DEPARTMENT OF MINERALS AND ENERGY
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DIVISION OF NATIONAL MAPPING
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TECHNICAL REPORT 17

GEODETIC MODELS OF AUSTRALIA

by

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ABSTRACT

Coordinates on the Australian Geodetic Datum, based on the geodetic adjustment of 1966, were adopted by the National Mapping Council of Australia and continue in use for mapping control, modified slightly in three densely populated areas. However, the adjustment of the Australian levelling and the mapping of the geoid in 1971 now enable distances to be rigorously reduced to the spheroid; two transcontinental base-lines have been measured for the Pageos world network; and with other improvements in data, theory and computer programs, the geodetic surveys in Australia were re-adjusted by the Division of National Mapping on 7 May 1973. Further readjustments by the Division are likely in the years to come. To emphasise that they are not for topographic mapping or for survey coordination, where permanence is the first essential, the new sets of coordinates are called Geodetic Models of Australia - GMA. In GMA 73, there are uncertainties of about 0.6" in azimuth, 2 parts per million in scale, and 10 metres in the location of the centre of the system relative to satellite systems whose origin is closer to the Earth's centre of mass.

1. THE AUSTRALIAN GEODETIC DATUM 1966

With the approval of the National Mapping Council, the geodetic surveys in Australia were adjusted in March 1966, to form the Australian Geodetic Datum. As reported at the time (1967 a, paragraph 20), the heights of the stations above the geoid were not well determined. Heights were carried by vertical triangulation, often over long, low lines, from distant individual tide gauges, and misclosures of 6 metres were sometimes found. The situation has been improved by the adjustment of the levelling surveys in Australia to form the Australian Height Datum, on which the heights of all stations in the 1966 geodetic adjustment have now been computed - see section 2.

In 1966, there was also complete ignorance of the height of the geoid above the spheroid, N, which was everywhere taken as zero. This situation has also greatly improved with the survey of the geoid in Australia in 1971 - see section 3.

The combined uncertainty in heights of stations above the spheroid may occasionally have attained 12 m, which would cause an error in spheroidal distance of 2 ppm.

It is also now possible to improve the computations. In 1966, the IAG had yet to make its recommendations at Lucerne about the Reference Ellipsoid 1967 and the Conventional International Origin. The Australian National Spheroid has the same major axis as the Reference Ellipsoid 1967, but the flattening is 1/298.25 exactly, instead of 1/298.247 167 427. The difference is trivial, only 0.203 min the length of the minor axis, but with coordinates on the AGD quoted to millimetres, it cannot be forgotten.

Before the 1966 adjustment, all astronomical observations were reduced to the BIH mean pole of epoch. As the mean date of observation was close to 1962.0 - the date of adoption of the FK4 catalogue - the minor axis of the spheroid was defined to be parallel to the mean pole of 1962.0, discrepancies due to the mean pole of epoch differing from the mean pole of 1962.0 being regarded as errors.

The CIO is 0.06" in x and 0.20" in y from the mean pole of 1962.0. An analysis of the change in the Laplace azimuths which would result from a change in the defined direction of the minor axis of the AGD, showed that the mean change in the 891 azimuths would be only +0.09"; and the National Mapping Council accordingly redefined the minor axis to be parallel to the CIO at their meeting in October 1970, without changing the AGD coordinates.

While a geodesist can be excused for wishing to recompute the network more rigorously, none of these matters render the Australian Geodetic Datum unsatisfactory as control for mapping and the nation-wide coordination of surveys, for which it was designed.

The 2506 stations in the 1966 adjustment merely provided a framework to which other surveys have been adjusted, using progressively improved versions of the original VARYCORD program (1967 b). Several survey departments have their own copies of these programs and the total number of stations now coordinated in the AGD is not exactly known. In the Division of National Mapping, the VARYCORD programs were run 565 times during 1972, and we have records of some 14,000 points. Great care is taken to avoid duplicate coordinates on the AGD for any one point.

2. THE AUSTRALIAN HEIGHT DATUM - See Figure 2

Full details of the adjustment of the Australian levelling network have been given by Roelse et al, 1971. A total of 97,320 km of levelling were adjusted rigorously by least squares as a coherent whole, observed mean sea level at each of thirty tide gauges well distributed round the coast being held at zero. The National Mapping Council adopted the AHD for all topographic mapping in 1971.

Most of the work was done with automatic levels and wooden staves, but the standard error of adjusted heights relative to sea level only attains 0.3 m in a small area in the centre of Australia.

All stations in continental Australia included in the 1966 AGD adjustment now have AHD heights. Levelling was not carried into every geodetic station, but connections were made at intervals of about 80 km where the levelling was abundant, and of 150 km or more in the centre of Australia. Observed differences in height along lines in the triangulation or traverse between levelling connections were adjusted by least squares, using a version of computer program LEVELONE used in the levelling adjustment, called TRIGHT. Height differences were weighted inversely as the square of the length of the line, and also weighted according to whether they were single-ended, reciprocal, or simultaneous reciprocal observations.

A relisting of all the stations in continental Australia which were included in the 1966 adjustment was issued in 1972 with the new AHD heights. The tabulated values of the observed distances were not changed to accord with the new heights, nor were the coordinates changed. The aim was simply to discourage the use of the old heights by cartographers.

AHD heights are not yet available for all the other points on the AGD. The intention is to have levelling connected to the traverse stations at intervals of about 150 km before computing and publishing AHD heights, so that once published they are reasonably definitive.

3. THE GEOID IN AUSTRALIA - See Figure 3

Full details of the geoid survey were reported by Fryer, 1971. The geoid was computed from 1133 astrogeodetic stations, all stations on the Australian Geodetic Datum. The forty-nine loops of geoidal profiles closed on average to 2.0 m, and after adjustment the greatest standard error of any point on the coast relative to Johnston Geodetic Station in the centre of Australia was 1.5 metres. The astronomical work was then supplemented gravimetrically by interpolating the deflections of the vertical and the height of the geoid at 1648 points on a half-degree grid - see Mather, Barlow and Fryer, 1971.

The question arose of what value of N to adopt at Johnston Geodetic Station. After analysis, a value of N = -6 metres was adopted to try to ensure that when geodetic models of Australia were recomputed with distances rigorously reduced to the spheroid using AHD heights and N values, there would be no overall change of scale. If a scale change had systemmatically changed the 1966 coordinates, the deflections of the vertical would change and the 1971 geoid would have to be recomputed.

For use with the AGD 1966 itself, the original spheroidal height of 571.2 m at Johnston is retained. It was formally adopted by the National Mapping Council in 1967, gazetted, and subsequently enshrined in legislation. With the AHD height of Johnston now known to be 566.3 m, this is equivalent to N = +4.9 m; and for use with the AGD, the 1971 geoid shown in Figure 3 will be republished with contour numbers increased by 11 metres.

4. DISTANCE MEASUREMENT

The Division of National Mapping's two laser Model 8 Geodimeters are frequently calibrated against Takeda Riken Model 5578 frequency counters, and are believed to give the best available measure of scale, with no known bias. The crystal frequency very seldom drifts as much as 1 ppm. The index error, or Geodimeter constant, is also very stable, and is easily checked by measuring a short line of known length.

The Division's first two Model 8 Geodimeters were unsatisfactory and were replaced by the manufacturers. In the two Pageos baselines, measured in 1967-70, only 31 lines were measured with Geodimeters and the other 223 lines with MRA4 Tellurometers. Nearly all previous work was measured with earlier models of the Tellurometer.

The high precision traverse (see Figure 1) from Johnston to Adelaide, Melbourne, Sydney and Culgoora, measured in 1971, and a short section of twenty lines on the north-south baseline, is the only work entirely remeasured with laser Geodimeters. A summary of the differences from the old Tellurometer measurements is at Annex A. Along the dry inland section from Johnston to Port Augusta, the differences are random, but as one gets into the mountains of eastern Victoria and NSW, where lines are higher, longer and the air more humid, there appears to be a systematic difference of around 4 ppm, the Tellurometer measurements being shorter.

To investigate this problem, the Division of National Mapping conducted two series of tests, with laser Geodimeters up 10 m towers, and Geodimeters and Tellurometers on the ground. The test line was 22.8 km long, and observations were made every half hour for 24 hours. The results of the first test were reported by Willington and Roelse, 1971.

Mounting such a test may seem simple, but it requires a lot of staff and overtime payments, and seriously disrupts other work, especially if the test is postponed by bad weather. In the event, the test took place on a day ideally suited to distance measurement, an overcast sky with a good breeze, and it was not possible to come to statistically significant conclusions about the best time of day to measure, nor whether accuracy was increased by measuring temperatures several metres above ground level.

The Tellurometers did, however, measure consistently shorter than Geodimeters, operated simultaneously under the same conditions. Atmospheric readings taken at instrument height, some 1.5 metres above ground level, did not have a significant adverse effect on the results, as long as measurements were made in a well-mixed atmosphere. The Geodimeter and MRA 4 distances measured at night were shorter by up to 2 ppm and 5 ppm respectively than those measured during the daytime.

A second test was attempted in 1972. Due to shortage of staff, the Geodimeter measurements were made separately, on 15-16 February. It was again a good day for measurement, and the mean length agreed to 2 mm, or 0.1 ppm, with the distance obtained the previous year. On 28 March, a 12-hour test was attempted with Tellurometers MRA 4 and MRA 2. The MRA 2 Tellurometers had been specially overhauled for the test, but kept blowing fuses. The MRA 4 results added little to the information obtained in 1971. It is not intended to publish the results.

It has often been suggested that an attempt should be made to determine the frequency error and index error of sections of old Tellurometer lines by measuring a sample of lines in each section with laser Geodimeters, and correct the old distances in future adjustments. But even if one assumes the Geodimeter to be free of all error, the Tellurometer distances have a standard error of 3 ppm, and it is very hard to make valid assessments of the errors in a section of the old work by measuring a sample of less than 50%. In preparing the data for GMA 73, the old distances have either been completely remeasured or left alone.

The only loop so far observed wholly with high precision traverse is shown in red on Figure 1, round the south-east part of Australia. It is 4300 km long. Of the 118 lines, 73 lines were observed with laser 8 Geodimeters and 45 with MRA 4 Tellurometers. There are reciprocal Laplace azimuths on 82 lines, and much the greater part is triangulation, not simple traverse. There is a geoidal profile around the loop and all distances were reduced to the spheroid. Angular observations were made with Wild T3 theodolites on at least two nights at every station. The loop closure was 1.7 ppm, which was initially thought disappointing, but with over a third of the lines measured with Tellurometers, it was perhaps optimistic to hope for anything better.

5. THE GEODETIC MODEL OF AUSTRALIA, 1973 - PLANS

The National Mapping Council has resolved to retain the AGD 1966 as a base for all topographic mapping; but one of the functions of the Division of National Mapping is to periodically readjust the geodetic surveys in Australia with a view to:

.1 Estimating the errors in the AGD 1966.

.2 Providing more accurate coordinates for satellite tracking stations and similar installations in Australia.

.3 Providing up-to-date sets of geodetic coordinates for transformation to a world datum.

At one time, it was proposed to distinguish these new sets of coordinates by using the term Australian Research Datum, but this term has been abandoned. Future sets of coordinates which are not to be used for topographic or survey coordination purposes will be called Geodetic Models of Australia - GMA.

The GMA 73 differs from the AGD 1966 as follows:

.1 It is computed on the Reference Ellipsoid 1967, not the Australian National Spheroid.

.2 Laplace azimuths have been rigorously computed in terms of the Conventional International Origin, to which the minor axis is now strictly parallel.

.3 Heights listed are above the Australian Height Datum.

.4 N values are listed, taken from Figure 3, with N = -6 metres at Johnston.

.5 Distances have been rigorously reduced to the spheroid.

.6 Much new data is included - see below.

No change was needed in the geodetic latitude and longitude at Johnston adopted in 1966. Figure 3 shows that these values were well chosen, and there is no systematic slope between the Australian Geodetic Datum and the geoid in Australia.

It would have been possible to reduce all angles rigorously for the deviation of the vertical and for skew normals. In the history of geodesy, the necessary information has seldom been available for an area as large as Australia, and the temptation to apply the corrections, as a sort of geodetic status symbol, was great. However, numerical examination revealed that even in the highest section of triangulation in the Australian Alps, where rays are high and sometimes steep, the maximum correction was only 0.1"; most of Australia is low and flat; and the angles are tightly contained between frequent Laplace azimuths, to which both corrections have in every case been applied. I was decided, therefore, not without regret, that the corrections would have no effect on computed coordinates, and they have been left out.

The chief additions to the data since 1966 are:

.1 The two Pageos base lines run between Culgoora, NSW, and Perth to the west, and Thursday Island to the north - see Figure 1. This work has been fully reported by Leppert, 1972. The baselines nearly always followed a traverse measured before 1966. All distances were re-measured, usually with MRA 4 Tellurometers; and reciprocal Laplace azimuths were observed over every line of simple traverse, and over alternate lines of triangulation. Astronomic observations at almost every station form a continuous geoidal profile along both baselines.

.2 The high-precision travere, to the same specifications as the Pageos baselines but wholly remeasured with laser Geodimeters, from Johnston to Adelaide, Melbourne, Sydney and Culgoora - see Figure 1.

.3 Such other traverses run since 1966 which contribute significantly to the strenth of the basic framework - an additional seventeen sections.

6. THE GEODETIC MODEL OF AUSTRALIA 1973 - COMPUTATIONS

The data for the 1966 geodetic adjustment was held on cards. In the years 1966-72, changes to station names and serial numbers were made when necessary; but no angles, azimuths or distances were changed, so that when the decks were passed through the computer, coordinates identical to those adopted in 1966 were obtained.

In 1972, all the original decks were rerun, and the output carefully checked. The data was then transferred to magnetic tape, on which it could be amended using UPDATE routines on the CDC 6600 computer. These amendments consisted chiefly of:

.1 Corrections of mistakes noted since 1966 (1967 a, paragraph 45).

.2 Replacement of BIH azimuths by CIO azimuths.

.3 Insertion of new CIO azimuths.

.4 Replacement of old Tellurometer distances by laser Geodimeter or MRA 4 distances, where available. For uniformity, the new distances were temporarily reduced with the old 1966 heights, but see below.

.5 Removal of the Hiran lines included in 1966, leaving the traverse up Cape York Peninsula as an unsupported spur, except when the Pageos azimuths were included - see Section 7.

The seventeen new sections observed since 1966 were added to the tape. For each section, old and new, a small card deck was prepared listing:

.1 New junction point terminal numbers, identifying the rods - see Figure 6 - increasing the number of rods from 161 to 210.

.2 The 1966 heights currently on the magnetic tape.

.3 The AHD heights which were to replace tnem.

.4 The N-values at each station, based on N = -6 metres at Johnston.

Program DATAMOD modified distances from AGD 66 to GMA 73, substituted new heights for the old, and added the N-value at each station to the tape, in a format ready for processing by the variation of coordinates program.

The program used for GMA 1972, both for the free adjustment of individual sections, and for the simultaneous adjustment of the "rods" all over Australia ("the rod adjustment") is called VARUDEL. It differs from the original VARYCORD program used in 1966 (1967 b) only in that:

.1 Rudoe's formula (G. Bomford, 1971, p 136) is used instead of Robbin's.

.2 It computes the parameters of station error ellipses relative to the fixed points.

.3 It lists both AHD heights and N-values.

.4 The maximum number of variable points has been increased from 100 to 200.

.5 The maximum number of elements in the band matrix has been increased from 10,000 to 50,000.

.6 It runs on the CDC 6600 computer.

VARUDEL on the CDC 6600 is about twice as fast as VARYCORD on the CDC 3600. The GMA 73 and 23,655 elements in the band matrix, and the normal equations were solved in 182 seconds.

The weighting systems built into the program are still those used in 1966. In the individual free adjustment of sections, the R option was used (1967 a, paragraph 12; 1967 b paragraph 21.5). Laser Geodimeter distances were given a specific weight of 9, and MRA 4 Tellurometer distances a specific weight of 4, compared with 1 for other Tellurometer distances. The program then allocated weights equivalent to standard errors of 3 cm + 3 ppm to MRA 1 and MRA 2 Tellurometer distances, 2 cm + 2ppm for MRA 4 Tellurometers, and 1 cm + 1ppm for laser Geodimeter and the factors by which the observation equations containing distances were multiplied were in the ratio 1:2:3.

From the free adjustment of individual sections, loop closures were calculated. They are shown in Figure 4 and Figure 6. Their standard deviation is 1.9 ppm, compared with 1.7 ppm in 1966, due in part at least to the 49 extra rods making the average loop smaller. The free adjustments were carefully checked, particularly in loops with big closures.

The length and normal section azimuths of the 210 rods linking the 131 junction points were computed using program AZARC, which uses Rudoe's formulae.

To minimise the bandwidth when the azimuths between the widely spaced Pageos stations were included, the junction point serial numbers were reallocated. The new numbers are shown in Figure 6, and run anticlockwise around circles of increasing radius centred on junction point 1, east of Johnston.

Johnston Geodetic station was held fixed at its 1966 coordinates, and AGD 1966 coordinates were used for the preliminary coordinates of the junction points, so that the computer output at once gave the changes GMA 73 - AGD 66. Great care was again taken to see that the azimuths of the rods and preliminary longitudes of the junction points fulfilled the Laplace condition, and the program then maintained the condition automatically.

In the rod adjustment, the weights given to the length and azimuth of each rod in 1966 were re-examined. Where Tellurometer MRA 4 or Geodimeter measurements had been made along old traverses, or additional Laplace azimuths had been observed, the rods received higher weight; but unless there had been additional observations, changes from the weights used in 1966 were not great.

For the rod adjustment, the X weighting option was again used in the VARYCORD program (1967 a, paragraph 11; 1967 b, paragraph 21.4) which additionally weights both the length and azimuth of each rod inversely as its length.

A test run on 17 April 1973 showed that the adjustments to the lengths of rods were small, while a reduction in the adjustments to azimuths would be welcome, just as in 1966 (1967 a, paragraphs 35-38). The average adjustment to length of the rod was 0.29 m and to an azimuth 0.71".

On 27 April 1973 the adjustment was re-run with the weights of all distances reduced by a factor of 0.6, just as in 1966, but the changes were not great: the average adjustment to the length of a rod went up to 0.35 m, and to an azimuth came down to 0.62".

On the problem of the correct allocation of weights between distances and azimuths in a rod adjustment, little progress has been made since 1966.

The adjustment accepted for GMA 73 was run on 7 May 1973. The adjustments to the rods are shown in two histograms in Figure 5 (which can be compared with 1967 a, Figures 4 and 5). The displacement of junction points from their 1966 positions is shown in Figure 6.

Forced adjustments of individual sections will be carried out exactly as in 1966 when required.

7. PAGEOS AZIMUTHS

Information about the azimuths of the three lines between the Pageos stations at Culgoora, Perth and Thursday Island were received in a letter from Hellmut Schmid (1972 a) the essence of which can be found in Schmid 1972 b. Dr Schmid provided two solutions to the Australian triangle. In both, the coordinates of Culgoora were held at their AGD 1966 values. The first contained the three azimuths and the east-west baselines, with no redundancy. Assuming Dr Schmid's axes were aligned with Z towards the CIO pole, and X towards the BIH mean Greenwich observatory, then the Laplace condition for the two azimuths out of Culgoora was satisfied by using the AGD 1966 longitude of Culgoora as provisional coordinates in the VARUDEL program; and the azimuth for the ray from Thursday Island to Perth merely needed a small correction to allow for the change in longitude at Thursday Island from the value computed by Dr Schmid in his triangle to the AGD 1966 value used in our adjustment.

Dr Schmid's second solution used the three azimuths and both baselines. Assuming the azimuths perfect, the north-south baseline appeared too long compared to the east-west baseline by 8.2 m or 3.6 parts per million, a disappointing result.

This misclosure is not easily explained by scale errors in the Tellurometer distances. The east-west baseline for the most part runs on short, low lines in dry desert, where the scale of the Tellurometer work should be good. The north-south baseline tends to run on long lines between reasonably high hills, not far from the Pacific coast. In these circumstances, Tellurometer distances might be too short. But the satellite results suggest that the north-south baseline, compared to the east-west baseline, is too long.

It is not easy to believe that either baseline contains a blunder; both baselines have had the distances measured twice, with a lapse of several years in between; both have simultaneous reciprocal Laplace azimuths on about 80% of the lines; and all except the last section of the north-south baseline up Cape York Peninsula form loops which close satisfactorily.

The three Pageos azimuths were included in a second rod adjustment, otherwise identical to that of 7 May, which was run on 18 May 1973.

The Pageos azimuths were each given a specific weight of 0.9, so that with a typical rod length of 3000 km, the X weighting option multiplied the observation equation by 3.6, compared with 4.8 for a 300 km rod with reciprocal azimuths on every line.

The satellite azimuths are compared with geodetic azimuths in the following table:

Line	Culgoora-Perth	Culgoora - Thursday Island	Thursday Island - Perth
Spheroidal Distance (km)	3196	2312	3580
Pairs of Plates	55	48	20
Standard Error (Schmid 1972a)	0.17"	0.12"	0.19"
Azimuth, degrees and minutes	258°12'	339°13'	224°56'
Pageos azimuth, with Laplace correction to AGD 1966 longitudes, from Schmid 1972a, first solution	10.70"	46.65"	20.01"
Azimuth from the baseline computations in Leppert, 1972	09.92"	46.21"	-
AGD 1966	10.06"	46.11"	19.16"
GMA 73 (7 May 1973)	09.89"	46.34"	18.97"
GMA 73 + Pageos azimuths (18 May 1973)	09.98"	46.41"	19.13"

It will be observed that on average, Dr Schmid's azimuths are about 0.6" greater than azimuths computed from astronomical observations in Australia.

This may seem too much to ascribe to chance. Discrepancies of about 0.6" are also obtained when one makes comparison in the other dimension:

	Culgoora	Thursday Island	Perth
Spheroidal height in Leppert 1972	211.8 m	61.7 m	32.5 m
Spheroidal height from Schmid 1972a	Held at 211.8 m	53.8 m	22.3 m
Difference	-	7.9 m	10.2 m
Equivalent to an error in elevation angle of:	-	0.70"	0.65"

Personal equation in the Australian astronomic longitudes may also contribute. About 18% were observed without moving-wire eyepieces. Personal equation of 0.08 s would make Laplace azimuths in latitude 30°S too small by 0.6".

In the adjustment of 18 May, five-sixths of the discrepancy was thrown into the Pageos azimuths. One could argue that the weights given to them were too low; but no reasonable weight could enable the three Pageos azimuths to rotate the whole network against the influence of the 891 Laplace azimuths. The effect of the Pageos azimuths is to move the Pageos stations clockwise around Johnston by about 2 metres, with some corresponding local distrubance, leaving the bulk of the network essentially unchanged.

8. WORLD DATUM COORDINATES

The Australian Geodetic Datum was positioned so as to fit the geoid in Australia, and Figure 3 shows that it does this well. Even in 1966, however, it was thought that the centre of the AGD coordinate system was about 160 m away from the earth centre of mass (1967 a, p 57 footnote). All later pictures of the geoid on a world datum have shown the geoid rising steeply and evenly from a low off Perth to a high near the Solomon Islands.

At the time of writing (June 73), the satellite tracking stations in Australia are still being coordinated on GMA 73, but comparisons with earlier AGD coordinates against the coordinates of eight doppler Tranet stations in Australia enable us to predict that the centre of the GMA 73 system will be close to the following point on the NWL Tranet system:

$$X = +123 \text{ m} \qquad Y = +30 \text{ m} \qquad Z = -142 \text{ m}$$

The vector distance will be close to 190 m, with a standard deviation from among the eight stations of 5 m.

Estimates of the separation of the two system centres will also be available from the Baker Nunn network (Lambeck, 1970); from VLBI work at Tidbinbilla and Island Lagoon (Gubbay, 1970); from gravity work at the University of New South Wales (Mather, 1970); and from observations with a mobile laser ranger at Carnarvon (Marsh, et al, 1971).

At the time of writing, only preliminary Pageos datum coordinates for the three stations in Australia have been received, which are likely to have been superseded by the time this paper is presented. The corresponding values of XYZ do not differ much from the figures above.

As neither the Pageos coordinates nor the GMA 73 coordinates are in any way definitive, it is not our present intention to deform the GMA 73 to fit the coordinates of the three Pageos stations on the world datum by least squares. At each Pageos station, when final coordinates are available, the intention is to convert both GMA 73 and Pageos coordinates to earth-centred cartesian coordinates XYZ, determine values for ΔX, ΔY, and ΔZ, and adopt a mean. Coordinate transformation from GMA 73 to a world datum can then be done using a program called DATUMCON, which converts latitudes, longitudes and spheroid heights on one spheroid to X, Y, Z; adds ΔX, ΔY and ΔZ; and computes latitudes, longitudes and spheroid heights on the other spheroid. Dr Schmid's preliminary coordinates suggest that there may be discrepancies of up to three metres at the three Pageos stations, but this is only about one-third of the uncertainty in the location of the centre of GMA 73; and observations within Australia will remain undistorted.

If ever some permanence in world datum coordinates is attained, it would be easy to rerun the latest GMA rod adjustment through the variation of coordinates program, with Johnston free, and the three Pageos stations - and any other satellite tracking station whose coordinates on the same world net was known - held fixed. At present, however, it seems best to leave the current geodetic model of Australia undistorted, and simply reposition it from time to time as more external data becomes available.

9. ACKNOWLEDGEMENTS

It will be evident to anyone who peruses the names of the authors of National Mapping's Technical Reports 10 to 14 that geodesy in the Division of National Mapping is a team effort from the Director, Mr B.P. Lambert, downwards. The author would particularly like to acknowledge the work done by Mr K. Leppert, the Supervising Surveyor of the Geodetic Branch, and by Mr A. Roelse, who is in charge of the Computing Section.

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COMPARISON OF GEODIMETER WITH TELLUROMETER MEASUREMENTS

Section: Johnston-Maurice (SA)

From	To	Geodimeter Model 8	Tellurometer MRA 1 or MRA 2	Tellurometer-Geodimeter metres	Tellurometer-Geodimeter ppm
Johnston	Cecil NM/G/68	47769.480	69.719	+0.239	+5.00
Cecil NM/G/68	Darling NM/E/22	13570.089	70.039	-0.050	-3.68
Darling NM/E/22	Parlue NM/E/21	13085.472	85.521	+0.049	+3.74
Parlue NM/E/21	Mead NM/E/20	24429.339	29.311	-0.028	-1.15
Mead NM/E/20	Grundy	39274.807	74.632	-0.175	-4.46
Grundy	Hearne NTS 239	38852.880	52.924	+0.044	+1.13
Hearne NTS 239	Barr	32004.504	-	-	-
Barr	Dillon	37295.261	-	-	-
Dillon	Yangalee	45391.921	-	-	-
Yangalee	Alexander	39418.587	-	-	-
Alexander	Western Bluff	42611.137	-	-	-
Western Bluff	Stewarts	28882.911	82.972	+0.061	+2.11
Stewarts	Dutton	29530.926	30.954	+0.028	+0.95
Dutton	Denison	45818.767	18.688	-0.079	-1.72
Denison	Margaret	39512.347	12.403	+0.056	+1.42
Margaret	Anna	21132.683	32.621	-0.062	-2.93
Anna	Low Cliff	37631.061	31.047	-0.014	-0.37
Low Cliff	Binda Boudna	45018.915	18.904	-0.011	-0.24
Binda Boudna	Serrated Range	37433.994	33.970	-0.024	-0.64
Serrated Range	Hogarth	23839.011	38.965	-0.046	-1.93
Hogarth	Paisley	26138.930	38.919	-0.011	-0.42
Paisley	Wingilpin	29695.024	94.833	-0.191	-6.43
Wingilpin	Hudson	21321.291	21.180	-0.111	-5.21
Hudson	Rawlinson	16609.365	09.262	-0.103	-6.20
Rawlinson	MacDowell	26020.770	-	-	-
MacDowell	Hanson	14439.381	-	-	-
Sandy Point	Emmies New	35141.149	-	-	-
Emmies New	Bernard	28917.294	-	-	-
Bernard	Oakden	32036.418	36.224	-0.194	-6.06
Oakden	Belo	45720.281	20.257	-0.024	-0.52
Belo	Uro	35180.574	-	-	-
Uro	Arden	37429.902	-	-	-
Arden	Stokes	49217.690	-	-	-
Stokes	Maurice	50370.398	-	-	-

Mean (with regard to sign) - 0.031 - 1.31
Mean (without " " ") 2.68

Section: Maurice (SA)–Gambier

From	To	Geodimeter Model 8	Tellurometer MRA 1 or MRA 2	Tellurometer–Geodimeter	
				metres	ppm
Maurice	Lock	27225.196	25.206	+0.010	+0.37
Lock	Campbell	23519.517	19.512	–0.005	–0.21
Campbell	Gregory	32988.457	88.473	+0.016	+0.49
Gregory	Stony Range	25617.579	17.551	–0.028	–1.09
Stony Range	Horrocks	13154.385	54.381	–0.004	–0.30
Horrocks	Macaw	29488.945	88.968	+0.023	+0.78
Macaw	Light	19904.126	04.177	+0.051	+2.56
Light	North Road	17354.942	–	–	–
North Road	Quartz	27269.471	–	–	–
Quartz	Lofty	33034.679	–	–	–
Lofty	Barker	21785.254	85.285	+0.031	+1.42
Barker	Gifford	28707.642	07.610	–0.032	–1.11
Gifford	Binnies	70063.539	63.893	+0.354	+5.05
Binnies	Boothby	22904.883	04.891	+0.008	+0.35
Boothby	Charles	35694.307	94.171	–0.136	–3.81
Charles	Monster	27504.582	04.640	+0.058	+2.11
Monster	Gip Gip	33173.709	73.715	+0.006	+0.18
Gip Gip	Bin Bin	21640.555	40.661	+0.106	+4.90
Bin Bin	Minecrow	16964.004	64.014	+0.010	+0.59
Minecrow	Camelback	31888.238	88.045	–0.193	–6.05
Camelback	Furner	26465.301	65.339	+0.038	+1.44
Furner	Muirhead	26461.845	61.892	+0.047	+1.78
Muirhead	Burr	8416.313	16.469	+0.156	+18.54
Burr	Gambier	25816.106	16.012	–0.094	–3.64

(a) Mean (with regard to sign)	+0.020	+1.16
Mean (without " " ")		2.70
(b) Ignoring the distance 8 km long: Muirhead–Burr		
(c) Mean (with regard to sign)	+0.013	+0.29
Mean (without " " ")		1.91

Section: Gambier-Imlay

From	To	Geodimeter Model 8	Tellurometer MRA 1 or MRA 2	Tellurometer-Geodimeter	
				metres	ppm
Gambier	Heath Point	58491.246	90.999	-0.247	-4.22
Heath Point	Napier	63535.297	-	-	-
Napier	Shadwell	68554.341	54.085	-0.256	-3.73
Shadwell	Elephant	35291.158	91.184	+0.026	+0.74
Elephant	Gellibrand	60517.722	-	-	-
Gellibrand	Flinders	63727.663	-	-	-
Flinders	Bellarine	27659.362	59.079	-0.283	-10.23
Bellarine	Arthurs Seat	37175.330	75.006	-0.324	-8.72
Bass Hill	Eccles Minor	42563.215	63.045	-0.170	-3.99
Eccles Minor	Hooghly	43199.496	99.567	+0.071	+1.64
Hooghly	Holey	44886.075	85.935	-0.140	-3.12
Moornapa	Taylor	37096.554	96.270	-0.284	-7.66
Taylor	Nowa Nowa	46807.938	07.727	-0.211	-4.51
Raymond	Cann	34191.438	91.129	-0.309	-9.04
Cann	Maramingo	56668.495	68.193	-0.302	-5.33
Maramingo	Imlay	30468.103	67.994	-0.109	-3.58
			Mean (with regard to sign)	-0.195	-4.75
			Mean (without " " ")		5.12

Section: Imlay-Culgoora

From	To	Geodimeter Model 8	Tellurometer MRA 1 or MRA 2	Tellurometer-Geodimeter	
				metres	ppm
Imlay	Wolumla	35058.105	58.043	-0.062	-1.77
Wolumla	Glenbog	42749.288	48.963	-0.325	-7.60
Glenbog	Hudsons Peak	26112.633	12.659	+0.026	+1.00
Hudsons Peak	Wambrook	37606.535	06.392	-0.143	-3.80
Wambrook	Clear	38599.491	99.469	+0.022	+0.57
Clear	Tennant	36228.922	-	-	-
Tennant	Yarrow Pic	29078.842	-	-	-
Yarrow Pic	Stromlo	31672.647	-	-	-
Yarrow Pic	Twynam	30629.969	29.794	-0.175	-5.71
Twynam	Towrang	57495.352	95.217	-0.135	-2.35
Towrang	Jellore	65905.811	05.545	-0.266	-4.04
Jellore	Razorback	37310.149	09.745	-0.404	-10.83
Razorback	Mulgoa	37092.932	92.764	-0.168	-4.53
Mulgoa	Conder	40922.020	22.088	+0.068	+1.66
Conder	Warrawolong	72063.056	62.352	-0.704	-9.77
Warrawolong	Sugarloaf	30687.918	87.719	-0.199	-6.48
Sugarloaf	Tyraman	45231.885	31.716	-0.169	-3.74
Tyraman	Cockcrow	43780.476	80.268	-0.208	-4.75
Cockcrow	Crawney	65958.707	58.421	-0.286	-4.34
Crawney	Piallaway	63183.137	82.977	-0.160	-2.53
Piallaway	Baldwin	43682.629	-	-	-
Baldwin	Gulf Creek	59111.647	11.324	-0.323	-5.46

Mean (with regard to sign)	-0.201	-4.14
Mean (without " " ")		4.50

Section: Maurice (Qld) - RM Point

From	To	Geodimeter Model 8	Tellurometer MRA 1 or MRA 2	Tellurometer-Geodimeter	
				metres	ppm
Maurice	Holly	45895.696	95.378	-0.318	-6.93
Holly	Plumtree	39261.400	61.221	-0.179	-4.56
Plumtree	Lion	28299.844	99.804	-0.040	-1.41
Lion	Etna	28985.235	85.281	+0.046	+1.59
Etna	Pointer	34449.608	49.458	-0.150	-4.35
Pointer	Brothers	36931.513	31.264	-0.249	-6.74
Brothers	Blacktop	29899.981	99.910	-0.071	-2.37
Blacktop	Salt Hill	37278.386	78.306	-0.080	-2.15
Salt Hill	Clairview	15318.621	18.539	-0.082	-5.35
Clairview	Christian	59843.667	43.676	+0.009	+0.15
Christian	Chelona	28107.722	07.561	-0.161	-5.73
Chelona	Sister	39131.963	31.626	-0.337	-8.61
Sister	West Pinnacle	16783.330	83.282	-0.048	-2.86
West Pinnacle	Rocky Mt.	37264.472	64.535	+0.063	+1.69
Rocky Mt.	Dingo	23334.501	34.577	+0.076	+3.26
Dingo	Foxdale	29186.771	86.868	+0.097	+3.32
Foxdale	Little Maria	40052.702	52.413	-0.289	-7.22
Little Maria	Little	24919.475	19.490	+0.015	+0.60
Little	Nobbies LO	33765.811	65.863	+0.052	+1.54
Nobbies LO	RM Point	16367.166	67.255	+0.089	+5.44

Mean (with regard to sign)	-0.078	-2.03
Mean (without " " ")		3.79

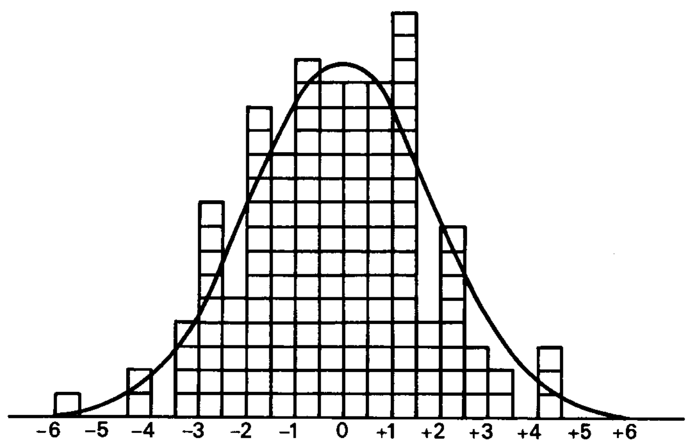

Fig. 4a. Closures of 71 loops in latitude and longitude, in parts per million of the loop length. Average closure 1.53 ppm. Normal distribution with $\sigma = 1.90$ superimposed.

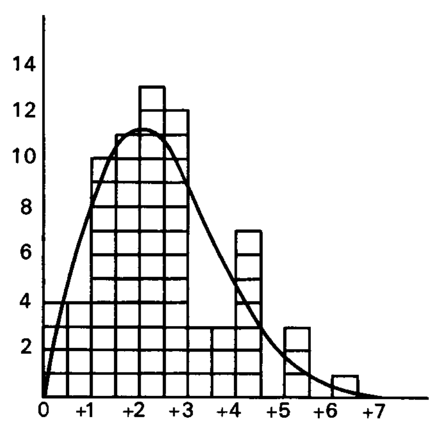

Fig. 4b. Vector loop closures of 71 loops as parts per million of the loop length. Average closure 2.39 ppm. Normal two-dimensional distribution with $\sigma = 1.9$ in each dimension superimposed.

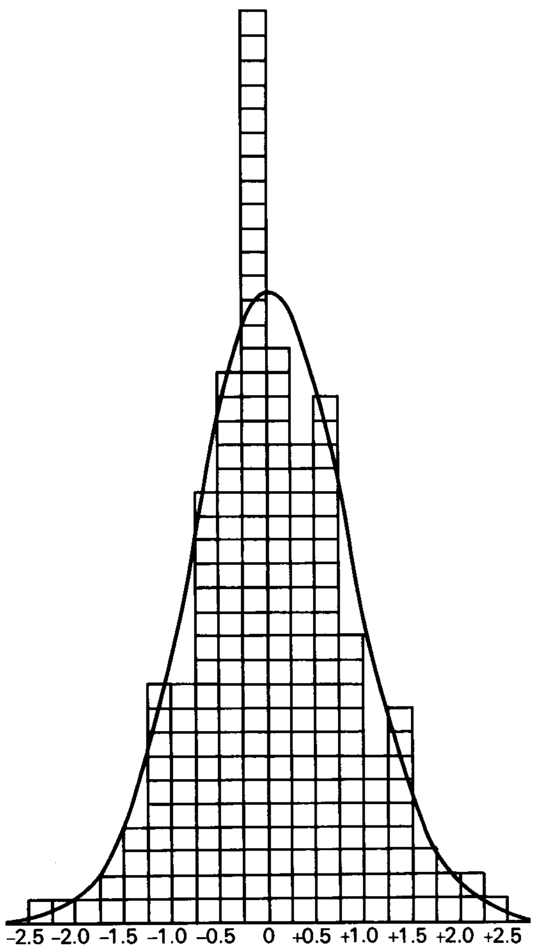

Fig. 5a. Adjustments to azimuths of 210 sections, in seconds. Average adjustment 0.62″ Normal distribution with $\sigma = 0.796$ superimposed.

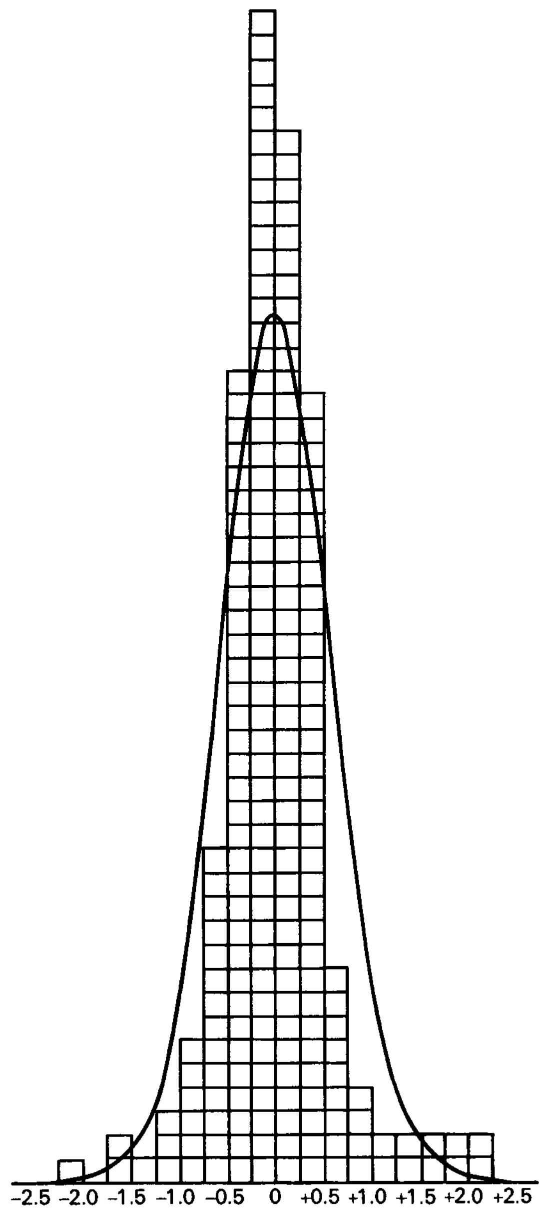

Fig. 5b. Adjustments to lengths of 210 sections, in metres. Average adjustment 0.39 metres, or 1.61 ppm. Normal distribution with $\sigma = 0.577$ superimposed.