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THE NATIONAL GEODETIC AND TOPOGRAPHIC SURVEY

INTRODUCTION

A basic knowledge of topography (*) is usually essential to the planning and execution of developmental projects, of defence, commercial and administrative operations and as an aid to air navigation.

The primary object of a topographic survey, of course, is the presentation of this data graphically in the form of a topographic map.

In addition, a topographic map provides an essential background to the graphical presentation of statistical and administrative data and the results of natural resources surveys.

In order that topographic surveys may proceed, and topographic maps be produced, in a systematic, orderly and economical fashion, it is necessary to first subdivide the relevant portion of the earth's surface into a framework of survey control stations. The establishment of these stations is the fundamental purpose of a geodetic (*) survey.

> (*)Both these words are derived from Greek sources; topography from *topos* - place, and *graphein* - to write; geodetic from *ge* - earth, and *daien* - to divide.

A knowledge of the present status and current trends of geodetic and topographic survey could be of considerable value to many engineers and research officers in their professional activities and should help to bring about a more practical requisitioning of surveys. Furthermore, this knowledge would undoubtedly indicate spheres in which their own work may be readily modified to assist in the general mapping of the nation.

It is the purpose of this paper to supply background information on these matters and in the course of so doing, various technical processes and other directly relevant factors will be described in sufficient detail to indicate their influence on the planning and progress of survey operations.

DEFINITION

The Commonwealth Government has a commitment for geodetic and topographic survey within the Territories under its control, while both the Commonwealth and State Governments have each their own requirement and responsibility for these types of survey within the respective State Areas. The Governments have therefore mutually agreed to co-ordinate their survey and mapping activities in Australia itself through a National Mapping Council consisting of the Director of National Mapping (Chairman) and the Commonwealth and State Surveyors General.

This Council, having considered the overall requirement for geodetic and topographic survey in Australia, has recommended the basic schemes of topographic and geodetic survey shown in figure 1 and figure 2; has agreed on systems of map projections and map sheet boundaries (vide Appendix A) and has adopted national standards for geodetic and topographic surveys, air photography and topographic mapping. The joint participation by Commonwealth and State authorities in the carrying out of these recommended schemes of survey in accordance with the Council's approved standards may well be termed the National Geodetic and Topographic Survey.

THE GENERAL PROBLEM

In planning the application of geodetic and topographic survey to Australian conditions, account must be taken of the vast areas to be surveyed and mapped, of the limited availability of funds and man power, of the existing developmental programme with its attendant need for progress mapping and of the fact that the results of many cadastral and engineering surveys can often be connected to the main geodetic framework to help build up an overall pattern of survey control stations.

In these circumstances the best approach to the problem falls into three phases :

firstly : assessing, and from time to time, reviewing the basic geodetic and topographic surveys required to meet all the general purposes of the Commonwealth and States;

secondly : periodically investigating the immediate demands for these surveys and reducing them to an essential minimum;

thirdly : planning production so as to ensure that as far as practicable;

the immediate minimum requirement is met and in so doing a contribution is made to the basic national programmes,

appreciable progress is made toward completion of these basic national programmes,

provision is made to utilise all relevant information that may be obtainable from cadastral and engineering surveys.

As already mentioned, the National Mapping Council has reached agreement on the first phase of the problem. The second and third phases are recurring annual problems which must first be considered by the appropriate Commonwealth and State authorities and then co-ordinated through the machinery of the National Mapping Council which usually meets once a year for this purpose. In addition further co-ordination is achieved by the regular interchange of reports and by direct correspondence between members on ad hoc matters.

In order that the activities resulting from this approach may be the better understood it is necessary first to consider, in broad outline, the technical factors affecting the situation.

GEODETIC SURVEY

The geodetic survey involves the establishment of both horizontal and vertical control stations and it is desirable to complete the major portion of this survey as quickly as practicable in order that the re-casting of existing maps may be reduced to a minimum, and advantage taken of the possibility of connecting many other types of surveys to geodetic stations.

Measurements made on, or close to, the earth's natural surface in the course of a geodetic survey are usually referred initially to equipotential surface corresponding to mean sea level and designated the geoid. This geoid is irregular in shape and, while providing a satisfactory datum for vertical control stations, does not provide a suitable reference surface for horizontal control surveys which require the adoption of some geometrical figure on which measurements can be based and thereafter subjected to mathematical treatment.

Actually the geoid surface corresponds very closely in shape to an oblate spheroid; that is an ellipsoid of revolution generated by rotating an ellipse around its minor axis. Although suitable reference figures can, and have been, determined so as to satisfactorily fit a national area, with the advance of modern international navigational aids, the likely increase in international air traffic and the desirability of a uniform basis for intercomparison of geophysical data, it would be a very sound practical approach for each national geodetic datum be determined, as nearly as practicable in terms of absolute geodetic coordinates.

An ideal basis to all horizontal control surveys would be an internationally determined and accepted ellipsoid having its centre coincident with the centre of the celestial sphere, its minor axis coincident with the earth's axis of rotation and positioned to make a best mean fit to the geoid.

In fact the International Union of Geodesy and Geophysics has already recommended the adoption of certain dimensions for an International Ellipsoid and it may therefore only be necessary to reach international agreement on the best location and orientation of this particular ellipsoid.

For practical purposes it would be necessary also to prepare a chart adequately portraying the contours of the geoid in relation to the accepted ellipsoid. Linear measurements could then be corrected for elevation above the spheroid instead of above mean sea level while the contours would indicate the slope of the equipotential surface and thereby permit correction of angular measurements and the conversion of astronomical observations for latitude and longitude to geodetic values by application of component corrections for the deviation of the vertical.

The basic operations in a geodetic survey are therefore :

the establishment of a suitable datum for horizontal control surveys and the determination of the position of appropriate stations with reference to that datum;

the establishment of a mean sea level datum and the determination of the elevation of vertical control surveys with respect to the equipotential surface passing through that datum.

Suitable Datum for Horizontal Control Surveys

A general description of the three major methods at present worthy of consideration, is given in Appendix B.

Of these the astronomical method appears most likely to give early practical results. An extensive programme of observations using this technique at about 20 observatories throughout the world, including Mount Stromlo and possibly Perth, will be carried out during the International Geophysical Year 1957/58.

Where the participating observatories are located at the ends of long first order geodetic surveys then the distances between them can be incorporated into the calculations to fix the distance from the earth to the moon and also the form of spheroid that best accords with the observational data.

As a result of this International Programme it is anticipated that the absolute geodetic co-ordinates of participating observatories will be determined with a probable error of ±40 to 50 yards and deflection of the vertical with a probable error of ±1 second of arc.

Methods of Establishing Horizontal Control

The simplest and most economical method of establishing horizontal control for small scale and reconnaissance type mapping is to make astronomical observations for latitude and longitude at a sufficient number of points and treat the observed values as absolute geodetic co-ordinates on some particular reference ellipsoid ignoring the effects of observational errors and the local deflection of the vertical.

Mapping at medium and large scales must be based on more accurate data and in areas where maps are required at these scales, surveys are carried out by the normal techniques of triangulation and traverse, which have been greatly changed by recently improved and newly developed equipment.

Angles may now be read easily and quickly by lightweight modern optical theodolites and the Bergstrand Geodimeter an electronic distance measuring device recently developed in Sweden, permits measurements of extreme accuracy between intervisible points. Local experience has shown that lines up from 4 to 15 miles long can be measured over two nights with such precision that the probable error of the mean result is not greater than ±0.04 feet. The mean of the probable errors of 11 lines measured last year was ±0.02 feet and comparisons with two first order base lines have shown agreement to within 1 part in 500,000 or better.

In triangulation and traverse the factors ruling progress, now, are the means of transport and weather conditions. Modern four wheel drive vehicles are being used to facilitate transport in all but the most difficult terrain and in the latter there is an increasing tendency to use of helicopters in order to speed up movement. The use of light aircraft permits the rapid completion of triangulation reconnaissance in most of the inland areas of the continent.

Radar and radio techniques have been developed for the measurement of distances up to 300 or 400 miles with an accuracy closely approaching that of first order geodetic survey. The radar techniques have proved most satisfactory for the geodetic and topographic purposes and the radio techniques for hydrographic surveys.

One of the most satisfactory types of radar equipment, known as Shoran, was developed in the USA. during the last war and a more precise model called Hiran is now in operation. The former equipment has proved capable of measuring with a probable error of ±10 metres, and it has been claimed that Hiran can measure with a probable error of ±4 metres. Using this type of equipment it is possible to carry out geodetic trilateration over extensive areas by measuring the sides only of combinations of triangles and thereby establishing a primary network of horizontal control stations. This primary network may be further broken down to provide immediate control for mapping by automatically recording at the time of exposure of an air photograph, radar distances from two ground stations whose position has already been established.

Radar methods in readily accessible terrain seem to use up much the same amount of manpower and money as normal ground methods with the advantage of a quick answer and the disadvantage of the absence of intermediate stations along the lines measured. In terrain where movement is difficult, or across areas of jungle, sea or desert, radar may be the only practical method to use.

Radar only measures length between stations, whereas both length and azimuth are adequately carried forward by either normal ground triangulation or traverse. As a result of this defect radar trilateration rapidly develops errors in computed azimuths and some form of azimuth control should be established about every 500 miles.

Methods of Vertical Control Survey:

The datum for mean sea level is usually established after analysis of results obtained from properly situated tide gauges, interconnected by first order lines of levelling.

The actual process of geodetic levelling remains fundamentally unchanged but modern optical levels permit faster work. This is particularly the case with the very recent self-levelling instruments in which the line of sight is automatically levelled by use of a special pendulum type glass prism.

In recent years there has been an increase in the knowledge of the effects of atmospheric refraction, earth movement and other systematic errors encountered in precision levelling.

In the course of horizontal control surveys trigonometric heights are still determined in the normal manner from reciprocal vertical angles.

Advances have also been made in the utilisation of aneroid barometers for determination of vertical elevations and these instruments can be used satisfactorily to fill in additional control between the higher order stations.

Investigations by the Commonwealth Scientific and Industrial Research Organisation have established that a series of normal readings of the barometers at standard meteorological stations can be utilised in conjunction with a roving barometer to determine station height in isolated areas to a quite reasonable degree of accuracy. Following on these investigations, simple operational techniques have been developed for use in Northern Australia during the *dry* season utilising pressure readings from a roving battery of barometers and correcting these on the basis of the standard daily readings at surrounding field meteorological stations. Repeated elevations determined at the same stations over a period of two years have been found to agree within ±20 feet.

Airborne radar equipment has been developed in Canada for the automatic plotting of ground profiles from a plane in flight. This technique has proved satisfactory in the provision of vertical control for small scale mapping but the equipment has not so far been used in Australia.

Application of these Methods to the National Geodetic Survey:

In view of the present status of geodetic and topographic survey in Australia and the lack of world wide gravity data, the soundest procedure in arriving at a datum for horizontal control surveys appears to be that of using the astronomical method to determine as closely as practicable the geocentric co-ordinates of an origin and then, as surveys extend, apply the geodetic method to determine the configuration of the geoid in relation to this origin and an international ellipsoid.

It should be possible to confirm this local configuration by the geophysical method and if sufficient gravity work is carried out during the forthcoming International Geophysical Year, to either confirm or modify the values of the origin.

If values could be so obtained at Canberra and Perth, horizontal control surveys could then proceed satisfactorily in the two major areas where intensive mapping is likely to be required but early completion of a survey connection between Perth and Canberra would permit use of this information in the calculations that will arise from the Photographic Moon Position Programme for the International Geophysical Year.

In proceeding with the actual geodetic survey itself, ground triangulation and traverse, utilising the latest electronic distance measuring equipment, and precision levelling are obviously the most satisfactory methods in areas where large scale mapping is likely.

In areas where only 4 mile to 1 inch mapping is likely, radar methods would provide adequate horizontal control and long range barometric methods adequate vertical control but, if a certain relaxation is accepted in the normal horizontal accuracy of mapping, uncorrected astronomical observations may be utilised for horizontal control at considerably less expense. In actual practice this latter procedure is followed except in areas where radar is being used in any case by the Bureau of Mineral Resources for control of its geophysical surveys and where it has been possible to arrange for the Bureau to undertake special radar controlled air photography.

In areas where only 8-16 mile to 1 inch photography is likely, normal astronomical observation and long range barometric methods are adequate for control purposes.

The extent to which surveys should be undertaken to interconnect areas of large scale mapping presents certain difficulties. One solution would be to establish, as precisely as practicable, an absolute origin for each such area on the assumption that the intervening areas are most unlikely ever to be connected up by large scale mapping and that the 4 mile or larger scale mapping of these areas would be based on control fixed by local astronomical observations. However, it may be reasonably anticipated that large areas of 4 mile to 1 inch mapping will eventually be controlled by radar methods and as radar trilateration must be related at intervals to lines of ground survey for azimuth control (in much the same way as base lines are used to control the scale of ground triangulation survey), there is likely to be a necessity for at least a skeleton framework of geodetic survey.

Moreover it can be anticipated that eventually the boundaries of Western Australia with the Northern Territory and South Australia and of the Northern Territory with South Australia will have to be fixed on the ground by either triangulation or traverse in terms of an absolute geodetic datum.

The Geodimeter has already proved its worth in the rapid measurement of first order base lines and will, it is anticipated, greatly increase the rate of precision traversing to the stage where it can compete in economy and speed with any other form of geodetic survey.

Having regard to these factors it is considered that the interconnecting surveys of the scheme of National Geodetic Survey as recommended by the National Mapping Council should still proceed and possibly the whole scheme be supplemented by radar measurements where the cost can be shared by joint geodetic/geophysical surveys of a particular area.

Existing Status of the National Geodetic Survey

The existing status of the horizontal control portion of the National Geodetic Survey is shown in figures 3 and 3A. At present the major survey area in the south east is based on the astronomical values of Sydney Observatory with the exception of Tasmania which, although connected by survey to Sydney, is still based on a local datum pending finalisation of a national geodetic datum. The West Australian survey is based on Perth Observatory. The surveys in northern Queensland are on local origins at Cairns and Townsville while the Stuart Highway Traverse in the Northern Territory has been computed in terms of an origin at Tennant Creek.

All States with the exception of Queensland are engaged on a limited amount of geodetic survey. The Commonwealth programme provides for a continuing and active programme of geodetic survey which will be carried out by the National Mapping Office and the Royal Australian Survey Corps. In Queensland horizontal control is usually computed through contiguous cadastral surveys.

The vertical control position of the National Geodetic Survey has lagged noticeably but the reason for this is undoubtedly the ready availability of good railway levels and other engineering levels throughout the more intensely developed areas. These levels have usually been found sufficient as a basis for mapping operations and to control any error that may have developed in elevations carried forward in the course of triangulation or traverse based on astronomical observations.

In Queensland particularly there is a State wide network of lower orders of levelling all co-ordinated to the one datum.

It is the intention of most States to carry out lines of precise levels and to co-ordinate available level information into one State datum based on Local Mean Sea Level. Ultimately the various State datums will be co-ordinated in terms of a National datum.

The present status of precision levelling is set out in Appendix D.

Several States have adopted Survey Co-ordination Acts which provide for the systematic recording of all forms of survey. By this means much useful data must eventually be incorporated into the general pattern of geodetic control.

TOPOGRAPHIC SURVEY:

Topographic data may be presented in various graphical forms varying from an individual photograph to a printed map at a large scale on which natural and cultural features are shown in great detail by appropriate symbols, and the relief is indicated by closely spaced contours.

Examples of the various forms of graphical presentation are shown in figure 4.

Normally the first stage in a topographic survey is the taking of near vertical photographs of a standard map sheet at an appropriate scale and in parallel flight strips with individual photographs overlapping each other by about 60% and flight strips overlapping laterally by about 20%.

Once these photographs become available topographic data may be presented in different graphic forms varying in both accuracy and the degree of information shown.

The most elementary form of presentation, and that usually put into effect as soon as photography is completed, is the uncontrolled photomap or photo index. This is made by photographically copying an assembly of air photographs in which edges have been matched as well as practicable and on which flight strips and photo numbers are appropriately shown.

In this form of presentation varying camera tilts and any variations in ground elevation will affect the matching of individual photos but the resultant photomap does give a broad general picture of the terrain and particular sections can be investigated in detail by stereoscopic examination of pairs of overlapping photographs. This type of presentation is increased in value if it is treated as an air photo index indicating the identification number of individual photographs.

Knowing the general elevation of the ground and the flight altitude of the aircraft it is possible to supplement the detailed stereoscopic examination with very approximate estimates of distance, azimuth and relative elevation. The important consideration is that information in this form can be made available within a few days of completion of air photography.

A more satisfactory form of presentation consists of either a controlled photomap or planimetric map. In the former, the position of individual photo centres and other photo control points is established graphically in relation to plotted geodetic control data and the individual photos specially rectified to accurately fit to the photo centres and photo control points. In the planimetric map the horizontal position of natural and artificial features is presented correctly with relief shown either by hachuring or hill shading possibly supplemented by isolated spot heights.

A special local technique has been developed for the production of *semi-controlled* photomaps in which the positions of the photographs along the edges of a map are established in relation to available control and the remaining photographs then fitted within this framework.

The final and most satisfactory form of presentation is the fully contoured topographic map on which distances and azimuths may be accurately scaled and heights interpolated from appropriately spaced contours.

The essential principal in providing topographic data for any purpose, is that, as much information as practicable must be provided in time for it to be of use.

The time factor for the topographic survey of a particular area may vary from a matter of *man/days* of work, to one of *man/years* accordingly as the form of presentation varies from a photomap providing say 50% of the desired information to a detailed contour map showing 100% the information. Moreover the effort required to produce maps at different scales varies inversely approximately as the square of the scale factor.

Therefore if a maximum of topographic information is to be made generally available as early as practicable, topographic survey programmes must be phased so as to successively produce photomaps, small scale maps and hen larger scale maps; preferably with the production at these scales of a complete planimetric coverage in advance of any contouring.

Fortunately both engineering and resources survey investigations almost invariably lend themselves to a reconnaissance technique in which the broad picture can be obtained from photomaps, possibly supplemented by ground or aerial inspection and the determination of a limited number of elevations by barometric means. In this way all but the most likely areas can be eliminated and the more intensive and expensive mapping can then be concentrated on these particular areas.

Methods of Topographic Survey

The production of uncontrolled photomaps has already been described.

Controlled photomaps and planimetric maps are produced usually on the basis of a slotted template assembly in which directions from the centre photographs are accepted as correct, templates are prepared for each photograph and assembled in their correct order to form a series of interlocking triangles that can be adjusted to fit the plotted position of the horizontal control survey stations.

For a limited area, a similar but alternative method of establishing the position of photo centres and photo control points can be carried out graphically, using ordinary. survey draughting equipment supplemented by a stereoscope.

When preparing a controlled photomap specially rectified prints are adjusted to fit these photo control points and when preparing a planimetric map, overlapping pairs of photographs are examined under a stereoscope, appropriate detail identified and marked on the photographs and this detail then transferred to fit into the photo control points using a fairly straightforward drawing office procedure.

If the elevation of eight or more points can be established in suitable locations on each alternate photograph it is possible to determine from these the elevations of additional points with the aid of simple parallax bar. The actual contours can then be sketched in while examining the photographs under a stereoscope and later transferred to the plotting sheet.

As mentioned earlier a special local technique of preparing *semi-controlled* photomaps has also been developed as a basis for small scale reconnaissance type mapping in less developed areas. In this technique the position of the photographs in flight strips surrounding and bracing across a map area are determined with the aid of slotted templates fitted to whatever limited control may be available. The intervening photographs are then mosaiced to fit within this framework. This type of photomap has the advantage of a restriction on the development of inaccuracies and the possibility of fitting adjoining photomaps to one another.

Where it is desired to obtain as accurate a result as possible from air photography, automatic stereoplotting equipment must be used for the topographic survey. Probably the simplest and most practicable of this equipment is the multiplex.

Other types of equipment exist using either optical or mechanical means of plotting. Some of these are capable of extreme precision and thereby obtaining the very utmost out of the air photographs. Stereoplotting equipment can also be used to fit several successive photographs to available control without the necessity of establishing control on individual overlaps.

Analytical techniques have also been developed for calculating the horizontal position and the elevation of photo control points on the basis of accurate measurements of their photographic co-ordinates and those of the images of ground survey control points, located at intervals of several photographs apart.

Generally, where it is practical and economical to do so, it is much more satisfactory to establish by ground survey, vertical control points on the area of overlap between succeeding photographs and horizontal control points at intervals of three to four photographs apart and then carry out the topographic survey within this control.

With normal air survey photography and using the simpler draughting methods it is possible to contour satisfactorily at an interval of i:250 of the flight elevation and accurately plot planimetric detail at about one half the scale of photography while with stereoplotting equipment, contours at from 1:500 to 1:1500 of the flight elevation and planimetry at from the same to five times the scale of photography are practicable.

It cannot be emphasised too much that, once air photographs are available, it should be possible for the average surveyor and survey draftsman, utilising very simple equipment and straightforward field survey techniques, to produce quite a reasonable topographic map of a limited area.

Application of these Methods to the National Topographic Survey

All mapping agencies have lately agreed to produce uncontrolled photomaps for use as photo indexes immediately air photography of an area is completed.

In certain areas plans are available showing accurately, the position of cadastral boundaries and if necessary these plans can be built up into small scale reconnaissance type maps by adding information on natural and artificial features as derived from uncontrolled photomaps. It has been found possible by this means to effect marked improvements in existing territorial maps and aeronautical charts.

In some areas it is possible to improve the value of these small scale reconnaissance type maps by determining elevations with the aid of an altimeter in a light aircraft.

Within the State sphere, Lands Departments generally undertake production of planimetric and photo maps and are all equipped with automatic stereo plotting equipment. They undertake quite an amount of large scale contoured mapping for special projects and in all but one or two States at least some progress is being made in the production of regular contoured maps conforming with the ultimate requirement of the National Topographic Survey. In one or two instances where States have not produced early planimetric maps but concentrated on contoured maps only, small planimetric mapping sections have appeared in the various user departments in order that the more immediate demand for this type of map may be satisfied.

Within the Commonwealth sphere, the National Mapping Office of the Department of Interior and the Royal Australian Survey Corps, both undertake topographic survey but the overall responsibility for co-ordination rests with the Department of Interior.

An analysis has been made of the requirements of various map using departments (vide Appendix C) and as a result the Commonwealth programme provides for the early production of the 1:1,000,000 series of maps. These will provide a basis for reconnaissance and for general regional resources surveys. The main effort however is to be concentrated on the production of 1:253,440 scale maps probably first as planimetric maps to which will be subsequently added 250 foot contours. The Royal Australian Survey Corps will continue to produce such contoured 1:63,360 and larger scale maps as are necessary for its training in this type of work and it is proposed that special large scale project mapping will be contracted out to private enterprise and costed against the project itself rather than the general mapping vote.

In this latter regard it is noteworthy that the Snowy Mountains Hydro Electric Authority has found it necessary to arrange with an aerial survey company for the preparation of detailed contour maps of the whole of the area under its control.

A great deal of air photography was carried out by the Royal Australian Air Force prior to mid 1953 but since that date air photography for Commonwealth purposes has been carried out by commercial agencies operating under contract. The same procedure is followed by some States while others hire the services of aircraft only and provide their own photographic equipment and operators.

Existing Status of the National Topographic Survey:

Figure 5 shows the present status of air photography and figures 6 and 6A the mapping achieved to date, the combined efforts of Commonwealth and State Authorities.

CONCLUSION

After consideration of all the factors relevant to the National Geodetic and Topographic Survey there evolves an appreciation of the necessity to proceed with an active programme on the main geodetic framework, of the necessity to assess the basic minimum mapping requirement and then to adopt a long range programme of topographic survey that will in the first instance provide a broad picture suitable for the general investigational purposes of most users and that will by appropriate stages provide the information for more detailed investigation and ultimately satisfy the basic minimum requirement.

The main problem in connection with mapping for particular projects is that of bringing about in the map user an appreciation of the relevant factors affecting topographic survey and of the basic approach that has been adopted toward the national survey. It is important that engineers and research officers in particular be seized of the advantages and the economy of effort that result from arranging their map requisitioning to fit in with the reconnaissance techniques they would normally apply within their own spheres of activity. Perhaps the most important of these advantages is that a timely approach to the appropriate topographic survey authority may make it possible to vary the general mapping programme to assist a particular project in which case most of the preliminary survey costs would not be a charge against the project itself but would be incorporated in the regular mapping expenditure.

The initial purpose of this paper was to draw the attention of engineers and research officers to the advantages of a knowledge of the present status and current trends in the national geodetic and topographic survey. It is therefore hoped that the information set out herein will help not only to bring about the fullest utilisation of the material at present available but that it will lead to a wider and more effective co-ordination of individual mapping requirements into the national scheme, to the mutual advantage of map users and map makers, and to a saving of expenditure from the public purse which in the long run must meet the cost of all survey and mapping activities.

Part 1 - Map Sheet Boundaries

The basic units are the International 1:1,000,000 (approximately 16 mile to 1 inch) Map sheets each of which, for the greater part of the earth's surface spans 6 degrees of longitude by 4 degrees of latitude.

These sheet boundaries, with slight modifications, have been adopted for the Australian portion of the World 1:1,000,000 Aeronautical Chart series (figure 7) which is being produced to the specifications of the International Civil Aviation Organisation (I.C.A.0.).

Australia has agreed to the production of a number of sheets of the International 1:1,000,000 Map of the World but progress has been delayed pending completion of those World Aeronautical Charts for which it has assumed responsibility.

In the interim the aeronautical charts have been adapted to produce a special Australian Geographic Series (A.G.S.) of maps for general use.

The International Map sheet unit is broken down successively into 1:253,440 (4 mile to 1 inch) and 1:63,360 (1 mile to 1 inch) map sheets as shown in figure 8. Sixteen of the 1:253,440 maps fit into an International Map sheet with each individual map covering 1½ degrees of longitude by 1 degree of latitude and being numbered as an integral part of the 1:1,000,000 map.

The 1:253,440 map sheets are each subdivided into twelve 1:63,360 map sheets covering 30 minutes of longitude in breadth and 15 minutes of latitude in depth. The numbering of these 1:63,360 map sheets is based on the zonal areas of the Australian National Grid and not on the subdivision of the 1:253,440 series.

Part 2 - Map Projections

The International 1:1,000,000 Map is drawn on a special Modified Polyconic projection with two Standard Meridians selected 2 degrees from central meridian.

The I.C.A.O. charts and A.G.S. maps are drawn on the Lambert Conformal Conic projection based on standard parallels selected 40 minutes within each 4 degree latitude band. Actually the difference between the I.C.A.O. and the International projections is very small.

The 1:253,440 and 1:63,360 maps are produced on the Australian National Grid. This is derived from a series of Transverse Mercator projections computed on the Clarke 1858 Ellipsoid. Details of these projections are shown in figure 9.

GENERAL DESCRIPTION OF VARIOUS METHODS OF ESTABLISHING A SUITABLE DATUM FOR HORIZONTAL CONTROL SURVEYS

The first, which may be termed the *geodetic method*, consists initially of determining by astronomical observations the latitude, longitude and azimuth at a starting point and tentatively adopting these as geodetic values on some arbitrary ellipsoid the surface of which is considered to be perpendicular at mean sea level to the vertical through the starting point.

The geodetic survey then proceeds by a combination of linear and angular measurements throughout the area while astronomical latitudes, longitudes and azimuths are observed at appropriate stations and the differences between survey and astronomic values are accepted as indicating the local geoidal gradient with reference to the adopted spheroid. From these gradients geoidal contours are determined and after a mathematical analysis of the observation data, corrections are deduced to the adopted latitude, longitude and possibly azimuth, of the starting point and new spheroidal dimensions deduced, or the currently accepted International Spheroid oriented, to give a best fit to the local geoid.

If a considerable number of astronomic determinations are available this procedure can be based on a determination of the actual geoid but if only a limited number of values are available then the investigation will need to be based on some form of isostatic assumption as was done by Hayford in the U.S.A. when deducing the dimensions of the Spheroid now accepted by the International Union of Geodesy and Geophysics as the International Spheroid. As a basis to this isostatic approach a reasonable knowledge of topography is necessary.

This was the actual approach envisaged when the present scheme of national geodetic survey was prepared, but it should be noted that owing to the absence of world wide interconnected surveys the results obtained by this method may differ slightly from the absolute values.

The second or *geophysical method* depends on the availability of well distributed gravity observations preferably at about 300 mile intervals all over the earth, including ocean areas. With this information available it would be possible to calculate in absolute terms, with respect to some particular reference spheroid, the general regional contours of the geoid, but some thousands of such determinations are still required particularly in the Southern Hemisphere before this can be done satisfactorily. However, given numerous gravity readings in a radius of about 100 miles around any particular point it is generally practicable to calculate the local geoidal contours with considerable relative accuracy and deduce a local deflection of the vertical. The actual density of gravity readings required would vary in intensity roughly as the square of the distance from the point but would depend to some extent on the pattern of local gravity anomalies that showed up in the process of the investigation.

The local deflections of the vertical determined in this way would be relatively consistent among stations in a particular area, but in Australia, owing to the lack of sufficient data in the Southern Hemisphere, the values so determined could differ from absolute geodetic values by amounts of the order of 3-5 seconds of arc.

To carry out investigations of this type it is necessary to have reasonable values for the horizontal positions of the gravity readings together with fairly accurate elevations. The undertaking of special gravity surveys for this purpose could be an extremely expensive business but advantage may be taken of the gravity work done by prospecting companies in particular areas. In these areas only limited additional work might be required.

A disadvantage of the geophysical method is, that although a general shape is obtained on the basis which astronomic latitudes and longitudes can be converted to geodetic values, distances between stations would depend on any ellipsoid adopted. Alternatively, first order surveys could be made between certain of these stations and by mathematical analysis the dimensions and orientation of the most suitable ellipsoid determined.

The third is known as the *astronomical method* and depends on observations of star occultations by the moon. This method of position determination has been known for many years and possesses special attractions from the geodetic point of view, in that moon and star positions are tabulated in terms of geocentric co-ordinates and the time at which the occultation occurs at a particular place depends on its position along its geocentric radius vector, without reference to the direction or intensity of gravity.

Hitherto, the method has not been capable of accurate results but with the current detailed investigation and charting of the moon's surface, the introduction of photo-electric timing techniques and a better determination of the moon's movement in its orbit, most of the inaccuracies have disappeared or may be eliminated by observational techniques.

In applying this technique an approximate value is adopted for the geocentric co-ordinates of the observation point and the differences between predicted and actual time expressed in terms of variations of these co-ordinates. Observations are then taken under as many varying conditions as possible and the best values for co-ordinate variation deduced by mathematical analysis
of the observational data. Disadvantages of the method in this form are the relative infrequency of occultations and the limited times at which they can be observed.

These disadvantages have been eliminated in a technique recently evolved at the United States Naval Observatory in which a special dual rate camera is employed in conjunction with a normal observatory telescope to photograph the stars in such a manner that the image of the moon is held fixed in relation to the stars, thereby enabling the position of the moon to be accurately determined whenever clear photography is possible.

If simultaneous observations could be made at a limited number of observatories throughout the world, over a period of about one year, it should then be possible to deduce the geocentric co-ordinates of these observations to within about ±50 yds.

APPENDIX C

ANALYSIS OF PARTICULAR MAPPING REQUIREMENTS

Defence : Topographic maps provide data essential to the planning and implementation, not only of field operations, but also to the strategic development of the nation. Particularly there is a requirement for contoured maps at scales of 4 and 16 miles to 1 inch (1:253,440 and 1:1,000,000 approximately) over the whole of Australian Territory, for 1 mile to 1 inch (1:63,360) contoured maps over about one third of these territories and for 1:25,000 scale contoured maps over specific limited areas. However, it is accepted that planimetric maps or even photomaps of an area are better than no maps at all and are certainly of value in the later planning of more intensive mapping. The early preparation of this type of map is therefore of some value for defence purposes.

Resources Surveys : Topographic maps are required to assist in geological and geophysical surveys, and for land research, soil and forestry surveys. Experience has shown that in the reconnaissance stages these requirements can usually be met by semi-controlled photomaps and subsequent detailed work can in most cases be carried out on the controlled photomap or planimetric maps that become available during the preparation of 4 mile to 1 inch maps. The availability of reconnaissance type maps results in a more precise determination of areas for subsequent intensive investigation and thereby tends to eliminate any unnecessary work at the later stage. When utilising photomaps and planimetric maps geologists must obtain their own spot elevations in the field by barometric methods. Photomaps have a decided advantage in that they show the pattern of the terrain to a degree of detail that is impossible on a planimetric map. There is a steady demand from mining companies for photomaps and indeed these are usually sought in preference to planimetric maps.

Administration : Planimetric maps in themselves, and with legal boundaries superimposed, are frequently used for the administrative purposes of the Commonwealth and States. The essential requirement in this type of map is that a good picture of artificial and natural features be given in proper relation to each other and at an appropriate scale but extreme accuracy is not generally required. There is a slight demand from commercial interests for special statistical maps printed on a very small scale topographic base.

Air Navigation : The Department of Civil Aviation requires topographic data in map form as a basis to the Australian Portion of the 1:1,000,000 scale World Aeronautical charts and for landing charts at a scale of 1:250,000 (approximately 4 miles to 1 inch) the latter covering an area of approach extending about 14 miles on each side of main aerodromes. This Department would like every endeavour made in the first instance to produce uncontoured topographic maps supplemented by spot heights at critical points and would particularly like to see this information obtained firstly in the vicinity of regular air routes.

Development Projects : Special engineering projects require large scale topographic maps for detailed planning and for implementation of the finally accepted schemes but normally the greater part of the early reconnaissance can be done on photomaps or planimetric maps and the expensive and time consuming large scale contour mapping can be restricted to particular areas.

Geodetic Survey : It has been found that the reconnaissance and design of geodetic surveys can be very greatly expedited if at least a photomap is available as use can then be made of a light aircraft to actually select station sites, check intervisibility and decide on a general scheme.

Public Demand : The greater part of the public demand is for maps that will assist in road travel and this demand is adequately met by planimetric maps at scales of 1:1,000,000 or 1:253,440. There is also a limited public demand for contoured 1:63,360 maps; usually from bush walkers or mountain climbers.

APPENDIX D

PRESENT STATUS OF CONTROL LEVELLING

Tasmania

Tide gauges have been established in recent years at Burnie (automatic) and Devonport (visual). First order levelling has been carried out between these gauges and extended to :

> Deloraine to connect with third order levelling brought up from the Hobart mean sea level by the Hydro Electric Commission;
>
> connect to the Launceston City Council datum.

Victoria

A series of closed loops of 1st Order levels is being run throughout the Western District based on Mean Sea Level obtained from a tide gauge at Point Lonsdale.

This system will eventually be connected to Mean Sea Level established at Portland.

A tide gauge is being installed at Port Welshpool in Gippsland in Eastern Victoria to obtain Mean Sea Level, and it is anticipated that a network will be commenced in the near future.

New South Wales

Levels are based on a Sydney datum which is connected to local mean sea level and a new tide gauge has been established at Eden to which it is hoped to connect the Snowy Mountains levelling.

About 180 miles of first order levelling has been completed in the Metropolitan area.

A line of 250 miles has been completed from Sydney to Quirindi and the following projects are in hand :

> Singleton to Howes Valley
> Sydney to Orange
> Quirindi to Tamworth via Goonoo Goonoo
> Quirindi to Tamworth via Werris Creek
> Tamworth to Gilgandra.

Western Australia

About 80 miles of first order levelling has been completed in the west coastal regions near Perth and second and third order levelling has been extended into particular map areas as required.

Queensland and South Australia

No geodetic levelling has been undertaken as co-ordinated engineering levels have so far provided satisfactory control for mapping purposes.

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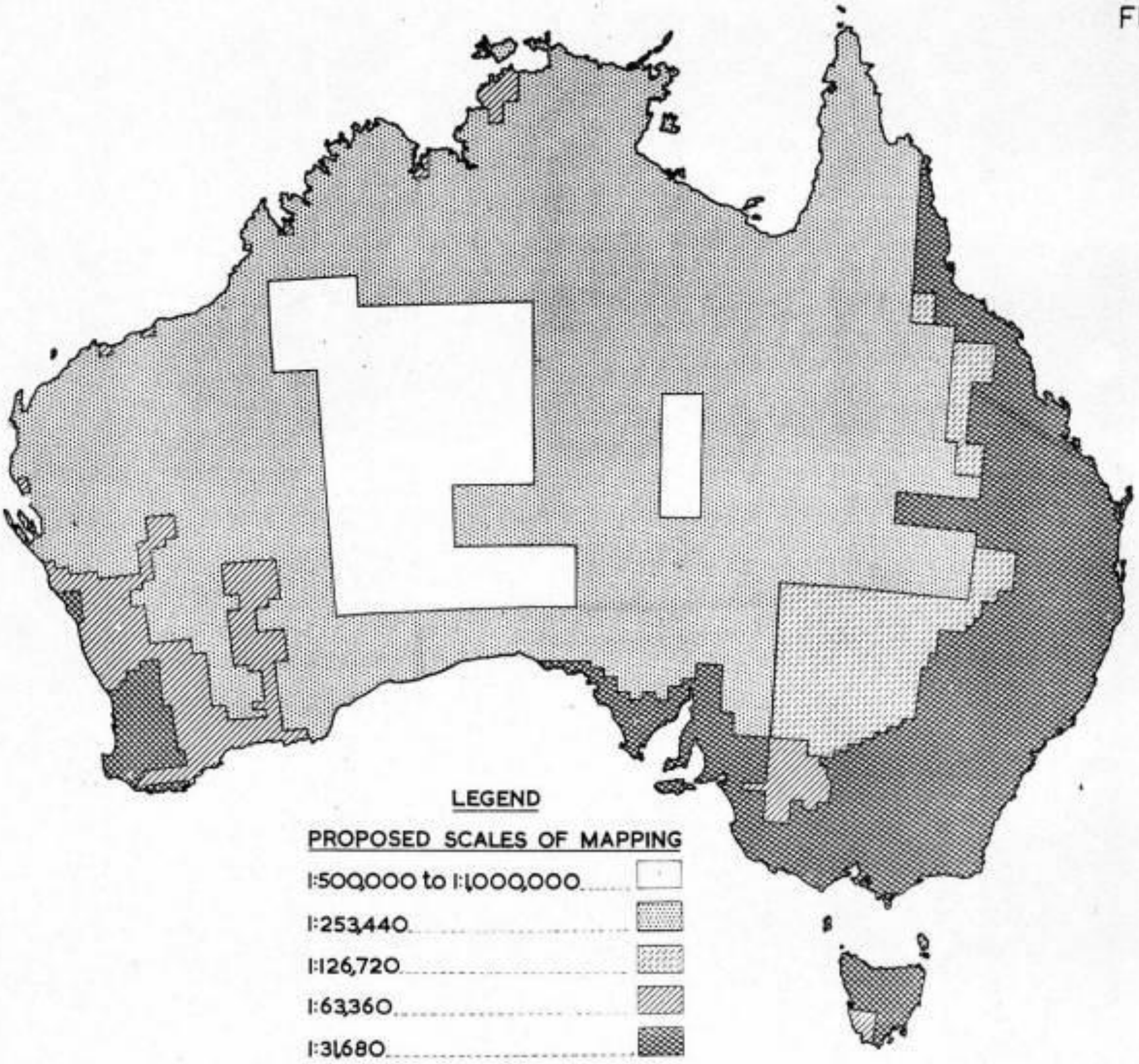
NATIONAL TOPOGRAPHIC SURVEY

RECOMMENDED BY

NATIONAL MAPPING COUNCIL OF AUSTRALIA

FIG. 1

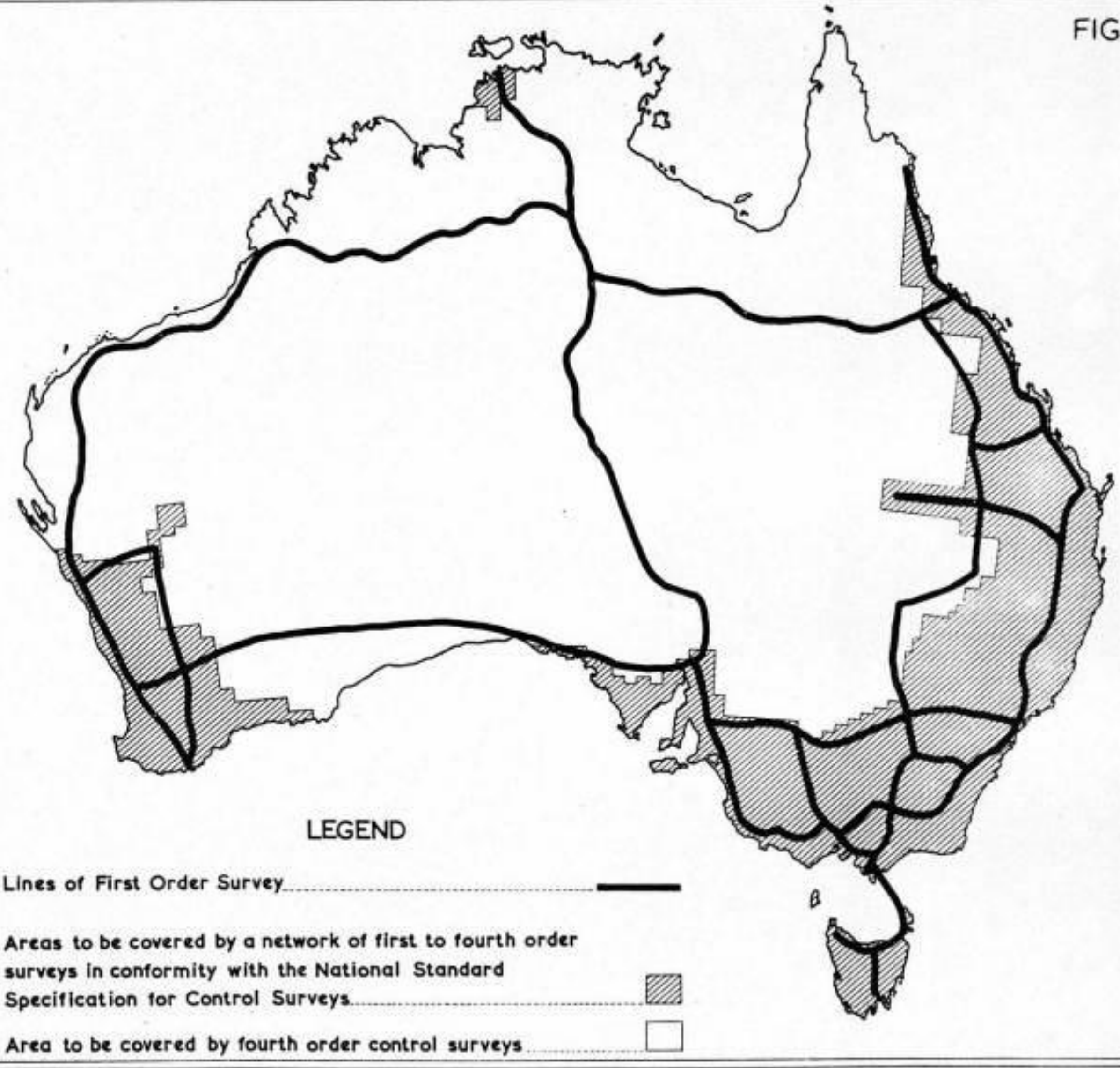


NATIONAL GEODETIC SURVEY

RECOMMENDED BY

NATIONAL MAPPING COUNCIL OF AUSTRALIA

FIG. 2



GEODETIC SURVEY

HORIZONTAL CONTROL

(Reference Ellipsoid: Clarke 1858)

FIG. 3

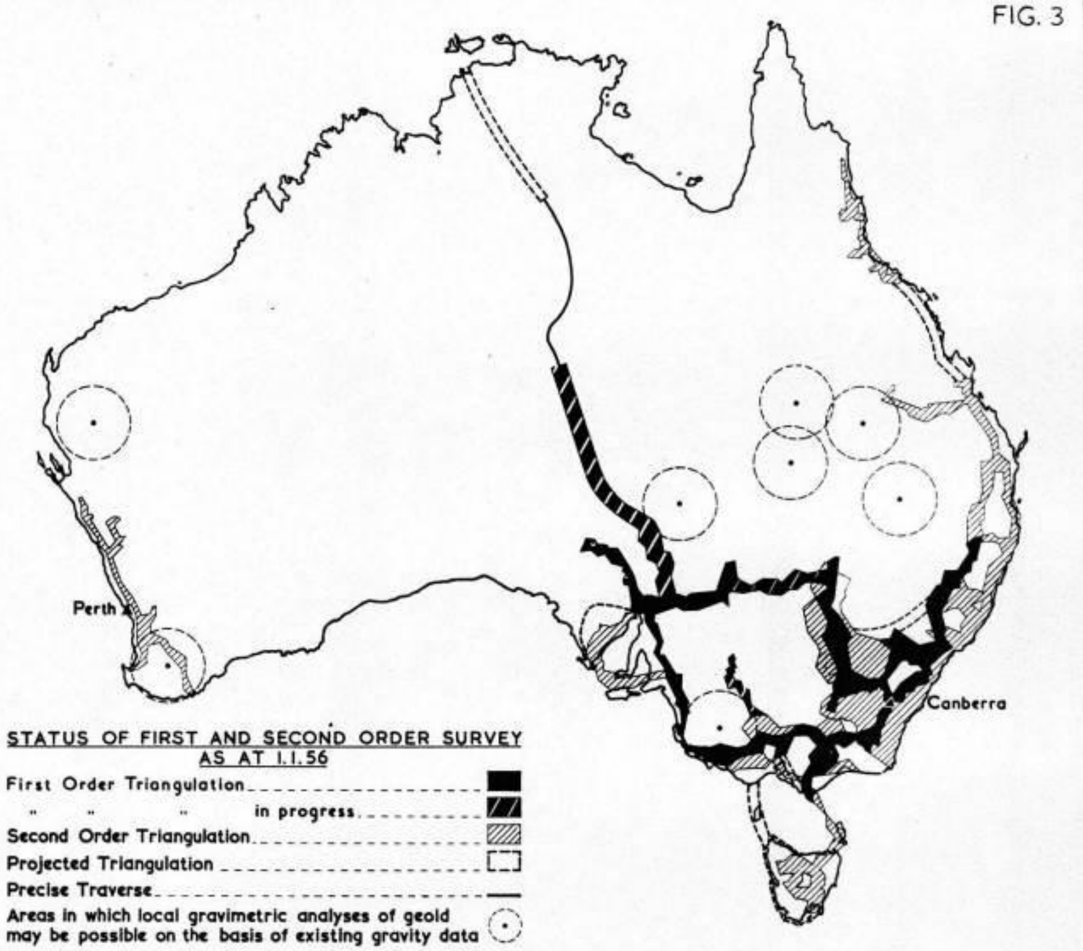


FIG. 3A

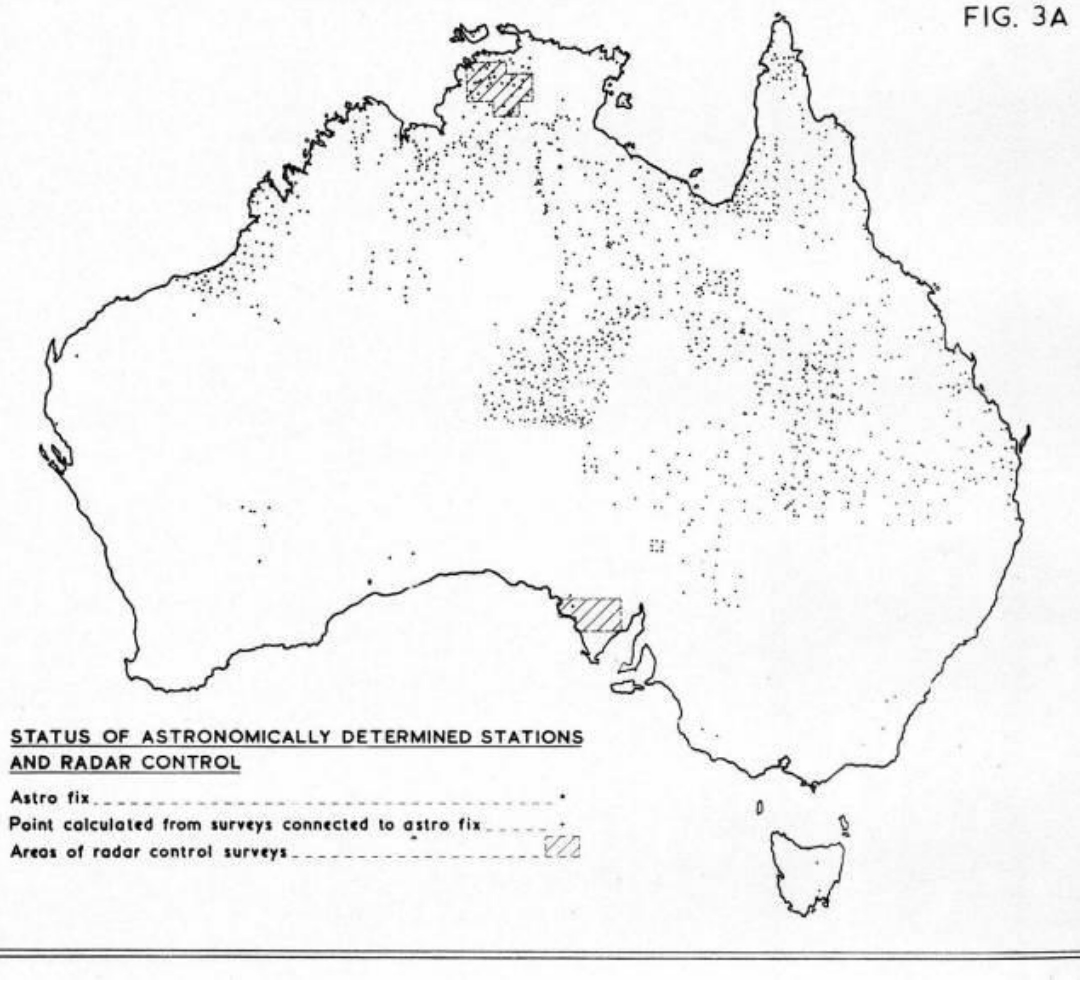
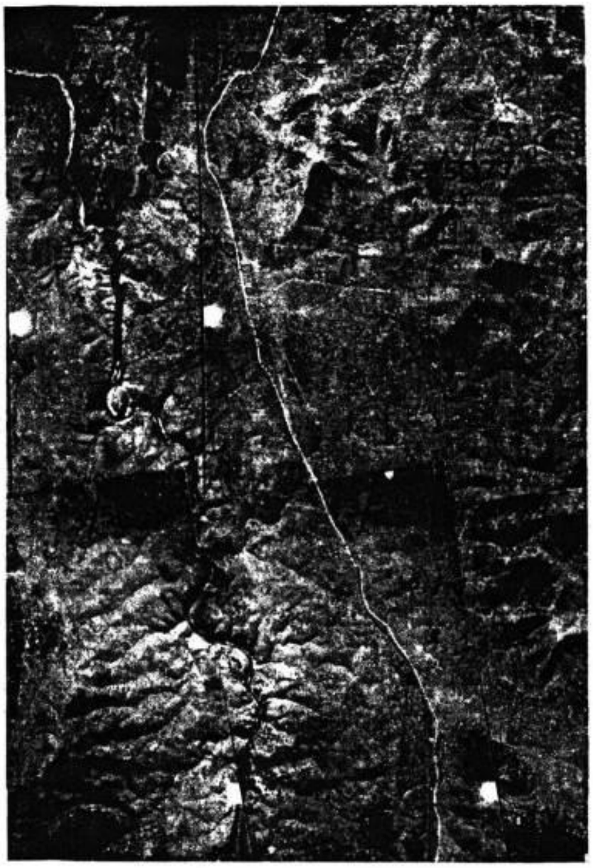


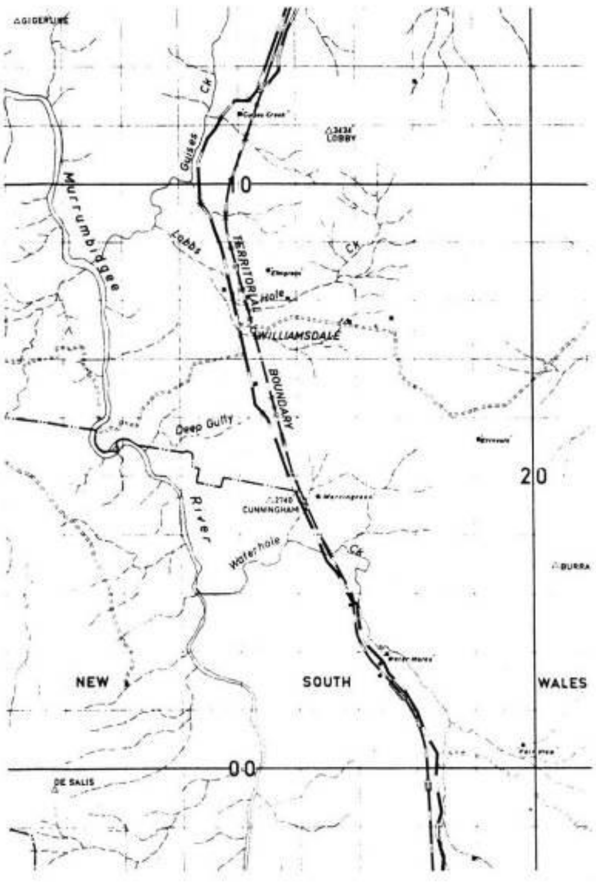
FIG. 4

PHOTO INDEX

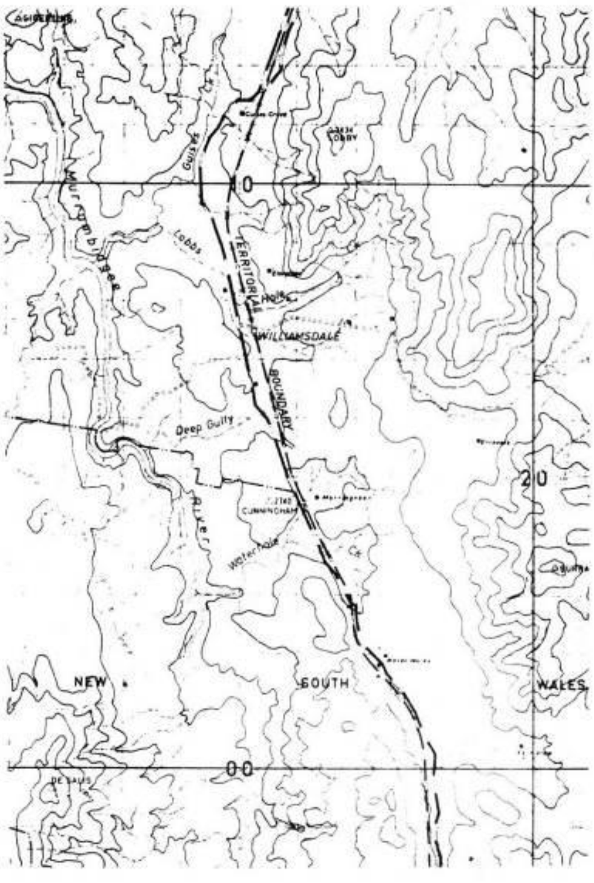


CONTROLLED PHOTOMAP

PLANIMETRIC MAP

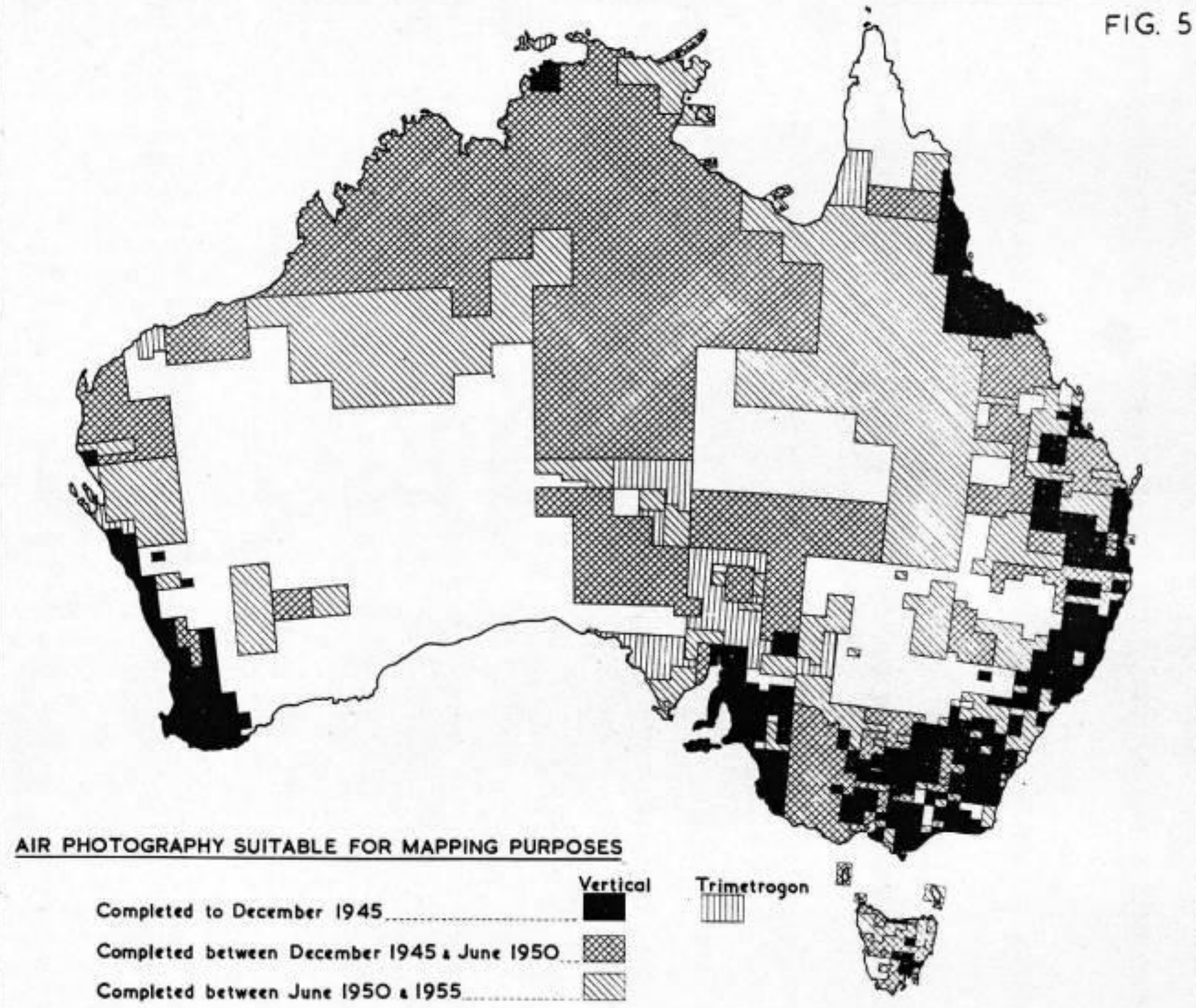


CONTOURED MAP



AIR PHOTOGRAPHY

FIG. 5



TOPOGRAPHIC MAPPING

FIG. 6

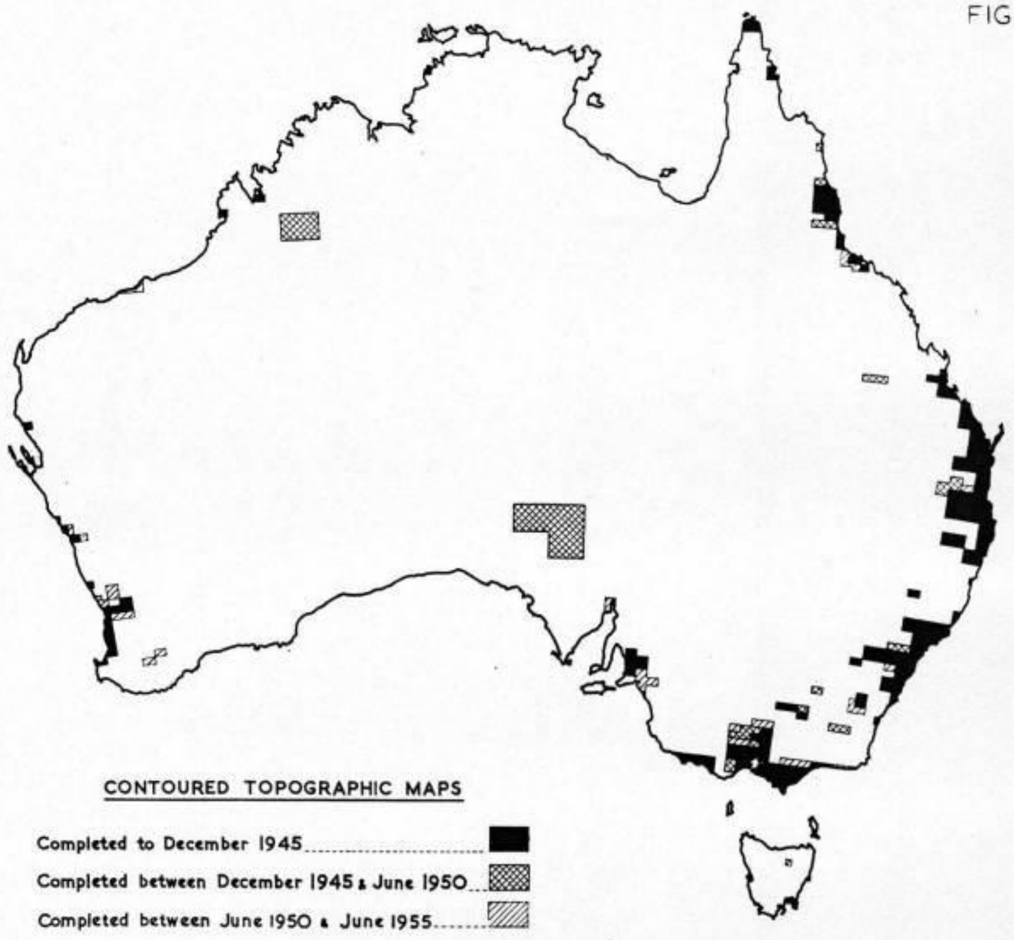


FIG. 6A

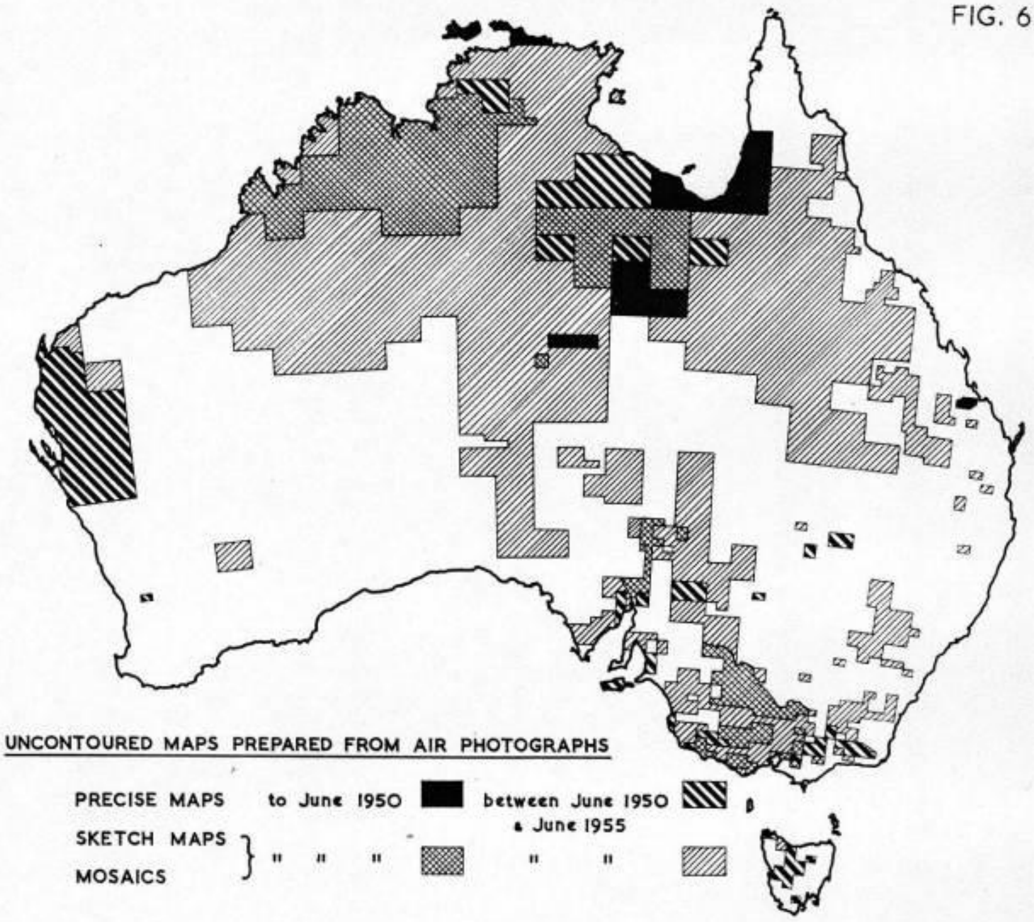
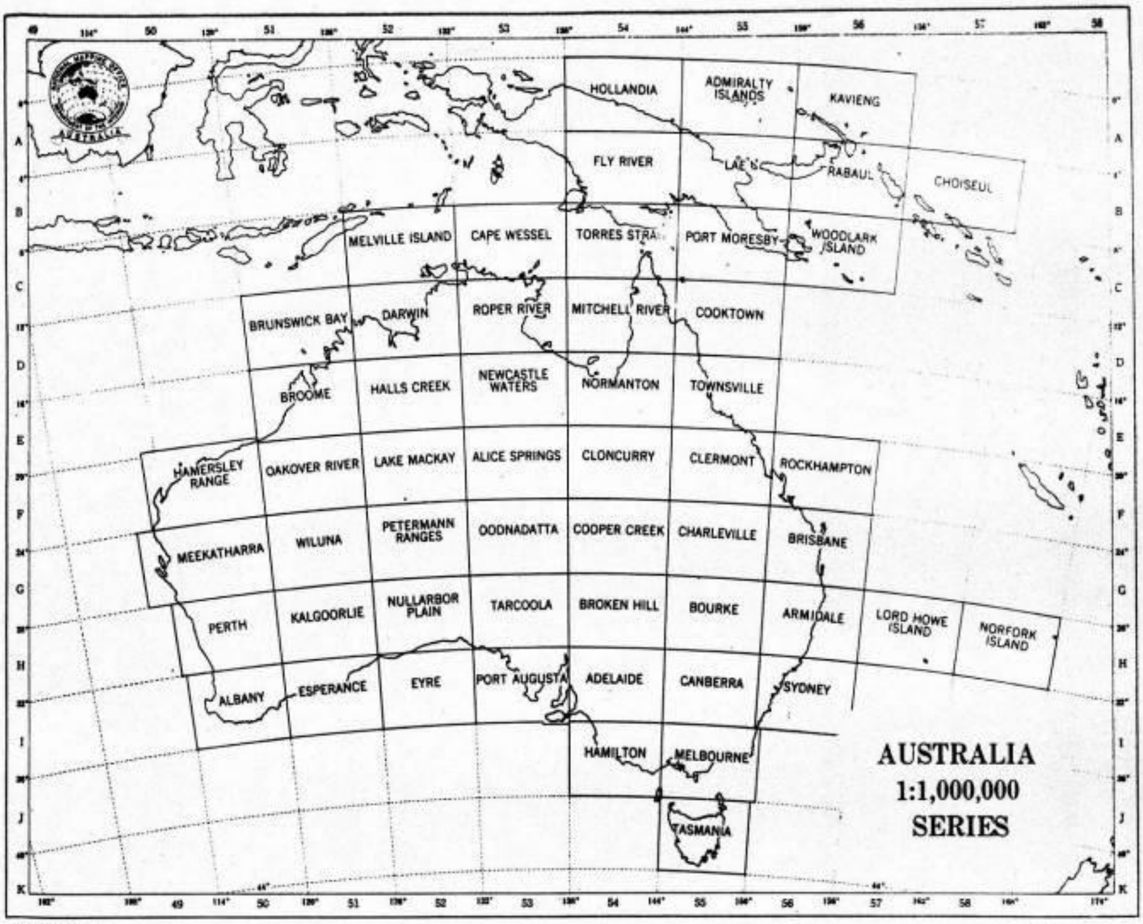


FIG. 7

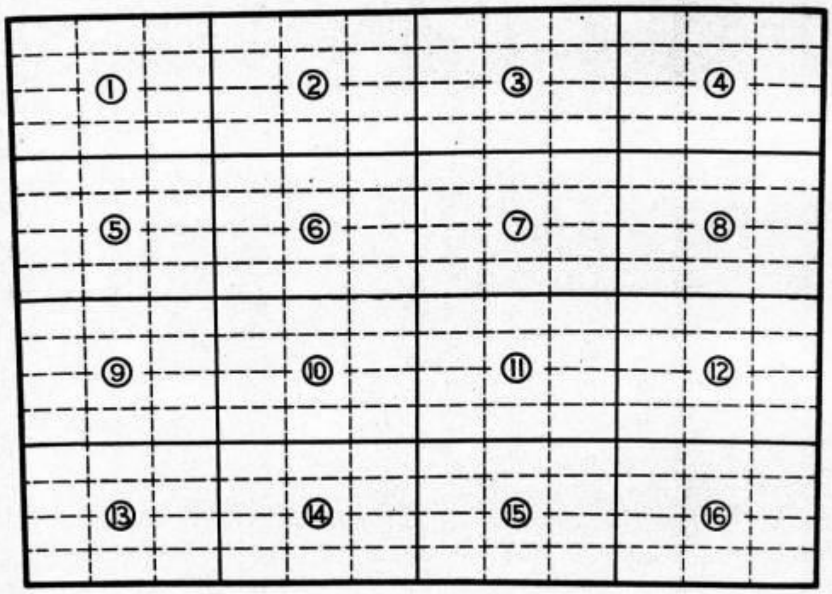


NMO/53/45.4

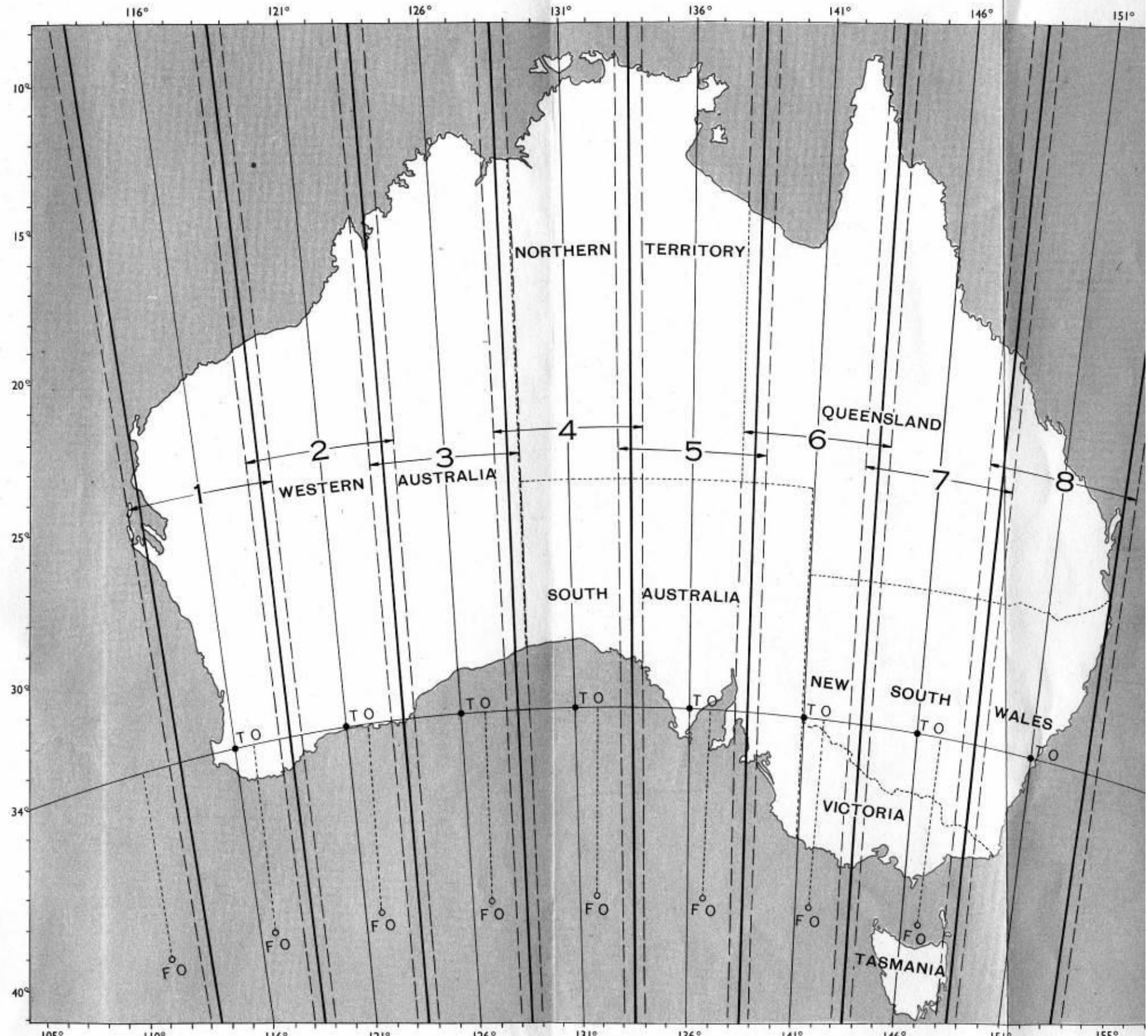
FIG. 8

SUBDIVISION OF 1 : 1,000,000 MAP SHEET

INTO 1 : 253,440 and 1 : 63,360 MAP SHEETS



TRANSVERSE MERCATOR ZONES



False origins are 400,000 yards west and 800,000 yards south of true origins.