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RECORD No. 1965/19

ESTABLISHMENT OF GRAVITY METER CALIBRATION RANGES IN AUSTRALIA, 1960 - 1961

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SUMMARY

During 1960 and 1961, eight gravity meter calibration ranges were established throughout Australia by the Bureau of Mineral Resources. The gravity intervals of these calibration ranges were determined using groups of gravity meters calibrated between Ferntree Gully and Kallista in Victoria against a gravity interval determined from several pendulum stations observed during 1950 and 1951.

The results of individual determinations have been assessed in terms of the known variation in the calibration factors of the gravity meters and the estimated accuracy of the measurement of the interval. Many inconsistencies are present, but the weighted means of groups of determinations are expected to provide reasonably accurate assessments of the gravity intervals across the ranges.

The Australian calibration system is compared with other calibration standards.

The establishment of gravity meter calibration ranges in all states of Australia permits organisations to achieve a common calibration for their gravity meters, and assists in the integration of independent surveys.

1. INTRODUCTION

Since 1946, gravity surveys have been conducted by the Bureau of Mineral Resources (BMR) in many parts of Australia. Private companies engaged in the search for oil and other minerals, Mines Departments of the various State Governments, Universities, and overseas organisations have also carried out gravity surveys over a period of many years throughout Australia.

The BMR is the Commonwealth authority on gravity investigations in Australia and is responsible for the provision of basic regional gravity data so that the results of independent gravity surveys can be integrated to form composite gravity maps over extensive areas for use in regional, geodetic, and sedimentary basin investigations.

A network of 59 gravity base stations was established throughout Australia in 1950 and 1951 using the Cambridge pendulums (Dooley et al., 1961). These base stations are used to reduce the individual gravity meter surveys to a common datum.

To facilitate adjustment of closure errors when various gravity meter surveys are tied together, it is also desirable that the meter should be calibrated against a common standard that is consistent with differences in gravity determined from the pendulum observations. Prior to 1960 most gravity meter operators used the calibration factors supplied by the manufacturers, although several local calibration runs were also used. Of these runs, the BMR calibration range between Ferntree Gully and Kallista, Victoria, was the only one whose gravity interval had been related to the pendulum station observations.

In 1960, the BMR decided to establish gravity meter calibration ranges at the various capital cities for the convenience of geophysical operators in the various states. In addition to these six capital cities (Melbourne, Adelaide, Perth, Brisbane, Sydney, and Hobart), two other centres (Alice Springs and Townsville) were also chosen as sites for calibration ranges. Alice Springs was selected because of the oil search activity in that area, which is about 1,000 miles from the nearest capital city, and Townsville was included to serve the northern part of Queensland.

The eight centres at which gravity meter calibration ranges were established are shown in Plate 1.

2. OUTLINE OF SURVEY

The gravity meter calibration ranges in Brisbane, Townsville, Sydney, Adelaide, and Perth were selected and measured in January and February 1960 by the author, who also selected the Melbourne and Alice Springs ranges in July and Ausust 1960. The measurement of the Melbourne calibration range was made by S. Waterlander and G.F. Lonsdale. M.J. Goodspeed made the necessary observations at Alice Springs. The Hobart range was selected and measured by A.J. Flavelle, who also made additional measurements on the Adelaide and Perth ranges. A further determination of the Melbourne calibration range was made by the author in March 1961.

The above measurements were all made using groups of gravity meters, and form the main basis for the determination of the gravity intervals across the ranges. As described in a later section of this Record, it was possible to compare accurately the Melbourne calibration range with the Ferntree Gully/Kallista range. The groups of gravity meters used to measure the interstate ranges were calibrated against either the Ferntree Gully/Kallista range or the Melbourne calibration range several times, both before and after each interstate measurement.

The results of subsequent calibration runs made on the interstate ranges have also been used in determining the gravity intervals across these ranges, but only in those cases where the calibration factors of the gravity meters were determined on the Ferntree Gully/Kallista range or on the Melbourne calibration range several times within a month of the interstate determinations. Gravity meter observations made by various officers of the BMR during the period from January 1960 to June 1962 have been used.

The numbers of determinations made on each range with the various BMR gravity meters are shown in Table 1 (page 3).

3. SELECTION OF CALIBRATION RANGE SITES

The selection of suitable station sites for a gravity meter calibration range should be made in accordance with the following requirements :

(a) The range should be within reasonable driving time of the centre it serves.

(b) The gravity interval between the calibration stations should be between 50 and 60 milligals.

(c) The driving time between stations should be as short as possible.

(d) The station sites should be accessible at all times to officers of private companies as well as government organisations.

(e) The sites should be permanent.

(f) The sites should be easily located and their exact position obvious to a new observer.

(g) The sites should be free from vibration due to heavy traffic and other causes.

(h) It is desirable that the station sites should be sheltered from gusty winds and preferably also from inclement weather.

Many of the above requirements conflict with each other and it is not claimed that the station sites of all ranges are ideally located, although all are considered satisfactory for the purpose for which they were selected.

TABLE 1

Gravity meters used to determine calibration ranges

WW = World-Wide
W = Worden
MW = Master Worden

Calibration range	Gravity meter	Number of determinations	Total number of determinations
Melbourne	WW35	1	
	W61	2	
	W169	2	
	MW548	1	6
Adelaide	W61	3	
	W140	1	
	W260	2	
	MW548	2	8
Perth	W61	3	
	W140	2	
	W260	2	
	MW548	2	9
Alice Springs	WW35	1	
	W61	1	
	W140	4	
	W260	5	
	MW548	3	14
Townsville	WW35	1	
	W61	1	
	W140	1	
	W260	1	4
Brisbane	WW35	3	
	W61	1	
	W140	1	
	W169	3	
	W260	2	
	MW548	2	12
Sydney	WW35	1	
	W61	2	
	W140	2	
	W169	1	6
Hobart	W61	2	
	W260	2	
	MW548	2	6

In order to obtain the required gravity interval, it was usually necessary to position the range on the side of a hill and to select station sites having a difference in altitude of about 800 ft. Exceptions to this general rule occur at Alice Springs and Perth, where the gravity intervals are the result of steep gravity gradients in these areas. It is interesting that the higher of the two calibration stations of the Perth range has the greater observed gravity value.

A brief description of the station sites of the various ranges is given in Appendix B and location diagrams are given in Plates 2 to 9.

4. DETERMINATION OF GRAVITY INTERVALS

The gravity intervals across the various gravity meter calibration ranges have been determined from measurements made with BMR gravity meters calibrated against a standard gravity interval between Ferntree Gully and Kallista in Victoria. This standard interval was originally determined from pendulum observations made on the Australian gravity network and has been adjusted in accordance with the revised values of the pendulum stations (Dooley, 1962). The methods of determining the gravity intervals across the various calibration ranges are described below.

Ferntree Gully/Kallista

Since 1951, gravity meters used by the BMR have been run between a gravity station at the main gates of Brenock Park (Ferntree Gully) and the BMR pendulum station PS 39 (Kallista). These runs were usually made in order to check the instruments for correct operation and for changes in calibration. However, the results can be used to determine the calibration factors of the gravity meters at the time of these earlier runs from the currently adopted value of the Ferntree Gully/Kallista gravity interval.

In 1957, gravity meter ties were made between the pendulum stations located at Melbourne, Kallista, Mildura, Bombala, and Yarram. The gravity interval between PS1 in Melbourne (National Gravity Base Station) and PS39, Kallista, was determined as 69.9 mgal. A set of gravity meters was used to determine the observed gravity value at the Ferntree Gully station, and the Ferntree Gully/Kallista calibration range was established with a gravity interval provisionally adopted as 55.60 mgal (Dooley 1959). This calibration range was used to calibrate the BMR gravitymeters during the period from 1957 to July 1961, when the Ferntree Gully/Kallista range was replaced by the Melbourne calibration range.

The Australian gravity network was adjusted during 1961, and an essential by-product was the revision of the gravity meter calibration factors used by the BMR. The adjustment of various BMR gravity meter surveys that are tied to more than one pendulum station required that a correction factor of 1.0016 be applied to the calibration factors of the gravity meters. The standard deviation for this correction factor is about 0.0002. The gravity interval across the Ferntree Gully/Kallista range was given a revised value or 55.69 mgal on the basis of this adjustment (Dooley, 1962).

The results of all calibrations made on the Ferntree Gully/ Kallista range have been re-computed using the revised gravity interval prior to determining the gravity intervals on the other calibration ranges.

Melbourne calibration range

In 1960, it was decided to replace the Ferntree Gully/ Kallista range with the present range for the following reasons:

(a) The driving time between the two calibration stations was unnecessarily long.

(b) Some observers had consistently read at the wrong station locations, the exact locations of which were not clearly defined.

(c) A quarry had been brought into operation near the Ferntree Gully site and accurate readings became difficult owing to vibration of the gravity meter beam.

(d) The station sites were not sheltered from inclement weather.

Two new calibration station sites were selected to form the Melbourne calibration range, which does not suffer the defects of the Ferntree Gully/Kallista range.

The determination of the Melbourne calibration range in terms of the accepted gravity interval across the Ferntree Gully/ Kallista range was not difficult. As shown in Plate 2, the four calibration stations forming these two ranges are near to each other and it was possible to take readings on all stations within each drift control loop. The gravity interval across the Melbourne calibration range was then determined from that across the Ferntree Gully/Kallista range using the ratio of the intervals as measured in scale divisions during repeated loops with various gravity meters.

The result is not affected by variations in the calibration factors of the gravity meters used in this determination and, from July 1961, the BMR gravity meters have been calibrated on the Melbourne calibration range.

Interstate calibration ranges

It was originally intended that the gravity interval across each interstate calibration range should be measured by a set of three gravity meters calibrated in Melbourne before and after the interstate measurement.

Discrepancies in the results of these measurements indicated that the calibration factors of the gravity meters, while interstate, were not necessarily the same as those determined in Melbourne immediately before or after the survey. While investigating this problem the results of all calibration runs made in Melbourne were carefully re-assessed. The results of these calibrations (which were made against the same gravity interval) showed that the calibration factor of a gravity meter varies considerably and often changes erratically. These changes are discussed in Appendix A, and are being investigated further.

The gravity intervals across the various interstate calibration ranges were finally determined from the mean results of many separate measurements made with several different gravity meters (see Table 1). An outline of the mathematical treatment of the results of these measurements is given in the next section.

5. COMPUTATION OF GRAVITY INTERVALS ACROSS INTERSTATE RANGES

The gravity intervals across the various interstate ranges were measured using gravity meters calibrated against the Ferntree Gully/ Kallista or Melbourne calibration range.

Because of the variations in the measurements of these ranges the results must be considered provisional. The mathematical treatment given to the measurements is not rigorous, but the lack of knowledge regarding the factors affecting these measurements does not justify the use of more refined techniques at present.

In the discussion, the results of the Melbourne calibrations of a single gravity meter are considered first, then the result of a single interstate measurement, and finally the determination of mean values for the interstate ranges.

Result of Melbourne calibrations of a single gravity meter

Result of a single calibration. Any single calibration is based on the result of a number of readings made alternately at the two calibration stations. A linear drift was assumed between successive readings at the same station and the results were plotted as drift curves at the upper and lower stations.

From a total of n readings, n-2 estimates of the interval in scale divisions (Di) were obtained from groups of three successive readings. Occasionally a point could not be fitted by any reasonable drift curve, presumably because of a reading error or a temporary tare (instantaneous jump in the reading). The estimate based on this point was omitted but those on either side of it were retained. For the remaining estimates a mean value ($\overline{D}$) and maximum probable error (E_D) was determined.

The calibration factor (K) was then obtained from:

$$K = G/\overline{D} \text{ mgal/scale division,}$$

where G is the accepted gravity interval across the calibration range and is expressed in milligals.

A maximum probable error (E_K) was also estimated for the calibration factor.

Graphs of calibration results for the gravity meters. The results of all calibrations for each meter have been plotted chronologically on a graph, which also shows the probable error in each determination as a vertical line. The graph also indicates dates on which the instrument was evacuated and periods during which it was repaired by the manufacturer. The graphs showing the calibration results for the various gravity meters used in this work are given in Plates 10 - 15. The results of determinations over interstate ranges are discussed later in this Record but have been anticipated here; they are also included in Plates 10-15.

Result of a single interstate measurement

Selection of calibration factor. Five expressions relating to the calibration factor of a gravity meter during an interstate measurement were selected after examining the graph of the Melbourne calibrations. These were :

K_A, the 'maximum possible value' (maximum calibration factor ever determined in Melbourne).

K_a, the 'maximum probable value' (maximum calibration factor determined in Melbourne within one or two months of the interstate measurement).

$\overline{K}$, the 'most probable value' (mean of all Melbourne determinations within two or three months of the interstate measurement).

K_b, the 'minimum probable value' (similar to K_a).

K_B, the 'minimum possible value' (similar to K_A).

The 'most probable value' of the calibration factor ($\overline{K}$) was used in the next stage of the computations, and the reciprocal of the spread between 'maximum and minimum probable values' ($K_a - K_b$) was used as a factor in deciding what weight should be given to this particular measurement.

All five values were used in a graphical analysis of the results, as discussed later.

Measurement of interval in scale divisions. Any single measurement of an interstate range was based on the mean result of a large number of readings made alternately at the two stations. From a total of p readings, p-2 estimates of the interval in scale divisions (d) were obtained as at Melbourne. Because of the drift of the meter during the measurement and limitations of reading accuracy, some uncertainty always remained in the estimated interval as measured in scale divisions. Normally, sufficient readings were taken to ensure that this uncertainty was small and, in cases where this was not so, the measurement was rejected. The mean value of the interval as measured in scale divisions ($\overline{d}$) was used in the next stage of the computations, and the reciprocal of the 'maximum probable error' (E_d) was used as a factor in deciding what weight should be given to this particular measurement.

Computation of the interval in milligals. The gravity interval (i) expressed in milligals is given by:

$$i = dK$$

The 'most probable value' for the result of the s th measurement ($_si^*$) is given by:

$$_si^* = {}_s\bar{d} \times {}_s\bar{K}$$

This measurement was allotted a weight $_sw$ given by

$$_sw = \frac{_sm}{(_sK_a - {}_sK_b)\ {}_sE_d},$$

where $_sm$ is the number of Melbourne calibrations used to determine the 'most probable calibration factor' $_sK$ and the 'maximum and minimum probable calibration factors' $_sK_a$ and $_sK_b$.

Determination of mean values for interstate ranges

Mathematical. From the individual measurements ($_si^*$) made on any one range, the mean ($\bar{i}$) and weighted mean ($\bar{I}$) were given by:

$$\bar{i} = \frac{\Sigma_s i^*}{N}$$

$$\bar{I} = \frac{\Sigma_s i^*\ {}_sw}{N\ \Sigma_s w}$$

where N is the number of measurements on that range.

The error in the weighted mean was taken as the standard error (σ) given by:

$$\sigma = \left[\frac{\Sigma\ {}_sw\ ({}_si^* - \bar{i})^2}{(N-1)\quad \Sigma\ {}_sw}\right]^{\frac{1}{2}}$$

The results for the various interstate ranges are given in Table 2.

TABLE 2

Mean values for interstate ranges

Range	N	$\bar{i}$	$\bar{I}$	σ
Adelaide	8	62.612	62.612	± 0.007
Perth	9	53.973	53.975	± 0.009
Alice Springs	14	52.082	52.104	± 0.014
Townsville	4	60.505	60.508	± 0.005
Brisbane	12	58.261	58.255	± 0.011
Sydney	6	58.991	58.995	± 0.016
Hobart	6	54.715	54.712	± 0.014

As shown in Table 2, the weighted mean is within 0.006 mgal of the mean for each range except in the case of Alice Springs, where the difference is 0.022 mgal.

For each range the weighted mean $(\overline{I})$ was accepted as the provisional determination of the gravity interval.

It should be pointed out that the estimate of the standard error itself has an error, which is large if the number of measurements is small. This is particularly so in the case of Townsville, where only four measurements have been made and the standard error is probably much greater than that indicated in Table 2.

Graphical. The results of the individual measurements on each range are summarised graphically in Plates 16 to 22.

The s th measurement is represented by a vertical line running between the values $_s\overline{d}\ _sK_B$ and $_s\overline{d}\ _sK_A$. The values $_s\overline{d}\ _sK_b$, $_s\overline{d}\ _s\overline{K}$, and $_s\overline{d}\ _sK_a$ are shown as intercepts on this line. The line thus represents the 'most probable value' and the uncertainty due to a precise lack of knowledge of calibration factor involved.

The uncertainty in the 'most probable value' due to the possible errors in the measurement of the interval in scale divisions is represented graphically alongside the value $_s\overline{d}\ _s\overline{K}$ by a vertical line extending to $\pm\ _s\overline{K}\ _sE_d$.

The mean result $(\overline{i})$ and the weighted mean $(\overline{I})$ are shown as horizontal lines, or levels, on the graph. It was expected that the mean value level would pass through the various measurements so as to intercept the vertical lines at points between $_s\overline{d}\ K_a$ and $_s\overline{d}\ K_b$, but this was not always so.

It was found that the 'most probable values' $_s\overline{d}\ _s\overline{K}$ were comparatively widely scattered, and for many measurements the mean value for a particular range indicated that the calibration factor lay outside the 'maximum and minimum probable limits' $_sK_a$ and $_sK_b$.

The spreads in the 'most probable values' $_s\overline{d}\ _s\overline{K}$ for the Alice Springs and Brisbane ranges are 0.20 and 0.13 mgal respectively. The spreads obtained for the other ranges are all less than 0.10 mgal.

6. ACCEPTED VALUES OF GRAVITY INTERVALS ACROSS RANGES

The accepted values of the gravity intervals across the various ranges and the standard errors in these accepted intervals are set out in Table 3.

The accepted values are also shown in Plates 2 to 9.

TABLE 3

Accepted values of gravity intervals and probable errors

Calibration range	Accepted value of gravity interval	Standard error
Ferntree Gully/Kallista	55.69	-
Melbourne	53.04	± 0.01
Adelaide	62.61	± 0.01
Perth	53.98	± 0.01
Alice Springs	52.10	± 0.02
Townsville	60.51	± 0.02
Brisbane	58.26	± 0.02
Sydney	58.99	± 0.02
Hobart	54.71	± 0.02

7. COMPARISON OF AUSTRALIAN CALIBRATION STANDARD WITH OTHER STANDARDS

The Australian calibration standard agrees fairly well with overseas standards, although as yet there is not very much information on which to base exact comparisons.

The calibration figures supplied by the manufacturer of the BMR Worden gravity meters are generally 0 to 0.3% higher than those determined by the BMR; the figure supplied with the BMR World-Wide meter is 0.2 to 0.4% higher.

Ties made by various overseas visitors indicate that calibrations made on the Australian system agree fairly well with both the 'Recent American' and '1957 European' systems described by Morelli (1957).

Measurements made on various Australian calibration ranges by observers using La Coste & Romberg geodetic gravity meters are compared in Table 4 with the gravity intervals as determined by the survey described in this Record.

TABLE 4

Comparison of accepted gravity intervals with those measured

by LaCoste & Romberg gravity meters

LaCoste & Romberg Gravity meter G20 - Bureau of Mineral Resources

LaCoste & Romberg Gravity meter G5 - United States Naval Hydrographic Office

LaCoste & Romberg Gravity meter DL1 - Scripps Institute (Expedition Monsoon)

Calibration range	Accepted value (mgal)	LaCoste & Romberg measurements (mgal)		
		G20	G5	DL1
Melbourne	53.04	53.03	53.01	
		53.03		
		53.03		
		53.02		
Adelaide	62.61	62.58		
		62.55		
Perth	53.98			
Alice Springs	52.10	52.21		52.06
		52.19		
		52.20		
		52.21		
Townsville	60.51			60.51
Brisbane	58.26	58.21		
		58.19		
Sydney	58.99	59.00		
Hobart	54.71			

Close agreement was obtained at the Melbourne, Townsville, and Sydney ranges and reasonably close agreement at Adelaide and Brisbane. The discrepancies at Alice Springs cannot be explained at present.

8. CONCLUSIONS AND RECOMMENDATIONS

Gravity meter calibration ranges have been established at eight centres throughout Australia. The gravity intervals of the various ranges have been determined relative to each other to an estimated accuracy of ±0.04% (±0.02 mgal). The standard interval against which these ranges were determined is consistent with the adjusted Australian gravity network.

Some discrepancies exist between the mean gravity intervals determined for various ranges and estimates of the same intervals measured by geodetic (single-dial) instruments. It is recommended that further determinations be made on these ranges after problems regarding variations in the calibration factors of gravity meters have been clarified.

The station sites at the various calibration ranges are considered permanent but it is recommended that arrangements be made to have suitable plaques erected at the various sites to facilitate re-occupations.

The establishment of additional calibration ranges near Darwin, Broome, and Port Moresby would be of assistance to operators carrying out gravity surveys near these centres.

It is recommended that all gravity meters used on future gravity surveys in Australia should be calibrated on one or other of the established ranges to facilitate integration of the results of the various surveys.

9. ACKNOWLEDGEMENTS

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The University of Queensland, which suggested the establishment of an additional range at Townsville and assisted in the selection of suitable sites at Brisbane.

Mines Administration Pty Ltd, which also assisted in the establishment of the range at Brisbane.

The Mines Department of South Australia, which assisted in the establishment of the range at Adelaide.

The University of Tasmania, which assisted in the establishment of the Hobart range.

Trans-Australia Airlines and Ansett-ANA, which assisted in the safe transport of the gravity meters.

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APPENDIX A

Variations in calibration factors of gravity meters

It is known that the calibration factor (or scale value) of a gravity meter is affected by a number of variables, and several overseas organisations have carried out research into this problem.

During the establishment of calibration ranges throughout Australia, the BMR gravity meters were calibrated frequently. The results of a total of 216 separate determinations of the calibration factors of six gravity meters, over the period from March 1954 to June 1962, were investigated while calculating the gravity intervals over the interstate ranges. Unfortunately the variables which are now known to affect the calibration factor were not precisely determined at the time of the observations, but it has been possible to obtain some data relevant to the problem.

Temperature effect

Inghilleri (1959) and Gantar et al (1960) have shown that the calibration factor of a gravity meter increases with temperature. For Worden gravity meters, estimates of the rate of increase range from 0.067 to 0.1% per 10°C. This effect has been confirmed by later workers, e.g. Damrel (1960).

Records of the minimum and maximum ambient temperatures prior to and during some of the BMR calibration runs were obtained from the Bureau of Meteorology. The calibration factors of the gravity meters were apparently unaffected by ambient temperatures differing by more than 20°C, but the effect may have been masked by erratic changes of a greater magnitude.

Ageing effect

Inghilleri (1959) and Saxov (1959) stated that the calibration factor decreases with increasing age of the meter and that, after repairs, the rate of decrease is at first large and then diminishes during the succeeding years. Estimates range from 0.13 to 0.50% per year during the first year, diminishing to 0 to 0.25% per year in succeeding years. Morelli (1957) stated that the rate of decrease was 0.12% per year and constant.

Later research indicates that this ageing effect may, in fact, be due to the gradual increase of pressure within the oscillation chamber of the meter.

Calibration data for six gravity meters have been obtained by the BMR during a period of some years. All of these meters have been evacuated regularly and generally at intervals of about six months. Graphs of the results of the various calibration runs are shown in Plates 10-15, which also indicate the dates on which the meters were evacuated. These graphs provide some evidence to indicate that an ageing effect may in fact occur, even if the meters are regularly evacuated, although the calibration results are fairly widely scattered. The results of some earlier calibrations of the BMR gravity meters indicate that the change in calibration factor over an extended period does not exceed the random variation (Dooley, 1962).

Pressure effect

Damrel (1960) and Gantar et al (1960) have shown that the calibration factor decreases with increasing pressure within the oscillation chamber of the gravity meter. The rate of decrease has been estimated as 0.01 to 0.06% per 10 mmHg pressure.

The results of the BMR calibration runs cannot be used to provide evidence of a rate of decrease of this magnitude. Calibrations carried out by the BMR several days before and after an evacuation generally showed no significant change in the calibration factor, but some results showed decreases of about 0.15% and others increases of the same order (the pressure drop during an evacuation is generally from about 30 to 7 mmHg). A group of five calibrations made on Worden 169, at a time when it is believed that the oscillation chamber was full of air owing to a faulty valve, gave results which are 0.3% low compared with the normal calibration factor obtained for this instrument.

Transport effect

There is some evidence to suggest that the calibration factor is affected by the mode of transport used to convey the gravity meter. Little is known about this effect, but the gravity interval measured between two stations using a helicopter for transport is generally different from that measured using a ground vehicle.

Erratic effects

Erratic changes have been detected in the calibration factor of all gravity meters used by the BMR. On two particular calibration runs, changes of 0.1% and 0.13% have been detected in the calibration factors of the meters concerned. On one occasion the interval across the Melbourne calibration range was measured using Worden 61 and the number of readings was '8 - 7' (i.e. readings were taken alternately at each station, giving a total of eight readings at the first station and a total of seven at the second). The results up to 2 p.m. indicate an interval of 588.0 scale divisions obtained from a '3 - 3' run with negligible drift. Results after 2 p.m. indicate an interval of 588.6 scale divisions obtained from a '4 - 4' run, also with negligible drift. The separate drift curves based on readings at the two stations diverge at 2 p.m. and the calibration factor apparently decreased by 0.1%. On the other occasion, a similar effect was noted with World-Wide gravity meter 35. A larger number of readings were taken, but in this case the drift of the meter was not quite so steady.

Even larger changes in the results of runs made on near-successive days are common, while over a period of two to three months the calibration factor of an instrument may vary by 0.25%. Naturally, the above assessment is based only on calibration runs for which sufficient readings were taken to ensure that the uncertainty in the measured interval due to instrument drift and reading limitations was not more than 0.1 scale divisions. The effect has been detected in all prospecting types of gravity meters used by the BMR.

APPENDIX B

Brief descriptions of calibration range sites

A brief description of the location of each calibration range and station site is given below. Plans showing the locations of the ranges and the exact positions of the stations are shown in Plates 2 to 9.

Melbourne calibration range

Near Upper Ferntree Gully, 18 miles east of Melbourne.

MCS1 In picnic shed, National Park, Upper Ferntree Gully.

MCS2 On verandah of shop near Ferny Creek.

Sydney calibration range

Near the Pacific Highway, ten miles north of Sydney.

SCS1 In picnic shed at Lane Cove National Park.

SCS2 On manhole cover, Illoura Avenue, Wahroonga.

SCS2a On concrete path next to water reservoir, Wahroonga.

Brisbane calibration range

Between Brisbane University, St. Lucia, and Mount Coot-tha, four miles west of Brisbane.

BCS1 Near the rear door of the Geology School, Brisbane University, St. Lucia.

BCS2 At trigonometrical station LD10 at the summit of Mount Coot-tha.

Townsville calibration range

On road to summit of Castle Hill, one mile north of Townsville.

TCS1 On pathway at the Townsville Central State School.

TCS2 At memorial to Captain Towns, Castle Hill Lookout.

Alice Springs calibration range

On Stuart Highway north of Alice Springs.

ASCS1 Next to the milepost, 11 miles north of Alice Springs.

ASCS2 Next to the milepost, 26 miles north of Alice Springs.

Perth calibration range

Between Hazelmere, five miles east of Perth, and Helena Valley.

PCS1 On concrete footpath in front of shop at Hazelmere.

PCS2 On terrace of Red Cross Hall, Helena Valley recreation ground.

PCS2a At entrance to men's toilets, Helena Valley recreation ground.

Adelaide calibration range

Between Kensington Gardens, three miles east of Adelaide, and Nortons Summit.

ACS1 On verandah of Scout Hall, Kensington Gardens Reserve.

ACS2 On verandah of Bill Brown's Scenic Hotel, Nortons Summit.

Hobart calibration range

Between the University and the summit of Mount Nelson, three miles south of Hobart.

HCS1 Near entrance to new Engineering School, Hobart University.

HCS2 On bottom step of entrance to Marine Board Building, Mount Nelson.

GRAVITY METER CALIBRATION RANGES
1960 – 1961

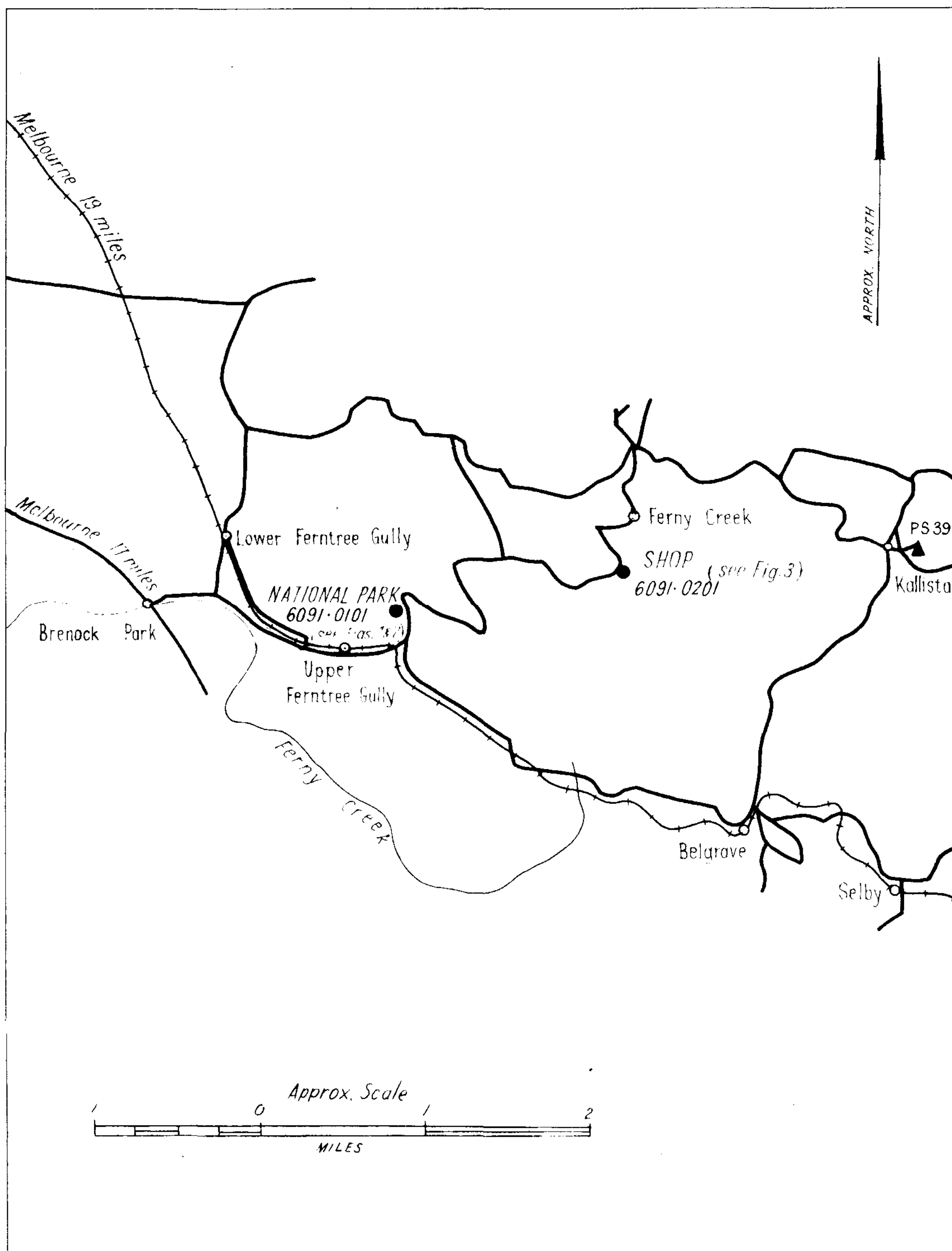


Fig. 1

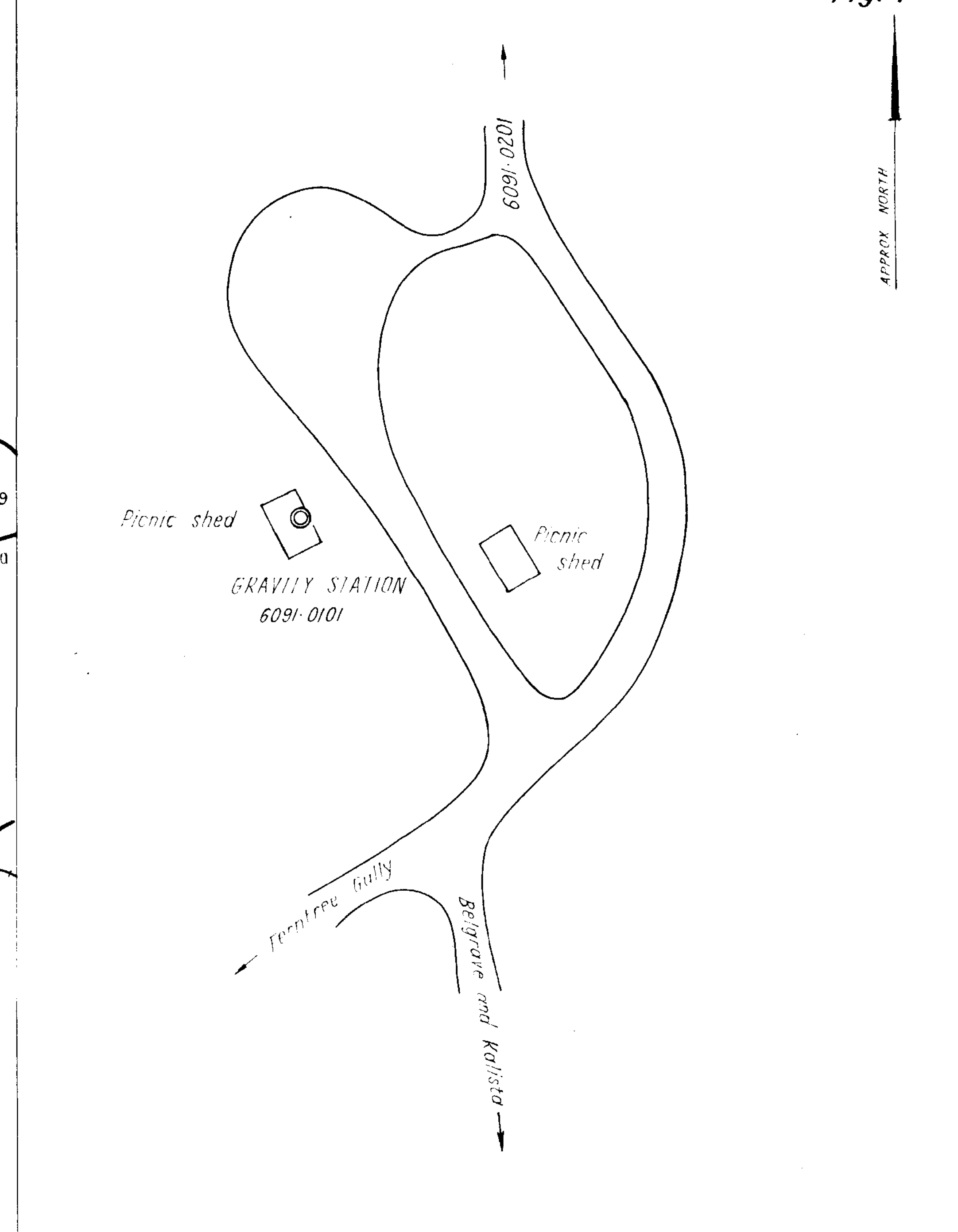


Fig. 2

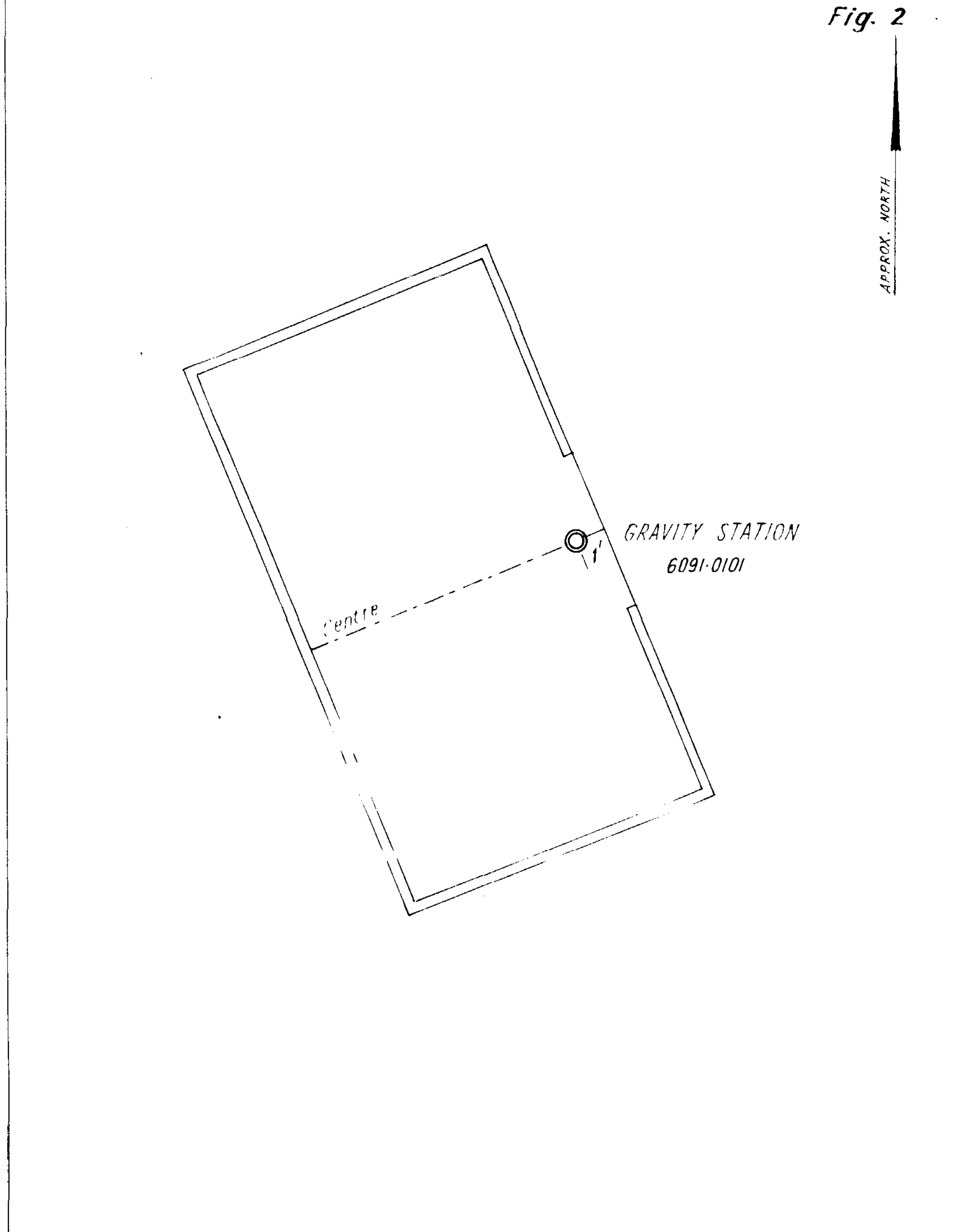
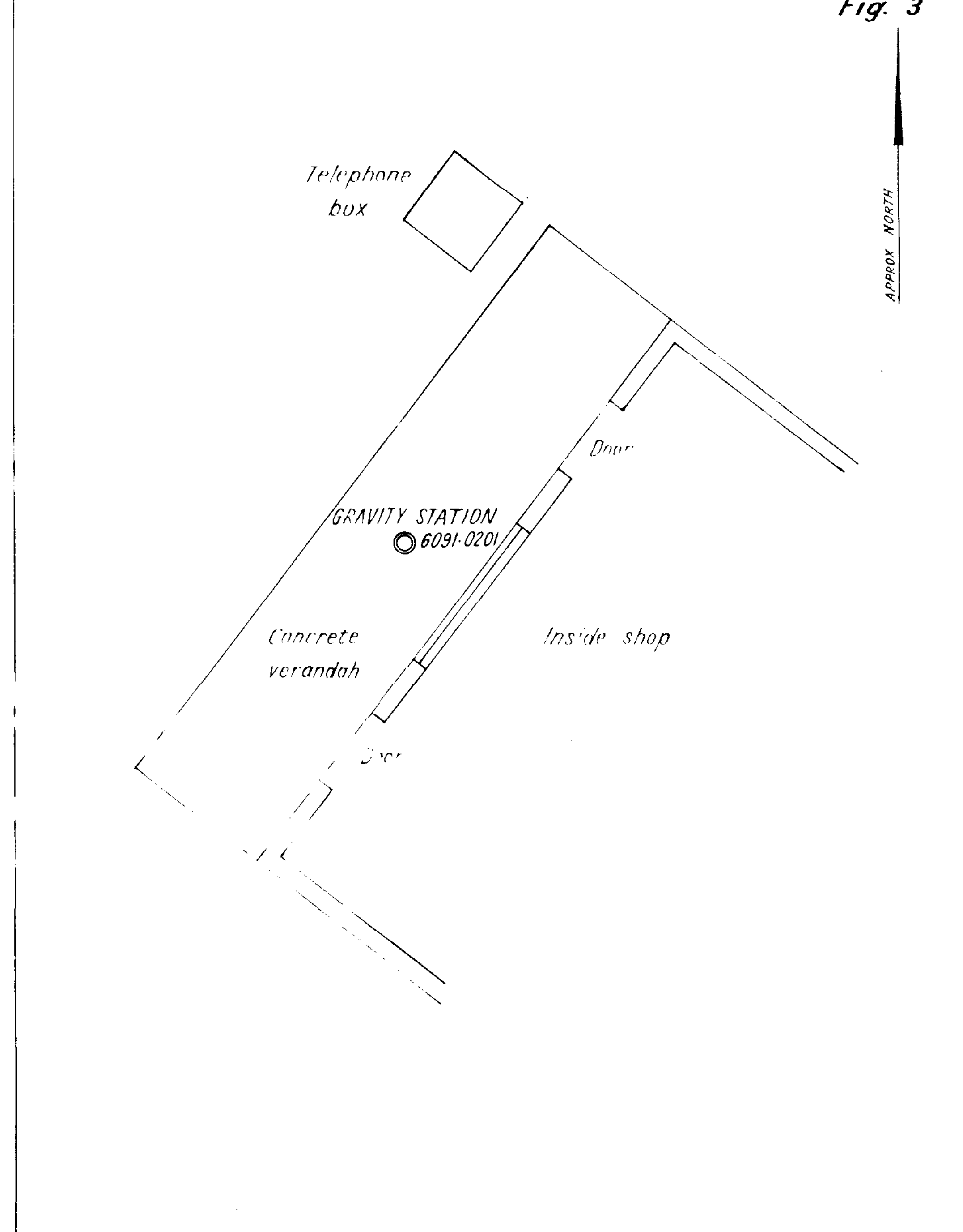


Fig. 3



Observed gravity interval
6091·0101 - 6091·0201 = 53·04 mgal (June 1962)
53·04 mgal (Feb. 1963)

Station 6091·0101 previously referred to as MCS1
" 6091·0201 " " " MCS2

GRAVITY METER CALIBRATION RANGE

MELBOURNE

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G24-2

To accompany Record Nº 1965/19

PLATE 2

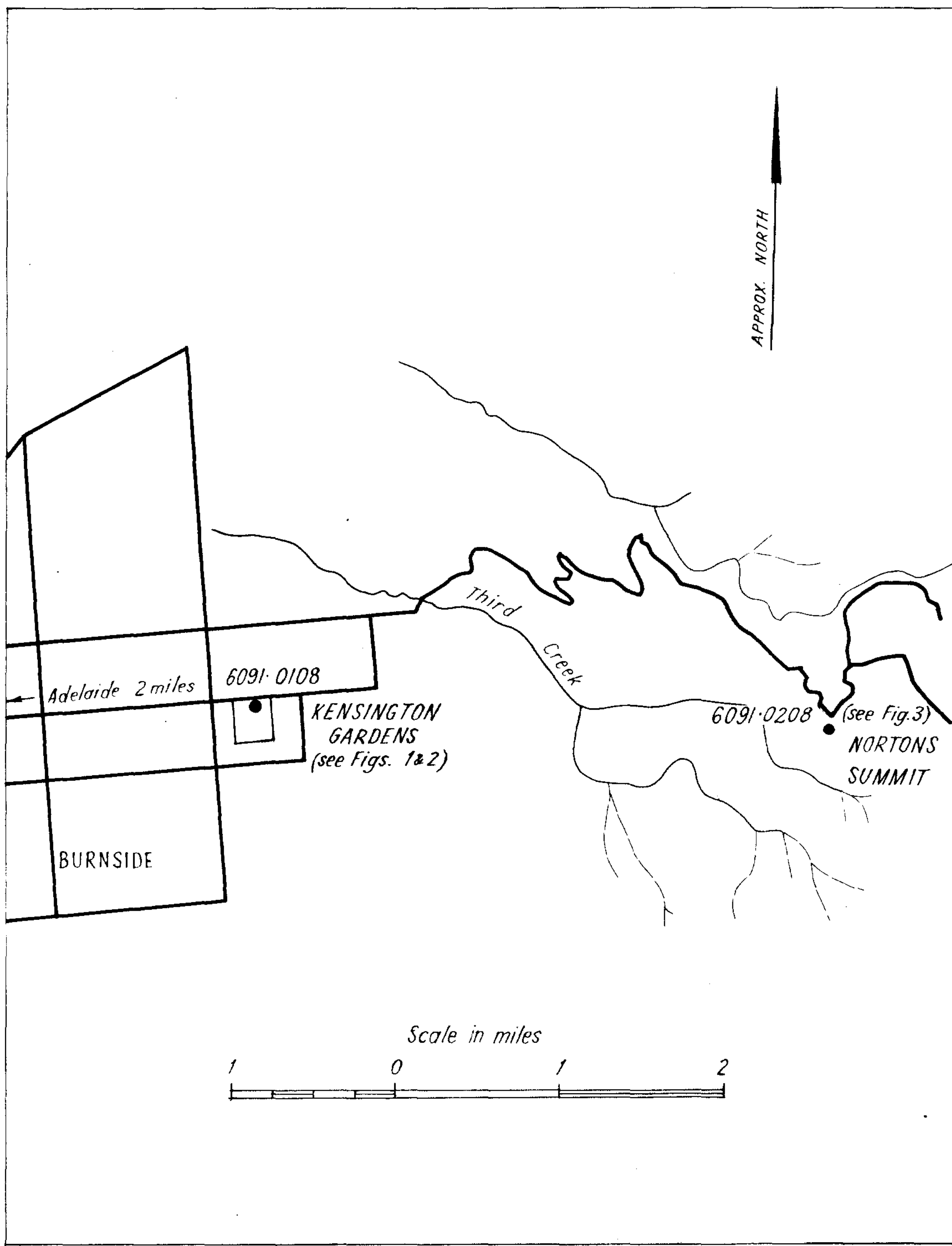


Fig. 1

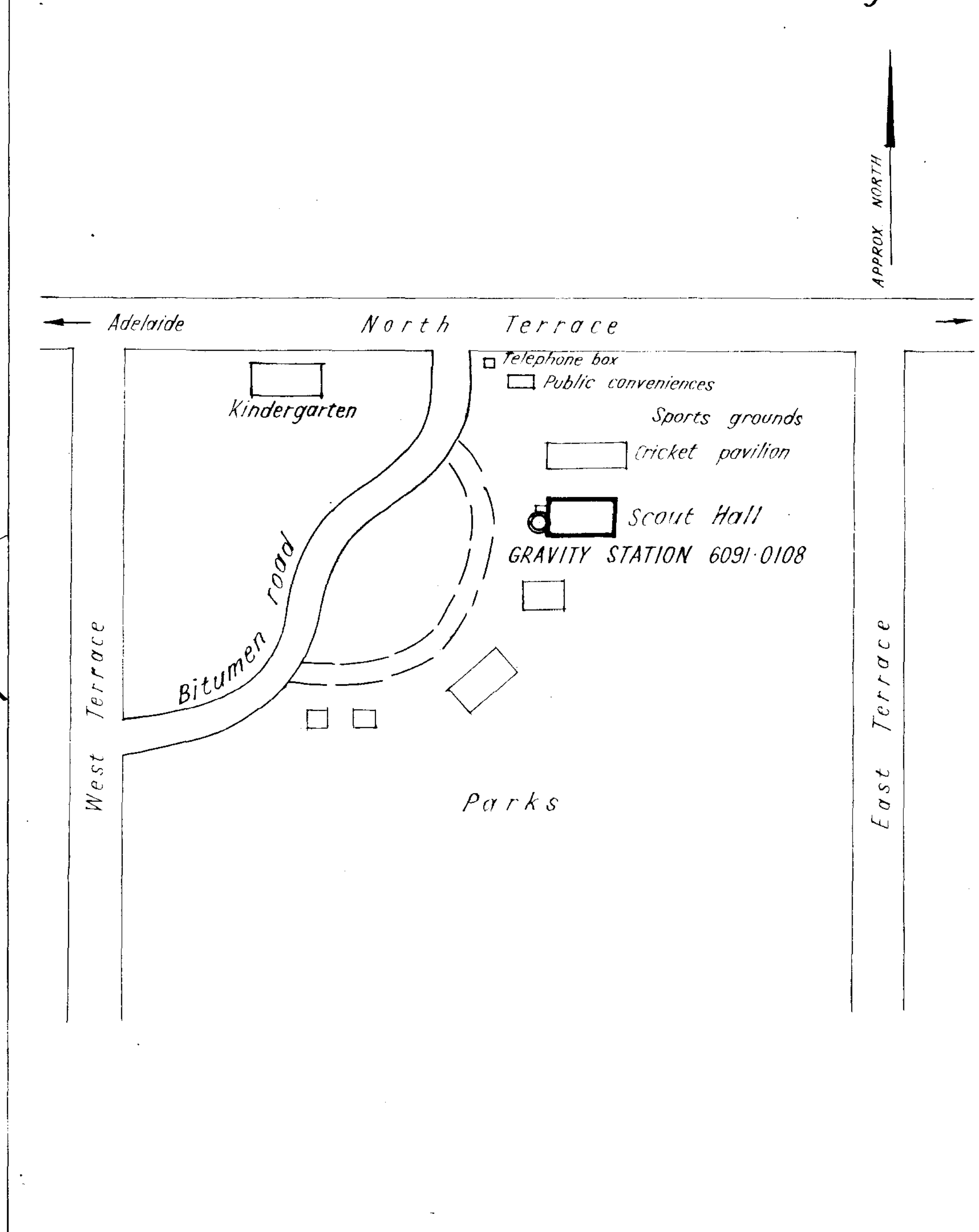


Fig. 2

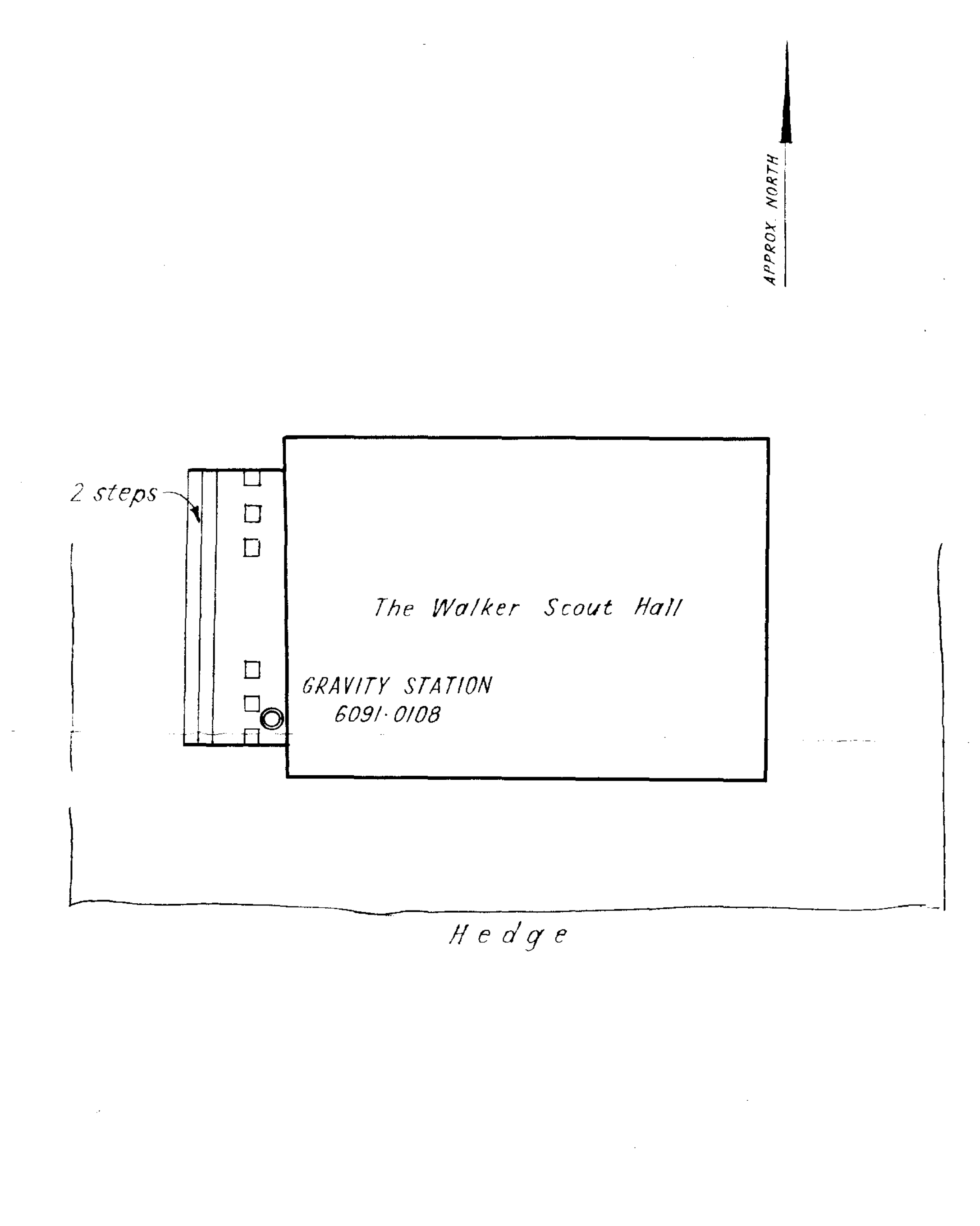
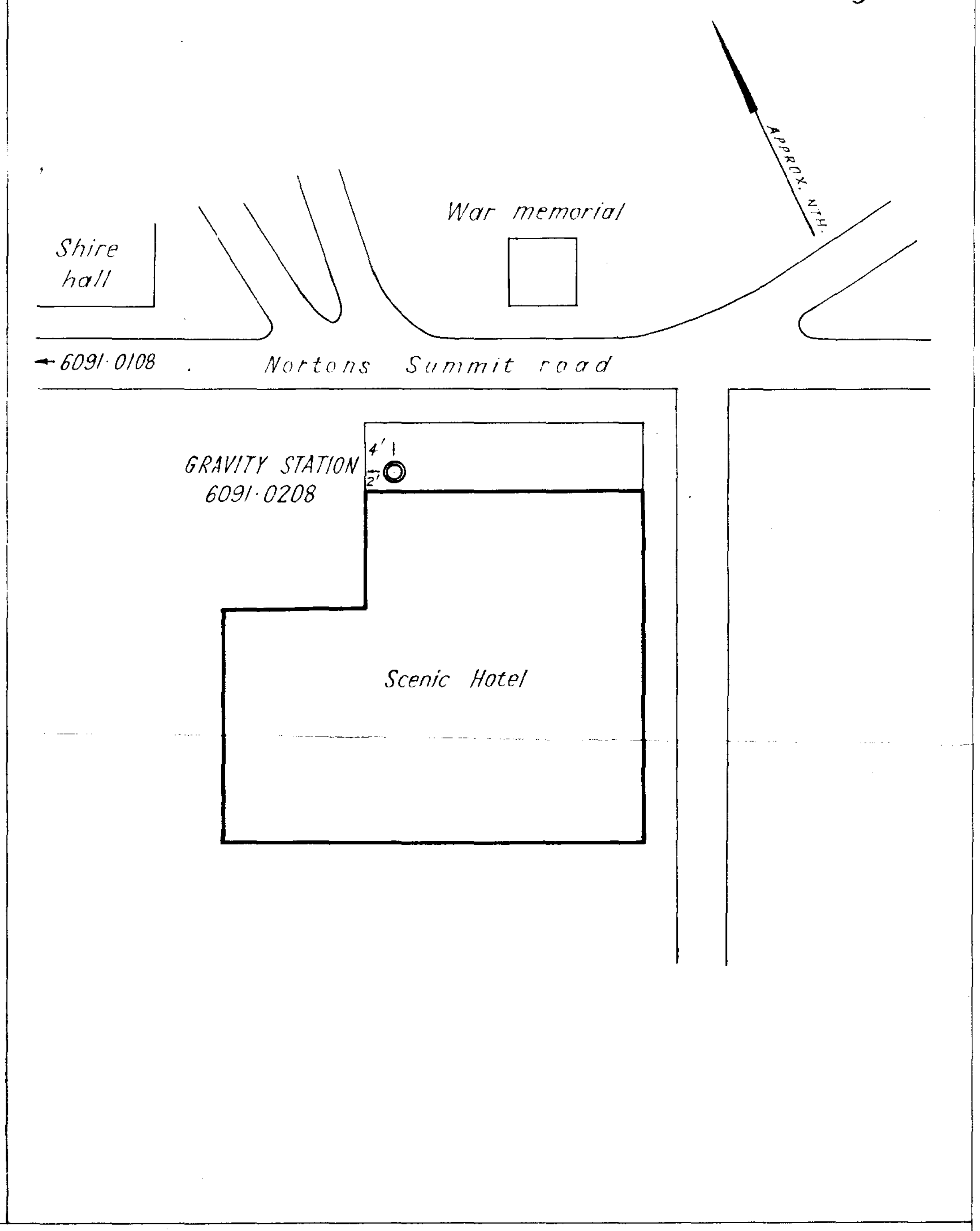


Fig. 3



Observed gravity interval
6091·0108 – 6091·0208 = 62·60 mgal *(July 1962)*
62.61 mgal *(Feb. 1963)*

GRAVITY METER CALIBRATION RANGE

ADELAIDE

Station 6091·0108 previously referred to as ACS 1
" 6091·0208 " " " " ACS 2

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 24-3

To accompany Record N° 1965/19

PLATE 3

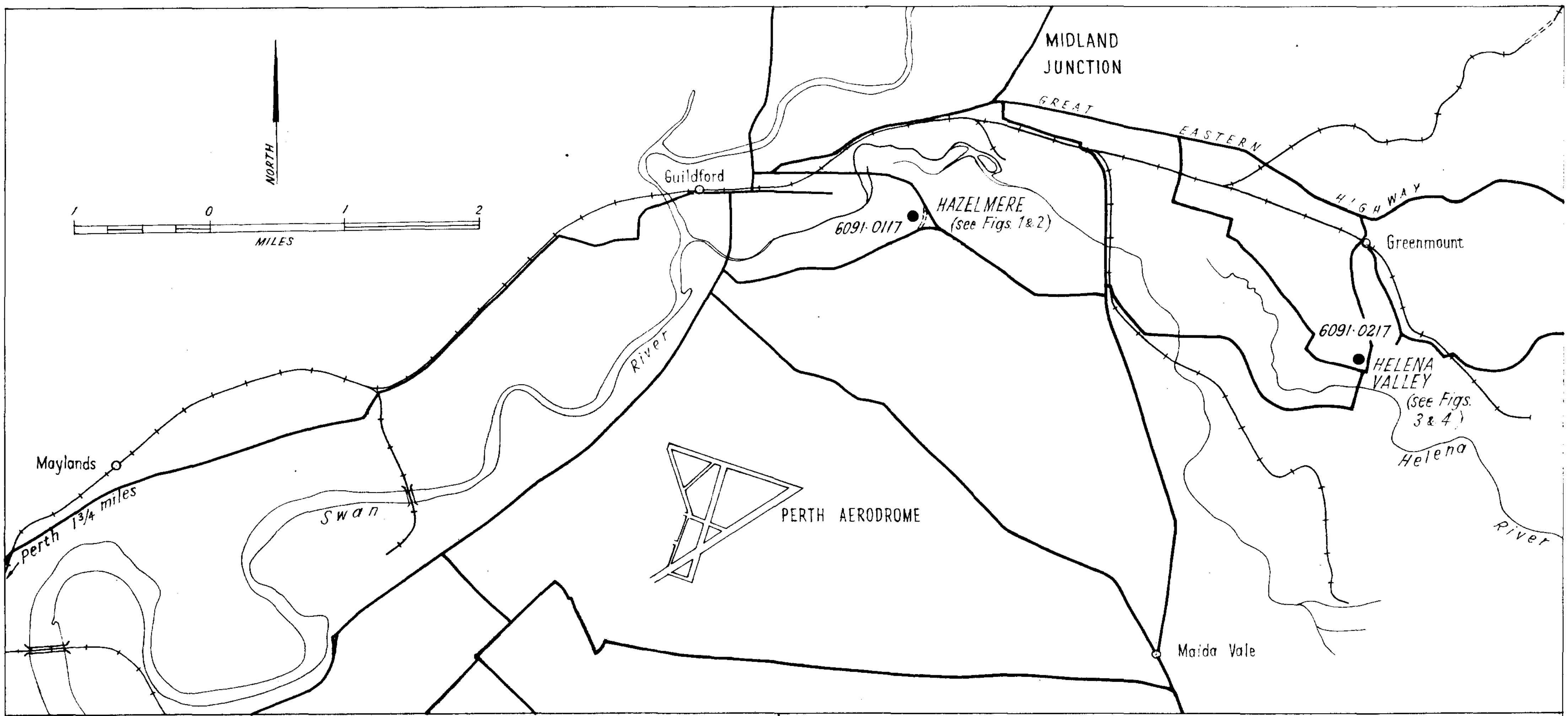


Fig. 1

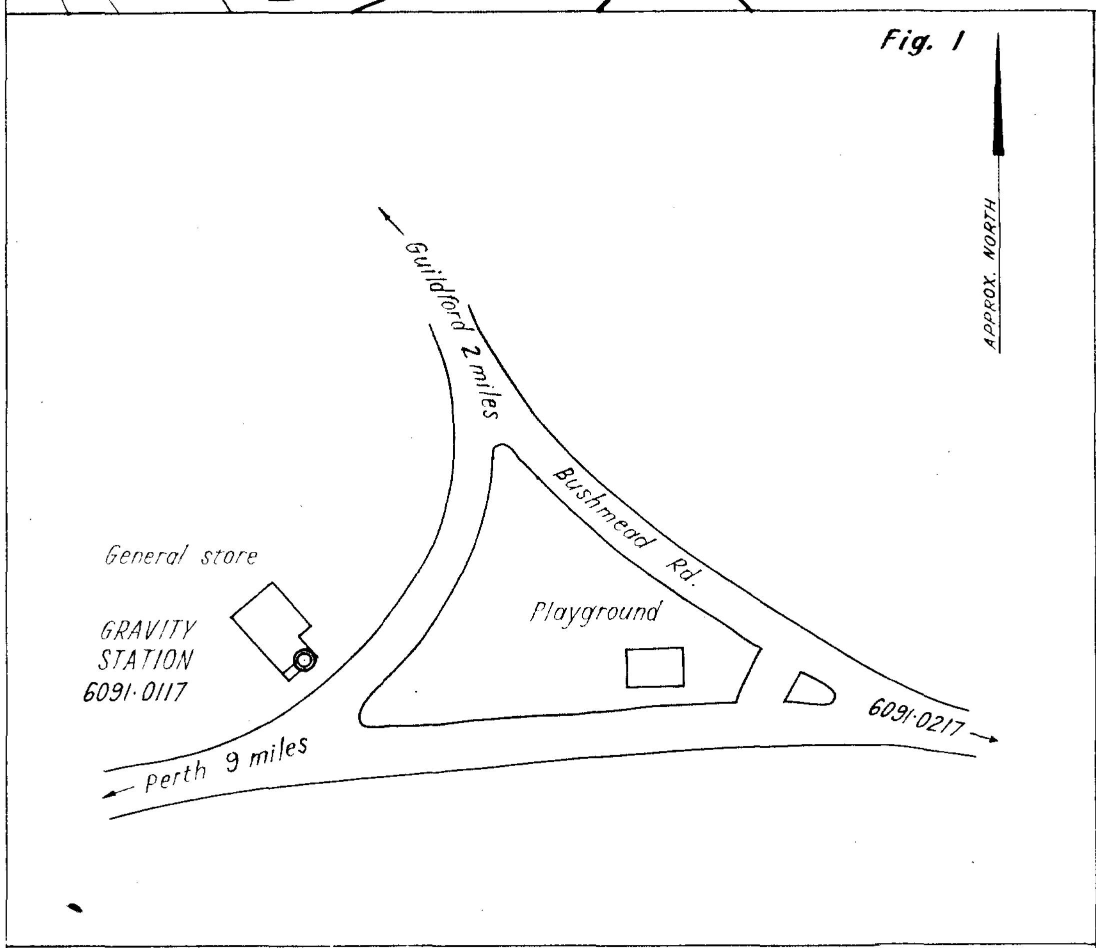


Fig. 2

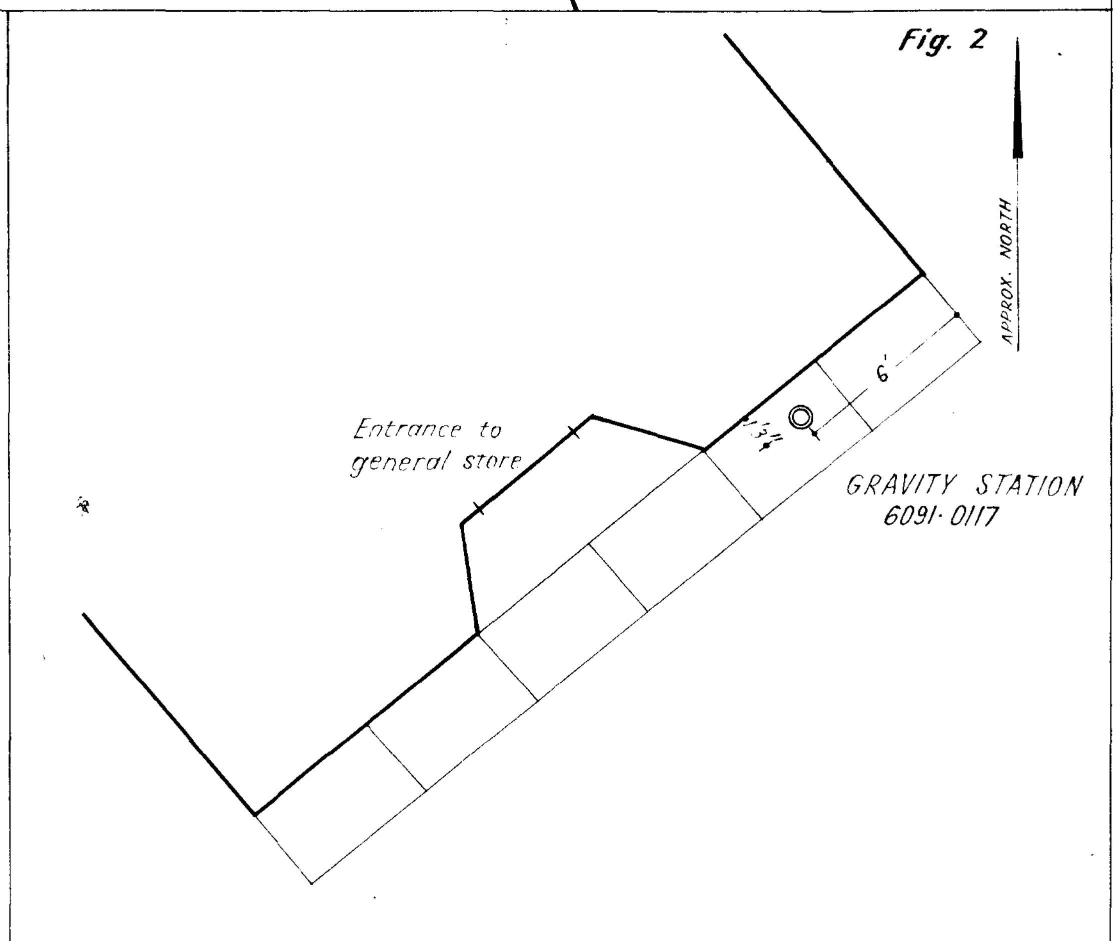


Fig. 3

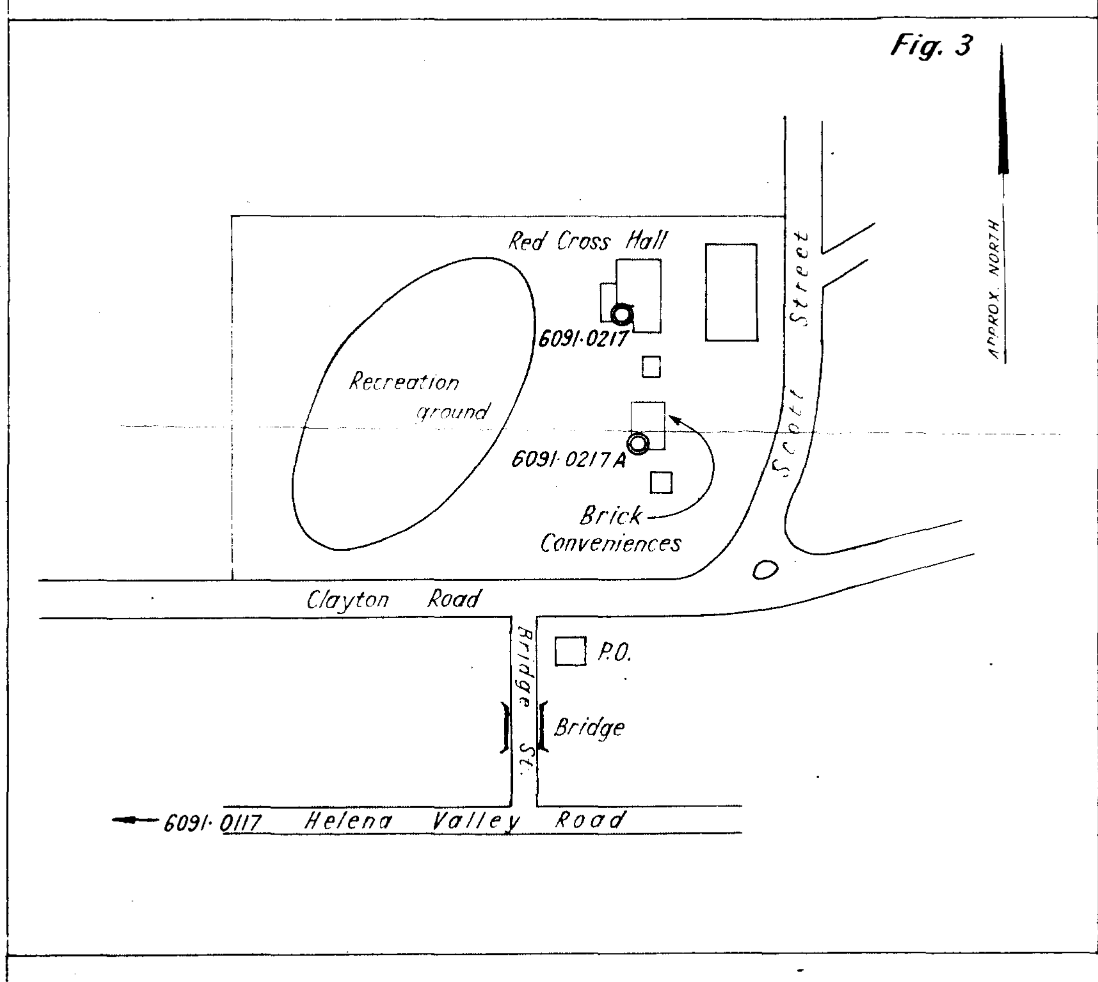
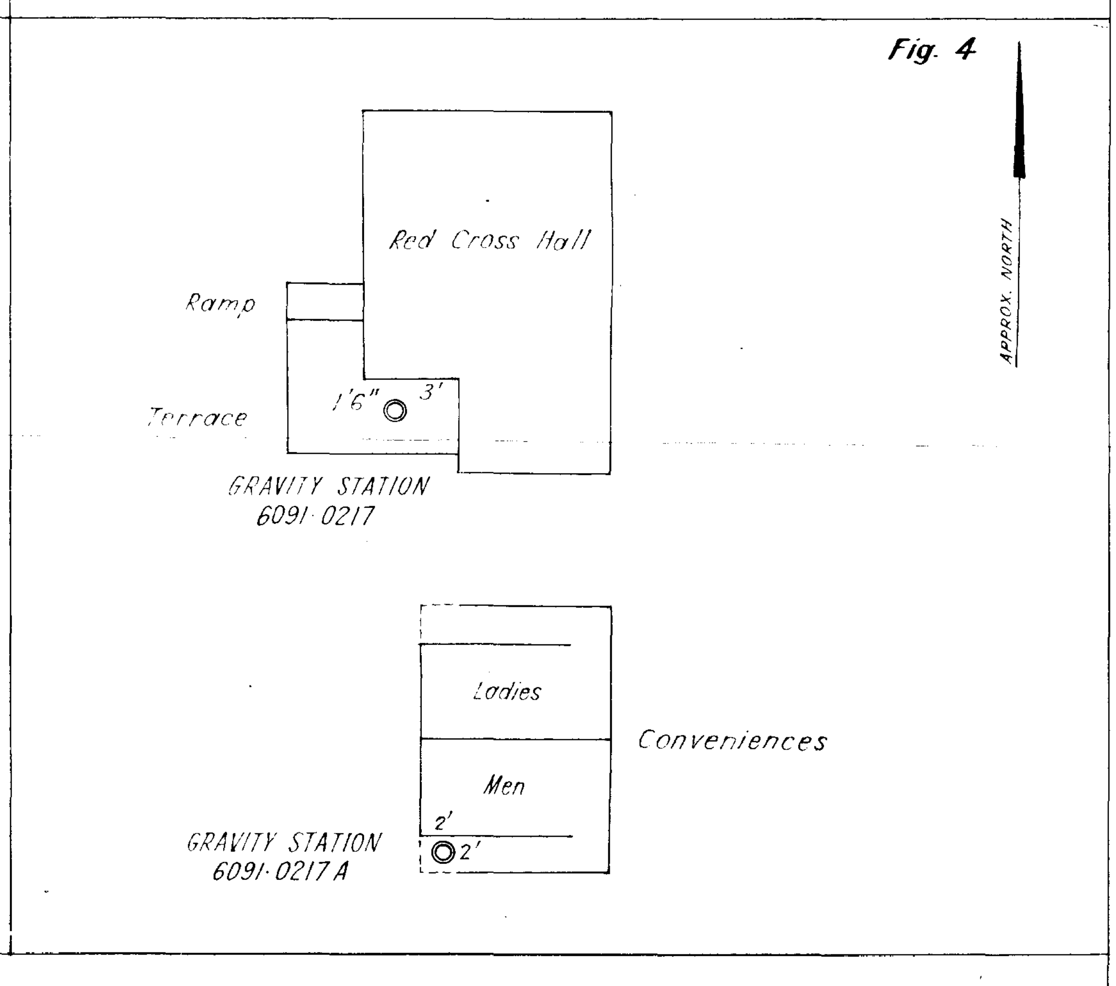


Fig. 4



Observed gravity interval
6091·0217 – 6091·0117 = 53·97 mgal *(July 1962)*
53·98 mgal (Feb. 1963)

Observed gravity at 6091·0217 is greater than that at 6091·0117

GRAVITY METER CALIBRATION RANGE

PERTH

Station 6091·0117 previously referred to as PCS 1
" 6091·0217 " " " " PCS 2
" 6091·0217A " " " " PCS 2A

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics

G24-4

To accompany Record No 1965/19

PLATE 4

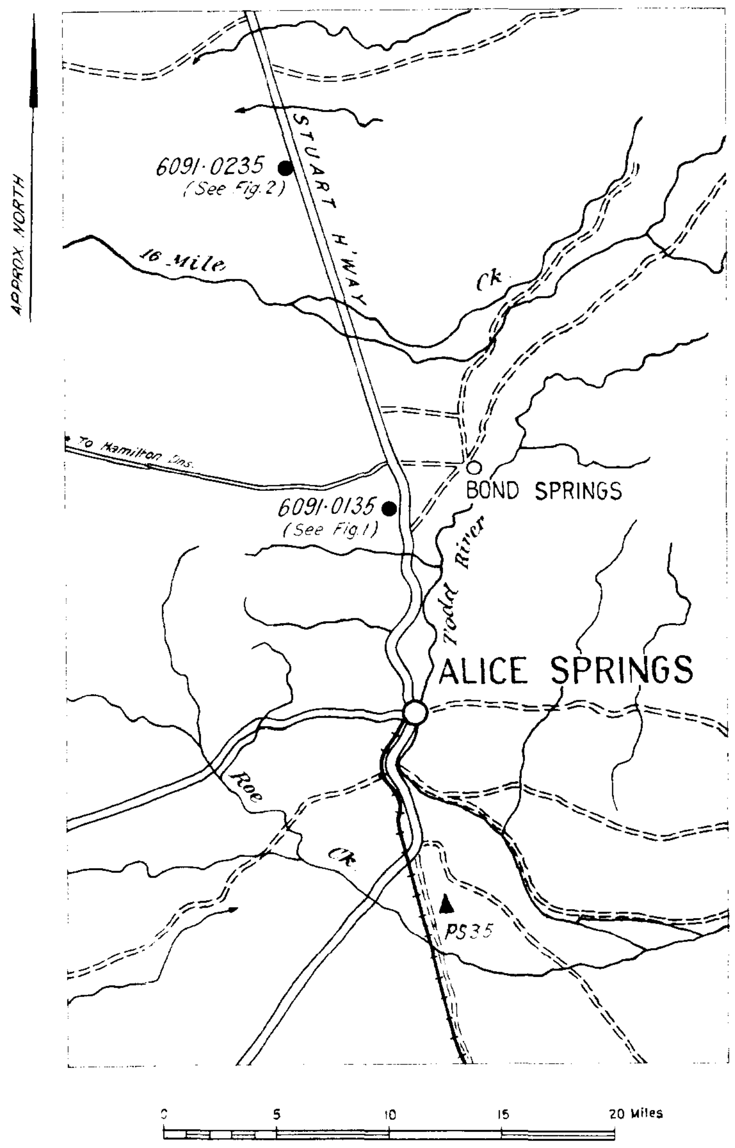


Fig. 1

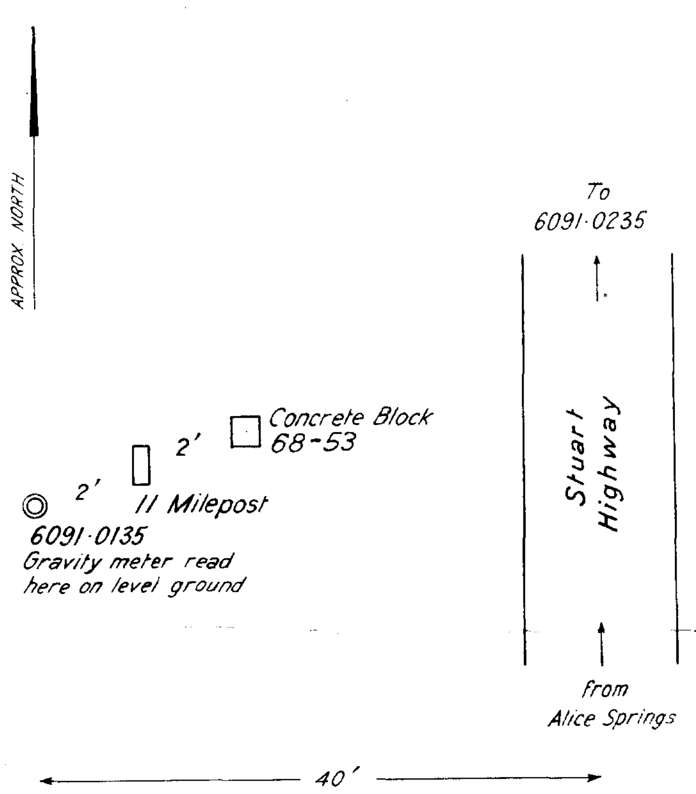
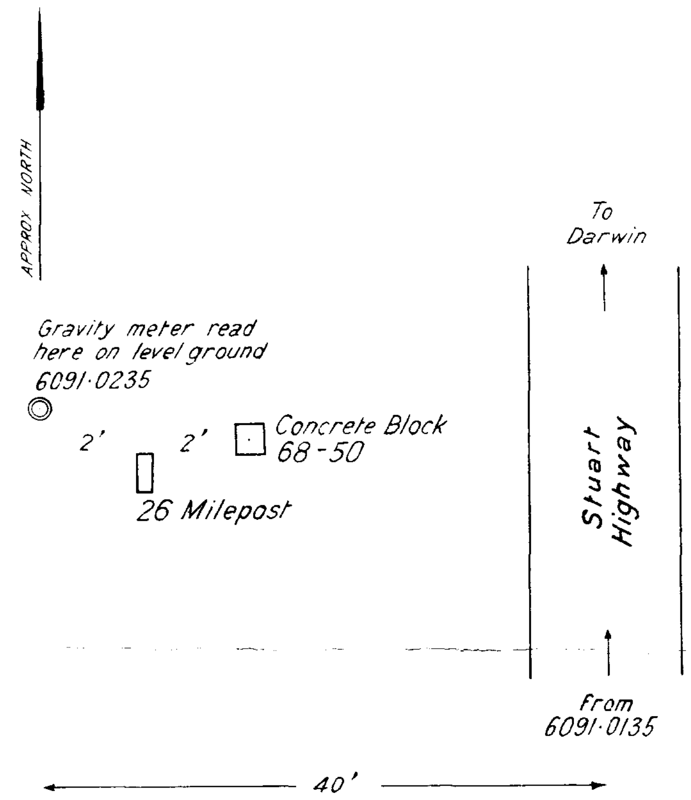


Fig. 2



Observed gravity interval

6091·0135 – 6091·0235 = 52·09 mgal *(July 1962)*

52.10 mgal (Feb. 1963)

GRAVITY METER CALIBRATION RANGE

ALICE SPRINGS

Station 6091·0135 previously referred to as ASCS 1

" 6091·0235 " " " " ASCS 2

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 24-5

To accompany Record N° 1965/19

PLATE 5

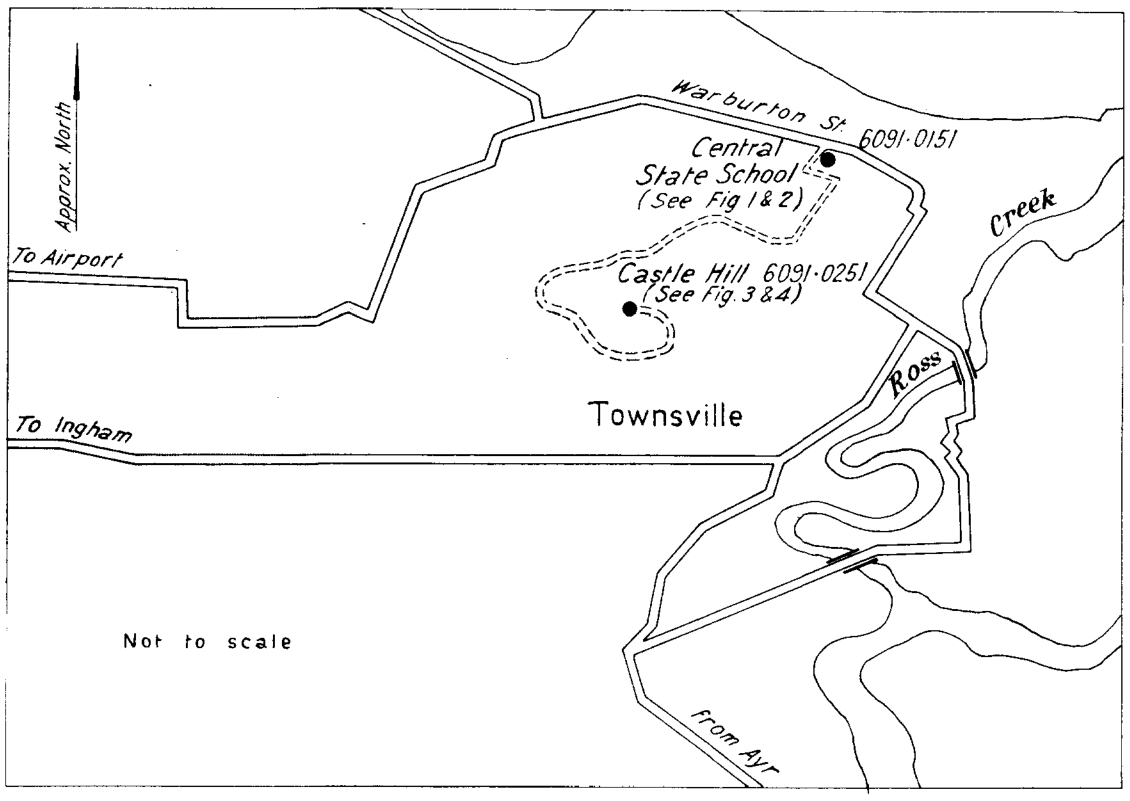


Fig. 1

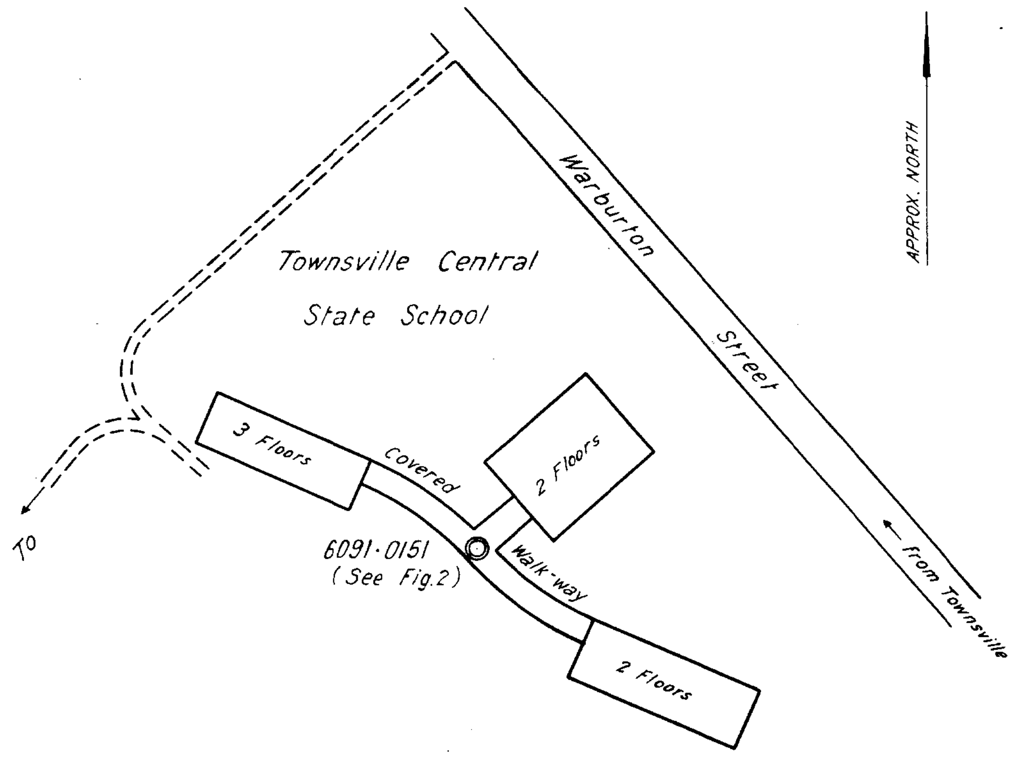


Fig. 2

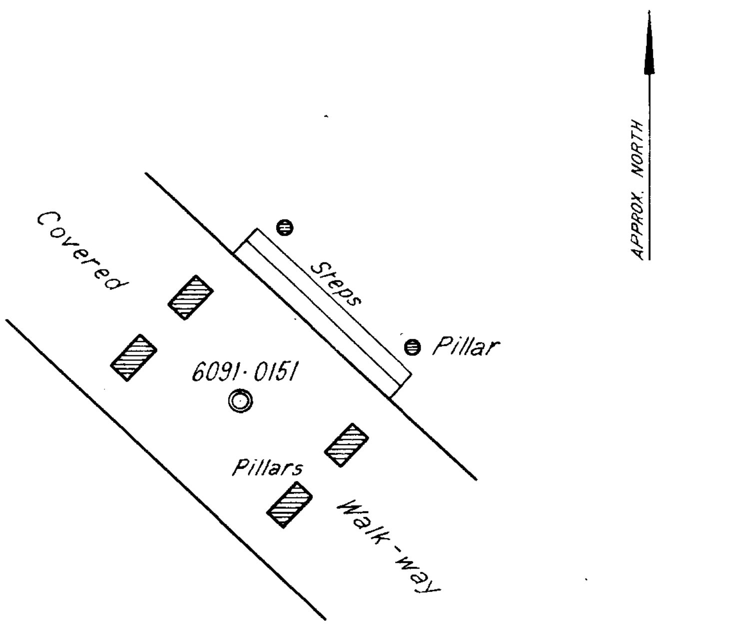


Fig. 3

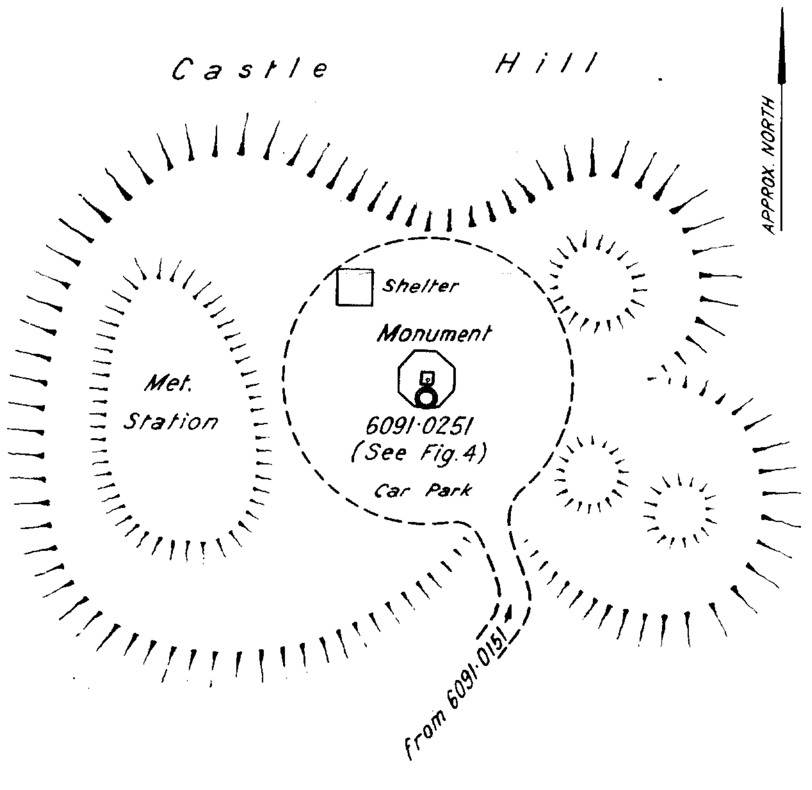
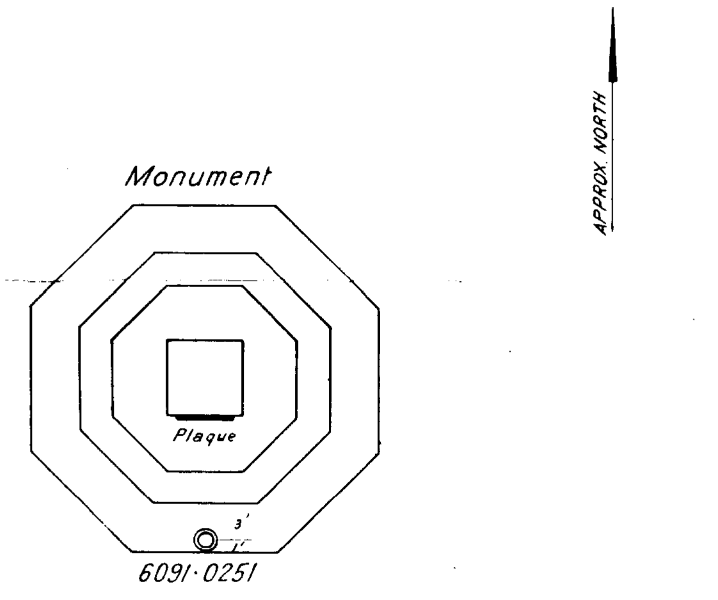


Fig. 4



Observed gravity interval
6091·0151 - 6091·0251 = 60·50 mgal *(July 1962)*
60.51 mgal (Feb. 1963)

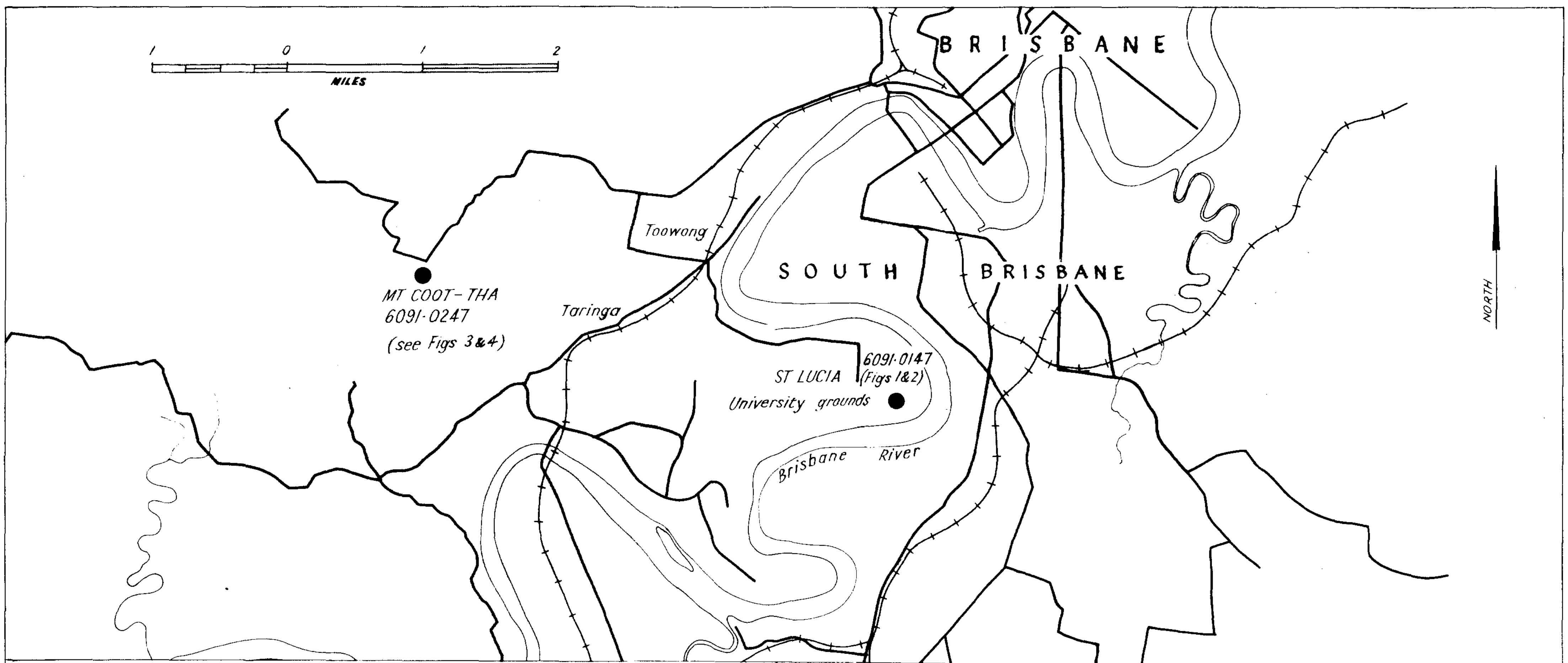
Station 6091·0151 previously referred to as TCS 1
" 6091·0251 " " " " TCS 2

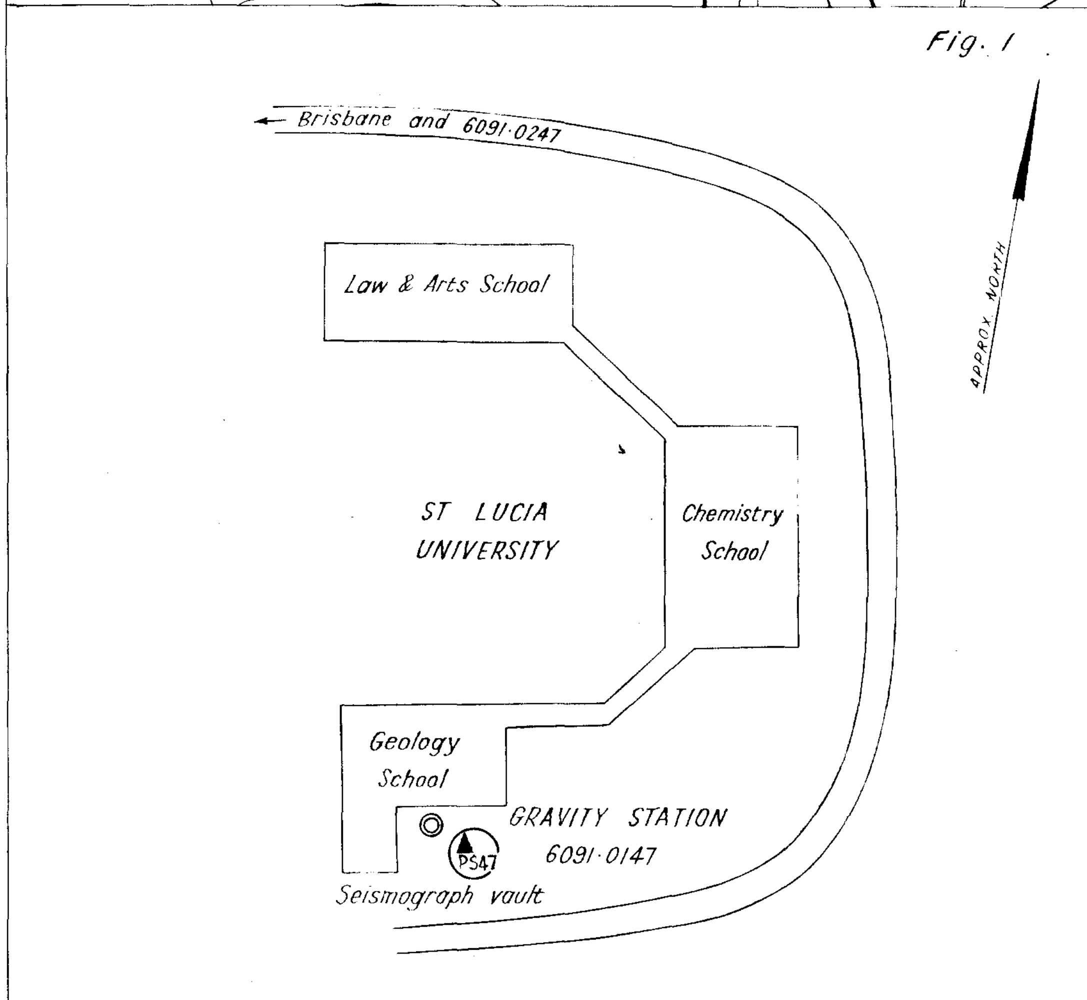
GRAVITY METER CALIBRATION RANGE
TOWNSVILLE

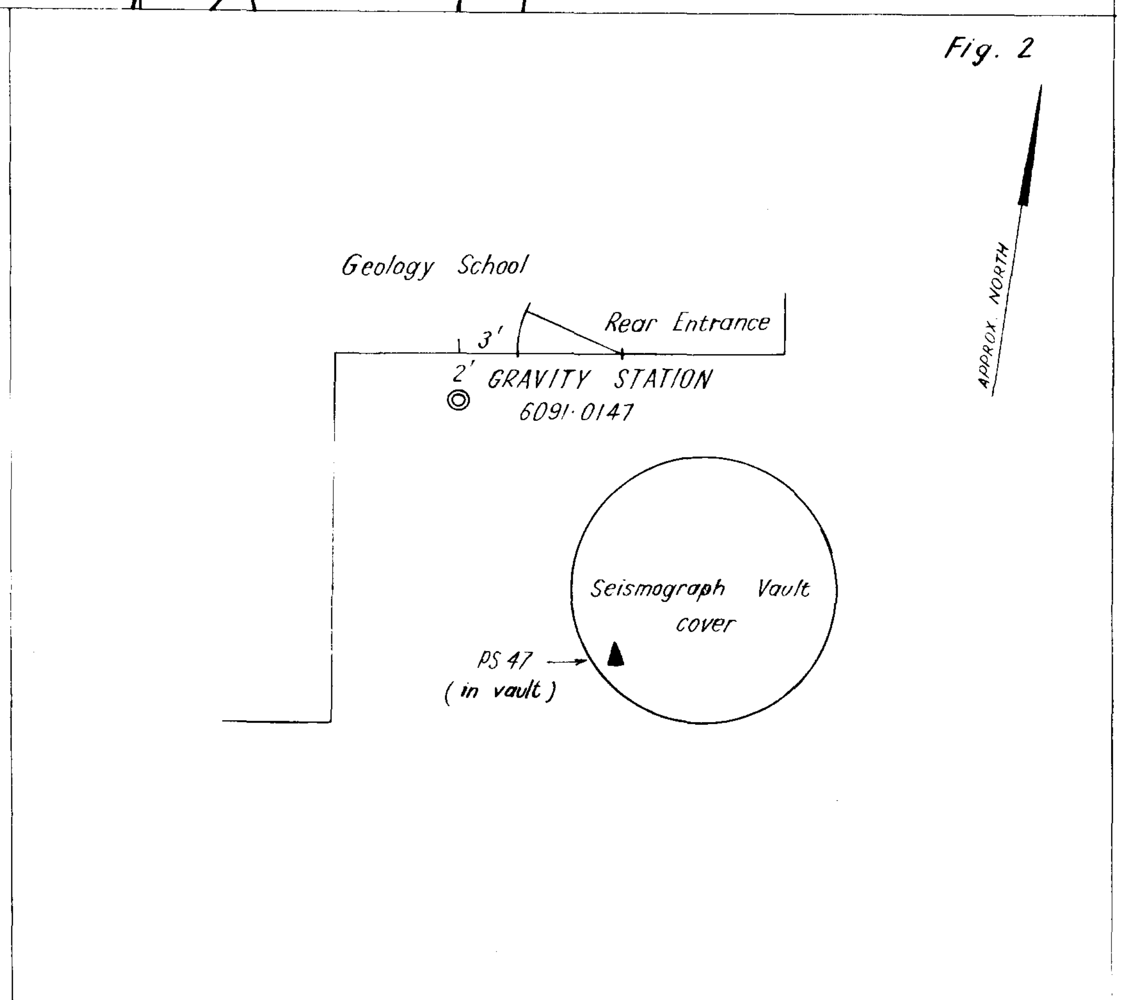
Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 24-6

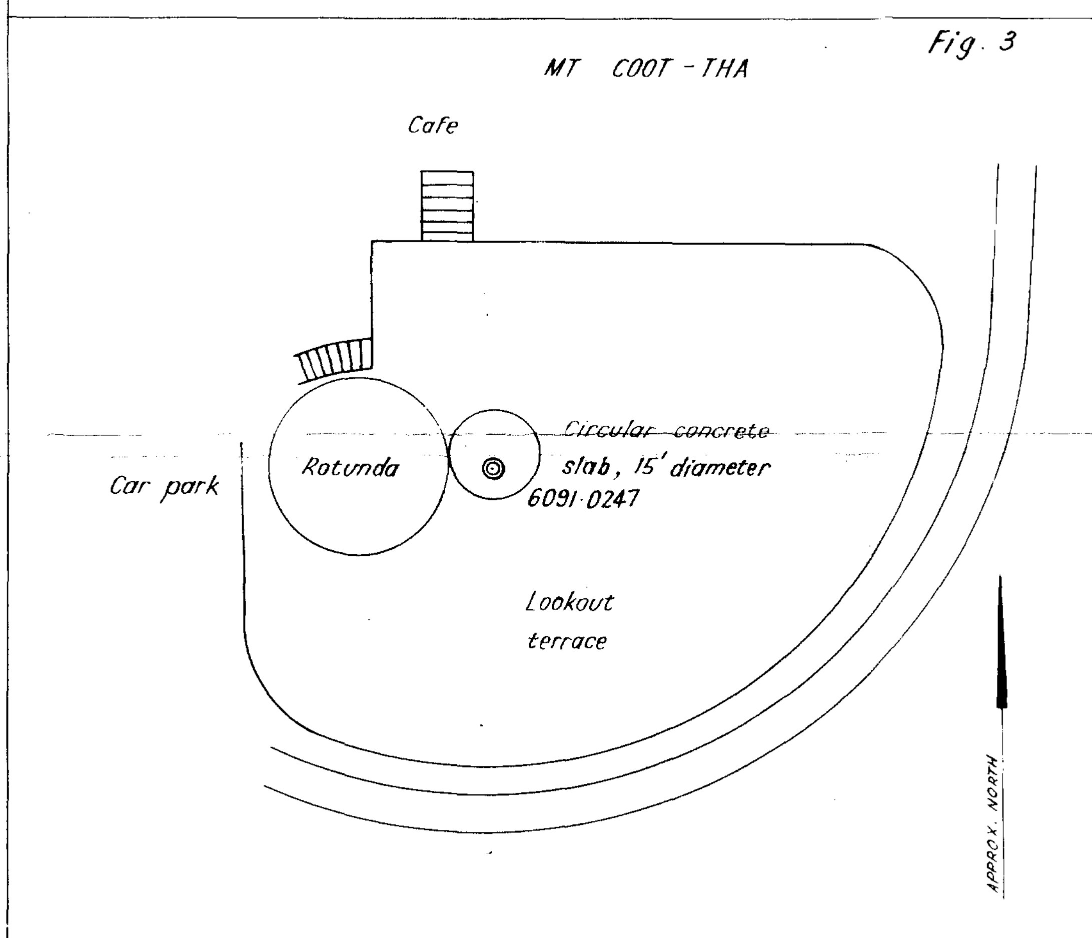
To accompany Record N° 1965/19

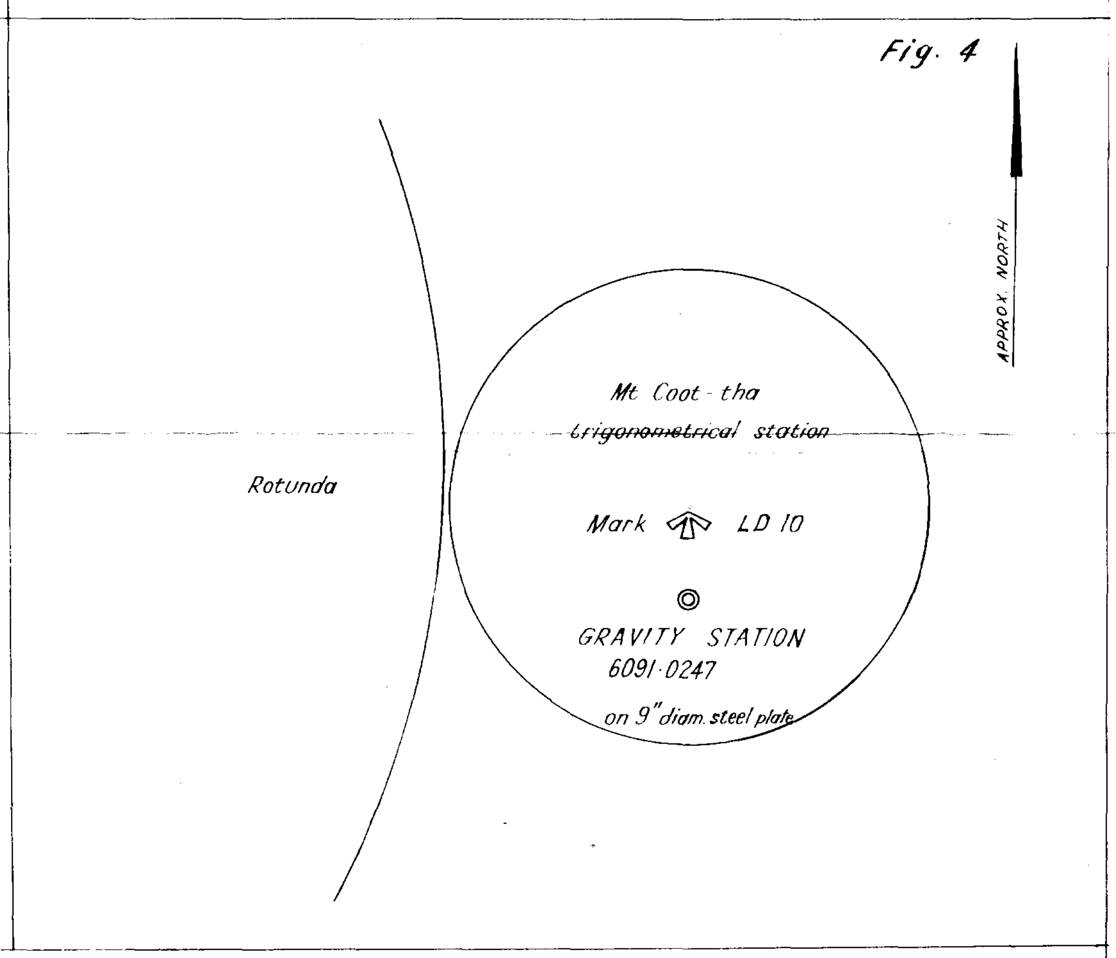
PLATE 6











Observed gravity interval

6091·0147 – 6091·0247 = 58·27 mgal *(Nov. 1961)*
58.26 mgal (Feb. 1963)

GRAVITY METER CALIBRATION RANGE

BRISBANE

Station 6091·0147 previously referred to as BCS 1
" 6091·0247 " " " " BCS 2

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 24-7

To accompany Record N° 1965/19

PLATE 7

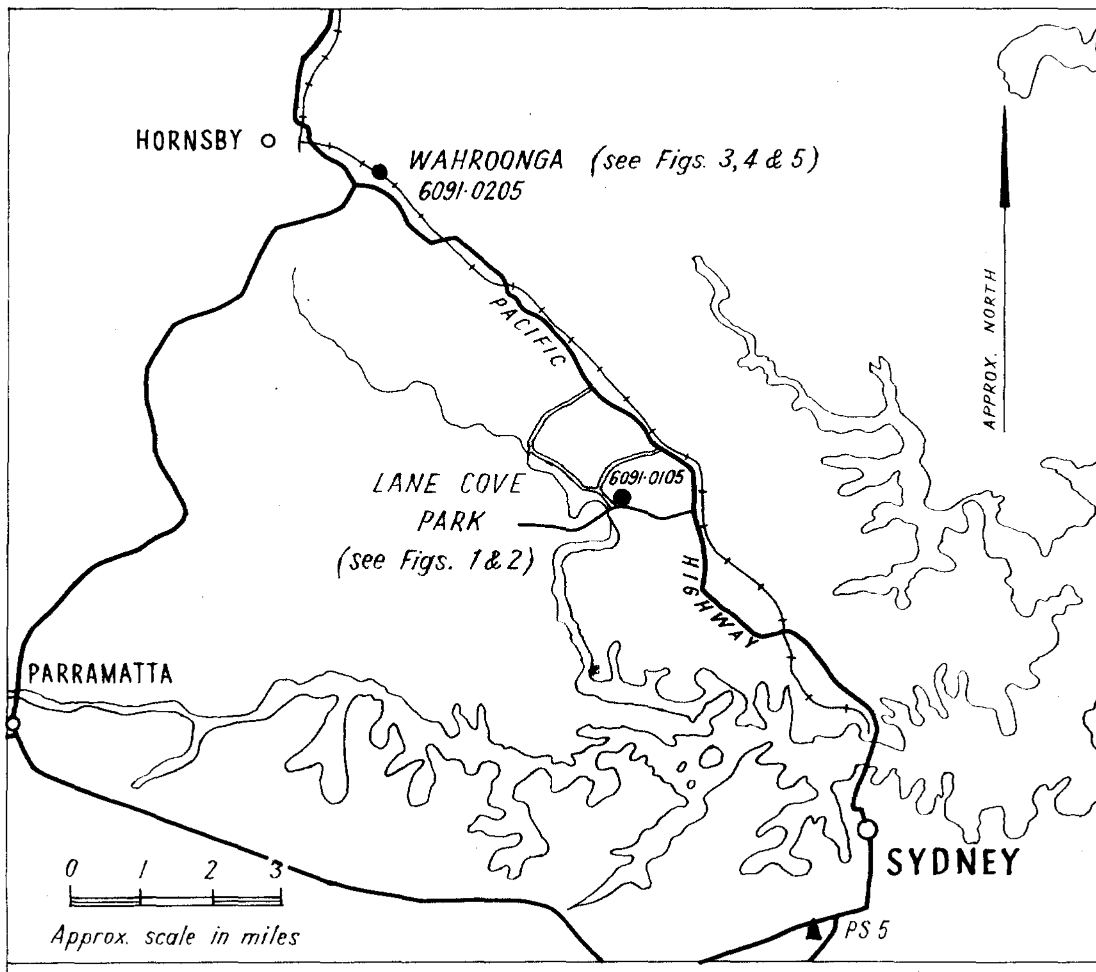


Fig. 1

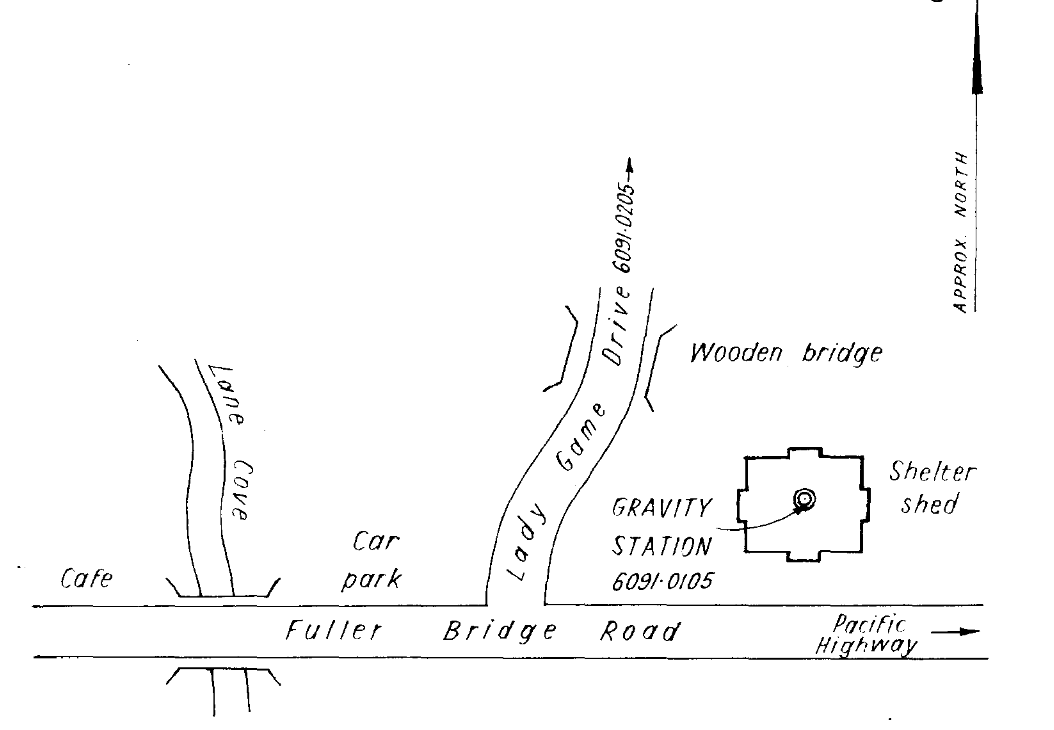


Fig. 2

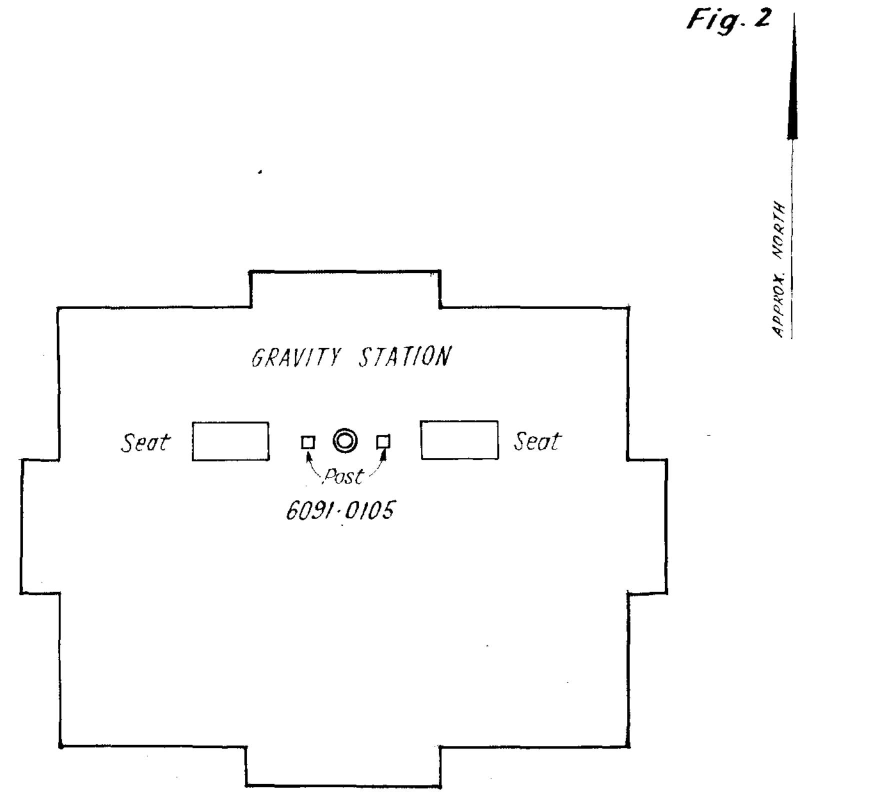


Fig. 3

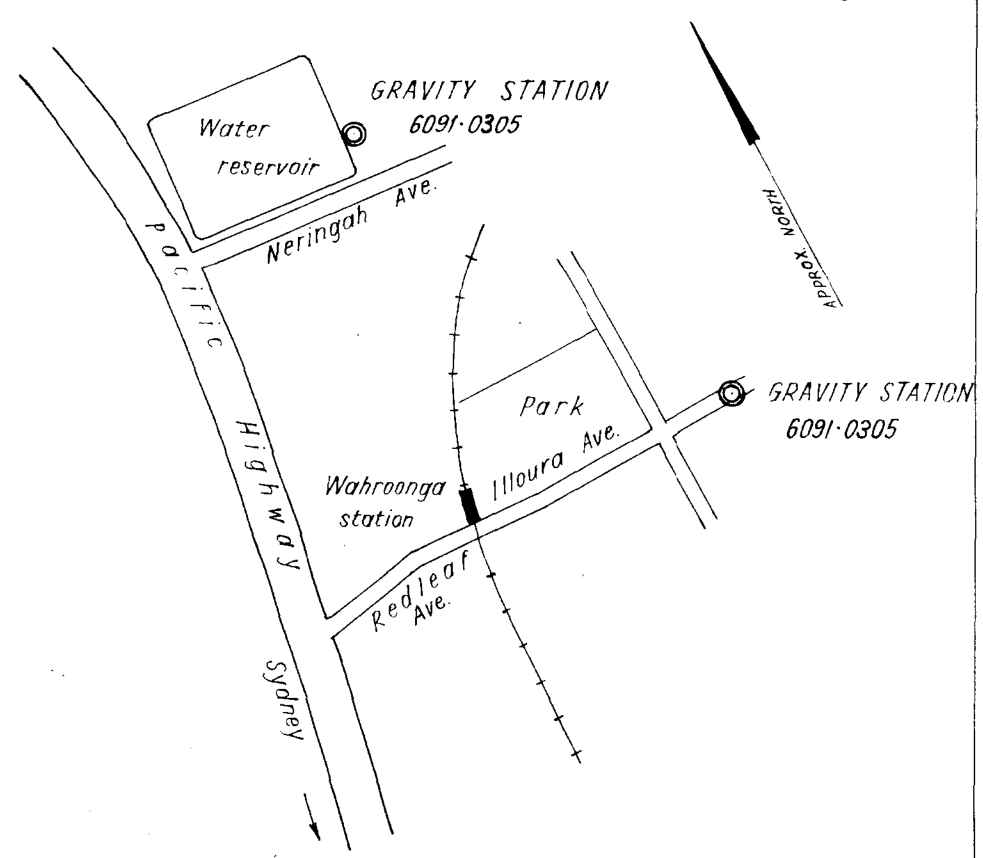


Fig. 4

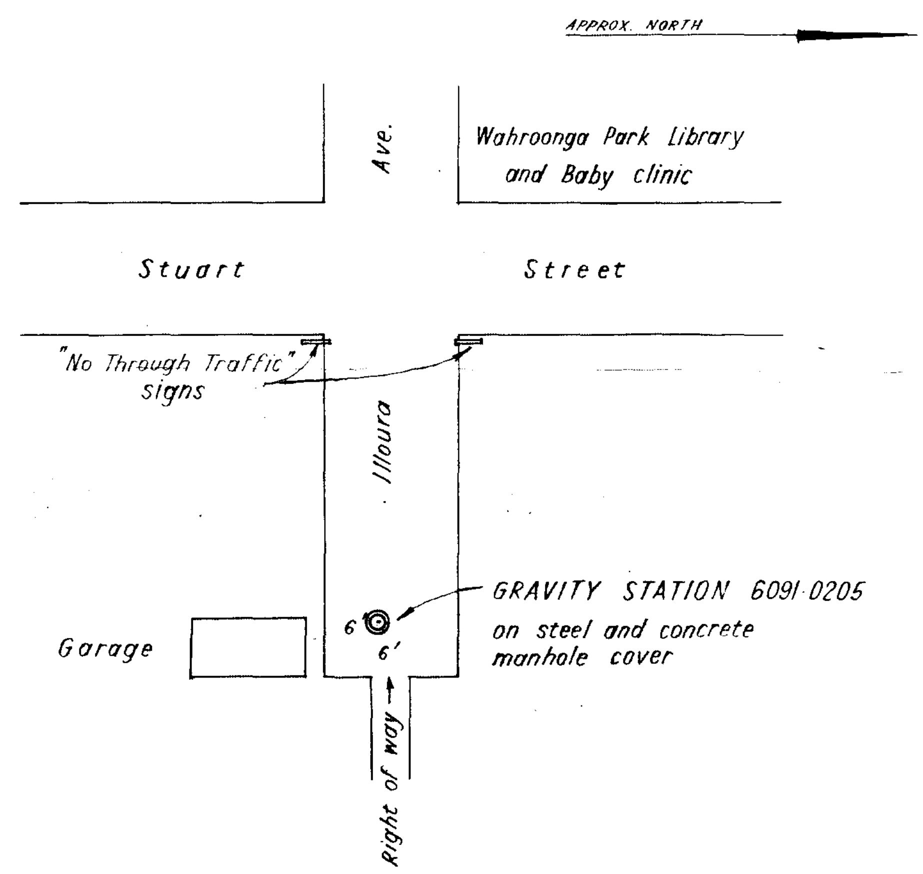
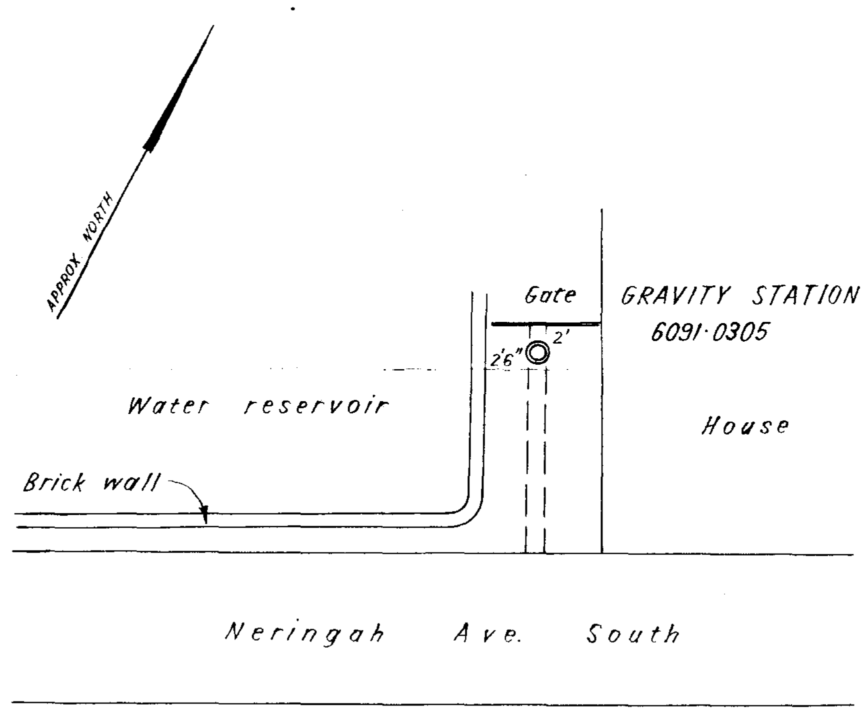


Fig. 5



Observed gravity interval

6091·0105 – 6091·0205 = 59·00 mgal (Nov. 1961)
58·99 mgal (Feb. 1963)
6091·0105 – 6091·0305 = 61·99 mgal (Feb. 1963)

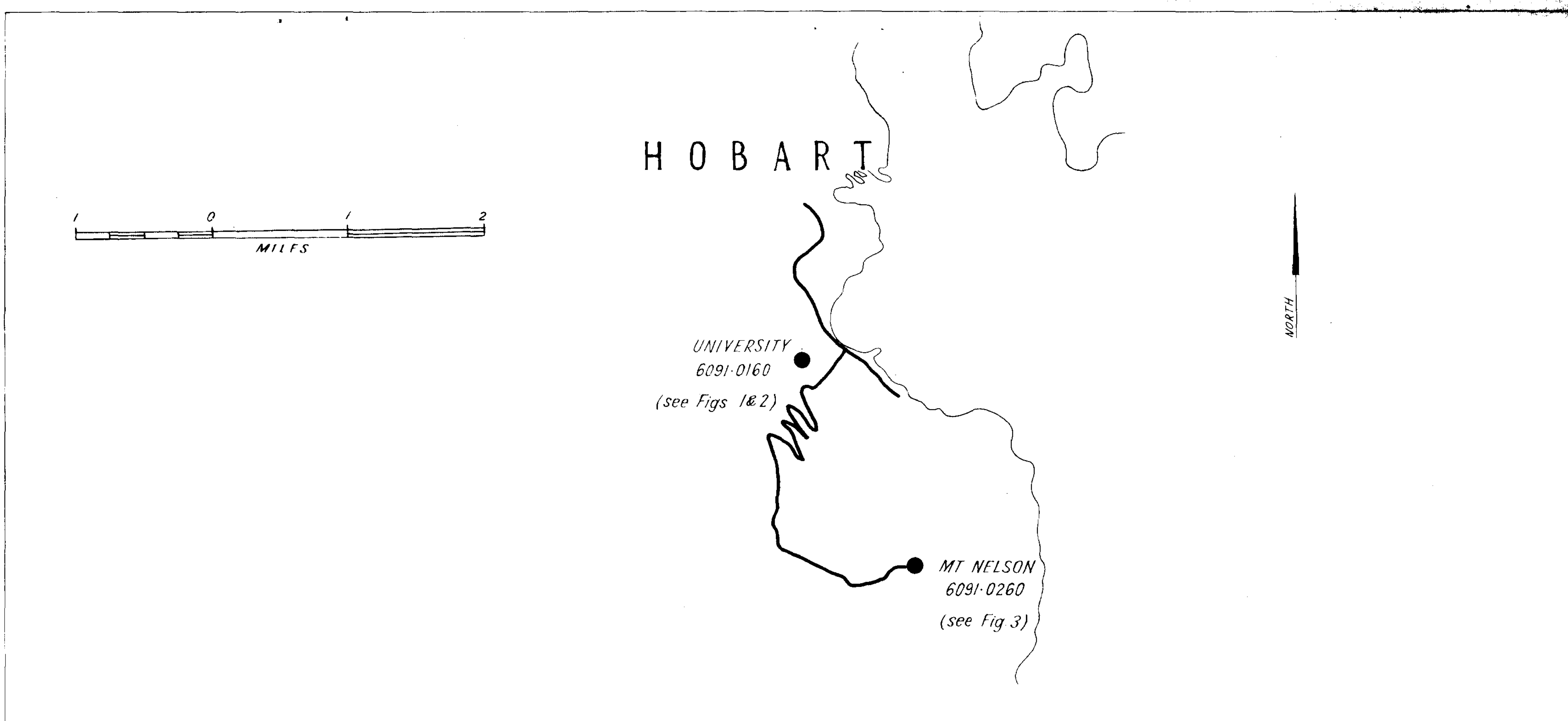
Station 6091·0105 previously referred to as SCS 1
" 6091·0205 " " " " SCS 2
" 6091·0305 " " " " SCS 2A

GRAVITY METER CALIBRATION RANGE
SYDNEY

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 24-8

To accompany Record N° 1965/19

PLATE 8



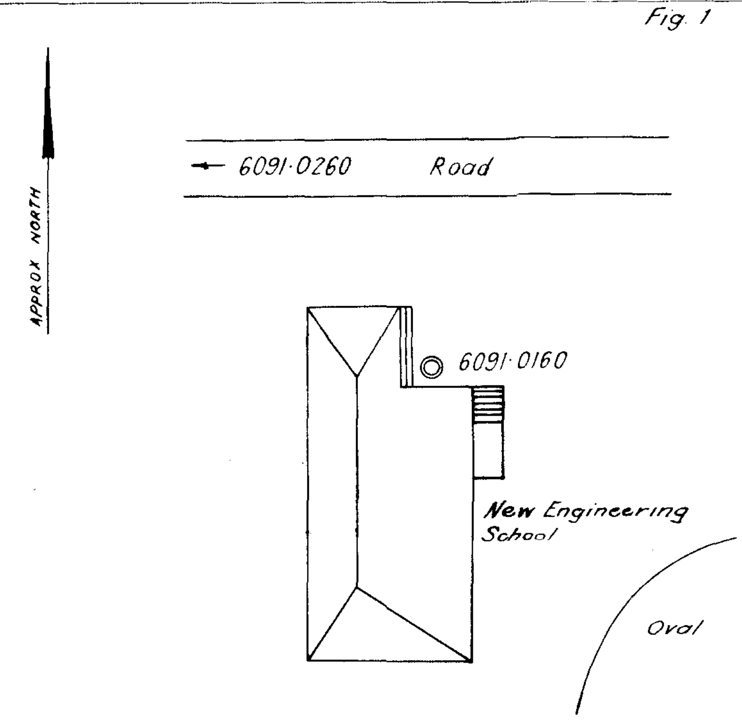


Fig. 1

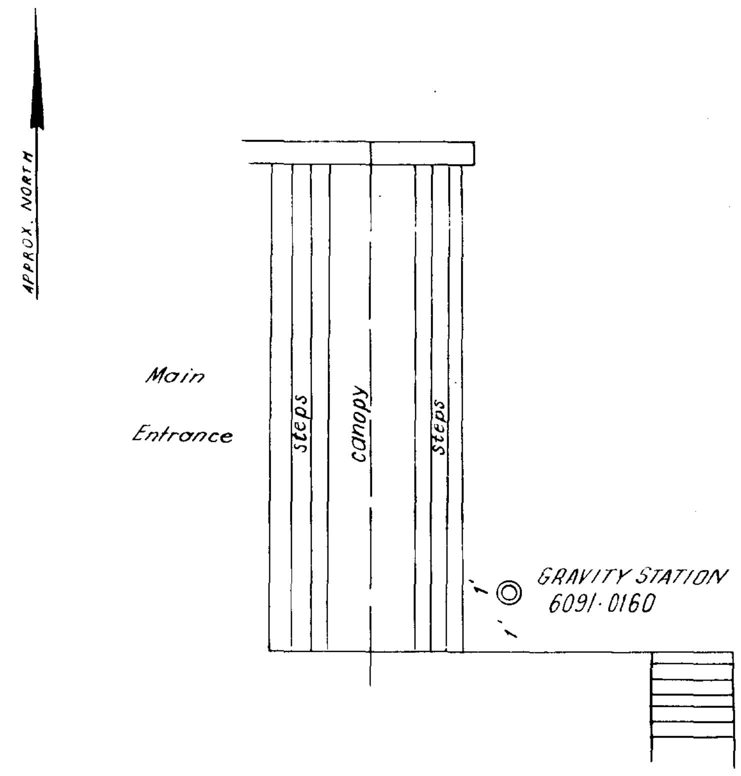


Fig. 2

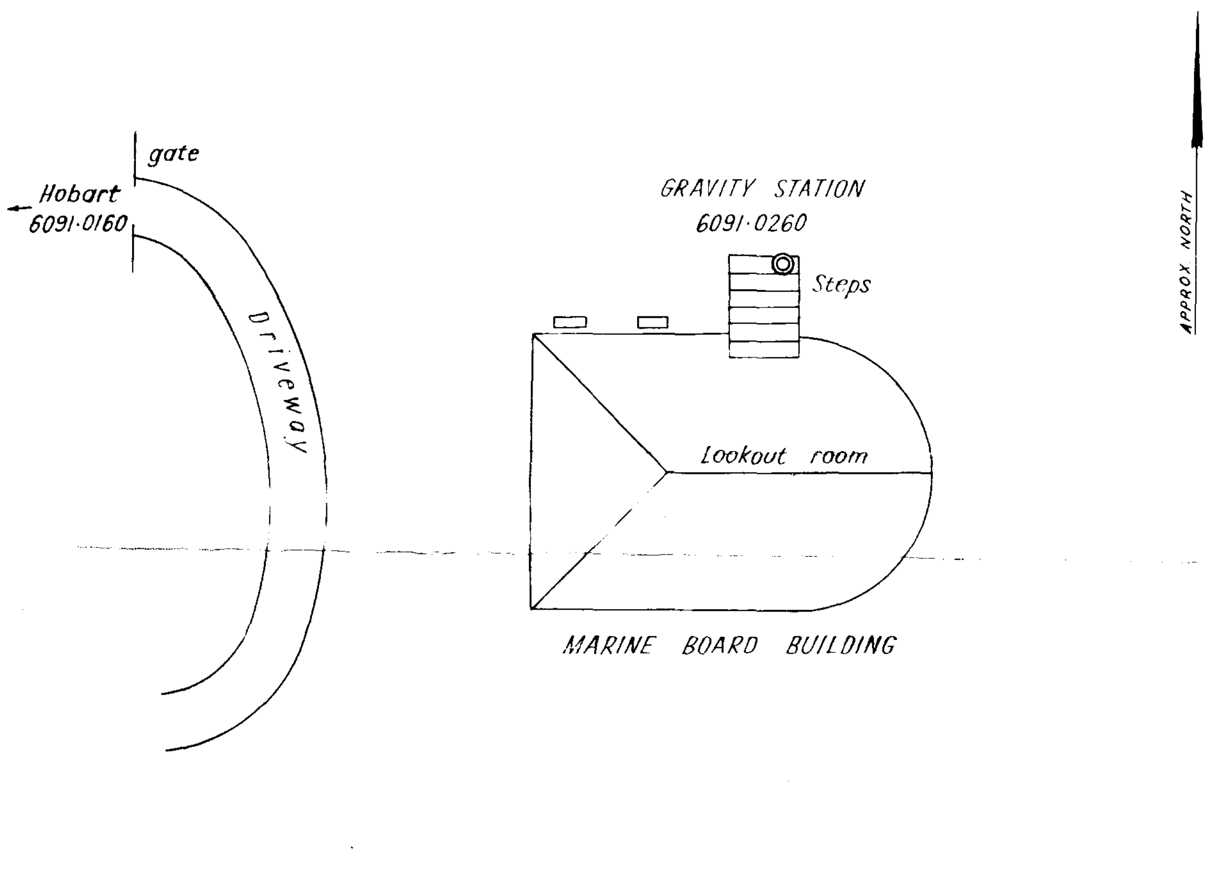


Fig. 3

Observed gravity interval

6091·0160 – 6091·0260 = 54·71 mgal *(July 1962)*

54·71 mgal (Feb. 1963)

Station 6091·0160 previously referred to as HCS 1

" 6091·0260 " " " " HCS 2

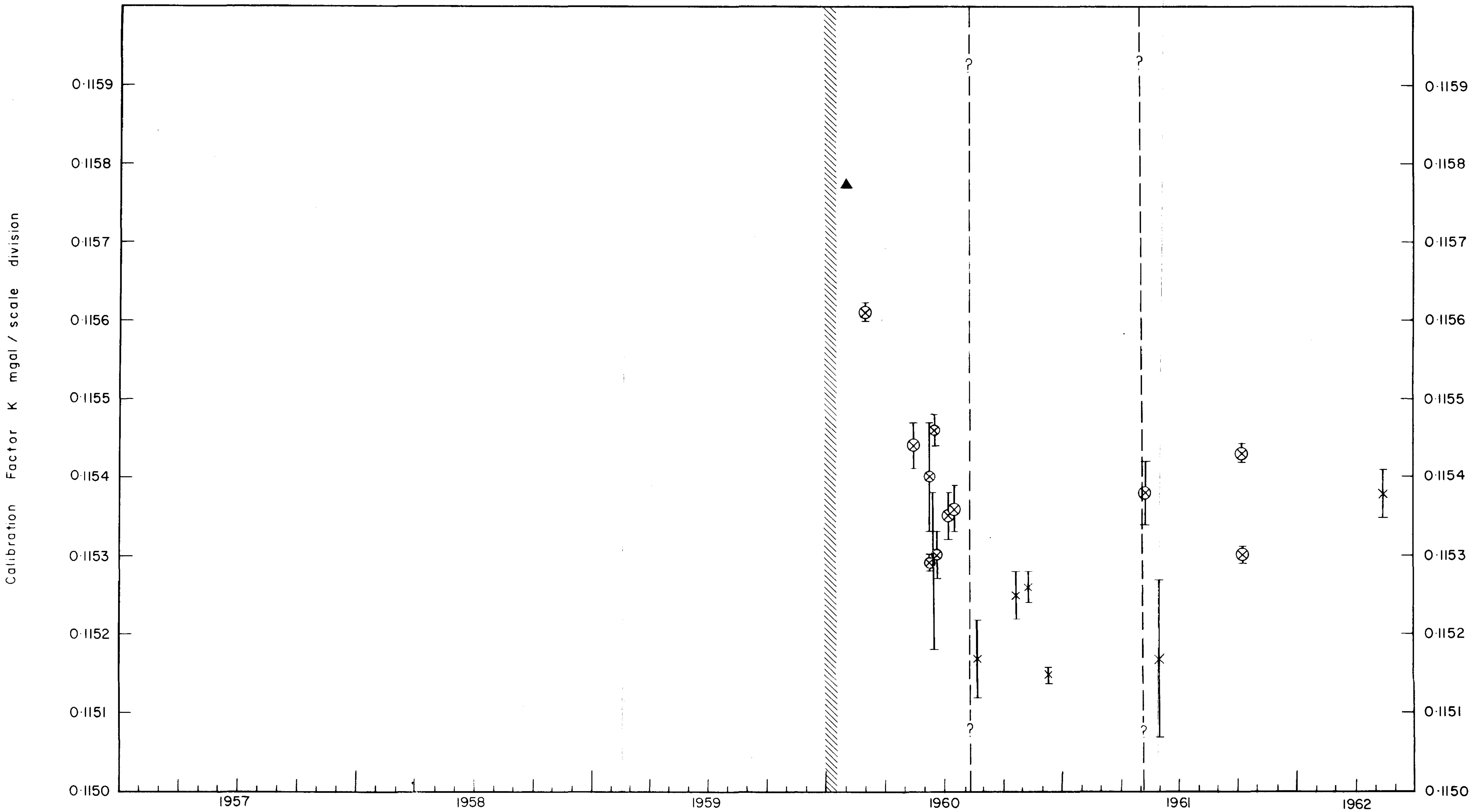
GRAVITY METER CALIBRATION RANGE

HOBART

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 24-9

To accompany Record N° 1965/19

PLATE 9



NOTE : Calibrations are plotted chronologically but may not be shown on exact date

LEGEND

Adjusted or repaired by manufacturer

Meter evacuated by B.M.R.

Exact date of evacuation not known

"Absolute" calibration factor supplied by manufacturer

Bureau calibration :

K + E_K

K

K − E_K

K = Calibration factor

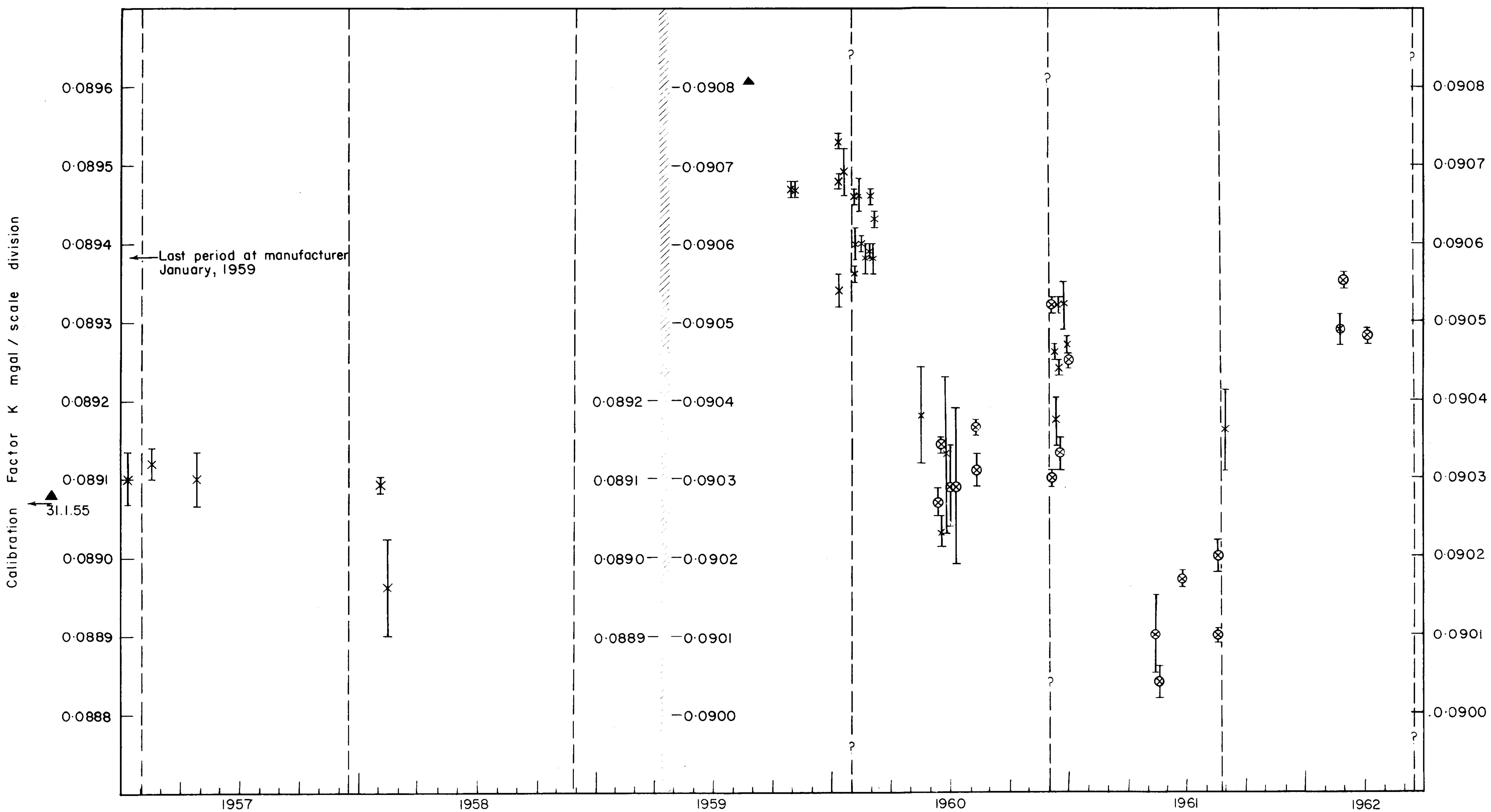
E_K = "Maximum probable error" in K

Melbourne calibration

SUMMARY OF CALIBRATION RESULTS
WORLD WIDE 35

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G65-85-1

To accompany Record N° 1965/19



NOTE: Calibrations are plotted chronologically but may not be shown on exact date

LEGEND

Adjusted or repaired by manufacturer

Meter evacuated by B.M.R.

Exact date of evacuation not known

"Absolute" calibration factor supplied by manufacturer

Bureau calibration:

K + E_K

K

K − E_K

K = Calibration factor

E_K = "Maximum probable error" in K

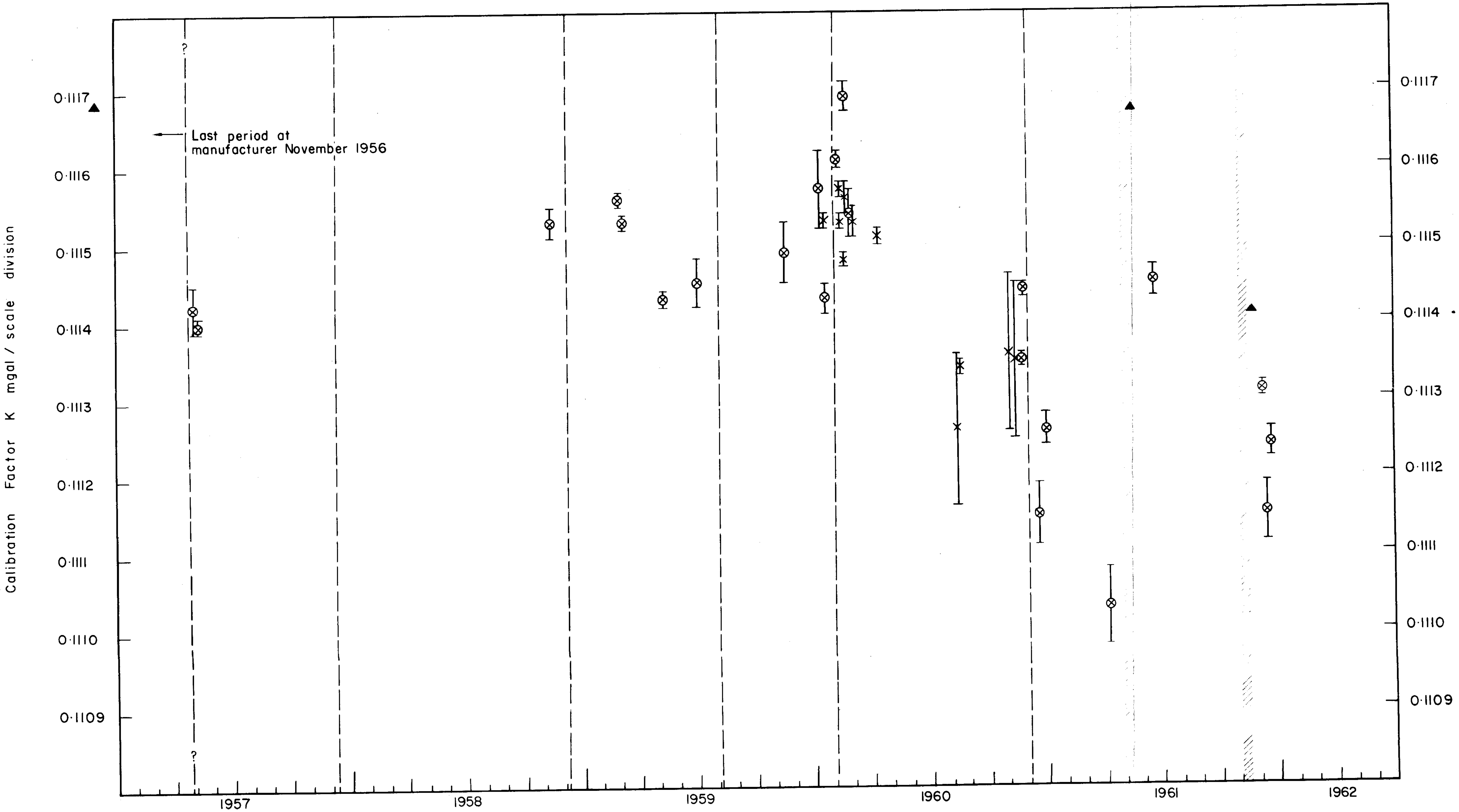
Melbourne calibration

SUMMARY OF CALIBRATION RESULTS WORDEN 61

Based on G65-85

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G65-85-2

To accompany Record N° 1965/19



NOTE : Calibrations are plotted chronologically but may not be shown on exact date

LEGEND

Adjusted or repaired by manufacturer

Meter evacuated by B.M.R.

Exact date of evacuation not known

"Absolute" calibration factor supplied by manufacturer

Bureau calibration :

$K + E_K$

K

$K - E_K$

K = Calibration factor

E_K = "Maximum probable error" in K

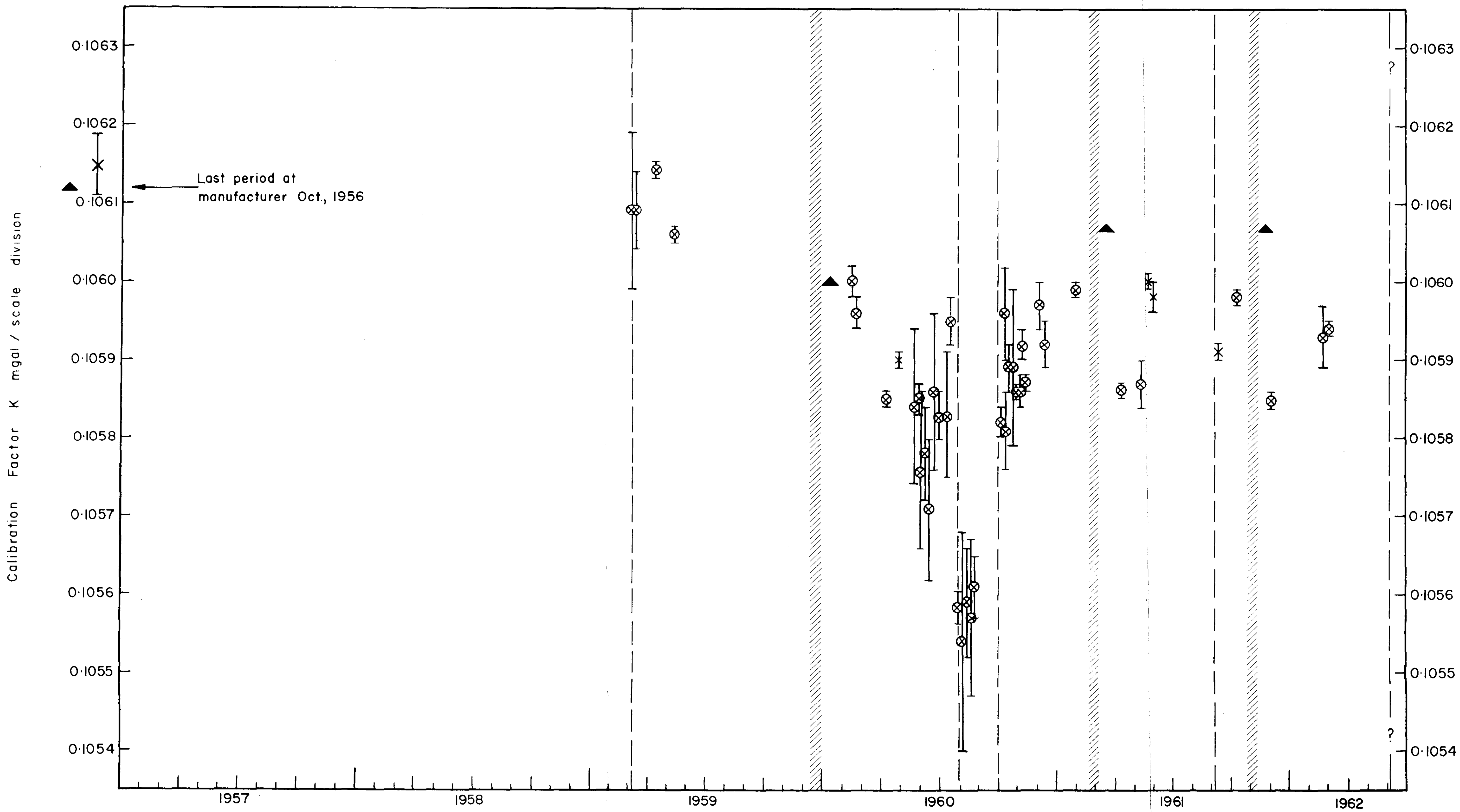
Melbourne calibration

SUMMARY OF CALIBRATION RESULTS WORDEN 140

Based on G65-85

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G65-85-3

To accompany Record N° 1965/19



NOTE : Calibrations are plotted chronologically but may not be shown on exact date

LEGEND

Adjusted or repaired by manufacturer

Meter evacuated by B.M.R.

Exact date of evacuation not known

"Absolute" calibration factor supplied by manufacturer

Bureau calibration :

$K + E_K$

K

$K - E_K$

K = Calibration factor

E_K = "Maximum probable error" in K

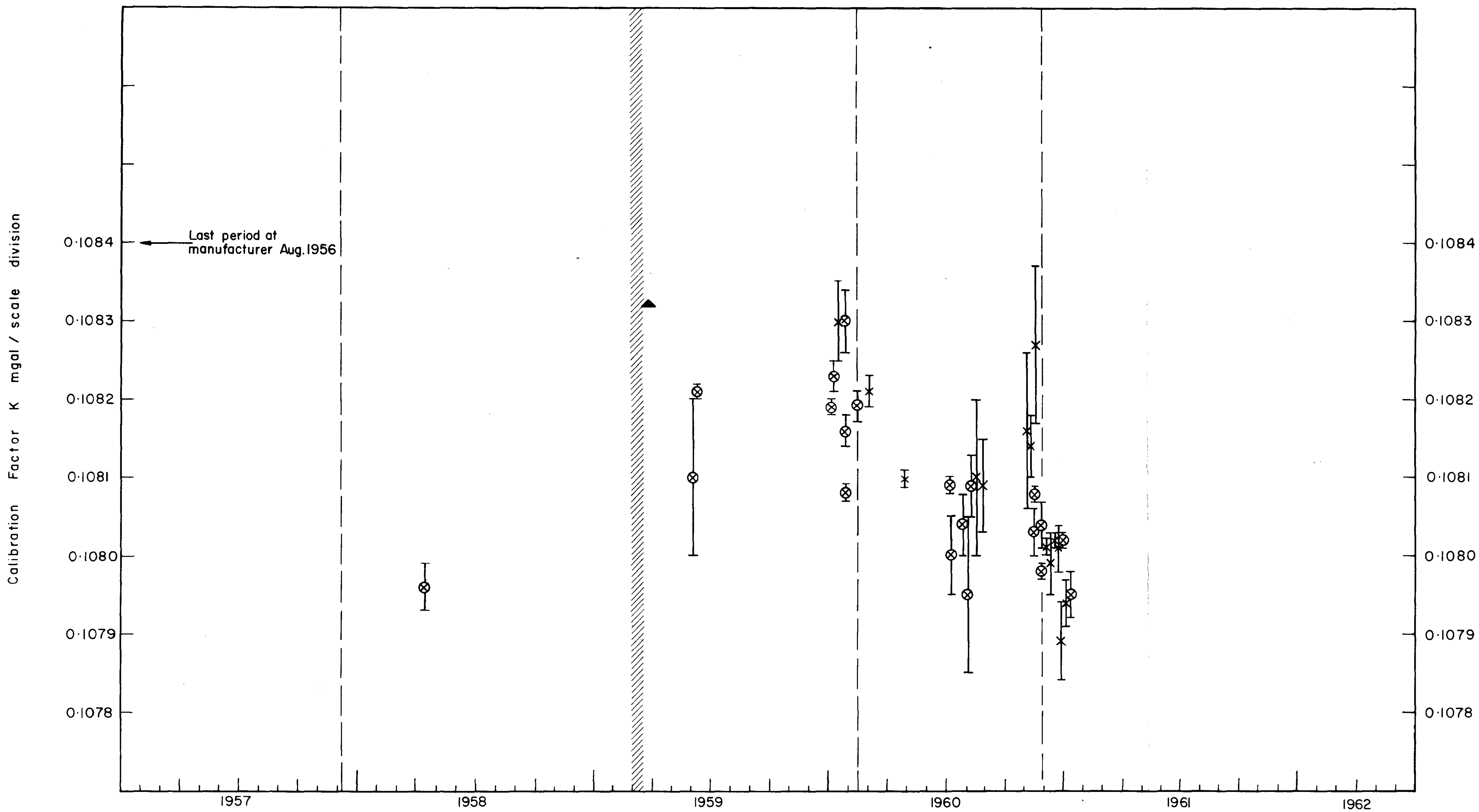
Melbourne calibration

SUMMARY OF CALIBRATION RESULTS
WORDEN 169

Based on G65-85

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics **G65-85-4**

To accompany Record N° 1965/19



NOTE : Calibrations are plotted chronologically but may not be shown on exact date

LEGEND

Adjusted or repaired by manufacturer

Meter evacuated by B.M.R.

Exact date of evacuation not known

"Absolute" calibration factor supplied by manufacturer

Bureau calibration :

$K + E_K$

K

$K - E_K$

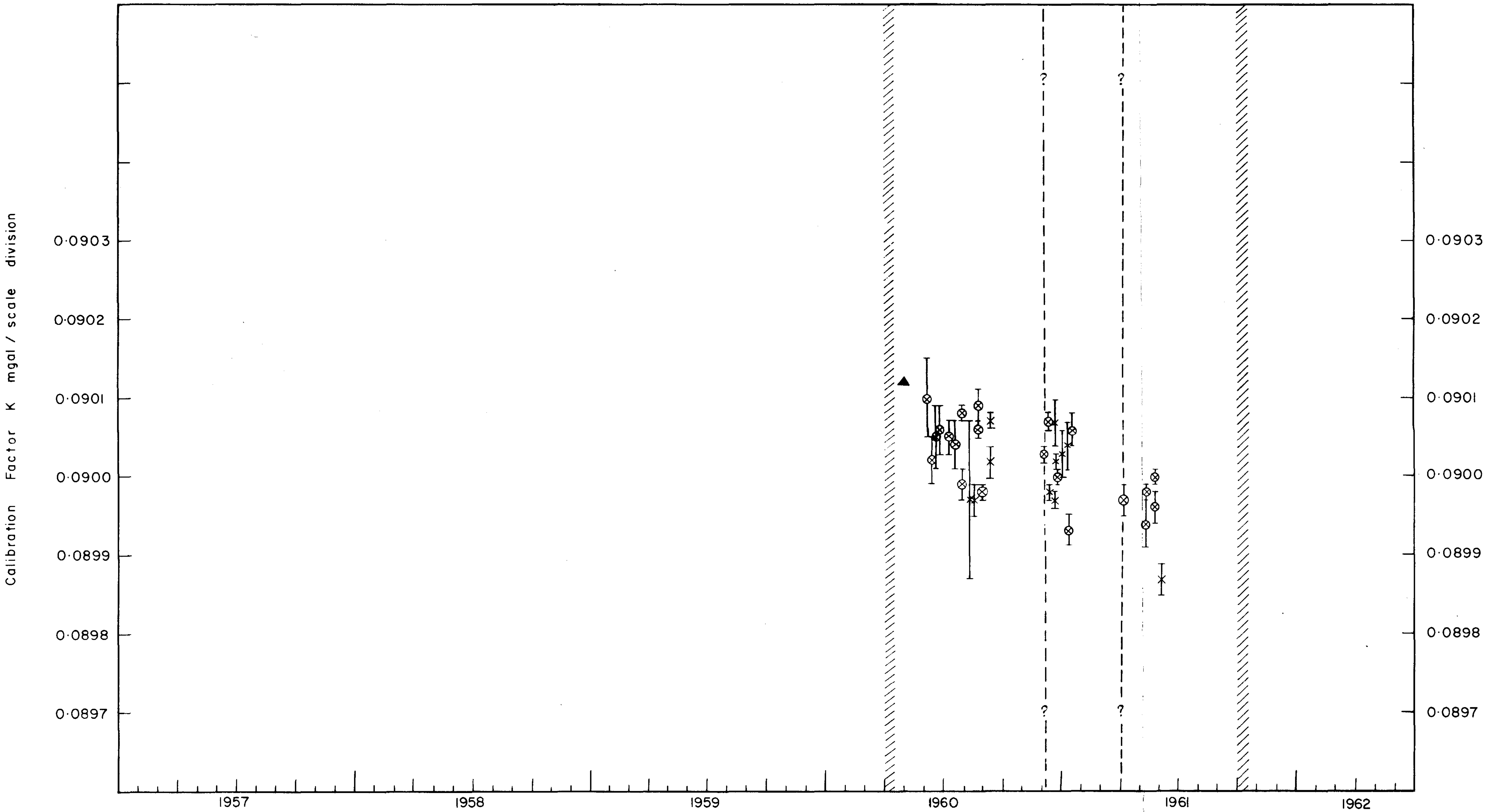
K = Calibration factor

E_K = "Maximum probable error" in K

Melbourne calibration

SUMMARY OF CALIBRATION RESULTS WORDEN 260

Based on G65-85



NOTE : Calibrations are plotted chronologically but may not be shown on exact date

LEGEND

Adjusted or repaired by manufacturer

Meter evacuated by B.M.R.

Exact date of evacuation not known

"Absolute" calibration factor supplied by manufacturer

Bureau calibration :

K + E_K

K

K − E_K

K = Calibration factor

E_K = "Maximum probable error" in K

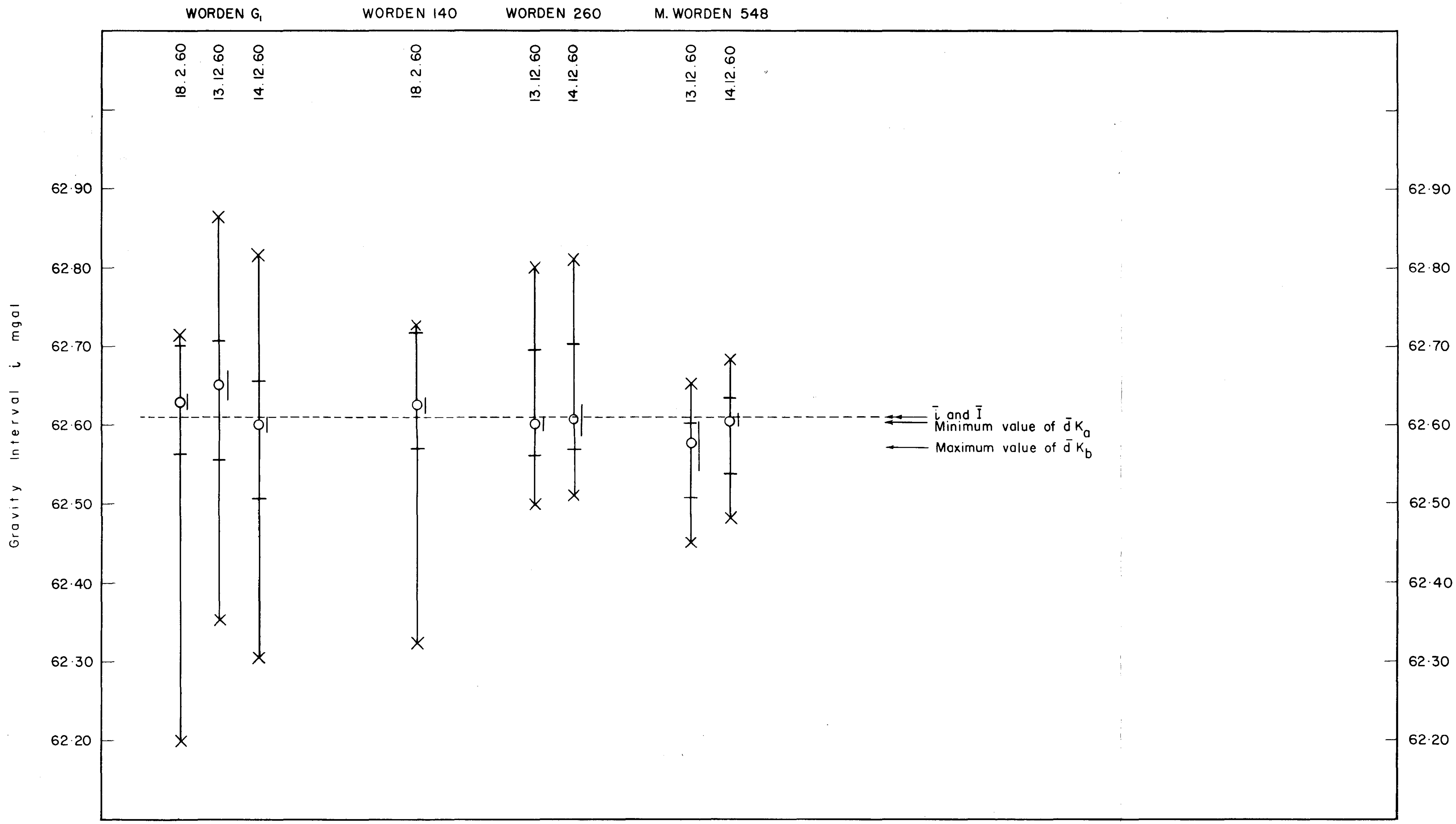
Melbourne calibration

SUMMARY OF CALIBRATION RESULTS
MASTER WORDEN 548

Based on G65-85

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics **G65-85-6**

To accompany Record N° 1965/19



LEGEND

- $\bar{d}\ K_A$
- $\bar{d}\ K_a$
- $\bar{d}\ \bar{K}$
- $\bar{d}\ K_b$
- $\bar{d}\ K_B$
- $\bar{d}\ \bar{K} \pm \bar{K} E_d$
- $\bar{I}$ Weighted Mean Value
- $\bar{i}$ Mean Value

K = Calibration factor of gravity meter (mgal / scale division)

K_A = "Maximum possible value" of K

K_a = "Maximum probable value" of K

$\bar{K}$ = "Most probable value" of K

K_b = "Minimum probable value" of K

K_B = "Minimum possible value" of K

d = Interval measured in scale division

$\bar{d}$ = Mean value of d

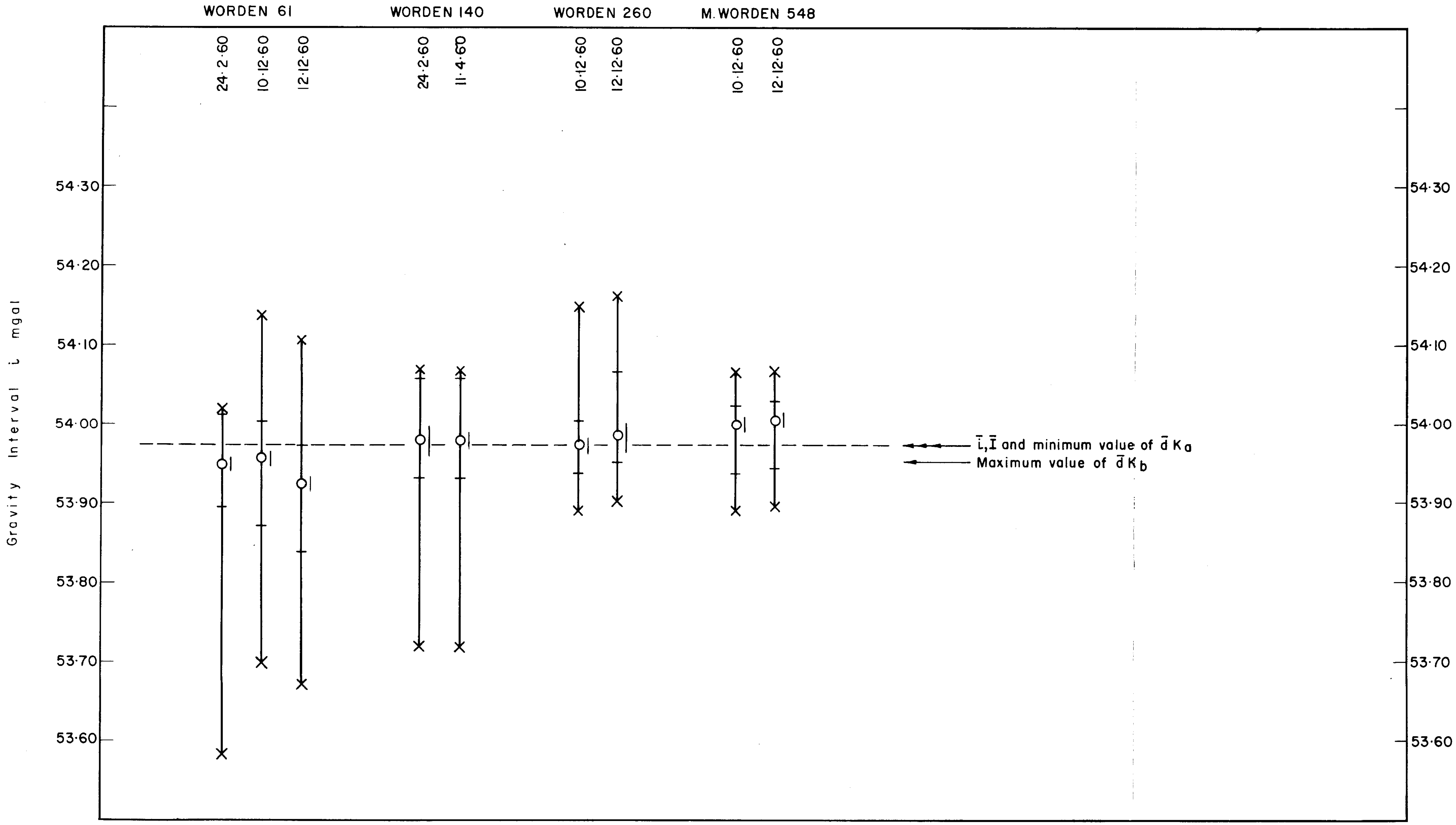
E_d = "Maximum probable error" in $\bar{d}$

GRAPHICAL SUMMARY OF MEASUREMENTS
ADELAIDE CALIBRATION RANGE

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G24-10-1

To accompany Record N° 1965/19

Based on G24-10



LEGEND

$\bar{d}\,K_A$

$\bar{d}\,K_a$

$\bar{d}\,\bar{K}$

$\bar{d}\,K_b$

$\bar{d}\,K_B$

$\bar{d}\,\bar{K} \pm \bar{K}E_d$

I Weighted Mean Value

$\bar{i}$ Mean Value

K = Calibration factor of gravity meter (mgal / scale division)

K_A = "Maximum possible value" of K

K_a = "Maximum probable value" of K

$\bar{K}$ = "Most probable value" of K

K_b = "Minimum probable value" of K

K_B = "Minimum possible value" of K

d = Interval measured in scale division

$\bar{d}$ = Mean value of d

E_d = "Maximum probable error" in $\bar{d}$

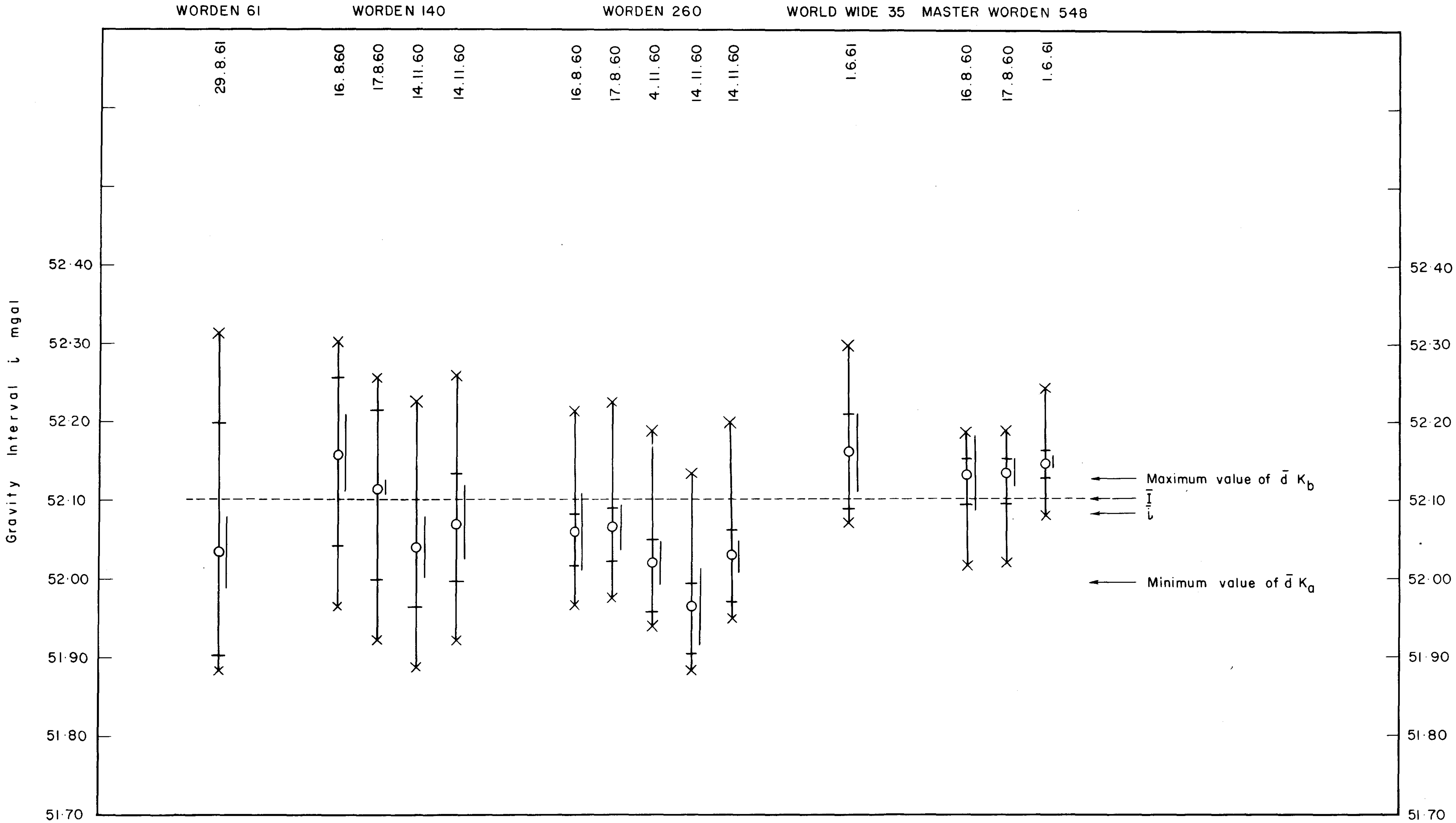
GRAPHICAL SUMMARY OF MEASUREMENTS

PERTH . CALIBRATION RANGE

Based on G24-10

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics **G24-10-2**

To accompany Record N° 1965/19



LEGEND

d̄ K_A
d̄ K_a
d̄ $\bar{K}$
d̄ K_b
d̄ K_B
d̄ $\bar{K} \pm \bar{K} E_d$
Ī Weighted Mean Value
ī Mean Value

K = Calibration factor of gravity meter (mgal / scale division)
K_A = "Maximum possible value" of K
K_a = "Maximum probable value" of K
$\bar{K}$ = "Most probable value" of K
K_b = "Minimum probable value" of K
K_B = "Minimum possible value" of K
d = Interval measured in scale division
$\bar{d}$ = Mean value of d
E_d = "Maximum probable error" in $\bar{d}$

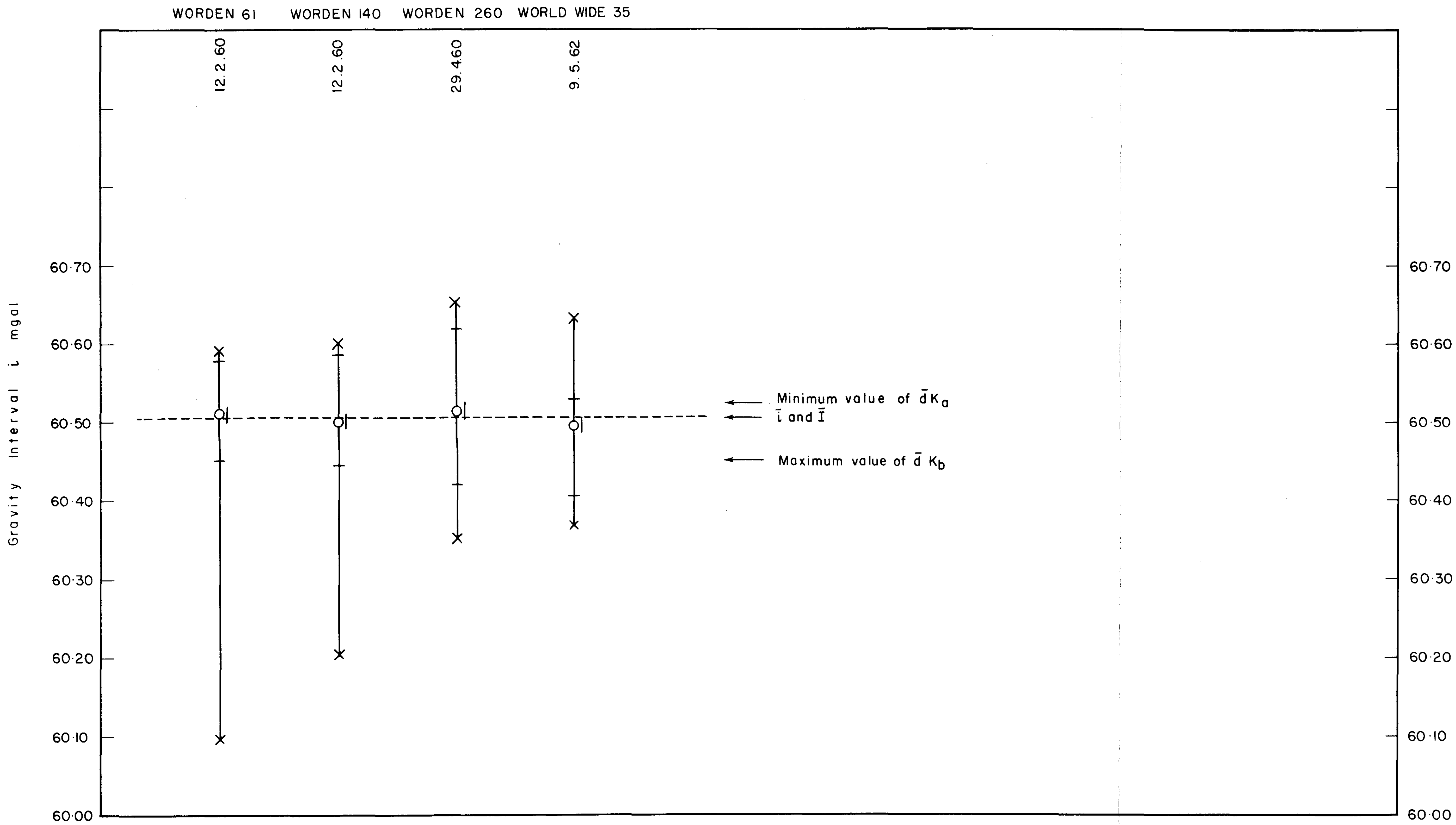
GRAPHICAL SUMMARY OF MEASUREMENTS
ALICE SPRINGS CALIBRATION RANGE

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G24-10-3

To accompany Record Nº 1965/19

Based on G24-10

PLATE 19



LEGEND

$\bar{d}\,K_A$

$\bar{d}\,K_a$

$\bar{d}\,\bar{K}$

$\bar{d}\,K_b$

$\bar{d}\,K_B$

$\bar{d}\,\bar{K} \pm \bar{K} E_d$

--- $\leftarrow \bar{I}$ Weighted Mean Value

$\leftarrow \bar{\iota}$ Mean Value

K = Calibration factor of gravity meter (mgal/scale division)

K_A = "Maximum possible value" of K

K_a = "Maximum probable value" of K

$\bar{K}$ = "Most probable value" of K

K_b = "Minimum probable value" of K

K_B = "Minimum possible value" of K

d = Interval measured in scale division

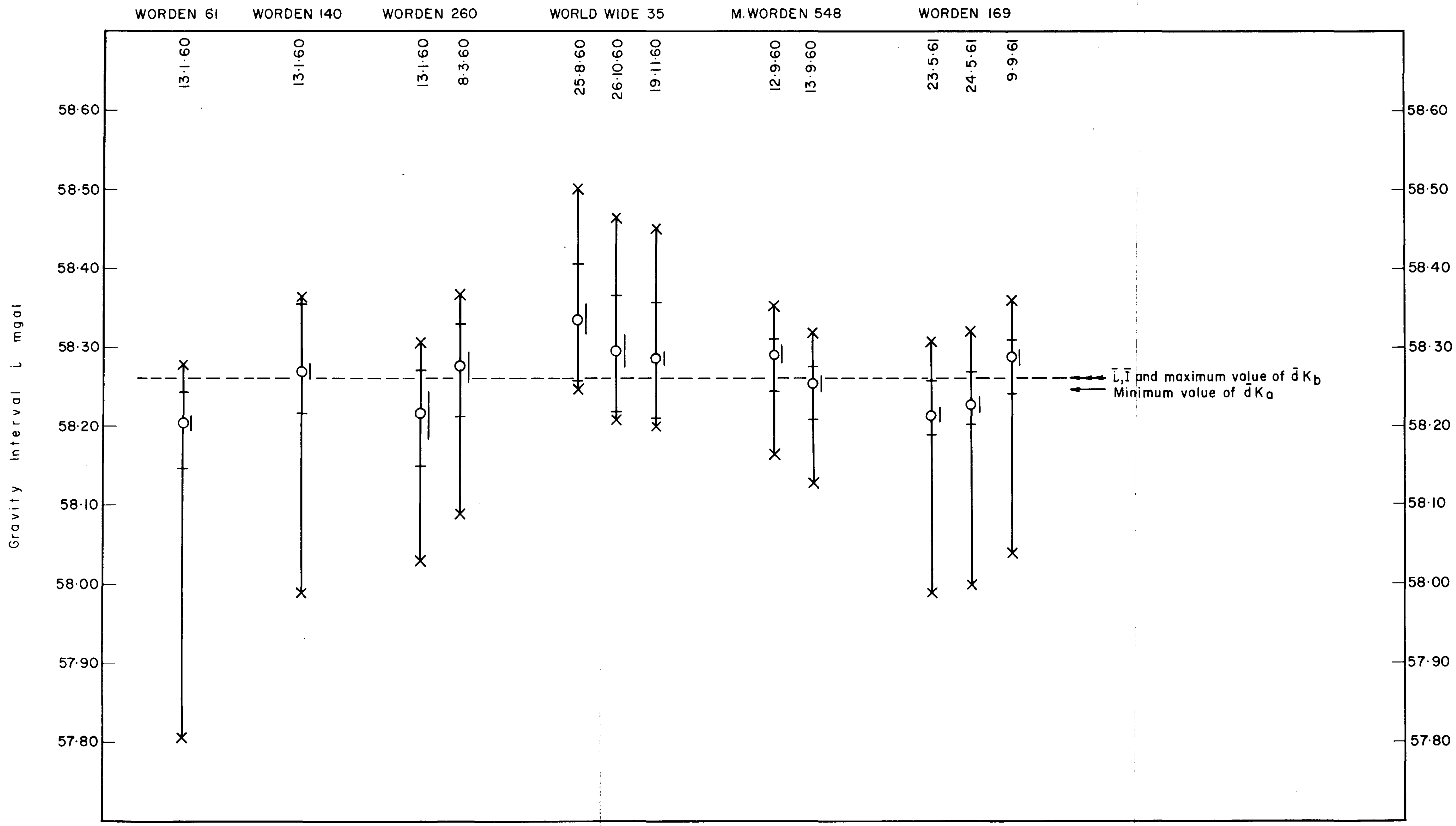
$\bar{d}$ = Mean value of d

E_d = "Maximum probable error" in $\bar{d}$

GRAPHICAL SUMMARY OF MEASUREMENTS
TOWNSVILLE CALIBRATION RANGE

Based on G24-10

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G24-10-4



LEGEND

$\bar{d}\ K_A$

$\bar{d}\ K_a$

$\bar{d}\ \bar{K}$

$\bar{d}\ K_b$

$\bar{d}\ K_B$

$\bar{d}\ \bar{K} \pm \bar{K} E_d$

I Weighted Mean Value

ι Mean Value

K = Calibration factor of gravity meter (mgal/scale division)

K_A = "Maximum possible value" of K

K_a = "Maximum probable value" of K

$\bar{K}$ = "Most probable value" of K

K_b = "Minimum probable value" of K

K_B = "Minimum possible value" of K

d = Interval measured in scale division

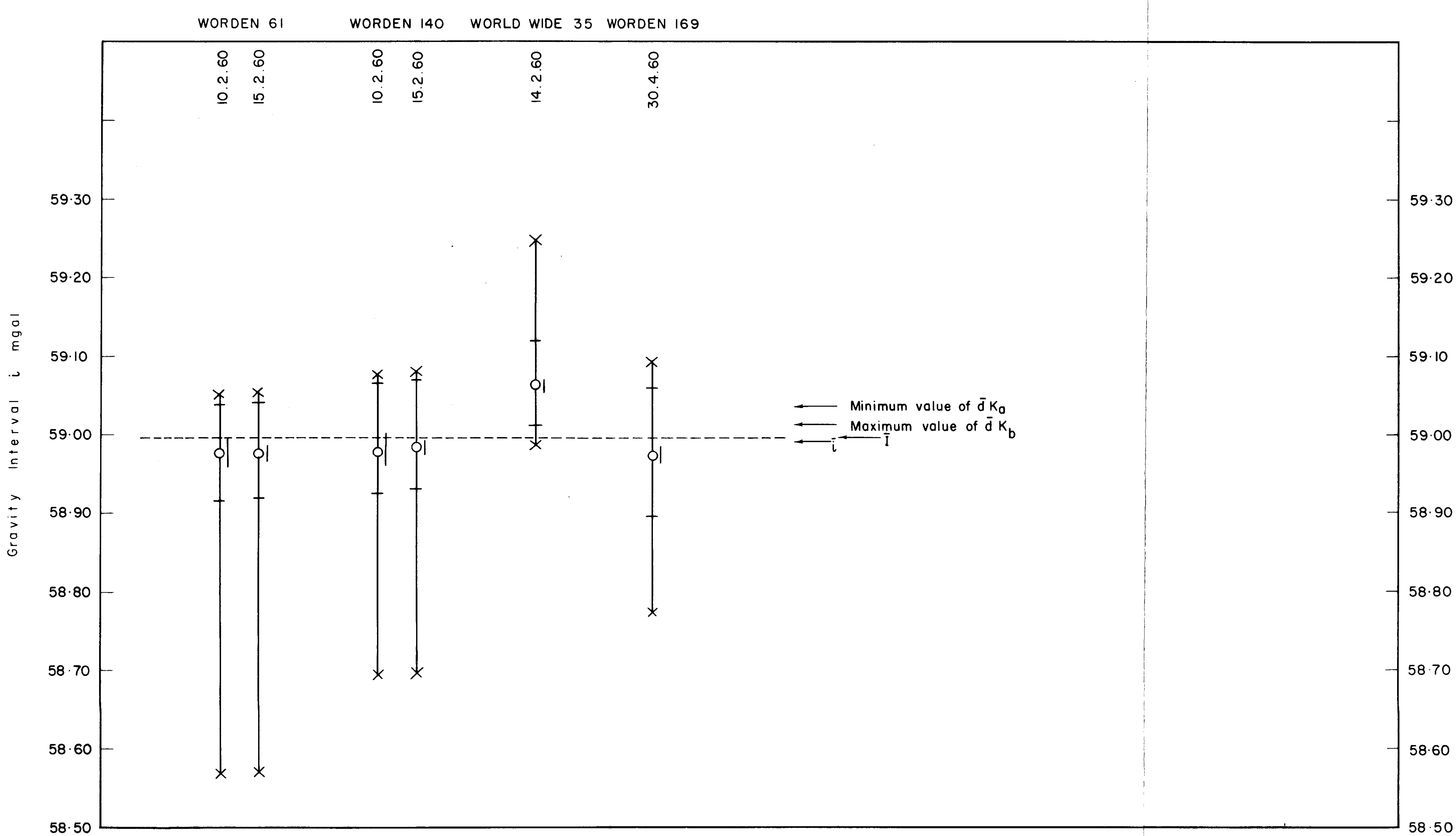
$\bar{d}$ = Mean value of d

E_d = "Maximum probable error" in $\bar{d}$

GRAPHICAL SUMMARY OF MEASUREMENTS
BRISBANE CALIBRATION RANGE

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics **G24-10-5**

To accompany Record No 1965/19



LEGEND

$\bar{d}\ K_A$

$\bar{d}\ K_a$

$\bar{d}\ \bar{K}$

$\bar{d}\ K_b$

$\bar{d}\ K_B$

$\bar{d}\ \bar{K} \pm \bar{K} E_d$

--- $\leftarrow \bar{I}$ Weighted Mean Value

$\leftarrow \bar{i}$ Mean Value

K = Calibration factor of gravity meter (mgal / scale division)

K_A = "Maximum possible value" of K

K_a = "Maximum probable value" of K

$\bar{K}$ = "Most probable value" of K

K_b = "Minimum probable value" of K

K_B = "Minimum possible value" of K

d = Interval measured in scale division

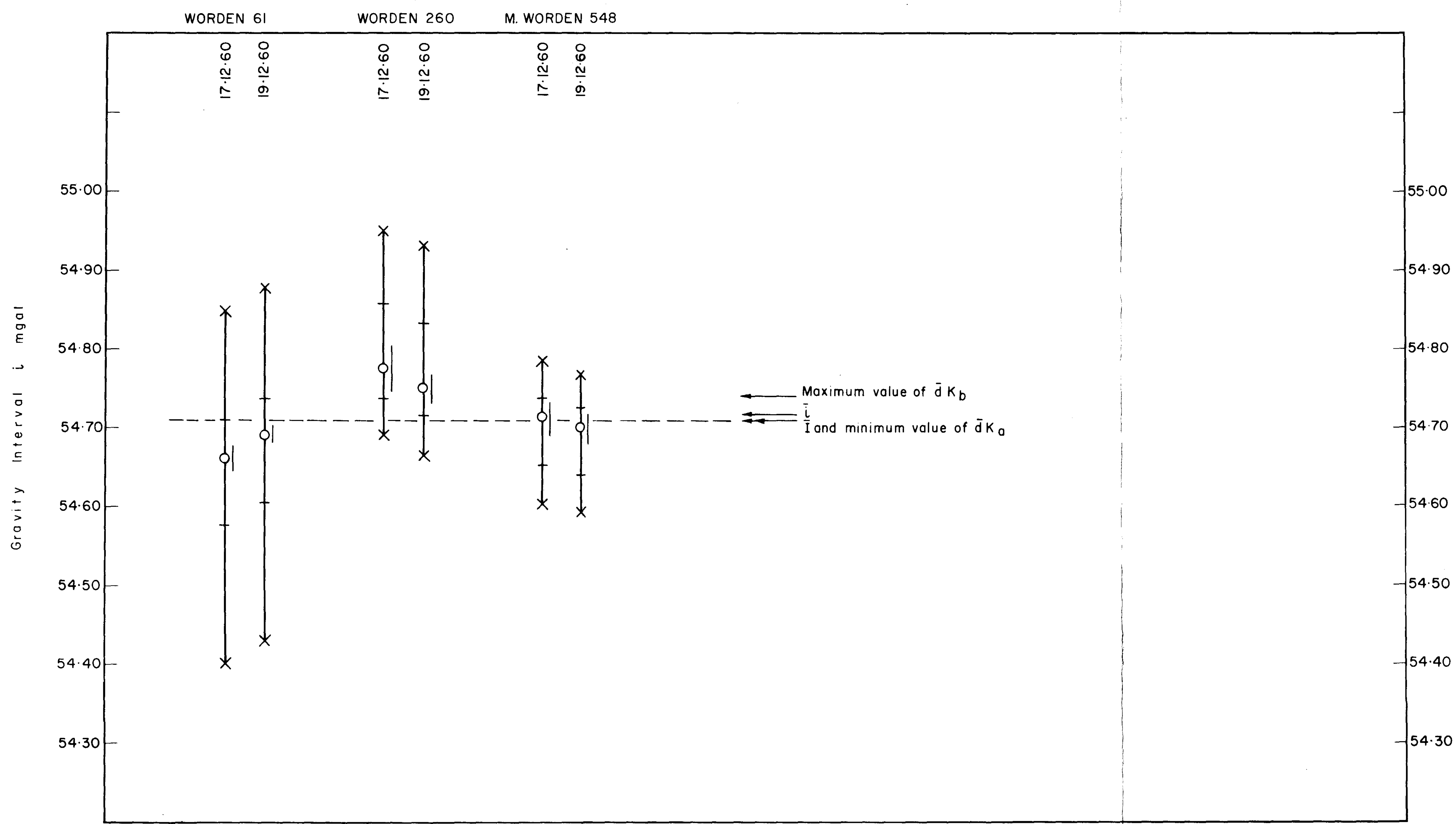
$\bar{d}$ = Mean value of d

E_d = "Maximum probable error" in $\bar{d}$

GRAPHICAL SUMMARY OF MEASUREMENTS
SYDNEY CALIBRATION RANGE

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics **G 24-10-6**

To accompany Record No 1965/19



LEGEND

$\bar{d}\ K_A$

$\bar{d}\ K_a$

$\bar{d}\ \bar{K}$

$\bar{d}\ K_b$

$\bar{d}\ K_B$

$\bar{d}\ \bar{K} \pm \bar{K} E_d$

$\leftarrow \bar{I}$ Weighted Mean Value

$\leftarrow \bar{i}$ Mean Value

K = Calibration factor of gravity meter (mgal / scale division)

K_A = "Maximum possible value" of K

K_a = "Maximum probable value" of K

$\bar{K}$ = "Most probable value" of K

K_b = "Minimum probable value" of K

K_B = "Minimum possible value" of K

d = Interval measured in scale division

$\bar{d}$ = Mean value of d

E_d = "Maximum probable error" in $\bar{d}$

GRAPHICAL SUMMARY OF MEASUREMENTS
HOBART . CALIBRATION RANGE

Based on G24-10

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 24-10-7
To accompany Record N° 1965/19