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DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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RECENT ADVANCES IN GRAVIMETRY FOR PHYSICAL GEODESY IN AUSTRALIA

by

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RECENT ADVANCES IN GRAVIMETRY FOR PHYSICAL GEODESY IN AUSTRALIA*

Submitted by the Government of Australia

by

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* Prepared by the Bureau of Mineral Resources, Geology and Geophysics

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1. INTRODUCTION

Gravimetric solutions for the geoid have been combined with astro-geodetic determinations to give a geoid map over the Australian region (Mather et al., 1971). These solutions have been made possible by the existing extensive gravity coverage controlled by the Australian National Gravity Network.

Improvements to the gravimetric solutions will result from current activities of the Commonwealth Bureau of Mineral Resources, Geology and Geophysics (BMR) directed towards strengthening of the control network, more accurate integration of existing data, and extension of the gravity coverage. BMR gratefully acknowledges the assistance of outside organisations; several overseas institutions have made valuable international gravity ties to Australia, compilations of gravity data by several State Mines Departments and private companies are assisting in this work, and, above all, the project is made feasible by the availability of gravity data throughout Australia from State Mines Departments, universities and exploration companies.

2. INTERNATIONAL DATUM VALUE

Until 1971 the base station for the Australian control network was the first order world gravity station at Melbourne. Adoption of the International Gravity Standardisation Network 1971 to supercede the First Order World Gravity Network, completion of an absolute determination of the gravitational acceleration at Sydney and recent international ties have downgraded the importance of the Melbourne base. The value of gravity at Sydney is now the most accurately known in Australia.

Dooley et al. (1961) recorded the adoption by BMR of 979 979.0 mgal relative to the old Potsdam datum for the acceleration due to gravity at the Australian National Gravity Base, Melbourne. This value had been calculated by Cook (1957) from the results of a Cambridge pendulum tie in 1950-51 between the United Kingdom and Australia and from observations on Worden gravity meters.

Later reassessments of this value (Dooley, 1965; Barlow, 1970) took account of further international pendulum and gravity meter ties. Insufficient evidence was found to warrant changing the adopted value.

A particularly significant international gravity tie to Australia was made during December 1972 and January 1973 following arrangements made by the Soviet Geophysical Committee of the Academy of Sciences of the USSR and by BMR. Six Soviet scientists made observations with 5 sets of OVM pendulum apparatus at Moscow (Ledovo) and Sydney. Moscow has already been accurately tied to Potsdam and this work gave an accurate tie between Sydney and Potsdam (Gusev, 1973).

Although the datum value at Melbourne has been held unchanged since 1957, improved measurements of the Melbourne-Sydney interval have led to successive determinations of the acceleration due to gravity at Sydney as listed in Table 1. The latest Soviet pendulum tie confirms the accuracy of the more recent determinations.

TABLE 1

Determinations of Gravity at Sydney A

(Old Potsdam Datum)

1.	Adopted by BMR 1957	979 684.9	mGal
2.	BMR Revised Value 1962	979 685.7	mGal
3.	BMR May 1965 Isogal Value	979 685.74	mGal
4.	BMR Provisional Value 1970	979 685.80	mGal
5.	OVM Pendulum Value	979 685.79 ± 0.06	mGal

An absolute determination of the gravitational acceleration at Sydney was completed by the National Standards Laboratory of the Commonwealth Scientific and Industrial Research Organisation in 1970. The method was free rise and fall of a metal corner reflector through planes defined interferometrically. A value of 979 672.0 ± 0.20 mGal was obtained for Sydney A. (Bell et al., 1973). Using the Soviet pendulum tie Sydney-Moscow, the appropriate correction to the old Potsdam datum given by the above determination is 13.79 ± 0.21 mGal which is in excellent agreement with other modern data.

The adoption of the International Gravity Standardisation Network 1971 (IGSN 71) by the International Association of Geodesy results in less importance being attached to the particular value of gravity assigned to just one datum point in the network. Nevertheless the absolute determination of gravity at Sydney ensures its importance as one of the key stations in the IGSN 71 which adopts a value of 979 671.85 mGal for Sydney A.

3. DETERMINATION OF SCALE

The precise determination of the calibration factors of all gravity meters to a common scale is of the utmost importance in the establishment of networks and the compilation of data from various surveys. The establishment of Australian calibration standards which are compatible with international milligal standards poses many difficulties. Measurements by BMR over the past few years and by a joint Australian-Soviet survey party this year are expected to resolve many of these difficulties.

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The first Australian gravity standard was set by the results (with magnetic correction) of the 1950-51 Cambridge pendulum measurements at 59 stations in Australia (Dooley et al., 1961). Gravity meter measurements between five of these pendulum stations in south east Australia were used to calibrate the meters in terms of the Cambridge pendulum milligal, but only over a limited range of observed gravity. The meters were then used to measure the gravity interval over a gravity meter calibration range of about 50 mGal near Melbourne. An essential by-product of the 1962 adjustment of the Australian gravity network was revision of the gravity interval over this calibration range in the light of more extensive comparisons between gravity meter and pendulum intervals (Dooley, 1965). Subsequent work has indicated that the revised interval is compatible with other calibration standards to about 1 part in 3000 and this short range calibration standard has been retained unchanged up to the present.

Eight other short gravity meter calibration ranges have been established near various cities throughout Australia (Barlow, 1967). The intervals on these ranges have been measured in terms of the Melbourne range to facilitate the calibration of all gravity meters against a common standard.

A chain of gravity base stations at cities along the east coast of Australia was selected to form the Australian Calibration Line (ACL) to facilitate calibration of geodetic gravity meters over substantial gravity intervals. As initially proposed the ACL ran from Melbourne to Cairns spanning a gravity interval of some 1500 mGal. The line was later extended to Hobart in the south and to Laiagam in the north so that it now spans nearly 3000 mGal (see Plate 2).

The 1962 values at Melbourne, Cairns and Darwin were considered to be particularly reliable, being based on several pendulum measurements as well as gravity meter ties. The mean milligal defined by the average given by the two intervals Melbourne-Cairns and Melbourne-Darwin was accepted as the "mean Australian milligal".

Subsequent comparisons between gravity meter measurements on the national network with results of the 1950-51 pendulum measurements show that the mean Australian milligal, as defined above, is compatible with the mean milligal defined by 47 of the 59 Cambridge pendulum measurements.

In 1965 the United States Air Force (USAF) made international gravity measurements along the Western Pacific Calibration Line (WPCL) (see Plate 1) and, in co-operation with BMR, also made measurements between Cairns and Melbourne along the ACL (Whalen, 1966; Shirley, 1966). Values for the intervals Melbourne-Darwin and Melbourne-Cairns were calculated using the manufacturer's calibration tables. The mean intervals from the five La Coste and Romberg gravity meters required a correction factor of 0.9997 to give the best fit to the intervals expressed in mean Australian milligals. Intervals for the ACL were then determined from the USAF/BMR observations using this correction factor. The USAF results on the WPCL and ACL are a major contribution to the IGSN 71 and enable a comparison to be made between the milligal standards used on the WPCL and ACL.

In 1969 BMR made observations along the WPCL and Japanese Calibration Lines (see Plate 1) using four La Coste and Romberg geodetic gravity meters (Cooke, 1973). In 1970 three of these meters were used over the full length of the ACL (see Plate 2) together with six quartz-type exploration gravity meters (4 Wordens and 2 Scintrex CG2)(op.cit.). The fourth La Coste meter previously used on the WPCL was used over the ACL in 1972. These measurements by BMR supplement the earlier work by USAF and similar measurements by the Dominion Observatory of Canada. The BMR measurements indicate that the scales of the Japanese and Australian calibration lines are very similar. Gravity meter ties between Japan and Australia together with pendulum ties by the Geographical Survey Institute of Japan have already shown that the national datums are compatible.

A joint Australian-Soviet project to refine gravity values along the ACL during 1973 was arranged by the Soviet Geophysical Committee of the Academy of Sciences of the USSR and by BMR. The objectives of this work were to measure the intervals along the ACL using a group of Soviet geodetic gravity meters type GAG2 and to compare the results of these meters with results from La Coste and Romberg geodetic gravity meters and Worden exploration meters. Because of the inherently lower accuracy at single stations of all sets of pendulum apparatus previously used in Australia, heavy reliance has been placed on the results from groups of geodetic La Coste and Romberg gravity meters. The possibility of systematic errors in this type of meter should not be overlooked. The Soviet gravity meters operate on a different principle, having a Worden-type quartz movement which is nulled by tilting the instrument. It is claimed that the results of this instrument are absolute so that it does not require calibration against intervals fixed by absolute or pendulum apparatus. Results obtained in USSR against intervals determined by the Soviet OVM pendulum apparatus give credence to this claim.

The survey party comprised six Soviet personnel making observations on 9 Soviet GAG2 meters and five Australian personnel making observations on 4 La Coste and 5 Worden meters. A chartered DC3 aircraft was used to transport the party between base stations of the ACL, drift control of the type ABAB being obtained for all intervals. During the 7 week period available for this survey it was not possible to observe all stations, eight of which were overflown.

The results of this work are expected to significantly improve the accuracy of the values along the ACL, particularly values for the southern and northern ends of the line.

4. AUSTRALIAN NATIONAL GRAVITY NETWORK

A gravity reference network was established in 1950-51 when the Cambridge pendulums were used to set up 59 base stations throughout the continent (Dooley et al., 1961). In 1962 a comprehensive adjustment of the gravity values of these 59 stations was made taking into account all gravity meter and pendulum ties by both local and overseas observers (Dooley, 1965).

The Australian National Gravity Network (ANGN) was considerably extended and strengthened by a series of surveys mainly in 1964 and 1967. These surveys, now referred to collectively as the "Isogal Project" (Barlow, 1970) established a series of base stations with at least three dissimilar gravity meters at intervals of 150-250 km along 12 east-west lines of approximately equal observed gravity across Australia. Aircraft were used for transport and drift control of the ABAB type was maintained for successive intervals. The east-west traverses are linked by three north-south traverses of which the most easterly is the Australian Calibration Line. All but two of the 1950-51 Cambridge pendulum stations are now included in the new network which is shown in Plate 3.

The design of the ANGN is such that the network as a whole can be readily adjusted to fit any improved values which may be determined for the ACL. It is proposed to adopt shortly revised values for all stations of the ANGN, taking into account the IGSN 71 values and all recent measurements to determine best values for datum and scale. The new values will be expressed in micrometers/second^2.

5. INTEGRATION OF EXISTING DATA

Since 1950 nearly all gravity surveys have been tied to base stations of the ANGN so that compatible observed gravity values can be calculated for virtually all gravity stations in Australia. Similarly nearly all stations have elevations tied to the Australian Height Datum network and horizontal positions known relative to the Australian Geodetic Survey. It is therefore possible to recompute most Australian gravity surveys to modern standards of observed gravity, elevation and horizontal co-ordinates. This work has commenced but will take several years as over 500,000 gravity stations are involved.

Over the last two decades BMR has compiled, without recomputation, all available gravity data in Australia and published these in the form of Bouguer anomaly maps to guide mineral exploration activities and regional structural investigations. Of these maps the best-known are the successive editions of the Gravity Map of Australia at a scale of 1 inch = 40 miles or 1:2, 534,400 which show 5 mGal Bouguer anomaly contours over an increasingly large portion of Australia. The latest edition shows coverage over 90% of the Australian continent.

This map contains many discontinuities which are due to datum shifts in the raw values of observed gravity and similar discrepancies, and in particular, changes in the assumed Bouguer density from area to area. In order to use the gravity data for geodetic purposes Mather et al. (1971) computed mean free air anomalies and found it was necessary to apply approximate corrections for datum shifts, area by area, before the data were sufficiently compatible to give accurate gravimetric solutions for the geoid. The recomputation and integration of existing gravity data will permit more accurate gravimetric solutions.

6. EXTENSION OF EXISTING COVERAGE

Reconnaissance or more detailed gravity surveys now cover 90% of the Australian Continent.

The greatest contribution to the broad reconnaissance coverage of the continent has been the data obtained during successive BMR reconnaissance gravity surveys using helicopter transport. The survey establishes gravity stations with minimum station density of one per 130 km^2 with adequate accuracy for geodetic purposes. BMR will complete the coverage of the remaining areas in the south east quadrant of Australia by the end of 1974.

During 1970-73 BMR obtained reconnaissance marine gravity coverage over the whole of the continental shelf and slope. These data will be available in a form suitable for geodetic purposes by the end of 1974.

The extension of the gravity coverage of Australia will enable more accurate gravimetric solutions to be made over a wider area. The marine data will be particularly useful in minimizing edge effects which have been particularly troublesome in earlier solutions.

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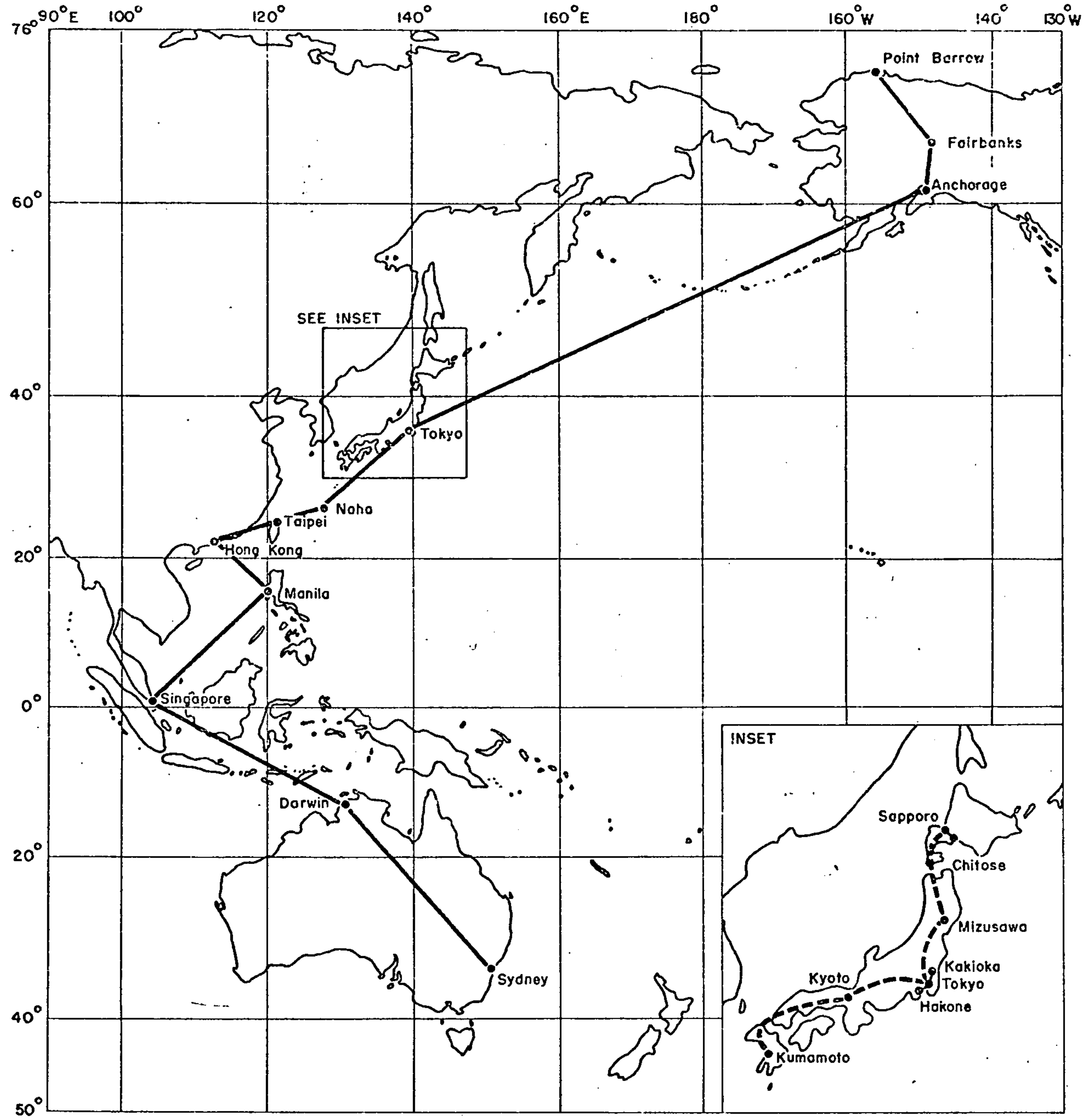
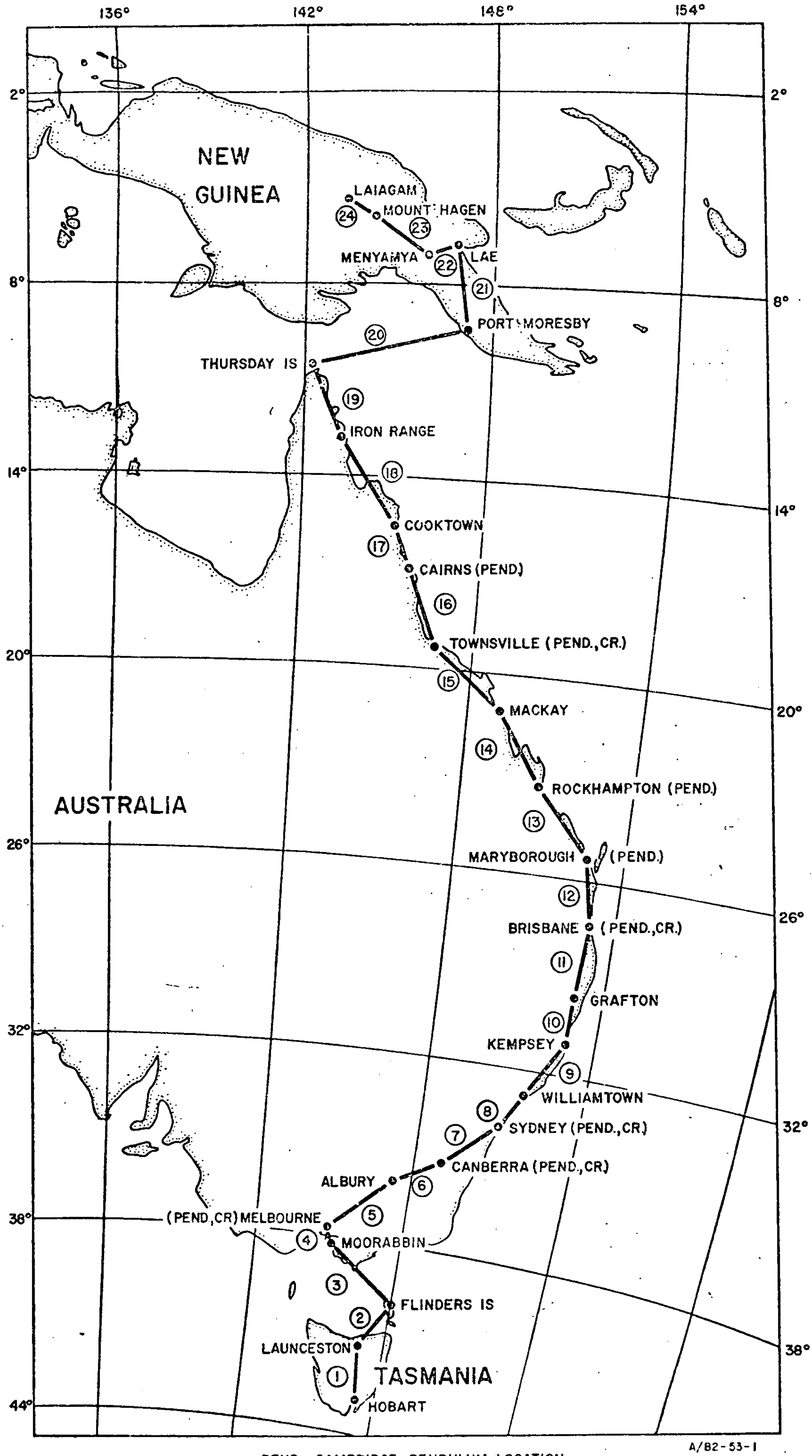


GRAVITY METER MEASUREMENTS

ON THE

WESTERN PACIFIC CALIBRATION LINE, 1969



PEND = CAMBRIDGE PENDULUM LOCATION
CR = LOCATION OF SHORT CALIBRATION RANGE

Locations of Australian Calibration Line stations and key to tie numbers


ISOGAL REGIONAL SURVEY
1964 TO 1970
LEGEND
CAMBRIDGE PENDULUM STATION
ISOGAL PRIMARY STATION
ISOGAL SECONDARY STATION
CALIBRATION RANGE (C.R.)
COMPILED BY GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS
AUSTRALIA
AND
NEW GUINEA
INDIAN OCEAN
TIMOR SEA
ARAFURA SEA
CORAL SEA
TASMAN SEA
GREAT AUSTRALIAN BIGHT
NEW GUINEA
PAPUA
NORTHERN TERRITORY
WESTERN AUSTRALIA
QUEENSLAND
SOUTH AUSTRALIA
NEW SOUTH WALES
VICTORIA
TASMANIA
Momote
Wewak
Rabaul
Mt Hagen
Lae
Daru
Port Moresby
To Honiara
Yirrkala Mission
Darwin
Weipa
Victoria River Downs
Daly Waters
Wyndham
Derby
Halls Creek
Normanton
Cairns
Tennant Creek
Anna Plains
Tanami
Townsville (C.R.)
Cloncurry
Port Hedland
Mount Isa
Hughenden
Mackay
Onslow
Clermont
Alice Springs
Boulia
Longreach
Rockhampton
Mundiwindi
Giles
Birdsville
Carnarvon
Maryborough
Warburton Range Mission
Oodnadatta
Quilpie
Roma
Wiluna
Brisbane (C.R.)
Mount Magnet
Laverton
Tibooburra
Geraldton
Forrest
Walgett
Kalgoorlie
Leigh Creek
Woomera
Armidale
Watheroo
Eucla
Ceduna
Merredin
Cobar
Broken Hill
Whyalla
Perth (C.R.)
Parkes
Esperance
Mildura
Hay
Sydney (C.R)
Adelaide (C.R.)
Wagga Wagga
Albany
Canberra (C.R)
Mount Gambier
Melbourne (C.R)
Kallista
Bombala
Yarram
Launceston
Hobart (C.R)