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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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SOVIET - AUSTRALIAN GRAVITY SURVEY ALONG THE AUSTRALIAN CALIBRATION LINE

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Abstract

The Australian gravity scale was refined by accurate measurements during 1973. A new National Gravity Base Station for Australia, Sydney A, replaces NGBS, Melbourne A. A gravity value of 979 671.86 mGal (IGSN71) at Sydney A was adopted as the new datum for Australia. The gravity scale for Australia is now defined along the 3 Gal Australian Calibration Line to an accuracy of 2.5×10^{-5} by measurements using GAG-2 Soviet gravity meters. All Australian gravity values will be recomputed to the new datum and scale, to be consistent with international fundamental standards (System International).

Introduction

The International Association of Geodesy recommended that the work of establishing a single worldwide standard for gravity determinations should be expanded [1]. In accordance with this recommendation, the Soviet Geophysical Committee, Academy of Sciences of the USSR, and the Bureau of Mineral Resources, Geology & Geophysics (BMR), Australia, organized a joint gravity survey to refine the values of gravitational acceleration previously determined at base stations on the Australian Calibration Line (ACL, Fig. 1). The survey was carried out during May and June 1973.

New Australian gravity datum

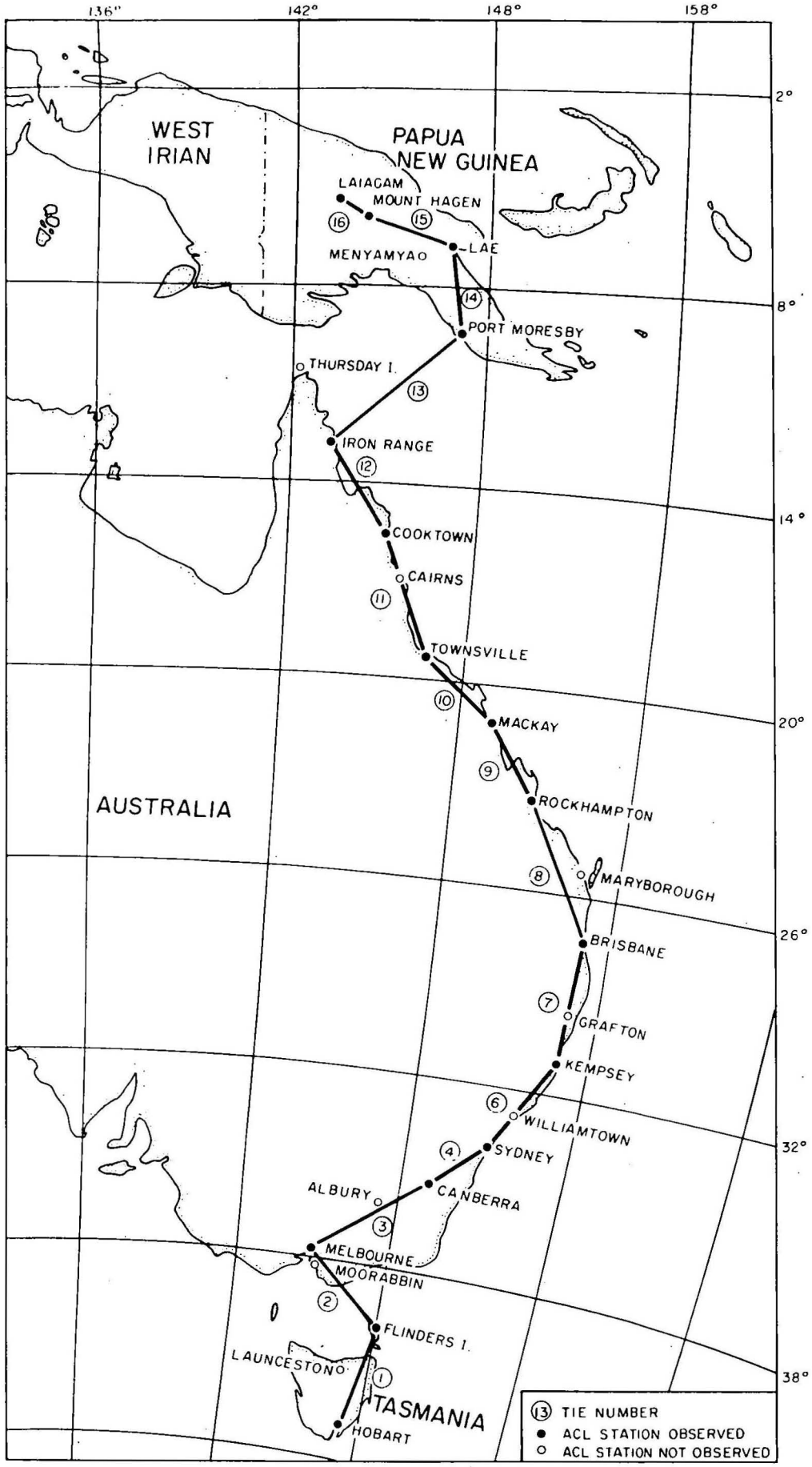
The datum in Australia is best based on the values of acceleration due to gravity at station 45331A, Sydney (BMR Station Number 5099.9905). This station is adjacent to the site of an absolute determination of gravity [2]. A value for this station has also been calculated in a 1971 review of international gravity ties and absolute determinations named IGSN71 [3]. An independent value for this station results from recent Soviet OVM pendulum ties Potsdam-Moscow-Sydney [4], and a correction to the Potsdam datum of $-13.95 \pm .05$ mGal resulting from Soviet work [5].

These three values for station 45331A are stated to be:

Absolute determination	979 672.00 $\pm$ 0.20 mGal (3 x s.d.)
IGSN71	979 671.86 $\pm$ 0.021 mGal (s.d.)
Soviet result	979 671.84 $\pm$ 0.06 mGal (s.d.)

The values agree within their stated accuracy. This station, and the gravity value of 979 671.86 mGal (from IGSN71), have been adopted as the National Gravity Base Station (NGBS) and datum value for the Australian

FIGURE 1



SOVIET - AUSTRALIAN GRAVITY SURVEY
ALONG THE AUSTRALIAN CALIBRATION LINE, 1973

AUSTRALIAN CALIBRATION LINE

To accompany Record No 1973/96

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National Gravity Network, as from 1973. This new NGBS replaces the previous NGBS, Melbourne A, which has been used since 1950 [6].

Measurement techniques

Gravity measurements were made using 8 Soviet GAG-2 gravity meters Nos 1, 2, 3, 30, 39, 40, 41, 43 (meter No. 42 malfunctioned) and four BMR LaCoste & Romberg gravity meters G20A, G101, G132, G252. Supplementary measurements of gravity intervals of less than 240 mGal were made with 5 Worden gravity meters.

The meters were transported along the ACL by a chartered DC-3 aircraft. It is considered that during flights the gravity meters were affected by aircraft vibration and by severe temperature fluctuations in the uninsulated cabin. At all stations south of Canberra, wind-induced ground vibration affected the precision of the observations.

Measurements with the GAG-2 meters had to be made close to the aircraft, so measurements at each airport were made only at a single station sited on the tarmac (Soviet Station). Each day three flights were made between the places A and B, giving drift control of the type A-B-A-B and a pair of estimates of the gravity interval AB. One pair of estimates of the gravity interval AB was obtained while progressing north and an independent pair of estimates was obtained while progressing south. For six intervals additional estimates based on supplementary measurements of the type A-B-A were necessary. During each Soviet observation the LaCoste meters were read at an existing permanently marked gravity base station (Australian Station), and at the completion of the Soviet measurements the meters were read at the tarmac site (Soviet Station), thus giving concurrent ties between the Soviet site and the Australian National Gravity Network

(ANGN). Gravity intervals for these and other ground ties are based on these results supplemented by measurements with Worden meters.

Measurements were made at 16 places distributed along the full length of the ACL (Fig. 1 & Table 1).

Reduction of GAG-2 gravity meter measurements and choice of milligal scale

Gravity intervals measured by the GAG-2 gravity meter are a function of the angles of tilt of the meter sensing element at the two stations, and of the acceleration due to gravity at one station; the observations are reduced using tables supplied by the manufacturer to intervals based on the international system of units. As the calibration is stable with time, intervals from these meters are available immediately after the measurement. The gravity intervals were calculated using the IGSN71 value of gravity at Sydney as a base. Tidal gravity corrections were applied; these were calculated by a BMR computer program.

For each tie the mean interval and uncertainty were calculated (Table 2), and other estimates of the uncertainty in the mean were calculated according to formulae given in [7] and [8]. Table 3 shows these errors for the 15 intervals. The estimates of the error in gravity difference Hobart-Laiagam, and the consequent error in scale, are shown at the foot of the table.

During the period 1950-1973 various milligal scales have been used in Australia [9] based mainly on Cambridge pendulum measurements in 1950-51 [6]. In 1965, as part of a series of international ties, using four LaCoste gravity meters, the United States Air Force (USAF) made measurements along the ACL which establish an independent scale [10]. Ground ties have been

TABLE 1: BMR GRAVITY STATION NUMBERS AND MAIN GROUND TIES

PLACE	SOVIET STATION α	AUSTRALIAN STATION β	$g_\alpha - g_\beta$ mGal	BMR 1970 STATION	IGSN71 STATION IGB No.	IGSN71 STATION BMR No.
Laiagam	7390.1029	6791.9029	+.164 ±.004	6791.9029	-	
Mount Hagen	7390.0178	6791.0178	-.538 ±.004	6791.0178	-	
Lae	7390.0177	6791.0177	+.644 ±.004	6791.0177	-	
Port Moresby	7390.0176	6791.0476	+.633 ±.004	6791.0476	34697J	6791.0176
Iron Range	7390.1073	6600.0025	-.309 ±.004	6600.0025	-	
Cooktown	7390.1072	7090.1072	+.204 ±.005	7090.1072	-	
Townsville	7390.0151	7090.0151	+.237 ±.003	7090.0151	38296A	5099.9951
Mackay	7390.0161	6491.0161	-.108 ±.003	6491.0161	41819J	6491.0161
Rockhampton	7390.0149	6499.0149	+.442 ±.003	6499.0149	41730K	6499.0149
Brisbane	7390.0147	7213.0147	+.362 ±.002	6491.0147	41773J	6491.0147
Kempsey	7390.1111	6491.9111	-.080 ±.002	6491.9111	45312J	6491.9111
Sydney	7390.0105	6891.0305	+.522 ±.002	6891.0105	45331A	5099.9905
Canberra	7390.0104	6893.0104	+.587 ±.004	6893.0104	45459J	6491.0104
Melbourne	7390.0101	6491.0101	+.046 ±.002	7090.0101	45474M	6491.0101
Flinders Is.	7390.1140	6491.9140	-.233 ±.002	6491.9140	-	
Hobart	7390.0160	6491.0160	+.327 ±.004	6491.0160	49027K	?6491.0160

TABLE 2: SUMMARY OF ACL RESULTS AND FINAL VALUES

TIE No.	PLACE	BMR STATION No.	GAC-2 GRAVITY METERS INTERVAL I mGal	GAC-2 GRAVITY METERS INTERVAL ±M_I μGal	GAC-2 GRAVITY METERS VALUE g mGal	GAC-2 GRAVITY METERS VALUE ±Mg μGal	LaCOSTE GRAVITY METERS INTERVALS FROM LaCOSTE TABLES G101 mGal	G132 mGal	G252 mGal	G20A mGal	Δg' * Δg' μGal	Δg' * ±M_L μGal	GRAVITY VALU ISOGAL 73 (mean GAC-2 scale) mGal
	LAIAGAM	7390.1029			977 488.642	65					-7	8	977 488.635
16			-173.915	18			-173.446	-173.869	.832	.858			
	MOUNT HAGEN	7390.0178			977 662.557	64					+1	9	977 662.558
15			-334.141	17			-333.204	-333.958	.972	.988			
	LAE	7390.0177			977 996.698	60					-31	7	977 996.667
14			-201.889	12			-201.385	-201.796	.758	.805			
	PORT MORESBY	7390.0176			978 198.587	59					-25	10	978 198.562
13			-132.818	18			-132.462	-132.790	.764	.769			
	IRON RANGE	7390.1073			978 331.405	56					-21	5	978 331.384
12			-96.542	11			-96.287	-96.524	.490	.508			
	COOKTOWN	7390.1072			978 427.947	55					-15	3	978 427.932
11			-181.846	22			-181.396	-181.818	.828	.823			
	TOWNSVILLE	7390.0151			978 609.793	51					+37	9	978 609.830
10			-109.850	18			-109.559	-109.811	.749	.774			
	MACKAY	7390.0161			978 719.643	47					+13	9	978 719.656
9			-140.661	31			-140.325	-140.634	.619	.645			
	ROCKHAMPTON	7390.0149			978 860.304	36					+44	11	978 860.348
8			-285.774	21			-284.931	-285.674	.583	.655			
	BRISBANE	7390.0147			979 146.078	29					+17	10	979 146.095
7			-266.199	18			-265.444	-266.035	.049	.066			
	KEMPSEY	7390.1111			979 412.277	23					-16	10	979 412.261
6			-273.890	22			-273.171	-273.767	.727	.805			
	SYDNEY	7390.0105			979 686.167	5					(-12)	8	979 686.167
4			+78.968	31			+78.699	+78.844	.874	.904			
	CANBERRA	7390.0104			979 607.199	31					+39	6	979 607.238
3			-340.225	16			-339.291	-340.023	.007	.054			
	MELBOURNE	7390.0101			979 947.424	35					+7	10	979 947.431
2			-243.375	19			-242.740	-243.296	.228	.271			
	FLINDERS ISLAND	7390.1140			980 190.799	40					-2	9	980 190.797
1			-245.233	17			-244.509	-245.116	.039	.121			
	HOBART	7390.0160			980 436.032	43					-50	8	980 435.982

* g' = g(mean LaCoste) - g(mean Soviet). LaCoste results adjusted to Soviet scale.

TABLE 3: ERRORS IN I FOR THE MEAN GAG-2 GRAVITY INTERVALS

Tie No.	Interval I mGal	$\pm \sigma$ μGal	$\pm \alpha$ μGal	$\pm x$ μGal	$\pm M$ μGal
16	174	13	18	12	18
15	334	9	17	19	17
14	202	7	12	14	12
13	133	13	18	14	18
12	97	10	11	11	8
11	182	20	22	15	11
10	110	14	18	13	18
9	141	29	31	16	28
8	286	14	21	17	21
7	266	16	18	13	15
6	274	20	22	17	22
4	79	27	31	16	28
3	340	18	20	16	20
2	243	18	19	14	17
1	245	17	17	14	18
Σ_1^{16}	2947	67	79	55	73
Error in Scale $\frac{\Sigma_1^{16} \text{error}}{\Sigma_1^{16} I} \cdot 10^5$	-	2.3	2.7	1.9	2.5

made (Tables 1 & 4) which enable accurate comparison of GAG-2 values with the USAF values listed in column 2 of adjustments 4 and 5 of [10]. In Fig. 2 the gravity differences gUSAF-gSOVIET are plotted against gSOVIET, and the regression coefficients are given in Table 5. The slope of the regression line is the difference from unity of the ratio of the two milligal scales. The USAF scale does not differ significantly from the Soviet scale. The USAF, Cambridge pendulum, and other gravity meter, pendulum and absolute determinations have been integrated in the calculation of IGSN71 gravity values for a number of stations on the ACL [3]. The scale defined by these gravity values (Fig. 2 & Table 5), gives a scale of intermediate between the USAF and Cambridge pendulum results. IGSN71 values for Hobart and Port Moresby are based on comparatively weak ties, and have been disregarded as they are clearly incompatible (Fig. 2). In 1970 BMR used LaCoste and Worden gravity meters to establish the ACL [11], using the scale defined mainly by the Cambridge pendulum measurements. This scale differs greatly from the Soviet scale (Fig. 2 & Table 5).

In Europe the Soviet scale defined by the GAG-2 gravity meters agrees with that of OVM pendulum measurements, and is in good agreement with the IGSN71 scale. It is believed that the discrepancy between the Soviet and IGSN71 scales in Australia is due to inclusion of data with incorrect scale in the IGSN71 calculations of scale in Australia.

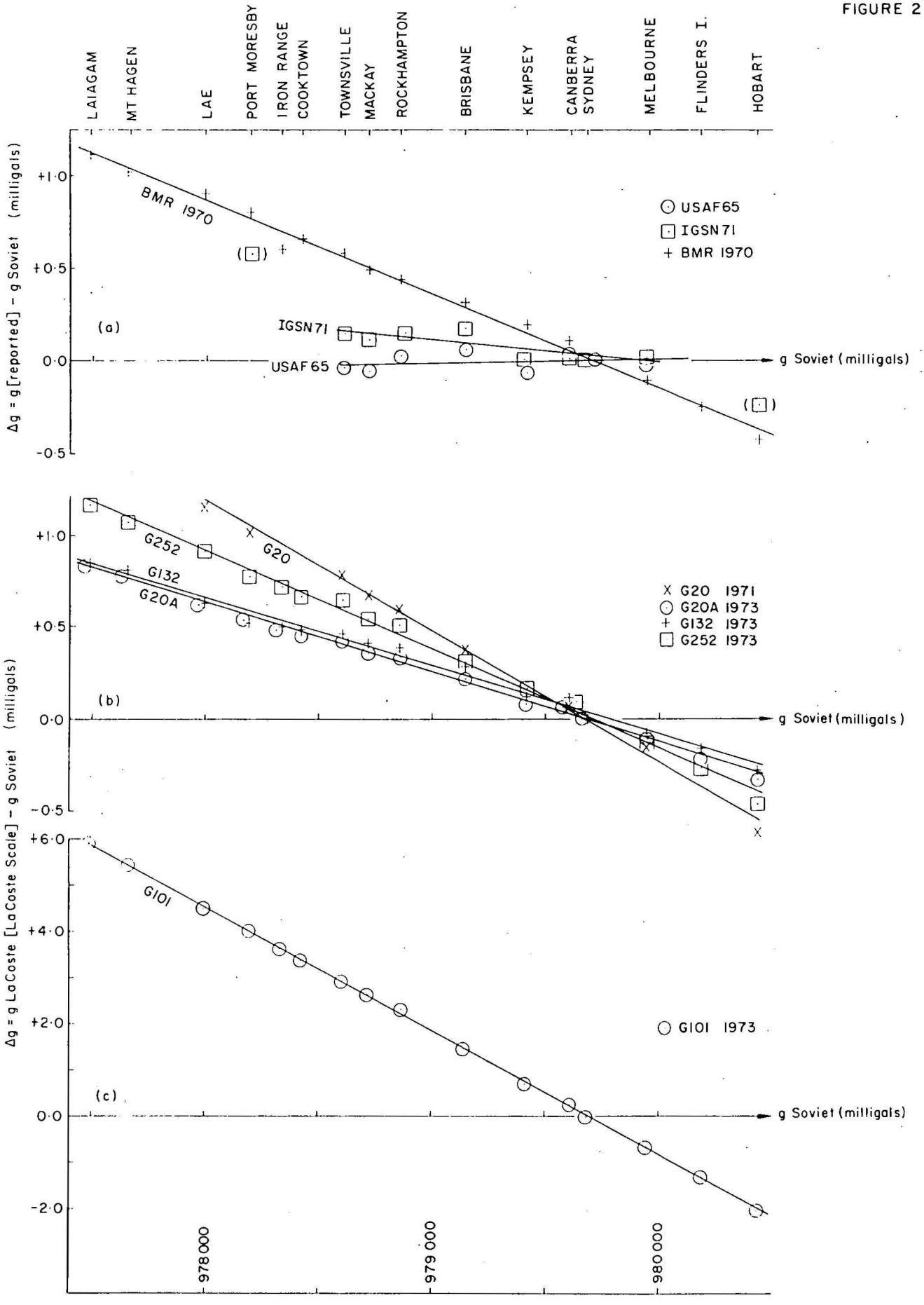
The milligal scale defined by the Soviet GAG-2 meters has been adopted as defining the Australian milligal as from 1973. The best estimate of the uncertainty of this scale is 2.5×10^{-5}. A higher accuracy would be achieved by OVM pendulum measurements at each end of the ACL.

TABLE 4: SUPPLEMENTARY GROUND TIES

Place	BMR Station Numbers		Gravity Difference $g_\alpha - g_\beta$ (Soviet Scale) mGal	$\pm M$ mGal
	α	β		
Port Moresby	6791.0476	6791.0376	-44.626	0.020
Port Moresby	6791.0376	6791.0176	+44.871	0.020
Townsville	7090.0151	5099.9951	-0.019	0.020
Brisbane	7390.0147	7390.0247	+0.682	0.004
Brisbane	7390.0247	6491.0147	+0.020*	0.01
Sydney	5099.9905	6891.0105	-13.001	0.004
Sydney	5099.9905	7390.0105	-14.307	0.008
Sydney	6491.0105	6891.0105	-0.08	0.020
Canberra	6893.0104	6491.0104	+0.267	0.020
Melbourne	6491.0101	7090.0101	+0.03	0.020

* Station 6491.0147 is now overlain by 0.1 m of new concrete. Station 7390.0247 is located on this new concrete within one metre horizontally of 6491.0147.

FIGURE 2



COMPARISON OF GRAVITY METER RESULTS BY REGRESSION

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TABLE 5: COMPARISON OF GRAVITY METER RESULTS BY REGRESSION

$$g = g(\text{other}) - g(\text{Soviet})$$
$$= B \times \left[g(\text{Soviet}) - g(\text{Sydney})\right] + A$$

	B	A	Mean-squares Deviation from Regression
		mGal	mGal
USAF65	+0.0000169	0.000	0.048
IGSN71	-0.0001495	+0.003	0.046
BMR 1970	-0.0005078	+0.020	0.040
G20 1971*	-0.0007121	0.000	0.034
G20A 1973*	-0.0003800	-0.002	0.022
G132 1973*	-0.0003683	+0.039	0.037
G252 1973*	-0.0005342	+0.016	0.036
G101 1973*	-0.0026800	+0.066	0.034

All gravity values adjusted to common datum Sydney A

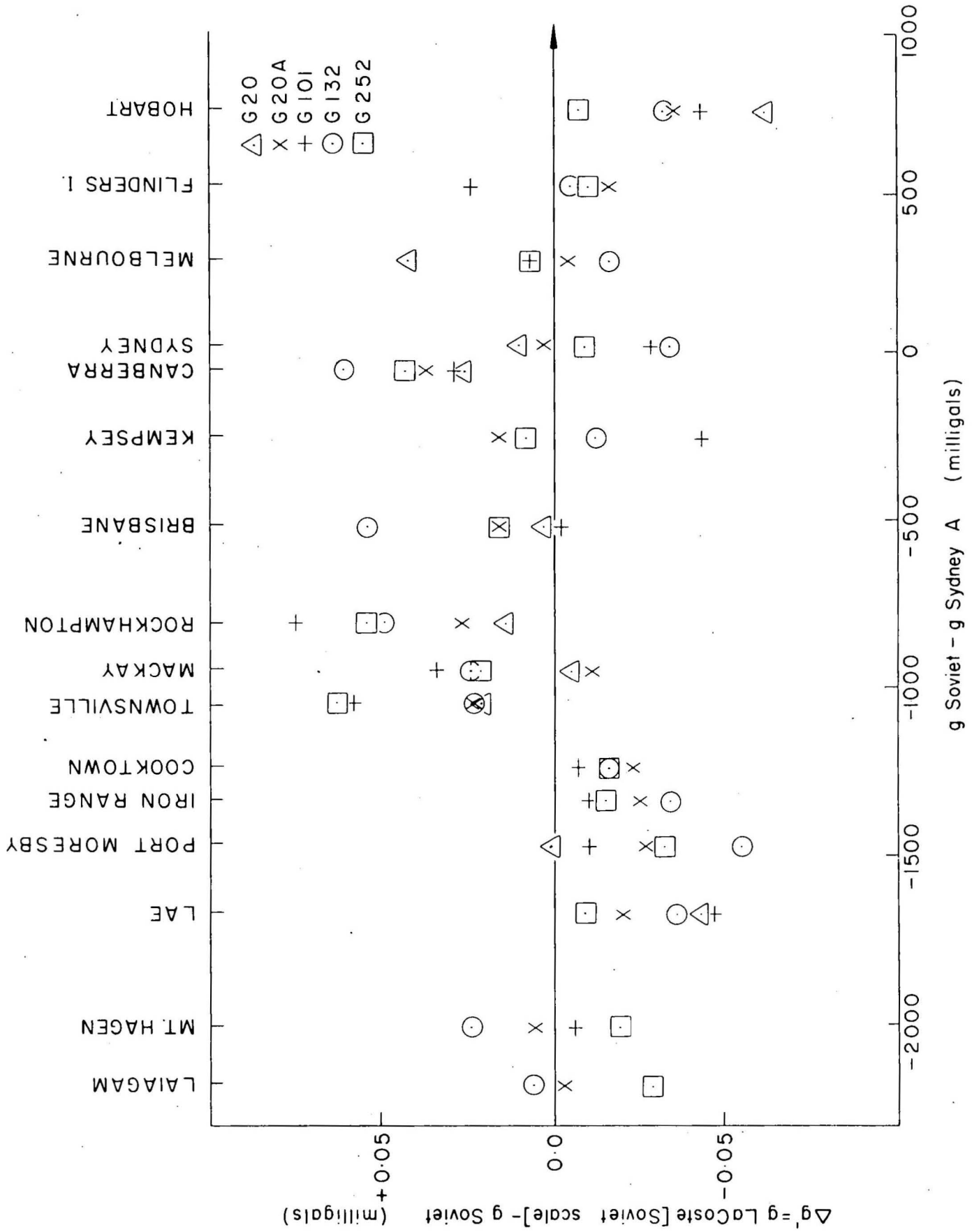
* Values of gravity were calculated from LaCoste tables.

LaCoste meter measurements

Meter observations were reduced to estimates of the gravity intervals by applying tidal corrections, removal of apparent meter drift, and conversion to milligal intervals using tables supplied by the manufacturer. From the behaviour of these meters before and during this survey it is postulated that normal meter drift between repeat observations during air ties does not exceed $\pm$ 0.05 mGal. Whenever the apparent drift during an air tie exceeded this amount the resulting estimate was rejected, because the presence of a drift tare would introduce an error of more than 0.02 mGal; 23% of the estimates were rejected for this reason. Mean intervals were calculated for each meter (Table 2). Gravity values were calculated for each meter relative to the accepted Sydney value, and these are compared with the Soviet values in Fig. 2 and Table 5. An independent set of intervals, available from measurements in 1971 using LaCoste meter No. G20 before its micrometer screw was replaced, is also shown in Fig. 2 and Table 5.

For each meter new gravity values based on the Sydney datum and Soviet scale were calculated. The differences between these new values and the Soviet values are shown in Fig. 3: small but significant systematic differences between the LaCoste and GAG-2 meters are apparent. For each station the mean difference $\Delta g' [= g(\text{mean LaCoste}) - g(\text{mean Soviet})]$ and its uncertainty were calculated (Table 2). The uncertainties in the GAG-2 gravity values relative to the Soviet scale are given approximately by the uncertainties of the GAG-2 intervals ($\pm M_I$), and these uncertainties are greater than the uncertainty in the mean LaCoste results on Soviet Scale ($\pm M_L$). The best estimates of the gravity values are therefore obtained by

FIGURE 3



DIFFERENCES BETWEEN SOVIET AND LA COSTE GRAVITY METER RESULTS ON SOVIET SCALE AND "SYDNEY A" DATUM

To accompany Record No 1973/96

G65-355-1A

adding these differences ($\Delta g'$) to the GAG-2 values. We have adopted these best estimates, which are listed in the last column of Table 2, as the control for revised gravity values of the Australian National Gravity Network. These gravity values will be referred to as ISOGAL73 values; they are based on the accepted value of the acceleration due to gravity at Sydney and the Soviet milligal scale.

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CAPTIONS FOR FIGURES

Fig. 1 Australian Calibration Line

Fig. 2 Comparison of gravity meter results by regression

Fig. 3 Differences between Soviet and LaCoste gravity meter results on Soviet scale and Sydney A datum.