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6TH BMR SYMPOSIUM
CANBERRA, 3-5 MAY, 1977
ABSTRACTS

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CONTENTS

MINERAL RESOURCE ASSESSMENT

L.C. Ranford

Australia has become a major source of minerals to the industrial nations of the world and the importance of this mineral trade will increase in the future. With about 5 percent of the land surface of the Earth and only about 0.3 percent of the population, we have a relative abundance of many minerals important in modern industrial society and it is imperative that we recognise the international implications and responsibilities of this endowment. Australia is the world's largest exporter of bauxite, mineral sands and iron ore, the second largest exporter of lead and zinc, and the third-largest exporter of coal and nickel. We have about one-quarter of the world's low-cost uranium reserves and the potential to become the world's principal exporter of uranium.

It is recognised in BMR that Australia's mineral endowment will focus increasing international attention on our country at a time when it is widely appreciated that the supply of non-renewable mineral resources may well prove to be a limiting factor in attempts to raise the general standard of living to that currently enjoyed in parts of the industrialised world.

To ensure that the Australian people obtain maximum benefit from our mineral resources, and that, subject to our own strategic requirements, supplies are made available to other consumers, it is essential that we have adequate data on which to base decisions concerning the mineral industry, decisions that may have far-reaching implications.

The prime requirement is for accurate assessments of our identified resources and of their likely availability through time. A start has already been made in BMR in this direction and preliminary assessments have been made of reserves of iron ore, tin, coal, mineral sands, and antimony, and we are attempting to update and publish each year estimates of demonstrated reserves of all major mineral commodities, and place these reserves in the context of world reserves and of Australian and world production. We are also undertaking more comprehensive appraisals of identified resources of certain minerals including copper, nickel, tungsten, arsenic and asbestos and are attempting to develop methods of expressing quantitatively the inferred extensions of identified resources.

While we recognise that data on identified resources are the prime requisite for short-term and medium-term planning, we are now facing an increasing requirement for information that will enable us to anticipate problems of longer-term mineral supply and land use. To provide the data required we need to tackle the problem of estimating undiscovered mineral potential. This is a relatively new subject, but assessments of undiscovered potential have already been undertaken in other countries, and research into the subject is increasing rapidly. BMR is already engaged in a program designed to assess the nation's total petroleum resources, and we are studying the various approaches which might be used to estimate undiscovered resources of other minerals. Our objective will be to provide properly documented and carefully explained quantitative estimates in a form which reflects both the degree of certainty of occurrence and the economic feasibility of extraction of the nation's total mineral resources. To achieve this objective will require increased expertise in certain fields in BMR, as well as co-operation and assistance from industry and other government agencies. We are aware of the problems involved in producing worthwhile estimates of undiscovered resources, and of the risk of misuse of the results, but we believe that where there is a demand, estimates will be made and it is our responsibility to ensure that the best possible assessments and appraisals are available.

ASSESSMENT OF UNDISCOVERED PETROLEUM RESOURCES

D.J. Forman

It is important for Government to consider and implement long-term policies to lessen the effects of forthcoming shortages of oil and gas. In addition to information on our discovered resources planners in Government need to know: the likely amount of oil and gas that may be discovered in the future; the probable distribution of new discoveries; the effort required to make the discoveries; the economic and technological conditions under which the discoveries may be exploited.

Resource assessment is the only process that will give probable answers to these questions.

There are two problems to be solved in estimating the volume of undiscovered petroleum. One is to calculate the probability of discovery; the other is to estimate the type and volume of any petroleum that may be found.

In estimating the probability of petroleum discovery in an area the rock types and their burial and deformation history are examined and compared with models based on knowledge of the occurrence of petroleum. For instance, a petroliferous area must have source and reservoir beds, a favourable thermal and structural history, and adequate sealed traps that have been preserved from subsequent destruction by deformation or erosion and from flushing.

At least three methods may be used to estimate the volume of petroleum that is likely to be discovered. Selection of the method or methods depends on how much is known about the geology.

The 'volumetric' method has been extensively used by government geological organizations in USA and Canada. The likely yield of petroleum per unit volume is determined by comparison with fully explored petroleum provinces elsewhere, and total ultimate recovery is determined by multiplying this yield factor by the volume of sediments in the area to be assessed.

The 'play' methods are more detailed (a 'play' is a set of geological circumstances under which petroleum may originate and be preserved in one or more traps). In one method a field-size distribution pattern is established for similar plays elsewhere. Total ultimate recovery is determined by adding up the resources of the individual fields in the section of this distribution that best matches the play to be assessed.

The 'prospect by prospect' method is the most detailed. A prospect is a trap, such as an anticline or dome, within which petroleum may occur. After recognition of the prospects, estimates are made of the volume and type of petroleum that may be trapped in each, based on a knowledge of the geology of the area itself.

Monte Carlo simulation is used extensively in all methods, to calculate the probabilities of discovering various amounts of petroleum in an area, and to add up the amounts and probabilities for each area to arrive at a total for a region.

A small group was formed by BMR in 1976 to undertake assessment of Australian oil and gas resources. So far the group has developed a computer program to meet present requirements and has used the 'prospect-by-prospect' method to make preliminary assessments of the undiscovered resources of several areas of offshore Western Australia.

Two other small basin study groups were included in the assessment task in 1977. The three groups are currently planning to complete a first assessment of Australia's undiscovered petroleum resources in a few years. To achieve this, they will be seaking co-operation from State Geological Surveys, companies, CSIRO, and other areas of BMR.

ORE RESERVES AND COST INFLATION AND ESCALATION

J. Erskine

When, over a long period, metal prices fall or mining costs rise, ore which had been in the category of mineral reserves is degraded in value into the category of sub-economic mineral resources. Over the past ten years the prices of the base metals copper, lead, and zinc, measured in constant money terms, have been falling for copper; more or less level for lead; and rising slightly for zinc. Over the same ten-year period mining costs have been rising faster than monetary inflation, or expressed in constant money terms mining costs have been rising - an escalation of mining costs. In the case of copper mines, with falling prices and rising costs the effect has been to make revenue less than working costs - certain deposits of copper minerals which had in the past been economic are therefore now uneconomic and must be reclassified from reserves to sub-economic resources.

Although the falling copper price has been significant, the single most important factor which has caused reserves to be degraded to resources has been cost inflation and escalation. Graphs are presented of cost inflation over the past ten years for fuel oil and distillate, for mine employees' wages compared with non-mine employees, and for heavy mobile mining equipment compared with equipment items such as the family car.

We then look at a hypothetical open pit copper mining project with 1 percent Cu ore and compare the costs of constructing and operating it in 1967 with the same costs in each of the ten years 1967 to 1976. A graph is presented of the Australian producer copper price over those years (a slightly downward trending line, compared with fuel, wages and equipment which trend upward).

Charts are presented which show, for each year from 1967 to 1976, operating costs for mine and mill, concentrate transport costs, smelting and refining costs, State royalty costs, and interest charges on borrowed capital. The graphs show the copper price that would have been needed in the first year of production for a mine started in each year during the recent ten year period to be profitable, and this copper price is compared with the actual price received. For a start up in any year after 1970 all costs plus return of capital and 10 percent profit would not have been recovered. Finally, there is a chart showing what grade of copper would have been needed each year, given the actual copper price that year, to cover all costs plus return of capital and 10 percent profit.

USING THE TEM METHOD FOR GEO-ELECTRIC SOUNDING

B.R. Spies

A knowledge of the resistivity of rocks at depth is invaluable in exploring for groundwater, oil and mineral deposits, and for geological mapping. The most common technique for electrical sounding of the earth is the electrical resistivity method. Resistivity depth soundings can be slow because of the need to dig electrode holes and lay out long lengths of wire.

The electromagnetic method can also be used for depth soundings. Present techniques involve varying the separation between transmitter and receiver, while keeping the frequency constant ("geometric sounding"); or alternatively varying the frequency while employing a fixed transmitter-receiver configuration ("parametric sounding"). Depth sounding using the transient electromagnetic, or TEM, method is also possible.

TEM measurements can be converted into apparent conductivity values that vary with sample time. This process is analogous to converting electrical resistivity data to apparent resistivity values which vary with electrode separation. The main advantage of TEM depth sounding compared to conventional methods is the speed and ease of measurement. The time taken for an average TEM reading (including laying out the loop) is about ten minutes.

Although master curves for quantitative interpretation of TEM soundings are yet to be developed, model studies over layered and finite structures show that apparent conductivity curves derived from TEM soundings can be used to interpret geoelectric sections qualitatively.

TEM depth soundings have been used to interpret geophysical surveys at Woodlawn, NSW, and in the Alligator Rivers area, NT. At Woodlawn TEM soundings indicate that the orebody has a conductivity of 20 s/m and this result is consistent with conductivity measurements made by other methods. In the Alligator Rivers area, TEM soundings were used to aid geological mapping of carbonaceous rocks covered by up to 100 m of alluvium. The TEM soundings in the Alligator Rivers area permitted anomalies caused by bedrock conductors to be distinguished from those caused by conducting surface clays.

AN ASSESSMENT OF THE FIXED-SOURCE, DOWNHOLE EM METHOD

R.D. Ogilvy

The possibilities of using EM techniques for off-hole mineral exploration have long been recognised. Early attempts were made over 20 years ago but relatively little has been published concerning the effectiveness of these techniques. In 1974, BMR purchased a Scintrex DHP-4 fixed-source downhole EM system. Field tests started in 1975, and were followed up with model studies in 1976. The model studies were carried out in conjunction with CSIRO Mineral Research Laboratories. Analysis of the model data is still at a preliminary stage.

Field trials made over the ore deposit at Woodlawn, NSW, indicate that the DHP-4 has only limited applications in its present form. Detectibility depends upon the mutual EM coupling relationships between the transmitter, conductor and downhole receiver, and varies significantly for differing geometrical situations. For optimum EM coupling the detection limit was shown to be of the order of 30m for the Woodlawn orebody. A quantitative interpretation of field results is currently hindered by the lack of an effective normalization procedure and a generalised interpretation scheme.

Theoretical and model studies highlight difficulties in the interpretation and development of fixed-source downhole EM systems. However model studies indicate that an improvement in detectibility could be achieved by measuring orthogonal and differential components of the subsurface magnetic field. In addition, fixed-source systems offer several advantages over alternative systems, including the possibility of directional information, the utilization of complex surface instrumentation, and the minimal expense involved for lost probes.

GUIDELINES FOR GEOPHYSICAL EXPLORATION IN THE COBAR AREA, NEW SOUTH WALES

P.G. Wilkes

Because of deep weathering and scarcity of outcrop, exploration in the Cobar area relies increasingly on geophysical methods. Although orebodies in this area are generally good geophysical targets the surface weathering makes them difficult to detect. The effective use of geophysics requires very careful selection of methods, survey design, and an unusually detailed interpretation. An exploration strategy is presented which integrates the use of magnetic, electrical, electromagnetic and gravity methods in the search for magnetic and non-magnetic ore bodies.

Magnetite and/or pyrrhotite are present in most of the deposits discovered to date. Accordingly the aeromagnetic method is regarded as the primary exploration method. If this yields exploration targets these can be followed up with ground magnetics and gravity, and drilling if warranted. The gravity and magnetic anomalies produced by pipelike orebody models and surficial sources have been computed, and the results used to produce guidelines for the use of these two methods. If the magnetic results are inconclusive it may be necessary to carry out electrical or electromagnetic work prior to gravity.

The search for orebodies which do not have a suitable magnetic expression is very difficult and a strategy of regional and detailed electrical surveys followed by detailed gravity and drill-hole geophysics is proposed. The response of electrical surveys in this area is illustrated by model studies and field examples of TEM surveys, resistivity soundings and borehole resistivity measurements. The results of the field surveys and model studies show that the deep weathering severely attenuates resistivity, IP and electromagnetic responses of conductive-chargeable sources in the unweathered rock. To overcome the effects of weathering, the importance of understanding the geo-electric section before designing and interpreting electrical surveys in this area is stressed, and it is recommended that methods used should be capable of distinguishing the response caused by the overburden from the response due to conductors in the unweathered rock.

PROTEROZOIC PATTERNS OF SEDIMENTATION NORTH AND NORTHEAST OF MOUNT ISA

G.M. Derrick

North and northeast of Mount Isa relations between the Haslingden Group, Surprise Creek Beds, Mary Kathleen Group and Mount Isa Group are examined.

Basalt and epicontinental sands of the Eastern Creek Volcanics and Myally Subgroup thin eastwards onto the Kalkadoon-Leichhardt and Ewen blocks, and a shoreline is proposed coincident with the long-acting Gorge Creek-Quilalar hinge zone.

A disconformity is postulated between the Myally Subgroup and the lower Surprise Creek Beds. Gentle epeirogenic uplift of Haslingden Group rocks was followed by onlap from the east and northeast.

Transgressive sandstone sheets of the lower Surprise Creek Beds were deposited in a coastal shelf-alluvial plain environment. It is proposed that the basal Surprise Creek Beds and Mary Kathleen Group are equivalent, that sedimentation was probably continuous across the basement block, and that the long-held concept of separate eastern and western depositional basins is probably not valid for this period. The broad shelf area is marked by at least two major lineaments, one extending north of Mary Kathleen, the other a broad anticlinal rise between Gunpowder and Mount Isa. Marked east-west facies changes are characteristic of some of the lithostratigraphic units.

A regional unconformity separates lower from upper Surprise Creek Beds, and may represent crustal disturbance associated with extrusion of the Fiery Creek Volcanics to the west. The basal unit of the upper Surprise Creek Beds is a fluvial and shallow shelf sand possibly equivalent to the Deighton Quartzite, and it grades upwards into flysch-like sandstone and siltstone in which some copper was concentrated.

Slight regional uplift terminated this cycle and resulted in deposition of the Warrina Park Quartzite blanket. Further transgression then quiescence culminated in the deposition of Pb-Zn ores at Mount Isa.

Apparently dissimilar copper deposits at Mammoth and Mount Isa share many sedimentological and tectonic features, such as proximity to basement highs, thinning and/or erosion of older units - particularly the regionally cupriferous upper Surprise Creek Beds - and deposition of ore in a structurally prepared host. Mount Isa copper may represent the optimum extension of the processes operative at Mammoth.

GEOPHYSICAL MAPPING OF BURIED PRECAMBRIAN ROCKS IN THE CLONCURRY AREA, NORTHWEST QUEENSLAND

A.J. Mutton

A program of geophysical mapping was carried out during 1975 by BMR in an area of 1700 km^2, located 50 km northeast of Cloncurry in northwest Queensland. The aim of the mapping was to determine the depth of burial, lithology, and structure of the Precambrian Cloncurry Complex in a region where the results of previous regional geophysical surveys indicated that such rocks are covered by only a thin veneer of younger sediments. Detailed gravity and ground magnetic work, combined with geological mapping, appraisal of drilling results, physical property analyses of rock samples, and a reinterpretation of regional aeromagnetic data proved to be a suitable combination of techniques for mapping the basement rocks in this area.

The results of the mapping indicate that the Cloncurry Complex extends beneath sediments of the Carpentaria basin for approximately 40 km beyond the eastern limit of outcrop of the complex. The eastern limit of the buried complex is marked by a major fault at which the complex ends abruptly and gives way to a less dense granitic basement. Interpreted depths to the buried complex indicate that in much of the survey area the young sedimentary cover is no more than 50 metres thick.

The mapping indicates that the buried Precambrian complex is composed of granites and metamorphic rocks belonging to the Corella Formation and the Soldiers Cap Group. The distribution of these rock types can be outlined by their geophysical response. Where granites have intruded rocks of the Corella

Formation a distinctive magnetic aureole is evident and is the locus for concentrations of magnetite and hematite.

The area is structurally complex. Apparent fold patterns are more complex than that suggested by the regional geophysical response. Several major magnetic lineaments interpreted within the buried Precambrian basement appear to reflect granite boundaries rather than major faulting.

The effective use of geophysical techniques for mapping shallow-buried basement rocks in the region could substantially expand the area of Cloncurry Complex available for prospecting.

PREDICTING THE EXISTENCE OF DIAMONDS IN KIMBERLITES FROM THEIR INCLUSIONS

J. Ferguson

Kimberlites contain a wide variety of ultramafic nodules. It is now generally accepted that these ultramafic nodules represent xenoliths that have been erupted from the upper mantle. By far the commonest of these xenolithic upper mantle nodules are lherzolites. There are two varieties of these xenoliths; in addition to olivine and two pyroxenes the stable aluminous phase is either spinel or garnet, giving rise to spinel and garnet lherzolites respectively. In that these lherzolite nodules are direct representatives of the upper mantle and hence the parent to most of the igneous rocks, they have been the subject of intense investigation. Experimental phase studies combined with thermo-dynamic considerations indicate that the compositional variations in the mineral assemblages present in these lherzolites are sensitive to temperature and pressure. Provided that equilibrium is preserved it is possible to estimate temperature and pressure from the mineral assemblages of the xenoliths. These temperature-pressure estimates define a palaeo-geotherm allowing predictions to be made concerning the possibility of finding diamonds in individual kimberlites. Where there is a low geothermal gradient the graphite-diamond stability curve is intersected at a shallower level compared to a high geothermal gradient. Evidence is presented to show that the fossil Cainozoic geothermal gradient in southeastern New South Wales is similar to the present-day high geothermal gradient - making the prospect of finding diamondiferous kimberlites, of Cainozoic age, in this part of Australia highly unlikely.

THE MORDOR COMPLEX, NORTHERN TERRITORY

A. Langworthy

The Mordor Complex in central Australia consists of a suite of highly fractionated potassic rocks ranging from phlogopite dunite, through phlogopite-rich wehrlite, lherzolite, shonkinite, and pyroxenite to melamonzonite, monzonite, and syenite. The syenite and monzonite are intruded by mafic differentiates (phlogopite shonkinite and melamonzonite) which are in turn intruded by numerous plug-like bodies (up to 200 m across) of ultramafic rock (phlogopite-rich peridotite and pyroxenite), pegmatite, and dykes of carbonate-rich breccia.

Whole-rock chemical analyses indicate that the ultramafic rocks are unusually enriched in large-ion lithophile (LIL) elements: K (up to 1.47 percent), Rb (up to 100 ppm), Ba (up to 3030 ppm), La (up to 70 ppm), and Sr (up to 464 ppm). In addition the analyses, when compared to those of normal ultramafic rocks, are typically low in Mg, and high in Al, Ca, K, and Ti. The syenite is low in Si and Na, and rich in Ca, K, and Mg relative to average syenite. All the rocks have very high K_2O/Na_2O ratios (3 to 7), and low K/Rb (110 to 280) and $MgO/(FeO + Fe_2O_3)$ (typically 2 in the ultramafic rocks). Rb-Sr data from whole-rock and mineral systems indicate an age of about 1150-1200 m.y., and relatively high initial $^{87}Sr/^{86}Sr$ (0.711).

The unusual chemical features of the rocks of the Complex indicate an affinity with rocks of the 'ultrapotassic series', a classification used by Carmichael et al. (1974) for world-wide occurrences of highly potassic mafic lavas (K_2O/Na_2O 3). In a similar manner to several of the extreme members of the ultrapotassic series elsewhere, the Complex mirrors many of the unusual features that isolate kimberlite from the mainstream of ultrapotassic mafic rocks.

Petrogenesis of the Complex possibly involved zone refining of deep-mantle partial melt, or partial melting of a phlogopite-bearing atypical upper-mantle source rock. Evolution of the liquid during uprise was followed by extreme magmatic differentiation in an intermediate-level magma chamber prior to intrusion of the products of differentiation to a high level in the crust. Evidence suggesting that the upper mantle may be heterogeneous is discussed.

ACCESS TO BMR INFORMATION

E.P. Shelley

The wide range of BMR activities result in the produ-tion of information ranging from raw field observations to published reports and maps. This information is made available to industry in a variety of ways.

BMR's formal publication series include Bulletins, Reports, Geological and Geophysical maps, Australian Mineral Industry quarterly and annual reviews, and the BMR Journal. Catalogues of publications are readily available and new releases are advised by means of a quarterly list. Unpublished Records are produced in limited numbers and contain, among other things, reports of geophysical surveys and progress reports of geological surveys; most are available on open file. Company reports of geophysical and drilling operations subsidized under the Petroleum Search Subsidy Act are also available for inspection and copying.

Preliminary results from geological and geophysical surveys may be discussed with BMR staff and when results have reached a suitable compilation stage they are released through the Australian Government Printer copy service. This facility enables companies and individuals to obtain and use information that usually takes considerable time to reach formal publication status.

Cores and cuttings received under the Petroleum Search Subsidy Act, the Petroleum (Submerged Lands) Act, and from BMR stratigraphic drilling operations are stored and much of the material is available for inspection and non-destructive testing.

The BMR Library is the largest and most comprehensive geoscience library in Australia. Industry personnel are always welcome to use the library's collections, and its inter-library loan and reference services are available.

It is the policy of BMR to make its information freely available as quickly as possible; company representatives and individuals have always been welcome to use BMR information services and to consult with BMR officers on subjects in which they are interested.

This paper will explain in more detail the various services mentioned above and describe a number of other services such as the Stratigraphic Index and the National Gravity Data Repository, and the availability of primary geophysical data.

GEOPHYSICAL MAPPING OF A PORPHYRY COPPER PROSPECT AT MOUNT TURNER, GEORGETOWN AREA, QUEENSLAND

J.A. Major

As part of BMR's evaluation of the mineral resources of the Georgetown region a program of geophysical mapping was conducted over a porphyry copper-molybdenum prospect at Mount Turner near Georgetown. Methods employed in the mapping program were resistivity/IP depth soundings, drilling, down-hole logging, magnetics and gamma spectrometry. The aims of the mapping program were to assist in determining the geological setting and economic potential of porphyry copper prospects in the Georgetown area; and to establish what geophysical techniques might be useful in exploring for and evaluating similar prospects in the region.

Gamma spectrometry was used to determine the radio-element concentration within the geologically mapped alteration system at Mount Turner. No correlation between radio-element concentration and alteration zoning was observed. Extensive ground magnetic traverses also failed to outline the alteration system.

The resistivity/IP work comprised vertical electrical soundings on a one kilometre square grid over an area of 30 km^2. Interpretation of the soundings was used to build a three-dimensional picture of resistivity and chargeability to a depth of approximately 200 m. Chargeability layering, predicted from the soundings, generally compared well with the results from down-hole logs, but resistivity logs compared less well. A comparison of the electrical soundings with surface geological mapping shows that a region of high chargeability and low resistivity appears to correlate with a zone of phyllic alteration; and near Mount Turner there is a correspondence between low chargeability and potassic alteration.

The distribution of chargeability and resistivity in conjunction with detailed geological work, provides a guide to the distribution of sulphides, alteration zoning and the level of erosion in the porphyry system.

BURIED REEF STRUCTURES IN THE LENNARD SHELF, CANNING BASIN, WESTERN AUSTRALIA

J. Rasidi

Upper Devonian reefs in the Canning Basin occur in the Lennard Shelf where they are found mostly at the surface. The recovery of a small quantity of oil from a structure associated with buried Devonian reef in Meda 1 highlighted the importance of reef structures in the basin as prospective drilling targets. Indeed petroleum exploration in the Lennard Shelf between 1959 and 1970 was directed almost exclusively to testing Upper Devonian reef structures. However, difficulties in identifying these structures appear to have been largely responsible for the disappointing result.

The successful use of geophysical methods for identifying reef structures is due mainly to the physical characteristics of reefs and their effect on the overlying sediment. The reef geometry, the decrease in thickness and the increase in seismic wave velocity within sediments above a reef structure give rise to many expressions on seismic data recorded above the structure. An important, but often neglected one is the increase in the frequency of seismic reflections due to velocity anomalies and the thinning of sedimentary layers above the structure. These frequency variations are usually very small but can conveniently be observed using a "Laser Scan". The result of a frequency analysis on two seismic records for the Meda structure supports the application of this method in identifying reef structures in the Lennard Shelf.

Several seismic records indicating possible reef structures were analysed and the result shows at least 6 undrilled structures, similar to that in Meda 1, exist in the area at a depth of about 1500 m below the surface.

PLAYING WITH THE 'GABHYD' HYDRAULIC MODEL OF THE GREAT ARTESIAN BASIN

G.E. Seidel

The GABHYD model consists of a group of computer programs designed to simulate by numerical methods the flow of water in the Great Artesian Basin. Its purpose is to predict how yields of artesian groundwater from the Great Artesian Basin would respond to different management interventions.

To demonstrate the accuracy of model predictions the model was run for a time period for which data were available, but without using these data in the model. The model's predictions were then compared to these data after the run. It was shown that the model is suitable for investigating large-scale regional effects of management interventions throughout the basin and small to medium-scale effects throughout most of the currently developed areas of the basin.

Based on these results and on model characteristics operating rules are defined for the model and the presently available management options are listed. Their use is explained by example of two model runs for the period 1970 to 1999, both with management interventions postulated for 1980. The first intervention is a selective conservation measure, the second is the provision of extra water in a newly developed area. The model's predictions are shown to be reasonable and in the expected order - but offering detail, which could not have been obtained by conventional methods.

SUBMARINE FANS AND THEIR HYDROCARBON POTENTIAL

R.V. Burne

Hydrocarbon search in deeper marine environments has focussed mainly on sunken rift basins on continental margins of separation. The sediments of these basins were generally deposited in water far shallower than their present depths. The only other major hydrocarbon prospects of the deep marine environment are the thick sedimentary wedges that accumulate at the base of the continental slope and in depressions on the slope, the so-called submarine fans. These sedimentary features may be classified according to their supposed hydrocarbon potential.

Oil has been recovered from ancient fan deposits at a variety of locations, for example the North Sea, Barbados, California, and Venezuela, but the potential of present day fans has yet to be established. Sedimentary processes operating on present day fans show great variety, ranging from mass transport processes through to hemi-pelagic sedimentations. These present-day processes, may not necessarily be similar to those responsible for the major accumulation of these types of deposits in the past. These processes are reviewed and the generative conditions of potential source and reservoir rocks in the fan system are outlined.

Studies of ancient fan sequences, coupled with an analysis of the distribution of environments on present day fans, have led to the proposition of typical sedimentary facies associations. These associations are presented, their significance to stratigraphic trap formation is analysed, and the probability of optimum juxtaposition of source and reservoir beds is assessed.

The geothermal gradient of the continental margins is not well known, but available data are used in an attempt to indicate the depth-time parameters for hydrocarbon formation in fan sediments.

It is possible to assign probabilities to the factors, source rock, maturation, reservoir, and migration and entrapment timing for the model fan situations. This approach helped to delineate several areas where the acquisition of additional data will greatly refine the models, thereby providing further justification for continued funding of deep sea fan studies.

THE MARGIN SOUTH OF AUSTRALIA AND THE PROBLEM OF INITIAL RIFTING

J.C. Mutter

Recently acquired seismic refraction measurements made on the southern continental margin of Australia have been combined with studies of the gravity and magnetic fields to reveal a crustal structure which is considerably at variance with generalized models of Atlantic margin structure.

The transition from continent to ocean, rather than being achieved by a gradual diminution of crustal thickness from shelf to abyssal plain, appears to take place across two discrete boundaries. These boundaries coincide with the landward and seaward limits of the magnetic smooth or quiet zone which occupies most of the continental margin. The crust flooring of the quiet zone can most usefully be treated as unique in its own right, being neither continental nor oceanic. The two crustal boundaries represent the juxtaposition of continental with quiet zone crust, and oceanic with quiet zone crust.

The observation of a spacially discontinuous crustal structure appears to be difficult to reconcile with models of Atlantic margin formation. Such models indicate the gradual thinning and modification of a continental crustal section going hand-in-hand with the development of a major rift-valley system on the earth's surface. The scheme culminates with sea-floor generation in the axial zone of the rift valley.

We suggest that continuous evolution of the deep crust and mantle structure is not necessarily the logical corollary of the continuous evolution of surface features. We propose that the deep structure of a rift system forms fairly quickly, then remains in a relatively steady-state situation while the surface structure evolves in response to the new stress conditions set up by the deep crustal changes. The unique quiet-zone crust is generated within the sharply defined borders of the rift zone; upon continental dispersal it formed the basement complex of much of the continental margin.

NOTE

The work presented here is not entirely that of the author. It was carried out at the Lamont-Doherty Geological Observatory, Palisades, New York in collaboration with its Director Prof. Monik Talwani and Dr Robert Houtz, and followed a co-operative marine geophysical investigation of the southern margin of Australia by Lamont and BMR.

INVESTIGATIONS OF THE COPPER-BEARING BRECCIA PIPES AT REDBANK, NORTHERN TERRITORY

T.H. Donnelly, John Ferguson, J. Knutson, I.B. Lambert and W.M.B. Roberts

Any model to explain the origin of the approximately fifty breccia pipes in a volcano-sedimentary sequence of Carpentarian age in the Redbank area has to take the following features into consideration:

1) steep to vertical disposition and cylindrical form;
2) limited diameter, with a maximum of 130 m;
3) almost entirely in situ brecciation, whereby mappable units in the undisturbed host rocks can commonly be traced through the breccia pipes;
4) minor tabular breccia zones of allochthonous material present in some of the pipes;
5) a small volume increase - the in situ brecciation usually being less than 10 percent;

6) cementing matrix of the breccia zones comprise any or all of the following: microbreccia, dolomite, ankerite-siderite, quartz, and, less frequently or in minor amounts, barite, pyrobitumen, chalcopyrite, apatite, leucoxene, rutile and galena;
7) magmatic, marine and "mixed" isotopic values for C and O from carbonates in breccia matrix and veinlets;
8) magmatic sulphur isotopic values for galena and relatively heavy values for chalcopyrite, pyrite and barite;
9) partly unfilled framework between the breccia fragments;
10) extensive K-metasomatism of breccia fragments, in cases producing near-monomineralic K-feldspar aggregates;
11) no alteration of the roof rocks other than minor brittle fracturing filled by dolomite, ankerite-siderite and accessory chalcopyrite;
12) location of pipes along northeast and east-trending lineaments;
13) apparent pre-Masterson Sandstone age.

It is suggested that a carbonated K-rich trachytic magma rose to a shallow depth below surface where a vapour phase was produced that was capable of carbonate and potash metasomatism. Conditions contributing to an overpressure situation resulted from a moderately impervious roof, sealing of isolated pores by K-rich metasomatising vapours, and drastic gas expansion. Any inherent weakness in the tectonic fabric of the overlying rocks would have been the focus of the pressure activity. Explosive pressure release would have taken place by hydraulic fracturing of the roof rocks. This sudden loss of high pore-fluid pressure created an implosion. This event is correlated with the formation of the breccia pipes, in which there is only a small volume expansion produced by the essentially in situ brecciation process. That further activity of a different style took place is indicated by the minor tabular zones within some of the pipes containing allochthonous breccias.

Following pressure release and brecciation, solids were precipitated from the vapour phase in the open cavities caused by the brecciation - where they were not already filled by micro-breccia rock flour. The isotopic data suggest temperatures of precipitation of the order of 250-350°C, and that the ascending fluid incorporated some connate water. The present-day open framework of the breccia columns indicates that there were insufficient dissolved solids in the magmatic vapour phase to entirely fill these cavities. "Non-magmatic" carbonates in the breccia pipes probably represent subsequent precipitation from heated connate brines which dissolved sedimentary carbonate from the surrounding (sedimentary) dolomites, and magmatic carbonate from the breccia pipes. In a similar manner the "non-magmatic" sulphur in the bulk of the chalcopyrite mineralization can be explained in terms of precipitation from connate brines which dissolved magmatic copper sulphides from the breccia pipes and possibly leached copper from sedimentary and igneous rocks, at sufficiently high temperatures for sulphur isotopic exchange or/and abiological sulphate reduction to occur. Pyrobitumen in the breccia pipes could represent oxidation of magmatic methane or leaching of organic matter from the sedimentary rocks.

RECORD
1977/6 - Part II

6th BMR SYMPOSIUM

'WHAT MAPS ARE NEEDED NOW'

A PANEL DISCUSSION

BY

D. Denham, G. A. Young, E. K. Carter, G. W. D'Addario,
B. Barlow and R. Whitworth.

4 May 1977

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B.C. Barlow & R. Whitworth

CONTENTS

INTRODUCTION

by

D. Denham

These notes provide background information for the panel discussion 'What maps are needed now'. They cover only most aspects of BMR's involvement in mapping.

Maps are an efficient, elegant, and in some respects unique means for presenting data which vary across a surface, and they provide easily comprehensible two-dimensional models. They are used in many aspects of modern life, and the world we live in would be very different without the knowledge that maps convey. Geoscience maps are used in mineral and petroleum exploration, research, education, and recreation. For most geoscientists they are one of the key tools of trade, and are used constantly, whether displaying pleasing colours and patterns in the board room, or out in the field in a dusty landrover.

Maps have played a significant role in the history of BMR. When BMR was set up in the late 1940s perhaps its most important task was to provide a systematic coverage of the surface geology of Australia in the 1:250 000 series of geological maps. Today, although the emphasis on 250 000-scale geological mapping has diminished, between one quarter and one half of BMR's effort goes into providing maps.

Recent maps are more specialised and diversified than those produced earlier by the Bureau, which, along with other map-producing institutions, has been influenced in recent years by two important technical advances. The first has been the use of aircraft and satellites to provide a new and extensive range of earth science data. Wavelengths of electromagnetic waves well outside the visible spectrum have been recorded from flights as low as a few hundred metres and from satellites at nearly 40 000 km. Of particular importance are the Landsat and Skylab imagery which have been used extensively in geological mapping throughout the world. The second advance has been the increased use, in map production, of large computers. These not only store and process data but also plot and contour the results. It is now commonplace to manipulate millions of bits of information in the computer to produce maps. Considerable emphasis has been placed on the development of software to store and process the data and also to collect and maintain data banks. The data banks themselves are becoming increasingly important because they determine the quality of the maps produced. Using manual methods one would usually have one data bank for each map. Now, using one data bank or set of data bases, maps can be produced at different scales and projections, showing different facets of the data. So the data banks have to be good.

Within the overall question of 'What maps are needed now?' are two subordinate and separate questions:

(1) What different kinds of maps should we be producing?
and
(2) In disciplines for which Australia-wide coverage is not yet complete (e.g. airborne geophysical surveys), what order of priority should be established for the remaining areas?

The notes that follow discuss some of the options available in the production of geological and geophysical maps, and provide background for the panel discussion.

AIRBORNE GEOPHYSICAL MAPS

by

G.A. Young

BMR has been carrying out airborne geophysical surveys for 25 years with the objective of producing complete reconnaissance magnetic coverage of the continent, and where applicable, associated radiometric coverage. Areas for which data are currently available in map form are shown in Figures 1 and 2.

A magnetic map at 1:2 500 000 scale, which illustrates residuals of total magnetic intensity based on the data bank available at 1975, was recently published. BMR plans to publish a second, and final, edition of this map in the late 1960s, at which time reconnaissance coverage should be complete.

Magnetic and gamma spectrometer results of current BMR surveys are released through the Australian Government Printer as preliminary profile and/or contour maps at 1:250 000, 1:100 000 or 1:25 000 scales within ½ to 1½ years of data acquisition. Examples of such maps (reduced scale) are shown in Figures 3, 4, 5, 6, 7 and 8.

Users of BMR airborne geophysical maps should be aware of the data used in compiling the various maps and profiles, and of its availability. Examples are:

1. Magnetic contours at 1:2 500 000 scale. Data sampled on 5-km grid.

2. Magnetic contours at 1:250 000 scale. Data sampled on 600 m by 1500 m grid.

3. Magnetic contours at 1:100 000 scale. Data sampled on 150-450 m by 300-1500 m grid.

4. Magnetic or gamma spectrometer profiles at 1:250 000 scale. Data presented at 60-m intervals along lines 1500 m apart.

5. Basic data. Post-1968: Stored on magnetic tape at 60-m intervals.
   Pre-1968: Continuous analogue records.

A series of maps showing magnetic data at 1:1 000 000 scale, produced by direct reduction of 1:250 000-scale data, is to be released shortly. This series complements the first edition of the Magnetic Map of Australia, covering a similar land area but retaining all information contained in the 1:250 000 maps.

BMR believes that there is a need to establish and maintain a comprehensive catalogue of airborne geophysical surveys flown in Australia for government or industry. Such a catalogue should help to promote exchange of basic data between companies. This could reduce the amount of overflying in some areas, or, where overflying is unavoidable, better survey design might be achieved. As an initial step, BMR will soon release an index covering work flown by or on behalf of BMR. This will assist users of airborne geophysical data to gain access to maps produced by BMR, and (where appropriate) to the basic data recorded.

As part of its long-term program to complete the reconnaissance coverage of Australia, BMR intends to concentrate work in the McArthur Basin and Albany-Ravensthorpe regions in 1977 and 1978. We see the completion of coverage of North Queensland as one of the next priorities. Accordingly, consideration will be given to surveying the region in the period 1979-81.

Demands are growing for more detailed and experimental surveys. We are considering the use of additional mapping tools, including magnetic gradiometers, high-crystal-volume gamma spectrometers, and electromagnetic techniques.

A demand probably exists for BMR to reprocess aeroradiometric data to provide maps from which the uranium resource potential of a region or province can be better assessed. An example of reprocessing for the Sandstone, Youanmi, Sir Samuel, Leonora, Menzies, Duketon, Laverton, and Edjudina 1:250 000

Sheet areas, published in 1970, is shown in Figure 9. The Yeelirrie orebody is located in the northeast corner of the Sandstone Sheet, at 27°10'S, 119°52'E.

GEOLOGICAL MAPS

by

E.K. Carter & G.W. D'Addario

The basic geological map produced by the Bureau of Mineral Resources is the 1:250 000-scale coloured map of an area bounded by 1° of latitude and 1½° of longitude (using the Australian Map Grid); it distinguishes rock (lithostratigraphic) units by age and rock type, and portrays the units by the use of standard colours modified by screens and overprints, accompanied by a descriptive reference. The series was started, first at a scale of 4 miles to 1 inch, in the publication in 1951 of the First Edition of the Urandangi Sheet. By agreement with State Geological Surveys, coverage of the whole of Australia was undertaken, either jointly or by the State or BMR alone, and presented at a standard scale and style. As Figure 10 shows, standard series maps of nearly 90 percent of the continent have now been published or are being published. In addition, in the late 1950s BMR produced several maps of part of the Pine Creek Geosyncline, NT, at a scale of 1 mile to one inch; each sheet covers ½° longitude x ¼° latitude. In recent years BMR (and some State Surveys) has begun to map areas, selected because of their economic interest or geological complexity, at a scale of 1:100 000. Each map sheet will cover an area of ½° x ½°. The first sheet, Mary Kathleen, was printed last year. The areas covered so far are shown in Figure 11.

Each of the Bureau's series maps is generally made available first as a Preliminary Edition, in 2 - 4 colours, before preparation of the coloured edition. The Bureau has also undertaken, in recent years jointly with the Geological Survey of

Papua New Guinea, the systematic mapping at 1:250 000 scale of most of Papua New Guinea and has mapped extensive areas of the Australian sector of Antarctica.

These basic maps provide the detail from which a variety of regional, national, and international geological maps at various scales have been compiled. They also provide the framework for interpretative maps, such as metallogenic, tectonic, rock type, and palaeogeographic maps, that the Bureau publishes.

The role BMR fulfils by its program of geological map publication is that of providing systematic fundamental data, and various types and levels of interpretation, to all who have an interest in graphically presented geological concepts. The motivation is essentially economic, and to that end the presentation of an inventory or systematic record of the geology of the continent is regarded as important.

In determining its priorities in the allocation of scarce resources and funds, BMR considers various viewpoints, needs, and requests. The session on the BMR's future map production program, to which this note relates, is part of the process by which BMR obtains the views of others. While most of BMR's map production program could be said to be internally generated (although taking into account State and industry viewpoints) many of the national and international maps are programmed at the request of other organisations, for example contributions to the Atlas of Australian Resources for our Department, groundwater maps for the Australian Water Resources Council, geological maps of Australia and Oceania for the Commission for the Geological Map of the World, maps of the southwest Pacific for the Circum-Pacific Map Project, and national maps produced in collaboration with the Geological Society of Australia. Some of the maps prepared for other organisations are published by BMR and others by the organisations making the requests.

The production of a geological map requires a substantial investment of time, skill, and money. A 1:250 000-scale geological series map of average complexity is rarely published in colour sooner than three years after field work ceases; our resources limit production to about 20 such sheets per year.

An idea of the average cost and time needed to produce series geological maps can be gained from the following figures.

Preliminary Editions (1:250 000 and 1:100 000)(2-3 line colours only)

Drafting time 3-9 months, cost $450-1500.

Printing time 6 weeks, cost $215 for 300 copies in 2 columns, $80 for extra colour

Number of maps produced per year: 25-30.

First Edition (1:250 000)(full colour)

Drafting time (contracted) 8 months, cost $1300.

Contract preparation and checking time 5 months, cost $1700.

Printing time 11 months, cost $4500 for 2500 copies (9 colour plates).

Number of maps produced per year: maximum of 20 @ 1:250 000, 4 @ 1:100 000.

The drafting time required to produce a 1:100 000 sheet is about three times that for a 1:250 000 sheet, and the cost of printing is about two-and-a-half times that for a 1:250 000 sheet.

The recent preparation and publication of the 4-sheet 1:2 500 000 Geological Map of Australia cost about $200 000 (printing cost $73 000); this figure includes the cost of compilation in addition to drafting, contract preparation, checking, and printing costs.

A list of the types of maps produced by BMR, or on program, follows.

Title of Map or Series	Scale	Remarks
Australian Geological Series, with Explanatory Notes	1:250 000	Coverage of Australia by BMR & States 90% complete. Also issued as Preliminary Editions.
Australian Geological Series	1:100 000	Only selected areas to be mapped. Series started recently. Also issued as preliminary Editions.
Regional geological maps	1:500 000 or 1:1 000 000	Generally cover all or part of a major structural unit (block or basin) mapped as a single project. Usually issued as part of BMR Bulletin, but available separately.
Marine geological map series	1:1 000 000	About one-quarter of Australian coastline covered by published maps. Show unconsolidated seabottom sediments.
Geology of Northern Territory		
(a) Geology	1:2 500 000	Published 1976. Notes (Bulletin) in preparation.
(b) Cainozoic geology	1:2 500 000	
Geology of Papua New Guinea	1:2 500 000	Published 1976. Other geological maps of PNG have been published including 4-sheet 1:1 000 000 map in 1973.

Geology of Australia	1:2 500 000	Published 1976. Notes (Bulletin) in preparation. A Tectonic Map of Australia scale 1 inch:40 miles, which was essentially a geological map, was drawn and published by BMR for the Geological Society of Australia in 1950. The map of Australia and Oceania (see below) provides a 4-sheet geological map of Australia and PNG at 1:5 000 000 scale.
Geology of Australia	1:10 000 000 1:12 000 000	Published 1976.) Published 1971.)
Geochemical map series	1:100 000	New series. First map - Forsayth - compiled; none published. Several maps, each covering selected groups of elements, for each 1:100 000 map sheet. Being prepared by automated cartographic techniques on flatbed and drum plotters.
Photogeological map series	Generally 1:250 000	Series discontinued. Each map was compiled prior to BMR field mapping of area. Available as dyelines.
Engineering geology of Canberra	1:10 000	First maps in preparation.
Metallogenic map of Australia and Papua New Guinea	1:5 000 000	Published 1972 with notes (Bull. 145)
Mineral deposits map of PNG	1:2 500 000	Published 1973 with notes (Bull. 148).

BMR Earth Science Atlas Topics to include: Basic geology & geophysics (magnetics and gravity) Mineral occurrences Tectonics & structural elements Sedimentary basins Rock types Metamorphism Drainage and offshore features Seismicity Palaeomagnetism Palaeogeography Plate tectonics Groundwater Soils Weathering	Generally 1:10 000 000, and of Australia only. Some topics will require smaller-scale maps covering adjoining seas.	Several maps in preparation. The Atlas is planned as a loose-leaf volume with a one-page map and one page of notes for each topic. The Atlas will therefore be able to be updated topic by topic. Subject matter of topics in the Atlas may be changed from time to time. The Atlas is designed to have a wide appeal. The base map for the 1:10 000 000 maps will extend out about 200 nautical miles from the coast.

Maps Produced for or in Collaboration with Other Organisations

(1) For inclusion in Atlas of Australian Resources by Geographic Section, Division of National Mapping, Department of National Resources.

2nd Series		
Geology	1:6 000 000	2nd edition published 1966. Compiled by BMR.
Mineral deposits	"	Published)Contributions by)BMR
Underground water	"	
3rd Series		On program. BMR to compile or contribute substantially. Publication by D.N.M.
Geology	1:5 000 000	
Geology	1:10 000 000	
Surface rocks and deposits	1:5 000 000	
Rock types of aquifers	1:10 000 000	
Mineral deposits	1:5 000 000	
Tectonic elements	1:10 000 000	

(2) Commission for the Geological Map of the World, I.U.G.S.

Geology of Australia and Oceania (13 sheets)	1:5 000 000	Published 1965 to 1971. Covers area from 108°E to 132°W and 24°N to 48°S excluding most of Indonesian archipelago.
Metallogenic map of Oceania	Scale to be decided	On program.

(3) Geological Society of Australia

Tectonic map of Australia	40 miles to one inch	Drawn and published 1960 by BMR.
Tectonic map of Australia and New Guinea	1:5 000 000	Published 1971 by G.S.A. Drawn and largely compiled by BMR.

(4) Australian Water Resources Council (Technical Committee on Underground Water)

4 groundwater maps of Australia	1:5 000 000	Published 1972 by AWRC. Substantial contribution by BMR.

(5) Circum-Pacific Map Project - Southwest Quadrant

Geology Mineral resources Energy		Contributions by BMR to these maps, at scales of 1:10 000 000 and 1:20 000 000, programmed.

A questionnaire on geological maps will be available at the BMR Symposium. Your answers to any of the questions will be appreciated, either at the panel discussion, or if mailed to the Director, Bureau of Mineral Resources, P.O. Box 378, Canberra City, ACT, 2601.

GRAVITY MAPS

by

B.C. Barlow

EXISTING MAPS

Over the last three decades BMR has produced many hundreds of gravity maps, using data from its own and other organisations' field operations. Those maps can be classified as follows:

Uniform map series

Production of a series of 1:250 000-scale (initially 4 miles to 1 inch) maps began in the late 1950s when reconnaissance gravity surveys using helicopters were introduced to accelerate coverage of the sedimentary basins and eventually the whole of the Australian continent.

These maps show Bouguer anomaly contours, and they overlay the 1:250 000 series of geological maps. Availability of these maps is shown in Figure 12. To conserve costs and storage space all maps in this series have been reduced to a uniform scale of 1:500 000 and are printed at that scale. Availability of these maps is shown in Figure 13.

All maps in these series were prepared for publication by standard manual cartographic techniques, although in recent years the final maps have been based on draft maps that were produced by automated cartography.

It is expected that publication of the last of the 1:250 000 and 1:500 000 series maps will be completed during 1977.

Many 1:250 000 geological maps have been overprinted with preliminary Bouguer anomaly contours, station positions, and elevations.

Gravity maps of Australia

The first gravity map of Australia was published in 1960. The contours were based on mean values of Bouguer anomaly calculated for about one half of the 1^{o} x 1^{o} squares over the continent of Australia.

In 1965 all major surveys in Australia were approximately adjusted to a common datum and the first edition of a preliminary Bouguer anomaly map was produced to overlay the 1960 Tectonic Map of Australia. Existing contour maps at various scales were cartographically reduced and assembled onto the 40 miles to 1 inch base map. No attempt was made to reduce the data to Bouguer anomalies calculated for a uniform Bouguer density, and Bouguer densities of 1.9 to 2.67 t/m^3 were used in various parts of the map. As further areas were covered, successive editions of that map were issued.

In 1976, BMR published a map at a scale of 1:5 000 000 showing Bouguer anomalies for a uniform density of 2.67 t/m^3 over the whole of Australia and free-air anomaly contours over the continental margins. Production of that map was made possible by the use of ADP for recomputation of the gravity data bank, and automated cartography for the production of the draft map from which the final map was fair drawn.

Also in 1976, BMR published coloured Bouguer and free-air anomaly maps (attached) at a scale of 1;25 000 000, derived from the same gravity data bank.

Special maps

Special maps have been prepared, in order to report the results of various surveys, to compile data in areas of interest, and to aid interpretative projects. Scales ranging from 800 feet to 1 inch to 40 miles to 1 inch have been used with various map projections; the type of gravity anomaly portrayed on these maps varies from map to map, and even within the one map. In short, these special maps are not compatible when juxtaposed.

Key index maps

Key index maps showing the areas covered by various gravity surveys have always been an essential adjunct to the gravity data bank. The complexity of overlapping coverage in some areas made publication of a full set of key maps impossible in earlier years, although maps indicating the extent and density of coverage have always been included in the National Reports on Gravimetry in Australia presented at the meetings of the International Gravimetric Commission. Automated cartography enabled a map to be prepared showing the distribution of data used to produce the 1976 1:5 000 000 Gravity Map of Australia (Fig. 14). Station positions are shown on the 4 miles to 1 inch, 1:250 000, and 1:500 000 maps.

WHAT MAPS ARE NEEDED NOW?

Gravity data can be reduced (mathematically processed) to different types of gravity anomalies, each having particular advantages in different applications. Thus, no one map or series of maps fills the needs of all users, some of whom require access to the principal facts which are the basis of the gravity maps produced by BMR.

Our highest priority is the compilation of a comprehensive gravity data bank which can be used to prepare composite maps. Reconnaissance coverage of the Australian continent is now complete and the data have been recomputed to common datums and stored on magnetic tape. Semi-detailed gravity surveys cover 20 percent of the continent (Fig. 15). Data from the semi-detailed surveys are being recomputed by contract and added to the data bank.

Because of the volume of data involved (600 000 gravity stations have been occupied), ADP must be used for all computation, storage, and retrieval processes. We envisage that principal fact data will be made available as printout on microfiche, on punched cards, or on magnetic tape in blocks of data corresponding to the standard 1:250 000 sheet areas.

Our second priority is to produce various series of maps which present the gravity data in the form of anomaly contours which best satisfy the needs of most users. These maps will be released progressively as the gravity data needed for their compilation are recomputed to modern control standards.

Uniform map series

There is a need for a uniform series of Bouguer anomaly contour maps to overlay the standard 1:250 000 geological map series. At that scale it is possible to show on the face of the map the locations of all gravity stations used in compilation, with the reduced principal facts of all reconnaissance stations and a fair sample of semi-detailed stations. That information is vital for valid geophysical interpretation of the contour pattern. A uniform Bouguer density of 2.67 t/m^3 will be used in accordance with international practice. Over 500 maps are involved. In order to publish these within a reasonable time the maps will be produced by automated cartography. The series will not show any topographic information. It is expected that the maps will normally be used as overlays to geological or topographic maps. The anomalies will be simple Bouguer anomalies because topographic information is not available for the calculation of terrain (or isostatic) corrections.

Two series of maps are planned at a scale of 1:1 000 000 to overlay the ICAO series of topographic maps. One will show simple Bouguer anomaly contours and the other free-air anomaly contours. Station positions will be shown on both series, but reduced principal facts cannot be shown at this scale.

Gravity Maps of Australia

It is proposed to produce a simple Bouguer anomaly contour map and a free-air anomaly contour map to overlay the 1976 map 'Geology of Australia' at a scale of 1:2 500 000.

Other maps at reduced scales are planned for wall display, atlas, and journal requirements.

Special maps

BMR will continue to produce special contour maps for its own purposes. It has the technical capability, but not the resources, to produce special maps for all users. That need must be met by the users themselves from principal facts made available by BMR.

Key Index Maps

Using automated cartography, there should be no difficulty in showing the data distribution for all future maps.

MARINE GEOPHYSICAL MAPS

by

R. Whitworth

When systematic geophysical coverage of the Australian continental shelf at a 10-n mile line spacing was started by BMR in 1965, we estimated that ten years would be needed to complete the field work. However, an intensive survey from 1970 to 1973, done mainly to aid deliberations on the Law of the Sea, resulted in a preliminary coverage of much of the shelf and continental slope down to the abyssal plain at about 4000 m water depth (Fig. 16). The area covered was 2½ million n miles^2, or about three times that originally envisaged. Line spacing varied from 10 n miles on the shelf in the northwest of Australia and in shallow water areas around New Guinea, to about 40 n miles in the deep-water areas off the west coast. Information collected comprises seismic, gravity, magnetic, and bathymetric data, except for the earliest work in the Bonaparte Gulf where magnetic data were not collected. The areas of the margin not yet covered by BMR are the Arafura Sea, Gulf of Carpentaria, Great Barrier Reef, and Bass Strait.

The quantity of data we now have is massive: in round numbers there are 34 000 n miles of single-channel seismic data, 101 000 n miles of six-fold seismic data, 130 000 n miles of gravity data, 131 000 n miles of magnetic data, and 135 000 n miles of bathymetric data. The volume of data and the size of the area covered have themselves created a problem - what is the most effective way of presenting the information? We see two groups of maps being required; a major group at large scale acting as a data base for users, with a much smaller group giving the regional picture at a small scale.

Data base maps

Data other than seismic are most usefully portrayed in map form, either as contours, profiles, or as posted data values. The use of manual techniques as in the past for converting such a large quantity of data to published maps is impracticable, both in manpower and time. Highly automated computer techniques have had to be developed to reduce the manpower and time needed, and to increase flexibility (Figs. 21 to 24). Despite this, the bulk of our output will need to be made available at a scale of 1:1 000 000 as dye-line prints in order to keep the effort within reasonable bounds (Fig. 17). The reasons behind this decision are considered further below.

Apart from small-scale regional maps of mainly pictorial value, most of the geophysical maps we currently produce are designed to form a data base for the user, and usually cover individual 1:250 000-scale sheet areas. The marine area covered to date includes about 500 such sheet areas, of which only about 50 have been published so far. With four major parameters to display - Bouguer anomaly, free-air anomaly, magnetic anomaly, and water depth (if separate track maps are excluded) - and if two parameters can be plotted on each map, a total of 900 maps are still required. However, by shifting to 1:1 000 000 scale and using standard map areas, only 50 sheet areas are involved. At this scale, the density of information precludes more than one parameter per map, resulting in 250 maps, or an almost four-fold reduction in numbers for track and contour maps. At present we do not see a clear requirement for maps of profiles or posted data values on a systematic basis.

Previously, final maps have been printed using lithographic techniques. As long as demand is high, the overheads involved are acceptable, but the method is generally considered uneconomic unless more than 300 copies are needed. This raises three problems:

(1) Even at 1:1 000 000 scale, the storage requirements would be considerable if all 250 maps were printed.

(2) While demand for selected areas could be high, it is unlikely that there will be a significant demand for more than perhaps half the sheet areas - but which areas?

(3) Lithographic printing of a map on a request basis in an attempt to circumvent (2) above would cause an unacceptable delay in availability.

The approach we have finally adopted for publishing the 1:1 000 000-scale maps is to produce transparencies, because dyeline prints or ozafilm copies of these can be produced quickly. This method has several other advantages:

(i) Storage requirements are greatly reduced - for 250 maps, only 250 transparencies need be held; each copy is then produced on request.

(ii) Variability in demand is not important, although a high demand for just a few maps will reduce the overall efficiency.

(iii) Later editions of any map may be introduced efficiently, into the reproduction system, and without creating out-of-date stock. This allows rapid updating of areas as new information becomes available.

Dyelines and transparencies of all final 1:1 000 000-scale maps will be obtainable from the Australian Government Printer Copy Service in Canberra.

While we expect that the 1:1 000 000-scale maps will fill the requirements of most users, the system is flexible enough to enable other maps to be produced. Almost any type of map that can be adequately reproduced by the dyeline process may be introduced as requirements dictate. The limiting factors then become the economics of producing a particular map or series of maps, and keeping the total number of maps in the system within reasonable bounds.

Regional maps

For those more interested in the regional picture, we will be producing contour maps for the marine area at 1:2 500 000 scale using the same projection (Simple Conic) as existing maps of the continent (Fig. 18). The data density would make simple black and white maps produced by automated means difficult to interpret, but the expected demand of about 100 copies per map does not justify the production of multi-colour maps like, say, the Gravity Map of Australia. However, a simple two-colour print showing positive and negative contours in different colours as in the Magnetic Map of Australia could have adequate clarity. Such maps can be produced by computer for silk screen printing at reasonable cost for the numbers required.

A small group of specialised maps will be produced for areas or problems of particular interest. Presently there are plans to produce stacked profiles for four areas - the Bismarck Sea, Tasman Sea, Great Australian Bight, and west Australian coast (Fig. 20). Further maps will be produced as and when required.

Looking to the future

The first of these large series of maps are now being produced and will continue to become available throughout 1977. At the present rate of progress, all 1:1 000 000-scale maps will have been drawn by the end of the year, and now is the time for us to look to the future to try and envisage where our effort will be best applied.

Presently, interpretation within the Marine Geophysics Group is hampered by lack of, or inaccessibility of, data from other sources. Presumably other users suffer from the same problem. We see compilation of data in advance of requirements from the many available sources as being one of the major tasks ahead. As a first step, a pictorial compilation of ships' tracks at 1:10 000 000 scale is planned. These compilations will be split into major regions, with overlap to minimise map requirements for particular purposes (Fig. 19). The maps will be kept as transparencies from which copies can be made when needed.

The computer-based techniques we have developed, the range of maps proposed, and the mode of reproduction chosen should be of benefit to the user for the following reasons:

(a) The 1:1 000 000-scale maps will be the main data base for the user in the marine area. As new information becomes available, individual transparencies held by the Australian Government Printer can be rapidly replaced without resulting in large numbers of redundant copies. Any user will always receive the most up-to-date version of any map.

(b) The 1:2 500 000 sheets will form a compilation base on a regional scale. The area covered by each map has been chosen to allow extension into more remote regions on a compatible base. A rough order of priority is shown in Figure 3. We expect that the track maps will also be available as transparencies from the Australian Government Printer.

(c) The pictorial compilation of ships tracks at 1:10 000 000 scale should keep people aware of the data available, and avoid a situation in which each user would need to maintain his individual version at considerable effort. The maps will be available from the Australian Government Printer.

(BASED ON A/BO-53-IA)   *BMR Symposium 1977*   A/BI-18A

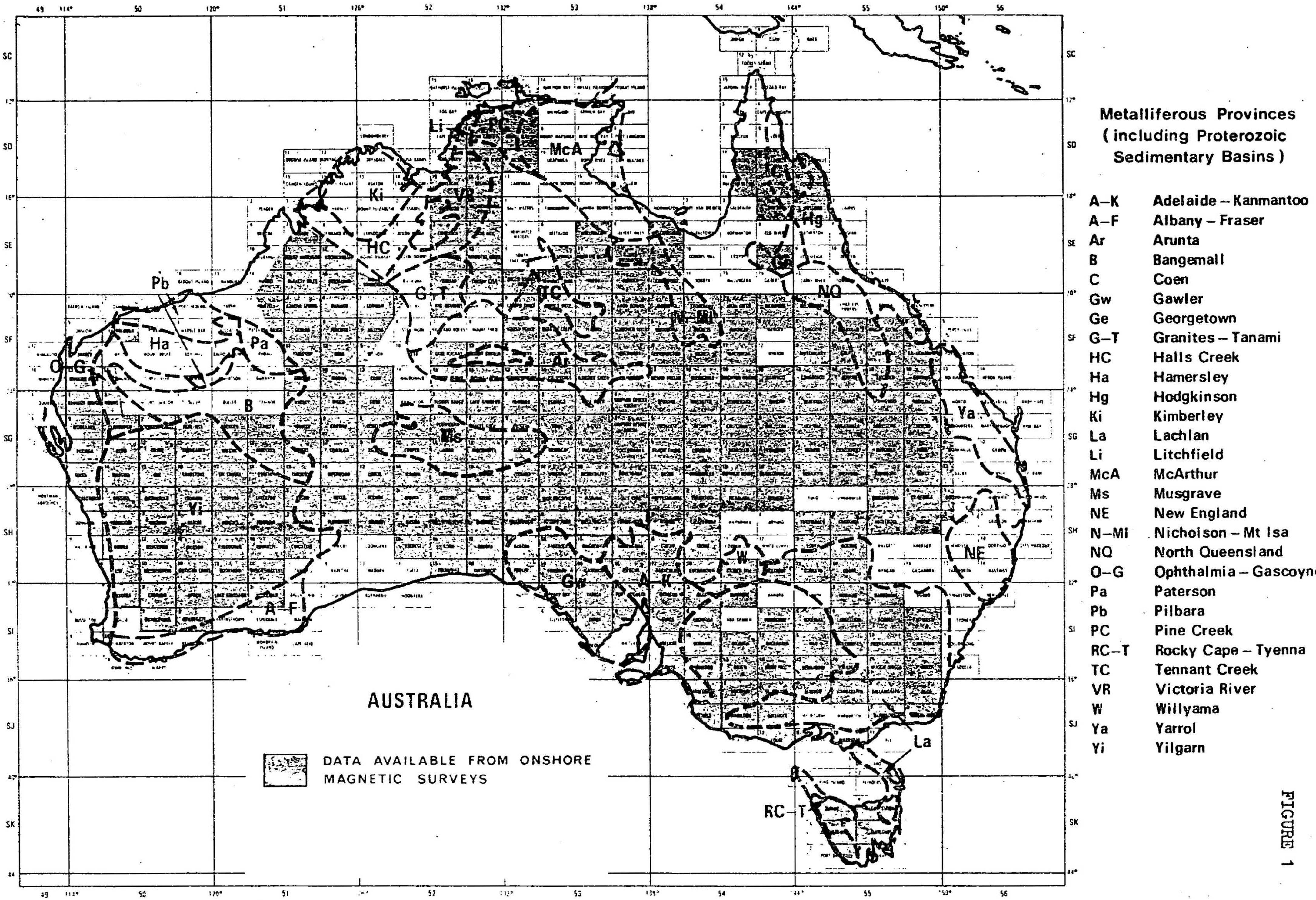
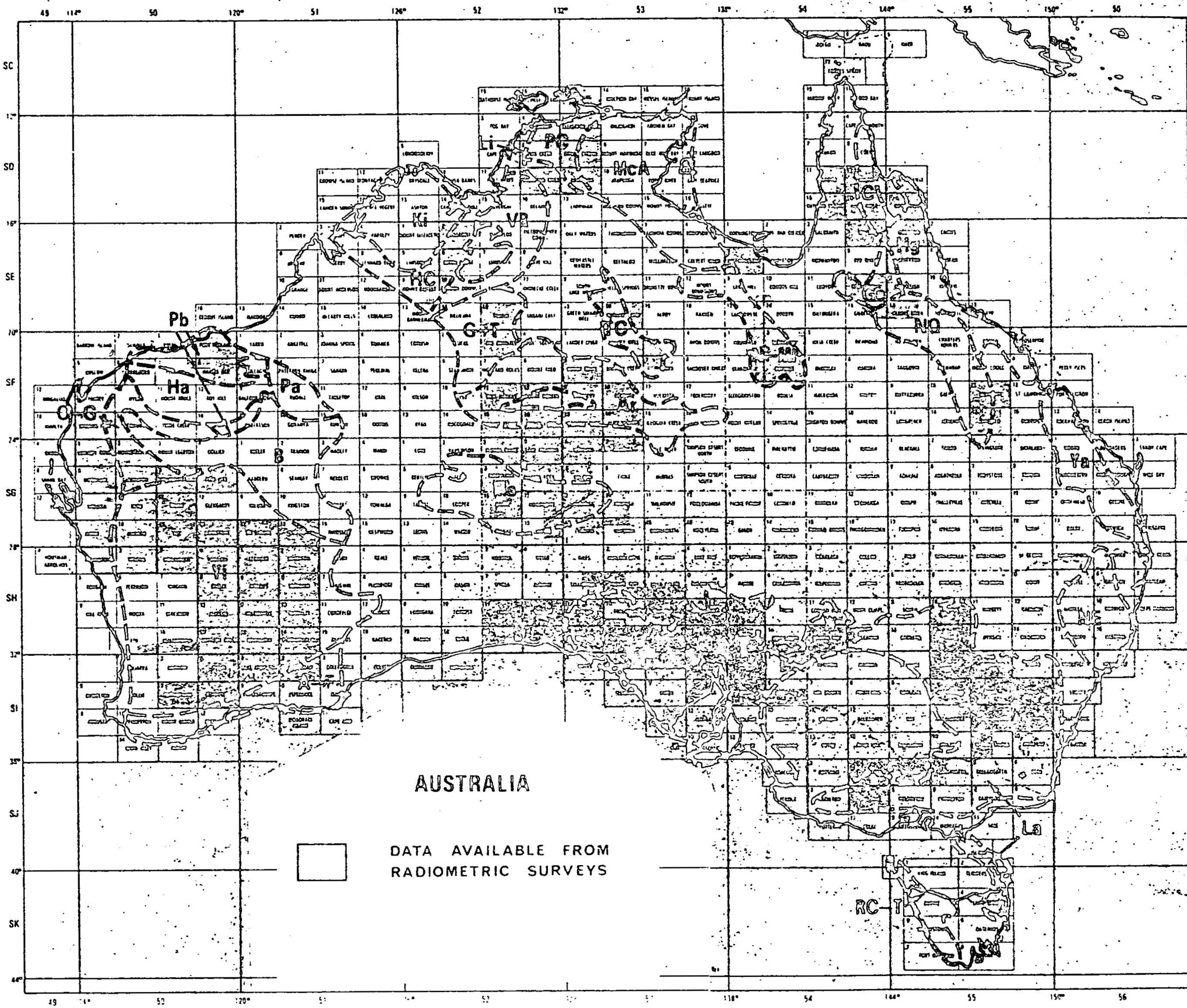


FIGURE 1

(BASED ON A/BO-63-1A)

BMR Symposium, 1977



Metalliferous Provinces (including Proterozoic Sedimentary Basins)

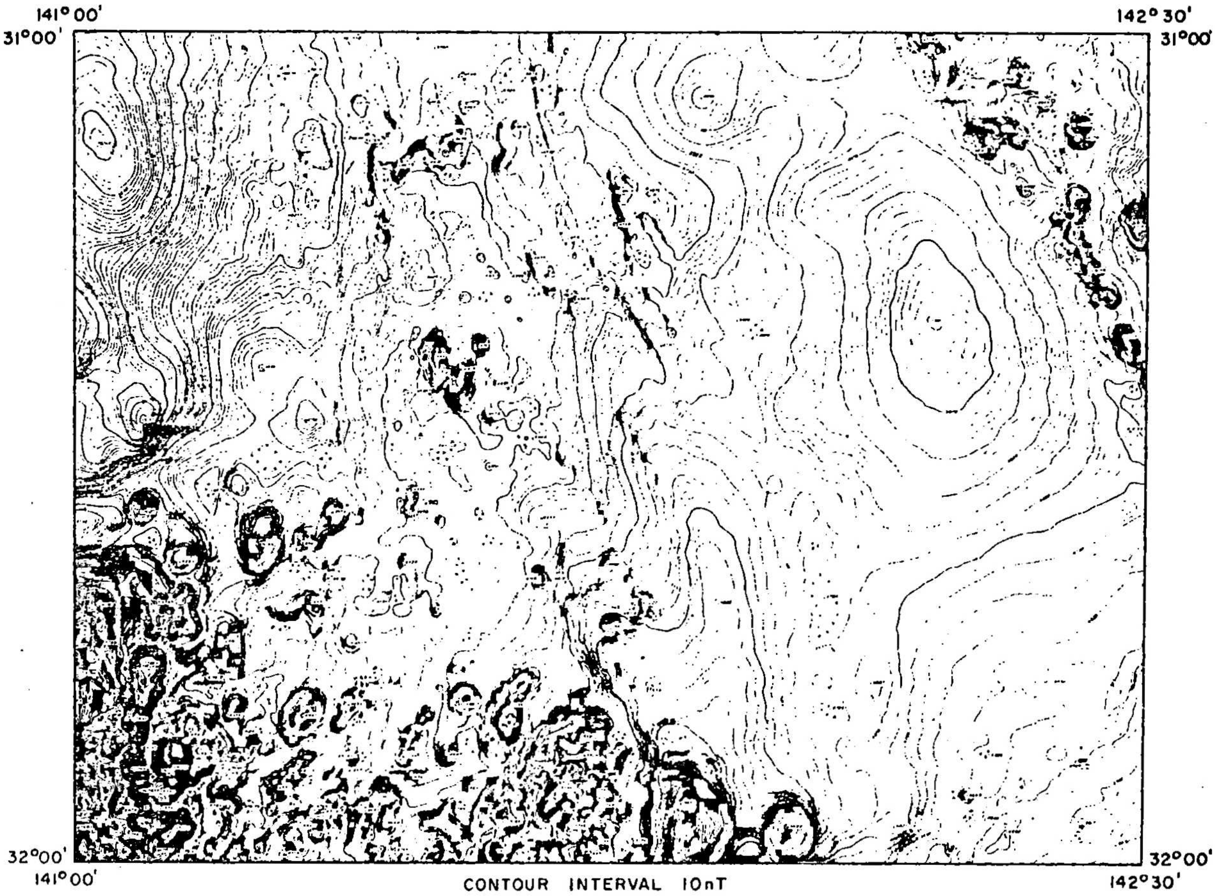
A–K	Adelaide – Kanmanto
A–F	Albany – Fraser
Ar	Arunta
B	Bangemall
C	Coen
Gw	Gawler
Ge	Georgetown
G–T	Granites – Tanami
HC	Halls Creek
Ha	Hamersley
Hg	Hodgkinson
Ki	Kimberley
La	Lachlan
Li	Litchfield
McA	McArthur
Ms	Musgrave
NE	New England
N–MI	Nicholson – Mt Isa
NQ	North Queensland
O–G	Ophthalmia – Gascoy
Pa	Paterson
Pb	Pilbara
PC	Pine Creek
RC–T	Rocky Cape – Tyenna
TC	Tennant Creek
VR	Victoria River
W	Willyama
Ya	Yarrol
Yi	Yilgarn

FIGURE 2

A/BI-19A

FIGURE 3

BROKEN HILL



CONTOUR INTERVAL 10nT

AIRBORNE SURVEY, BROKEN HILL, N S W 1975

TOTAL MAGNETIC INTENSITY

SCALE 1:1 000 000

10 0 10 20 30 40 50 KILOMETRES

LOCATION DIAGRAM

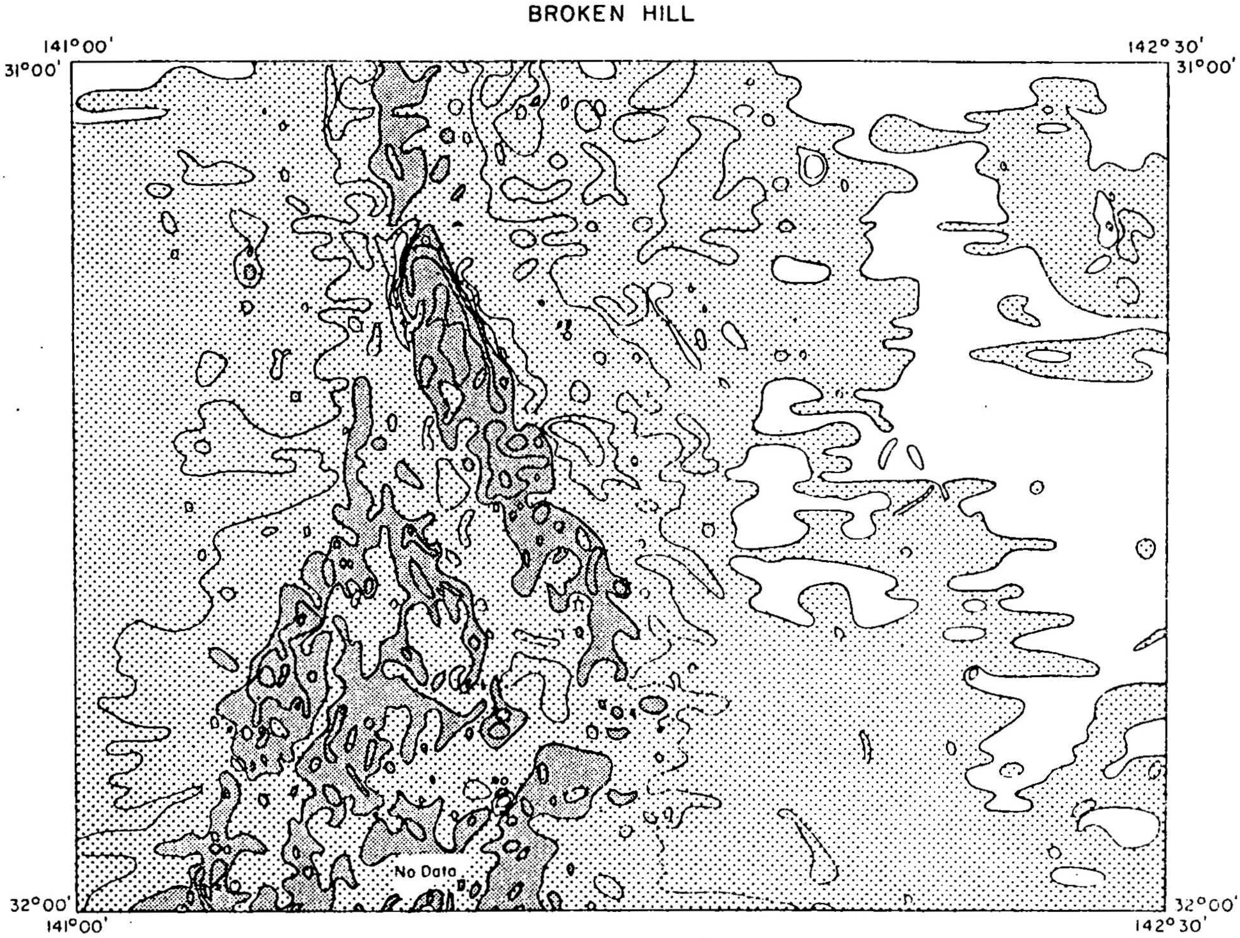
REFERENCE TO 1:250 000 MAP SERIES

FROME	COBHAM LAKE	WHITE CLIFFS
CURNAMONA	BROKEN HILL	WILCANNIA
OLARY	MENINDEE	MANARA

First released in Record No. 1976/91
BMR Symposium, 1977

H54/B1-127A

FIGURE 4



AIRBORNE SURVEY, BROKEN HILL, NSW 1975

RADIOMETRIC CONTOURS

TOTAL COUNT

SCALE 1:1 000 000

10 0 10 20 30 40 50 KILOMETRES

LEGEND

- *>150 counts/s*
- *50–150 counts/s*
- *<50 counts/s*

LOCATION DIAGRAM

REFERENCE TO 1:250 000 MAP SERIES

FROME	COBHAM LAKE	WHITE CLIFFS
CURNAMONA	BROKEN HILL	WILCANNIA
OLARY	MENINDEE	MANARA

First released in Record No. 1976/91
BMR Symposium, 1977

H54/B1-125A

CONTOUR INTERVAL 10nT

AIRBORNE SURVEY, BROKEN HILL (DETAILED) NSW, 1975

TOTAL MAGNETIC INTENSITY

SCALE 1:400 000

5 0 5 10 15 20 25 KILOMETRES

LOCATION DIAGRAM

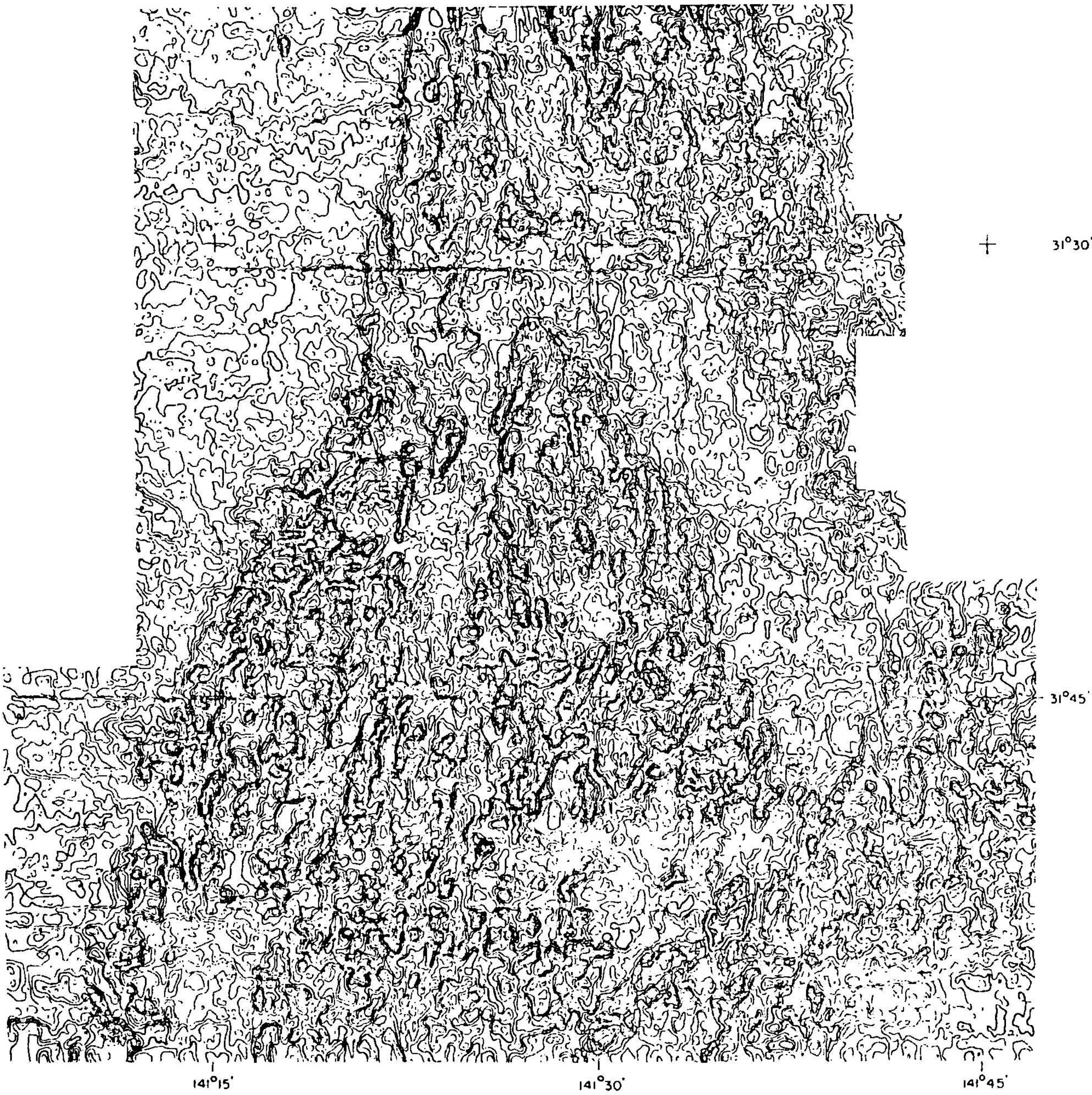
REFERENCE TO 1:250 000 MAP SERIES

FROME	COBHAM LAKE	WHITE CLIFFS
CURNAMONA	BROKEN HILL	WILCANNIA
OLARY	MENINDEE	MANARA

First released in Record No. 1976/91
BMR Symposium, 1977

H54/B1-128A

FIGURE 6



AIRBORNE SURVEY, BROKEN HILL (DETAILED), NSW 1975

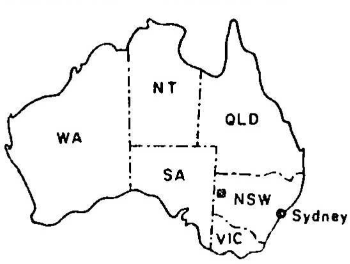
RADIOMETRIC CONTOURS, TOTAL COUNT

CONTOUR INTERVAL: 10 counts/s

SCALE 1:400 000

5 0 5 10 15 20 25 KILOMETRES

LOCATION DIAGRAM



REFERENCE TO 1:250 000 MAP SERIES

FROME	COBHAM LAKE	WHITE CLIFFS
CURNAMONA	BROKEN HILL	WILCANNIA
OLARY	MENINDEE	MANARA

First released in Record No. 1976/91
BMR Symposium, 1977

H54/B1-126A

FIGURE 7

BROKEN HILL (DETAIL)

PROFILE VERTICAL SCALE 1000 nT/cm

TOTAL MAGNETIC INTENSITY PROFILES

SCALES IN KILOMETRES

E-W 1:400 000

4 0 4 8 12 16 20

1 0 1 2 3 4 5

N-S 1:100 000

FIGURE 8

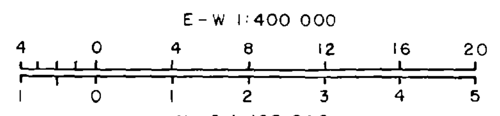
BROKEN HILL (DETAIL)

PROFILE VERTICAL SCALE 400 c/s/cm
BASE 50 c/s

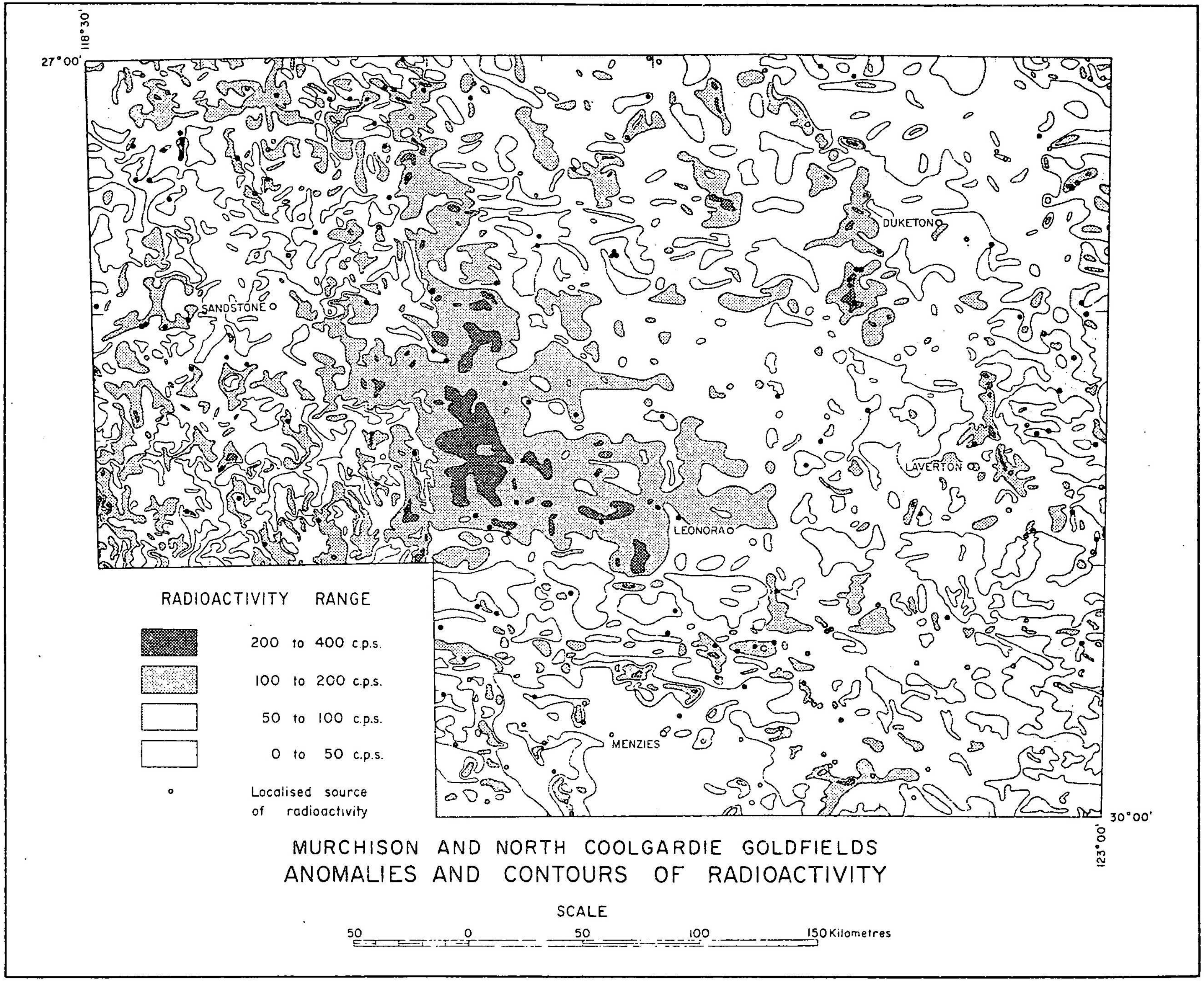
RADIOMETRIC PROFILES
TOTAL COUNT

SCALES IN KILOMETRES

E-W 1:400 000



N-S 1:100 000



BMR Symposium, 1977
First released in Record No. 1971/78

G50/B1-111A

FIGURE 9

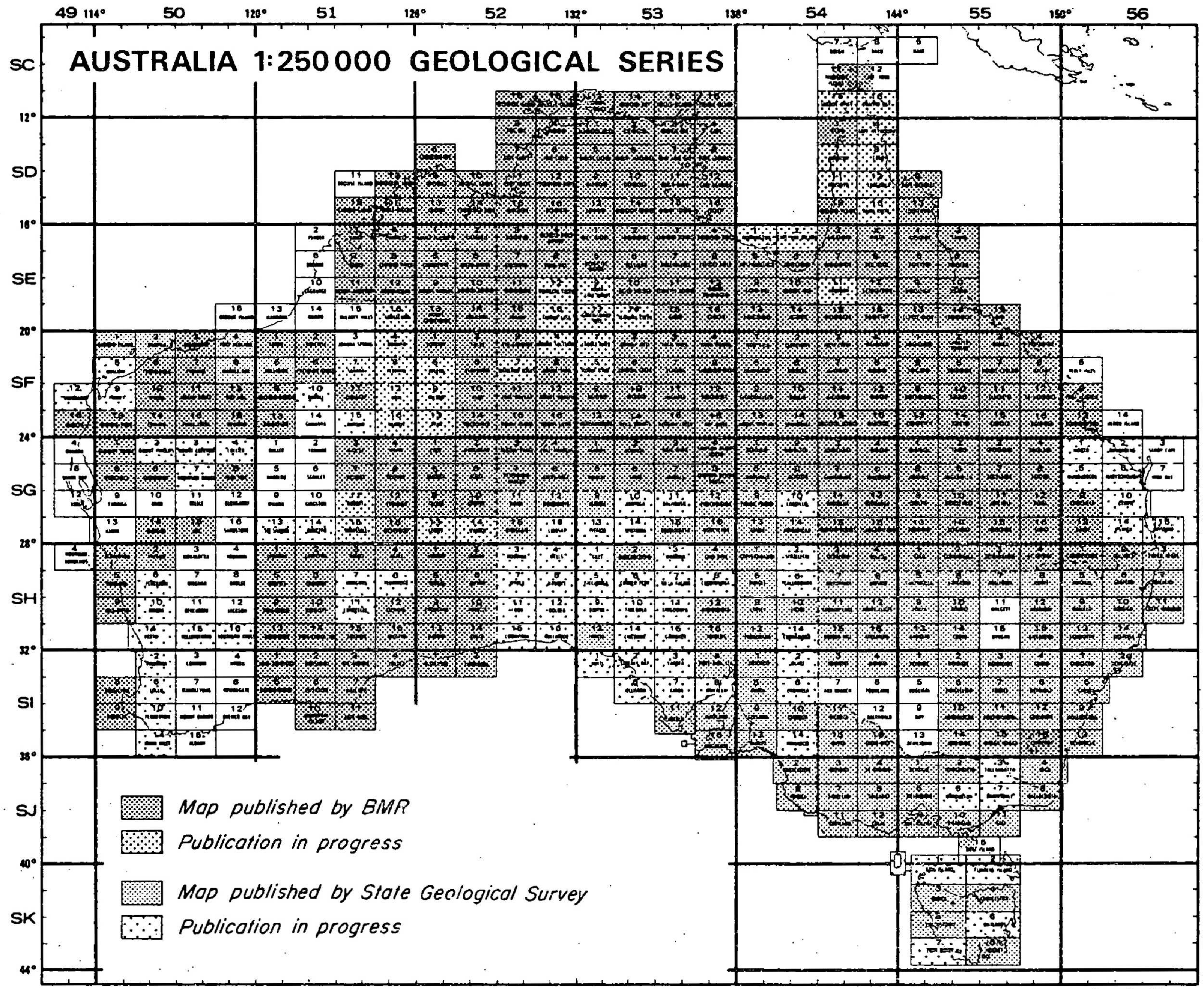


Fig.10

Aus 5-18

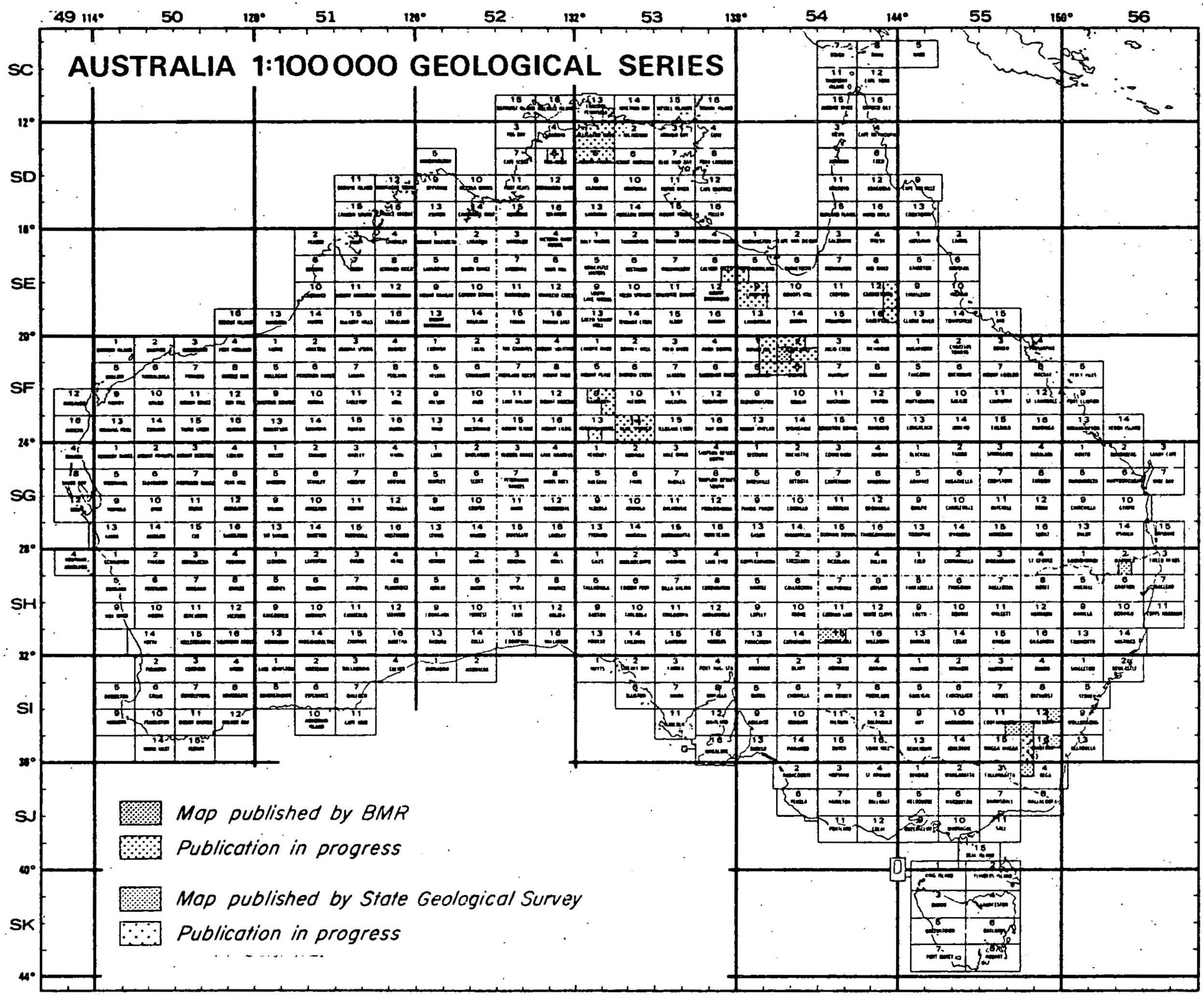
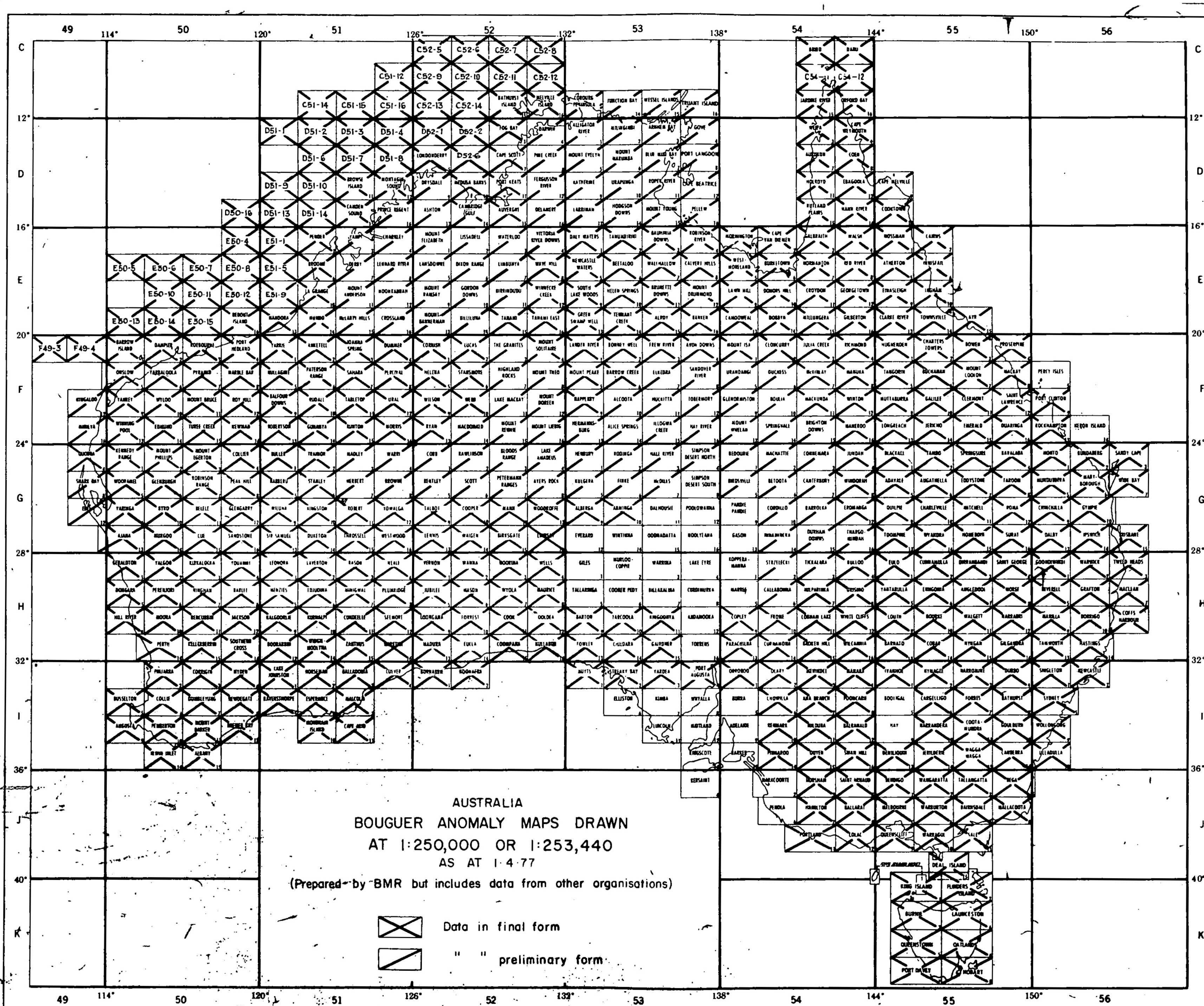


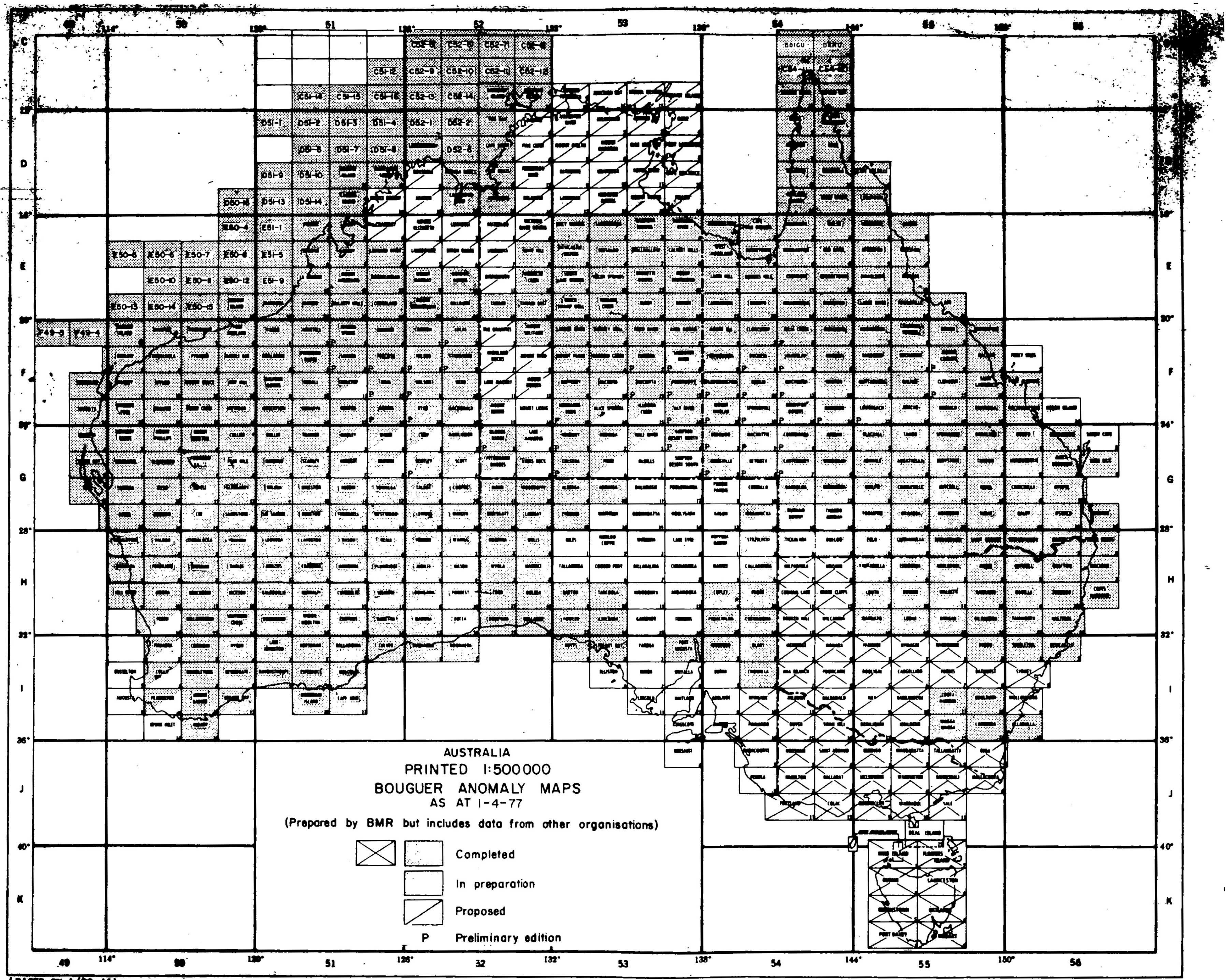
Fig. II

Aus 5-17



(BASED ON A/BO-14) FIG. 12

A/B2-28



(BASED ON A/80-14)

FIG. 13

A/B2-31

FIG. 14 DISTRIBUTION OF DATA USED TO PRODUCE 1976 1:5000000 GRAVITY MAP OF AUSTRALIA

A/B2-143A

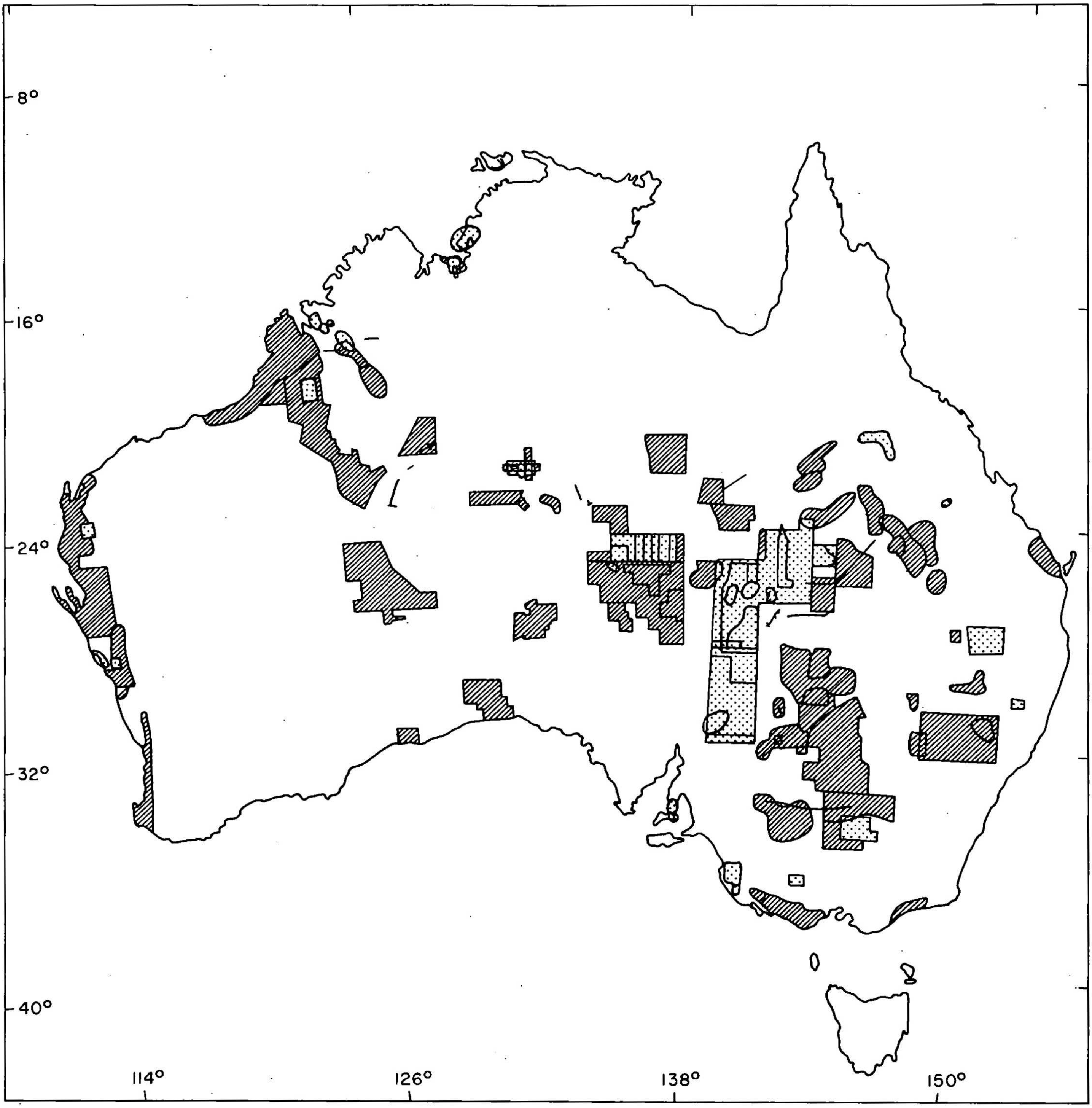
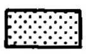


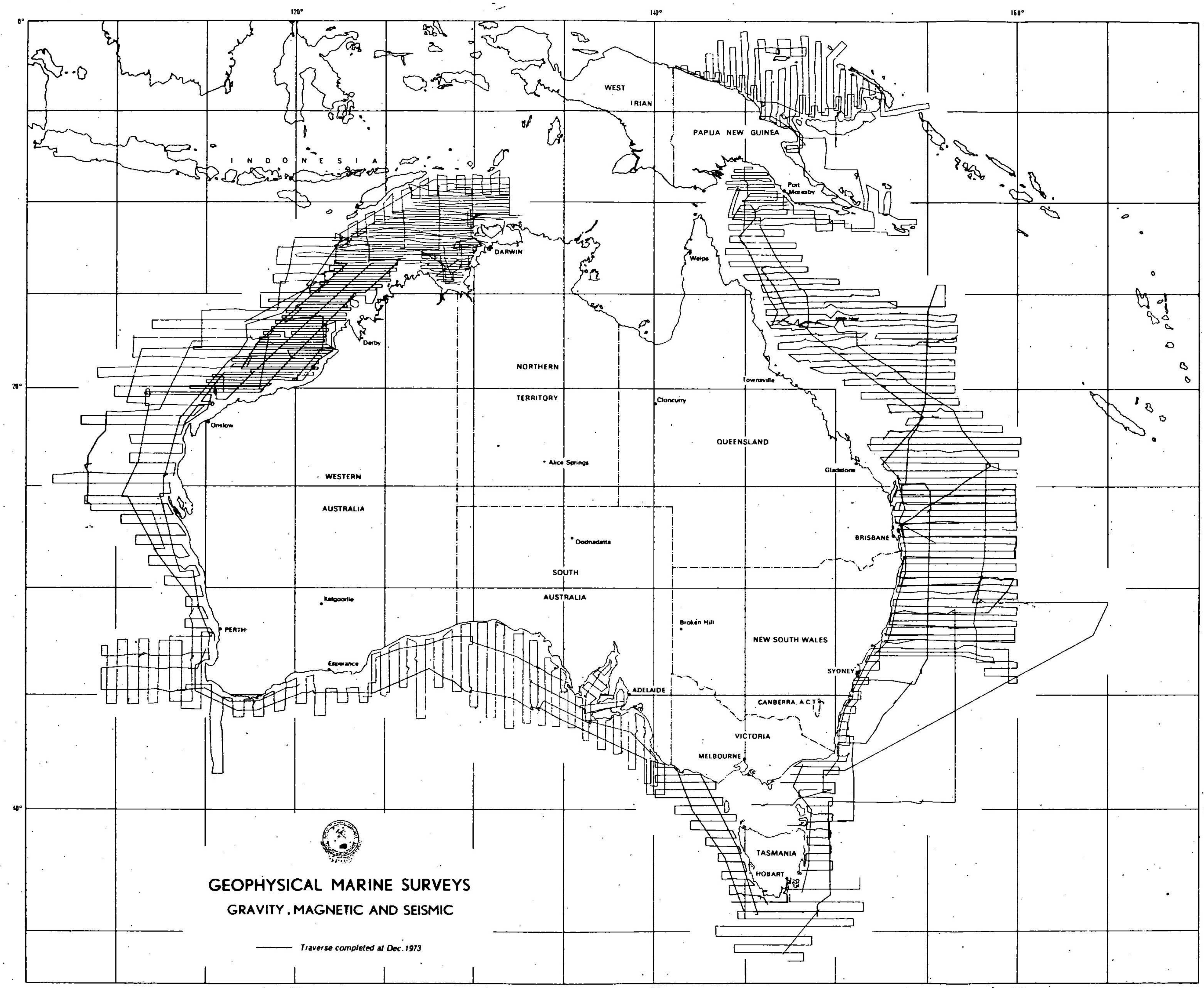
FIG. 15 SEMI-DETAILED GRAVITY SURVEYS

To be on tape by 1978 under approved contract



Recommended to be put on tape under proposed contract

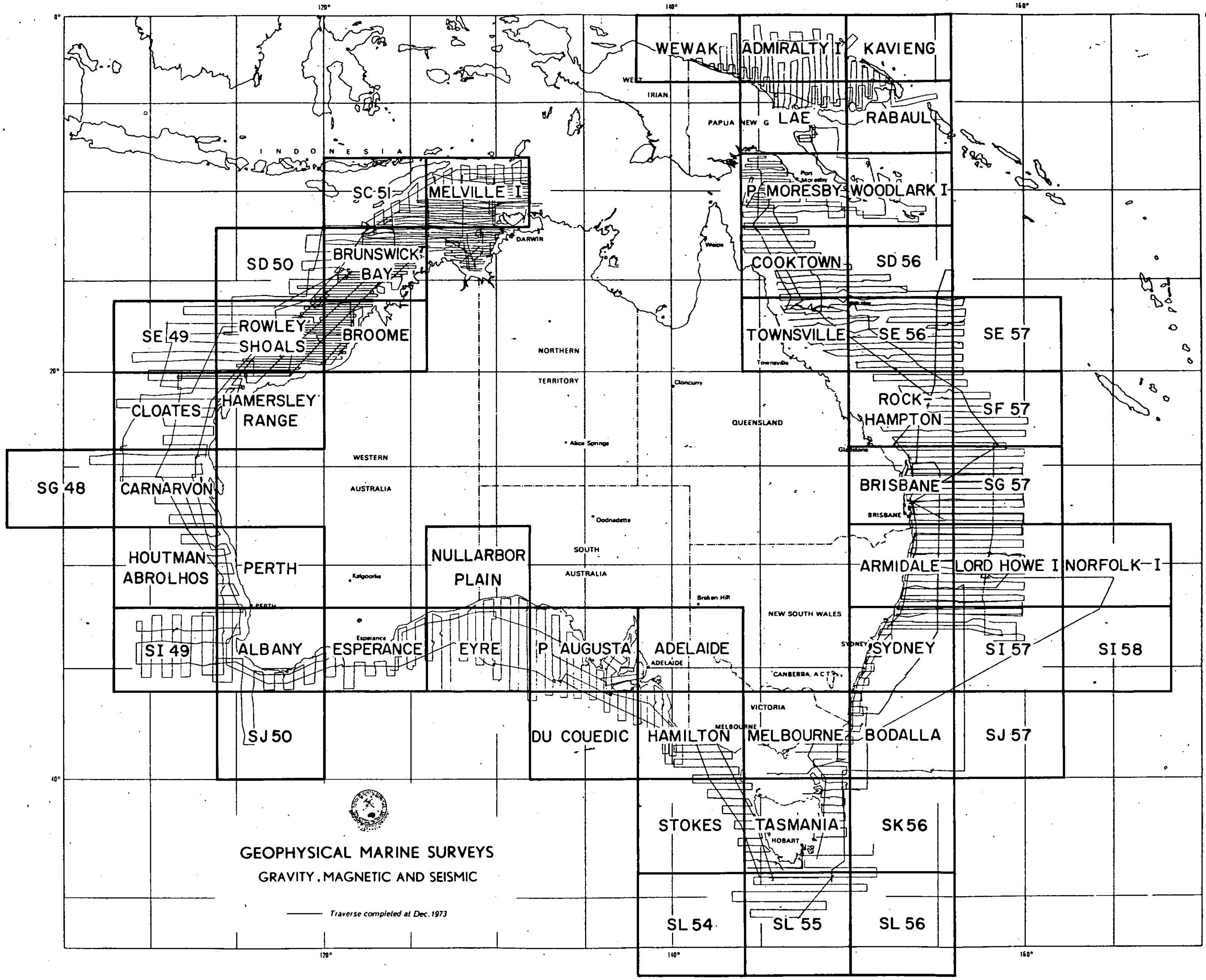
A/B2-142 A



MARINE GEOPHYSICAL WORK DONE BY BMR

A/B8-7-14

FIG. 17



1:1 MILLION SHEET AREAS TO BE PUBLISHED

A/B8-7-15

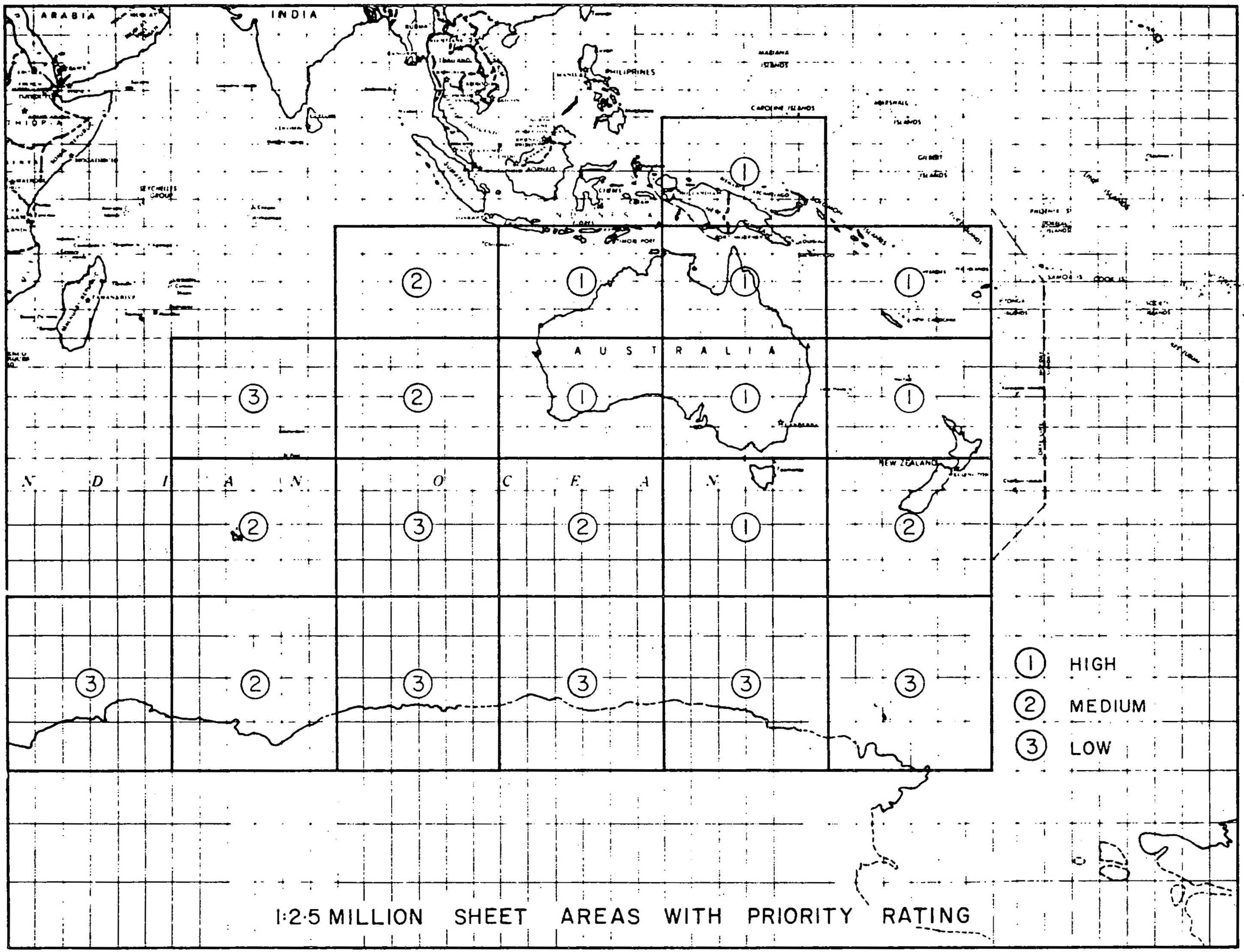
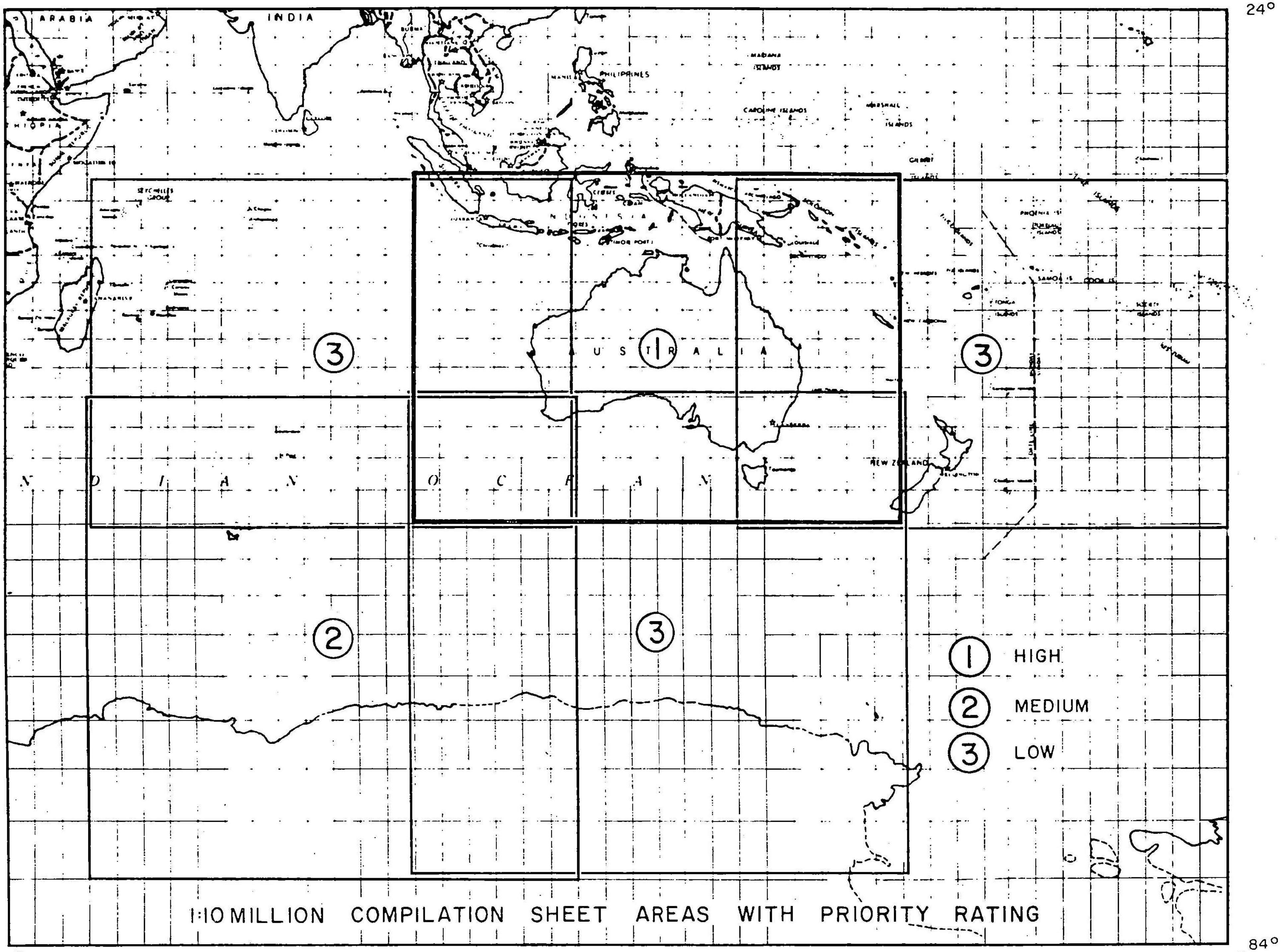


FIG. 18

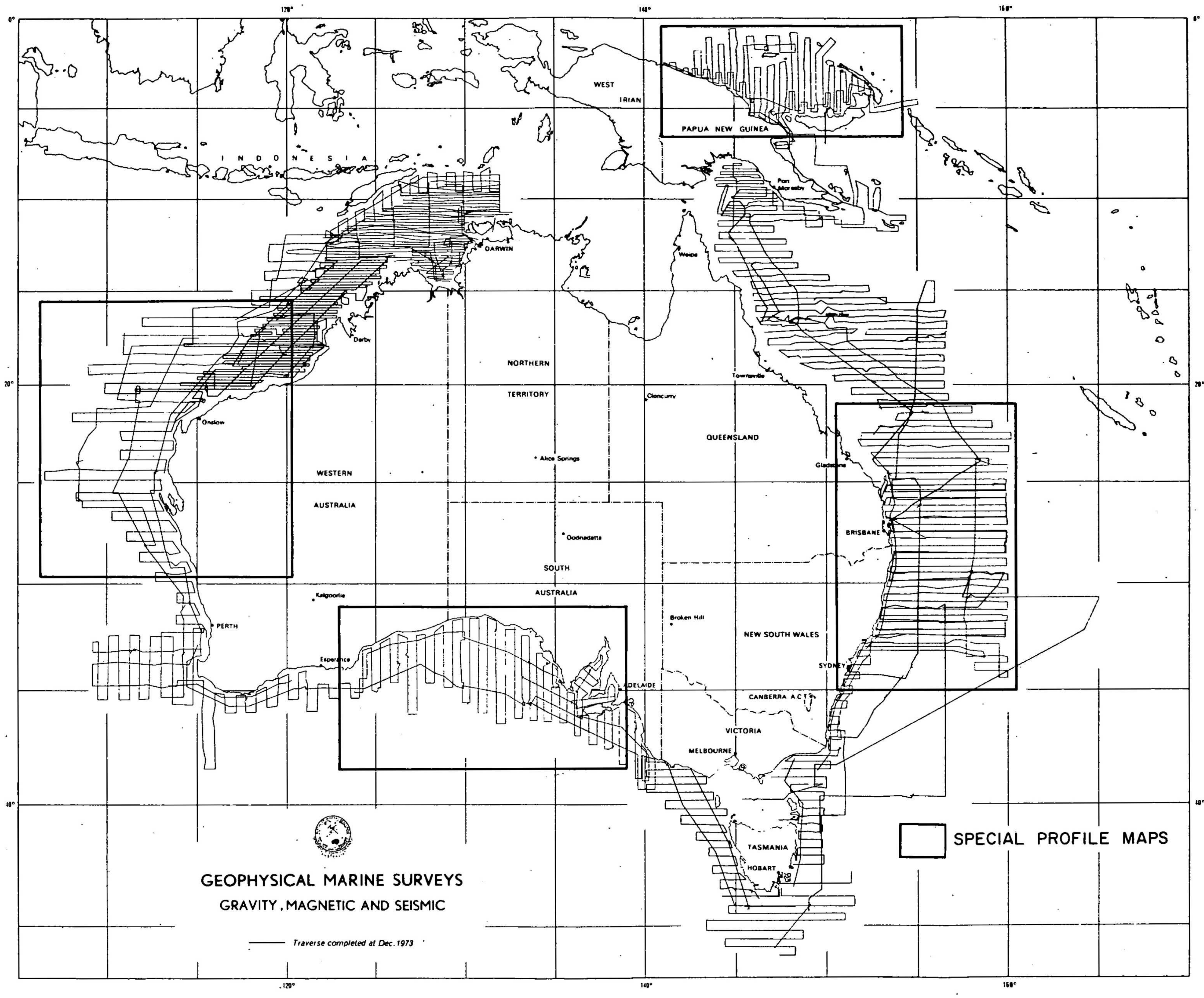
W/B8-86A



1:10 MILLION COMPILATION SHEET AREAS WITH PRIORITY RATING

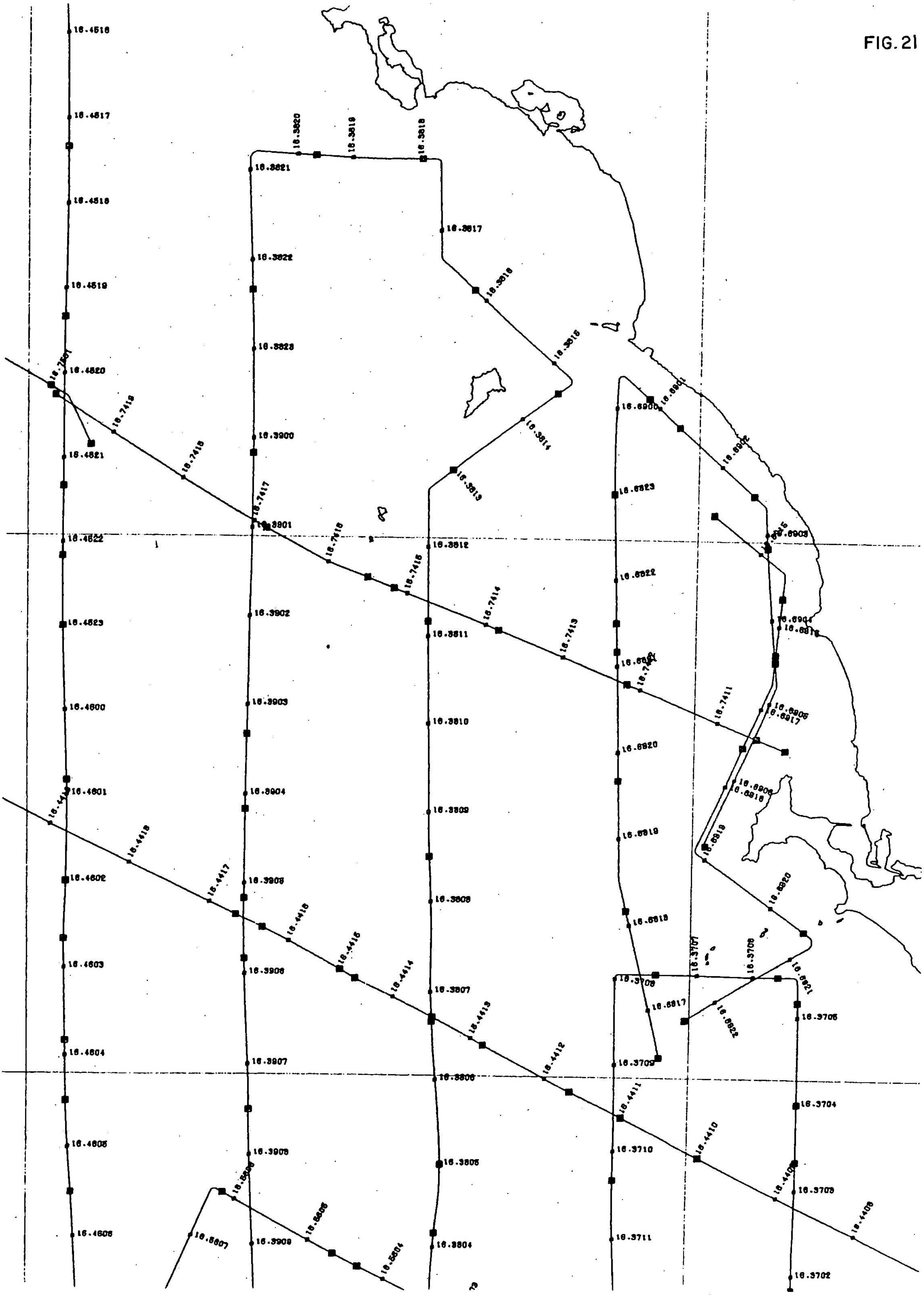
FIG. 19

W/B8-87A



SPECIAL MAPS TO BE PUBLISHED

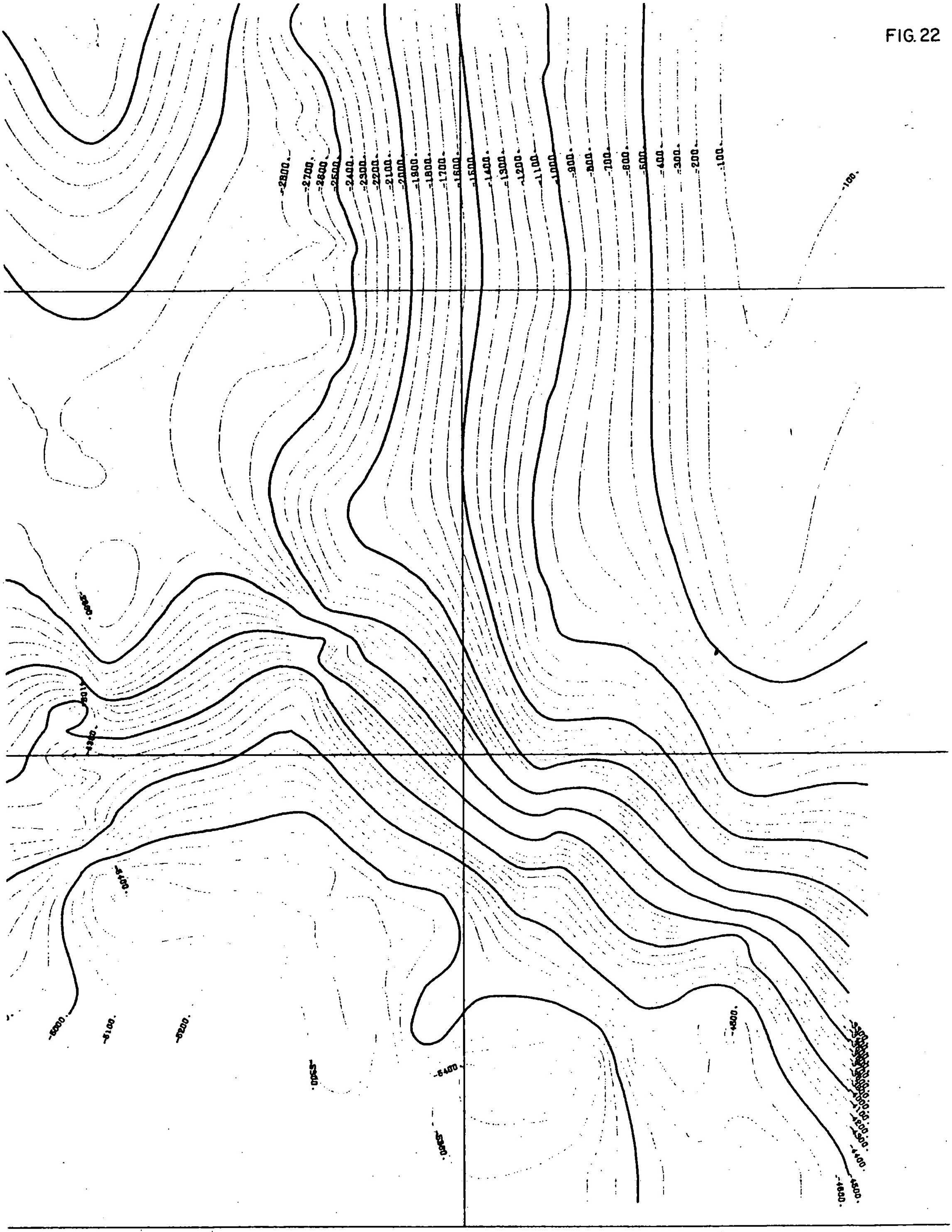
FIG. 21



TRACK MAP

G449-179A

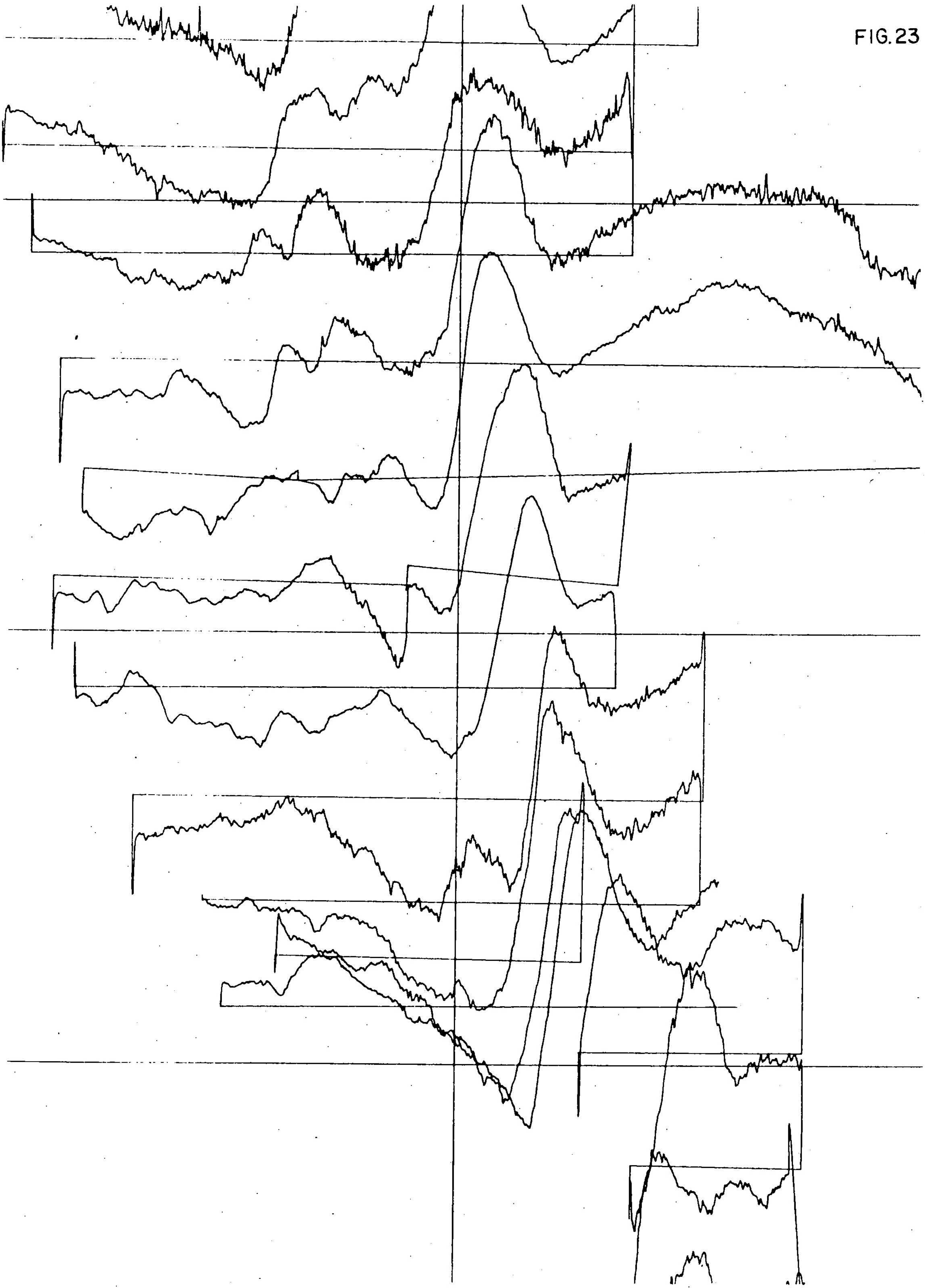
FIG. 22



CONTOUR MAP

G449-180A

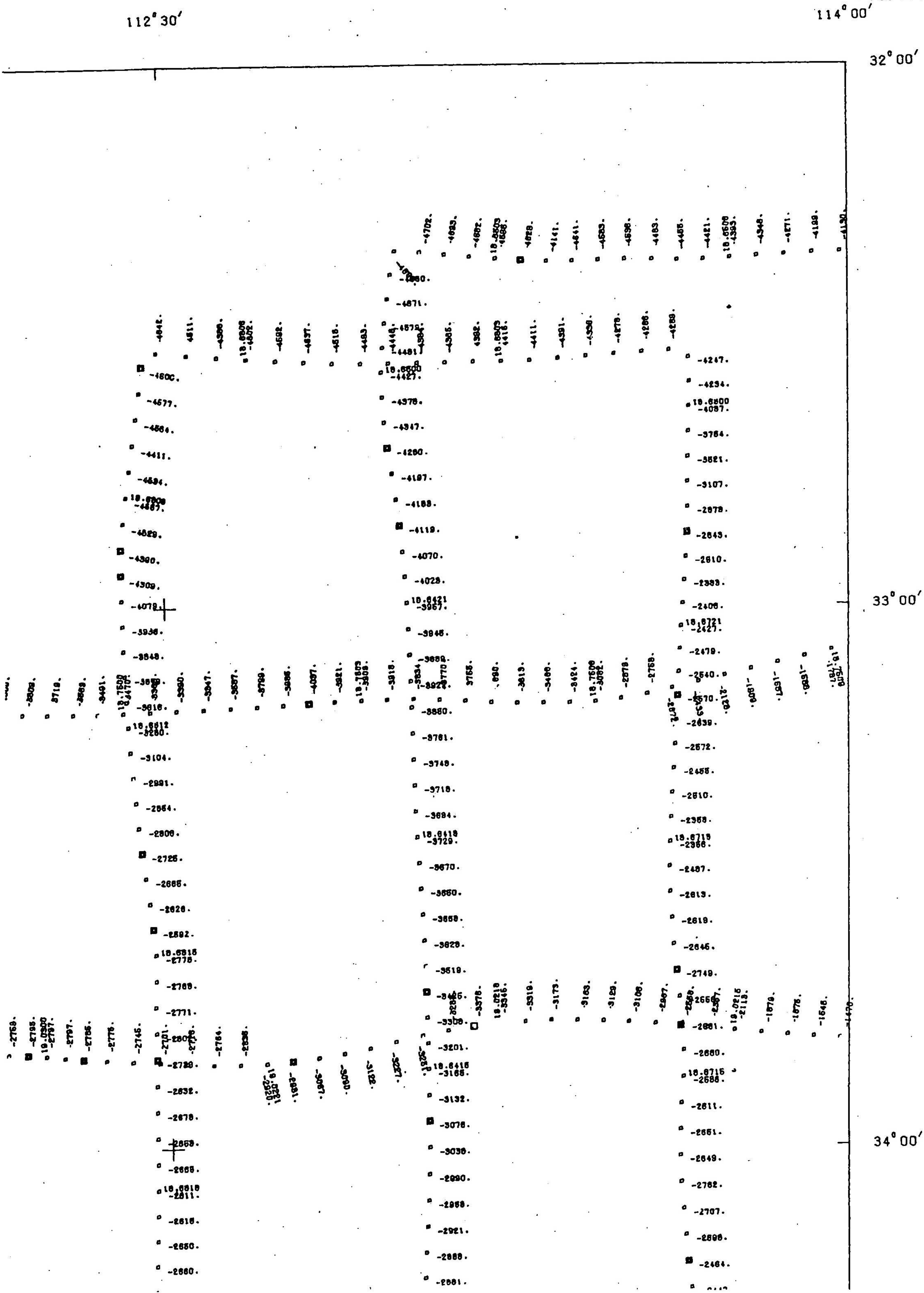
FIG. 23



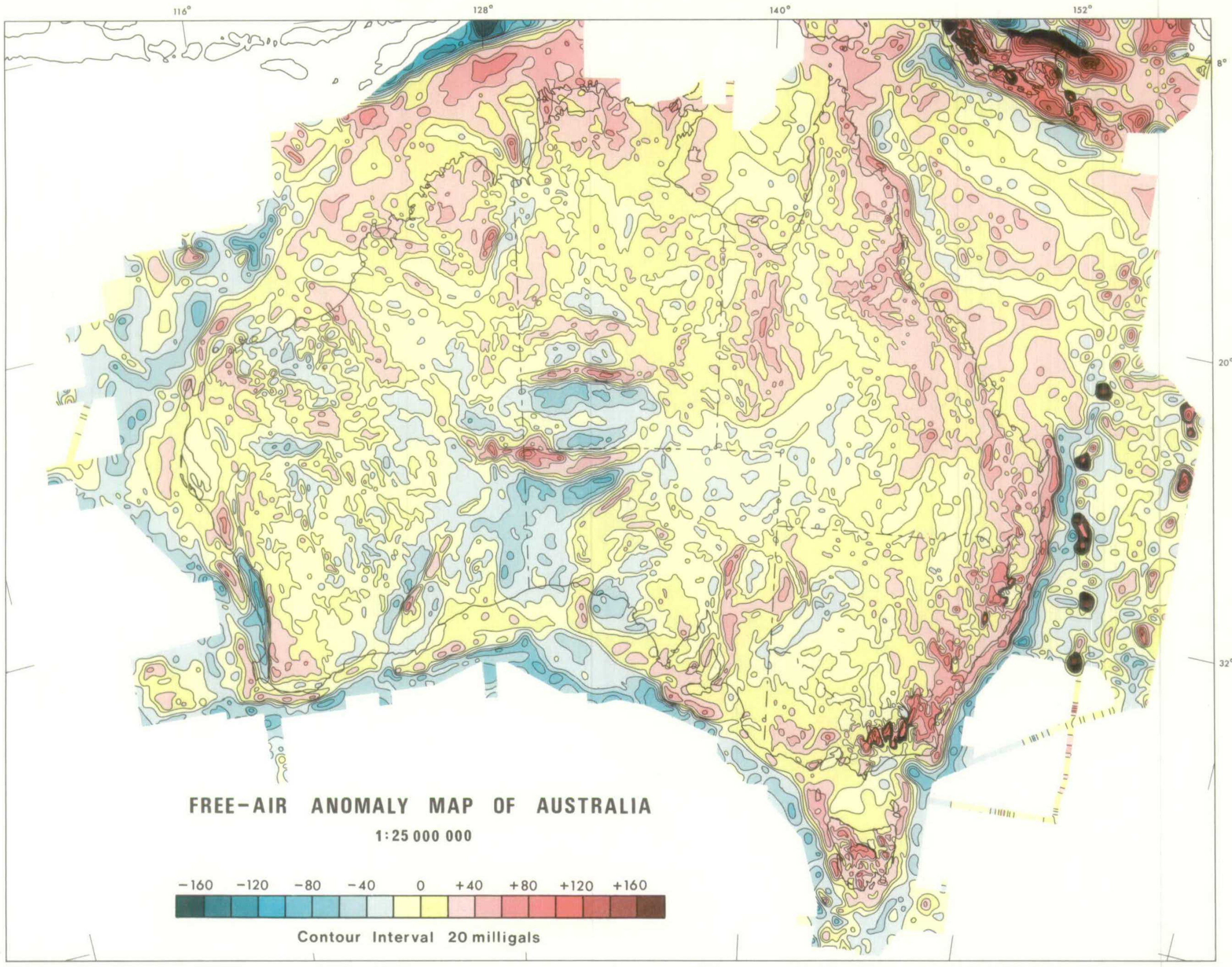
PROFILE MAP

G449-181A

FIG. 24



DATA POSTING MAP



These two 1:25 million gravity maps were published in the December 1976 issue of the BMR Journal of Australian Geology and Geophysics. Details of the sources of data, reduction of observations, accuracy of the anomalies and techniques used for smoothing and contouring are contained in "Compilation and production of the 1976 Gravity Map of Australia" by Anfiloff et al. in the same issue.

The free-air anomaly map of Australia is a smaller version of an unpublished map prepared as an overlay to the 1:2.5 million 1976 Geological Map of Australia; its projection is Simple Conic. The Gravity Map of Australia is a smaller version of the 1:5 million 1976 Gravity Map of Australia. It shows Bouguer anomalies (ρ = 2.67 t.m^{-3}) on shore and free-air anomalies at sea; its projection is Lambert Conformal. Both maps were prepared from the same data bank as the 1:5 million gravity map of Australia with the addition of some marine observations obtained near the southern end of the Great Barrier Reef by the "Gulf Rex".

The maps were drawn by P. Moffat and A.J. Maxwell of BMR's Geophysical Drawing Office and printed by the Division of National Mapping, Department of National Resources.

Substantial contributions of gravity data were provided by:
Bureau of Mineral Resources, Geology and Geophysics
Flinders University
Gulf Research and Development Company
New South Wales Mines Department
Ocean Research Institute, Hawaii Institute of Geophysics
Oil Companies who operated under the Petroleum Search Subsidy Acts
South Australian Mines Department
Tasmania Mines Department
United States Navy
University of New South Wales
University of Tasmania
West Australian Petroleum Pty Ltd