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A COMMON GRAVITY DATUM AND CALIBRATION LINES FOR INDEPENDENT SURVEYS IN AUSTRALIA

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by

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In interpreting the results of gravity surveys in a potential oil-bearing area, it is useful to have a gravity anomaly map of a region much larger than that of immediate interest. Such a map need not have the same station density, nor need it be as accurate as the detailed map to be interpreted in terms of structural targets for seismic or drilling. The regional gravity map is helpful in outlining the main sedimentary basins and their relations to each other and to major geological features of the continent. It can also help the interpreter to decide on the broader regional trends in gravity, which must be separated from the relatively local anomalies before the latter can be interpreted satisfactorily.

One of the objectives of the Bureau of Mineral Resources is to prepare such regional maps on the basis of all available gravity data, and ultimately to combine these into a complete gravity anomaly map of Australia. The Bureau is able to prepare such a map not only from its own survey results, but also from surveys conducted under the Petroleum Subsidy Search Act, and from data which have been generously supplied by State Mines Departments, Universities, and exploration companies from unsubsidized surveys.

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In order to combine these results into one map it is necessary to have a reference netwrok of reliable gravity base stations, and to establish means whereby the calibration factors of the various gravity meters used can be referred to a common basis.

It is also desirable that the national networks and calibrations factors used in various countries should be consistent, in order to facilitate large scale regional investigations for geodetic purposes, and studies of crustal structure, isostasy, and internal constitution of the earth. The International Gravimetric Commission of the International Association of Geodesy is concerned with establishing a world network of gravity base stations, and major international calibration lines.

The world datum for gravity measurements is based on an absolute measurement made at Potsdam about 1900. It is now known that the value used for Potsdam is incorrect by about 12 mgal; however the newer determinations of absolute gravity and the ties between them using pendulums or gravity meters are not in good enough agreement to enable a satisfactory new value to be adopted.

As a matter of interest, an absolute determination of gravity is in progress at the National Standards Laboratory in Sydney. In this the rise and fall of a reflecting body will be used; its position will be measured by an optical interferometer.

The First Order World Gravity Network (F.O.W.G.N.) comprises about 30 stations, including Kyoto, Singapore, New Delhi Melbourne and Christchurch. Melbourne is used as the National Gravity Base station for Australian surveys.

Many pendulum and gravity meter connections have been made between Melbourne and other first order stations since 1950. These include measurements by University of Wisconsin, Expeditions Polaires Francaises, University of California Los Angeles, Cambridge University, Geographical Survey Institute of Japan, Australian Bureau of Mineral Resources, and more recently the U.S. Navy "Project Magnet" planes and the U.S. Air Force. Cook (1957) determined an adjusted value for the difference Cambridge to Melbourne, which gives g = 979.9790 gal at Melbourne. This measurement appears to be reasonably consistent with later measurements, and this value is still used, but may be subject to revision when an official adjustment is made of the F.O.W.G.N.

Four calibration lines are planned, one through Europe and Africa, one in America, one through Central Asia, and one along the western margin of the Pacific Ocean. The European line is the most advanced and is nearing a stage where definitive values can be adopted. The Western Pacific line is proposed through Fairbanks, Anchorage, Tokyo, Naha, Taipei, Hong Kong, Bangkok, Longkhla, Kuala Lumpur, Singapore, Djakarta, Darwin, Sydney, Melbourne, with a branch through Manila. Measurements have begun only recently along this line, and it may be some years before it can be finalized.

AUSTRALIAN GRAVITY REFERENCE NETWORKS

The first attempt to establish a gravity reference network throughout Australia was made in 1950-51, in which 59 stations were established, more or less evenly distributed throughout the continent, with the Cambridge pendulums (Dooley et al, 1961). However in recent years it became increasingly apparent that there were many discrepancies between the various stations of this survey and it was felt that steps were necessary to establish the values more accurately. Between 1950 and 1959 many visits were made by overseas observers, principally from the University of Wisconsin, with both gravity meters and pendulums, and a large number of readings was made at several stations distributed well in latitude throughout Australia. In 1962 an adjustment was made of the gravity values at the original pendulum stations using all available ties by overseas and also by local observers; the adjustments were made at the original pendulum stations because these had been used for some time for tying local surveys. The available information is shown on Plates 1, 2 and 3. Plate 1 shows the original 59 pendulum stations and also ties with pendulums which have been made between them by observers since 1951. Plate 2 shows the ties which have been made with gravity meters by overseas observers between these stations. Plate 3 shows ties which have been made by local observers, principally the Bureau of Mineral Resources. Although many companies and other authorities have done gravity surveys, few of these have been carried out on such a scale or under suitable conditions for establishing ties between pendulum stations that could be used in adjusting the network.

The local work includes a survey which was carried out in 1960-61 by the Bureau of Mineral Resources with the special intention of making ties between fifteen pendulum stations in the eastern states (Flavelle, 1965). It was originally intended to make an adjustment after carrying out this survey. However, loop closures showed that the desired accuracy was not obtained on this survey, and the more comprehensive readjustment was undertaken. Measurements by observers from Wisconsin University, Expeditions Polaires Francaises, University of California Los Angeles, and the Geographical Survey Institute of Japan have also been used.

The method used was to ascribe gravity values to all stations visited during a survey on some arbitrary datum. The datum was then adjusted so that the average departure of these values from the pendulum values was zero. (This procedure was necessary because all surveys did not have a common datum). All the gravity values at each station were then averaged to give an approximate value of gravity for the station. The correlation of observed values for each survey with the corresponding average values was calculated to determine a calibration factor adjustment where necessary. Each survey (or in some cases a group of surveys) was then assigned a weight according to its R.M.S. departure of observed values from average values. A second approximation was then obtained, using the new calibration factors, and calculating a weighted average for each station. The calibration factors and weights were re-determined in relation to the second average, and a third approximation was calculated by the same procedure. The changes between the second and third approximations were found to be small enough to indicate that another repetition of the procedure was not warranted.

Estimated standard errors were determined from a consideration of the total weight of all surveys visiting each station, and of the residual departures of observations at each station. These represent errors in the relation of the gravity value at a station to the network as a whole, and not in absolute values. 15 stations have an accuracy of 0.1 mgal, 12 have an accuracy of 0.2 mgal, and 16 have an accuracy of 0.3 mgal. The standard errors in the remaining 14 stations range from 0.4 to 0.7 mgal.

An essential by-product of the adjustment is a revision of the gravity meter calibration factors used by the Bureau. Wherever possible, B.M.R. surveys were related to the Ferntree Gully-Kallista calibration range, using the adopted value of 55.60 mgal. The resulting adjustment necessary for this group of B.M.R. surveys is to increase the calibration factors by 1.6 parts in 1,000 i.e. to apply a correction factor of 1.0016. This figure has a standard deviation of about 0.2 parts per 1,000.

Connections to Christchurch, Singapore and Tokyo were included in the adjustment. Values for these stations relative to the Australian network were determined so as to facilitate readjustment of the network when the first order world gravity network is adjusted by the International Association of Geodesy.

This adjustment has been described in detail by Dooley (1965). As the result of the 1962 adjustment a reasonably accurate chain of stations was established along the east coast of Australia.

As the next phase in establishing an accurate national reference network, a survey known as the "Isogal" survey was carried out in 1964. (Barlow, in preparation). The principle used was to survey a series of lines roughly east-west across Australia with gravity meters, each line following an "isogal", i.e. a line of approximately equal observed gravity values. In this way errors due to uncertain calibration factors in the gravity meters are minimised. Each line was selected so that the gravity values of the stations along it were within small dial range of the gravity meters, that is about 50-60 milligals. A chartered light aircraft was used to transport three gravity meters (sometimes four) and an observer between base stations at intervals of about 100 miles. Gravity meter drift was established by flying each tie with at least two repeats, i.e. in the form ABAB; if satisfactory results were not obtained from the first flight the observer was instructed to make an additional repeat. In general very few additional repeats were necessary. Repeat observations were obtained at each station within 2 or 3 hours. The path covered by the survey and the stations established are shown on Plate 4.

At each base station ties were made to as many existing gravity surveys as possible and additional excentres were established as convenient. The complete survey took about 8 months and included ties to Tasmania. It is proposed that several more east-west traverses in Central and Western Australia will be flown in 1966 in order to complete the network; possibly some north-south traverses in Central and Western Australia will also be flown.

It is believed that this survey is unique of its kind as an attempt to establish systematically a uniform network of base stations over a whole continent.

In early 1965 a visit was made by U.S. Air Force observers carrying 4 geodetic gravity meters, which were read along a chain of stations from Darwin down the east coast of Australia and to New Zealand, and then returning by the same route. An observer from the Bureau of Mineral Resources travelled with this party with a fifth La Coste geodetic gravity meter. Results of these observations have improved the accuracy of the east-coast chain, and these have been combined with the Isogal survey to establish values for the reference stations throughout Australia. Results to date indicate a standard error of 0.1 milligal in the gravity value at a station relative to the basic east west traverse passing through that station. A standard error in the gravity value at a station relative to the network as a whole is expected to be about 0.2 milligals.

Approximately 95% of the gravity surveys in Australia are already tied to the new network and nearly all of the remainder will be tied during 1966.

CALIBRATION OF GRAVITY METERS

During 1960 and 1961, 8 local gravity meter calibration ranges were established throughout Australia by the Bureau of Mineral Resources, each with an interval of 50 to 60 mgal. Gravity intervals of these calibration ranges were determined by using groups of at least three gravity meters calibrated between Ferntree Gully and Kallista in Victoria. The value of the Victorian Range was established in the first place from pendulum stations in Victoria of the Cambridge pendulum survey and was revised as a result of the 1962 adjustment of pendulum stations through Australia. The Ferntree Gully - Kallista Range was replaced by a somewhat more convenient one between Ferntree Gully and Ferny Creek in 1962. The results of the measurements at the stations have indicated the magnitude of variations in calibration factors of the gravity meters used and an estimate of the accuracy of the measurement of each interval has been made. Many small inconsistencies appear to be present, but the accuracy of each range relative to the others is estimated to be ±0.02

milligals or $\pm$ 0.04%. The establishment of these ranges has been described by Barlow (1965), who gives station descriptions, values for each range and details of the measurements.

A new gravity meter calibration range was established near Canberra in 1965, as the Geophysical Branch of the Bureau of Mineral Resources will be transferring to Canberra during 1965. The 9 centres in which gravity meter calibration ranges have now been established are Melbourne, Sydney, Canberra, Brisbane, Adelaide, Perth, Hobart, Alice Springs and Townsville. Measurements at Australian stations were made by the U.S. Air Force during 1965 using four La Coste-Romberg gravity meters which had been used on the European Calibration Line. The results indicate that the Australian milligal is reasonably consistent with the European milligal.

During the calibration range measurements erratic changes have been detected in the calibration factors of all gravity meters used. These changes do not appear to be correlated with temperature, or internal or external pressure of the gravity meters. Changes of 0.1% have sometimes been observed to occur in periods of less than 1 hour. The effect is being further investigated. A La Coste and Romberg Geodetic Gravity meter appears to have advantages over the quartz type of gravity meter in that the calibration factor is more constant with time; however defects in the screw apparently cause some variations with latitude, and drift tares need to be watched.

CONCLUSION

A stage has now been reached where practically all gravity observations made in Australia can be readily integrated with other observations, thus facilitating preparation of a uniform gravity map. Under the Petroleum Search Subsidy Act arrangements, oil prospecting companies are obliged to calibrate their gravimeters on one of the B.M.R. calibration ranges, and to tie their surveys to a station of the reference network. State Government Surveys and Universities have also willingly co-operated in doing this.

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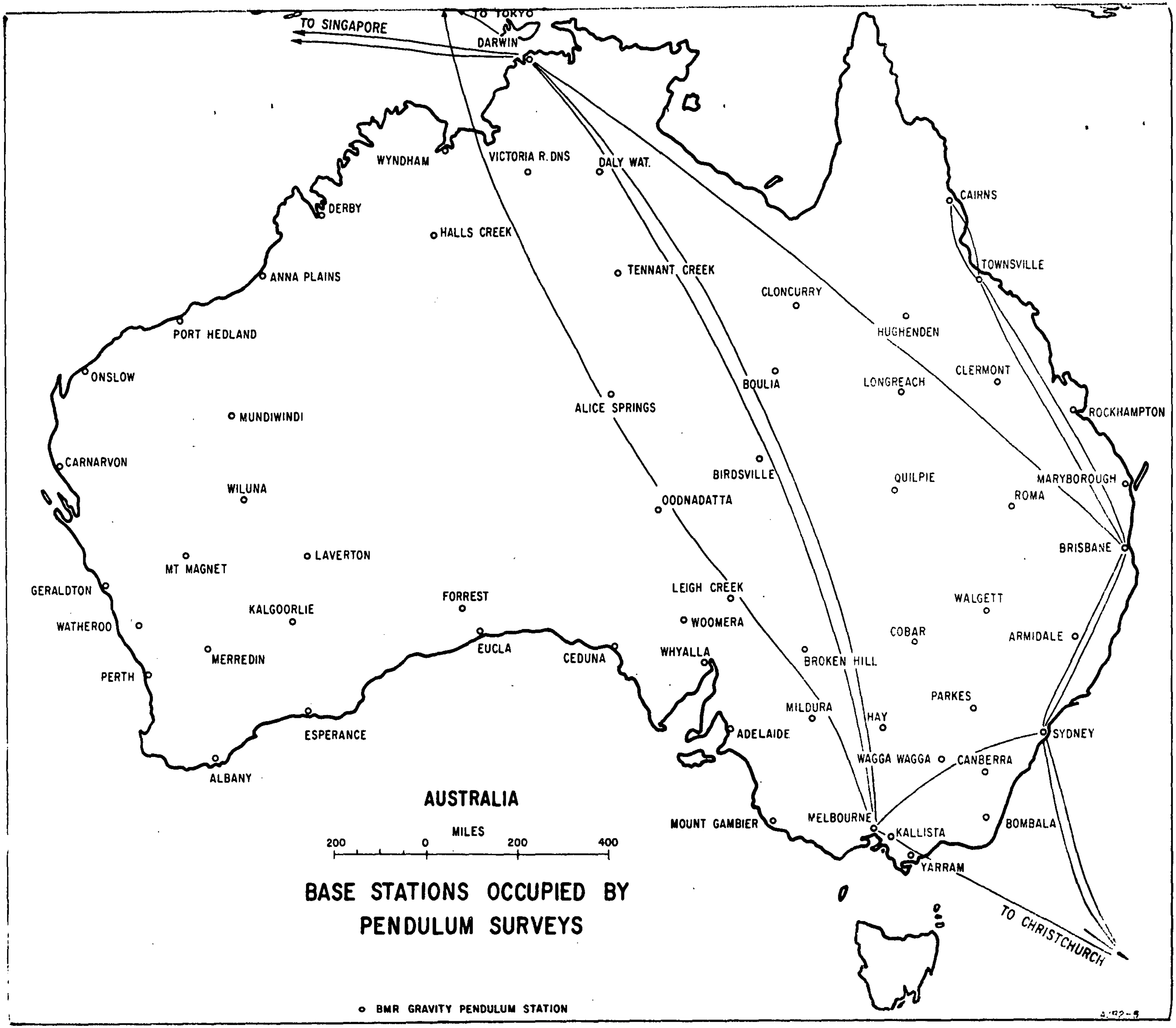
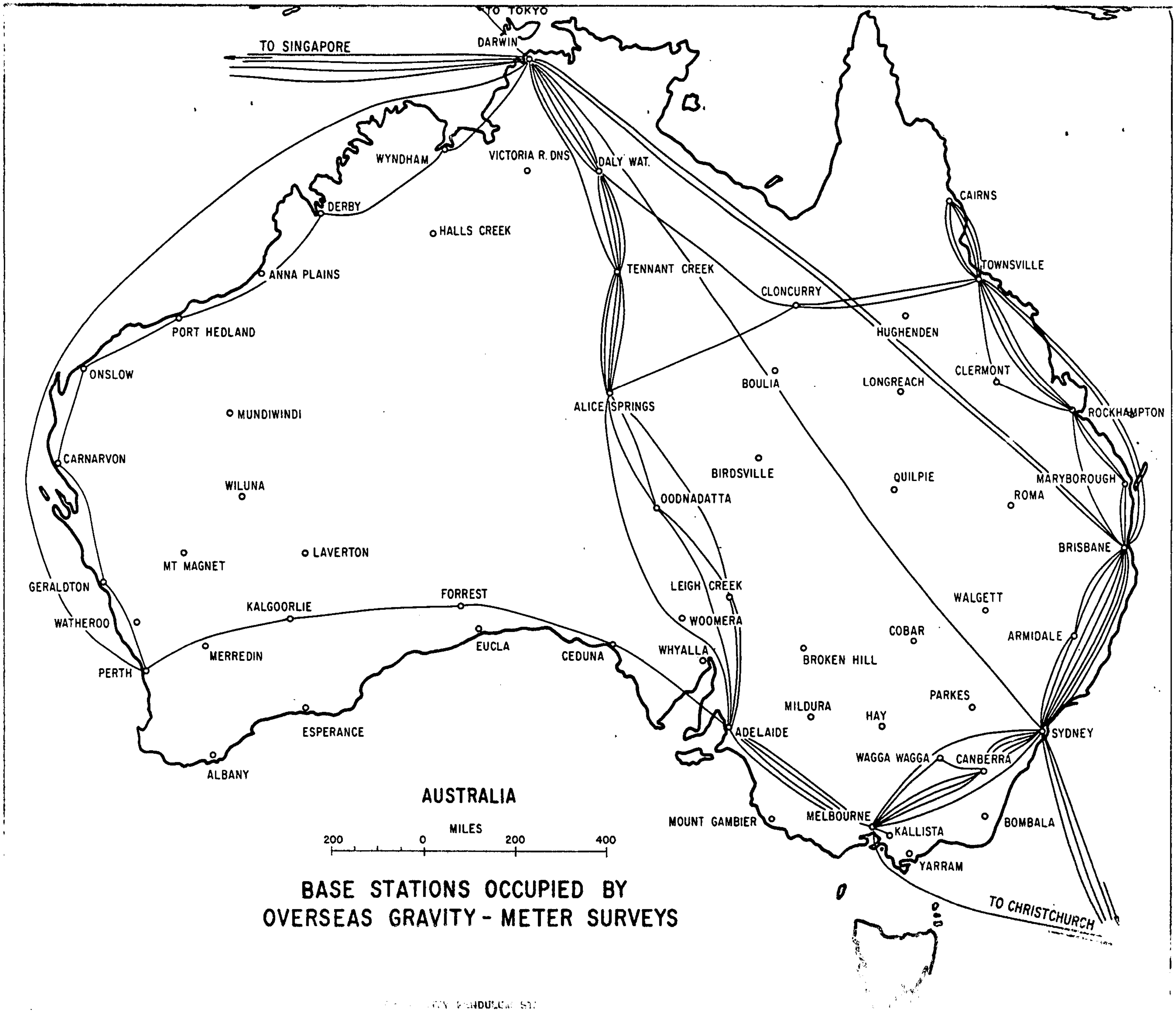


BASE STATIONS OCCUPIED BY PENDULUM SURVEYS



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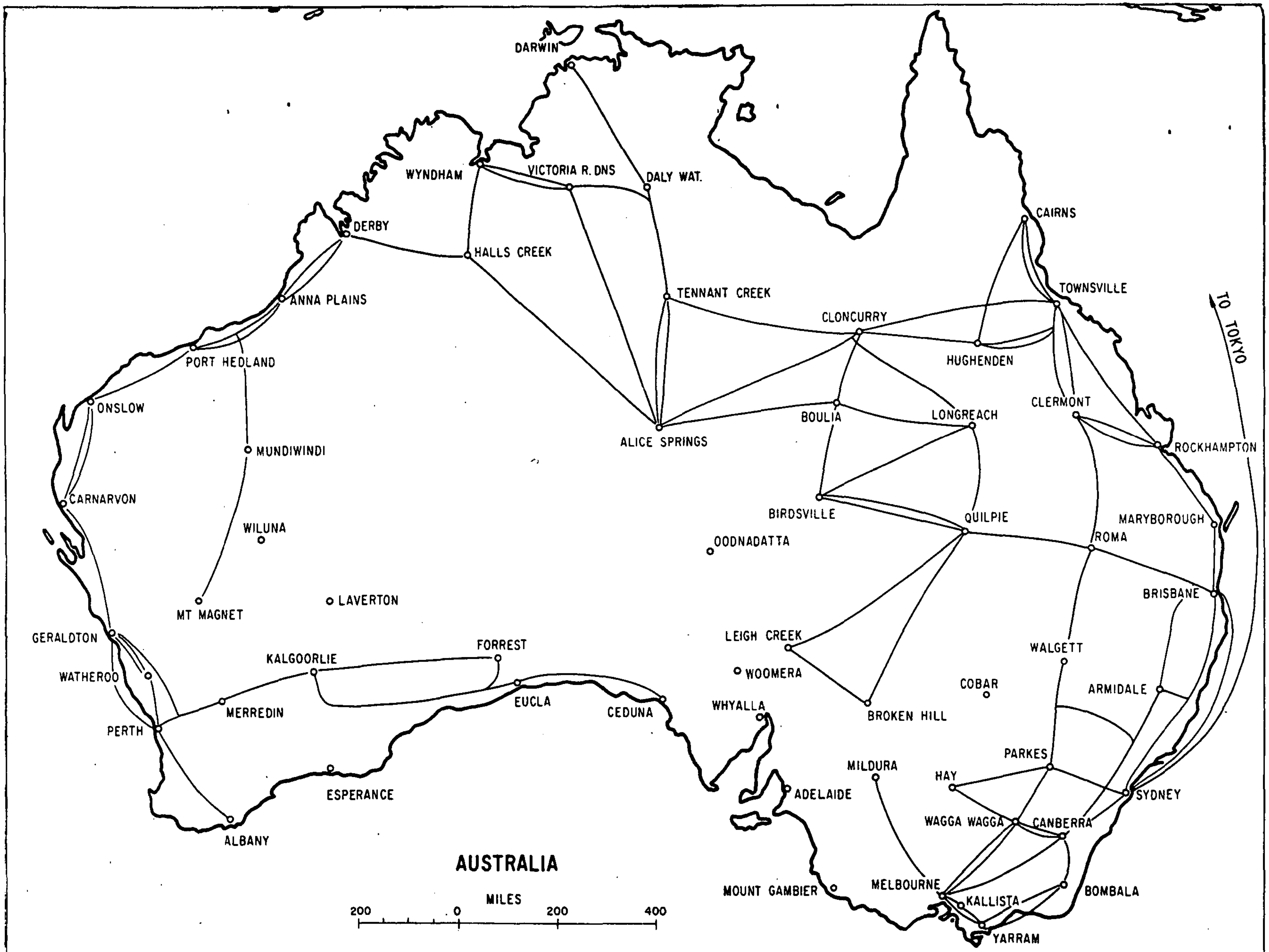

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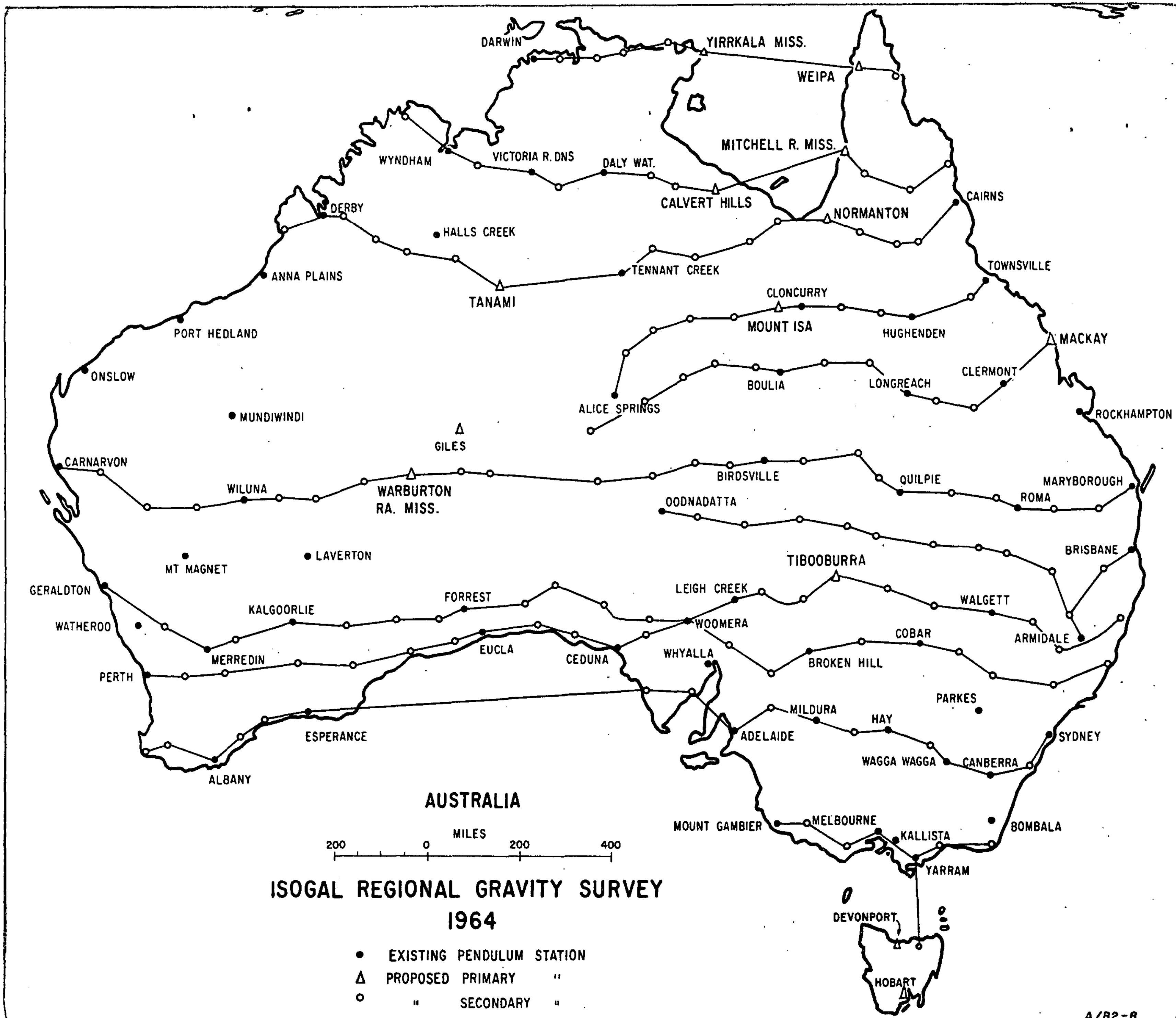

ISOGAL REGIONAL GRAVITY SURVEY 1964