DEPARTMENT OF
MINERALS AND ENERGY

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1975/24

Preliminary gravity measurements on crustal movement survey markers, Markham Valley, PNG, 1973

by

J.C. Dooley

Record 1975/24

Preliminary gravity measurements on crustal movement survey markers, Markham Valley, PNG, 1973

by

J.C. Dooley

Contents

Figures

Summary

Six survey markers were established during 1973 by Division of National Mapping in the upper Markham Valley, Papua New Guinea. These sites straddle a fault zone which is presumed to be currently active, and it is intended to resurvey these markers at intervals of a few years in an attempt to measure any relative movement between them.

Gravity readings were taken in November 1973 at these markers using a LaCoste & Romberg gravity meter. An estimate of the magnitude of the secular variation in gravity associated with possible crustal movements shows that these measurements are probably not accurate enough to permit reliable detection of a change in gravity over a period of a few years unless comparatively large movements accompany an earthquake; it is intended to carry out a more accurate survey in 1975. The present measurements were useful in establishing the gravity values at the stations, and will assist in planning the logistics of the next exercise.

Introduction

The Markham-Ramu Valley in PNG is believed to be associated with a fault zone, and there is evidence to suggest that this fault is still active (Dow, 1974). A site in the western Markham Valley was selected as a suitable place for measuring current movement on this fault zone, and six survey markers were established by the Division of National Mapping, three on either side of the valley of the Umi and Yati Rivers, tributaries of the upper Markham River (see Fig. 4 for locations). Measurements of the distances, azimuths, and elevation differences between pairs of markers were made in August-September 1973, with the intention of repeating the measurements in 1975 (Cook & Murphy, 1974). It is desirable to measure gravity variations in connection with a survey of positional variations, as these could indicate whether the movements observed at the surface are associated with the transfer of mass at depth.

Although no earthquake epicentres have been located in the immediate area of the station markers, there is marked activity within 50-100 km to the north and east (Denham, 1973). Focal mechanism solutions for some of the larger events show strike-slip or normal faulting in a variety of azimuths (Johnson & Molnar, 1972; Ripper, 1975).

In November 1973, a LaCoste & Romberg gravity meter was being used for a regional survey in PNG, using a helicopter for transport. This provided an opportunity to make preliminary measurements of the gravity differences between the markers. Ideally, such measurements should be made by several gravity meters, with repeat measurements several times at all stations. As it was not feasible to program such an operation until 1975 the preliminary measurements were undertaken with two objectives - firstly, to establish the gross gravity values and differences between the stations, and to find any logistic problems which might need special precautions; and secondly, there is a possibility that the measurements with a single gravity meter may enable earlier detection of gravity variations if they are large enough, e.g. in the event of substantial displacements accompanying an earthquake.

Magnitude of expected gravity changes

In order to estimate the possible magnitude of changes in gravity that might be observed, the effects of a few idealized models are calculated. Probably none of these alone would represent the true physical situation, but some combination of them should approximate reality. The relation of the gravity changes to observed movements is critical in seeking an explanation.

1. Vertical fault movement

The main objective is to measure relative changes in gravity between the stations of the network. Thus we may consider a station A distant x_1 on one side of the fault plane as stationary, and another station B distant x_2 on the other side as uplifted by Δh to B^1 (Fig. 1). We suppose that the near-surface density is ρ_1, and at depth d there is an originally horizontal surface below which the density is ρ_2; the fault movement also uplifts part of this surface by Δh.

The change Δg in gravity from B to B^1 relative to A will arise from three effects:

(a) Decreased attraction at B^1 relative to B because of increased distance from centre of the Earth (free-air effect):

$$\Delta g_1 = -3.086\,\Delta h\ \mu m/s^2 \quad (\Delta h \text{ in metres})$$

(b) Increased attraction at B^1 relative to A of the slab Δh above the original surface. If x_1 and x_2 are large compared with Δh, this will be very close to the infinite slab model:

$$\Delta g_2 = +\,0.4185\,\rho_1 \Delta h$$

(c) Increased attraction at B^1 relative to A due to the higher density of the slab between depth d and d + Δh.

The infinite slab approximation applies in this case for x_1 and x_2 large compared with d: $\Delta g_3 = + 0.4185 (\rho_2 - \rho_1) \Delta h$

The magnitude of Δg_3 decreases as x_1/d or x_2/d decreases.

Thus, for distant stations the nett effect is

$$\Delta g_1 + \Delta g_2 + \Delta g_3 = (-3.086 + 0.4185 \rho_2) \Delta h \qquad \ldots\ldots\ldots\ldots (1)$$

i.e. the Bouguer anomaly calculated using ρ_2.

For a deep density contrast (i.e. d large compared with $x_1 + x_2$), Δg_3 becomes small, and the total anomaly is approximately

$$\Delta g_1 + \Delta g_2 = (-3.086 + 0.4185 \rho_1) \Delta h \qquad \ldots\ldots\ldots\ldots (2)$$

i.e. the Bouguer anomaly calculated using ρ_1.

Thus with this model, we expect the Bouguer anomaly to remain approximately constant when the correction is calculated using an appropriate density for the change in elevation Δh. The appropriate density would be that at a depth somewhat less than the station separation. For typical densities, a change of observed gravity of $0.1 \mu m/s^2$ would correspond to about 0.05 m vertical movement. The point of interest is to determine the choice of density for which the change in Bouguer anomaly is zero, and to compare this with the near-surface densities.

The range of gravity changes involved is limited to the difference between equations (1) and (2) i.e. Δg_3. For $\rho_2 - \rho_1 = 0.5 \ t/m^3$, and $\Delta g_3 = 0.1 \mu m/s^2$ (the reading accuracy of a LaCoste & Romberg gravity meter), Δh must be 0.5 m.

2. <u>Vertical movement due to expansion or contraction</u>

It is assumed for this model that a horizontal layer of thickness t and density ρ_2 undergoes a change of density $\Delta \rho$ while retaining constant mass, the corresponding change in volume being accommodated in a vertical direction. We suppose that the bottom surface of this layer remains stationary, while the top surface and any overlying material will be uplifted by Δh.

It is assumed that the change in density is gradual, so that the initially horizontal surface becomes slightly inclined.

Thus we have (see Fig. 2):

$$\Delta h/t = -\Delta\rho/\rho_2$$

As in case (1), for a distant station we have a Bouguer correction with density ρ_2 (neglecting quantities of order $\Delta\rho\ \Delta h$), together with a decrease in attraction in the lower layer of

$$\Delta g_4 = -\ 0.4185\Delta\rho t$$
$$= -\ 0.4185\ \rho_2\ \Delta h$$

Thus the nett Bouguer correction corresponding to Δ h is zero; i.e. the free-air anomaly remains unchanged.

3. Horizontal movement

This model is devised to account for gravity changes accompanying horizontal movements without change in height.

The situation is illustrated in Figure 3, where strike-slip motion occurs. There is an anomalous mass on one side of the fault, and a station the other side moves relatively to this mass, and hence to the anomaly associated with it.

Gravity changes accompanying this type of motion depend on the existence of a significant gravity gradient at the station. The only gravity measurements in this area were made by St John (1967) at fairly widely scattered stations. Denser coverage (though still of a reconnaissance type) exists in the areas to the north and northwest (Zadoroznyj & Coutts, 1973; BMR, 1969, 1972). Examination of these data suggests that gradients up to .05ks^{-2} could occur. Thus a horizontal movement of at least 2 m would be required to produce a gravity change of 0.1μm/s^2. It would probably be several decades before such a change could be detected reliably if it were caused by continuous creep movement, but a measurable effect might occur rapidly as the result of an earthquake.

4. Change in density of layer without change in volume

This could lead to an observed gravity change without any movement being detected at the surface. It might occur through compaction of materials into a confined space or stoping and batholith formation by a less dense magma; however, one would expect these processes to occur (if at all) at a large depth, so that differential effects over the network would be small. The other possibility is infiltration of a porous medium, e.g. a change in the depth to the water-table.

For example, with rocks of porosity 25%, the density change due to infiltration of water is 0.25. For a rise in the water-table of 1 m, gravity will increase by 0.1 $\mu m/s^2$; this affects both Bouguer and free-air anomalies by the same amount.

We may summarize the following possible situations:

1. Vertical fault movement - constant Bouguer anomaly accompanying height change
2. Vertical movement due to expansion or contraction - constant free-air anomaly accompanying height change
3. Horizontal movement - possible small observed gravity changes depending on local gradients, without any height change
4. Change in density (but not volume) of a layer - observed gravity change without change in height or horizontal movement.

Actual observed effects may well be a combination of some of these types of movement. The first type of movement appears the most probable one that would show a measurable change in observed gravity, but unless departures from constant Bouguer anomaly can be measured little information would be obtained other than that already known from the elevation changes.

According to a recent theory of the mechanism of earthquakes, in some areas these are preceded by dilatancy in the neighbourhood of the epicentre, and then by fluids filling the resulting pore spaces (see for example Nur, 1972).

These movements would correspond to models 2 and 4 as outlined above, and may be large enough to be associated with detectable gravity variations. Harada (1968) has measured gravity variations in association with the Matsushiro earthquake swarm (see also Kasahara, 1970). Nur (1974) interprets these as due to such movements. However, monitoring of these movements for purposes of earthquake prediction would require measurements to be repeated at shorter time intervals than envisaged in the present program.

Fujita et al. (1974) reported a gravity decrease accompanying subsidence following an earthquake near Hokkaido; thus the change is opposite to that expected for models 1 and 2 above. Presumably the subsidence must have been accompanied by outward flow of mass at depth, causing a decrease in density (model 4) with a larger effect than the effect due to subsidence and with opposite sign.

Gravity measurements

The measurements were made on 12 November 1973 using LaCoste & Romberg gravity meter G252. The feet of the dish-type tripod were set on the guide plate on top of the trig. station pillar at each site, so that the meter was centrally situated over the pier; the base of the case of the gravity meter was 9 cm above the top of the pier. Details of the measurements and data treatment are given in the Appendix.

Readings were taken at Lae airport Isogal station before and after the Markham Valley readings to enable reduction of the gravity measurements to the Australia-PNG datum. It was intended to occupy the Isogal station at Kaiapit, but owing to reconstruction work at the airport this station could not be found, and had presumably been destroyed.

Each station was situated on a spur projecting from the main range of hills in order to ensure inter-visibility. The helicopter was able to land on each of the spurs within about 50 m of the pillar. Time between successive readings averaged about 10 minutes under normal conditions.

Readings were taken for two complete rounds of the six sites; a third round was attempted but was not completed successfully for the following reasons:

(a) Seismic waves from an earthquake (origin time 03h 53m 44.0S U.T., epicentre 6.15^{o}S, 154.46^{o}E, depth 50 km, magnitude 5.6 MB, 5.9 MS) caused ground vibrations and made it impossible to read the meter for about 20 minutes at NMJ/36; a reading was attempted at 1418 local time (i.e. 0418 U.T.), but the drift curves suggest that the reading was disturbed.

(b) Increasing wind after about 1400 (local time) made a reading impossible at NMJ/33 and difficult at NMJ/31; the reading estimated for the latter station appears to be disturbed.

(c) Because of threat of afternoon rain combined with the high wind, it was decided to abandon any further attempts to take readings.

The pillars at all sites were disturbed by walking on the adjacent ground, as shown by movement of the gravity meter cross hair. The helicopter excited the curiosity of the local population, who at most sites rapidly climbed the spurs to investigate. This increased the difficulty of reading, as it was impossible to get them all to stand still at the same time.

<u>Results</u>

The meter readings at each station and the times of reading are listed in Table 1. These were converted to $\mu m/s^2$ using the makers' tables (Wellman et al., 1974, Appendix 3F, p.81), with a correction applied to the interval factor $+5.3 \times 10^{-4}$ (op. cit., Table 5, p. 25).

A tidal correction was calculated (Murray, 1974) and applied. The corrected readings (Table 1) are consistent with zero drift within the reading accuracy of the gravity meter ($0.1\ \mu m/s^2$), except for the third readings at NMJ/36 and NMJ/32, which were disturbed by the earthquake and high wind respectively; these two readings were therefore rejected. Gravity intervals were then determined from the mean readings at the stations, and 'absolute' gravity values were calculated (Table 1) using the value of 9.779,960,43 m/s^2 for Lae K 6791.0177 (op. cit., Appendix 6, p.150).

Table 2 lists the gravity values together with the station co-ordinates from Cook & Murphy (1974), the free-air anomalies, and the simple Bouguer anomalies for density of 2.67 t/m^3; these values are also shown in Figure 4. Terrain corrections have not yet been calculated; they are not significant for determining gravity changes likely to accompany crustal movements, but because of the siting of the pillars, they would be large enough to be significant if the results were to be used for geophysical interpretation.

The accuracy of the measurements can be assessed only from their self-consistency. For relative measurements between the sites, this is about as good as the accuracy with which the gravity meter can be read ($0.1 \mu m/s^2$). The measurements at Lae were also consistent to this accuracy; however, because of the longer time interval between readings and the lack of overlapping drift control, the gravity difference between Lae and the survey stations may not be as accurate as the difference between the survey stations.

Possible sources of error

1. Calibration factors of gravity meters

The range of observed gravity values is about $370 \mu m/s^2$. It is now possible to measure calibration factors to an accuracy of a few parts in 10^5 by occupying stations of the Australian Calibration Line (Wellman et al., 1974). About 2 parts in 10^4 would be adequate for an accuracy of $0.1 \mu m/s^2$.

This type of calibration, however, is subject to the assumption that no secular variation occurs at the stations of the ACL. Occupation of several consecutive stations should check this, unless all the stations concerned were varying in a systematic manner.

Another check could be made by studying the correlation of gravity changes at the network stations with the gravity values themselves. The pattern of observed gravity variations (Fig. 4) makes it unlikely that secular variation due to a simple fault motion would show any marked correlation with the gravity values. In particular, stations 32 and 35, at the southeast and northwest extremities of the area, have very nearly equal gravity values; thus any measured difference between them would not be due to a calibration error.

2. Water-table changes

As shown above, a change in depth to water-table of 1 m could cause a gravity variation of $0.1 \mu m/s^2$; thus changes of a few metres could affect the results.

G. Jacobson (pers. comm.) advises that the aquifers in this region are lenticular, and that the pattern of variation in water-levels is likely to be complex. Variations of a few metres might occur at one site seasonally or between wet and dry years.

The main variations in water-table are likely to occur underneath the floor of the valley. As the markers are sited well up on the flanks, the attraction of additional water would be reduced substantially below that calculated for an infinite 'slab'.

Changes in water-table are likely to be seasonal rather than secular, so errors could be reduced by making repeat observations at the same time of the year. Also, fluctuations are likely to be related on both sides of the valley, so that the significance of the errors for relative measurements is reduced.

The water-table is unlikely to change consistently over periods of several decades, so in the long term, any errors are likely to be smoothed out. Nevertheless, it might be appropriate to collect any information on groundwater and its variations in the area, and if it seems necessary, to monitor the water-level in nearby bores at the time of reading.

3. Terrain corrections

Because of the siting of the stations for inter-visibility, terrain corrections are certain to be large. However, for the small changes in level and/or position expected, they are unlikely to change significantly.

4. Horizontal movements

Apart from any intrinsic interest relating to possible movement of subterranean masses, horizontal movement of a station relative to an anomalous mass might introduce an effect which should be corrected for in considering the relation of gravity changes to vertical movements.

As shown above, this is probably negligible for movements less than about 2 m. The Bouguer anomalies plotted in Figure 4 show a maximum gradient of about 0.045 ks^{-2} in a SSW direction, i.e. across the supposed fault plane. This is consistent with the regional trend found by St John (1967); the stations are probably located on the southern flank of an extension of the Bismarck Gravity Low (Zadoroznyj & Coutts, 1973). Thus, if the horizontal movement is of the expected shear type along the fault plane, the relative movement of the stations is likely to be approximately parallel to the Bouguer anomaly contours, and the effect will be even smaller.

However, locally higher gradients could occur near some of the stations; these could be determined only by a more detailed survey.

Recommendations

The gravity readings between the survey markers should be repeated as soon as practicable; present plans are for this to be done about mid-1975.

Gravity variations if any would be very small, apart from those associated with variations in elevation by the usual Bouguer anomaly, so it is desirable that the next reoccupation should be made with as high an accuracy as practicable. A reasonable program would be to use say four LaCoste & Romberg gravity meters, and to reoccupy the stations five or six times, with extra repeats if discrepant readings are obtained.

The calibration factor of the meters used should be checked at a time close to the field measurements, over an interval several times as large as the range of the gravity values at the stations (i.e. about $370 \mu m/s^2$). Reoccupation of several stations on the calibration line is recommended. An 'absolute' method of calibration, such as use of a tilting table, is to be preferred if available.

If a substantial earthquake is reported in the area, both positional and gravity surveys should be repeated as soon as practicable. If large horizontal movements are observed on reoccupation (i.e. a few metres), gravity surveys should be carried out around each site to determine the local gradients. Terrain effects would have to be calculated, so as to separate these from subsurface effects.

Cook & Murphy (1974) state that 20 intermediate levelling benchmarks on the valley floor were permanently marked. It is recommended that gravity should be measured at these sites as well as at the terminal sites, as they will be relevelled in the future. Such measurements should help to determine the pattern of any changes observed at the main sites.

The water-table in the area, and its possible variations, should be assessed; if necessary, the level should be measured near each station at reoccupation times.

A helicopter appears to be ideal for occupying the main markers. With road transport, the time required for climbing to the markers would be three or four times the total reading time interval using the helicopter; the latter would naturally be even more advantageous if several gravity meters are to be used. However, road transport might be as efficient, and less costly, for valley floor stations.

Because of the climatic pattern of afternoon rain and strong winds, measurements should be planned for the morning, finishing about midday each day.

The observer instability of the piers as a platform for gravity observations at first sight might lead to some doubt about their suitability as secular movement markers; however those movements concerned would be very small and presumably of an oscillatory nature which would not show up as secular movement.

Acknowledgement

The careful and accurate observations and attention to planning details by Mr D.A. Coutts are gratefully acknowledged.

Table 1

GRAVITY OBSERVATIONS

Station	Time	Reading Scale	Reading $\mu m/s^2$	Tidal corr^n	Corr^d rdg	Average	Observed gravity mm/s^2
Lae K	0928	1634.09	17180.59	+0.16	17180.75	0.71	9779.960 43 (adopted base value)
	1612	.06	0.27	0.40	.67		
NMJ/35	1109	1500.14	15771.90	+1.29	15773.19		
	1249	.08	1.27	1.85	3.12	3.21	9778.552 93
	1351	.11	1.59	1.73	3.32		
NMJ/36	1118	1492.38	15690.29	+1.38	15691.67	1.70	9778.471 42
	1257	.34	89.87	1.86	1.73		
	1418	.40	90.50	1.55	2.05*		
NMJ/34	1131	1515.97	15938.38	+1.48	15939.86		
	1307	.94	8.06	1.86	9.92	9.87	9778.719 59
	1428	.97	8.38	1.46	9.84		
NMJ/33	1144	1506.98	15843.84	+1.58	15845.42	5.39	9778.625 03
	1316	.95	3.52	1.84	5.36		
NMJ/32	1156	1527.99	16064.79	+1.66	16066.45	6.42	9778.846 14
	1327	.97	4.58	1.82	6.40		
	1453	.95	4.37	1.25	5.62*		
NMJ/31	1207	1499.37	15763.80	+1.72	15765.52		
	1338	.35	3.59	1.79	5.38	5.49	9778.545 21
	1504	.43	4.44	1.15	5.59		

* Rejected reading

Table 2

Principal Facts

Station	Latitude $6^{o}S$ +	Longitude $146^{o}E$ +	Elevation m	Observed gravity 9778 mm/s^2 +	Normal(1) gravity 9780 mm/s^2 +	Free-air correction mm/s^2	Free-air anomaly mm/s^2	Bouguer correction mm/s^2 (2)	Simple Bouguer anomaly mm/s^2
NMJ/31	10'48.2"	13'33.5"	467.71	.5452	.9168	1.4434	-.9282	.5226	-1.4508
NMJ/32	12'47.0"	10'06.1"	445.28	.8461	.9231	1.3741	-.7029	.4976	-1.2005
NMJ/33	09'55.6"	05'44.0"	475.22	.6250	.9141	1.4665	-.8226	.5310	-1.3536
NMJ/34	08'57.2"	04'48.5"	438.07	.7196	.9110	1.3519	-.8395	.4895	-1.3290
NMJ/35	07'35.9"	05'23.8"	466.68	.5529	.8997	1.4402	-.9066	.5215	-1.4281
NMJ/36	07'37.7"	06'00.3"	491.03	.4714	.8985	1.5153	-.9188	.5487	-1.4605

(1) Normal gravity according to 1967 International Gravity formula
$1\ mm/s^2 = 0.1$ Gal

(2) Density used for Bouguer correction: 2.67 t/m^3

REFERENCES

BMR, 1969 - Bouguer anomalies, Madang 1:250 000 sheet, scale 1:500 000. Map B55/B2-6 (R).

BMR, 1972 - Bouguer anomalies, Ramu 1:250 000 sheet, scale 1:500 000. Map B55/B2-5 (R).

COOK, D.P., & MURPHY, B.A., 1974 - Crustal movement survey, Markham Valley, Papua New Guinea, 1973. Div. Nat. Mapping, Tech. Rep. 18.

DENHAM, D., 1973 - Seismicity, focal mechanisms, and the boundaries of the Indian-Australian plate, In The Western Pacific: Island Arcs, marginal seas, geochemistry (P.J. Coleman, ed.). Univ. Western Australia Press.

DOW, D., 1974 - Geological background. In Cook & Murphy (1974).

FUJITA, N., FUJII, Y., & TADA, T., 1974 - Crustal activities in the eastern part of Hokkaido, Japan (abstract). International Symposium on Recent Crustal Movements, Switzerland, 1974.

HARADA, Y., 1968 - Geodetic work in Japan with special reference to the Matsushiro earthquakes (Summary): EOS, 50, p.390.

JOHNSON, T., & MOLNAR, P., 1972 - Focal mechanisms and plate tectonics of the south-west Pacific. J. geophys. Res., 77, p. 5000.

KASAHARA, K., 1970 - The source region of the Matsushiro swarm earthquakes. Tokyo Univ. Earthquake Research Inst. Bull., 48, p. 581.

MURRAY, A.S., 1974 - The Australian National Gravity Repository computer system. Bur. Miner. Resour. Aust. Rec. 1974/68 (unpubl.).

NUR, A., 1972 - Dilatancy, pore fluids, and premonitory variations of t_s/t_p travel times. Bull. seismol. Soc. Amer., 62, p. 1217.

NUR, A., 1974 - Matsushiro, Japan, earthquake swarm: confirmation of the dilatancy - fluid diffusion model. Geology, May 1974, p. 217.

RIPPER, I.D., 1975 - Earthquake focal mechanisms in the New Guinea/ Solomon Islands region to 1968. Bur. Miner. Resour. Aust. Rep. 178.

St JOHN, V.P., 1967 - The gravity field in New Guinea. Univ. Tasmania, Ph. D. Thesis (unpubl.).

WELLMAN, P., BOULANGER, Y.D., BARLOW, B.C., SHCHEGLOV, S.N., & COUTTS, D.A., 1974 - Australian and Soviet gravity surveys along the Australian Calibration Line. Bur. Miner. Resour. Aust. Bull. 161.

ZADOROZNYJ, I., & COUTTS, D.A., 1973 - Central Highlands helicopter gravity survey, New Guinea, 1970. Bur. Miner. Resour. Aust. Rec. 1973/14 (unpubl.).

Appendix

Technical details of gravity observations

Survey number: 7311

Base station: Lae K 67910177

Gravity value used for base station: 9.779 660 43 m/s^2 (Wellman, et al., 1974)

Gravity meter: LaCoste & Romberg G252

Calibration from makers' tables given in Appendix 3G, p.81 of Wellman, et al., 1974, corrected by an interval factor of $1 + 5.34 \times 10^{-4}$ (loc. cit., Table 5, p.25). N.B. On p. 24 of Wellman et al., (1974), the correction factor is given as (1 + B), where B is determined from Table 5; this should read (1 - B).

Tidal Corrections calculated from program TIDYTIDE (Murray, 1974)

Elevations and positions from Cook & Murphy (1974).

Simple Bouguer corrections applied for density 2.67 t/m^3; no terrain corrections applied.

Observers: All readings were taken by D.A. Coutts and checked by J.C. Dooley.

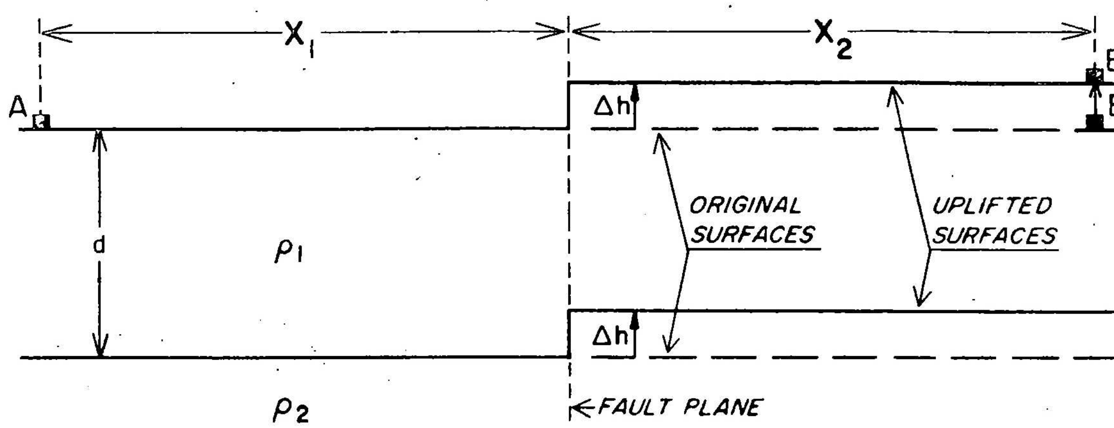

Fig.1 — Vertical movement on a fault

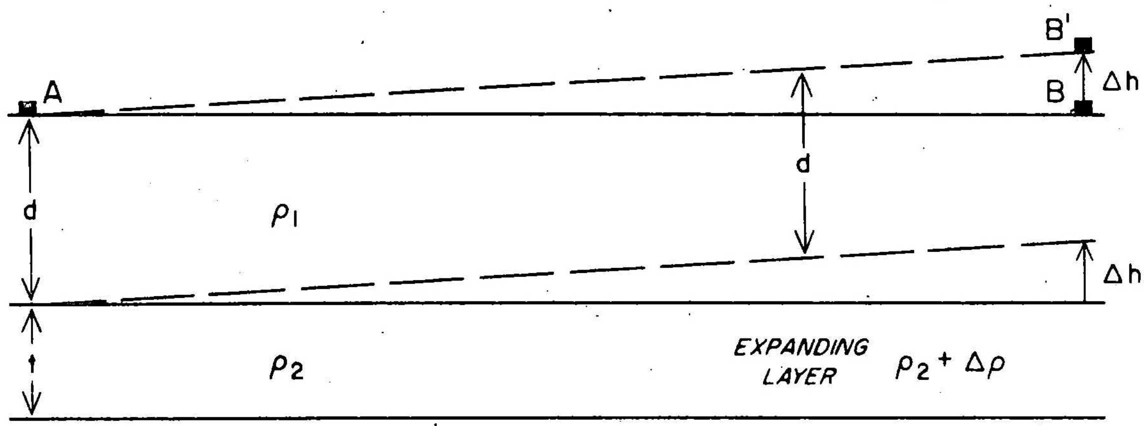

Fig. 2 — Vertical movement due to expansion

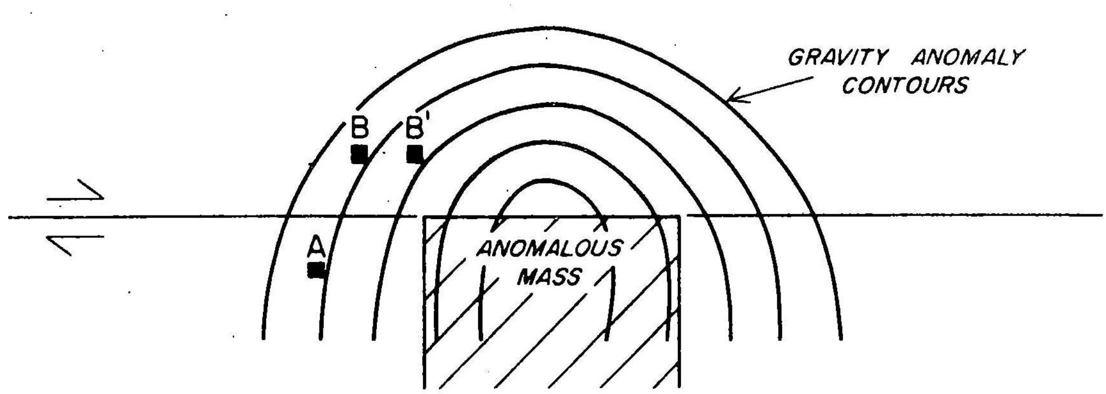

Fig.3 — Horizontal movement relative to a subsurface mass

NOTE — A and B are gravity observation sites; B moves to B'

Record No. 1975/24

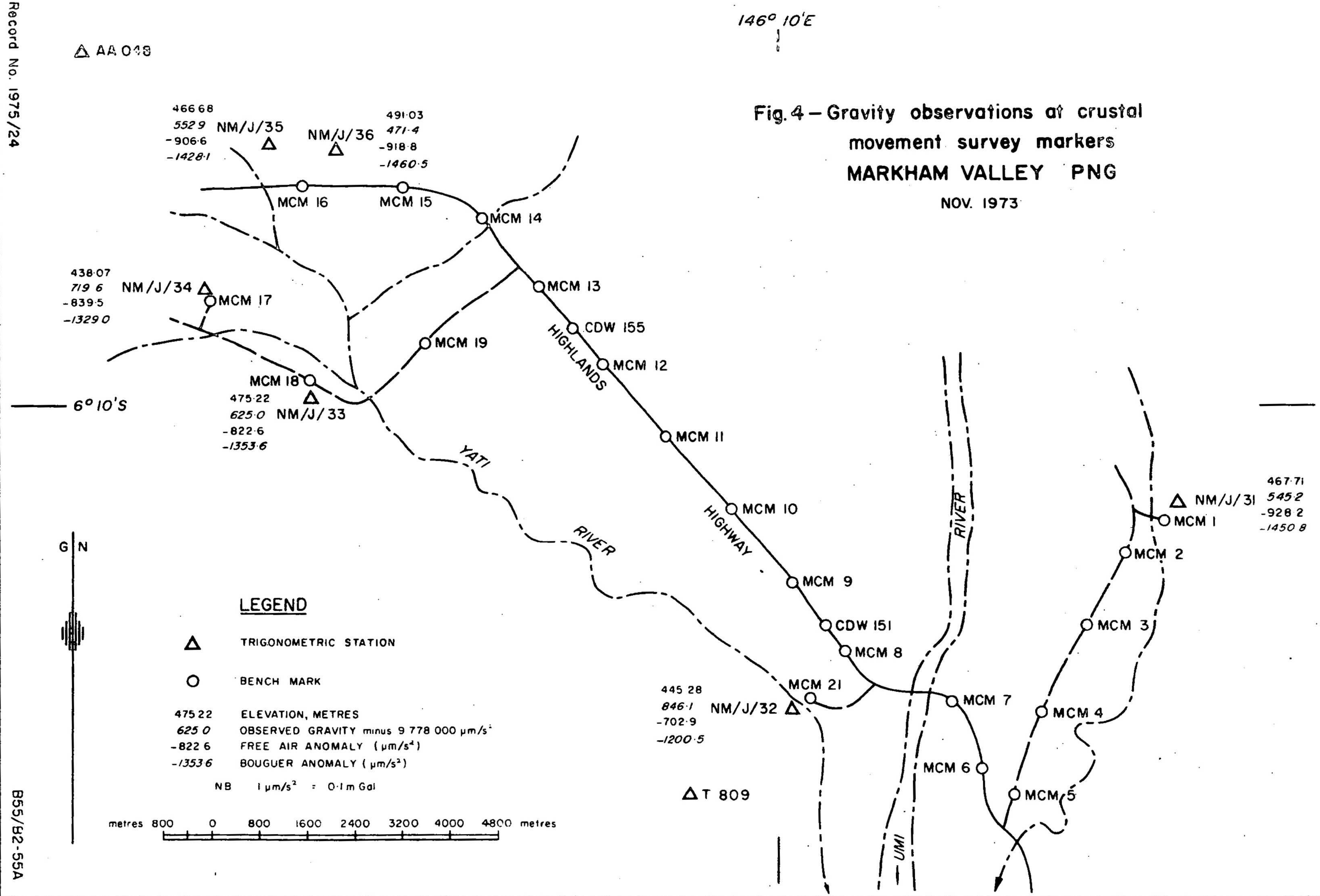

Fig. 4 — Gravity observations at crustal movement survey markers MARKHAM VALLEY PNG

NOV. 1973

B55/B2-55A