proceedings of Geological Association of Canada, Vol. 19, pp. 57-65.

MAGNITSKY, V.A., (1963) Fundamentals of Earth Physics, Nedra Press, Moscow.

MALMQVIST, L., (1980) Exploration under Northern conditions - some general considerations, pp. 49-59, in Weiss, A. (Ed.,), Computer Methods for the 80's in the Mineral Industry, Society of Mining Engineers.

MARMO, V., (1960) On possible relationship between sulphide schists and ores, 21st International Geological Congress Report, Part 16, pp. 160-163.

MARMO, V., (1960b) On sulphide and sulphide graphite schists of Finland, Geological Survey of Finland, No. 190, pp. 1-80.

MARQUARDT, D.W., (1963) An algorithm for least-squares estimation of non-linear parameters, Journal of the Society for Industrial and Applied Mathematics, II, pp. 431-441.

MARTIN, R.F., (1966) A chemical and petrographic study of the granitic rocks of New Brunswick, Canada, M.A. Thesis, Penn. State University (unpublished).

MAWSON, D., (1912) Geological Investigations in the Broken Hill Area, Mem. Roy. Soc. South Australia, Vol. 11, No. 4.

McGRATH, P.H., (1970) Magnetic investigations of the Charlotte and Pokiok intrusions, Southern New Brunswick, Geological Associationn of Canada, Proceedings, Vol. 21, pp. 25-32.

McGRATH, P.H. and HOOD, P.J., (1970) The dipping dyke case: a computer curve matching method of magnetic interpretation, Geophysics, Vol. 35, No. 5, pp. 831-848.

McGRATH, P.H., KORNIK, L. and DODS, S.D. (1976) A method for the compilation of high quality calculated first vertical derivative aeromagnetic maps. Report of Activities Part C in Geol. Surv. Canada Paper 76- pp. 9-17.

McINTYRE, J.I. and WYATT, B.W., (1978) Contributions to the regional geology of the Broken Hill area from gephysical data, BMR Journal of Geology and Geophysics, Vol. 293, No. 4. pp. 265-280.

McINTYRE, J.I., (1979) Aeromagnetics - an effective geological mapping for Willyama Complex, *Bull. Aust. Soc. Expl. Geophysics*, Vol. 10, No. 1, pp. 42-53.

McINTYRE, J.I., (1980) Geological significance of magnetic patterns related to magnetite sediments and metasediments - a Review, *Bull. Aust. Soc. of Expl. Geophy.*, Vol. 11, No. 2, pp. 19-33.

McINTYRE, J.I., (1981) Accurate display of fine detail in aeromagnetic data, *Bull. Aust. Soc. Expl. Geoph.*, Vol. 12, No. 4, pp. 82-88.

MESHREF, W.M. and HINZE, W.J., (1970) Geologic interpretation of aeormagnetic data in Western Upper Peninsula of Michigan, Report of Investigation 12, *Geological Survey Michigan Department of Natural Resources*.

MICHELMORE, T.R., (1971) Geology of copper mineralized areas in the Olary Province, B.Sc. (Hons.) thesis, University of Adelaide (unpublished).

MIDDLETON, T.W., (1975) Tricentrol Australia Ltd., Mutooroo EL63 Final Report, A Technical Report, South Australian Department of Mines and Energy, Open File Envelope 2315, (unpublished).

MILTON, B.E. and PARKER, A.J., (1973) An interpretation of Geophysical Observations on the Northern margin of the Eastern Officer Basin: *Quart. Geol. Notes* No. 46, pp. 10-14, Geol. Surv. South Australia.

MIKKOLA, A.K. and YUDRELA, P., (1974) Ore-bearing areas as related to the linearity of Finnish bedrock, in Problems of Ore Deposition, *Fourth IAGOD Symposium Varna Ud. II*, pp. 493-503.

MIRIAM, R.C., (1966) Field relationship of the Anabama granite, *Tran. Roy. Soc. South Australia*, Vol. 85, pp. 121-154.

MIRIAM, R.C., (1961) The geology of the Manunda Military Sheet (Explanation of the geological map), *Report of Investigation 19, South Australia, Department of Mines* (Geological Surveys Division).

MIRIAM, R.C., (1962) The geology of the Manunda Military Sheet (explanation of the geological map), Report of Investigations, 19, South Australia Department of Mines, *Geol. Surv. South Australia*, Vol. 19, pp. 1-40.

MIYASHIRO, A., (1961) Evolution of Metamorphic Belts *Jour. of Pet.* Vol. 2, p. 277-311.

MORE, J.J., (1978) The Levenberg-Marquardt Algorithm: Implementation and theory in Watson, G.A. (Ed.) Numerical Analysis - Dundee, 1977 Lecture Notes in Mathematics 630. Springer-Verlag, Berlin.

MURTY, P.S.N., ASWATHANARAYANA, and MAHADEVAN, C., (1962) Geochemistry of the siliceous black slates at Nagarjuna Sagar Dam-site India, Econ. Geol., Vol. 57, pp. 614-616.

O'BRIEN, D.P., (1972) Compudepth: A new method for depth to basement computation; 42nd Ann. Mtg., Soc. Expl. Geophysics, Anaheim, California (Preprint).

O'DRISCOLL, E.S.T. and KEENIHAN, S.L., (1980) The Toowoomba - Charleville Lineament in South Queensland, APEA Journal 20, (1), pp. 16-24.

O'DRISCOLL, E.S.T. (1981a) Structural Corridors and Landsat lineament interpretations Mineralium deposits, 16, pp. 85-101.

O'DRISCOLL, E.S.T. (1981b) A broad-scale structural characteristics of major nickel sulphide deposit of Western Australia, Economic Geology, 76, pp. 1364-1372.

O'DRISCOLL, E.S.T. (1982) Deep tectonic foundations of the Eromanga Basin, Symposium Eromanga Basin of South Australia, Adelaide, pp. 5-17 (unpublished).

O'DRISCOLL, E.S.T. (1982) Patterns of discovery - the challenge of innovative thinking, 1981 PESA Australian Distinguished Lecture, PESA Journal 1, pp. 1-31.

OGAWA, K. and TSU, H., (1976) Magnetic interpretation using interactive computer graphics, Japan Pet. Dev. Corp. Techn. Res. Centre, Rep. 3, pp. 19-39.

OLIVER, R., (1983) Department of Geology and Mineralogy, University of Adelaide.

PANKHURST, R.J., (1979) Isotope and trace element evidence for the origin and evolution of Caledonian granites in the Scottish Highlands in Atherton, M.P. and Tarney, J. (Eds.), Origin of granite batholiths, Orpington Kent, Shiva publishing, p. 18-33.

PARASNIS, D.S., (1966) <u>Mining Geophysics, Methods in Geochemistry and Geophysics</u>, Vol. 3, Olsevier Publishing Company, London.

PARASNIS, D.S., (1972) Pseudogeological Maps from regional geophysical data and their transformation into hologeological maps (Abstract), <u>24th International Geological Congress</u>, (Section 9) pp. 33.

PARKER, A.J., (1972) A petrological and structural study of a portion of the Olary Province West of Wiperaminga Hill, South Australia, B.Sc. (Hons.) thesis, University (unpublished).

PARKER, J., (1983) Personal, communication, Regional Geology, South Australia, Department of Mines and Energy.

PATERSON, N.R., (1974) Canadian Mining Geophysics, 1974, <u>Bull. Can. Soc. Expl. Geophy</u>. Vol. 10, No. 1, pp. 9-22.

PECANEK, H.T., (1975) Interpretation of geophysical data from the Broken Hill area, M.Sc. thesis, University of Adelaide (unpublished).

PECHERSKIY, D.M., (1968) Of the granitoids of the Verkhoyansk - Chukotka fold region and the Okhotsk - Chukotka volcanic belt, <u>Inter. Geol. Review.</u>, Vol. 7, No. 11, pp. 1963-1976.

PELTOLA, E., (1960) On the black schists in the Outokumpu region of Eastern Finland, <u>Bull. Geol. Survey of Finland</u>, No. 192, pp. 1-105.

PELTOLA, E., (1968) On some geochemical features in the black schists of the Outokumpu region in Finland, <u>Bulletin, Geological Society of Finland</u>, Vol. 40, pp. 39-50.

PETERS, L.J., (1949) The direct approach to magnetic interpretation and its practical application, <u>Geophysics</u>, Vol. 4, pp. 290-319.

PHILLIPS, W.J., (1972) Hydraulic fracturing and mineralization, <u>Journ. Geol. Soc. London</u>, Vol. 128, pp. 337-359.

PHIPPS, C.B. and REEVE, A.E., (1969) Structural geology of the Malvern, Abberley and Ledbury Hills, Quart. <u>Journal Geol. Soc. London</u>, Vol. 125, Part 1, pp. 1-38.

PIDGEON, R.T., (1967) Rb-Sr Geochronological study of the Willyama Complex, Broken Hill, Australia, <u>Journal of Petrology</u>, Vol. 8, pp. 283-324.

PITCHER, W.S., (1975) On the rate of emplacement of batholiths, <u>Jour. of Gol. Soc. London</u>, Vol.131, p.587-589.

PITCHER, W.S., (1978) The anatomy of batholiths Jour. Geol. Soc. London, Vol. 135, p. 157-182.

PITT, G.M., (1976) Geology of the MacDonald Corridor, Olary Provice, Quart. Geol. Notes, Geol. Surv. South Australia, No. 39. pp. 3-7.

PITT, G.M., (1978a) The mineral potential of the Willyama Complex, South Australia, South Australian Department of Mines and Energy Report 78/2 (unpublished).

PITT, G.M., (1978b) An indexed bibliography of the Willyama Complex and Adelaide System, Olary Province, South Australia, Department of Mines and Energy, Report Book No. 78/67A.

PITT, G.M., (1981) Precambrian of the Curnamona area (Progress Report) Dept. of Mines, South Australia, Report 81/120 (unpublished).

PLANT, J., BROWN, G.C., SIMPSON, P.R. and SMITH, R.T. (1980) Signatures of metalliferous granites in the Scottish Caledonides, Trans. Instn. Mining Metall. (Section. B Applied Earth Sci.), Vol. 89, pp. B198-B210.

POWELL, D.W., (1963) The significance of differences in magnetization along certain dolerite dykes, Nature, London, Vol. 199, pp. 674-676.

POWELL, D.W., (1967) Fitting observed profiles to a magnetized dyke or fault - step model, Geoph. Prosp. Vol 15, No. 2, pp. 208-221.

POWELL, M.J.D., (1970b) A hybrid method for non-linear equations in Rabinowitz, P. (Ed.), Numerical Methods for Non-linear Algegbraic Equations, Gordon and Breach, London.

PRICE, N.J., (1971) Laws of rock behaviour in the earth's crust, 11th Int. Congress Rock Mechanics, Berkeley, pp. 2-23.

PRICE, N.J., (1975) Fluids in the crust of the earth, Science Prog. Vol. 62, pp. 59-87.

PRIGOGINE, I., (1967) Introduction to the thermodynamics of irreversible process, Wiley Interscience, New York.

PULLAIAH, G., IRVING, E., BUCHAN, K.L. and DUNLOP, D.J., (1975) Magnetization changes caused by burial and uplift, Earth and Planetary Science Letters, Vol. 28, pp. 133-143.

PURANEN, M., MARMO, V. and HAMALAINEN, U., (1968) On the geology, aeromagnetic anomalies and susceptibilities of Precambrian rocks in the Virrat Region (Central Finland), Geoexploration, Vol. 6, pp. 163-184.

RAGAN, D.M., (1973) Structural Geology (Second Edition), John Wiley.

RAMSAY, J.B., and GRAHAM, R.H. (1970) Strain variations in shear belts, Canadian Journal of Earth Sciences, Vol. 7, pp. 786-813.

RAO, A.D. and BABU RAM, H.V., (1981) Nomograms for rapid evaluation of magnetic anomalies over long tabular bodies, Pagoph., Vol. 119, pp. 1038-1049.

RAO, B.S.R., MURTHY, I.V.R. and RAO, C.V., (1973) Two methods for computer interpretation of magnetic anomalies of dykes, Geophysics, Vol. 38, No. 4, pp. 710-718.

RAYNER, R.A. and ROWLANDS, N.J., (1980) Stratiform copper in Late Proterozoic Boorloo Delta, South Australia, Mineral Deposits Vol. 15, No. 2, pp. 139-150.

REFORD, M.S., (1964) Magnetic anomalies over thin sheets, Geophysics, Vol. 29, No. 4, pp. 532-536.

REFORD, M.S., (1980) Magnetic Method, Geophysics, Vol. 45, No. 11, pp. 1640-1658.

REGAN, R.D., CAIN, J.C. and DAVIS, W.M., (1975) A global magnetic anomaly map, Journ. of Geophysical Research, Vol. 80, No. 5, pp. 794-802.

RICE, M.H. and WALSH, J.M., (1967) Equation of state of water to 250 kilobars, Journ. Chem. Physics, Vol. 26, pp. 824-834.

RICHARD, D.J. and WALRUEN, F., (1975) Airborne geophysics and ERTS Imagery, Minerals Science and Engng., Vol. 7, No. 3, pp. 234-278

ROBERTSON, R.S., (1972) Petrological and structural investigation of the Willyama Complex rocks Wiperaminga Hill area, South Australia, B.Sc. (Hons.) thesis, University of Adelaide (unpublished).

ROBIE, R.A. and WALDBAUM, D.R., (1968) Thermodynamic properties of minerals and related substances at 298.15°K (250°C) and one atmosphere (1.013 Bars) pressure and at higher temperature, Geol. Surv. Bull., 1259, pp. 1-248.

ROMBERG, F.E., (1958) Key variables of gravity, Geophysics, Vol. 23, No. 4, pp. 648-700.

ROUX, A.T., (1980) The magnetic method: Geophysical Field Manual for technicians No. 1, South African Geophysical Association, (Eds.) Biesheuvel, K., Curner, B. and Goddard, P.

ROWLANDS, N.J., (1974) The gitology of some Adelaidean stratiform copper occurrences in Bartholomew, P., (Ed.) Gisements stratiformes et Provinces Cupriferes, Societe Geologique de Belgique, pp. 419-427.

RUTLAND, R.W.R., PARKER, A.J., PITT, G.M., PREISS, W.V. and MURRELL, B., (1981) The Precambrian of South Australia in The Precambrian Geology of the Southern Hemisphere, Hunter, D.R. (Ed.), Elsevier Scientific Publications.

SATO, T., TANIMURA, S. and OHTAGAKI, T., (1974) Geology and ore deposits of the Hokuroku district, Akita Prefecture, in Geology of Kuroko Deposits, Society of Mining Geologists of Japan, Mining Geology - Special Issue 6, pp. 11-18.

SHAW, S.E., (1968) Rb-Sr isotopic studies of the m?? sequence rock at Broken Hill, in Broken Hill Mines: Aust. Inst. Min. Metturl., Monograph 3, pp. 185-198.

SHOLOPO, L. Ye (1977) Use of rock magnetism for solving geological problems, Nedra Press, Leningrad.

SIMONENKO, T., (1969) Relation of magnetic anomalies to topography and geology in USSR, American Geophysical Union Monograph, Vol. 13, pp. 415-421.

SKEELS, D.C., (1947) Ambiguity in gravity interpretation, Geophysics, Vol. 12, pp. 43-56.

SMELLIE, D.W., (1956) Elementary approximations in aeromagnetic interpretations, Geophysics, Vol. 21, pp. 1021-1040.

SOKOLOV, K.P., (1956) Geological interpretation of magnetic surveys, Geogeolotchizdat, Moscow.

SPECTOR, A. and PARKER, W., (1979) Computer compilation and interpretation of geophysical data in Hood, P.J. (Ed.) Geophysics and Geochemistry in the Search for Metallic ores, Geol. Surv. Can. Econom. Geol. Report 31, pp. 527-544.

SPRIGG, R.C., (1954) Geology of the Radium Hill mining field, Bull. Geol. Survey South Australia, No. 30, pp. 7-69.

SPRY, A.H., (1977) Petrology of the Olary region, Amdel Report No. 1172 for South Australia Department of Mines and Energy, 1/1/170 (unpublished).

STEVENS, B.P.J., (1980) Records of the geological survey of New South Wales, Vol. 20, Part 1, Geol. Surv. New South Wales.

STEVENS, B.P.J., STROUD, W.J., WILLIS, I.L., BRADLEY, G.M., BROWN, R.E., and BARNES, R.G., (1980) A stratigraphic interpretation of the Broken Hill Block, in Stevens, B.P.J. (Ed.) Records of the Geological Survey of New South Wales, Vol. 20, Part 1, pp. 9-32.

STEWART, I.C.F. and BOYD, D.M., (1983) Enhancement of aeormagnetic trends from Broken Hill using the second derivative, Bull. Aust. Soc. Exp. Geoph., Vol. 14, No. 1, pp. 11-21.

STOCKWELL, C.H., (1969) Tectonic map of Canada, Geol. Surv. Canada, Map, 1251A.

STRAKHOV, N.M., (1959) Ocherki geokhimii verkhnepaleoza skikh otlozhenii gumiduogo tipa, Trudy Geol. Inst. U.S.S.R. Academy of Sciences, Vol. 23, p. 223.

STRANGWAY, D.W., (1965) Interpretation of the magnetic anomalies over some Precambrian dykes, Geophysics, Vol. 30, pp. 783-796.

STRANGWAY, D.W., (1966) Rock magnetism and geological correlation, Mining Geophysics, Vol. 1, pp. 54-66.

SUTTON, D.J. and MUMME, W.G., (1957) The effect of remanent magnetization on aeromagnetic interpretation, Aust. Journal of Physics. Vol. 10, pp. 547-557.

TALBOT, J.L., (1962) A study of the structural and metamorphic relationships between older and younger Precambrian rocks in the Mount Lofty-Olary arc, South Australia, Ph.D. thesis, University of Adelaide (unpublished).

TALBOT, J.L., (1967) Subdivisions and structure of the Precambrian (Willyama Complex and Adelaide System) Weekeroo, South Australia, Trans. Roy. Soc. South Australia, Vol. 91, pp. 45-58.

TALVITIE, J., (1971) Seismotectonics of the Kupio Region, Finland, Comm. Geol. Filnlande 248, (Bull. Geol. Survey of Finland), 1973.

TALWANI, M. and HEIRTZLER, J.R., (1964) The computation of magnetic anomalies caused by tw-dimensional structures of arbitrary shape: Contribution 621 of Part 1, Computers in the Mineral Industry, Stanford Univ. Publ. Geol. Science, Vol. 9, No. 1, pp. 464-480.

TALWANI, M., WORZEL, J.L. and LUNDISMAN, M., (1959) Rapid gravity computations for two-dimensional bodies with application to the Mendocino submarine fracture zone: Jour. Geoph. Research, Vol. 64, pp. 49-59.

TESKEY, D.J., (1978) Design for semi-automated three-dimensional interpretation system for potential field data, Ph.D. thesis, McGill University.

THOMSON, B.P., (1966) The lower boundary of the Adelaide system and older basement relationships in South Australia Journ. Geol. Soc. Aust., Vol. 13, pp. 203-228.

THOMSON, B.P., (1969a) The Barrier Ranges, Post Willyama sediments in the Geology of New South Wales, Journ. Geol. Soc. Australia, Vol. 16, No. 1, pp. 55-64.

THOMSON, B.P., (1969b) The Precambrian crystalline basement, in Parkin, L.W. (Ed.) Handbook of South Australia, Geol. Surv. South Australia, Adelaide.

THOMSON, B.P., (1970) A review of the Precambiran and lower Palaeozoic tectonics of South Australia, Trans. Roy. Soc. South Australia, Vol. 94, pp. 193-221.

THOMSON, B.P., (1973) Ore deposits in relation to the tectonic development of Eastern Australia, Bull. Bur. Min. Resources, Vol. 141, pp. 95-105.

THOMSON, B.P., (1974) Tectonics and regional geology of the Willyama, Mount Painter and Denison Inliers areas, Dept. of Mines Report 74/1 (unpublished).

THOMSON, B.P., (1976a) Regional geology of the Gawler Craton, in Knight, C.L. (Ed.), Economic Geology of Australia and Papua New Guinea, 1 Metals, Monograph 5, Australia Inst. Min. Metal, Melbourne, pp. 461-466.

THOMSON, B.P., (1976b) Precambrian basement cover: The Adelaide System, in Handbook of South Australia Geology, Parkins, L. (Ed.), Geol. Survey of South Australia, pp. 49-83.

TUCKER, D.H., (1975) Magnetic and gravity interpretation of an area of Precambrian sediments in Australia, Ph. D. thesis, University of Adelaide (unpublished).

TUCKER, D.H., (1983) The characteristics and Interpretation of Regional Magnetic and Gravity fields in the Broken Hill District : Aust. Inst. Min. Mett. pp. 81-113.

TYAPKIN, K.F., (1980) A study of abyssal fractures in the Ukrainian Shield by Geophysical method, Geophysical Prospecting, Vol. 28, pp. 935-944.

WATERHOUSE, J.D., (1971) Geology of the Walparuta and Ethiudna Mine Areas, Olary Province, South Australia, B.Sc. (Hons.) thesis, University of Adelaide, (unpublished).

WEBB, A.R., (1970) Progress reports on Amdel Geochronology projects 1/1/122, 1/1/123 and 1/1/126 in Thomson, B.P., 1970, Precambrian and Lower Palaeozoic Tectonics in South Australia, Trans. Roy. Soc. South Australia, Vol. 94, pp. 193-221.

WEBB, A.W., (1976) Geochronology of the eastern basement rocks, Amdel Report No. AN 1/1/40 (Progress Report) (unpublished).

WEBB, A.N. and HORR, G. (1979) The Rb-Sr age and petrology of a flow from Beda volcanics, Qart. Geol. Notes, Geol. Surv. of South Australia, Vol. 66, pp. 10-13.

WEBB, J. and WDYZBUN, P., (1967) Report on Stages 1 and 2 of the Interpretation of the results of airborne magnetometer survey covering S.M.L. 139 and 152 South Australia Dept. of Mines S.R. 11/5/250, Env. 768

WELLMAN, P., (1976) Regional variation of gravity and isostatic equilibrium of Australian crust, Bureau of Mineral Resources, Journ. of Australian Geology and Geophys., 1, pp. 297-302.

WERNER, S., (1953) Interpretation of magnetic anomalies at sheet-like bodies, Arsts, Sver. Geol. Unders. Ser. C. Auhandl, seh Uppsat., Vol. 43, No. 6.

WHITTEN, G.F., (1966) Suggested correlation of iron ore deposits within South Australia, Quart. Geol. Notes, Geol. Surv. South Australia, Vol. 18, p. 771.

WHITTEN, G.F., (1970) The investigation and exploitation of the Razorback Ridge iron deposit, Rep. Invest. Geol. Surv. South Australia, Vol. 33.

WHITTLE, A.W.G., (1949) The geology of the Boolcoomata granite Transactions of Royal Society of South Australia, Vol. 72, pp. 228-243.

WHITTLE, A.W.G., (1954) Mineragraphy and petrology of Radium Hill mining field, Bull. Geol. Surv. South Australia, Vol. 30, pp. 51-69.

WILLIAMS, D.J., (1980) Rosenet: A FORTRAN IV program for production of rose diagrams compatible with Gould or Calcomp plotting facilities, Computers and Geoscience, Vol. 6, pp. 95-103.

WILSON, A.F., (1953) The significance of lineation in Central Australia, Aust. Journ. Sci. Vol. 16, p. 47-50.

WILTSHIRE, R.G., (1975) The structural geology of the Old Boolcoomata area, Ph.D. thesis, University of Adelaide, (unpublished).

WON, I.J., (1981) Application of Gauss' method to magnetic anomalies of dipping dykes, Geophysics Vol. 46, No. 2, pp. 211-215.

WON, I.J., (1981) Written communication, Department of Marine, Earth and Atmosphere Sciences, North Carolina State University, U.S.A.

WONES, D.R. and EUGESTER, H.P., (1959) Biotites on the join phologopite ($KMg_3AlSi_3O_{10}(OH)_2$) - annite ($KMg_3AlSi_3O_{10}(OH)_2$) Carnegie Instn. Waddington Yearbook, Vol. 58, pp. 127-132.

WOPFNER, H., (1969a) Depositional history and tectonics of South Australian Sedimentary basins (ECAFE Document I and NR/PR 4/57 Symposium on the Development of petroleum resources of Asia and the Far East, Canberra, 1969).

WOPFNER, H., (1969b) Lithology and Distribution of the Observatory Hill Beds, Eastern Officer Basin, Trans. Roy. Soc. South Australia, Vol. 93, No. 1, pp. 39-44.

WRIGHT, P.W., (1981a) Gravity and magnetic methods in mineral exploration, in Skinner B.J. (Ed.) Seventy-fifth Anniversary Volume, Economic Geology, 1981, pp. 829-839

ZAVOYSKIY, V.N., (1982) Use of magnetic susceptibility tensor for solving problems in structural geology, Izvestiya Earth Physics, Vol. 18, No. 3, pp. 217-223.

ZURFFARDI, P., (1978) Possibilities and limitations of remote sensing in ore mineral exploration, Global Tectonics and Metallogeny, Vol. 1, No. 1, pp. 88-91.

THE UNIVERSITY OF ADELAIDE COMPUTING CENTRE Cyber User's Guide to Software Facilities, May, 1979.

THE UNIVERSITY OF ADELAIDE COMPUTING CENTRE Local Publication, 503, 1978.

ZWART, H.J., (1967) The duality of orogenic belts, Geol. Mijnbouur, Vol. 46, p. 283-309.

ZWART, H.J., (1969) Metamorphic facies series in the European orogenic belts and their bearing on the causes of orogeny. Sepcial Paper, Geol. Assoc. Canada, Vol. 5, p. 7-16.