COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1966/117

PROBLEMS ASSOCIATED WITH ANTARCTIC GRAVITY MEASUREMENTS

by

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SUMMARY

The problems discussed are basically those of gravity meter performance under extremes of operational and climatic conditions.

Two problems of particular concern are examined. These are the construction of the overall gravity meter drift curve over long intervals of travel between Melbourne and the Antarctic bases and the study of the behaviour of the gravity meter when subject to extreme and sudden temperature changes.

Uncertainty in the currently accepted method of applying the gravity meter large-dial calibration factor is discussed.

Other peculiarities in behaviour between gravity meters are mentioned. A study of other problems is included in a programme of gravity meter performance tests being carried out by the Bureau of Mineral Resources.

1. PROBLEMS ASSOCIATED WITH ANTARCTIC GRAVITY MEASUREMENTS

The material contained in this Record was originally presented as a paper at the Gravity Symposium at the A.N.Z.A.A.S. Meeting in Hobart in 1965.

The problems associated with gravity measurements between Australia and the Antarctic stations and within Antarctica are basically problems of gravity meter performance under extremes of operational and climatic conditions.

The Bureau of Mineral Resources (BMR) has carried out such measurements with quartz gravity meters since 1953. The results for the work within Antarctica, generally obtained in connection with ice thickness measurements, have been published by Goodspeed (1958), Goodspeed & Jesson (1959), Jesson (1959), and Walker (in preparation). A study of the gravity ties between Australia and the Antarctic bases has been made by Langron (1966). There are many aspects common to both of these types of work, but this paper is more concerned with the problems associated with evaluating gravity intervals between Australia - and usually this means the National Gravity Base Station (N.G.B.S.), Melbourne - and the Antarctic stations.

The problems associated with temperature, ageing, pressure, and transport effects become even more accentuated when one considers the conditions under which the work is carried out in Antarctica.

As regards temperature effects, Inghilleri (1959) and Gantar, Morelli, and Pisani (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 $10^{\circ}C$. This effect has been confirmed by later workers, e.g. Damrel (1960).

With regard to the 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.

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. It is felt that this factor could be significant in the work of the BMR because of the necessarily long periods between evacuations of the gravity meters. It has not been practicable to carry out evacuations on gravity meters whilst in Antarctica and it has been noted that the pressures inside some instruments on return to Melbourne have often been well above the figure recommended by the maker.

With regard to transport effects, there is some evidence to suggest that the calibration factor is affected by the mode of transport used to convey the gravity meter. Little tangible evidence is available about this effect but it is known from work done in Australia, for example, that the gravity interval as measured between two stations using a helicopter for transport is generally different from that measured using a ground vehicle.

Applying these remarks to the BMR Antarctica work it has been found, for example, that when the gravity meter is removed from the heated cab of the snow vehicle (or ship) a reading has to be obtained within three minutes, otherwise it becomes impossible to null the beam because of drift. Drift rate could be complicated further if an intermediate stage (say by helicopter or launch) is involved in transport between ship and mainland. In addition, of course, these various modes of transport probably have a significant effect on the 'rhythm' of the gravity meter (the term 'rhythm' is used in the same sense as used by the French for the distinction between stationary and transported drift). The difficulty of obtaining an accurate reading is also increased because of the tendency of the instrument telescope and the observer's spectacles to fog up quickly and because of the intense background glare, which often makes it difficult to see the graticule clearly.

However, two problems are of particular concern here : the construction of the overall gravity meter drift curve during the period of travel between Melbourne and the Antarctic bases; and the study of the behaviour of the gravity meter when subject to extreme and sudden temperature changes. The first of these problems is also discussed by Williams, Goodspeed, and Flavelle (1961), from whom most of the following comments on this problem are drawn.

In order to compute the gravity interval from N.G.B.S., Melbourne, to the corresponding Antarctic station it is necessary to interpolate a drift curve over the interval that the gravity meter is away from the base station. The 'most likely' interpolation, in the statistical sense, depends on two factors :

(a) The probable accuracy of the assumed drift curve, bearing in mind the physical causes of the drift and how they may be affected by temperature changes, vibration encountered in transportation, etc.

(b) The probable accuracy of the observed readings, assuming a particular drift curve and regarding deviations from this curve as due to such causes as random errors in reading.

The first of these factors is difficult to assess. It is generally assumed that the basic drift of a gravity meter, measured under ideal conditions (e.g. constant temperature and no vibration) and allowing for tidal effects, is produced by fatigue of the components, and is a linear function of time. More certainly, any deviation from linearity is more likely to be measurable over periods of months than over a few days. Under the more usual conditions where the instrument is subject to movement, vibration, and temperature changes between readings, this linear drift is disturbed. The effect of external temperature changes has been mentioned.

The effects of mechanical vibration and shock are less well known. Experience suggests that, up to a minimum acceleration level which is not often exceeded in normal transport, the effects are very small but that, beyond that level, changes in drift rate lasting for intervals of a few days, and almost instantaneous 'jumps' of a few tenths of a milligal, can be produced by shock or excessive vibration.

In principle, drift curves of considerable complexity could be fitted to the observed data in order to increase factor (b) by reducing the scatter of the observations about the drift curves. Such curves would follow the variations which have been attributed to temperature changes. Where drift information exists at intermediate stations it has been used to construct the interpolated part of the drift curve, otherwise a straight line interpolation has been used.

It is necessary, of course, to have reliable calibration of the large dial of the gravity meter. The large dials of some of the gravity meters have been calibrated over a large known gravity interval (e.g. from Hobart to Brisbane). In addition the large dial/small dial ratios for some meters have been measured at several latitudes. The large dial calibration curve over this range of latitude has been plotted using values for the small dial based on calibrations on Australian ranges established by Barlow (1965). There is the usual fairly large scatter associated with values for this ratio, but in one instance the large dial calibration curves so constructed differ markedly from the maker's curves. In the absence of sufficient information on this point the maker's curve has been used, but it is felt that a source of considerable error could lie in this stage of the reduction.

With regard to the effect of extreme and sudden temperature changes, tests carried out so far show that the drift of the various gravity meters is downward with decreasing temperature, but at a different and a non-uniform rate. This effect becomes very marked at the low temperature experienced in Antarctica. It is also known, that there is a certain 'recovery time' (which could be of the order of several weeks) in relation to the calibration of the meter when it is brought back to warmer temperatures.

Tests on Worden 169 gravity meter showed that the meter exhibited a steady drift rate when kept in air at a constant temperature, but that when the air temperature was changed suddenly the meter showed a very high drift rate for about 36 hours before settling down to a steady rate, which was different from that at the previous temperature.

Although only a few tests have been made on the other Worden meters, their drift rates also become erratic after a temperature shock; however, from the field results obtained with those meters, it is apparent that there are some significant differences in behaviour between them and Worden 169. The quantitative analysis of these tests and the full series of tests have not been completed but these results will no doubt have an important bearing on the final values for work in Antarctica.

Plates 1-4 illustrate some of the above points and the methods which have been used to construct some of the drift curves. Plate 1 is a plot of the behaviour of Master Worden 548 during a cold test at the BMR Footscray Laboratory, Melbourne. The meter was not thermostatically controlled. Readings decreased by approximately 250 divisions at the lower temperature and then gradually recovered once the meter was returned to room temperature. The curve indicates that at least a week is required for complete recovery of the meter.

Results of tests carried out in the cold chamber at Point Cook using Master Worden 548 and Worden 169 were even more interesting. Both instruments were read and then placed for one day in the cold chamber at a temperature of $-60^{\circ}C$. The Master Worden was thermostatically controlled to $-21^{\circ}F$ and here the dial readings decreased by approximately 260 divisions. On the other hand, Worden 169 showed a slight rise of about 35 dial divisions. A recovery curve was not plotted for these tests.

Plate 2 shows the drift curve for Worden gravity meter No. 169 for the period January to May 1955; it is one of the most regular drift curves obtained, perhaps because the period between the repeat sets of readings at Melbourne is relatively short.

Plate 3 shows the drift curve of the same meter for the period March, 1956 to June, 1959. Here a smooth extrapolated curve has been constructed using intermediate data for drift control. It can be seen that the measured difference between the Melbourne and Mawson drift curves constructed on this basis could vary by up to 5 milligals.

Plate 4 shows the drift curve for Worden gravity meter No. 260. Here the instrument drift as indicated by repeat readings at intermediate stations was contrary to that obtained for the repeat readings at Melbourne. In this case, the drift was assumed to be linear between successive control points and lines of best fit were drawn through points obtained by re-occupation of field stations. The composite curve was drawn (shown dashed in the illustration) to obtain the gravity difference between Melbourne and the field stations. The line joining the two sets of readings at Melbourne is only slightly curved and the composite curve is balanced about this line. Another calculation was carried out by averaging the linear drift for Melbourne and the drift obtained by re-occupation of the intermediate field stations. The gravity intervals between N.G.B.S. and Mawson obtained by these two methods differ by a maximum of 2.1 milligals.

Plate 5 shows the closure diagram for Antarctic gravity ties and is included for completeness. Gravity values have been established in the first place for six stations at which several measurements were made. These values have been considered as 'fixed' for the purposes of adjusting data at other stations. No attempt has been made at this stage to perform a rigorous adjustment using data from other sources (e.g. Woolard & Rose, 1963).

Because of the factors already discussed it is concluded that the values obtained for the gravity intervals between Melbourne and the Antarctic bases could be in error by as much as 7 to 8 milligals. The accuracy of the measured intervals between Antarctic stations is better than this; possibly ±2 milligals. A comparison between BMR values and those obtained by other workers such as Stahl (1954), Woollard and Rose (1963), Sparkman (Thiel et al, 1959), etc. for the principal gravity intervals indicates that in almost all instances the BMR values are slightly higher. This could be due to slight differences in calibration factors of the instruments.

An attempt was made to use a thermostatically controlled meter (Master Worden 548) during one round trip of Antarctic stations, but because of difficulties experienced with charging facilities in the ship the gravity meter could not be kept on heat, so the advantage of using this type of meter was lost.

It is highly desirable that the six 'fixed' stations (indicated in Plate 5) be occupied with La Coste and Romberg gravity meters and pendulum apparatus, or both, as soon as possible. It is hoped to be able at least to commence the work with the La Coste and Romberg meters in the near future.

In addition, a programme of gravity meter performance tests is being carried out, and although it will be some time before these are completed and analysed, it is felt that results of such work are essential for a full evaluation of Antarctic gravity data.

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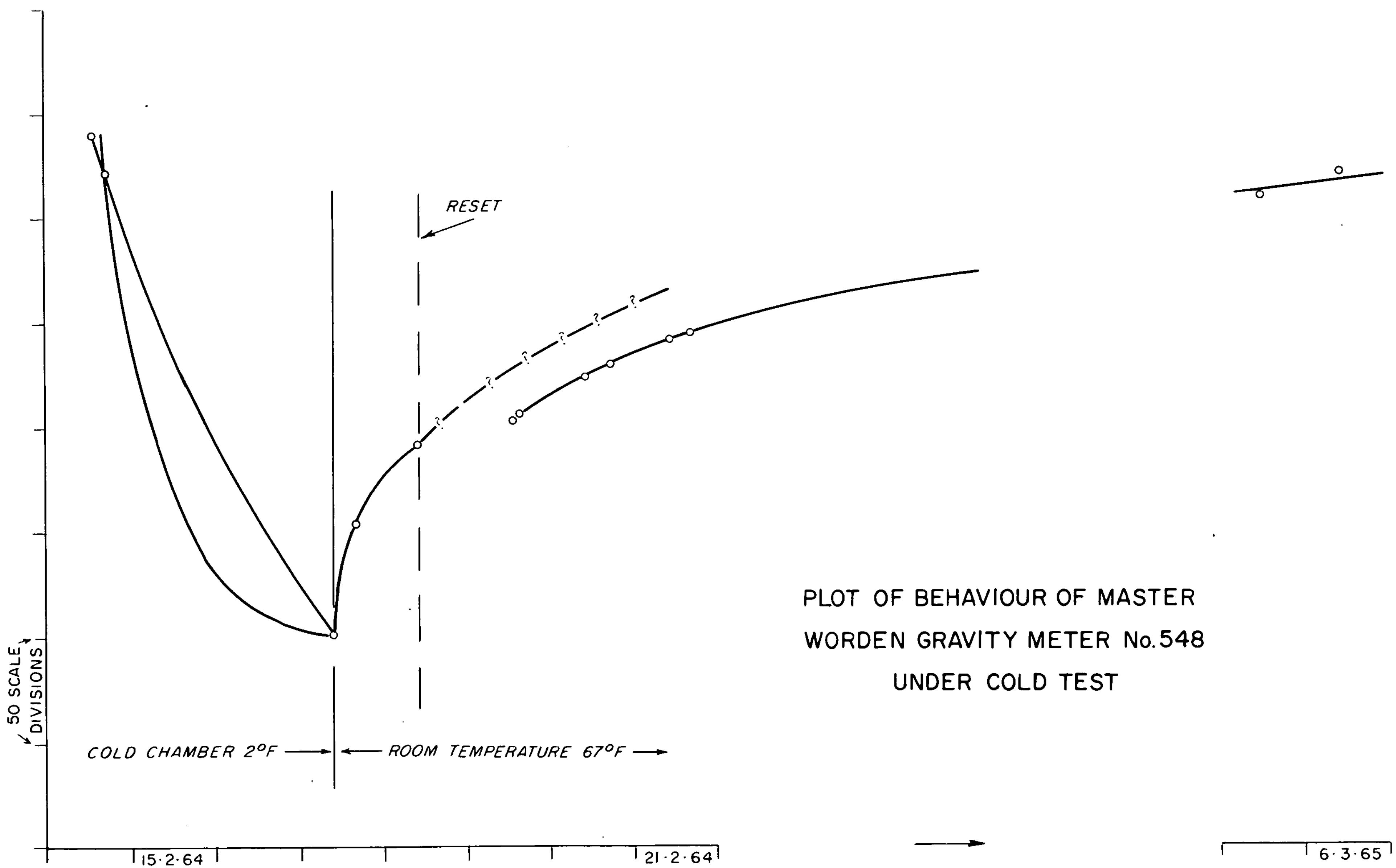
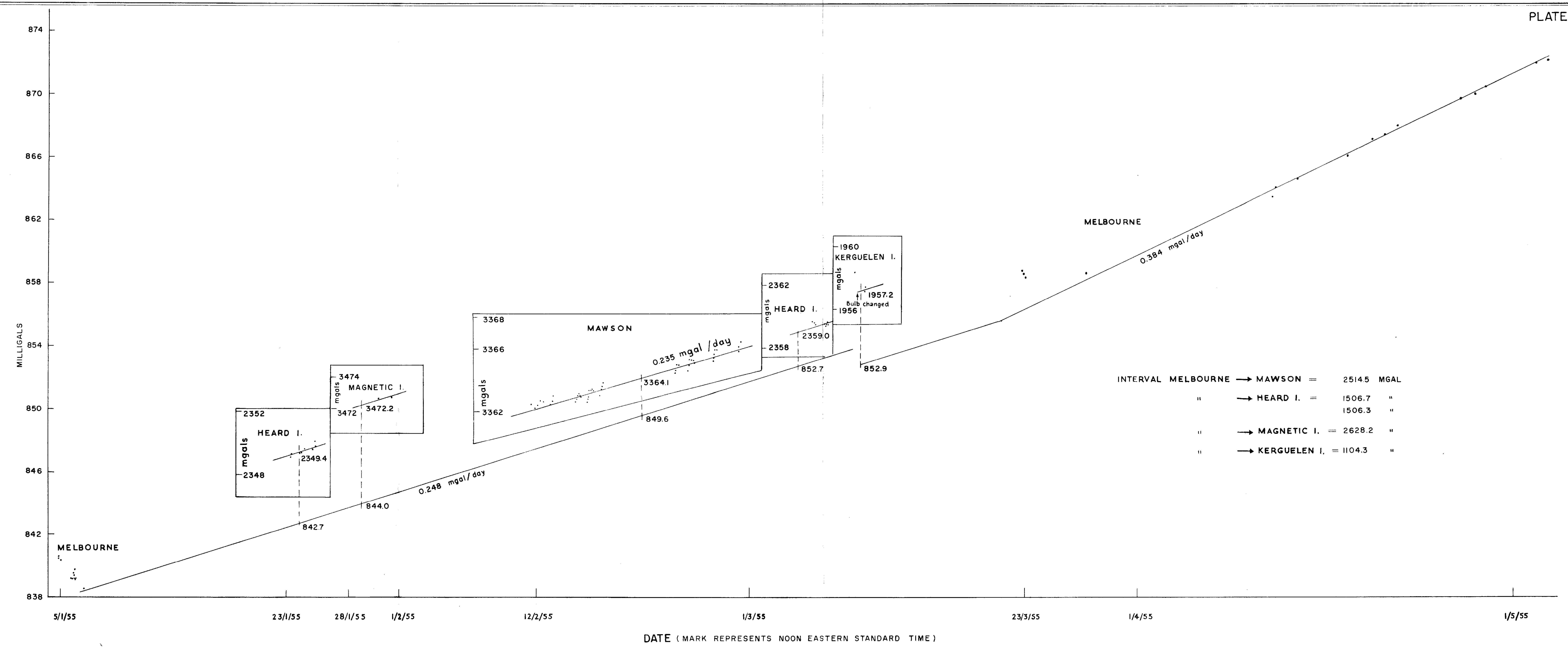


PLOT OF BEHAVIOUR OF MASTER
WORDEN GRAVITY METER No. 548
UNDER COLD TEST

PLATE 2



DRIFT CURVE

WORDEN GRAVITY METER No. 169

JANUARY-MAY, 1955

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics. G 265-4

TO ACCOMPANY RECORD NO 1966/117

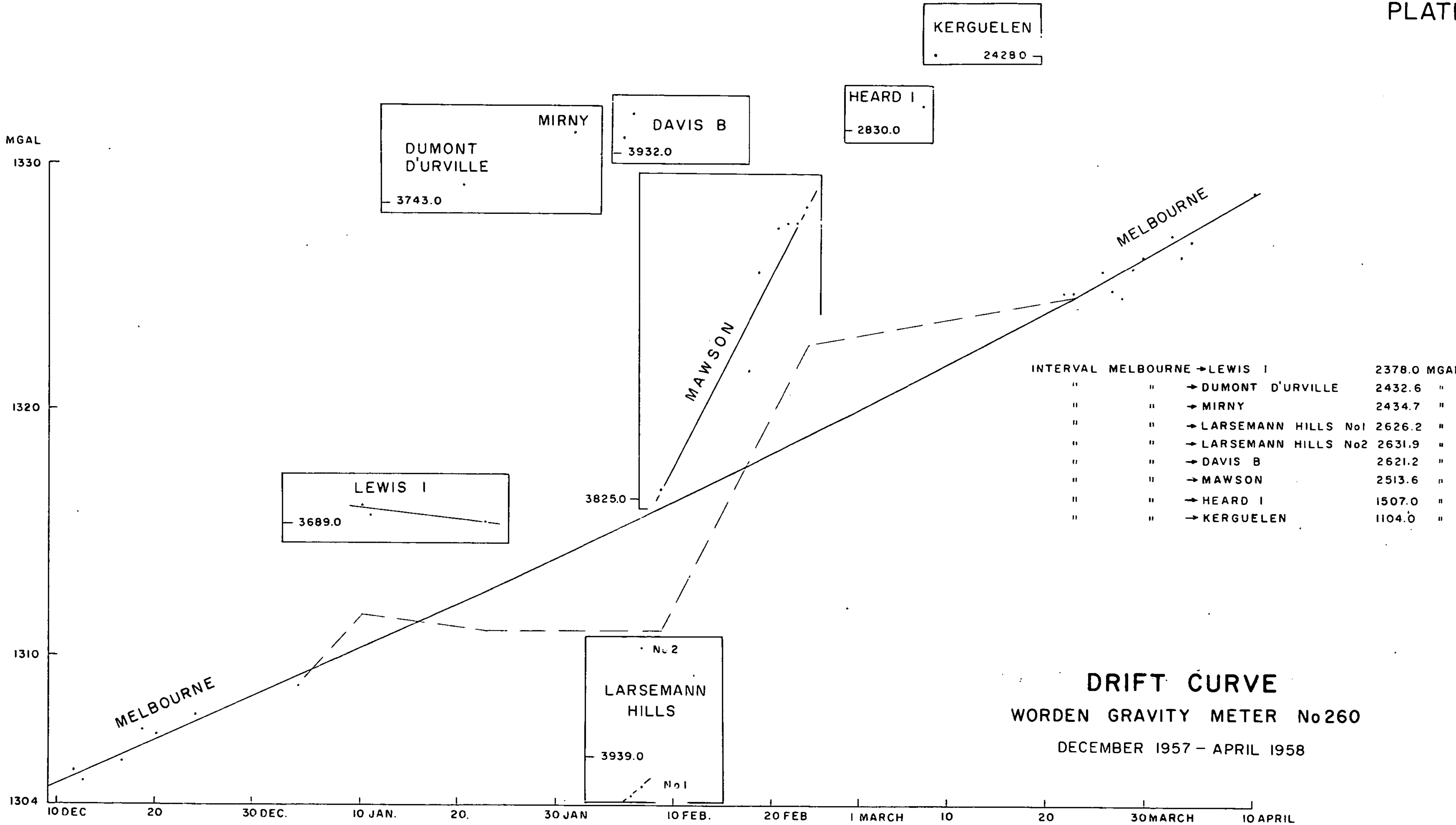
DRIFT CURVE

WORDEN GRAVITY METER No.169

MARCH 1956 – JUNE 1959

Geophysical Branch, Bureau of Mineral Resources, Geology and Geophysics G 265-94

PLATE 4



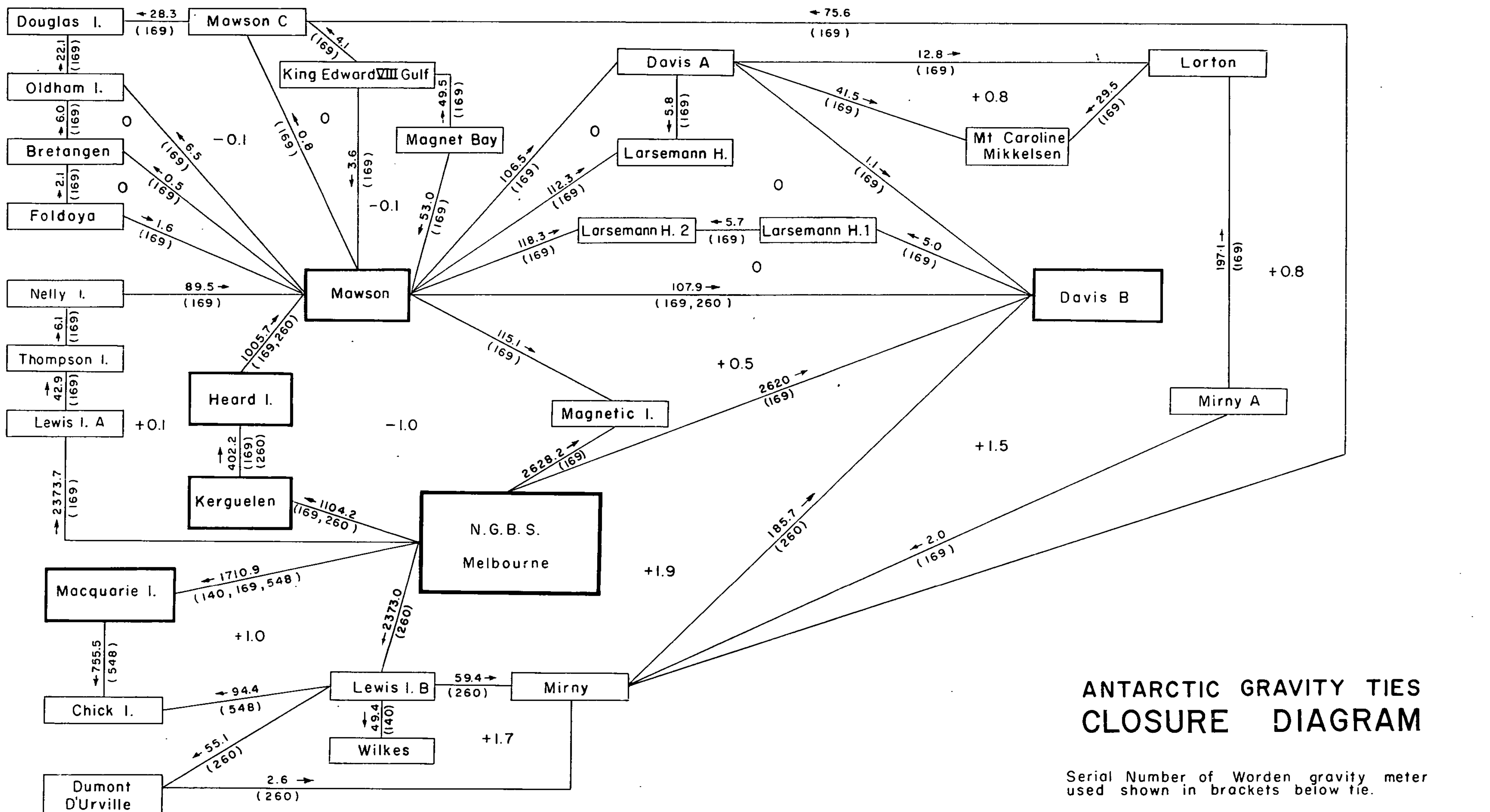
DRIFT CURVE

WORDEN GRAVITY METER No 260

DECEMBER 1957 – APRIL 1958

GEOPHYSICAL BRANCH, BUREAU OF MINERAL RESOUCES, GEOLOGY AND GEOPHYSICS G 265-91

TO ACCOMPANY RECORD NO 1966/117



ANTARCTIC GRAVITY TIES
CLOSURE DIAGRAM

Serial Number of Worden gravity meter used shown in brackets below tie.

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