DEPARTMENT OF NATIONAL DEVELOPMENT DIVISION OF NATIONAL MAPPING

TECHNICAL REPORT No. 3

THE WOOMERA GEOID SURVEYS, 1962 - 63

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A.G. BOMFORD, M.A., A.R.I.C.S., M.I.S. A U S T., M.A.I.C.

NMP/63/071

COMMONWEALTH OF AUSTRALIA
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CANBERRA, A.C.T., AUSTRALIA.

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Abstract

To locate a rocket in flight, two simultaneous photographs suffice, provided that the location of the cameras and the directions of their axes is known. Conventional survey gives heights and vertical angles with reference to the geoid, whereas calculations are necessarily performed on a model surface of revolution called the spheroid.

The inclination and separation of the two surfaces near Woomera was found by star observations at 60 stations. The inclination is of the order of 10 seconds of arc, and the separation varies up to 40 feet. The necessary changes to observed vertical angles and heights are given.

The Need for a Geoid Survey

To locate the instantaneous position of a rocket in flight, two simultaneous photographs suffice, provided :

- The locations of the cameras are known in a single reference system in all three dimensions. An accuracy of 1 foot is desirable.
- The directions of the camera axes are known in the same reference system. An accuracy of 1" of arc is desirable.

An x, y, z coordinate system is often used, with the origin near the launch point, y down range, x to the right, and z vertically upwards.

With regard to the location of the cameras, conventional survey gives :

- Latitudes and longitudes of the cameras referred to some arbitrarily defined spheroid; or eastings and northings referred to a plane projection of the spheroid. Accuracy of the order of a foot is obtainable.
- Heights above the geoid. Accuracy of the order of 0.1 foot is easily obtainable by spirit levelling, but the geoid surface may lie 10 or even 100 feet above or below the surface of the spheroid, if the latter has not been well chosen.

With regard to directions :

- Zenith distances can be determined with the aid of bubbles and dials relative to the local vertical, which is a line at right angles to the geoid. Accuracy of about 1" is obtainable, but the vertical may make an angle of about 10" with the normal to the spheroid.
- Azimuths can be determined from the stars with a theodolite with an accuracy of about 1"; but astronomical azimuths differ from geodetic azimuths, rigorously computed on the spheroid, by the Laplace correction, which may amount to about 5".
- The instantaneous azimuth and altitude of the axis of a camera can be obtained by photographing the stars; and the directions will be with reference to the geoidal or spheroidal systems according as one enters the computations with astronomic or geodetic latitudes and longitudes.

At Woomera surveys are computed on the Clarke 1858 spheroid Sydney origin. It does not fit the geoid at all well, the spheroidal surface being tilted by about 10" in an east-west direction relative to the geoid. This has three effects :

- The vertical at a camera station is displaced by about 10" from the spheroidal normal defined by the station's geodetic latitude and longitude, and observed and computed zenith distances will differ by this amount unless a correction is applied.
- If the surfaces of the spheroid and geoid are defined to coincide at the launch point, they separate by about 25 feet for every hundred miles westwards. The z coordinate of a camera whose height has been given by spirit levelling will be in error by this amount, unless a correction is applied.
- The Laplace correction to geodetic azimuths contains an artificial component of about 5". However, such a large artificial swing has not been incorporated in the geodetic survey. Surveyors working on the Clarke 1858 spheroid Sydney origin, have habitually ignored the Laplace correction and distributed the resulting distortion of their horizontal angles, together with the random errors of observation, by the method of least squares.

In 1962, a geoidal survey was therefore undertaken near Woomera, to observe the deviation of the vertical from the spheroidal normal at 44 stations, and hence to determine the varying separation of the geoid and the Clarke 1858 spheroid Sydney origin.

Observations at a further 16 stations were made in 1963, making a total of 60 stations in all. See Figure 1.

Method

Astronomical latitudes and longitudes were observed in the field as described in the following section. Geodetic latitudes and longitudes on the Clarke 1858 spheroid Sydney origin, were supplied by the Supervising Surveyor, Woomera. Longitudes (λ) are reckoned negative eastwards from Greenwich, and latitudes (ϕ) negative southwards from the Equator.

The astronomic coordinates define the direction of the local vertical; the geodetic coordinates define the direction of the normal to the spheroid; and the two components of the deviation of the vertical were obtained as follows :

Xi = ξ = component of deviation in the meridian, positive when geoid zenith is north of spheroidal normal

= astronomic latitude - geodetic latitude

or ξ = $\phi A - \phi G$ (1)

Eta = η = component of deviation in the prime vertical, positive when geoid zenith is west of spheroidal normal

= (astronomic longitude - geodetic longitude) cos ø

or η = $(\lambda A - \lambda G) \cos \phi$ (2)

Values for ξ and η are shown in Figures 2 and 3.

If the line joining two stations is in azimuth A,

Chi = X = component of deviation in azimuth A, positive when the geoid zenith is behind the spheroidal normal

= $- \xi \cos A + \lambda \sin A$ (3)

If the length of the line from Station a to Station b is L, and N is the height of the geoid above the spheroid,

$\Delta N = N_b - N_a = + \frac{1}{2} (X''_b + X''_a) * L * \sin 1''$ (4)

in the same units as L.

Formula (4) is an approximation. Experience has shown that unless the geoid is unduly disturbed, satisfactory values for ΔN can be economically obtained if L is about 15 miles (Bomford, 1962, p.321). The average length of line in Figure 1 is 12.1 miles; but 5 lines exceed 20 miles, of which 2 exceed 28 miles.

Values for ΔN obtained from Formula 4 were adjusted by least squares to close round each loop. See Figure 4.

The dimensions of the Clarke 1858 spheroid are of course fixed :

a = 20 926 348 feet 1/f = 294.26

The Sydney origin partly defines the spheroid's orientation, at Sydney observatory the spheroidal normal is defined to be parallel to the local vertical. However, the spheroid still has one degree of freedom - its centre is free to move parallel to the Sydney vertical - and we may thus arbitrarily define the geoid and spheroid surfaces to coincide at any one point we choose. Accordingly, N was defined to be zero at station 60,

With N defined at one station, the adjusted values of ΔN gave unique values for N at the other 59 stations. One-foot contours of N were interpolated. See Figure 5, which shows the geoid near Woomera with respect to the Clarke 1858 spheroid Sydney origin.

Field Work

In 1962, observations were made between 28 January and 2 March by a party of eight from the Division of National Mapping with two assistants from WRE, Salisbury, forming four observing teams each with a Wild T3 geodetic theodolite. The theodolites had special 5-wire diaphragms, and graduations on the alidade bubbles. In 1963, three similar teams observed during the period 3 - 14 February.

For latitudes, circum-meridian altitudes of four or more pairs of stars were observed.

For longitudes, six or more pairs of stars were timed by stop-watch to 0.05 seconds as they crossed the Almucantar circle of 30° elevation within 10° of the prime vertical. Stars were timed across all five wires, and the level bubble was read each time. Five WWVH radio time signal *tocs* were timed between each star.

All observations were predicted on the IBM7090 computer at Salisbury, using new programmes specified by the writer and prepared by Messrs Andrews and Sagg, IG.3.25.1 and IG.3.23.1. Observations at a station were completed within three hours on a single night, cloud permitting.

These simple and economical methods have one disadvantage in the longitude observation, individual observers have a significant personal error.

Repeated observations were therefore made by all observers at station 28. Here the astronomical longitude had previously been determined by the method of Meridian Transits with a Wild T4 astronomical theodolite with an *impersonal* eye-piece. In addition to the initial training period, each observer re-observed at station 28 at intervals of about a week, and the mean difference between his T3 longitudes and the T4 longitude (when both were properly corrected), was initially taken as his personal equation - see TABLE 1, Column 1.

TABLE 1

Observer		PE(1)	PE(2)
1962:	HDC	- 1.34	- 2.46
	IKC	- 0.78	- 1.90
	RFS	+ 0.01	- 1.11
	GJC	+ 0.56	- 0.56
1963:	GJC	- 0.42	- 1.54
	IJ	- 0.17	- 1.29
	JA	- 0.06	- 1.18

Observers' personal equations in seconds of arc.
PE(1) is based on station 28: - 135° 20' 53.05″
PE(2) is based on station 28: - 135° 20' 54.17″

(HDC - Henry Couchman, IKC - Ian Cameron, RFS - Ron Scott, GJC - Gerry Cruickshanks, IJ - Ian Johnson, JA - John Allen, not mentioned is B. Campbell (booker) in Ford (1979).

In 1962, observations for longitude were made at 11 other stations where the longitude had previously been observed with an *impersonal* Wild T4 astronomical theodolite. Not all were stations on the Woomera geoidal survey. The differences between T3 and T4 longitudes are shown in TABLE 2, Column 7.

From TABLE 2, two facts appear :

- The longitude differences in column 7 are all of negative sign. This suggests that the T4 longitude of station 28 is too great by about 1.12″, and a better value may be :

  135° 20' 54.17″

  This value was adopted. The revised personal equations are shown in TABLE 1, column 2, and the revised T3 longitudes and their differences from the T4 longitudes, in TABLE 2, columns 8 and 9.

Some of the T3 longitudes shown in TABLE 2 differ by up to 0.03" from those shown in TABLE 5. This was due to the adoption in 1962 of provisional values of the time signal correction. The effect on the adopted value of station 28 is only 0.01", and it has been ignored.

- Where two T3 observations have been made at the same station (with different instruments, by different observers, and on different nights) the difference between the T3 observations is generally less than the difference between the T3 and T4 observations. The T3 observations have the advantage of absolute uniformity in the methods of observation and computation, and have been used for the geoid survey in preference to the T4 observations. While the intrinsic accuracy of the latter should be higher, they were made by different observers in different years, and one has the uneasy feeling that the discrepancies may be due to small variations in procedure.

TABLE 2

1	2	3	4	5	6	7	8	9
Station	Observer	Degrees	Minutes	T4 Seconds	T3(PE1) Seconds	(5)-(6)	T3(PE2) Seconds	(5)-(8)
28	All	- 135	20	53.05	53.05	-	54.17	+ 1.12
4	IKC	- 135	52	12.91	12.78	- 0.13	13.90	+ 0.99
12	GJC	- 136	28	26.80	26.21	- 0.59	27.33	+ 0.53
26	GJC	- 136	46	50.36	50.11	- 0.25	51.23	+ 0.87
29	RFS	- 136	25	40.97	40.59	- 0.38	41.71	+ 0.74
32	HDC	- 136	22	49.08	46.79	- 2.29	47.91	- 1.17
43	GJC	- 136	50	10.88	09.91	- 0.97	11.03	+ 0.15
52	RFS	- 136	48	16.77	15.78	- 0.99	16.90	+ 0.13
Wild	HDC	- 133	10	14.92	14.77	- 0.15	15.89	+ 0.97
	IKC				14.23	- 0.69	15.35	+ 0.43
Black	HDC	- 132	04	56.83	55.44	- 1.39	56.56	- 0.27
	IKC				56.12	- 0.71	57.24	+ 0.41
Bates	HDC	- 131	51	31.75	29.30	- 2.45	30.42	- 1.33
	IKC				28.88	- 2.87	30.00	- 1.75
Unalla	GJC	- 136	10	11.76	9.28	- 2.48	10.40	- 1.36
	RFS				10.13	- 1.63	11.25	- 0.51
MEAN						- 1.12		- 0.00

Comparison of T3 and T4 longitudes in 1962.
In column 6 the observer's personal equation is based on station 28: -135°20'53".05
In column 8 the observer's personal equation is based on station 28: -135°20'54".17

In 1963, an additional five comparisons between T3 and T4 longitudes became available, see TABLE 3. They confirm that the observed T4 longitude for station 28 is too great, and fit the adopted value satisfactorily.

Eighteen comparisons between T3 and T4 latitudes are also available and are listed in TABLE 4. The T4 observations consisted of 16 or more Talcott pairs, using Boss catalogue stars, converted into terms of the FK14. catalogue.

All observations were either made at or reduced to the WRE trig points. These points are either surmounted by a beacon, or have a plate cast into the concrete ground mark bearing the station name or number.

TABLE 3

1 Station	2 Observer	3 Degrees	4 Minutes	5 T4 Seconds	6 T3 (PE1)	7 (5)-(6)	8 T3 PE(2)	9 (5)-(8)
Colona	HDC	- 131	52	09.54	08.86	- 0.68	09.97	+ 0.44
	IKC				07.03	- 2.51	08.15	- 1.39
Oak	IJ	- 134	22	36.92	35.92	- 1.00	37.04	+ 0.12
	JA				34.54	- 2.38	35.66	- 1.26
NME 89	IJ	- 130	49	06.34	06.12	- 0.22	07.24	+ 0.90
MEAN						- 1.36		- 0.24

Additional comparisons between T3 and T4 longitudes available in 1963.

TABLE 4

Station	Observer	Degrees	Minutes	T4 Seconds	T3 Seconds	T4-T3
28	HDC	- 30	57	46.53	46.37	- 0.16
	IKC				46.36	- 0.17
	RFS				45.89	- 0.64
	AGB				46.55	+ 0.02
	GKC(62)				46.84	+ 0.31
	GKC(63)				46.59	+ 0.06
	IJ				46.67	+ 0.14
	JA				45.60	+ 0.07
4	IGC	- 31	03	56.39	56.47	+ 0.08
12	GJC	- 30	58	28.02	28.72	+ 0.70
26	GJC	- 31	06	09.59	10.82	+ 1.23
29	RFS	- 30	51	02.84	03.12	+ 0.28
32	HDC	- 30	28	43.31	43.92	+ 0.61
43	GJC	- 30	49	09.91	09.02	- 0.89
52	RFS	- 31	08	37.55	37.72	+ 0.17
Oak	IJ	- 32	10	57.98	58.28	+ 0.30
	JA				56.68	- 1.30
NME 89	IJ	- 31	34	59.66	59.20	- 0.46
MEAN						+ 0.02 or ± 0.42

Comparison of T3 and T4 latitudes. The mean difference is + 0".02, or ± 0".42 without regard to sign.

TABLE 5

Adopted values of Astronomic and Geodetic Latitude and Longitude

Station	Latitude	Astro	Geo	(A-G)	Longitude	Astro	Geo	(A-G) cos ϕ
1	-30° 55'	- 8".44	-11".44	+3.00	-135° 35'	-10".32	-23".83	+11.59
2	-30 7	-49.43	-46.72	-2.71	-134 56	-47.19	-56.81	+ 8.32
3	-30 57	-59.94	-62.88	+2.94	-134 48	-31.65	-43.56	+10.21
4	-31 3	-56.51	-59.39	+2.88	-135 52	-13.87	-22.91	+ 7.74
5	-31 12	- 2.95	- 6.11	+3.16	-137 7	- 5.46	-14.13	+ 7.42
6	-31 24	-33.14	-36.12	+2.98	-136 56	-51.66	-61.49	+ 8.39
7	-30 57	- 1.02	- 4.13	+3.11	-136 31	-34.89	-44.49	+ 8.23
8	-30 50	-33.05	-36.08	+3.03	-136 29	-17.58	-25.88	+ 7.13
9	-30 47	-25.95	-28.54	+2.59	-136 24	-32.15	-42.76	+ 9.11
10	-30 54	- 4.51	- 7.63	+3.12	-136 19	-45.48	-56.43	+ 9.39
11	-30 45	-36.14	-40.12	+3.98	-136 18	-32.74	-42.06	+ 8.01
12	-30 58	-28.74	-31.18	+2.44	-136 28	-27.32	-36.51	+ 7.88
13	-31 23	-29.32	-31.35	+2.03	-136 52	-37.56	-46.50	+ 7.63
14	-30 41	- 2.62	- 5.51	+2.89	-136 10	-18.99	-31.62	+10.86
15	-31 22	-57.11	-58.67	+1.56	-136 53	- 9.51	-18.74	+ 7.88
16	-30 31	- 1.82	- 3.74	+1.92	-135 57	-50.68	-61.87	+ 9.64
17	-30 40	-40.09	-45.23	+5.14	-135 50	- 1.02	-10.97	+ 8.56
18	-30 48	- 8.60	-11.59	+2.99	-136 2	-18.83	-29.92	+ 9.53
19	-30 22	- 6.94	- 9.79	+2.85	-136 15	-54.84	-66.76	+10.28
20	-30 34	-36.56	-39.56	+3.00	-135 25	-17.08	-27.53	+ 9.00
21	-29 56	-42.75	-40.95	-1.80	-135 17	-10.90	-22.16	+ 9.76
22	-30 52	-56.62	-59.48	+2.86	-136 13	-38.97	-50.69	+10.06
23	-30 0	-57.60	-54.72	-2.88	-135 11	-32.01	-42.04	+ 8.68
24	-30 48	- 1.94	- 3.81	+1.87	-136 46	-32.88	-43.06	+ 8.74
25	-30 33	-36.31	-39.44	+3.13	-135 39	-25.84	-39.06	+11.39
26	-31 6	-10.85	-12.46	+1.61	-136 46	-51.20	-59.53	+ 7.13
27	-31 1	-27.78	-32.57	+4.79	-135 59	-57.58	-67.88	+ 8.83
28	-30 57	-46.30	-47.47	+1.17	-135 21	-54.17	- 6.28	+10.40
29	-30 51	- 3.14	- 5.50	+2.36	-136 25	-41.70	-51.09	+ 8.06
30	-30 53	-19.33	-22.61	+3.28	-136 1	-37.73	-45.98	+ 7.08
31	-30 16	-30.23	-28.06	-2.17	-134 53	-24.93	-33.03	+ 7.00
32	-30 28	-43.95	-48.08	+4.13	-136 22	-47.90	-60.40	+10.77
33	-31 16	-56.64	-57.77	+1.13	-136 38	- 3.92	-13.74	+ 8.39
34	-30 27	-40.14	-42.61	+2.47	-134 49	-54.82	-64.73	+ 8.54
35	-30 17	-27.01	-26.36	-0.65	-135 12	-11.72	-21.39	+ 8.35
36	-29 52	-21.14	-18.07	-3.07	-135 14	-32.24	-41.98	+ 8.45
37	-30 42	-30.21	-32.22	+2.01	-135 11	-42.76	-56.97	+12.22
38	-30 56	-12.74	-13.63	+0.89	-135 53	-32.28	-42.42	+ 8.70
39	-30 4	-35.72	-34.19	-1.53	-135 48	-37.72	-46.79	+ 7.85
40	-30 45	- 5.45	- 7.94	+2.49	-136 4	- 5.93	-15.26	+ 8.02
41	-30 9	- 2.75	- 1.98	-0.77	-136 5	-10.62	-18.58	+ 6.88
42	-30 32	-28.44	-31.61	+3.17	-136 4	-38.99	-50.07	+ 9.55
43	-30 49	- 9.02	-11.69	+2.67	-136 50	-11.04	-20.63	+ 8.23
44	-30 57	-39.94	-39.23	-0.71	-135 4	-20.67	-34.24	+11.64
45	-31 4	- 2.34	- 2.73	+0.39	-136 55	-47.04	-56.45	+ 8.06
46	-30 16	-57.25	-55.47	-1.78	-135 27	-51.42	-64.38	+11.19
47	-30 54	-43.48	-45.79	+2.31	-136 58	- 0.14	- 9.60	+ 8.12
48	-30 0	-35.83	-34.68	-1.15	-135 33	-32.38	-43.05	+ 9.24
49	-29 46	-46.75	-44.57	-2.18	-135 6	-18.94	-30.65	+10.16
50	-30 41	- 2.95	- 3.03	+0.08	-136 31	-40.84	-50.47	+ 8.28
51	-29 42	-25.34	-21.32	-4.02	-135 11	-11.20	-24.55	+11.60
52	-31 8	-37.75	-40.63	+2.88	-136 48	-16.88	-25.76	+ 7.60
53	-29 58	- 6.35	- 2.16	-4.19	-135 0	-34.80	-44.61	+ 8.50
54	-30 16	- 8.14	- 9.48	+1.34	-136 12	- 0.68	- 9.95	+ 8.01
55	-31 24	-13.44	-15.89	+2.45	-136 50	-45.99	-57.23	+ 9.59
56	-30 46	- 1.24	- 2.40	+1.16	-135 20	-14.91	-25.90	+ 9.44
57	-31 4	- 7.84	- 9.47	+1.63	-136 26	-16.86	-27.79	+ 9.36
58	-30 42	-15.62	-16.64	+1.02	-134 42	-53.30	-65.06	+10.12
59	-30 20	-32.18	-30.50	-1.69	-135 46	-11.48	-23.43	+10.32
60	-30 56	-37.31	-40.39	+3.08	-136 31	- 9.48	-18.67	+ 7.88

Computations

All observations were checked and abstracted in the field, and the results entered on data sheets for the IBM 7090 computer. Astronomic latitudes and longitudes were computed by programmes IG.3.25.5 and IG.3.23.2, specially prepared for this task. In 1962, some of the early latitudes were unsatisfactory due to a hysteresis effect in the bubble slow-motion screw on two of the theodolites. As a result of the prompt computations, this was detected, and a drill devised to prevent the recurrence of the error. Re-observations for latitude were made at five stations.

All latitudes and longitudes were computed in accordance with *Small Corrections to Astronomic Observations* published by the Division of National Mapping, with the following exception. In 1962, declinations and right ascensions were interpolated linearly from *Apparent Places of Fundamental Stars*, ignoring short period nutation and second differences. In 1963, rigorous interpolation was made electronically on the Sirius computer, using the programme *Star Coordinates from Apparent Places Mark 2*.

Geodetic coordinates were supplied in the form of eastings and northings on the Transverse Mercator projection. They were converted to latitudes and longitudes on the IBM 7090, using programme IG.1.7.1. The adopted values of latitude and longitude, both astronomic and geodetic, are shown in TABLE 5.

The length and azimuth of the lines shown in Figure 1 were obtained from latitudes and longitudes on the IBM 7090 using programme IG.1.7.6.

The components of the deviation, ξ , η , and X were obtained electronically from Formula (1), (2) and (3) with the programme *Deviations of the Vertical* on the Ferranti Sirius computer (please refer to Annexure A). Values of ξ and η are shown in Figures 2 and 3.

Values of ΔN were computed from Formula (4) on a desk machine. These unadjusted values and loop closures are shown in Figure 4.

The 107 values of ΔN were adjusted by least squares to close exactly round the 48 loops shown in Figure 4 using programme IG.1.7.9 on the IBM 7090. The adjustment was by condition equations, values of ΔN being weighted inversely as the length of each line. The time in the computer was about 2 minutes.

With N defined to be zero at station 60, the values of ΔN from the least squares adjustment gave unique values of N at the other 59 stations. These values are shown in Figure 5. One-foot contours have been drawn, interpolating linearly between stations. These contours depict the geoid with reference to the Clarke 1858 spheroid Sydney origin. The effect of the ill-chosen Sydney origin is clearly seen, the spheroid rising 38 feet with respect to the geoid across the width of the survey.

Making use of the results of the Survey

Before converting observations from the Clarke 1858 spheroid Sydney origin, into the x, y, z range coordinate system :

- All zenith distances observed with reference to the local vertical need correction to transfer them to the spheroidal normal, using the deviations given in Figures 2 and 3 with Formula (3).
- All surveyed heights, whether from spirit levelling or triangulation, which refer to the geoid, need to be corrected from geoid to spheroid using values of N from Figure 5.

The True Nature of the Geoid at Woomera

Computations and adjustment of the National Geodetic Survey are now proceeding on the *165 spheroid* :

a = 6 378 165 metres 1/f = 298.3

The dimensions of this spheroid are very close, and may even be identical, to those of the spheroid likely to be adopted internationally for satellite studies.

The Central origin now in use is based on 150 precise astronomical stations distributed all over Australia with the exception of Cape York and Tasmania. It is unlikely that future astronomic observations in Australia will require this origin to be changed by as much as 0.5 seconds of arc.

For stations near Woomera, the change required to convert geodetic coordinates from the Clarke 1858 spheroid Sydney origin, to the *165 spheroid* central origin, is about +0.56″ in latitude and +8.82″ in longitude. There is a variation of about 0.5″ in these values over the width of the survey. The figures quoted are those for station 28. If we rotate the Clarke 1858 spheroid about the origin of the range coordinate system through these small angles, we can remove the effect of the ill-chosen origin at Sydney and obtain some idea of the true physical nature of the geoid near Woomera. Ignoring the change in the values of a and I should not give errors exceeding 0.5″ in the deviations and 1 foot in N over the area of the survey.

The necessary changes in N from the values shown in Figure 5 have been calculated from the approximate formula :

$$\Delta N' = (\Delta e * \Delta\lambda \cos ø + \Delta n * \Delta ø) \sin 1''$$

where $\Delta N'$ is the change in N due to changes of $\Delta\lambda$ and $\Delta ø$ in the geodetic coordinates, and Δe and Δn are differences in eastings and northings from the origin of the range coordinate system.

The resulting values of N are shown in Figure 6. The geoid slopes away to the north and west, the total fall between station 6 and station 58 being about 10 feet.

To estimate the corresponding deflections on the *165 spheroid* central origin, values given in Figure 2 need to be changed by -0.56″ and values in Figure 3 by (-8.82″ * cos ø), about -7.58″.

Future Plans

If observations are corrected as above, computations on the Clarke 1858 spheroid Sydney origin, will be on a sound theoretical basis; but the use at a rocket range of a spheroid artificially tilted at 8" to the geoid has little to recommend it.

Work on the present ill-fitting Clarke 1858 spheroid Sydney origin, can only be rigorously computed within the area of the present geoid survey, that is, for the first 100 miles down the range. At greater distances, the effect of neglecting the geoid-spheroid separation increases systematically, and at 1,000 miles, uncorrected heights will be in error by about 200 feet. For satellite computations, the use of the Clarke 1858 spheroid Sydney origin, can lead to nothing but confusion.

When the adjustment of the National Geodetic Survey of Australia is completed, geodetic coordinates for many stations near Woomera will be available on a modern, well-oriented spheroid. With an electronic computer, the transformation of all the geodetic coordinates near Woomera on to the new spheroid will be a simple matter. The approximations above can be discarded, and values of ξ , η , and N rigorously computed using the new geodetic values. No new observations will be required and the computations will be easy.

It will therefore be wise to discontinue the use of the Clarke 1858 spheroid Sydney origin, as soon as the adjustment of the Geodetic Survey of Australia is completed in 1965.

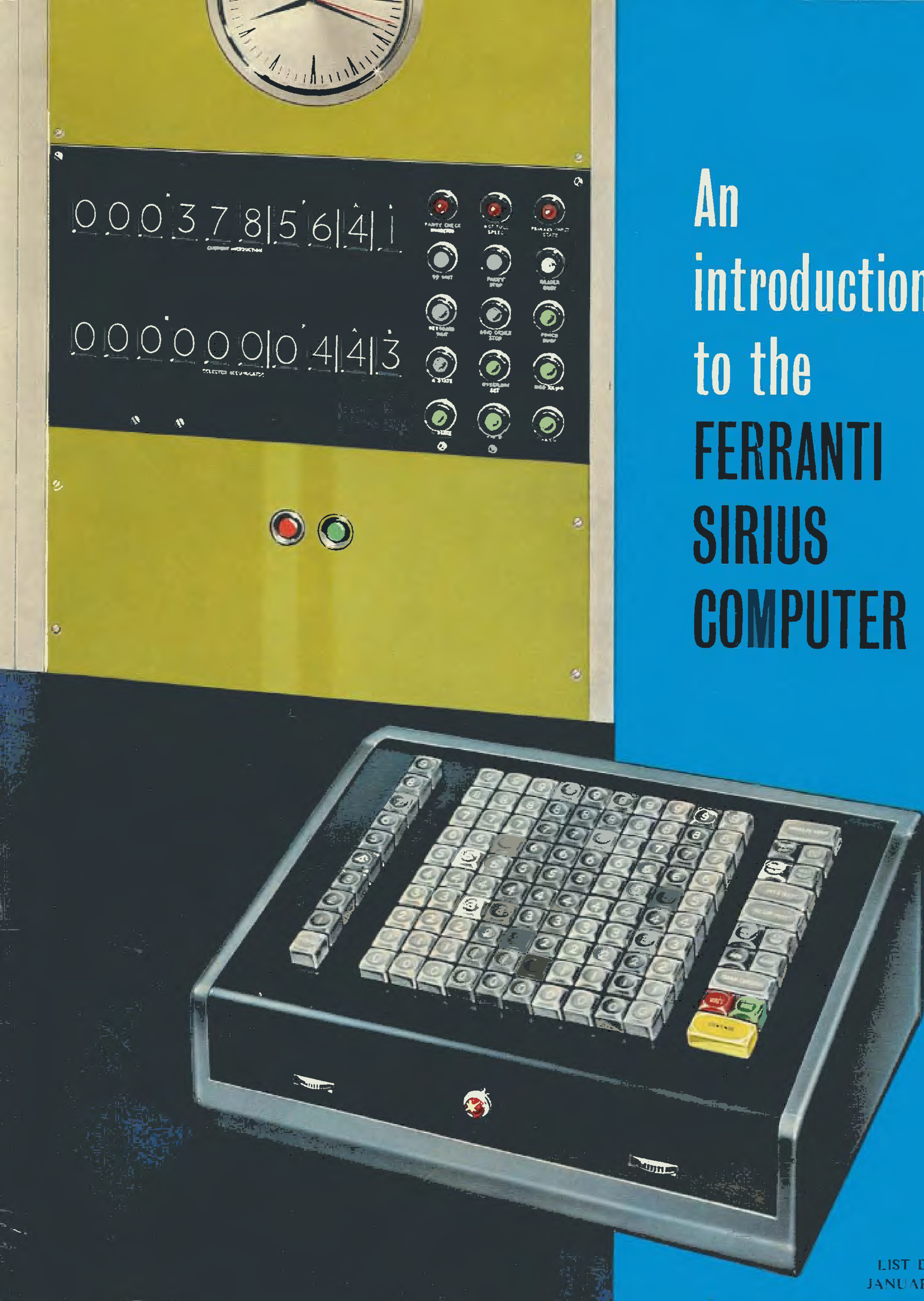
References

Bomford, Guy (1962), *Geodesy*, Oxford University Press, London.

Ford, Reginald A (1979), The Division of National Mapping's part in the Geodetic Survey of Australia, The Australian Surveyor, Vol. 29, No. 6, pp. 375-427; Vol. 29, No. 7, pp. 465-536; Vol. 29, No. 8, pp. 581-638.

First order geodetic station on the Great Australian Bight occupied by John Allen as part of the Woomera Geoid survey.

Annexure A



An introduction to the FERRANTI SIRIUS COMPUTER

LIST DC.42A
JANUARY 1961

The Basic Sirius Computer.

An introduction to the Ferranti Sirius Computer

LIST DC.42A
JANUARY 1961

An introduction to the Ferranti Sirius Computer

Introduction

Sirius is a small general-purpose digital computer with wide applications in industry, commerce, science and technical education.

It is designed particularly for those establishments and departments which have no need for a large computer installation, but nevertheless require a true computer possessing the essential features of versatility, speed and reliability, associated with ease of maintenance and low capital and running costs. Given appropriate peripheral equipment, it can also be employed on data-logging and a variety of control work.

Sirius is especially easy to use. Numbers and instructions are represented in decimal form and are displayed to the operator in this decimal form on the front panel of the computer. The provision of eight accumulators and a single-level store results in ease of programming with a much smaller number of instructions than are required for other computers of comparable size. For the benefit of those who need to use Sirius from time to time, but who do not need to become full programmers, an automatic coding facility (Autocode) has been provided. The computer normally operates entirely automatically, but the provision of a keyboard similar to that of a desk calculator makes manual operation easy when this is required.

The small size and modest installation and maintenance requirements of Sirius arise from the evolution of new engineering techniques that have been accepted only after lengthy trials, and which give confidence of high operating reliability.

Physical Characteristics

Sirius is compact and may quickly be installed in the average-sized office with little or no preparatory work. The basic computer is in the form of a narrow cabinet standing on the floor along the back of a 6 ft. 6 in. desk. The cabinet is 4 ft. 9 in. high and 6 ft. 9½ in. wide, but only 10 in. deep; a projection occupies part of the knee-hole of the desk. Access doors open to the rear for maintenance.

On the desk are a small control panel and the input paper tape reader. There remains ample space for working papers, and the desk drawers are available for storing programme tapes and documents.

To the right of the computer desk there will be a Teletype punch, mounted on a small cabinet. Adjacent to this will normally be a Tape Editing Set for preparing input tapes by the manual operation of a keyboard and for printing results from the output tape. If the computer is to be used intensively on certain classes of work additional tape-editing equipment will be needed in another room.

Electric power is required from a stable 230-volt 50 c/s 5-amp supply; no special precautions are necessary unless the variations of voltage or frequency are excessive.

A Sirius Computer in use.

Sirius is especially designed so that it may be extended to suit the needs of the user. Additional tape readers can be attached and placed on the desk; additional computer storage units, additional tape punches, and a card reader and punch are supplied in the form of separate free-standing cabinets which may be sited in any convenient position reasonably close to the computer. Magnetic-tape equipments are available.

Functional Characteristics

Sirius operates with strings of ten decimal digits, which are called computer 'words'; they may represent either a number used in the computation or a coded control instruction for the computer to obey.*

Work is put on the computer by breaking down the method of solution into sequences and then into simple steps in each sequence. By reference to the Instruction Code, a list of written instructions is prepared, called a 'programme', any sequence of which may be called into use many times. The programme is typed on a teleprinter to produce a punched paper tape, and this tape can be run through the tape reader for the programme to be put into the computer store whenever necessary; the instructions are then available at very short notice, and are, in fact, obeyed at a rate of up to 4000 a second.

Any sort of a computer word may be put into any part of the single-level store. This is a very flexible facility which is absent on many small computers. It allows the programmer to employ the store to best advantage whatever the nature of the computation.

The special feature of eight accumulators in which arithmetic is carried out greatly simplifies and shortens programmes and speeds their preparation. The contents of

* A 'word' may also have other uses – for instance to represent several short numbers of say two or three digits, or half a double-length number of twenty digits, or five alphabetical characters.

any accumulator may be used to 'modify' the address of an instruction so that repetitive procedures are easily programmed. An accumulator used for modification may also hold a 'counter' for controlling the repetitive process. These comprehensive facilities are among the most important aspects of a computer.

Programming Features

The Instruction Code comprises more than 60 different instructions, in a particularly handy form, to cover the operations of addition, subtraction, multiplication, division, decimal shifts up and down, collation, jumps, input, output and so on. It should be noted particularly that the division instruction is built-in, so that division does not have to be programmed as on some machines.

The basic Instruction Code is shown in Appendix 'A'. The Programming Manual gives a full explanation of the instructions, with a liberal use of examples. Programming Courses are offered so that a user's staff may learn the technique quickly and thoroughly from experienced instructors.

In the course of a calculation a number may arise which is outside the permissible range of the computer. If this should occur, an overflow indicator will give warning to the programmer, who includes instructions in the programme to deal with this situation.

Following the great success of the Library Service provided for other Ferranti computers, programming routines which are commonly needed for Sirius are being thoroughly developed by Ferranti staff and will be made available in the form of programme tapes and specifications for their employment. Thus the user will have the great advantage of being able to concentrate on the master programme specific to his problem, drawing on the library for routines which are in common use. The library will also include complete programmes for the solution of common problems, using standard forms for the supply of data and presentation of results.

A simplified means of using the computer has been developed, so that in a day or two anyone may learn to put work on Sirius with little or no help from a trained programmer. The notation is identical with that of the well-tried and popular Autocode for the Pegasus computer; in fact Pegasus Autocode programmes are acceptable by Sirius with very little alteration. The Autocode has also proved its worth to trained programmers because, although there is necessarily some sacrifice in the speed of the computer, the preparation and the development of a programme are so much quicker that there is a considerable overall saving in the time needed to obtain the results.

Input, Output and Checking

The basic Sirius computer is supplied with one Ferranti TR5 punched paper tape reader for input, and one Teletype tape punch for output. Extra input/output equipment may be added, as described below.

The new fast transistorised tape reader, TR5, operates photo-electrically at speeds up to 300 characters per second. A character may be either a number, a letter, or a symbol, represented by a pattern of up to five holes across the paper tape. The character code is the same as for Pegasus and Mercury, the representation of decimal figures being self-checking.

When a written programme is converted to punched paper tape on a teleprinter, a typewritten version is produced automatically for proof-reading. For programmes which are to be used frequently, the standard input routine provides the facility of a available for the use of continuous pre-printed stationery on both machines. For those applications where the output is required in graphical form, special plotters are obtainable to plot a family of curves automatically from the output tape.

The input and output facilities which are available are extensive, and they allow a wide variety of peripheral devices to be attached. Every Sirius computer is fitted with two input and two output channels, and to each of these may be attached a 5-way switch-box so as to provide ten input and ten output channels under control of the programme with instantaneous switching. Each channel operates on the new standard Ferranti system so that peripheral equipment which is developed for other computers may be used with Sirius. Such equipment will include additional tape readers and punches, direct-coupled Creed 75 teleprinters, Creed 3000 tape punches (operating at 300 characters per second), Magnetic Products Ltd. magnetic-tape equipment providing simple character-by-character reading and writing, 7-channel paper tape readers and punches, and, for data-logging and process-control, a wide variety of specialist equipment as described in Section 9.

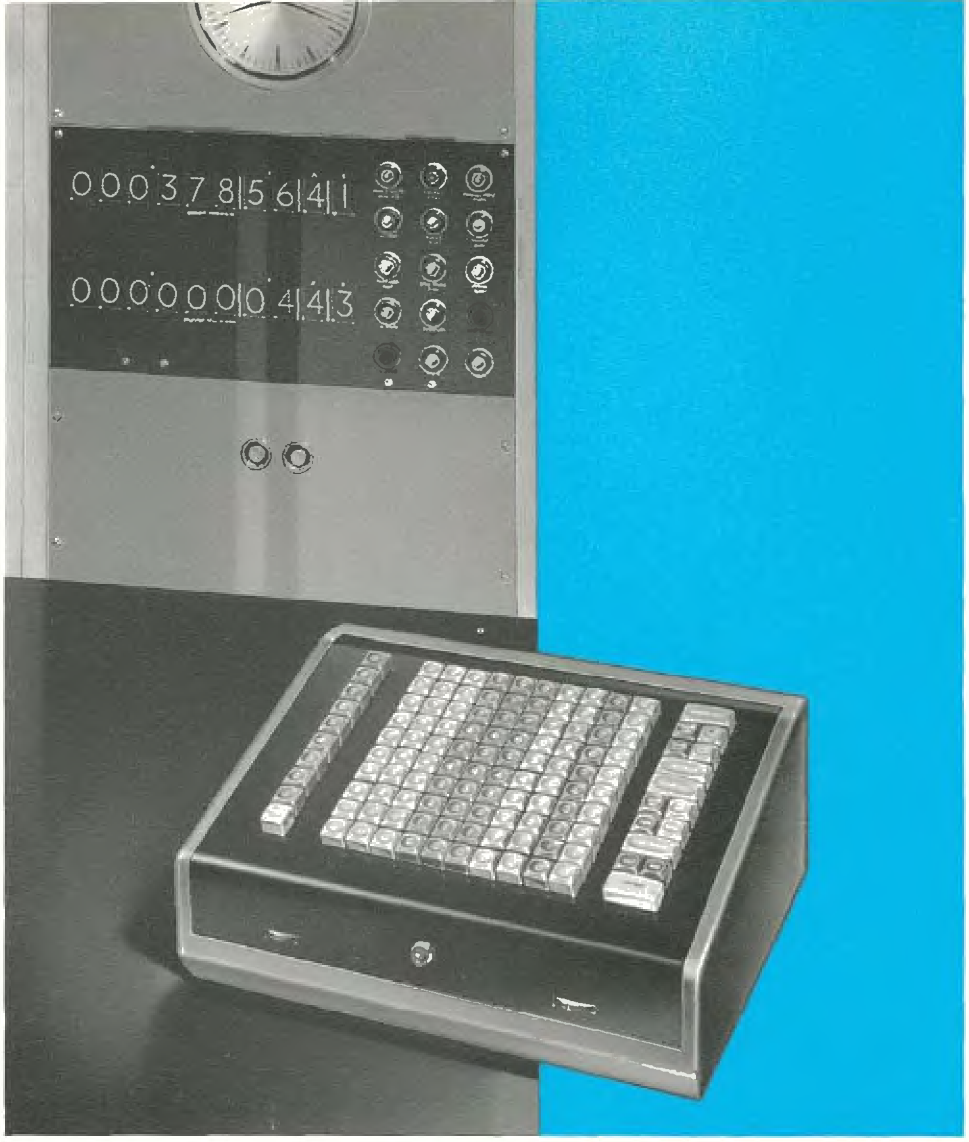
The punched card equipment for use with Sirius is the Bull PRD Reproducer, which comprises both a reader and an independent punch for 80-column cards, working at a rate of 120 cards per minute. Cards of Bull, Hollerith or I.B.M. type can be used. The PRD has check reading stations on both the reader and the punch. The control electronics are housed in a cabinet the same size as a 3000-word additional store cabinet for Sirius.

When cards are used 50-word buffer stores are provided, and also buffer transfer instructions. Disciplined and undisciplined buffers are both available to the programmer. With disciplined cards each column is represented as two Sirius decimal digits, one for the upper curtate and one for the lower curtate. Thus, with ordinary decimal punching, programmed conversion is unnecessary. All the 160 possible digits from one card can be held in the first 20 Sirius words of a 50-word buffer. With undisciplined cards each column is held as half a Sirius word with each hole separately represented. Thus it is possible for any code to be deciphered by programme or for any form of binary punching to be dealt with.

Storage

The basic Sirius computer is provided with 1000 words of storage, all of which are parity checked and available for use by the programmer for any purpose, as indicated in the foregoing paragraphs. The first 200 words will normally be allocated to the standard routines for input, monitor, and output; but they may be over-written when the programme and data have been read in if this space is required during the computation. There is a special facility for restoring these routines if required at a later stage when the space becomes available again. By this means, and by 'packing' techniques facilitated by the 'collate' instructions, the greatest possible use may be made of the whole of the store.

If further storage is needed, it can be provided in free-standing cabinets without structural alteration to the basic computer. Every such cabinet is capable of holding 3000 words, but it is only necessary to insert as many plug-in packages of 100 words as are required. Additions may be made at any time, either filling up a cabinet or adding an extra cabinet. The maximum is three cabinets, providing a total store of 10,000 words. The extra storage is available to the programmer in exactly the same way as the basic store of 1000 words.



The Sirius Displays and the Keyboard.

Speed of Operation

The Sirius computer is nearly twice as fast as any other existing computer at its price, both as regards speeds of input and output and speeds of computation.

The addition or subtraction of numbers in the multiple accumulators occupies 240 microseconds including modification of the address. Instructions which involve reference to the store require a total of 4 milliseconds. Both multiplication and division take from 4 to 16 milliseconds, with an average of about 8 milliseconds. Analysis of existing programmes has shown that only about 10% of instruction require reference to the store and that about 5% are for multiplication or division. Thus about 1000 instructions in a programme would be obeyed in 1 second.

It is not possible to give an exact comparison between the speeds of Sirius and Pegasus, as this will depend on the nature of the programme. As an example, the solution of 27 simultaneous linear equations takes 3 minutes on Pegasus and 6 minutes on Sirius. In applications where input and output predominate over computation, the speed of Sirius will closely approach that of Pegasus. The Autocode will run twice as fast on Sirius as on Pegasus.

Teaching Facilities

Sirius has excellent facilities for teaching, as it may be made to operate at any speed, to stop at any desired point in the programme, and to display the contents of any accumulator or any 'word' in the store in the form of decimal digits. It may also be operated manually for demonstration purposes, or to correct a programming error.

One of the two numerical displays on the front of the computer cabinet always shows the instruction which has just been obeyed. On the other display may be selected the contents of any accumulator. Thus it is easy to demonstrate the effect of each instruction, the accumulation of numbers, the effect of modifiers, the movement of counters, jump instructions – in fact all the basic essentials of computer work – on the readily-understood decimal displays.

There is a switch to determine whether the computer will operate automatically at full speed or will only obey one instruction each time a button is depressed, and there is a rotary knob whereby any intermediate speed may be selected.

Apart from 'Wait' instructions which may be written into the programme, the handkeys on the desk may be set to cause the computer to wait at any chosen point in the programme. The handkeys may also be used for the display of any word in the store, to alter any word in the store or an accumulator, or to operate the computer manually.

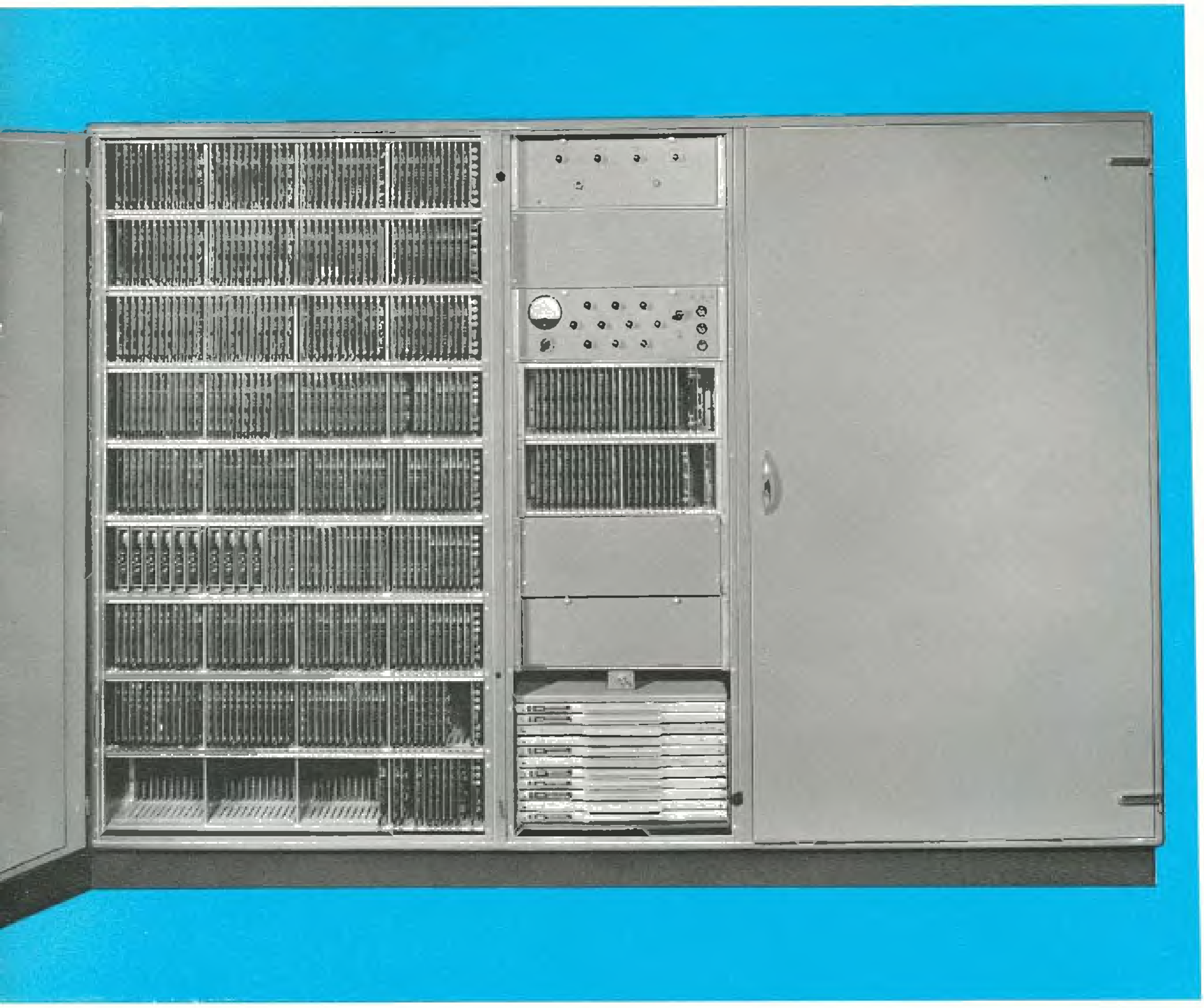
It is believed that these instructional facilities are of the greatest importance for imparting a rapid understanding of the basic characteristics of a computer, and for giving early familiarity and confidence to a programmer.

Data-Logging and Process-Control

Sirius can be used for data-logging and process-control and the computer itself needs no alteration in order to be able to perform such functions.

The computer must have access to digital and analogue information from a large number of sources and this data will be fed into the computer via the input channels, which are fitted with scanners as necessary. Digital data, perhaps derived from hand-set dials, relays and switches, is acceptable in either packed or unpacked form in the same way as data from a standard input device. Analogue inputs require conversion into digital form before the machine can accept them. Economic reasons usually prevent an analogue-to-digital converter being attached to each input and it is necessary to have some form of switching mechanism prior to the converter so that a large number of inputs can be converted, in turn, by the one device. Various methods of input selection can be provided, the most appropriate method for a particular application being determined by the sizes of analogue signals to be selected, and the speed required. It is sufficient to say that a large number of signals, which may be of the order of volts, milliamps or millivolts, can be selected and converted quickly and accurately. The selector may scan the inputs in a fixed order or it may be controlled by the computer so that inputs can be called for in any sequence demanded by the programme.

The normal output channels on Sirius are sufficient for any data-logging/alarm-monitoring requirements. A direct coupled teleprinter, paper tape and alpha-numeric displays should satisfy most logging demands. In addition, if the machine is to be used for control work, analogue outputs can be produced by means of a digital-to-analogue converter or converters, and digital control signals can be produced to operate selectors, relays, etc. A number of suitable input/output devices have already been developed.



REAR VIEW OF SIRIUS. The delay line trays are at the bottom of the centre compartment and the accumulator packages are on the fourth shelf up at the extreme left.

It will thus be seen that Sirius is suitable for data-logging and process-control applications and, since the computer itself does not need to be altered to do this type of work, it can still be used at any other time as a general-purpose computer.

Installation and Maintenance

Sirius is easily transportable and, as mentioned above, it requires only a moderate amount of space and a normal power supply at 230 volts, 50 c/s, and 5 amps., free from excessive fluctuations. The small amount of heat generated by the basic computer does not call for special arrangements for room ventilation.

Inside the computer, the logical and storage elements are mounted on plug-in 'packages' and, if a fault should develop in one of these, it is quickly replaced and the computer put back into service.

When Sirius is run on a daily basis, it will be normal to start with test programmes, occupying about $\frac{1}{4}$ hour, to prove that it is in full working order. Periodically the computer and the mechanical equipment incorporated in the input and output channels should be tested more exhaustively and adjusted, and any discarded packages should be repaired by an expert.

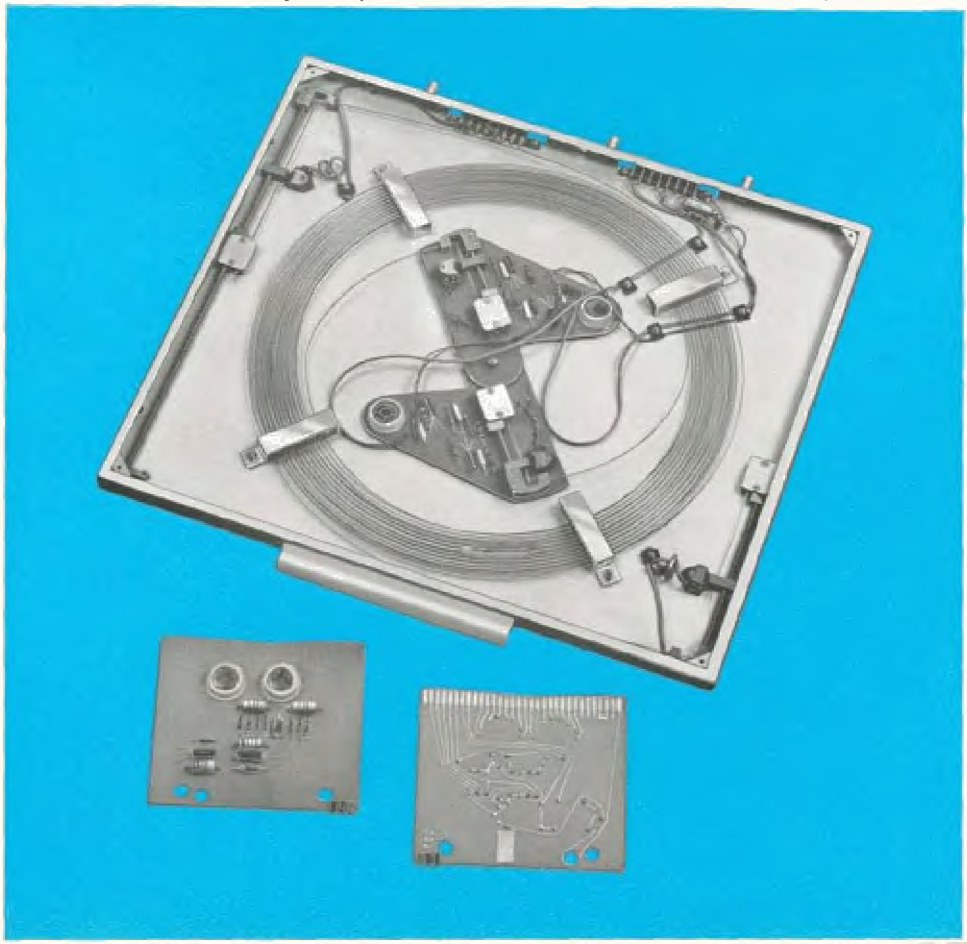
Accordingly, for the United Kingdom, Ferranti Ltd. offer to install and commission the computer, to maintain an engineer on site for two months to ensure its initial good running and to instruct the purchaser's staff in the daily test routines; also to undertake visits each fortnight thereafter for the next ten months to carry out comprehensive checks and adjustment, to provide an on-call maintenance service, and to provide all necessary spare parts. Arrangements can be made to continue this maintenance after the first year, as required. Customers who wish their own engineers to be responsible for the computer after the initial period may send them to the factory for training.

Conclusion

Large computer installations require justification by the number and volume of major tasks which they are to fulfil. Sirius is a true computer which offers considerable speed, power and flexibility at a modest outlay where the work load is not so great.

In the Ferranti tradition Sirius is engineered for reliability and convenience in its use, and is so designed that the size of the store may be extended whenever the need may arise. This offers a great opportunity for the economical introduction and development of modern computer techniques.

SIRIUS COMPONENTS. A delay line tray with cover removed and front and back of a neuron package.



Appendix A Sirius Basic Instruction Code

Instruction layout
10 decimal digits

N (digits 1–6), F (digits 7–8), A (digit 9), B (digit 10)

N is a main store address or a constant
F is a function from the table shown below
A and B are accumulators
n, a, b are the contents of N, A, B respectively
a' is the contents of A after the operation
OVR is the overflow indicator.

In all instructions up to 69, b is added to N before the instruction is obeyed.
This is the basic instruction code, and only includes the commonly used functions.
The full code is given in List CS.244 'Sirius Programming Manual'.

00	$a' = a + (N + b)$	20	$a' = 10a + (N + b)$
01	$a' = a - (N + b)$	21	$a' = 10a - (N + b)$
02	$a' = -a + (N + b)$	22	$a' = -10a + (N + b)$
03	$a' = -a - (N + b)$	23	$a' = -10a - (N + b)$
04	$a' = N + b$	24	$a' = 10a + $ M.S.D. of $(N + b)$
05	$a' = a + 10^4(N + b)$	25	$a' = 10a + 10^4(N + b)$
06	$a' = a - 10^4(N + b)$	26	$a' = 10a - 10^4(N + b)$
07	$a' = -a + 10^4(N + b)$	27	$a' = -10a + 10^4(N + b)$
08	$a' = -a - 10^4(N + b)$	28	$a' = -10a - 10^4(N + b)$
09	$a' = 10^4(N + b)$	29	$a' = 10a + $ M.S.D. of $10^4(N + b)$
10	$a' = a + n$	30	$a' = 10a + n$
11	$a' = a - n$	31	$a' = 10a - n$
12	$a' = -a + n$	32	$a' = -10a + n$
13	$a' = -a - n$	33	$a' = -10a - n$
14	$a' = n$	34	$a' = 10a + $ M.S.D. of n
40	$a' = (a + 5)/10$ Arithmetical Shift down (Rounded)		
44	$a' = a/10$ Arithmetical Shift down (Unrounded)		
45	$a' = (a + 5)/10 + $ L.S.D. of N (Rounded)		
49	$a' = a/10 + $ L.S.D. of N (Unrounded)		
50	Dummy	55	Jump to N unconditionally
51	Jump to N if M.S.D. of $a \neq 0$	56	Jump to N if M.S.D. of $a = 0$
52	Jump to N if $a = 0$	57	Jump to N if $a \neq 0$
53	Jump to N if OVR set	58	Jump to N if OVR clear
54	Jump to N if $a > 0$	59	Jump to N if $a < 0$
	Instructions 53 and 58 clear the OVR		
60	$n' = a$	70	x_s' = quotient, a' = remainder, on dividing (a, x_s) by b. Unsigned
64	$n' = 0$	71	a' = TAPE
66	$a' = a$ & N	72	(TAPE)$' = a$
68	$a' = a$ & $10^4 N$	73	(TAPE)$' = a$ and a' = TAPE
69	$a' = x_s$ and jump to N	79	$(a, x_s)' = b \times x_s$
99	Wait		

Appendix B Technical Details of Sirius

Basic binary digit frequency	$\frac{1}{2}$ megacycle per second.
Number system	Decimal, fixed point. Each decimal digit is represented by 4 binary digits.
Mode	Serial.
Word length	10 decimal digits, each of 4 bits.
Word time	80 microseconds.
Instruction code	Multiple accumulator, single address instructions with modification of address.
Store	Single-level on 50-word delay lines using torsional propagation. 1000 words in basic machine, all available to the programmer.
Checking	Parity bit stored with every word.
Input	Paper tape with self-checking code for decimal digits at up to 300 ch/sec. 2 input channels available.
Output	Paper tape with self-checking code for decimal digits at 60 ch/sec. 2 output channels available.
Extensions	Additional input and output channels. Extra storage up to a total of 10,000 words. Punched card input and output at 120 cards per minute. Magnetic-tape available.

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LILY HILL, BRACKNELL, BERKS.

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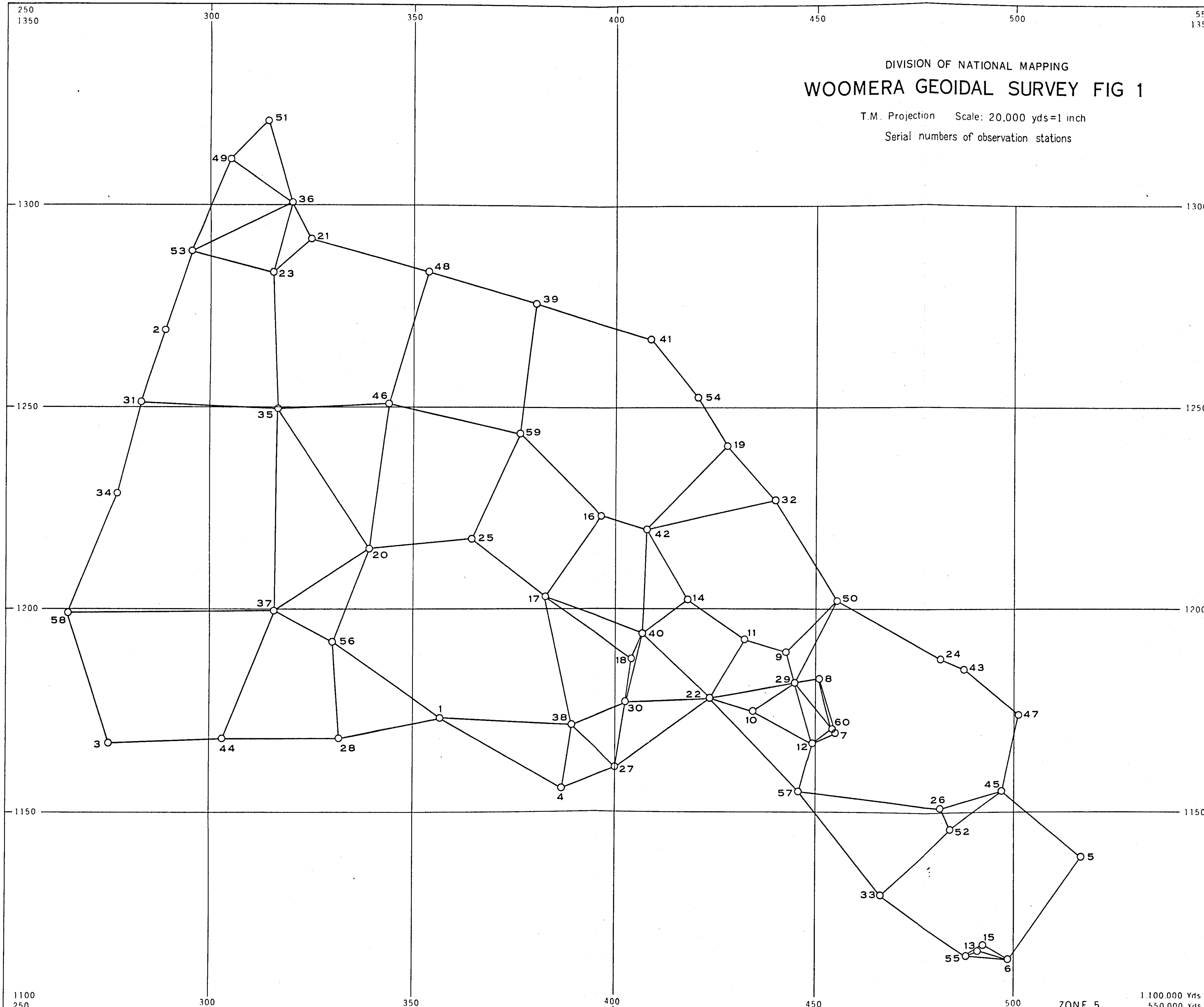

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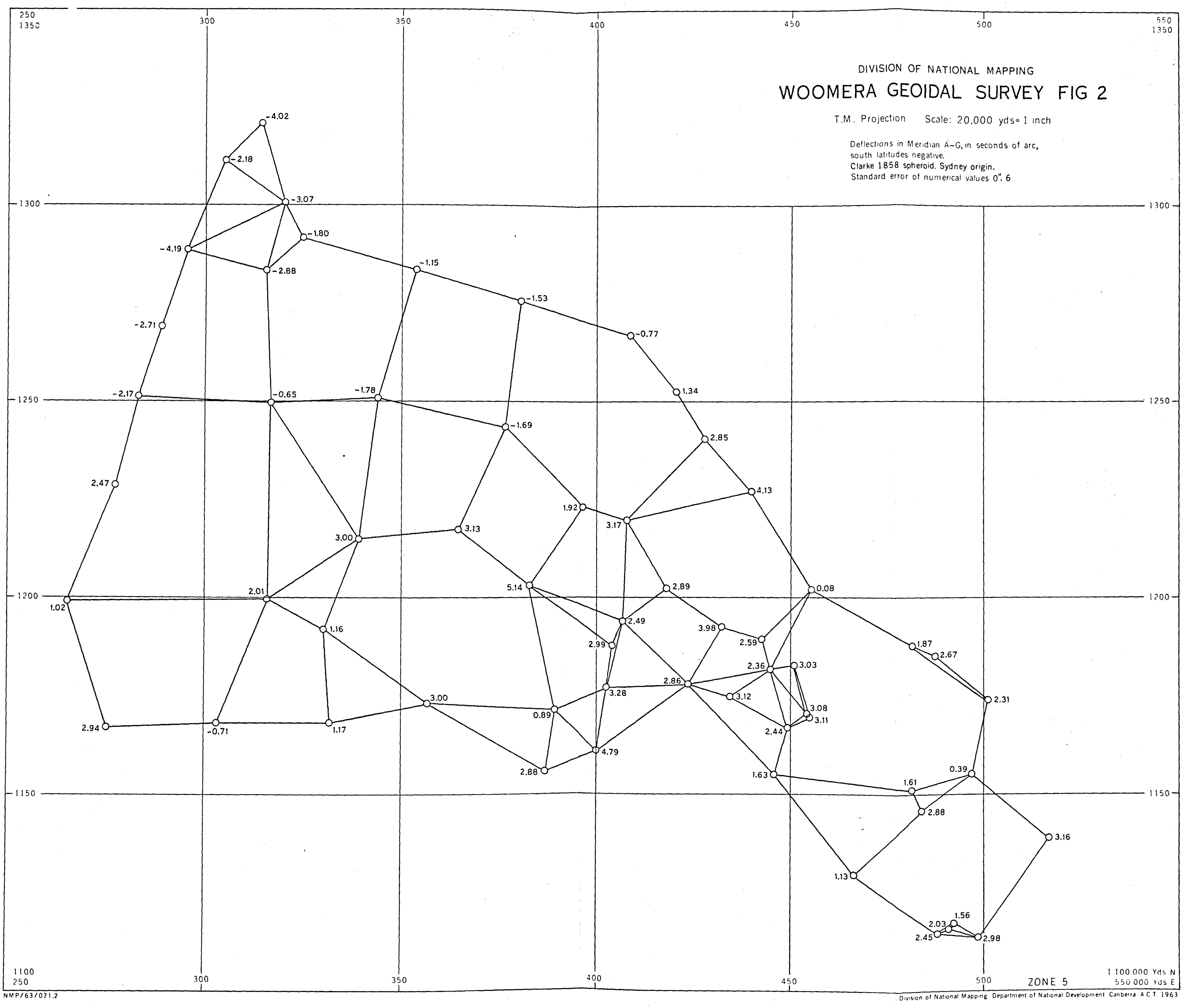
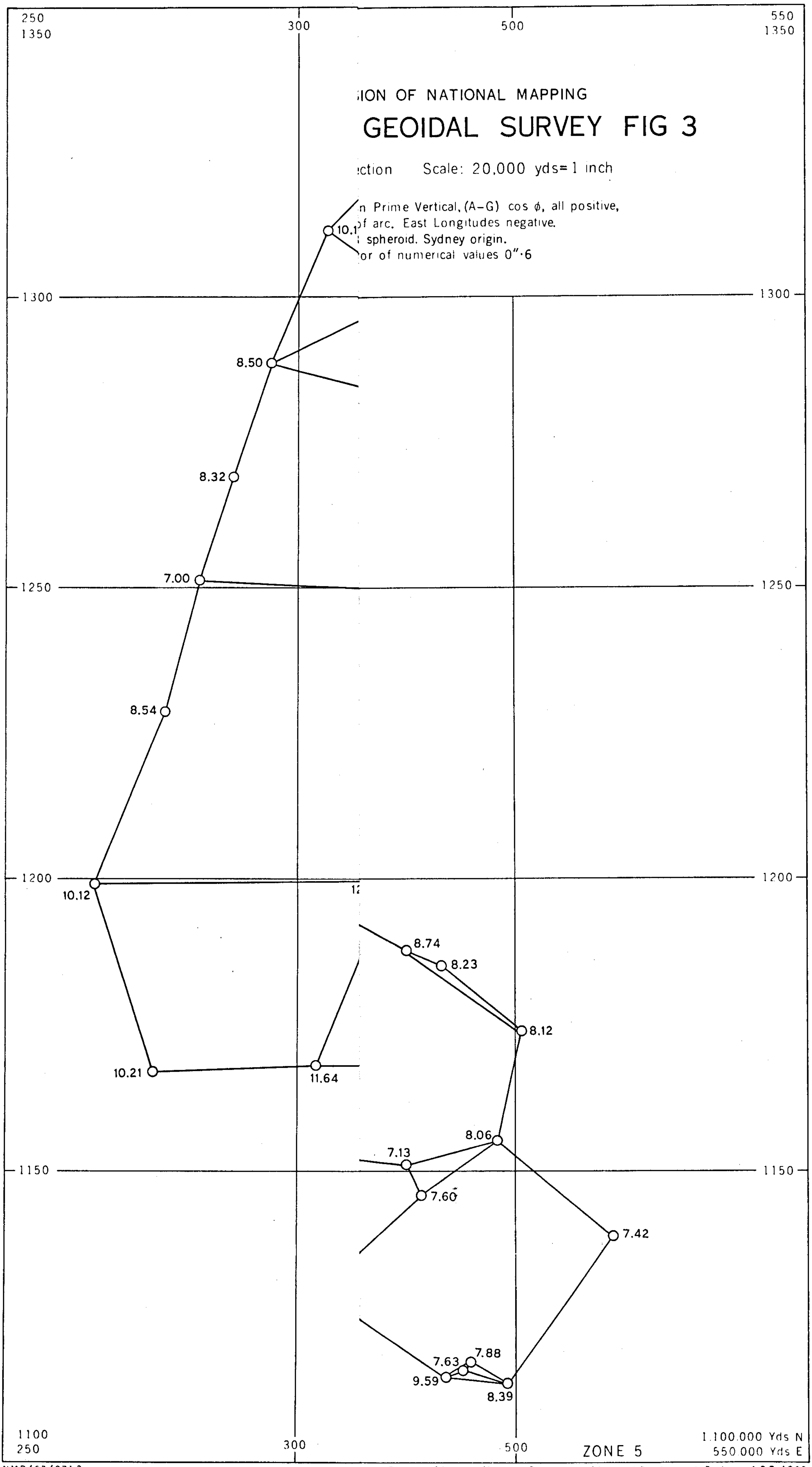


DIVISION OF NATIONAL MAPPING
WOOMERA GEOIDAL SURVEY FIG 2
T.M. Projection Scale: 20,000 yds = 1 inch
Deflections in Meridian A–G, in seconds of arc, south latitudes negative.
Clarke 1858 spheroid. Sydney origin.
Standard error of numerical values 0".6
250
1350
300
350
400
450
500
550
1350
1300
1250
1200
1150
1100
250
300
350
400
450
500
1 100 000 Yds N
550 000 Yds E
ZONE 5
-4.02
-2.18
-3.07
-1.80
-4.19
-2.88
-1.15
-1.53
-0.77
-2.71
-2.17
-0.65
-1.78
1.34
-1.69
2.85
2.47
4.13
1.92
3.17
3.00
3.13
5.14
2.89
0.08
2.01
1.02
2.49
1.16
3.98
2.99
2.59
1.87
2.67
2.36
3.03
2.86
3.28
3.12
3.00
3.08
3.11
2.31
0.89
2.44
2.94
-0.71
1.17
4.79
2.88
0.39
1.63
1.61
2.88
3.16
1.13
1.56
2.03
2.45
2.98
NMP/63/071.2
Division of National Mapping Department of National Development Canberra A.C.T. 1963



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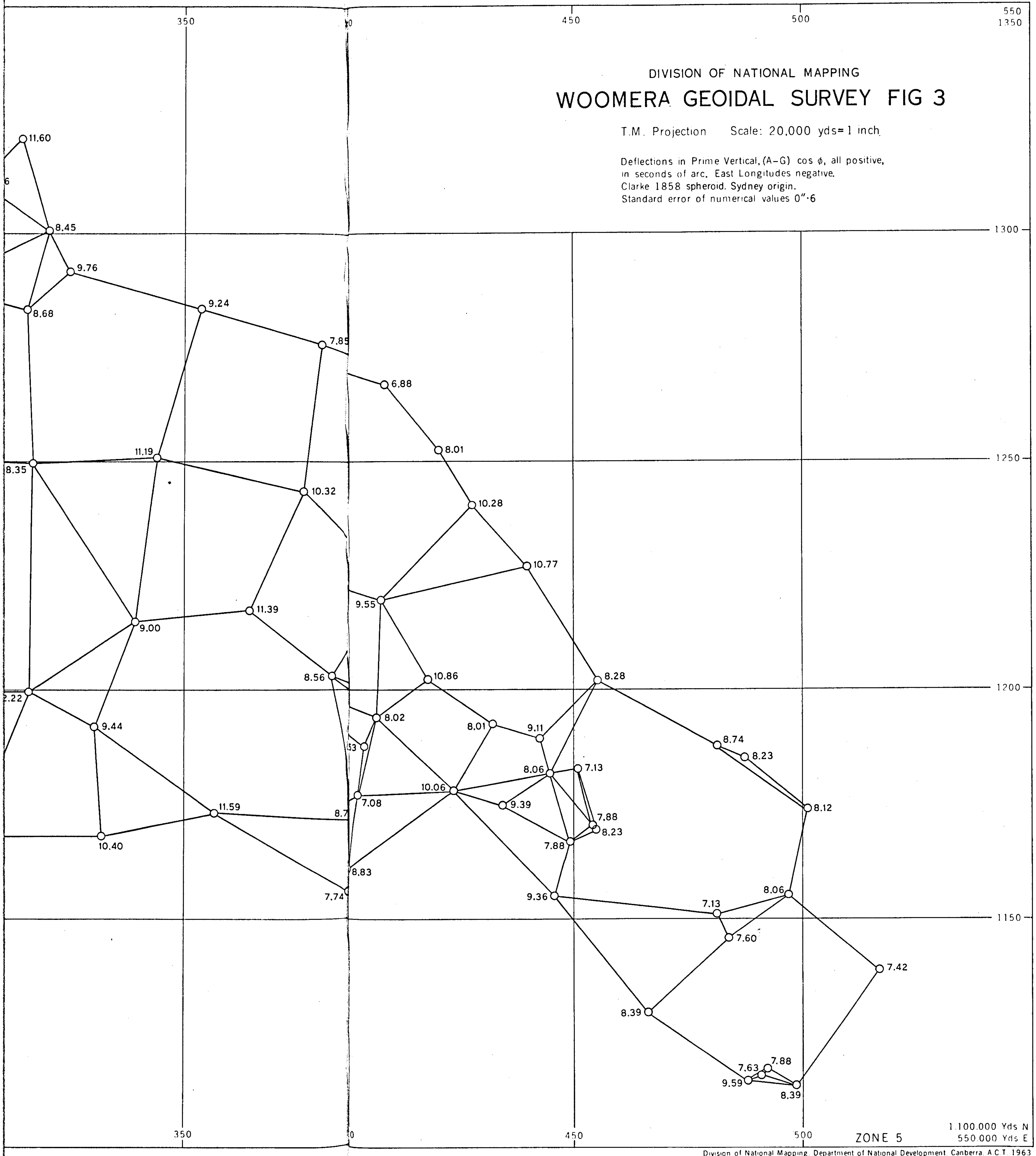

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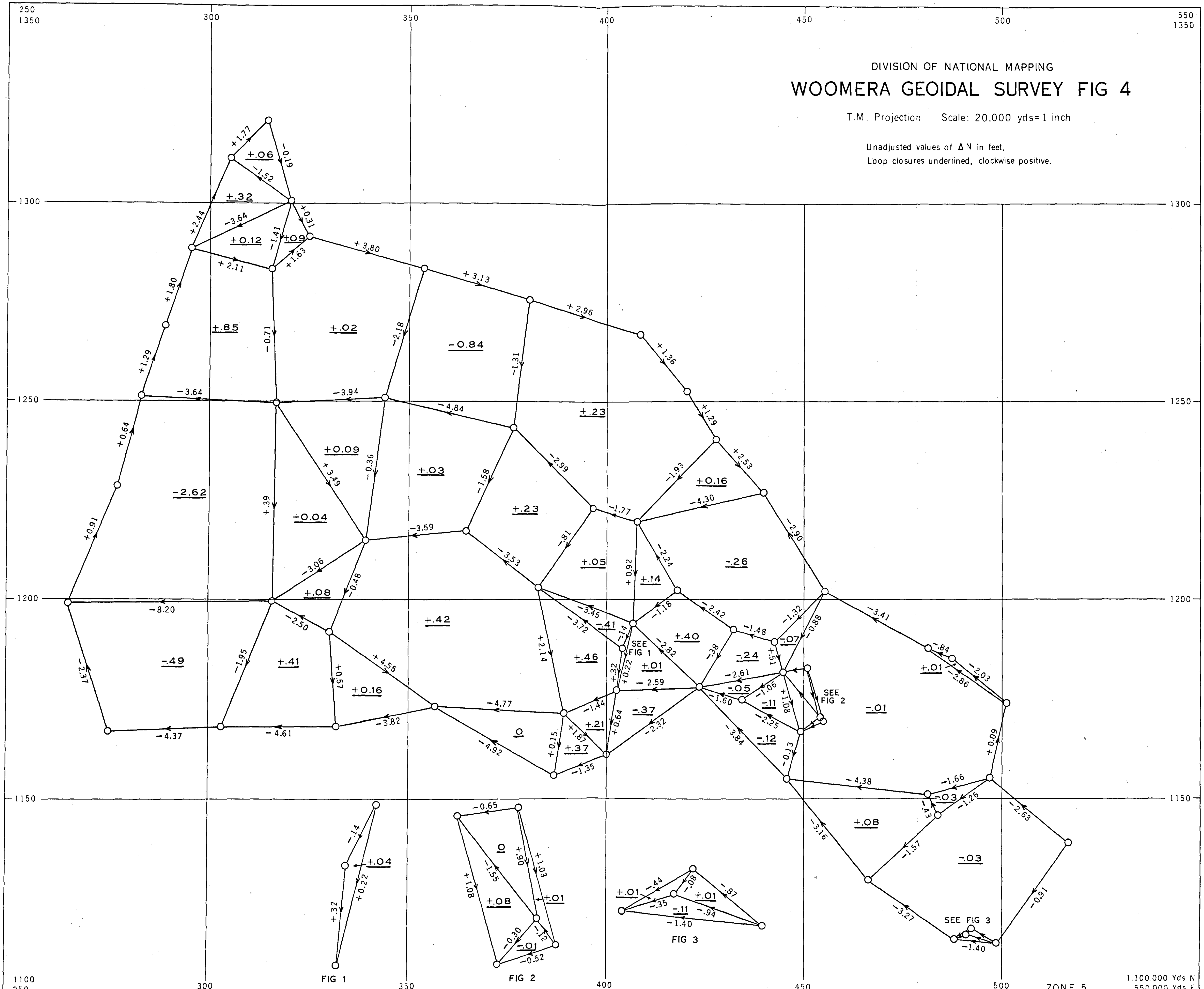
DIVISION OF NATIONAL MAPPING

WOOMERA GEOIDAL SURVEY FIG 4

T.M. Projection   Scale: 20,000 yds = 1 inch

Unadjusted values of ΔN in feet.
Loop closures underlined, clockwise positive.



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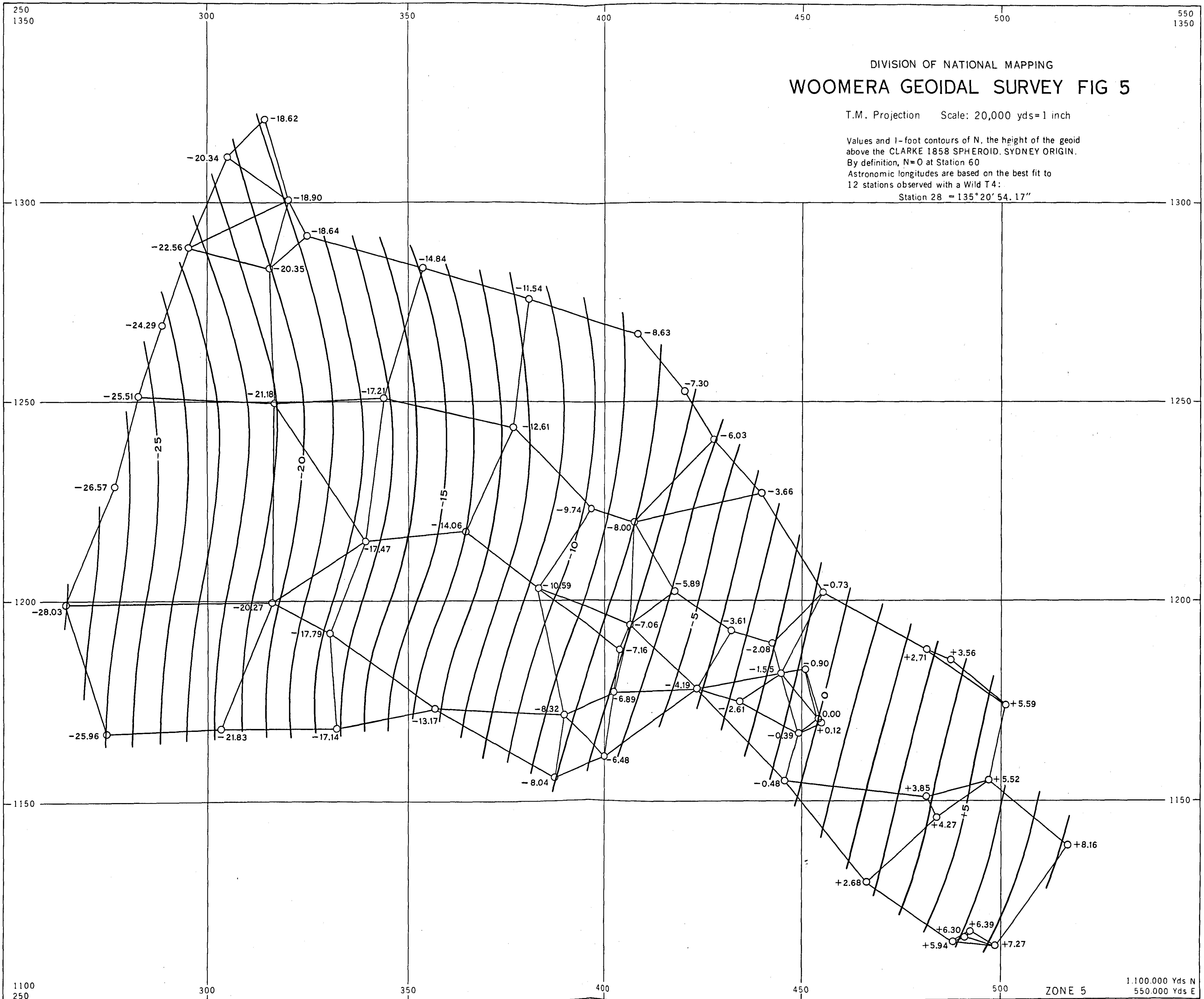

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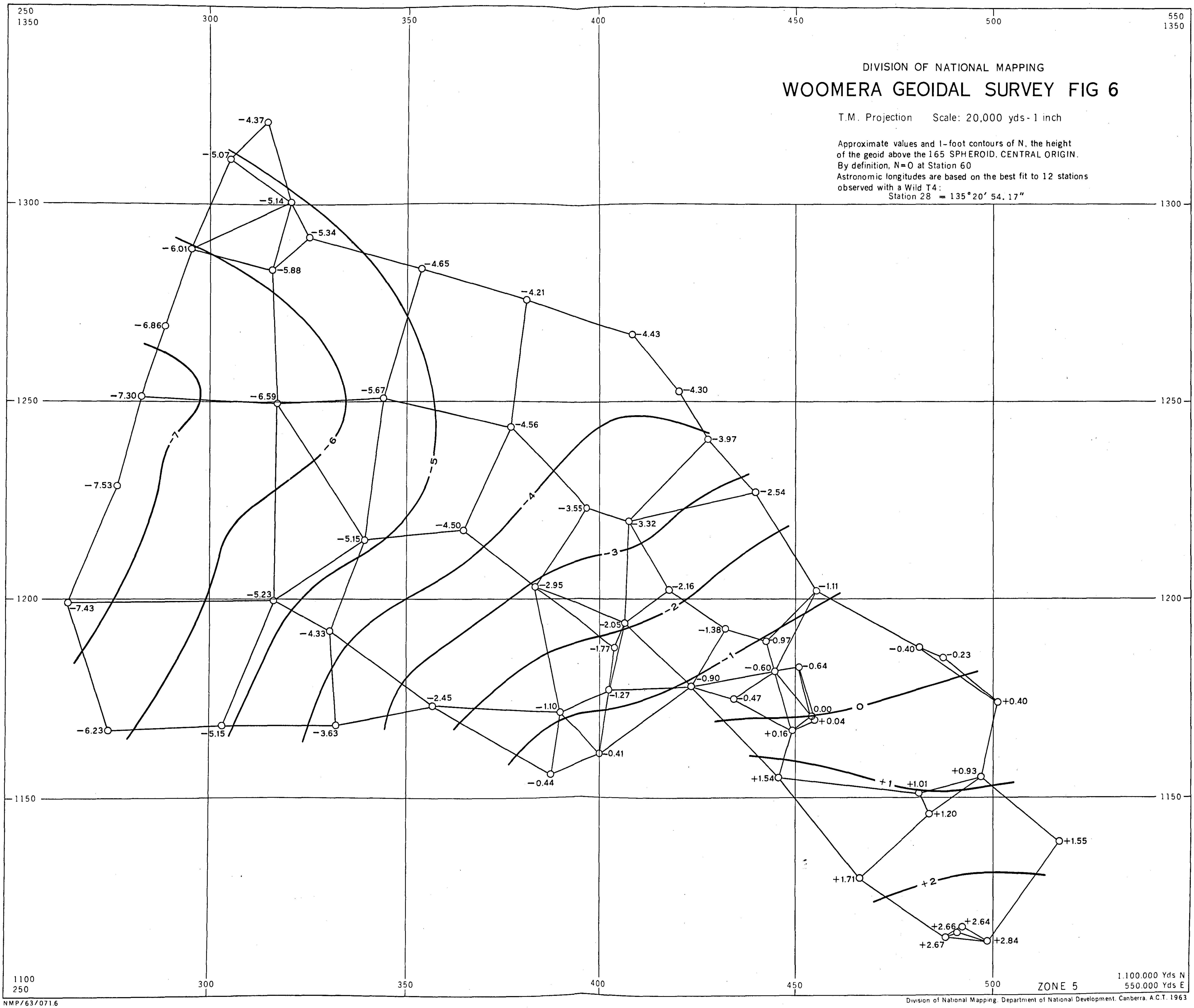

DIVISION OF NATIONAL MAPPING
WOOMERA GEOIDAL SURVEY FIG 6
T.M. Projection Scale: 20,000 yds - 1 inch
Approximate values and 1-foot contours of N, the height of the geoid above the 165 SPHEROID, CENTRAL ORIGIN.
By definition, N=0 at Station 60
Astronomic longitudes are based on the best fit to 12 stations observed with a Wild T4:
Station 28 = 135°20′ 54.17″
-4.37
-5.07
-5.14
-5.34
-6.01
-5.88
-4.65
-4.21
-4.43
-6.86
-4.30
-7.30
-6.59
-5.67
-4.56
-3.97
-7.53
-2.54
-3.55
-3.32
-4.50
-5.15
-2.95
-2.16
-1.11
-5.23
-7.43
-2.05
-1.38
-4.33
-1.77
-0.97
-0.40
-0.23
-0.60
-0.64
-0.90
-1.27
-0.47
+0.40
-2.45
-1.10
0.00
+0.04
-6.23
-5.15
-3.63
+0.16
-0.41
-0.44
+1.54
+0.93
+1.01
+1.20
+1.55
+1.71
+2.66
+2.64
+2.67
+2.84
-7
-6
-5
-4
-3
-2
-1
0
+1
+2
1100 250
1.100.000 Yds N
550.000 Yds E
ZONE 5
NMP/63/071.6
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