THE 1971 GEOID FOR AUSTRALIA AND ITS SIGNIFICANCE IN GLOBAL GEODESY

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(With 1 Table and 2 Text-Figures)

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ABSTRACT

A review is presented of all solutions for the geoid in the Australian region, culminating in the 1971 determination, based on a combination of astro-geodetic and gravimetric techniques. It is shown how the principles underlying this combined solution can be used to establish a World Geodetic System which would provide an alternate method for studying the secular variations in position, of points at the surface of the Earth.

INTRODUCTION

Research into the practical aspects of physical geodesy, which deals with studies of the size, shape and space characteristics of the Earth's gravitational field, has been in progress in Australia over the last decade. This has eventuated in a solution for the geoid over the Australian region with an accuracy of ± 1 m on a *relative* basis, except in certain limited regions where there are inadequate data for reliable calculations. The accuracy is generally better than ± 2 m even in these areas which comprise approximately 5% of the continent. Such figures are significantly better than those achieved in any determination made over comparable extents elsewhere, and are the consequence of improvements based on the results of previous test solutions.

Determinations which approximate, with adequate accuracy, to the *geoid*, defined as the equipotential surface of the Earth's gravitational field corresponding to Mean Sea Level, can be made by either one of two totally independent methods. In the first, the shape of the geoid over the region is deduced from the directions of the local vertical for the area, as determined by astronomical means. These are dependent on local fluctuations in the shape of equipotential surfaces and, in general, will differ in Earth space orientation from those of the normal to the *ellipsoid* (*i.e.* the figure obtained by rotating an ellipse about its minor axis), which is used as the reference frame for geodetic computations. Such discrepancies, called *deflections of the vertical*, are a measure of the slope of the equipotential surfaces, and hence the geoid, in relation to the ellipsoid. This, in turn, gives changes in geoid height which can be used to produce a map of geoid undulations on a relative basis (*e.g.* Fryer, 1971).

Such a determination is called *astro-geodetic*. The reference ellipsoid in this case, has a location in Earth space which is governed by the geodetic co-ordinates adopted at the origin of the geodetic datum. Thus the ellipsoid used in the definition of the Australian Geodetic Datum (AGD) has its centre approximately 170 m from the Earth's centre of mass (or *geocentre*) by virtue of the co-ordinates adopted at the Johnston Origin situated near the South Australia-Northern Territory border, alongside the Stuart Highway. These values are given by Lambert (1968, p. 95).

The second method of determination of the geoid is by the use of values of the acceleration due to gravity, measured at the surface of the Earth. Changes in these values are influenced by density anomalies which, in turn, affect the shape of equipotential surfaces of the Earth's gravitational field. The geoid can be completely defined with respect to a reference ellipsoid if the gravity field is known at *all points* on the Earth's surface. The ellipsoid is implicit in the formula adopted for the computation of normal gravity when determining the free air anomaly. It can be shown (Mather, 1968, p. 524) that the *free air geoid*, obtained by the use of free air anomalies in Stokes' integral (*e.g.* Heiskanen & Moritz, 1967, p. 92), is a good approximation to the geoid in all but very mountainous regions. The correction to be made to the elevation of the free air geoid above the ellipsoid, to give that of the geoid itself, is called the *indirect effect*. The magnitude of the latter is dependent on the nature of the topography exterior to the geoid, being due to the same causes which give rise to the terrain correction applied to the Bouguer reduction when computing Bouguer anomalies.

The variation of the indirect effect across Australia does not exceed 60 cm and hence has not been considered when determining the geoid from gravity values. Such solutions are called *gravimetric* determinations and have the implicit characteristic that the ellipsoid of reference has its centre at the geocentre.

The comparison of gravimetric and astro-geodetic solutions for the geoid over the same area affords several interesting possibilities.

(i) It provides a means of defining the Earth space displacement between the centre of the reference ellipsoid used for the regional datum, and the geocentre. This, in turn, can be used to define a World Geodetic System (Mather, 1971*a*; Mather, 1971*b*).

(ii) It affords a unique means for assessing the accuracy attained in determining the geoid.

(iii) It permits the combination of solutions by each of the two methods, both of which are subject to error at the time of writing, in a manner which enhances the accuracy of the determination.

(iv) It provides, in the long term, the foundations of a technique for resolving, with certainty, some of the problems associated with secular variations in position and hence, with basic concepts concerning the dynamics of plate tectonics and notions of continental drift on a global scale.

A REVIEW OF GEOID SOLUTIONS FOR AUSTRALIA

Astro-geodetic solutions

The first attempt at an astro-geodetic solution for the geoid in Australia was by Bomford for the Woomera region (Bomford, 1963). All the astro-geodetic data available in Australia at the time were also used in the definition of the Australian Geodetic Datum in order that the reference ellipsoid be made parallel to the mean geoid slope across Australia. More details are given by Mather & Fryer (1970). Such a procedure is of advantage for geodetic computations as it enables ordinary orthometric elevations to define reductions to the reference ellipsoid without significant error.

An astro-geodetic geoid for Australia was produced by the U.S. Army Map Service in 1967 and referred to the Australian Geodetic Datum (Fischer & Slutsky, 1967). This was based on approximately 550 astro-geodetic stations and will be referred to as the *1967 astro-geodetic solution.* A further solution was made by the Division of National Mapping, Canberra in 1971. The latter was based on approximately 1150 stations (Fryer, 1971). The *framework* defined by these stations will be called the *1971 astrogeodetic solution.* It is almost entirely based on astro-geodetic information, the exceptions being given by Fryer (1971, p. 6).

The network of astro-geodetic stations in Australia is unique, having been established over a period of 20 years (1950-1970) using standard observational techniques. This also applies to the bulk of the geodetic determinations. Consequently, the establishment of the astro-geodetic network in Australia has been referred to overseas as being a 'textbook effort' and is the only such solution of continental extent available anywhere in the world at the time of writing.

Gravimetric solutions

Gravimetric solutions call for a knowledge of gravity anomalies at all points on the Earth's surface. Such information is not available at the present time on the basis of gravity determinations at the surface of the Earth alone. Reliable practical solutions could not be made till 1960 when it became possible to evaluate long wave variations of the Earth's gravity field by a study of the orbital perturbations of artificial Earth satellites. Due to the limits imposed on the minimum elevation of satellites in view of the air drag problems, it is unlikely that variations in the gravity field with half wavelengths less than 2000 km, can be determined with confidence from satellite data alone, using systems which are operational at the present time.

The shorter wavelength terms as determined from orbital analysis are of questionable quality. They can however be shaped to fit the gravity field at the surface of the Earth by using a technique initially suggested by Kaula (1966). The success of such a procedure depends on the amount of data available at the surface of the Earth. Those specialising in such solutions claim that all variations with half wavelengths longer than about 1300 km can be adequately represented with the data available at present. This would imply that geoid features which are a consequence of those density anomalies closer to the surface of the Earth, could only be delineated if the effects of adjacent regions were computed from surface gravity data alone.

A favourable set of conditions prevail for the Australian region. The gravity data in the area are referred to the uniform reference system afforded by the Australian National Gravity Network established by the Bureau of Mineral Resources, Geology & Geophysics (Mather, Barlow & Fryer, 1971, p. 6). The entire Australian continent is expected to be covered by the reconnaissance gravity survey of Australia not later than 1974 with a station density of one per 130 km^2. The representation available at present exceeds 90% of the area.

The initial gravimetric determination of the geoid in Australia was performed at the University of New South Wales in 1967 for the state of South Australia. A determination for Australia was made in 1968 and called the *1968 free air geoid.* The surface areas of the Earth which were in excess of 2000 km from the point of computation were represented by the long wave variations of the gravity field described above. The region within 2,000 km was represented by the available surface gravity data which were incomplete. Hence, considerable use had to be made of prediction methods for the definition of the gravity field in unsurveyed areas. A further solution, called the *1970 free air geoid* was also made for the reasons given below. The free air geoid was adopted as the gravimetric solution because the indirect effect, as stated in the previous section, has a variation less than 60 cm across Australia and is not of significance in relative determinations.

A gravimetric solution has also been produced for Australia at the Moscow State University using a slightly different technique (Grushinsky & Sazhina, 1971). This paper describes tests carried out in comparison with the 1968 free air geoid.

The comparison of solutions

The comparison of the 1968 free air geoid with the 1967 astro-geodetic solution indicated that the predictions made in the preparation of the former were significantly affected by systematic error (Mather, 1969, p. 513). Consequently, a revised procedure was adopted for the prediction of values. A consistent data set resulted for the representation of the gravity field and the resulting gravimetric solution was called the 1970 free air geoid.

The comparisons of various astro-geodetic and gravimetric solutions for the geoid, after appropriate transformation, are given in Table I. The quantities $\delta\phi$, $\delta\lambda$ and δN indicate the changes necessary to the geodetic co-ordinates ϕ, λ and the elevation h above the ellipsoid at the origin in order that the centre of the astro-geodetic datum may coincide with the geocentre.

The precision with which the two solutions match each other, is given by the *root mean square (rms)* residual $M\{\sigma_n\}$, given in the sixth column of Table I. The details of computation are given by Mather (1970, p. 72). In general, the smaller the value of $M\{\sigma_n\}$, the more closely do the two solutions match. The individual residuals for the solution given in the third row of Table I, are shown in Figure 2 as being strongly position dependent. This indicates the existence of slowly varying systematic effects in both types of solutions.

It can also be seen from a study of rows two and three of Table I that there is a marked decrease in $M\{\sigma_n\}$ and hence a better match between solutions when the density of astro-geodetic stations is doubled. This is indicative of the reliability of the gravimetric solution, which should have a standard error smaller than ± 1.5 m.

The 1971 geoid map of Australia

The 1971 geoid map of Australia was based on a combination of astro-geodetic and gravi-

TABLE I

Comparison of astro-geodetic and gravimetric solutions for the geoid in Australia

Astro-geodetic solution	Gravimetric solution	$\delta\phi$ sec	$\delta\lambda$ sec	δN m	$M\{\sigma_n\}$ $\pm$m	No. of stations
1967	1968	+4·7	+4·4	14·1	5·2	550
1967	1970	+4·2	+5·0	7·2	2·5	550
1971	1970	+4·0	+4·6	8·3	1·6	1150

Note:— Geoid elevation at origin assumed equal to zero metric determinations of the geoid. The latter was used to interpolate values between those established along sides of a framework of astro-geodetic levelling. The gravimetric values were adusted, loop by loop, to fit the astro-geodetic framework (Mather, Barlow & Fryer, 1971, p. 21). The adoption of this procedure was of significance as each solution complemented the other. The gravimetric solution was generally weak at the continental margins due to the paucity of gravity observations at sea, while the astro-geodetic solution in these regions was based on a relatively high station density, giving strong control. The gravimetric solution is usually more reliable in regions where the station spacing on the astro-geodetic framework is great. The geoid map for Australia was prepared in this manner, being based on determinations at approximately 3000 points instead of just the 1150 astro-geodetic stations alone. The resulting determination is shown in Figure 1.

It should be noted that the geoid shown therein is referred to the Australian Geodetic Datum which has been aligned parallel to the mean geoid slope across Australia. Hence it does not reflect any geoid undulations which are a consequence of anomalies with half wavelengths in excess of 3000 km, *i.e.*, harmonics of degree six or less. Such harmonics are generally attributed to mass anomalies at the core-mantle boundary and dominate global geoid determinations from satellite orbital perturbations. The geoid for the Australian region is shown on such maps to lie along a uniform slope whose normal makes an angle of approximately 5 arcsec with, and in a direction south-west of, the ellipsoid normal.

The adoption of the technique where the geoid is referred to an ellipsoid placed parallel to the mean geoid slope, is of great assistance in highlighting regional features of the geoid. A study of Figure 1 shows that the geoid over the Australian continent is dominated by the

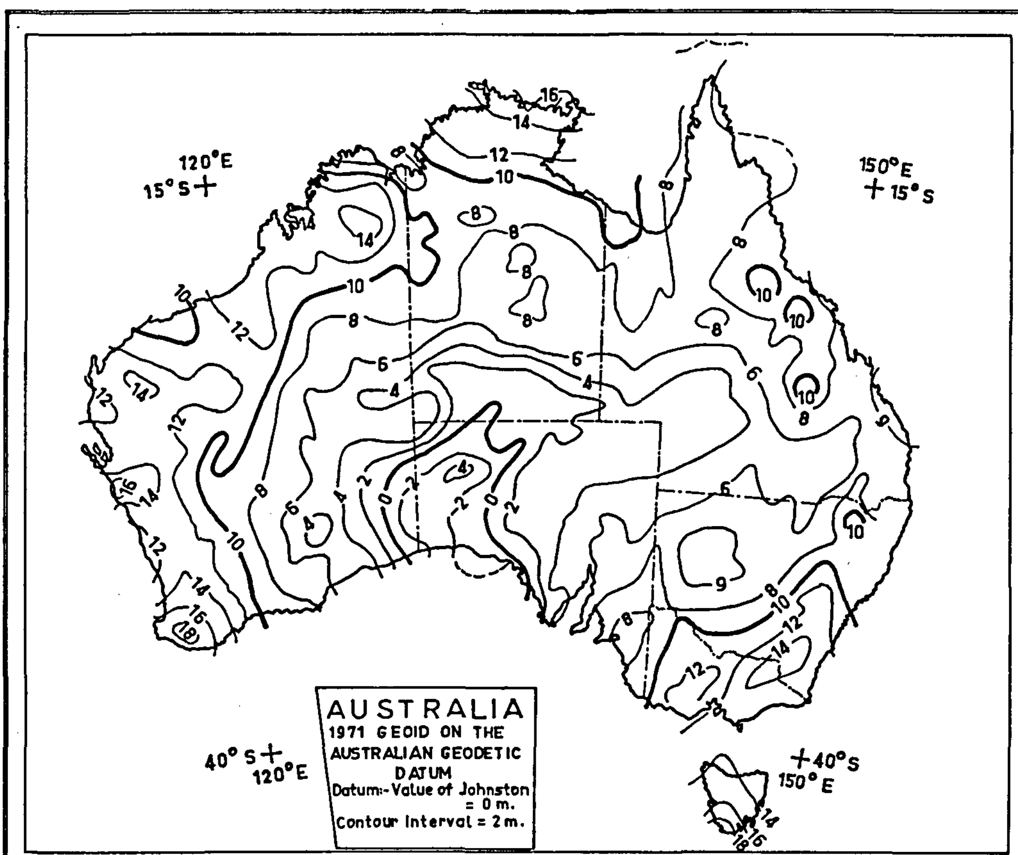

Fig. 1

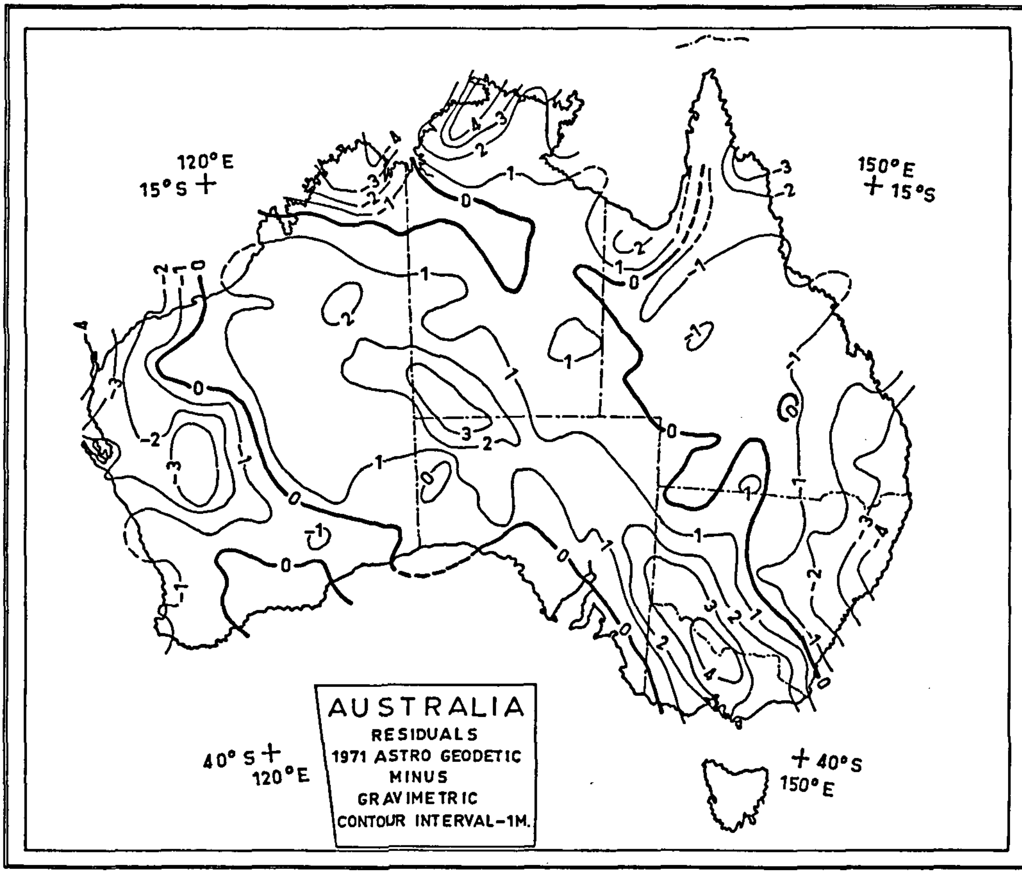

Fig. 2

geoidal low centred near the Officer Basin in South Australia. This major feature has clearly shown up on all earlier solutions on the AGD (Fischer & Slutsky, 1967; Mather, 1970, p. 76), with its axis lying northeast to southwest. Further, the geoid rises in all directions from the dominant low when approaching the coastline, though the gradients are not necessarily uniform. It can also be seen that geoid rises are associated with all mountain ranges, though the pattern over the MacDonnell ranges is complicated by the existence of the geoid low.

The occurrence of more positive geoidal elevations on the continental margin poses a question about the size of the reference ellipsoid. It *could* be inferred that the geoid curvature in the Australian region is greater than that implicit in the reference ellipsoid adopted. The latter is generally held to be one which best fits the Earth (IAG Resolutions, 1967). On the other hand, a major global analysis of the available gravity data (Kaula, 1959) appears to indicate that free air anomalies depart, through positive values, from a linear correlation with elevation in the neighbourhood of continental margins. While this analysis was based on a relatively scanty sample, the observation is generally true for Australia and is a subject worth closer investigation in view of its geodetic and tectonic implications.

It is unlikely that there is any region in Australia where the relative geoid is not known to better than ±2m, the errors being less than ±1 m over 95% of the continental area. Those in excess of ±1 m occur in three localised areas which are not coastal. The available astro-geodetic solution was based on an inadequate station density in two of these regions, while the third is due to both this reason and a largely predicted gravity field.

It can be concluded with confidence that the technique used is adequate for the production of geoid maps over continental regions without errors much in excess of ±1 m if

(a) an evenly spaced gravity coverage, with a density similar to that available in Australia, were established over the entire region; and
(b) the spacing of astro-geodetic stations were reduced, where necessary, to represent disturbed regions adequately.

Greater accuracy is required only when computing elevations above ellipsoid with a precision approaching that of geodetic levelling. The accuracy of a few centimetres which is required in such a case, would call for a significantly different approach. This is not warranted at the present time in view of the incompleteness in the representation of the global gravity field.

THE ROLE OF GEOID SOLUTIONS IN GLOBAL GEODESY

The determination of the geoid in relation to an ellipsoid of reference is of importance in regional geodesy as it enables observations to be correctly reduced to the ellipsoid prior to computation. It can also be used to connect various regional datums into a unified world geodetic system (WGS). The technique is based on a combination of gravimetry and astro-geodesy. The geoid is determined using each technique in turn, the solution from gravimetry being referred to a geocentric ellipsoid, while that from astro-geodesy is referred to the regional ellipsoid, as described in the first section. It is possible to define the *geocentric orientation vector*, which is the vector separation of the centre of the regional ellipsoid from the geocentre, by comparing the curvature of the surfaces so determined, after allowing for the difference in location of the two ellipsoids in Earth space.

The implementation of such a scheme faces certain problems. Firstly, the astro-geodetic data available at the present time are limited and hence the shape of the geoid determined from astro-geodesy is subject to error, as indicated by a study of rows two and three in Table I. Secondly, the gravity anomaly field is not fully represented, as discussed on page 22.

In considering an area the size of Australia, which is covered by a reliable astro-geodetic determination, it can be assumed that any errors in the representation of the gravity field with a half wavelength *less* than 3000 km, will be detected and allowed for when defining the geocentric orientation vector. The representation of the gravity field with half wavelengths *greater* than 3000 km is essentially based on the orbital perturbations of artificial Earth satellites. Any error in the evaluation of the related harmonic coefficients, which are those of degree six and orders zero and one, will not be detected and allowed for in such a case. It is fortunate that these are the harmonics most reliably determined from orbital analysis. Further, any world geodetic system program can be used to verify the correctness of these values provided reliable astro-geodetic data are available (Mather, 1971*a*, p. 98).

The present hope of geodesists is to provide an unambiguous world geodetic system with the greatest accuracy that is attainable with available techniques, and which will be representative of the current decade. Many will question the wisdom of such a goal in view of the limited accuracy (±0.2 arcsec or ±6 m in each co-ordinate) possible with present procedures. Laser techniques and dispersion methods in optical ranging appear to promise more precise results. While it is possible that laser technology will attain timing accuracies over return ranges which are equivalent to ±2 cm in distance in the next decade or two, there are many dynamic problems concerning both the orbit of the moon and the rotational characteristics of the Earth which require solution before the technique can be unambiguously used for the above purpose and achieve the vastly greater accuracy. A source of uncertainty is the model of the Earth's atmosphere which must be adequately defined before the sophisticated timing accuracies are converted to equivalent estimates of the distance. In addition, there has been a disturbing tendency for systematic differences to occur when the results from different tracking techniques are compared. A final point to note is that tracking systems of this type are expensive. Portable systems are possible, but the higher precisions claimed can only be obtained as a consequence of a prolonged series of observations.

In view of these uncertainties, the goals specified in the first sentence of the previous paragraph still remain meaningful. Further, the world geodetic system obtained by matching the shapes of the same surface as determined from gravimetry and astro-geodesy respectively, can also be used to study the variation of position with time. Quantitative measures of this phenomenon to date have been as a consequence of astronomical evaluations at specially established observatories, while satellite methods have been used for monitoring the motion of the pole. The former technique only reflects changes in angles on the celestial sphere between the observer's zenith and the pole of reference in conjunction with a related plane. The local vertical could change direction in Earth space as a consequence of either changes in position or the re-distribution of masses in the vicinity of the observing station. These effects could be separated by the analysis of residuals using the method proposed above, over an acceptable period of time.

A recent development which will significantly affect the viability of the scheme proposed, is the possibility of measuring absolute values of the acceleration due to gravity with a precision of ± 1 μgal (*i.e.* 10^{-6} cm sec $^{-2}$), using a portable apparatus. A prototype of such an instrument may become available within the next five years.

The writer envisages quantitative studies of secular variations in position to be based on a control system of the following type.

i. *Fundamental stations for intercontinental connections*

Such links will be based on a framework of first order fundamental stations which include at least one or two points on every major datum. The complex array of equipment at each station will be capable of

(a) monitoring variations in the direction of the local vertical and of the Earth's axis of rotation; and

(b) changes in distance with respect to other stations in the scheme.

Each of these fundamental stations will be very expensive to establish. The equipment will include, in addition to all equipment ordinarily housed at a high quality observatory, aids for utilizing the latest developments in laser technology and the principles of very long base interferometry (VLBI). In addition, the secular trends in the gravity field must be monitored by repeated absolute determinations of gravity at regular intervals. The Bureau International des Poids et Mesures (BIPM) in Paris has already established a practice of doing so (Sakuma, 1971).

It is obvious that all the equipment may not be located at the same site, but the actual locations should be accurately tied to the regional datum. Expense is going to restrict the number of such stations to one or two per datum, the systems being non-portable.

ii. *Regional reference systems*

These should be based on approximately ten regional control stations per one million km^2, and permanently marked so that re-occupation in a meaningful sense, is possible after the lapse of a century. The permanency of such stations will have to be guaranteed by government protection against developers. The network of stations must then be connected by a first order geodetic survey, including levelling operations.

The stations should be capable of re-occupation for both observations defining the direction of the vertical and gravity determinations with the greatest accuracy that is possible with portable equipment. Re-observations would be made with a frequency dependent on the nature of the secular variations monitored at the fundamental stations mentioned in the previous sub-section. The latter will, of course, be installations at which continuous observations are made.

If the equipment and observation techniques in use at present were resorted to, the establishment and maintenance of a world geodetic system on the lines indicated should be able to validate the higher estimates made for vertical (5 mm yr^{-1}) and horizontal (10 cm yr^{-1}) motion within a century, without recourse to orbit dynamics.

IMPLICATIONS FOR THE AUSTRALIAN REGION

It is extremely desirable that the WGS stations described above be established in the next decade. Geodesists working on the problems associated with the monitoring of secular variations in position should have the same relation to advocates of various theories on crustal motion that public servants are expected to have with respect to politicians. If they are to provide evidence for any such variations, it is necessary to adopt a neutral stance and devise systems which will not overlook any possibility. For example, no theory in vogue at the present time appears to call for a rotational motion of limited extents about a radial axis after reversing the Earth's diurnal rotation. This is a possibility which should not be ruled out when devising geodetic reference systems.

Any such motion would seriously jeopardise conclusions drawn from a study of a limited number of fundamental stations which were described in previous section. It is important that such stations be established on stable regions which are not prone to seismic activity so that noise effects (*i.e.* local changes in position) are minimal in relation to any secular variation which may occur.

Geodetic work carried out in Australia using modern techniques has received international recognition for its reliability. At the time of writing, we badly lack a first order geodetic level network though a third order net has recently been established by the Division of National Mapping. It is likely that the establishment of such a net will be undertaken in the near future. One of its tasks should be the establishment of about 100 stations which will comprise a regional reference system on the lines outlined in the previous section, for the study of crustal movements. These stations will, in turn, be referred to a world geodetic system (WGS) and therefore be defined with respect to stations on all other regional reference systems.

The frequency of re-observation will, of course, be dependent on the nature of the data monitored at the fundamental station. Until the pattern of secular variations is established, it will be desirable to repeat measurements of absolute gravity at the regional stations at five to ten year intervals, as this will be the least complicated operation that can be carried out at a reasonable cost.

It would be desirable to have at least three fundamental stations in Australia. With the cost of establishing each new station running into millions of dollars on current prices, not to mention the short term difficulties of staffing, it would be more realistic to hope for the establishment of one such station. In the absence of reliable quantitative evidence on crustal movement over continental extents, it is reasonable to suggest that such a station should be sited in the stablest portion of central Australia. If such funds are not forthcoming in the short term, the concept of a fundamental station will have to be replaced by a consortium of the facilities already available in the southeast and central south of the continent. This cannot be considered to be the most satisfactory arrangement from a purely scientific point of view.

CONCLUSIONS

There is little doubt that we are approaching a watershed in geodetic history. It is very likely that more than one world geodetic system will be established in the next decade with an accuracy approaching 1 part per million (*i.e.* 6-10m in position).

Further significant improvement will only be as a result of a total revision of both techniques and mathematical models incorporating the dynamics of the Earth's crust.

The present geoid for Australia will be of adequate accuracy for all purposes, except for the definition of ellipsoidal elevations with the same precision as results from first order geodetic levelling, and for studies in geodynamics.

There is little doubt that the basic principles underlying the establishment of a world geodetic system from a combination of gravimetry and astro-geodesy can be successfully adapted to future developments and thereby afford techniques for the analysis of changes in position with time. Such methods can be more directly related to physical characteristics of the Earth than those available or proposed at the present time, which are based on geometry alone.

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REFERENCES

BOMFORD, A. G., 1963: Woomera geoid surveys. *Tech. Rep. Div. Nat. Map. Aust., 3.*

FISCHER, I. & SLUTSKY, M., 1967: A preliminary geoid chart for Australia. *Aust. Surv., 21*, pp. 327-331.

FRYER, J. G., 1971: The geoid in Australia — 1971. *Tech. Rep. Div. Nat. Map. Aust., 13.*

GRUSHINSKY, N. P., & SAZHINA, M. B., 1971: The gravitational field and the geoid of Australia. *J. geol. Soc. Aust., 18*, pp. 183-199.

HEISKANEN, W. A., & MORITZ, H., 1967: *Physical Geodesy*. Freeman, London.

I.A.G. RESOLUTIONS, 1967: Resolutions adopted at the XIV General Assembly, Lucerne. *Bull. géod., 86*, 367-383.

KAULA, W. M., 1959: Statistical & harmonic analysis of gravity. *Tech. Rep. U.S. Army Map Service, 24.*

———, 1966: Tests and combination of satellite determinations of the gravity field with gravimetry. *J. geophys. Res.*, *71*, pp. 5303-5313.

LAMBERT, B. P., 1968: The Johnston geodetic survey station. *Aust. Surv.*, *22*, pp. 93-96.

MATHER, R. S., 1968: The free air geoid as a solution of the boundary value problem. *Geophys. J. R. astr. Soc.*, *16*, pp. 515-530.

———, 1969: The free air geoid for Australia. *Geophys. J. R. astr. Soc.*, *18*, pp. 499-516.

———, 1970: The geocentric orientation vector for the Australian geodetic datum. *Geophys. J. R. astr. Soc.*, *22*, pp. 55-81.

———, 1971*a*: A world geodetic system from gravimetry. *Geophys. J. R. astr. Soc.*, *23*, pp. 75-99.

———, 1971*b*: Practical techniques for the establishment of a world geodetic system from gravity data. *UNISURV Rep.*, *22*, pp. 41-60. Univ. N.S.W. [unpublished].

MATHER, R. S., & FRYER, J. G., 1970: Orientation of the Australian geodetic datum. *Aust. Surv.*, *23*, pp. 5-14.

MATHER, R. S., BARLOW, B. C., & FRYER, J. G., 1971: A study of the Earth's gravitational field in the Australian region. *UNISURV Rep.*, *22*, pp. 1-37. Univ. N.S.W. [unpublished].

SAKUMA, A. 1971: Observations experimentales de la constance de la pesanteur au B.I.P.M. *Bull. géod.*, *100*, pp. 159-163.

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