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100 Years of Topographic Mapping

HISTORY OF GEODESY IN AUSTRALIA

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Abstract

Australian Topographic Mapping is underpinned by a consistent geodetic framework extending across the whole country. Today this framework is directly compatible with GPS satellite positioning. However this was not always the case and the development of such a strong geodesy network only commenced in the second half of the last century under the National Mapping Council. The development of this geodetic framework and associated fundamental datums is examined in this paper, which highlights the guidance and cooperation of a national geodesy group under a progression of State and Federal coordinating bodies. Currently it is a permanent sub committee of the Intergovernmental Committee on Surveying and Mapping.

Whilst the last geodetic adjustment framework was introduced on a geocentric datum in the year 2000, technology continues to advance producing an increasing demand for greater accuracy of positional coordinates. It has become necessary to link Australian Geodesy to the motion of the dynamic planet and to carry those advances back into precise positioning within the Australian plate. This requires an increased permanent multi- technique geodetic framework contributing to global organisations and producing near real time precise values for users

HISTORY OF GEODESY IN AUSTRALIA

1. Introduction

Australian Topographic Mapping is underpinned by a high level national geodetic framework this is the result of modern day state and federal cooperation .But at times, in the last 100 years it also had a rather chequered history in government administration through competition, personal rivalry, and divided responsibility between States, Commonwealth civilian and military survey bodies. The story of the Australian Geodetic Survey is one of overcoming technical difficulties and hard fieldwork by many surveyors in harsh conditions over a time span of 200 years. But increasingly it has been the clever applications of high technology and cooperation which has provided a uniform basis for spatial data across the nation.

As the individual early colonies developed, the need for a geographic positional framework to support its land tenure grew, and thoughts turned to linking local piecemeal surveys together. Embryonic trigonometric surveys were commenced in each state by:

- Tasmania – James Sprent in Tasmanian 1833 to 1859
- NSW – Thomas Mitchell in from 1827
- W.A- John Septimus Roe from 1829
- S.A -Colonel William Light from 1834
- Victoria- Captain Andrew Clarke 1853

In Victoria, the colony remained part of New South Wales until 1851 and surveyors were largely employed on cadastral development work. The first Surveyor-General, Captain Andrew Clarke, Royal Engineers, started the trigonometric survey using sappers from the British survey in 1853. In 1858 the Government Astronomer Ellery also commenced laying out a gridded system, similar to the one used in North America, as the basis for the sale and selection of Crown lands. It was termed the ‘geodetic’ survey as it laid out meridians and parallels of latitude, distinct from the rival trigonometric survey. (Chappel 1966)

The trigonometric surveys in the colonies used baselines and classic angle measurements, albeit with variable quality. Apart from Tasmania, which was covered by triangulation in 1859, (the brilliant work of surveyor James Sprent) difficulty was encountered in carrying the survey chains forward due to lack of indivisibility in featureless terrain and continued resourcing problems. In 1892 an Intercolonial Conference between the various Examining Boards of Surveyors and the respective Surveyors Institutes discussed the poor state of the trigonometric surveys and benefits from a national geodetic survey and passed a resolution urging action:

> *The conference would further urge the desirableness of extending and connecting the trigonometric surveys of the colonies, as by this means the measured baselines could be used as bases for verification, and the results applied to statutory surveys as well as the elucidation of many points in connection with the figure of the earth. (McComb 1935)*

In 1893 the Australian Association for the Advancement of Science expressed similar views. These had no immediate impact and at the close of the 19th century, the geodetic surveys in the various colonies were still fragmented, and proving technically very difficult in the areas of flat terrain, and unsuccessful politically in obtaining resources.

2. Towards a national approach

The Federation of the Colonial States of Australia in 1901 created an air of optimism in the development of the country. The constitution of the new Commonwealth of Australia identified astronomy as a potential national benefit, but it did not transfer land administration ownership or powers related to a national approach to coordination of surveys or mapping from the states. J.D.Lines, Assistant Director of National Mapping for more that a decade, and who was personally responsible for much of the progress towards national map coverage, identified the lack of a clearly defined responsibility in the constitution as a crucial problem for ongoing coordination and funding in saying:

> *This shared authority was to severely hamper the progress of the national geodetic survey and mapping of Australia, and to be the root cause of much fragmentation and lack of coordination between the states and the commonwealth for many years to come (Lines 1992)*

This was indeed to prove an ongoing concern through much of the 20th century. With the lack of specific powers in the constitution for the commonwealth civilian government to undertake general survey and mapping programs, the initial commonwealth mapping activities occurred within the Army under the authority of the Defence acts. This led to the establishment of a mapping survey unit in 1908 within the Australian Intelligence Corps. However it took time to establish direction and to get resources and progress was slow. Advice was sought from Colonel Close in England and a small survey section began measuring baselines for local surveys. Some maps were produced around Melbourne and in Tasmania of training areas, but little was achieved nationally before World War 1. (Lines 1992 pp 46-7)

On 1 January 1911 the Commonwealth acquired its first land administration responsibilities with the transfer of the Northern Territory and the Australian Capital Territory from the states. An area at Jervis bay was added later in 1915. With its responsibility for good civilian government administration under the constitution and the need to discuss survey and mapping issues, which had arisen since federation, the Commonwealth Government hosted a conference in 1912 to review the situation. It was held in Melbourne between the Director of Commonwealth Lands and Surveys, the Surveyors-General of the states and New Zealand, together with the NZ astronomer. The agenda was to discuss the Geodetic survey of Australia; the reciprocity of surveyor's licenses; and the uniformity of plans of surveys.

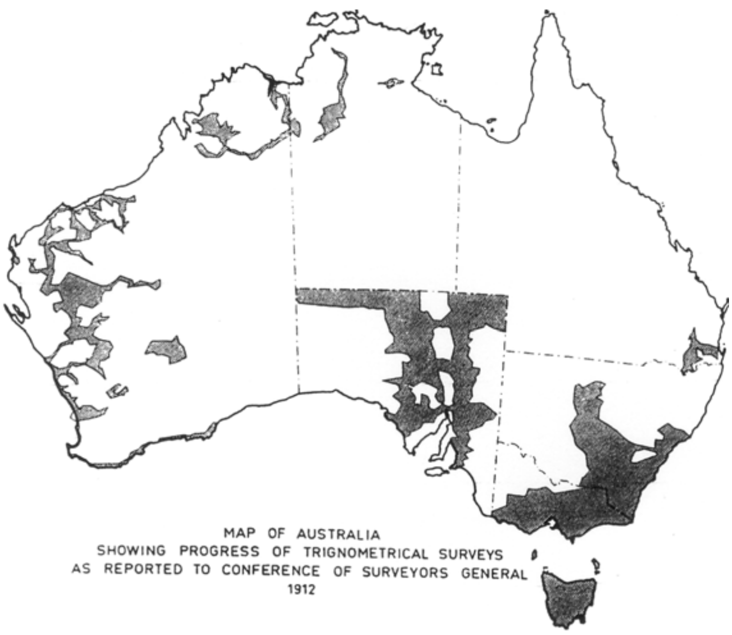

Figure 1: ***Progress of State Trigonometrical Surveys in 1912 (Conference of Surveyors- General, 1912***

The total extent of the geodetic work in Australia reported at that time in Appendix B of the report is shown as in the figure 1 above. The conference went for five days and discussions considered the stalled state of various colonial geodetic surveys, the lack of a common origin, consistency of observation, marking and lack of survey connections across state borders. Subsequently a far-reaching resolution was prepared which included items relating to Geodesy:

1. *That a geodetic survey of Australian should be undertaken.*

2. *That in order to give effect to the foregoing resolution, this Conference respectfully recommends that such a survey be undertaken by the Commonwealth Government and submits in support thereof the following reasons.*

   (a) *That the time has arrived when the commonwealth should take its place in the scientific investigations of the world, not the least important of which are the determination of the figure of the earth, its density, and other cognate matters.*
   (b) *That the work of this character, involving the highest form of survey should be effected under the supreme authority of Australia, as it is essential that it should be carried out with the greatest degree of accuracy on a uniform basis and a definite plan, the individual parts being coordinated an eventually forming one homogeneous whole.*
   (c) *That the system that has hitherto prevailed by which the individual states carried out this work with instruments of varying character has resulted in varying standards of accuracy, rendering the work to a great extent unsatisfactory and, though much of it is of high grade, portions of it are impossible of reconciliation with a continental scheme.*
   (d) *That desirableness of this work being undertaken by the Commonwealth Government is evidenced by the fact that the Geodetic survey of the United States is carried out under the direct control of the Federal Government and that the South African Geodetic Survey is also under one control.*
   (e) *That such survey is absolutely necessary for the production of accurate maps will be of high value in connection with Cadastral of Geological surveys and form the basis for topographical work for defense and other purposes. It will moreover provide a standard of accuracy for surveys of every description throughout the Commonwealth. (Commonwealth of Australia, 1912)*

Funding sources or administration strategies were not clearly identified and no productive follow up action occurred. However reorganization within military operations that year led to the establishment of a small trigonometric sub section within the survey section, Royal Australian Engineers (RAE) to undertake national triangulation surveys along the lines of the resolution as a framework for topographic mapping. It seems likely that this decision was made to take advantage of the resolution from the conference, with the realization that such grand vision was not likely to be resourced from the civilian Department of Home Affairs.

The early complex evolution of military mapping in further described by Lines (1992 p57-61) and Couthard-Clark (2004). Despite the move to establish a survey unit, the Australian Intelligence Corps was decentralized in 1912 and then disbanded just prior to the start of the world war in July 1914 with the Australian Survey Corps being raised as a unit in 1915. The world war stopped virtually all activity within Australia and a survey section RAE was reformed in 1919 when military operations resumed in Australia after the war.

From 1920 surveyors, returned servicemen leagues, mining and engineering disciplines, commenced lobbying for the creation of a civilian national geodetic survey. The Association for the Advancement of Science and the International Union of Geodesy and Geophysics also contributed to build pressure, but the turmoil left by lack of defined authority and subsequent unclear financial responsibility continued to cloud the issues. Apart from some military mapping activity little was achieved between the world wars. The Australian Survey Office, Department of Home Affairs was formed early to carry out land surveys for the Commonwealth in its new territories but little civilian geodetic survey or mapping activity took place between the two world wars. Lines (1992 pp 62-83) documents the ebb and flow from major initiatives towards the creation of a responsible national authority in the period between the wars.

Although military survey activity commenced in the first decade of the 20th century, it was under resourced proceeded very slowly and it was not until 1932 that the dormant Australian Survey Corps was re-activated as a body and a small geodetic unit was formed. Then a serious start was made on national connections between local surveys, with a chain of first order triangulations extending from South Australia across Victoria and eastern New South Wales. Advances were made in base line measurement techniques needed for this triangulation and in 1934 Fitzgerald reported on the extensive field work activity in which lead to the adoption of Sydney observatory as the origin for all mapping in the eastern states. (Fitzgerald 1934)

The first interstate Conference of the Australian State Surveyors Institutes had been held in 1927. The conference addressed the justification for expenditure of large sums of money for surveying and mapping and prepared a single document to be presented to all governments. This led the Victorian Institute of Surveyors to establish an Australian Survey Committee to argue this case. The committee prepared an impressive comprehensive report advocating the establishment of a national survey, headed by a Director General reporting directly to the Commonwealth Minister (The Australian Survey Committee, 1930). This was submitted to the federal Department for Home affairs in November 1929 and eventually to cabinet via the Prime Ministers Department. This approach was approved by Cabinet 26th February 1930, but was deferred for funding and circulation to the states for comment. This proposal then seemed to get lost in the machinations of inter government relations.

With this set back Australian remained a large unmapped country, which hampered development and a memorandum from V.L.O. Sheppard of the Cadastral and Land Record office London to R.G. Casey, Minister of Home affairs in 1933, commented that:

> *'The survey of Australia is certainly the worst in any of the Dominions, and falls far behind the survey of the Colonies" (Lines 1992.p33)*

The 1930s saw the continuation of lobbying for a national geodetic survey from the Institution of Engineers, The Australian Association and New Zealand Association for the Advancement of Science, and the Australian Survey Committee amongst other bodies. This resulted in the establishment of a Commonwealth Survey Committee in late 1935 consisting of Commonwealth Surveyor General and the representatives of each of the Defence services, with the provision: that "the states be advised and invited to cooperate"

The first task of the committee was a report and recommendations concerning coordination of surveys throughout the Commonwealth of Australia, which it submitted in July 1936. This vigorous report is described in full by Lines (1992 pp 79-81). It recommended a wide range of actions concerning a first order triangulation; aerial photography by RAAF; topographic mapping; and identified ongoing levels of finance support required for the next three years. Lines (op cit) notes that it was circulated from the Prime Minister to the State Premiers in September 1936. It drew cool responses from the states on the difficulty of cooperative resourcing at the time and was again deferred due to funding problems.

In 1937 Frank Debenham the learned Australian geologist and chair of Geography at Cambridge wrote to the Department of Interior saying that he was:

> *Dismayed at the paucity of topographic information in Australia and aware of the backwardness of my country in the matter of fundamental surveys … that triangulation should be in the hands of the Federal Government… no topographic map of any real value can be made without such a framework.*

The derived mapping will provide the real and overwhelming saving (Commonwealth Archives Record CRSA976 - cited in Lines 1992 p82)

In 1938 and again in 1939 Federal Cabinet deferred the subject of funds to initiate a national survey and mapping program. There was a prevailing lack of perception of the value of mapping to economic development. The momentum was then overtaken by global events and Australia entered the Second World War with immense deficiencies in geodetic survey and with only about one percent of the country properly mapped.

3. The National Mapping Council Geodesy initiative

Under the wartime emergency mapping scheme there was a new understanding of the importance of mapping. Resources were now made available and the military capability greatly increased. Triangulation was extended in support of key areas for 1 mile to the inch mapping for army training areas and coastal defence regions. But there was much to do and the state of the first order geodetic survey at the end of the war was still minimal as shown in figure 2 below.

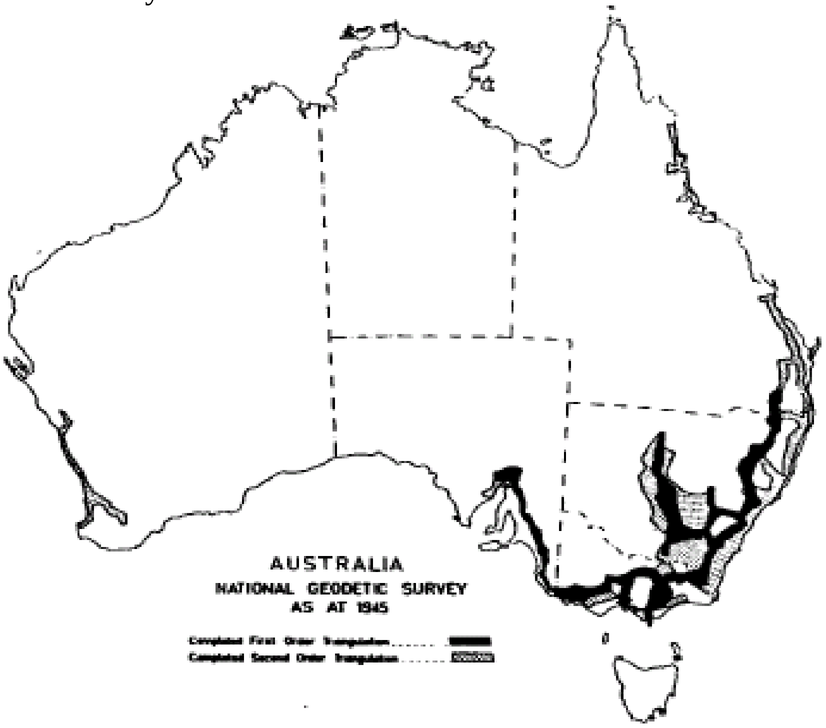

Figure 2: State of first and second order triangulations in 1945 (Lines 1992 p211)

In 1944 the Commonwealth Surveyor General F.M. Johnston was able to chair a reconvened Commonwealth Survey Committee and prepare an excellent status summary of events and itemize recommendations of the past nine years of the committee. He succeeded in his suggestion for a meeting with State Surveyors- General in Canberra on 15th January 1945 that meeting resulted in the formation of the National Mapping Council (NMC) chaired by the Commonwealth Surveyor General. The functions on the NMC were to be:

1. To assist in the implementation of the decisions of this and subsequent conferences
2. To coordinate and correlate mapping on a national basis
3. To determine standard methods and minimum accuracy of requirements of trigonometric surveys
4. To determine approved methods and minimum standards of accuracy for photogrammetry and cartography (Lines 1992 p170)

Following Federal Government approval on 7 March, the National Mapping Council's first meeting was held in Melbourne on 17th September 1945 and one of the first items was a resolution concerning the national geodetic survey:

> *"The completion of the geodetic triangulation is of the utmost importance and should have A1 priority"*

A new approach was vital as the quality and condition of the state networks were considered to be too variable in many aspects. With the exception of recent work in NSW by the Army, the 19^{th} century colonial trigonometric work was considered to be largely unrecoverable. The early years of the NMC were preparatory in nature and provided the stage for bickering amongst the Commonwealth representatives. In 1948 the NMC technical sub committee was formed to look at technical matters referred by council. This was the engine room for productivity and goodwill between members. Many technical documents on surveying, aerial photography, photogrammetry, cartography, and Geodesy were published including "Specifications for Horizontal and Vertical Control Surveys" as Special Publication No.1 and also" Calibration of Survey Tapes".

In 1949 a fresh start was made on the civilian Geodetic survey of Australia when G.R.L. Rimington undertook a reconnaissance of a triangulation connection across Bass Strait with support from the HMAS Warrego. Although the first project was the reconnaissance, the first National Mapping field party operation in the Geodetic Survey was to carry a second order triangulation chain with along Eyre Peninsula to the Port Lincoln area in 1951. This linked the southernmost station on the existing Army Survey Corps network to stations established by RAN during recharting the adjacent waters. Rimington initiated the work and training before Joe Lines take over party leadership. Angle observations were carried out by Reg Ford, Phil Lennie and Dave Hocking using T2 theodolites. The following summer the triangulation to Tasmania was completed, again with support from the HMAS Survey vessel Warrego. Wild T3 theodolites were used for the first time and used exclusively from then on by National mapping Survey parties.

The history of National Mapping Geodetic Survey parties activities contributing to the first national geodetic adjustment were well documented by Reg Ford in a major work which recorded the geodetic activities based in the Division of National Mapping's Melbourne Office from 1951 to 1969. This included details of work carried out, with location, dates and the names of the party members involved each year. It was republished as a series in the Australian Surveyor in 1979 (Ford 1979). The general areas of operations each year were identified as:

1951 Eyre Peninsula triangulation
1952/53 Bass Strait triangulations
1953 Minor triangulation N.T
1954 Broken Hill – Flinders Rangers
1955 Broken Hill – Cobar and Maree – William Creek
1956 Eyre Peninsular – Gawler Range and William Creek – Rodinga
1957 Rodinga – Devils Marbles Triangulation, Tellurometer traversing N.T and S.A.
1958 Triangulation N.T- S.A. border. Traversing in N.T., W.A and S.A.
1959 Tellurometer Traversing N.T. W.A. and S.A.
1960 Tellurometer Traversing N.S.W., Qld., S.A., N.T. and W.A
1961 Tellurometer Traversing N.T. re-observing S.A. and N.T
1962 Tellurometer Traversing W.A., S.A., N.S.W. and Qld.
1963 Tellurometer Traversing S.A., W.A. and N.S.W., beaconing Qld.
1964 Tellurometer Traversing W.A. and Qld.
1965 Tellurometer Traversing W.A., S.A, N.T and Qld

Figure 3: T3 Triangulation observations at Broken Hill in 1954

The second half of the 20th century however saw a remarkable development in geodesy from the triangulation techniques of the Survey of India with the introduction of electronic distance measurement equipment in the 1950s, use of computers for calculations in the 1960s, and positioning from satellites with Satellite Laser Ranging in the 1970s. This heralded a move from datums on local best fit geoid models to earth centred datums. By the end of the century geodesy in Australia was monitoring the movement of the Australian tectonic plate at some 6 cm per year using permanent GPS installations and offered rapid on line computation of GPS observations on a geocentric datum.

Figure 4 The Natmap MRA1 Tellurometer in South Australia in 1956

To survey the whole country was a huge task particularly the vast interior and it is appropriate to acknowledge the work was done when Lt Col H.A. Johnson joined National mapping as Senior

Geodetic Surveyor. Initially taking over from Lambert in the field in 1954 on a project to support the work of BMR in the Broken Hill district, the unswerving dedication of this man had a major impact on the fieldwork of the national Geodetic Survey. Two years later the Prime Minister, R.G.Menzies, announced transfer of National Mapping functions to the Department of National Development from Department of Interior in May 1956 as a separate funded entity.

Meanwhile the visionary Director Bruce Lambert was looking at new electronic means to address the massive survey task ahead. Shoran was in use by BMR for airborne positioning and it was unsuccessfully tried to be adapted over land. However the major advance came soon after when Lambert purchased and introduced the first Swedish AGA Geodimeter instrument. This system was cumbersome and required vehicle support but was successfully developed by Rimington and later C.K. Waller as vital tool for distance measurement. Initially used in 1954 to verify the Army measured baselines at Carrieton established by Survey Corps in 1939 and then baselines in Victoria, NSW and Queensland. (Rimington 1956) It confirmed the quality of the original work in the baselines and avoided the tedious measurement of baselines but was not suitable for off road operations. A second geodimeter was purchased and loaned to Western Australia in 1956.

The visible light Geodimeter was soon replaced by the forward looking Lambert with the Tellurometer microwave distance measuring equipment developed by the South African scientist T.L Wadley. The first pair of master and remote Tellurometer instruments used in Australia was only the eleventh pair produced but had an immense impact on the Geodetic Survey of Australia and Tasmania. Rimington and Waller were able to show that the sides of a triangle could be measured and used to obtain equal accuracy. No longer was it necessary to carry forward a triangulation chain only by measuring angles. Further with good integration of angles and distance measurements, traverse loops rather than triangles could be used and from July 1957 field operations were exponentially more productive and the survey was really on. (as was the associated hard work).

This precision traversing approach was adopted for the inland areas of Australia with the addition of precise Laplace reciprocal astronomical azimuths to correct for angular drift in the traverses. In addition to the contribution by national mapping geodetic parties in those hectic field seasons State authorities cooperated with the application of Tellurometer to re-observe their state networks and to link them to the primary framework. Army had contributed much and the National Mapping Council and its Technical Committee kept the goodwill sprit high. It now required a huge task of computing the massive field observations. Through the late 1950s desktop calculators had advanced and the 1960s saw the application of early computers, which were brilliantly applied to produce a national adjustment by A.G. Bomford in his brilliant Variation of Coordinates (VARYCORD) geodetic adjustment package.

In 1958 Lambert arranged for the responsibility for surveying and mapping in the Australian Antarctic Territory to be transferred to the Division of National Mapping and for ten years wintering surveyor were provided to the Australian National Research Expeditions as described in Australian Antarctic Science, *The first 50 years of ANARE* (Manning 2002). The Division of National mapping also carried out Tellurometer surveys in Papua New Guinea in the 1960s under the leadership of H.A. Johnson for number of years and these were included to produce coordinates in AGD66 adjustment.

The field work for the primary Australia geodetic network was subsequently completed in 1965 and computed in 1966. This was considered an amazing achievement by many world wide observers and continually drew comment such as that from the Directorate of Overseas Surveys Great Britain :

"The Australian geodetic network, a great part of it completed in ten years, must always be historically considered one of the survey wonders of the world". (DOS Newsletter April 1974.)

4. The Australian Geodetic Datum 1966 (AGD66)

In Australia authority for the national datum is with the Commonwealth Government of Australia but in practice this is done in conjunction with State and Territory governments through the National Mapping Council and its successor the Inter-governmental Committee of Surveying and Mapping (ICSM).

Prior to the 1966 national adjustment, there were some twenty different datum's in Australia; using four different figures of the earth, but the spheroid in general use until 1961 was the Clarke 1858 spheroid. Most triangulation was computed from bases measured in British feet and there were a number of distinct astronomically determined origins. National integration of individual state surveys was commenced in the late 1950s and for a short period in 1962, geodetic computations were performed on the so-called "NASA" spheroid and then on a preliminary local spheroid (the "165" spheroid). In April 1965, it was decided to change to a better fitting local ellipsoid, which was called the Australian National Spheroid. This figure was later adopted by the International Astronomical Union as the International Spheroid 1967. Although this ellipsoid was used to best fit to the local geoid surface in Australia, its centre did not coincide with the centre of mass of the earth - i.e. it was non-geocentric.

From May 1965 to March 1966 a complete least squares adjustment of the Australian geodetic network was carried out (Bomford, 1967). The twenty-fourth meeting of the National Mapping Council adopted the new Australian Geodetic Datum (AGD66) on the 21st April 1966. The datum was subsequently proclaimed in the Australian Commonwealth Gazette of 6 October 1966 and the grid coordinates derived from a Universal Transverse Mercator projection of the AGD66 coordinates were termed the Australian Map Grid coordinates (AMG66).

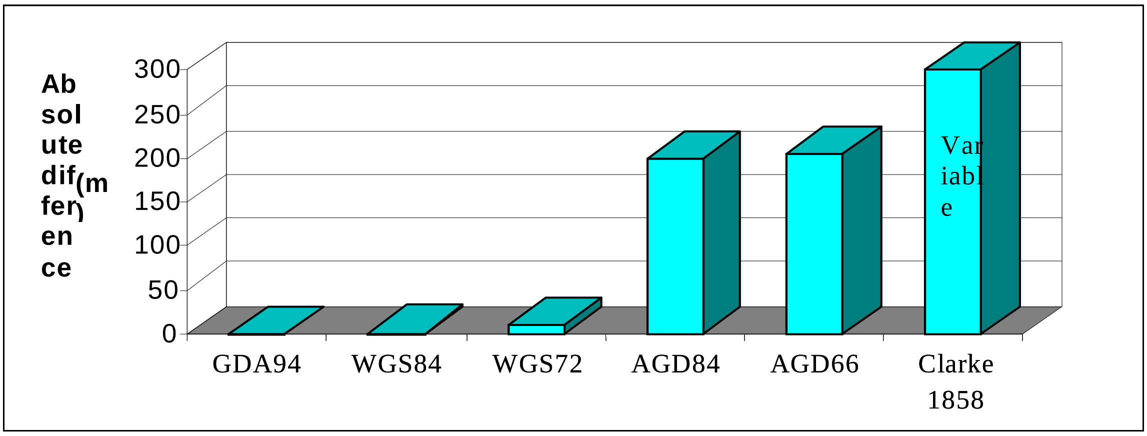

Figure 5: Indicative difference between coordinates on different Australian datums

With the horizontal datum defined work continued on a national vertical datum. In 1971 a simultaneous adjustment of 97,230 kilometres of two-way levelling was completed. It was constrained to mean sea level at thirty tide gauges around the coast of the Australian continent. The resulting datum surface was termed the Australian Height Datum (AHD) and was adopted by the National Mapping Council at its twenty-ninth meeting in May 1971 as the Australian Height Datum 1971. (Roelse et al 1975). This remained the vertical reference datum for Australia at the end of the 20th century.

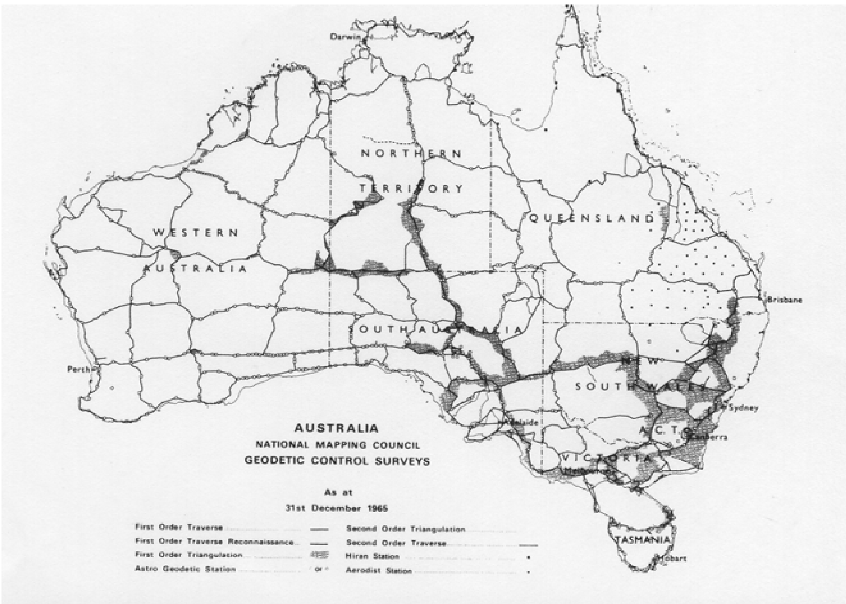

Figure 6 Status of the geodetic network in 1966

Whilst this adjustment providing a consistent set of coordinates on a uniform datum across Australia, technology continued to advance globally. In the mid 1970s Bruce Lambert arranged for satellite laser ranging in the Orroral valley being undertaken by the Smithsonian institute to be transferred to Division of National Mapping and a new site was developed above the Orroral Valley by Peter Morgan head of a newly formed Astro Geodetic section to undertake laser ranging to the Armstrong mirrors on the moon. This began to tie Australia closely to the geodetic models of the planet tighter with VLBI observations at Tidbinbilla and the Hobart. Space Geodesy technology moved ahead primarily from lunar ranging to satellite ranging and with the American Yaragadee site in WA being transferred to Australia and the Orroral site moved to Stromlo in the 1990s. Satellite geodesy was to play and increasingly important role in domestic Australian Geodesy

5. The Australian Geodetic Datum 1984 (AGD84)

In 1982 a new national adjustment computation was performed to improve the accuracy of the AGD66 coordinate set. It used the Australian National Spheroid and incorporated all previous data as well as additional terrestrial and space-based Transit Doppler observations. This corrected a number of deficiencies in AGD66 and also included geoid-ellipsoid separations, which had previously been assumed to be zero in the 1966 adjustment. The resultant coordinate data set was accepted by the National Mapping Council in 1984 and is known as the Australian Geodetic Datum 1984 (AGD84). In adopting these values it was recognised the need for Australia to eventually adopt a geocentric datum but it was not clear at that time which definition to use.

Not all states and territories implemented AGD84 and shortcomings of the original 1966 data set and duplication and anomalies with the 1984 data set were later highlighted by the increasing use of global position fixes using Space Geodesy techniques (eg Doppler and GPS). By the early 1990s it was obvious that in some areas the old coordinate sets were no longer accurate enough and the potential benefits of a direct connection with space technology in the form of GPS were very significant. Consequently it was decided to move to a new single datum. With introduction and development of the Global Positioning System it was inevitable that Australia needed to come into line with that technology. This was reinforced in 1988 when ICSM, recommended the adoption of an appropriate geocentric datum by 1 January 2000.

With demise of the National Mapping Council its Technical Sub Committee was also disbanded. When the new body ICSM was set up it quickly moved to establish a Permanent sub committee on Geodesy, formed from representatives of all state and federal surveying bodies. This body has continued to be active to this time with much goodwill generated between its representatives. In 1988 National Mapping was taken over by the Australian Survey office to form AUSLIG with an objective of providing user paid services and a restricted national interest program. The geodesy section and provided the chairman to the national geodesy group. It was this body which during lean times maintained a spirit of national cooperation at both the state and federal level. The difficult issues of technology, coordination and resourcing these were positively addressed and much was achieved in moving to this geocentric datum.

Whereas much of the difficult and remote field geodetic work for the AGD had been undertaken by Natmap field paries the strength of geodesy in Australia had grown in the state bodies that had the capability to undertake complex geodetic adjustments. The state authorities varied in their need for better and more accurate geodetic frameworks but significantly agreed to participate in a new national observation and adjustment project.

6. The Geocentric Datum of Australia 1994 (GDA94)

The ICSM Geodesy committee arranged for a new joint readjustment of the geodetic survey framework of observations with terrestrial observations pinned to the satellite positioning system by a framework of permanent continuous GPS sites. The driving reason to change to a Geocentric Datum was so Australia could make more efficient use of GPS to produce widespread economic benefit across the community as it provided:

- Compatibility with satellite navigation systems, already in use internationally by ICAO and IHO
- Compatibility with all national mapping programs being carried out on a geocentric datum, such as Defence agencies
- A single standard for the collection, storage and dissemination of spatial information at global, national and local levels.
- Benefits to precision agriculture, emergency services, fleet management, asset management,
- Compatibility with global Wide area GPS, systems
- Compatibility with resolutions of the International Association of Geodesy and the resolutions of the United Nations Regional Cartographic Committee for Asia and the Pacific.

It was decided to adopt the civilian International Terrestrial Reference Frame (ITRF) rather than the military world global system such as WGS84 as the basis for the new geocentric datum. One reason was that the ITRF products and satellite orbits were freely and readily available through the International GPS Service (IGS) and was based on several hundred global sites. WGS84 was a military fixed system based on five mainly equatorial control stations and at the time did not take into account plate velocities at those stations. GPS observations for Australian sites were computed in both ITRF and WGS84 and it was shown that the difference in positions was less than one metre. Since that time however the WGS84 reference frame has been updated on several occasions and is now compatible with the civilian reference frame being only a few centimetres different to ITRF (Malays et al, 1997). The WGS84 system now incorporates dynamic tectonic motion at the master control stations to maintain this close connection with ITRF in the future.

In 1992, as part of the worldwide International GPS Service (IGS) campaign, continuous GPS observations were undertaken on eight geologically stable marks at sites across Australia, which form the Australian Fiducial Network (AFN). During this campaign, GPS observations were also carried out at a number of existing geodetic survey stations across Australia. These were supplemented by further observations in 1993 and 1994, producing a network of about 70 well determined GPS sites, with nominal 500 km spacing across Australia. These sites are collectively known as the Australian National Network (ANN). The GPS observations at both the AFN and ANN sites were combined in a single regional GPS solution in terms of the International Terrestrial Reference Frame 1992 (ITRF92) and the resulting coordinates were mapped to a common epoch of 1994.0.

The original positions for the AFN sites are estimated to have an absolute accuracy of about 2 cm at 95% confidence (Morgan, 1996), while the ANN positions are estimated to have an absolute accuracy of about 5 cm. This determination by Peter Morgan well in advance of developing technology was outstanding and established the solid national platform for the positions of the AFN sites were used to define the Geocentric Datum of Australia (GDA). The existing Australian terrestrial geodetic networks were then adjusted to these ITRF92 positions to propagate the new datum across Australia in a compatible geodetic infrastructure. As recommended by the International association of Geodesy (IAG) the Geodetic Reference System 1980 ellipsoid (GRS80) was used to express the positions as latitude and longitude and when converted to a Universal Transverse Mercator projection they are known as Map Grid of Australia 1994 coordinates (MGA94).

The meeting of the Inter-governmental Committee on Surveying and Mapping held in Canberra on 28-29 November 1994 adopted the above new geodetic datum for Australia and reaffirmed its progressive implementation Australia-wide by 1 January 2000. It has an origin that coincides with the centre of mass of the earth (i.e. geocentric). The distance between the centre points of the GDA and AGD ellipsoids is approximately 200 metres. This translates to a coordinate difference from AGD to GDA of approximately the same amount but varies slightly depending on where you are in Australia.

While the origin of both the AGD66 and AGD84 datums was the Johnston Geodetic Station, today's technology means that a new datum can be based on several well-determined points and the position of the AFN points were gazetted in the Commonwealth of Australia Government Gazette on 6 September 1995 as the positional standard for the Geocentric Datum of Australia. However though the AFN provides Cartesian coordinates in three dimensions, only the horizontal components have been adopted. Heights in Australia remain on the separate Australian Height Datum (AHD), which is based on mean sea level at coastal tide gauges.

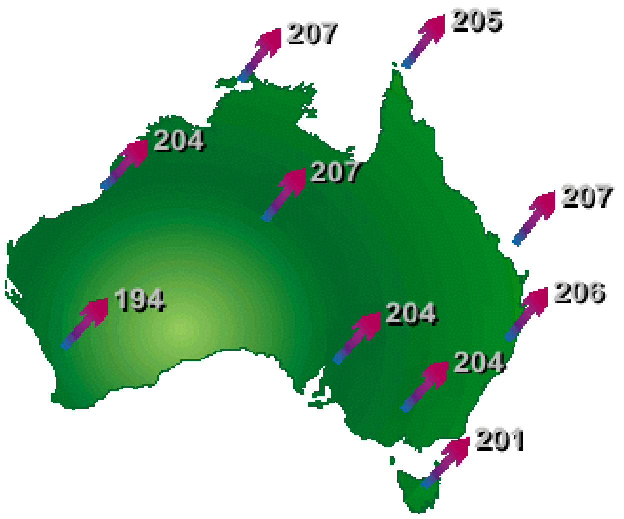

Figure 7: Indicative shift from AGD to GDA94

The technical task of observing a precise GPS framework in each state computing the geodetic infrastructure on a geocentric datum in itself took several years; it was greatly assisted by the work of John Allman in computing and adjusting the data sets. It also took considerable time and effort for the coordinate change to flow down to spatial data sets in each state jurisdiction. The new datum was progressively propagated to lower order geodetic networks and was actively promoted as the preferred datum for all spatial information. This implementation was shared and governmental agencies were faced with a decision to recompute coordinates or to use transformation parameters to produce GDA94 coordinates in their digital data sets. Both approaches were used depending on the circumstance with transformation parameters for each state being produced by Phil Collier, Melbourne University, for ICSM web publication (Collier and Steed, 2001). Eventually the new horizontal datum was implemented in 2000. This corrected many of the anomalies in the state lower order networks and effectively brought the national coordinate sets compatible with GPS values. The introduction of the new datum saw a change in approach in assessing the positional accuracy from an input order to a measure of computed uncertainty. Steed and Allman researched the positional error of the new national adjustment with this technique and concluded

> "that the vast majority of points positional uncertainty of points with vast majority less than 20 cm and many less that 10cm at the 95 % confidence level" (Steed and Allman ,2005)

The assessment of the positional uncertainty was greatly assisted in the use of AUSPOS and independent direct computation of position from GPS positions with a brilliant algorithm developed by John Dawson (Dawson et al 2002) using the observational information from the fiducial GPS trackers which formed the basis of the adjustment. The new datum was also strongly supported in its market application by a comprehensive on line GDA Technical Manual developed by Jim Steed. (ICSM 2001)

It takes a long time and many resources to establish or change Australia's national geodetic datum and implement dependent spatial information data sets beyond the geodetic field survey. It is a complex task with potential unforseen implications in boundaries and other legislation changes. Not all hardcopy records are capable of change in the short term such as some cadastral records. But despite the hard work involved in the introduction of a geocentric datum, it has already produced a massive benefit to the navigation and spatial data community, which is now flowing on to all users of space positioning.

It is important to also consider that a single uniform set of fixed coordinates within a datum will not last forever as the space positioning technology continues to produce more accurate positioning in real time within the global environment. Since declaring the geocentric datum in Australia, GPS has improved its utility with the end of selected availability and raw absolute positions of less than several metres are normally available using cheap hand held instruments.

However the planet earth has a dynamic nature and whilst the original observation had been in 1994, the Australian plate has continued to move at some 6 cm per year. In 2011 in absolute terms, the geodetic infrastructure positions in Australia have moved nearly one metre since the declared epoch date of 1 January 1994 due to tectonic plate motion (approaching one and a half millimetres per week). To compensate for this in the short term precise independent GPS coordinates can be readily transformed to the GDA94 datum using the national plate deformation model developed and monitored by Geoscience Australia.

7. Beyond the 20th century

At the end of the 20th century Australia was well served by a satellite compatible positioning framework. The national geodetic survey of Australia has come a long way with many unsung contributors both state and federal agencies. However the world of technology moves on and the community continually wants better and better locations and positions more easily determined in real time. So the move to real time centimetre positioning has been commenced, there are real time GPS networks growing in NSW, Victoria and Queensland as the ongoing demand is for near real time positional accuracy of centimetre level positions to be readily available to a wide variety of users.

The number of precise users has grown and improvement in positioning technology continues at about an order of magnitude every decade. Australia is on a dynamic plate on a deforming planet and GDA94 is no longer serving the precision positioning applications. Nationally there are funded plans for exponentially greater infrastructure accuracy for an Australian National Geospatial Reference system, which will underpin an enhanced national framework.

This would establish a national network of space based integrated techniques systems to monitor the scale, motion and deformation of the Australian continent for both science and general spatial applications. (Drummond 2006) But Australia is not alone in monitoring the deformation of the dynamic planet. Globally the Global Geodetic Observing System (GGOS) uses a collaborative framework to provide quantitative measurement of the dynamic nature of the earth including

- Plate tectonics/intraplate tectonics
- Anthropogenic subsidence
- Earth quake induced crustal deformation
- Sea level rise
- Atmospheric modelling

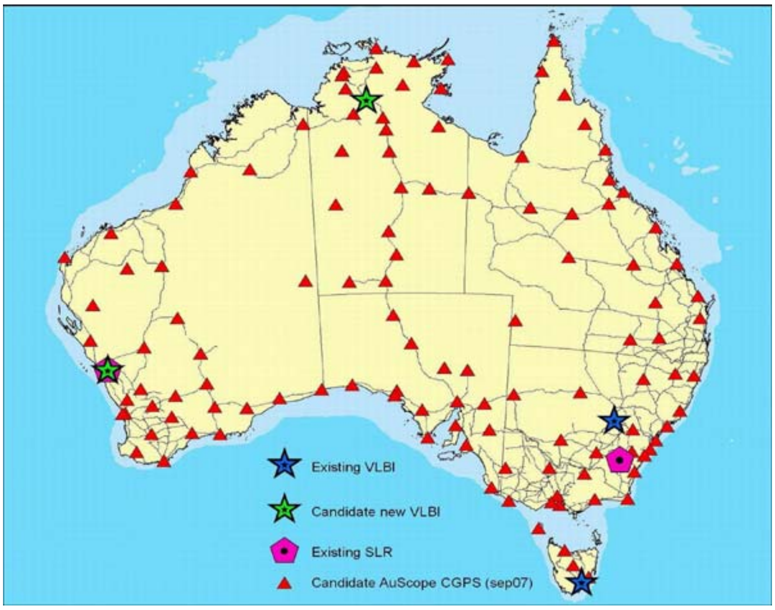

Figure 8. The AuScope Geospatial infrastructure above

Australia plays a significant role in globally defining the International Terrestrial Reference Frame and contributes to GGOS with observations, precise solutions, inter-technique ties for GPS, SLR, VLBI and Gravity key sites. Nationally it does this through the new AuScope Geospatial Infrastructure Program, see figure 8, which includes:

- Three new 12m VLBI dishes

- VLBI correlator
- Four new gravity instruments
    - One MicroG FG5 absolute gravity meter
    - 3 g phone earth tide metres
- 100 new GNSS sites
- Upgrade to the Mt Stromlo SLR observatory

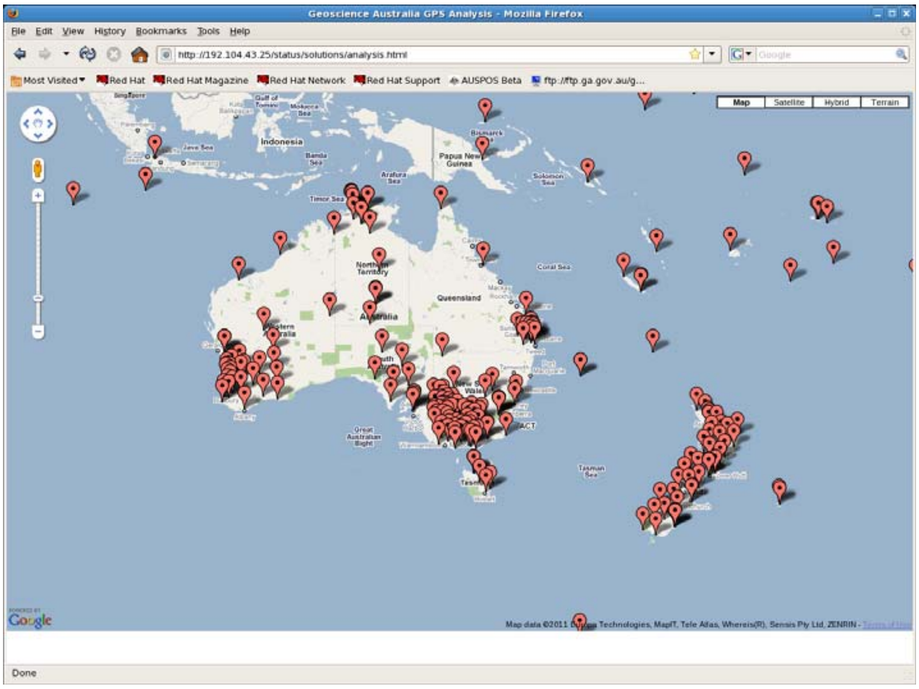

Figure 9 Geoscience Australia regional GPS analysis

Currently some 300 regional GPS sites are analysed and processed daily at Geoscience Australia as shown in figure 9 above.

8. Conclusion

The development of Geodesy in Australia has progressed a long long way in the 19th century. State authorities ambitiously commenced building triangulation networks circa 1850s but it was a big flat harsh country and a daunting task in the 1850s, using Survey of India techniques. Even 100 hundred years later in the 1950s it was still a daunting task and technology had not changed until the Tellurometer was developed from WW2 technology.

The hectic ten years of catch up Australian geodesy from 1955 to 1965 using developing technology and the first monumental computer adjustment put Australian Geodesy at world class standing. This standard of application continued with GDA Geocentric Datum. But the world is dynamic and a new era has evolved with in AuScope. Australia's major contribution to the highest level of global geodetic scientific bodies such as IERS, ITRF, GGOS whilst providing the monitoring of Australian and regional GPS tracking sites. The story continues.

Acknowledgements

There are many quite outstanding persons who have contributed to Australian geodesy and it would be wrong not to acknowledge the great work of some these , such as Bruce Lambert, R.L.Rimmington, Reg Ford, John Allman, Jim Steed, Brigadier Fitzgerald, Tony Bomford and Colonel HA Johnson. I also acknowledge the ongoing contribution of Gary Johnston who took over from the Chairman of the ICSM Geodesy sub committee in 2004

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