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NATIONAL REPORT ON GRAVITY IN AUSTRALIA
JULY 1974 TO JUNE 1978

by

P. WELLMAN

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SUMMARY

In 1974 USSR and Australia carried out an OVM pendulum tie Moscow-Port Moresby (Papua New Guinea)-Hobart (Australia). The scale defined by the interval Port Moresby-Hobart is the same, within experimental error, as the scale defined by Soviet GAG-2 gravity meters over the same interval, and the same as the scale defined by IGSN-71 values on the Western Pacific Calibration Line.

A systematic reconnaissance gravity coverage of Australia and its continental shelf and slope was almost complete by 1974. Major extensions of coverage in 1974-1978 have been surveys of oceanic areas adjacent to the continental slope by ships operated by overseas institutions. Compilation of all available gravity data continues. The first result of this work was the publication of a coloured gravity map of Australia at 1:5 million scale in 1976.

A rough gravity reconnaissance survey of the coastal portion of Enderby, Kemp, and Mac.Robertson Lands in Antarctica has resulted in gravity maps of this area.

A study has been made of calibration errors of quartz-type gravity meters. Tidal gravity has been recorded at eight places in Australia.

1. INTRODUCTION

This report describes gravity work undertaken in the Australian region during the period July 1974 to June 1978. It is intended for presentation at the eighth meeting of the International Gravity Commission (IGC) of the International Association of Geodesy, to be held in Paris in September 1978. Earlier work is covered by the national reports to the previous meetings of IGC prepared by Dooley (1959), Langron (1966), Dooley (1965), Barlow (1970) and Wellman (1974). The IGC reports are overlapped by national reports to the general assemblies of the International Association of Geodesy. A review of gravimetry in Australia 1819 to 1976 was given by Dooley & Barlow (1976).

Acknowledgement is made of information supplied by Division of National Mapping, Department of Minerals & Energy; Mines Departments of South Australia and New South Wales; Geology Department, University of Tasmania; and School of Surveying, University of New South Wales. Acknowledgement is also made to petroleum and mineral exploration companies who have contributed to the gravity coverage of Australia.

The Bureau of Mineral Resources, Geology & Geophysics (BMR) is the responsible Australian Government authority on gravity matters. This report has been prepared in the Geophysical Branch of BMR.

2. AUSTRALIAN DATUM, SCALE, AND NATIONAL GRAVITY NETWORK

In the period 1950 to 1973 gravity measurements in Australia were made relative to the Melbourne pendulum station (45474A, BMR No. 5099.9901) with an adopted gravity value of 979 979 0 $\mu m.s^{-2}$, using a scale compatible with the Cambridge pendulum results. Gravity values used in the period 1965 to 1973 were called May 1965 Isogal values. Since 1973, measurements have been relative to a new National Gravity Base Station in Sydney (45331 A, BMR No. 5099.9905) adopting the IGSN-71 value of 979 671 8.6 $\mu m.s^{-2}$ and using a scale based on Soviet GAG-2 gravity meter measurements along the Australian Calibration Line of 30 000 $\mu m.s^{-2}$ (Boulanger & others, 1973). Gravity values can be changed from the old to the new datum and scale by the provisional formula

$$g_{1973} = 979\ 671\ 8.6 + 1.000\ 511\ 8\ (g_{1965} - 979\ 685\ 7.4).$$

The GAG-2 gravity meters define a scale to 2.5 parts in 10^5. This scale differs from the earlier scale based on pendulum results by 5 parts in 10^4, and from the scale defined by IGSN-71 values along the east coast of Australia by 15 parts of 10^5. However, it differs by only 3 ± 1 parts in 10^5 from the scale defined by IGSN-71 values on the Western Pacific Calibration Line, and is the same, within experimental error, as the scale defined by OVM pendulum measurements Port Moresby-Hobart (Boulanger & others, 1973; Wellman & others, 1974 a, b; Gusev, 1975).

The OVM pendulum measurements were carried out by the Central Research Institute of Geodesy, Aerial Survey and Cartography of USSR in 1974; they were arranged by the Soviet Geophysical Committee and carried out in cooperation with BMR and the University of Tasmania. Ties are as follows: Moscow (USSR)-Port Moresby (Papua New Guinea)-Hobart (Australia)-Port Moresby-Moscow. The gravity intervals found were Moscow (Ledovo)-Port Moresby D = 33 491.83 $\pm$ 0.55 $\mu m.s^{-2}$, Port Moresby D - Hobart B = 22 156.55 $\pm$ 0.054 $\mu m.s^{-2}$ (Gusev, 1975).

The Australian National Gravity Network (Barlow, 1970) consists of a series of east-west traverses between airports of nearly equal gravity, joined by three north-south traverses. This network was established during the period 1964-1967. In 1975 the gravity intervals were recalculated, and the network values recalculated to the new 1973 datum and scale (McCracken, in press). It was found that the standard error of a single A-B-A-B air tie with one LaCoste & Romberg and two quartz-type gravity meters is 0.39 $\mu m.s^{-2}$, and gravity values at stations forming the net are determined to an accuracy of about 1.0 $um.s^{-2}$. The values of gravity derived by McCracken are consistent within experimental error with the IGSN-71 values for stations away from the east coast of Australia, viz. Perth, Darwin, Alice Springs, and Mount Isa.

Gravity intervals on Australian calibration ranges have been calculated to the 1973 scale using all known interval determinations by LaCoste & Romberg gravity meters (Wellman & McCracken, 1974). New calibration ranges of 500 and 2300 $\mu m.s^{-2}$ have been established in Canberra.

3. LAND AND MARINE COVERAGE OF AUSTRALIA

The reconnaissance gravity coverage of the Australian land area was completed in 1974. About one-half of the country was covered to a station density of one station per 130 km^2; the remainder has a more dense coverage (Plate 1; Fraser & others, 1976; Terron & others, 1976). Since 1974, extensive gravity road traverses have been carried out by BMR in conjunction with seismic refraction surveys in the Pilbara area of Western Australia and the Lachlan Geosyncline of southeastern Australia. Smaller areas have been covered in detail by mineral companies, BMR, State mines departments, and universities. These surveys have been over mineralised or potentially mineralised areas, coalfields, possible groundwater areas, or areas of complex structure. The accuracy of the available gravity data on land has been discussed by Mather & others (1976) and Barlow (1977).

A systematic marine reconnaissance gravity survey of the continental shelf and slope was carried out by BMR during 1965-1974 (Plates 1 & 4). Gravity traverses over oceanic areas in the Australian region have been undertaken by a number of organisations since 1935. In the period 1974 to 1978 several major surveys have been made of areas just off the continental margin. Vema (Lamont-Doherty Geological Institute) has made many surveys both south and north of Australia, and the Atlantis II (Woods Hole Oceanographic Institution) and Valdivia (of the German Institute for Geosciences and Natural Resources) have surveyed northwest of Australia (Plate 2). These surveys have been made in co-operation with BMR.

4. COMPILATION OF GRAVITY DATA, COMPUTER PROCESSING, AND PRODUCTION OF GRAVITY MAPS

By 1974 many organisations in Australia were using computers to facilitate the reduction, compilation, and retrieval of gravity data in Australia (e.g. Morony, 1975). BMR had developed a suite of programs for the reduction of land and marine surveys, compilation of the data into a library of principal fact files, and the display of data in the form of tables of principal facts and contour maps (Murray, 1974). These programs are run on a CDC Cyber 76 computer.

During 1974 to 1978 the Australian National Gravity Repository Computer System has been refined and extended to provide a more powerful and reliable tool for fast processing of large amounts of gravity data. The contouring program now produces accurate, smooth contours from an unrestricted amount of irregularly spaced data covering any area of the globe at any scale and with a choice of five map projections (Murray, 1977). Programs have been written or are under development for the production of gridded values generated by any polynomial trigonometric function of latitude and longitude and by 3-dimensional bodies of arbitrary density with planar sides or circular section. The mathematically derived grids can be subtracted from the observed anomaly grids to produce residual grids which can be contoured. Gridded data files can be manipulated, edited, and masked with ease and may be displayed in the form of contour maps at any stage.

In BMR a major project has been the listing on magnetic tape of all available gravity data, and adjusting it to the national gravity datum and scale and the national height and positional datums (Australian Height Datum, Australian Geodetic Datum). Observations made on reconnaissance helicopter surveys and regional ground surveys have been adjusted where necessary, and some errors have been removed.

By 1976 a complete reconnaissance gravity coverage of Australia and the surrounding shelf and slope were available on tape (Plate 1), but many surveys required further adjustment and checking. By June 1978, data on magnetic tape included 338 000 land stations from semi-detailed surveys of which 215 000 were from oil company surveys. There still remains a considerable amount of work in correcting errors, putting the remaining land and marine surveys on tape, and adding marine data from foreign institutions to the Australian data bank.

In 1976 a coloured gravity map of Australia and the surrounding continental margin and slope was produced at 1:5 million scale (BMR, 1976; Anfiloff & others, 1976). The map shows slightly smoothed 5-milligal simple Bouguer anomaly contours for a density of 2.67 $t.m^{-3}$ on land and 10-milligal free-air contours at sea. Two 1:25 million coloured gravity maps were published in the December 1976 issue of the BMR Journal of Australian Geology & Geophysics. One is a reduced version of the 1:5 million map but with 20-milligal contours, and the other shows free-air anomalies both on land and at sea. Copies of these maps are included here as Plate 6.

Maps showing gravity station positions and values and 5-milligal contours are available for 1:250 000 sheet areas on land and on the northwest shelf (Plate 3); these can be obtained as dyelines or transparencies at 1:250 000 scale, or as printed reductions at 1:500 000 scale. For the BMR continental margin gravity survey the preliminary Bouguer and free-air anomaly contours are available at 1:2.5 million scale (Plate 4). Most of these maps are produced by BMR and may be purchased from the Production Section, Commonwealth Printing Office, Wentworth Avenue, Kingston, ACT 2604, Australia. The maps produced by the Mines Department of South Australia are available from the Director of Mines, 191 Greenhill Road, PARKSIDE, South Australia 5063, Australia.

A new series of computer-drawn maps is planned; these will show stations of all known regional and semi-detailed surveys with gravity and position adjusted to modern datums. These data will also be available as principal facts on computer tape.

5. GRAVITY MEASUREMENTS IN ANTARCTICA AND ON OCEANIC ISLANDS

Gravity intervals from Australia to Antarctica, and to oceanic islands, have been measured with groups of LaCoste & Romberg gravity meters. Ties from Australia (via New Zealand) to McMurdo, the South Pole, and Byrd station were carried out in 1966 by Antarctic Division (Department of Science) and in 1973 by BMR (Coutts, 1975); both surveys were carried out in co-operation with the U.S. National Science Foundation. Gravity ties between Australia and the Australian Antarctic bases Mawson, Davis, Casey, and Wilkes and the subantarctic Macquarie Island were made by Antarctic Division, BMR, and the University of New South Wales (Wellman, 1976a). BMR carried out gravity ties to Christmas Island (near Indonesia) in 1973 (Wellman, 1976a) and to Cocos and Christmas Islands in 1976.

A gravity survey of Macquarie Island was carried out by the University of New South Wales in 1970 (Williamson & Rubenach, 1972). A survey of Christmas Island was made by BMR in 1973 (Polak, 1976) and extended in 1976.

On the Antarctic continent the Antarctic Division has observed gravity along glaciological traverses; these extend from Mawson Base to Knuckey Peaks in Enderby Land, and cover the Law Ice Dome near Casey Base.

A traverse extending from Pioneerskaya Base to Dome C at 74°S, 125°E was observed by a glaciologist attached to a Soviet expedition. BMR in co-operation with Antarctic Division carried out gravity surveys of the Davis-Mawson-Prince Charles Mountains area during 1969-1974 (Wellman & Tingey, 1976) and in Enderby and Kemp Lands in 1976-1977 (Wellman & Tingey, in press). A gravity map of the coastal section of Enderby, Kemp, and Mac.Robertson Lands is given in Plate 5.

6. GRAVITY INTERPRETATION IN TERMS OF EARTH STRUCTURE

Some information on the relation of gravity anomalies to upper crustal structure is given in most reports of gravity surveys. A bibliography of major reports to 1976 including a key map is given by Terron & others (1976). A more complete bibliography is in preparation. Interpretation and operational reports published or released since 1976 are marked * in the references. A symposium on gravity interpretation was held by the Australian Society of Exploration Geophysicists in Sydney in 1977 (Emerson & Falvey, 1977).

Studies of the isostatic compensation of the Australian crust included an investigation of the depth of isostatic compensation using seismic and gravity data (Dooley, 1976, 1977), investigations of the isostatic compensation of topography (Wellman, 1976c; McNutt & Parker, 1978), and the isostatic compensation of blocks of dense metamorphic rock (Wellman, 1978). An interpretation of central Australian gravity by crustal warping is given by Mathur (1976) and Kennewell, Mathur & Wilkes (1977).

Qualitative interpretations of the gravity field include a summary of the gravity provinces recognised in Australia (Fraser, Darby & Vale, 1977), and investigations of the extent of cratonic blocks from both gravity trends (Wellman, 1976b) and 'dipole' anomalies at craton block boundaries (Wellman, 1978).

7. RESEARCH IN PHYSICAL GEODESY

The following work has been carried out at the Department of Geodesy, University of New South Wales.

A simulation study was made to establish the optimum configuration of absolute gravity stations for the recovery of secular geodynamic parameters (Mather & others, 1977; Masters & others 1978).

The Australian gravity data bank was converted to a set of gravity anomalies (AUSGAD 76) for use in sea surface topography determinations as suggested at the 1974 International Gravity Commission meeting. The data set is compatible with IGSN-71 to $\pm$ 1 $\mu m.s^{-2}$. It is also estimated that the errors in the data bank with wavelengths greater than 3000 km are less than 1 $\mu m.s^{-2}$ (Mather & others, 1976).

The successful assembly of a global data bank of GEOS-3 altimetry provided the basis for the definition of the geoid as sampled in ocean areas only (Mather, 1977). Numerical evaluations based on the best set of GEOS-3 orbits available at the end of 1977 gave the potential for the geoid (W_o) as W_o = 62 636 828 $\pm$ 3 m^2s^{-2}; this value is subject to the correctness of an unverified calibration of the GEOS-3 altimeter (Mather & Rizos, in press).

The geoid as defined above can be used to examine continental gravity data banks for the height of mean sea level at the implied regional levelling datum. The analysis of the gravity data banks for Australia (AUSGAD 76) and for central North America shows that the gravity anomaly sets computed from these data banks agree with the 1976.0 altimeter-defined geoid to $\pm$ 1 $\mu m.s^{-2}$ (Mather & others, 1978; Mather & Rizos, 1978).

8. CALIBRATION AND PERFORMANCE OF GRAVITY METERS

A detailed investigation was made of the systematic errors in results from quartz-type gravity meters. Twenty-one meters owned and operated by government and industry throughout Australia were evacuated, adjusted, and then calibrated both on a hillside calibration range and on a PEG-1 tilt table on loan from the USSR Academy of Sciences. Most meters showed a linear relation between dial revolutions and gravity to within experimental error. The tilt calibrations are systematically 0.14 $\pm$ 0.05 percent larger than the field calibrations on the Canberra Calibration Range. This discrepancy is thought to be due to the field calibration being incorrect because of a pressure effect on the quartz-type gravity meter readings of 0.33 $\pm$ 0.11 $nm.s^{-2}Pa^{-1}$. Using a vacuum chamber in the laboratory the pressure effect was found to be 0.2 $nm.s^{-2}Pa^{-1}$, and field observations at stations with the same and different elevation give a pressure effect of 0.13 $\pm$ 0.04 $nm.s^{-2}Pa^{-1}$. These results suggest that

there may be small systematic errors in the present National Gravity Network gravity values, because they are based partly on measurements with quartz-type gravity meters.

9. EARTH TIDE RECORDING

In the period 1975 to 1977, tidal gravity was recorded at eight locations throughout Australia; these were Canberra, Armidale, Broken Hill, Perth, Hobart, Darwin, Charters Towers, and Alice Springs. Recording at Alice Springs is being continued, to provide a 13-month continuous record at this site. The project is a co-operative one between the International Centre for Earth Tides at Bruxelles, the Department of Geodesy at the University of New South Wales, and BMR. The provision and maintenance of the instrument sites is organised through BMR, the Mines Branch of the Department of Northern Territory, the Australian National University, and the Universities of New South Wales, Queensland, New England, and Tasmania. The results have been given by Ducarme & others (1976), and additional aspects were covered by Mather & Bretreger (1975), Bretreger & Mather (1976), Ducarme & Melchior (1978), and Bretreger & Mather (1978).

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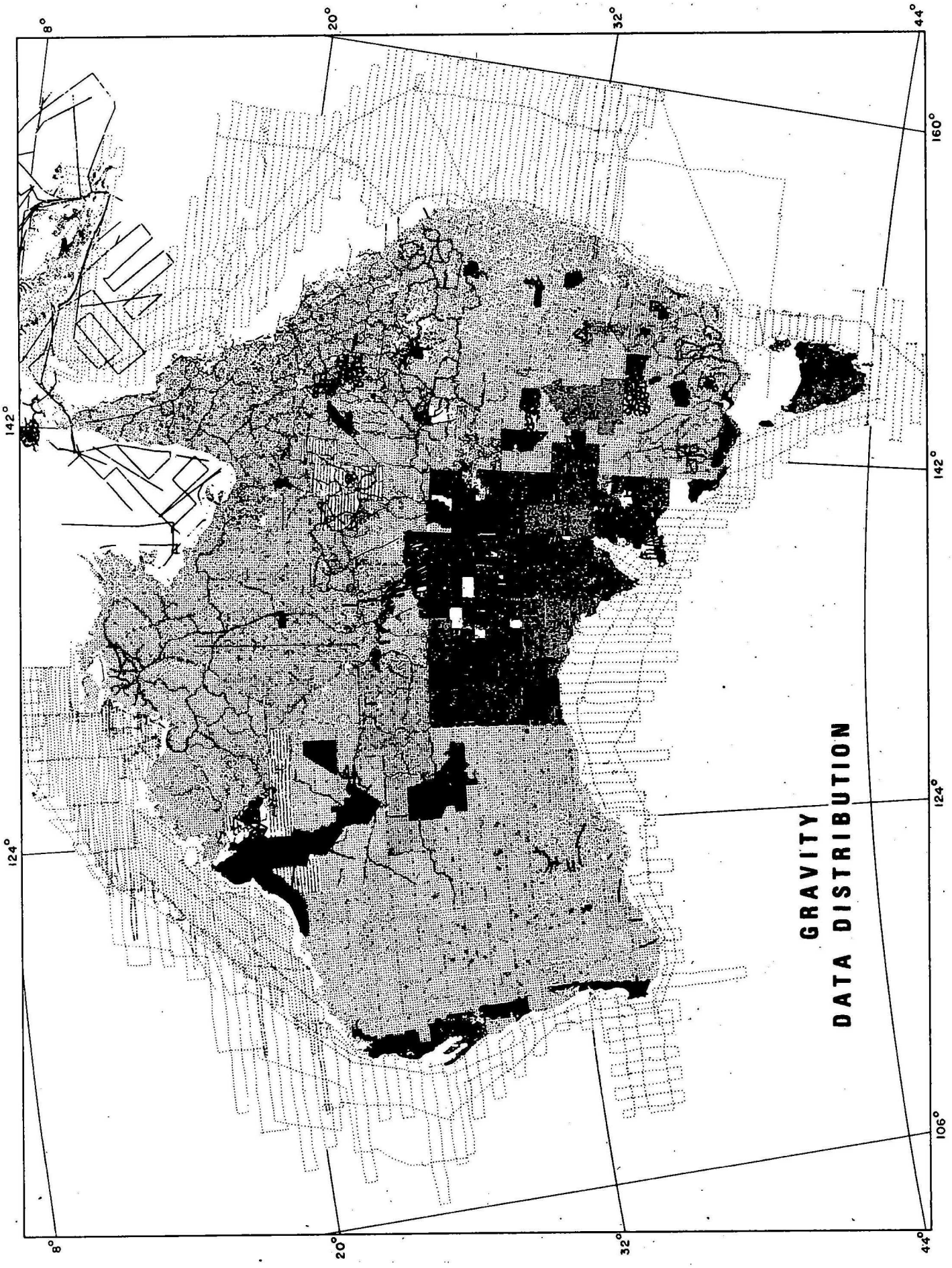
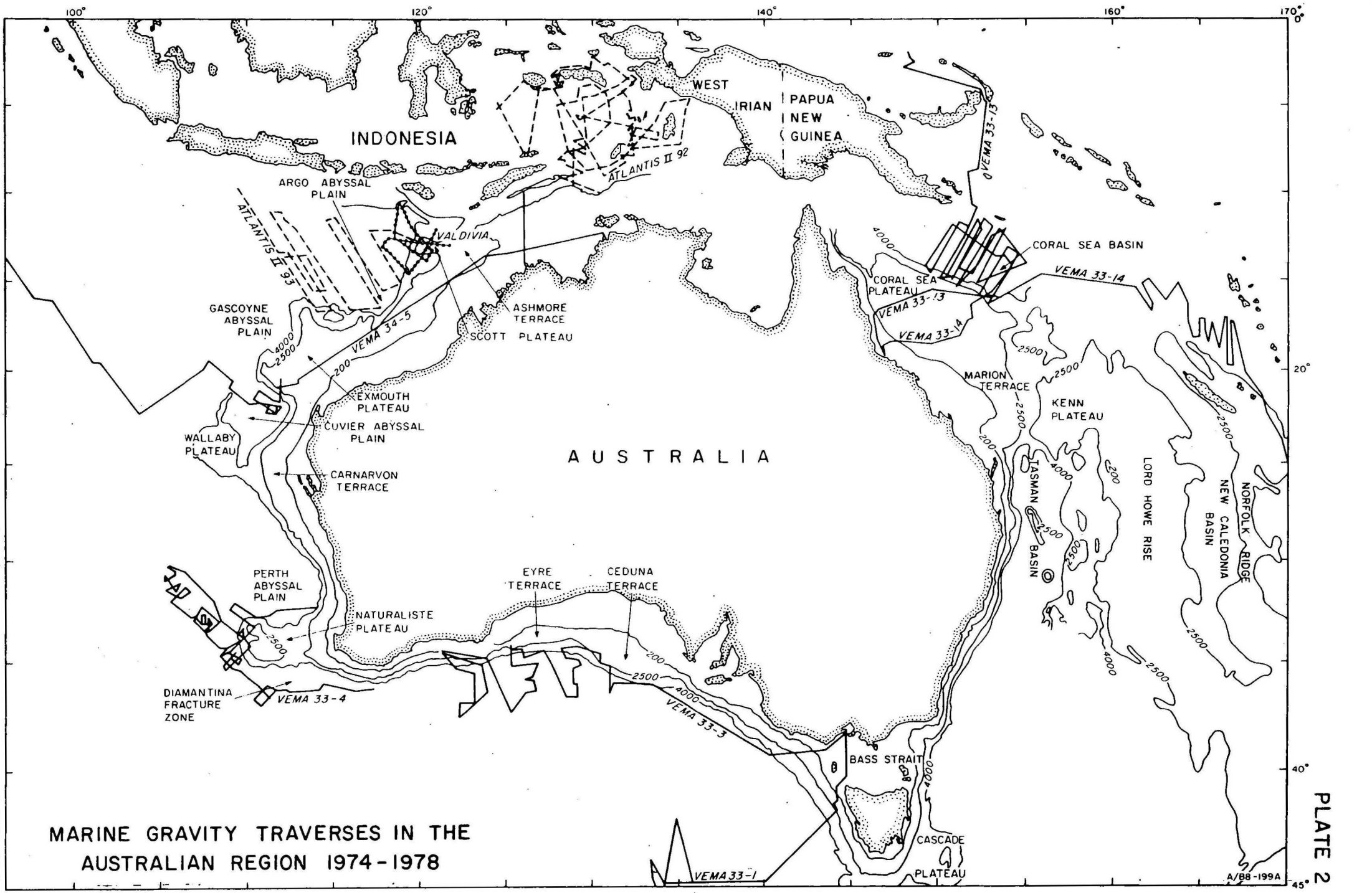
PLATE I



DISTRIBUTION OF GRAVITY DATA ON MAGNETIC TAPE AS AT 1976

Record No. 1978/76

A/B2-143A

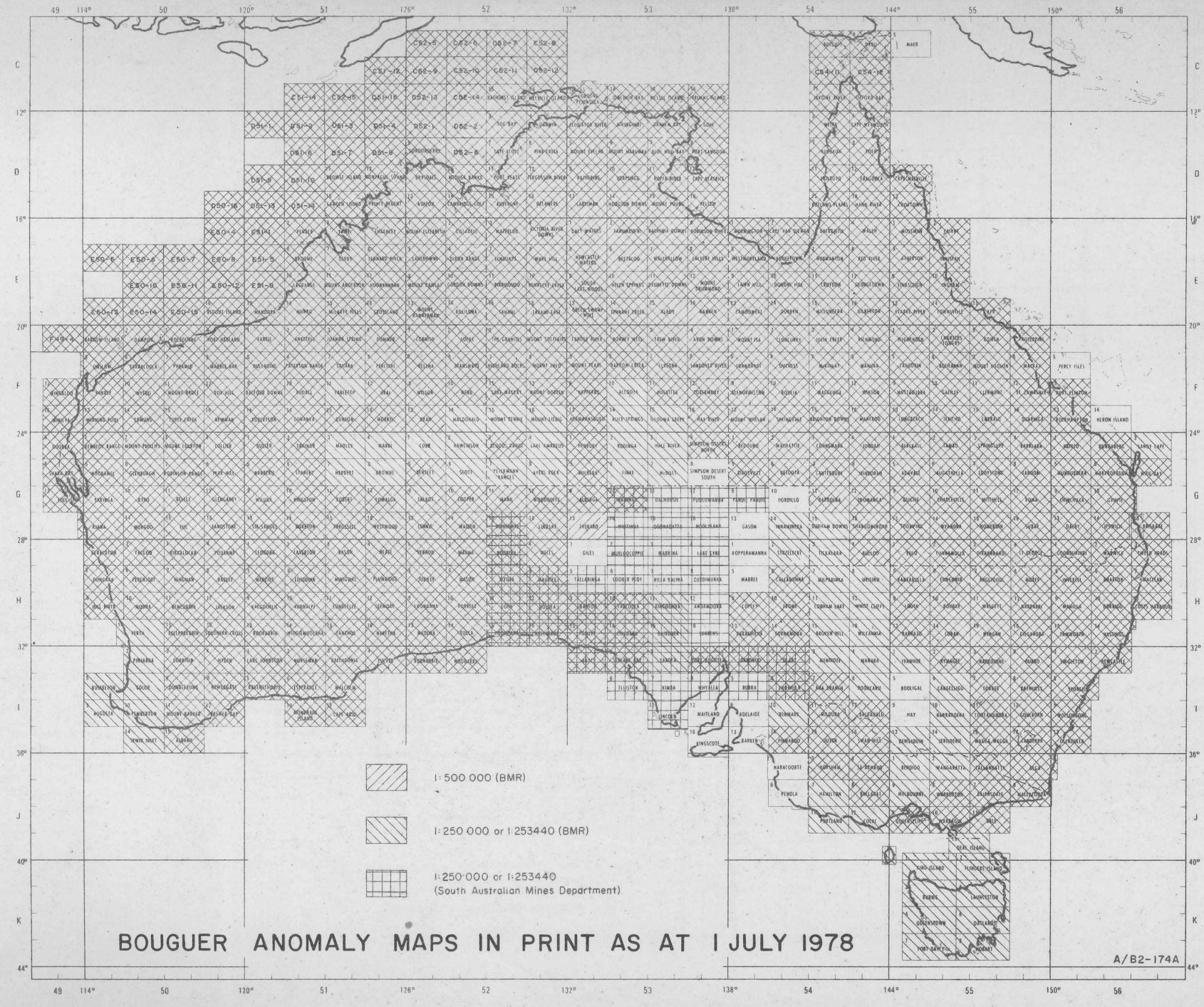


MARINE GRAVITY TRAVERSES IN THE AUSTRALIAN REGION 1974-1978

PLATE 2

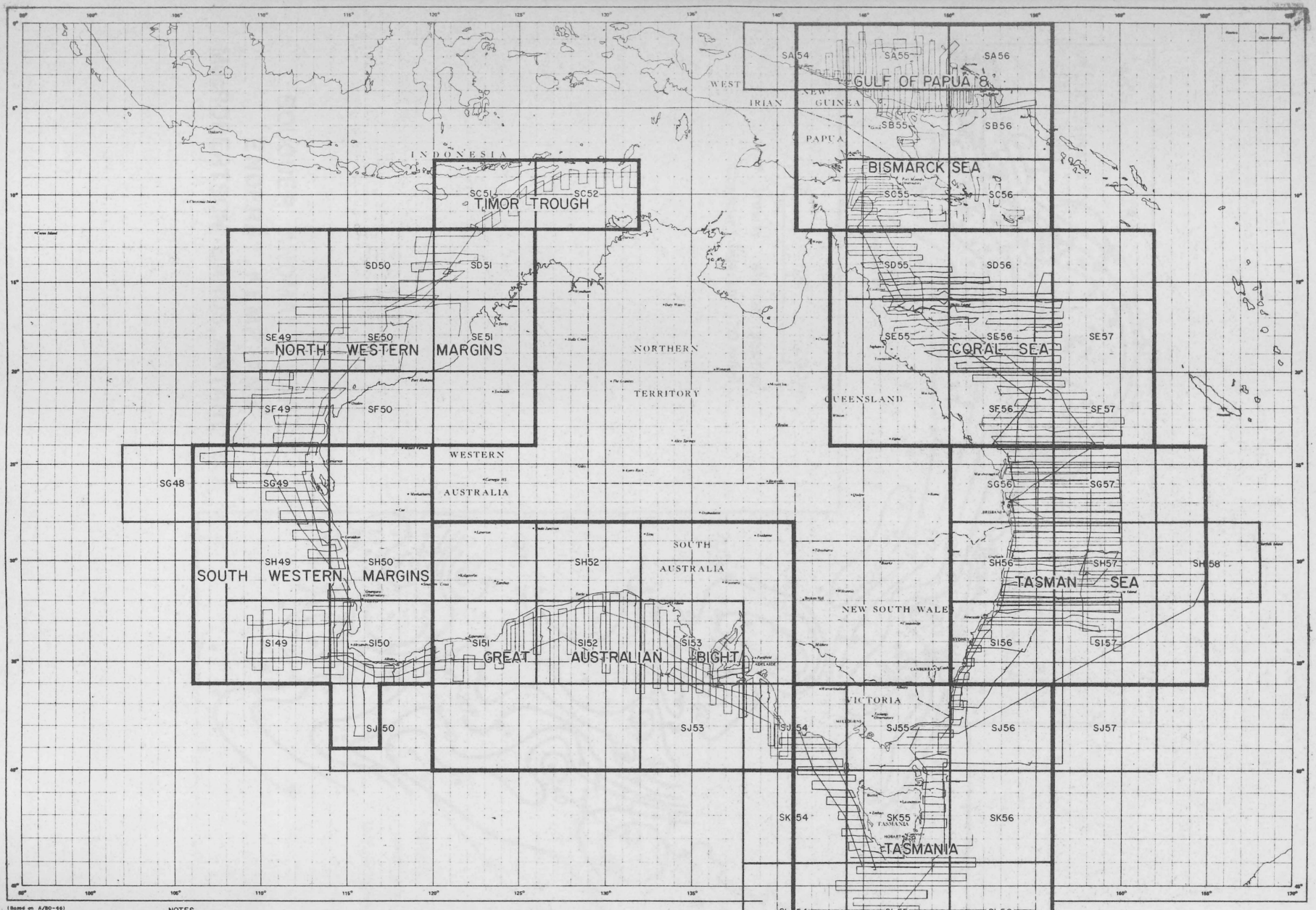
Record No 1978/76

A/88-199A



BOUGUER ANOMALY MAPS IN PRINT AS AT 1 JULY 1978

Record No. 1974/114, 1978/76



(Based on A/80-46)

NOTES

SCHEMATIC SHIPS TRACK

SH49 1:1 000 000 INTERNATIONAL MAP SHEET (PRELIMINARY SHIPS TRACK MAPS ARE AVAILABLE AT THIS SCALE)

CORAL SEA 1:2 500 000 MAP AREAS (PRELIMINARY COMPUTER-PLOTTED MAPS SHOWING:
a. SHIPS TRACK
b. WATER DEPTH CONTOURS
c. BOUGUER ANOMALY CONTOURS
d. FREE AIR ANOMALY CONTOURS
e. MAGNETIC ANOMALY CONTOURS
ARE AVAILABLE AT THIS SCALE)

BMR MARINE GEOPHYSICAL SURVEYS 1970-1973

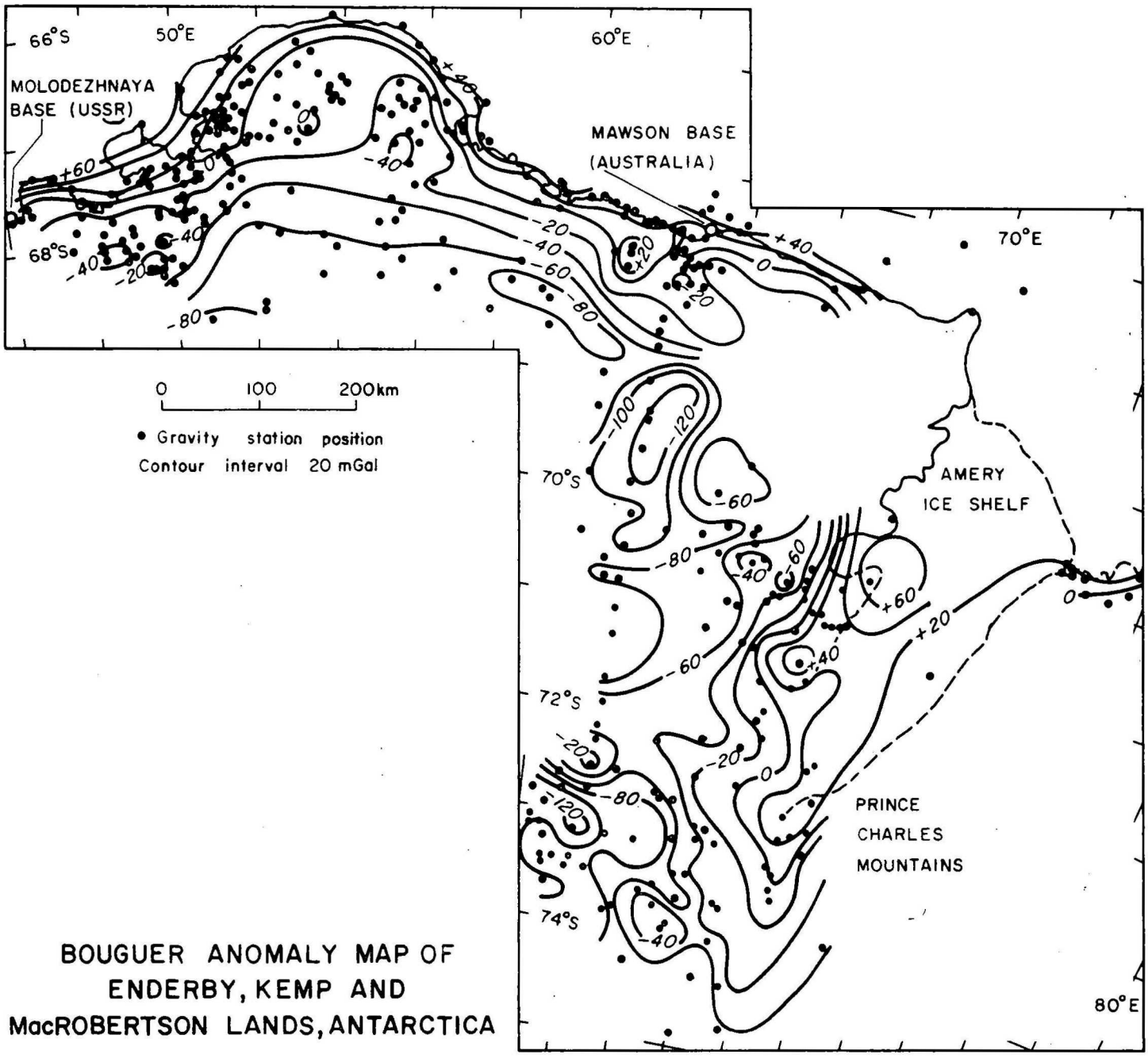
SCHEMATIC TRACK AND INDEX MAP

ALL MAPS AND SEISMIC SECTIONS FOR THESE SURVEYS CAN BE PURCHASED FROM THE COPY SERVICE, GOVERNMENT PRINTER (PRODUCTION), G.P.O. BOX 84, CANBERRA, 2600.
A SEPARATE CIRCULAR ON THE AVAILABILITY OF SEISMIC SECTIONS CAN BE OBTAINED FROM THE DIRECTOR, BUREAU OF MINERAL RESOURCES, P.O. BOX 378, CANBERRA CITY, 2601

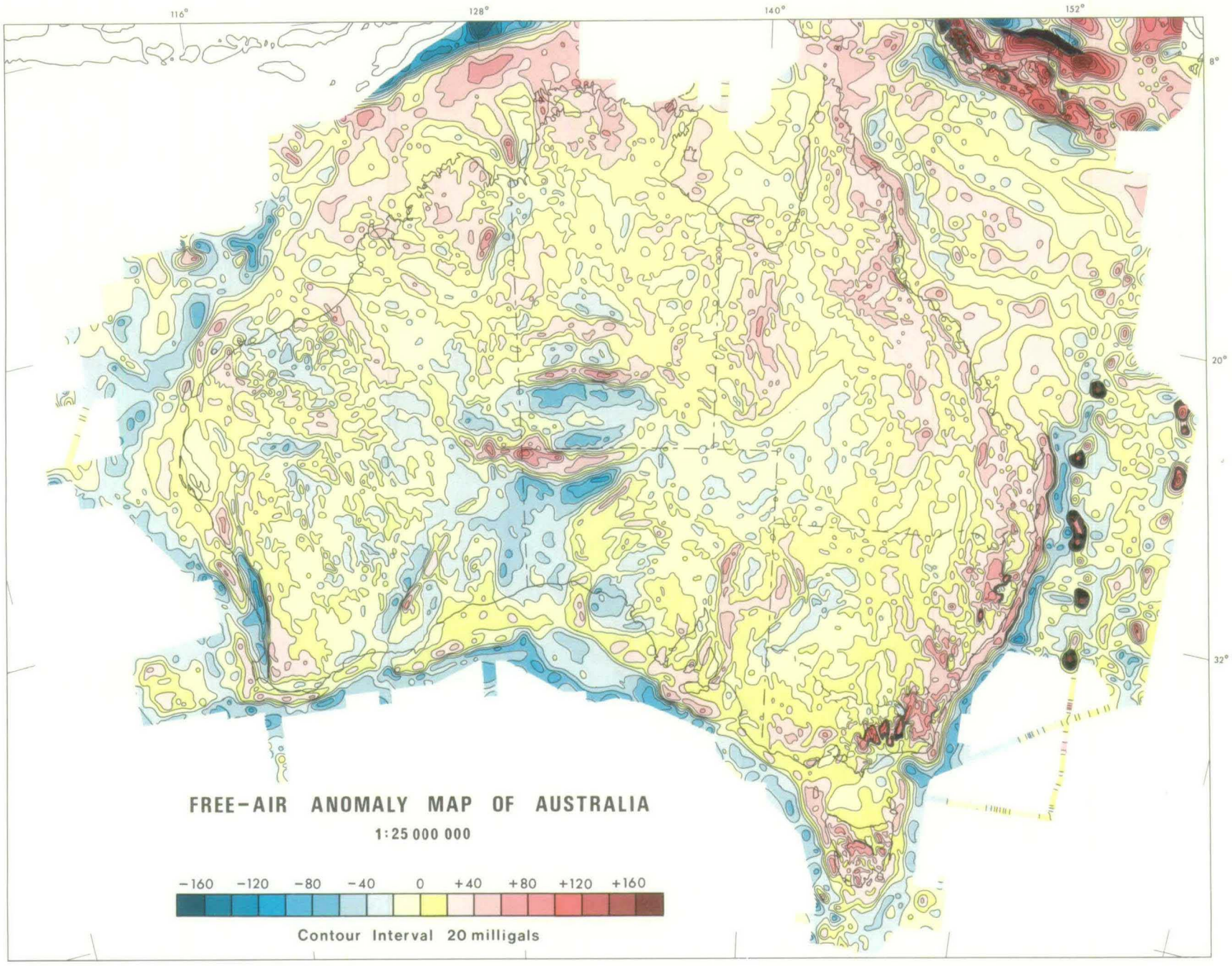
A/88-7-9AR

PLATE 4

PLATE 5



BOUGUER ANOMALY MAP OF ENDERBY, KEMP AND MacROBERTSON LANDS, ANTARCTICA



FREE-AIR ANOMALY MAP OF AUSTRALIA

1:25 000 000

−160 −120 −80 −40 0 +40 +80 +120 +160

Contour Interval 20 milligals

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 Development

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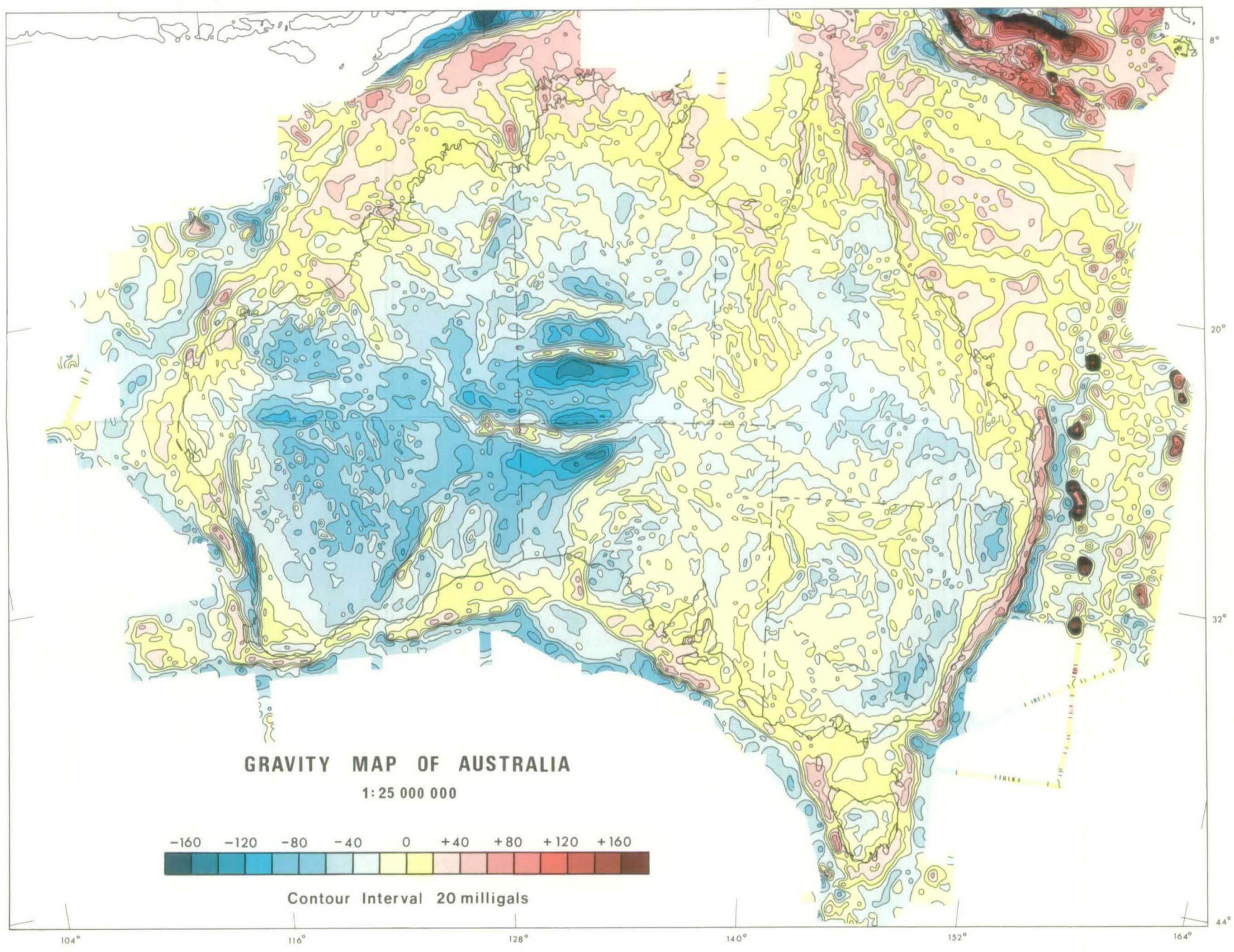
Oil Companies who operated under the Petroleum Search Subsidy Acts
South Australian Mines Department
Tasmania Mines Department
United States Navy
University of New South Wales
University of Tasmania
West Australian Petroleum Pty Ltd



GRAVITY MAP OF AUSTRALIA

1:25 000 000

−160 −120 −80 −40 0 +40 +80 +120 +160

Contour Interval 20 milligals