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EDWARD G. ANDERSON
School of Surveying, University of New South Wales

2

TOPOGRAPHIC SURVEY AND CARTOGRAPHY

2.1 INTRODUCTION

The surveys, which provide essential support for the various scientific programmes, are of two types:

1. surveys associated with topographic and detailed mapping, and
2. surveys to determine three-dimensional co-ordinates of discrete points, for glaciological and geomorphological measurements.

A network of accurately co-ordinated control stations is an indispensable pre-requisite of both types of survey, and additionally provides a fixed reference frame for any continuing or future comparative studies. This report is concerned largely with survey activities from the time of involvement of the author (mid-1972), and does not provide details of the survey work of the 1971-1972 expedition, directed by C. Randell Champion.

2.2 OUTLINE OF ACTIVITIES

Field work was divided between the two expeditions, CGE 1971-72 and CGE 1972-73, and has been described briefly in the relevant reports (Champion & Radok, 1972; Anderson, in Radok & Champion 1972 and in Peterson 1973). The greatest obstacle to preparation of a basic topographic map of the area was the complete lack of any control survey. Accordingly, the CGE 1971-72 devoted a great deal of its efforts to establishing a primary control network. This work was largely completed with adequate measurements to fix 54 stations. In addition a network of snow accumulation and glaciological stakes, on the Meren and Carstensz glaciers, were surveyed and tacheometric observations for topographic mapping of the majority of the Meren and Yellow valleys were obtained.

During 1972 the control network was adjusted by Dr J. S. Allman at the University of New South Wales, and the remaining data were reduced and plotted by Champion. Also at this time, a set of U.S. Airforce trimetrogon aerial photographs of the area was obtained (see cover photograph, Radok & Champion 1972) and it was decided to complete the topographic mapping by photogrammetric methods. Consequently, photo-control surveys became a major concern in the CGE 1972-73 programme. As well as photo-control, survey activities of the CGE 1972-73, supervised by Anderson, included resurvey of the glacier fronts and stakes for comparative studies, fixing of the positions of a series of glacier drill holes, determination of the elevations of the major peaks and significant geomorphological features, and extension and strengthening of the 1971-72 control network. A further 16 control stations were added to the total network.

2.3. EQUIPMENT AND METHODS

2.3.1. Preparation

The adjusted control network co-ordinates and the aerial photography were of considerable benefit in planning the 1972-73 programme. A computer listing of control network bearings and distances was prepared, and was an invaluable aid in the field. Identification of control stations, preliminary field calculations, and general efficiency of triangulation observations in poor atmospheric conditions were thus greatly facilitated. The air photos were used to advantage in planning and reconnaissance.

A possible requirement for approximate positions during the walk from Ilaga to the Meren Valley base camp led to a decision to prepare for day or night astronomical position fixes. This preparation was also considered to be a useful alternative, in case of the need to position photo control points beyond the extent of existing control.

2.3.2 Equipment

As transportation plans included the use of chartered light aircraft and native carriers, weight and volume of the equipment had to be minimised. A Wild T2 theodolite was chosen for most observations, supplemented by a Wild T16 for lower order triangulation work and tacheometry. An illumination set for the T2, a transistor short wave radio receiver (3-25 MHz), and a Heuer split-hand stopwatch were included for astronomical observations. A four-section aluminium staff was used for tacheometry. Base line measurements were not needed as adequate base lines had been set out in 1971-72 with electronic distance measuring equipment.

Efficiency in field reduction and checking of observations was greatly enhanced by using a Compucorp 320G portable calculator. The ability to provide provisional co-ordinates in the field with little delay was appreciated in all aspects of the scientific programme, and ensured the absence of gross errors in the survey data. Nevertheless, mathematical, astronomical and stadia tables were included as backup.

2.3.3 Methods

Conventional triangulation methods were employed in extending the control and in determination of elevations. Generally, for control work, four arcs

of horizontal directions and two sets of zenith angles were observed with the T2. Because of the likelihood of rapid deterioration of weather conditions and visibility, the first and third horizontal arcs and one set of verticals were observed first, to form a contingency set. The remaining observations were almost always completed, though often with some difficulty.

Existing control stations were chosen as photo control points at the western end of the strip, necessitating only field identification. However, at the eastern end, it was necessary to extend the survey to the north-east, across the Northwall by way of New Zealand pass. A number of stations in the vicinity of the pass, which had been selected and marked by the CGE 1971-72, but not observed, were fully established and used in the north-east extension of the network. Three photo control points were thus fixed at the eastern end of the strip.

Tacheometric surveys of the terminal white ice boundary of the Meren and Carstensz glaciers were made from existing control stations. These were reduced and plotted in the field.

Resection and intersection were both employed in fixing the glacier drill holes. Difficulty was experienced with both methods. When resecting from a drill hole station on the glacier, there was usually the problem of maintaining satisfactory levelling of the theodolite. On sunny days, when this problem was greatest, the use of ice screws to support the tripod legs was found to be helpful. As an alternative, intersection from at least three surrounding control stations on rock posed the problem of completing a large number of observations from widely separated stations, preferably in the same day to minimise the effect of glacier movement. Time was always limited due to weather conditions, the afternoon being invariably unsuitable. Despite these difficulties, good results were obtained showing satisfactory agreement between both methods.

Elevations were determined trigonometrically. In the case of the high peaks, where it was not feasible to occupy the station, over-determined intersections were employed. It was therefore desirable to establish a suitable beacon on the Carstensz Pyramid, and this was achieved when J. Peterson and E. Anderson placed a 2 m pole and flag on the summit, on 6th February, 1973. Beacons consisting of bamboo snow accumulation stakes had been established on Ngga Pulu and Second Top, an adjacent peak to the west, during the CGE 1971-72.

2.4 RESULTS

2.4.1 Control surveys

Details of the control networks are summarised in Table 2.1. Horizontal co-ordinates and elevations were computed and adjusted in a plane co-ordinate system, reduced to a base plane at 4000 m elevation. Station MG (latitude $4^{0}04'57''.8$ S, longitude $137^{0}09'47''.8$ E), near the CGE base camp in Meren Valley, was arbitrarily selected as a horizontal datum,

Table 2.1 Survey control networks

	Number of stations		Number of observations		
	Fixed	Adjusted	Horizontal directions	Distances	Zenith angles
CGE 1971-72 control	2	52	215	46	197
CGE 1972-73 control	16	16	74	3	60
CGE 1972-73 Meren drill holes	12	9	36	-	-

and a false origin was adopted 10,000 m south and 20,000 m west of this point. Vertical datum is based on the elevation of station WO (North) (3,615.07 m), which is related by triangulation and differential levelling to mean sea level, as determined from tide gauge readings by Bechtel Corporation at bench mark Portsite. Orientation of the grid to true north was based on an astronomical azimuth between stations WO (North) and BP (Able). Geographical co-ordinates, elevations, and orientation are based on data supplied by G. W. Therriault of Bechtel Corporation, derived from their geodetic surveys for the Freeport Indonesia Inc. Ertsberg Mine. These surveys link Portsite on the south coast to the mine, approximately 120 km inland, and comprise precise triangulation, trilateration, and differential levelling.

Adjustment of the CGE control surveys was completed in two stages. The CGE 1971-72 network, connected to four Bechtel Corp. stations, was adjusted by Dr J. S. Allman (School of Surveying, University of New South Wales), using his routines developed for the University's IBM 360/50 computer. The parametric method of variation of co-ordinates was used to produce a rigorous least squares solution. Following the second expedition, the CGE 1972-73 network was adjusted by Anderson, using Dr Allman's routines. Sixteen stations, common to the 1971-72 network, were held fixed. A statistical evaluation of the data, incorporated in the adjustment procedure, indicated satisfactory results, and the internal consistency of the total network was found to be well within the requirements imposed by the mapping and scientific programmes.

Adjusted co-ordinates and elevations of all stations are listed in Table 2.2. The more important stations, relevant to photo control and the glaciological and geomorphological studies, are shown on the topographic map (Map 2). Most CGE stations were beaconed with two-section, tubular steel tent poles. Ground marks were not usually placed.

2.4.2 Photogrammetry

Six selected photo control points were fully determined and field identified. These points were chosen with a distribution adequate to control a strip of five stereoscopic models, extending from the Grasberg in the west to Lake Larson in the east, and covering the Carstensz Meadow, Northwall Firn, Meren Valley and Glacier, and part of the Yellow Valley and Carstensz Glacier. Six vertical photographs were used in plotting, numbered 4CS-

5MC20-23V-115 to 120. These are part of a run of trimetrogon photography, flown by the United States Air Force, apparently in 1942. They were used in the compilation of a map, at a scale 1:100,000, published by the Dutch in 1956 (Topografische Dienst 1956).

All photogrammetry was undertaken by S. G. Bervoets at the Department of Surveying, Melbourne University. Initially, it was anticipated that a conventional aerial triangulation would provide sufficient control to orient all five models. However, inadequate stereoscopic coverage, due to a change in flight direction, was discovered near the centre of the strip. This difficulty was overcome by introducing additional ground control (from the CGE 1971-72 network) and incorporating further triangulated tie points in the oblique photographs to the north and south of the strip. These were observed using a monocomparator, and an analytical triangulation, followed by block adjustment of all data, was completed by computer. Other difficulties, arising from considerable cloud coverage and lost ground due to topographic relief and shadow, were handled by conventional techniques. Relief differences up to 1,000 m occurred in some models, representing more than one quarter of the effective flying height.

2.4.3 Glacier measurements

Glacier surveys were carried out by Champion in 1971-72 and shared by Anderson and the glaciologist, I. Allison in 1973. Results of the mapping of the terminal outlines of the Meren and Carstensz glaciers, and the resurvey of glacier stakes, are recorded and analysed in Chapters 3 and 4. Determination of the positions of drill holes in the Meren glacier and their short-term movements are reported here, largely to illustrate the reliability of the measurements from a survey point of view.

Details of the horizontal control network for four of the five Meren drill holes are summarized in Table 2.1. Observations were made on a number of different days, but only on the 29th January and 15th February, 1973, was it possible to observe all four drill holes: D, E, A and B. A simultaneous least squares adjustment of all of these observations was applied, treating each drill hole observed on each occasion as a separate point. The adjusted co-ordinates and apparent motions are summarized in Table 2.3. Overall reliability is illustrated in Figure 2.1, where the vector motion over 17 days, and the standard error ellipses derived from a statistical analysis of the observations, are plotted for each drill hole, at the same scale.

2.4.4 Elevations

Sufficient trigonometric observations were completed to compute elevations for the Carstensz Pyramid, Ngga Pulu, a prominent peak immediately west of Lake Larson (tentatively referred to as Temple Peak), and Lake Larson. Attempts to observe a beacon on the snow summit adjacent to, and immediately west of, Ngga Pulu on the Northwall (designated as "Tweede

Table 2.2 Adjusted co-ordinates and elevations of survey stations (metres)

Station identification	Co-ordinates East	North	Elevation	Height of beacon
Bechtel Corp. Stations:				
WO (North)	15066.48	9878.03	3615.07	1.87
BP (Able)	15091.73	9150.55	3605.35	2.27
Carst. Barat East	14847.06	10026.89	3682.09	0.80
Charley	15382.40	9347.14	3674.93	1.52
CGE control:				
CA	19983.23	9742.08	4357.66	1.52
CB	20352.64	8714.46	4586.44	1.52
CC	20365.66	9410.44	4502.83	1.52
CD	19650.80	9895.89	4406.84	1.52
CE	18694.41	10215.34	4475.10	1.74
CE ecc.	18692.11	10217.84	4475.90	–
CF	19771.02	9490.44	4318.50	1.52
CG	20059.40	9315.85	4407.27	1.46
CH	19417.42	9604.35	4313.50	1.52
CJ	18730.08	9964.85	4278.41	1.03
CK	17965.84	9992.98	4279.83	1.17
CL	17382.07	10520.17	4288.50	1.37
CN	16388.73	10905.24	4235.92	1.60
CP	17257.06	9757.85	4576.80	1.52
CR	16043.99	10738.70	4055.01	1.44
CS	20030.44	9109.28	4490.54	0.89
CT	20719.16	8570.01	4641.03	–
FA	20435.97	9940.70	4317.95	1.52
FB	20819.31	9628.59	4478.71	1.52
FB ecc.	20818.76	9626.24	4479.34	–
MA	16735.50	11393.19	3885.07	1.52
MB	16982.65	11261.33	3933.89	1.52
MC	17474.61	10866.78	3963.01	1.52
MD	18036.95	11066.67	4044.68	1.52
ME	19204.26	10599.37	4240.90	1.52
MF	19692.97	10344.16	4261.75	1.52
MG (Datum)	20000.00	10000.00	4250.74	1.80
MH	20452.59	9671.67	4492.66	1.56
MH ecc.	20449.25	9672.31	4493.90	–
MJ	19114.09	10315.07	4246.87	1.52
ML	18892.06	10342.60	4351.21	1.52
NA	20634.65	10222.00	4417.45	1.49
NB	20431.44	10263.01	4430.22	1.55
NC	20271.95	10462.42	4445.57	1.44
ND	19816.65	10712.15	4502.31	1.65
NE	16121.30	12649.23	4216.47	1.33
NF	17042.20	12112.28	4368.27	0.97
NH	17411.54	11744.87	4519.31	1.50
NN	18591.83	11892.65	4541.03	1.70
NN ecc.	18591.80	11900.57	4538.71	–

Station identification	Co-ordinates East	North	Elevation	Height of beacon
CGE control:				
NO	19211.44	11362.64	4523.13	1.84
NP	20179.50	11283.81	4588.90	1.74
NQ	18080.90	11387.69	4546.11	1.53
NR	19282.81	10917.45	4408.08	1.61
WA	14829.20	10318.12	3629.91	1.52
WB	14498.58	11024.54	3690.43	1.52
WC	14756.66	11398.54	3691.43	1.52
WD	15274.52	12080.00	3806.11	1.22
WE	16145.44	11886.83	3679.50	1.52
WF	15200.05	10567.09	3631.07	1.52
WG	15206.68	10805.80	3628.09	1.52
WH	15513.62	11238.55	3617.34	1.52
WJ	15513.48	11438.48	3622.99	1.52
ZA	20386.20	11321.81	4657.37	1.90
ZA ecc.	20389.75	11323.85	4658.62	–
ZB	20071.01	11548.09	4588.02	1.87
ZC	20640.45	11743.80	4458.07	1.39
ZC ecc.	20642.05	11744.73	4457.73	–
ZQ	21248.87	11625.54	4402.92	1.94
Photo B	21244.90	11613.34	4402.48	–
ZX	20688.94	12179.20	4403.98	1.52
Topographic features:				
Carstensz Pyramid	19152.53	9159.50	4883.87	1.64
Ngga Pulu	22273.38	10452.78	4861.63	2.30
Second top			4855	2.30
ZZ (Temple Peak)	21697.19	13347.54	4448.18	1.52
Photo A (Lake Larson)	22614.75	12919.28	3976.43	1.60

Top" in Dozy 1938) were repeatedly frustrated by cloud cover. However, a single set of zenith angles, combined with data from the photogrammetry provided a reasonable estimate of the elevation. All of these results are included in Table 2.2. The internal consistency of the vertical observations, as derived from a statistical analysis, is better than 0,1 m. However, the final elevations, with respect to a sea level datum, are dependent on many external factors, including the Bechtel corporation surveys, and it is thus not possible to derive the overall accuracy. Taking into account the survey methods and instruments involved, the final values should be reliable to 1 or 2 m.

A comparison of the elevations of five points, as determined by the Colijn expedition in 1936 (Map p 47 in Dozy 1938) with those established by the CGE 1971-72 and 1972-73 is made in Table 2.4. Although it is not possible to be sure that these measurements refer to exactly the same points, the error on this account is unlikely to exceed 10 m, allowing for

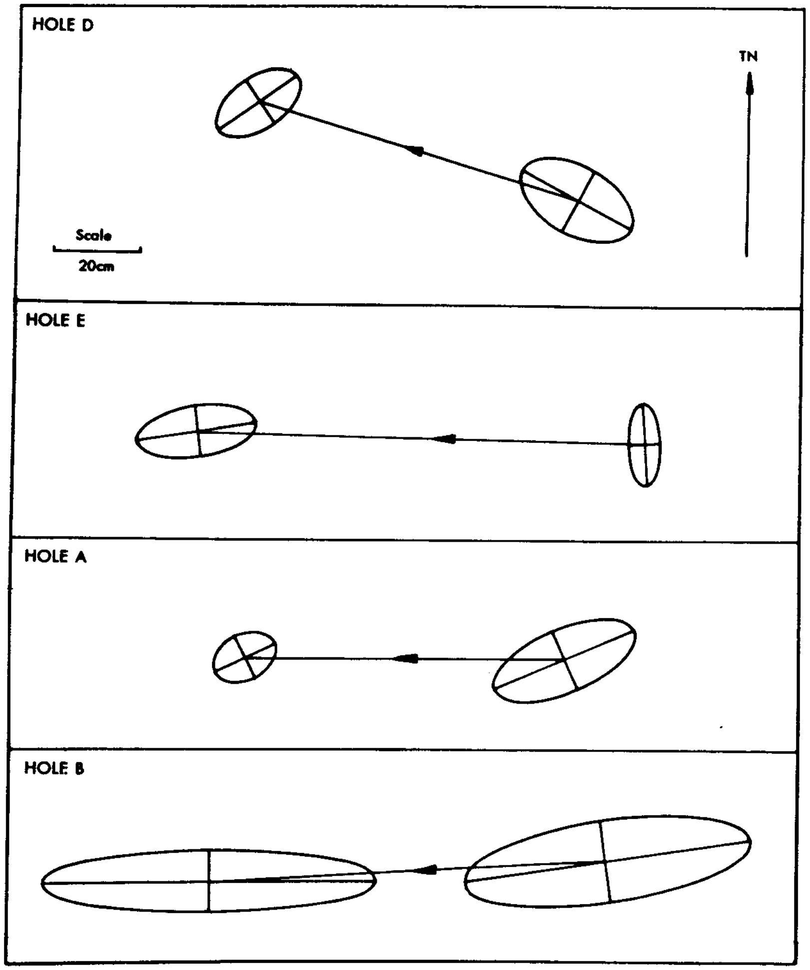

Figure 2.1 Movement of Meren Glacier bore holes, between 29 January and 15 February 1973, and standard error ellipses at same scale

the terrain near each point. A consistent difference between the Colijn expedition and CGE values is evident, and may be explained by the possibility of a systematic error in the earlier values which were dependent on barometric observations. However, the elevations for Ngga Pulu differ by a noticeably greater amount, indicating the possibility that this summit has been reduced in elevation by approximately 45 m since 1936 due to loss of snow and ice.

Table 2.3 Movement of Meren Glacier drill holes

Hole	Approx. elevation (m)	Co-ordinates (m) 29 Jan. 1973	15 Feb. 1973	Vector motion	Rate m/day
D	4365	20628.95E	20628.22	286° 26'	0.045
		9962.75N	9962.96	0.761	
E	4417	20856.27	20855.25	271° 35'	0.060
		9907.63	9907.66	1.018	
A	4470	21084.75	21084.00	270° 19'	0.043
		9843.83	9843.84	0.728	
B	4523	21301.28	21300.37	266° 58'	0.053
		9810.33	9810.28	0.907	

In 1910 the Dutch Military Expedition (Wollaston 1914) determined the heights of the Carstensz Pyramid (4,866 m) and Mt Idenburg (4,688 m) by repeated theodolite observations from the south coast. These estimates were in fact closer to the true heights than any subsequent surveys based on aneroid or boiling point measurements.

2.4.5 Topographic map (Map 2)

The south-east portion of the topographic map, covering most of the Meren Glacier and Valley and the Carstensz Glacier and Yellow Valley, was compiled from detailed field surveys by the CGE 1971-72, supervised by Champion, who also reduced and plotted the tacheometric and other observations. The remainder was compiled by photogrammetric methods, supervised by S. G. Bervoets, using 1942 USAF trimetrogon aerial photography, and CGE ground control.

Where possible, names used by the early expeditions of Wollaston (Wollaston 1914) and Colijn (Dozy 1938) have been adopted, after translation. Some confusion has arisen from the reports of Harrer (Harrer 1964), Temple (Temple 1962) and the Cenderawasih Expedition (Hamid et al. 1964), largely resulting from considerable topographic inaccuracies in their accompanying maps. No doubt consistently bad weather and resulting poor visibility contributed to these distortions, but it is a pity that the earlier maps were not more closely followed. In particular Dozy's maps, based on the geological structure, display exceptional accuracy. The

Table 2.4 Comparison of elevation: Colijn Expedition — CGE 1971-73

Colijn Expedition 1936 (after Dozy 1938)		CGE 1971-73		
Location	Elevation	Station	Elevation	Difference
Carstensz Meadow	3750	WJ	3623	127
Meren Valley Camp	4090	MC	3963	127
Meren Glacier Camp	4380	MF	4262	118
Yellow Valley	4435	CH, CF	4315	120
Ngga Pulu	5030	Ngga Pulu	4861	169

position of Ngga Pulu seems to have been mis-interpreted by Harrer and Temple, though there is no doubt that they climbed to its summit during their traverse of the Northwall. However, the whereabouts of their "Sunday Peak" remains uncertain. Where there is no possibility of mis-identification, names applied by Harrer and Temple have been retained unless official Indonesian names have been applied since 1962.

2.5 NOTES ON CONDITIONS AFFECTING THE SURVEYS

The design and execution of all surveys in the area are dominated by weather conditions. Early morning work is usually hampered by ground mist and fog. Afternoon observations are virtually always precluded by the persistent rain and enveloping cloud. Thus the daily interval available for observing is commonly limited to less than five hours. Night astronomical observations are rarely possible (two nights in a period of six weeks suitable) and none were taken during the expeditions. Morning sun or daylight star observations would often be practical. These remarks are all based on experience and records of weather conditions for the period December to February.

Surveys of points above the firn line are severely limited by the lack of bedrock sites for stable stations and the extensive areas of deep, soft snow.

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