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Cezary LIPERT

Committee on Polar Research
Polish Academy of Sciences
PKiN. 00-901 Warszawa. POLAND

Photogrammetric works in the Werenskiold Glacier area, Spitsbergen

ABSTRACT: Great ablation of the Werenskiold Glacier created the need of recording the changes, particularly superficial ones, after melting of its icings. Ground stereophotogrammetric photos done during the Polar Expedition of the Polish Academy of Sciences in 1983 enabled to prepare a map in the scale of 1:10,000 covering by its two sheets the whole glacier, a system of open crevasses inclusive. The map presents the actual state of the glacier and enables a comparison with earlier photogrammetric measurements carried out several times since 1957.

Key words: Arctic, Spitsbergen, geodetic map.

Introduction

During the 6th Polar Expedition of the Polish Academy of Sciences "Spitsbergen 1983/84" the ground stereophotogrammetric surveys on the Werenskiold Glacier were carried out from September 11 to October 7, 1983, on the initiative of Professor Marian Pulina (Silesian University). The survey was carried through to register the actual state of the whole glacier, and particularly its frontal area. The fieldworks were preceded by a considerable ablation, in consequence of which the superficial snow and ice layers completely melted and a pure structure of the glacier got uncovered, with all its crevasses and crackings. Such a phenomenon is very rare, but owing to its occurrence the cartographic registration could be done. The ablation was not so effective in the glacier cirque; slight differences only in glacier altitudes were noted in relation to the measurements of 1957.

The ground stereophotogrammetric surveys enabled to prepare a geodetic map of the Werenskiold Glacier area, useful for glaciologic and geomorphologic purposes. Two sheets of maps covering the whole glacier:

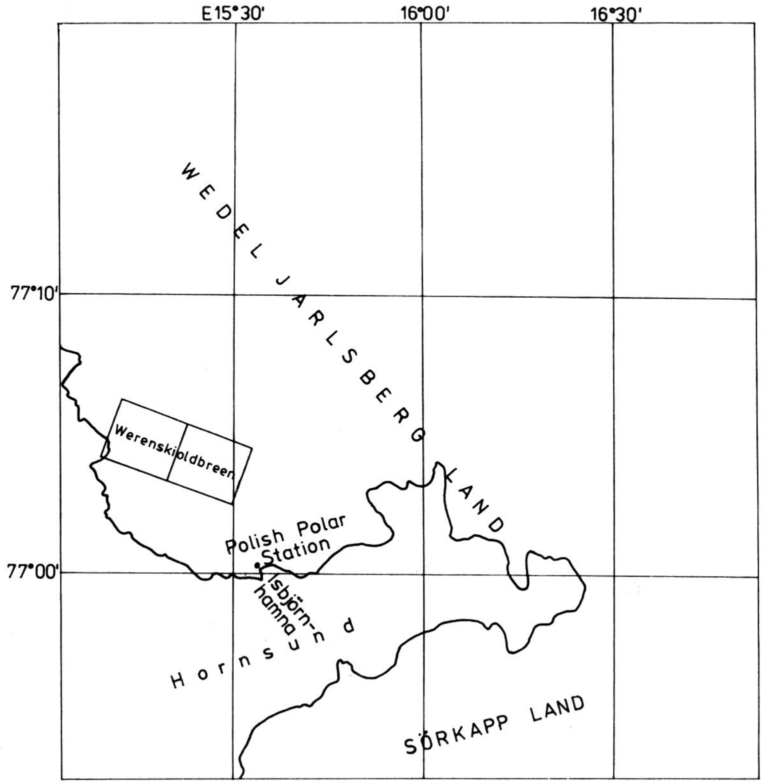

Fig. 1. Location of sheets of a geodetic map of the Werenskiold Glacier in the scale of 1:10,000

its snout, morainal area and the cirque, were prepared (Fig. 1). The maps cover also the southern slope of Jens Erikfjellet, the northern slope of Angellfjellet and the proximal part of the outwash plain (Figs. 2—5).

Geodetic survey

In the nearest surroundings of the Werenskiold Glacier there are the Norwegian bench marks, necessary for a photogrammetric preparation of maps. Trigonometers of the Norwegian geodetic network, together with geodetic defined mountain summits in the glacier vicinity, enabled to make the existing network denser. It was necessary for geodetic incisions, finding the measuring bases and their development.

Benches of the Norwegian geodetic network used for the prepared maps are presented in Table 1. Characteristic mountain summits with a geodetic determination are presented in Table 2. These benches were

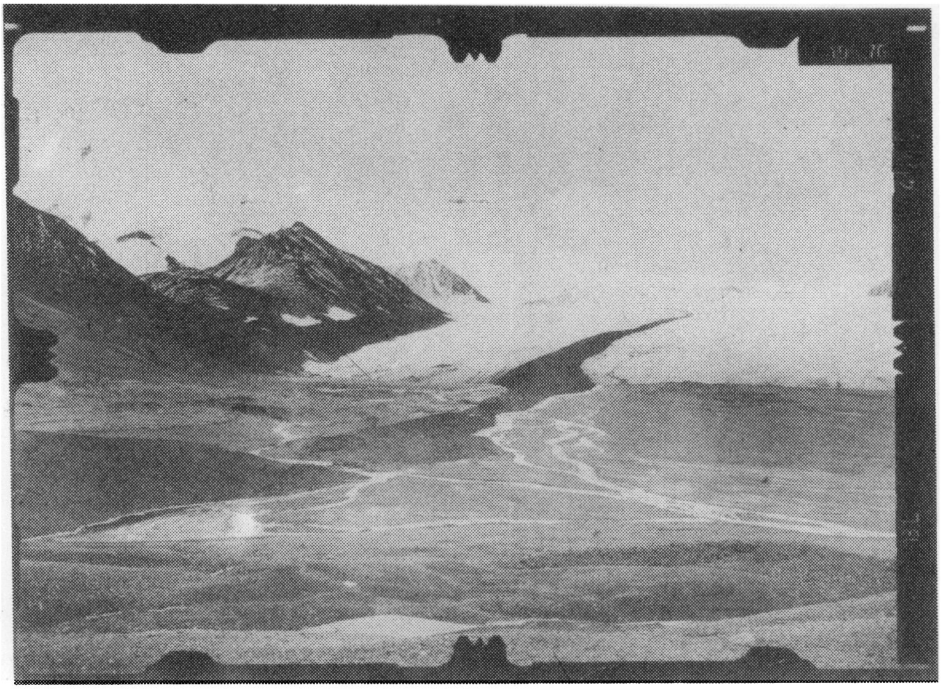

Fig. 2. Snout of the Werenskiold Glacier with degraded median moraine in the marginal part and glacier streams. In the background the glacier cirque

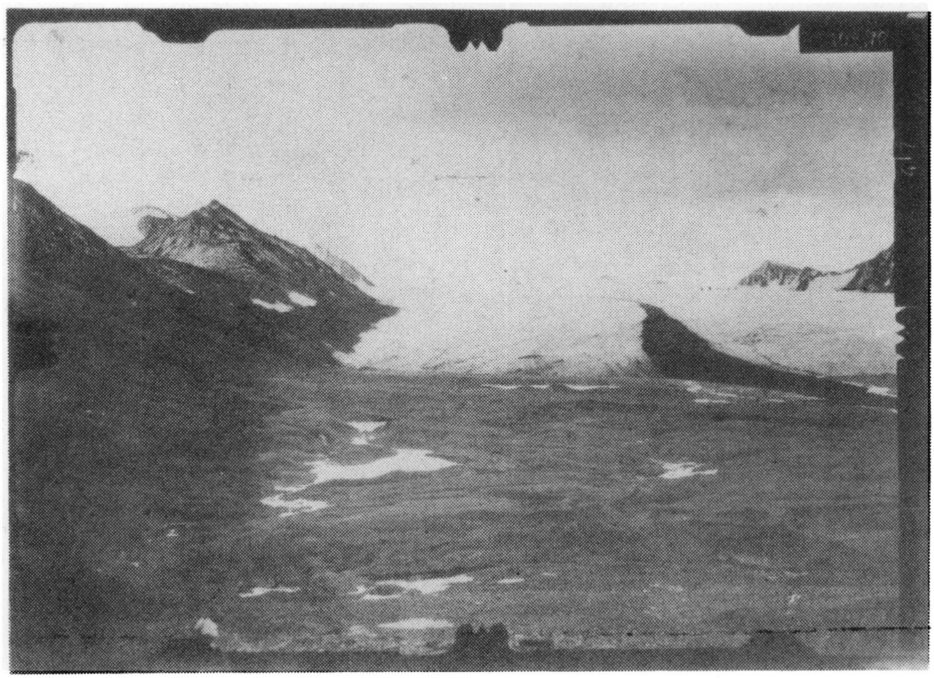

Fig. 3. Northern side of the Werenskiold Glacier with the lateral and median moraine. In the foreground the marginal part of the glacier with streams and ponds. To the left the Wernerknaten mountain, in the background the glacier cirque, to the right the Skålfjellet massif

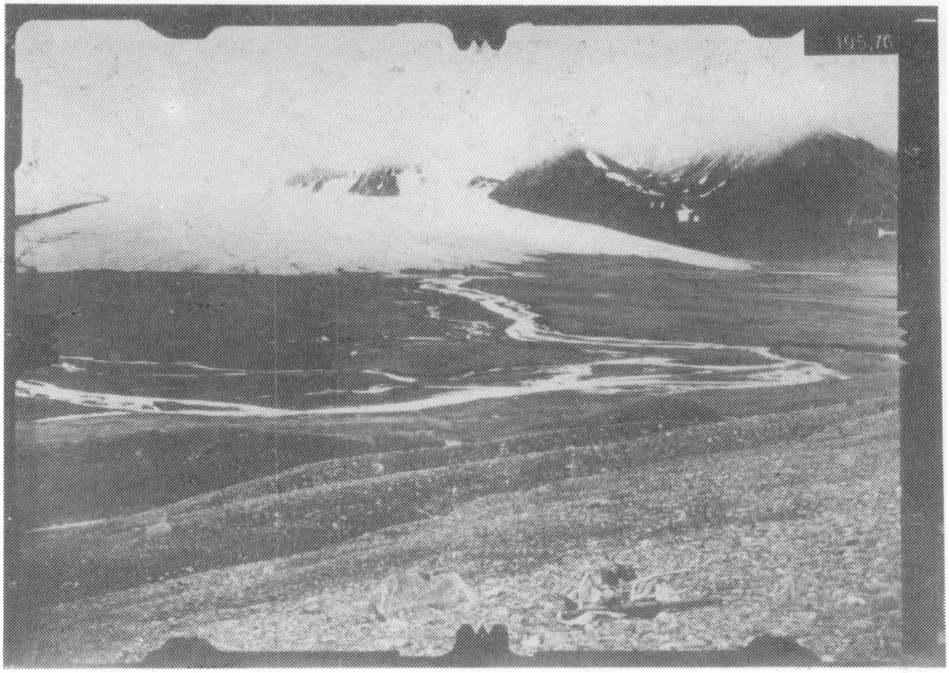

Fig. 4. The Werenskiold Glacier snout area with the marginal part and fragments of a terminal moraine in the foreground. In the middle a glacial stream, in the background to the right the Angellfjellet massif, in the background to the left the frontal part of a terminal moraine.

Fig. 5 Southern side of a terminal moraine of the Werenskiold Glacier; in the background the Nottinghambukta Bay, in the foreground the marginal part with numerous small ponds

Table 1

Points of the Norwegian geodetic network

Name	X	Y	H	Location, sheet no.
Tonefjellet	63020.2	108 152.3	935.4	—
Jens Erikfjellet	62406.2	105422.0	575.9	I
Angellfjellet	57659.4	107036.0	590.7	I
Gulliksenfjellet	56751.7	104907.5	551.6	—
Torbjörnsenfjellet	53479.7	107276.0	663.4	—

Table 2

Characteristic points determined geodesically during the Polish polar expeditions

Name	X	Y	H	Location, sheet no.
A7	60876.1	105029.5	—	
A3	60174.2	104750.2	—	
Slyngfjellet	59788.0	111549.0	659.0	II
Well	59058.6	109554.3	—	II
B2	58527.7	105889.0	—	I
Stone on the median moraine	59051.7	109541.0	—	II
Block on the median moraine	59044.8	109767.0	303.3	Block apex II
B1	58424.1	105609.9	—	I
Mast of the Glaciologic Station	58067.1	111284.8	386.5	cylinder basis II
Deilegga	57448.0	112670.0	588.0	II
Eimfjellet	56952.0	109636.0	641.0	II
Skålfjellet	56423.0	111602.0	670.0	II

measured during the expeditions of the Polish Academy of Sciences since 1957 (Lipert 1958, 1982; Fellmann 1982, Gaertig 1982). Geodetic measurements were performed with a use of the Zeiss-Jena Th 2 theodolite.

Some geodetic points necessary for a preparation of previous maps of the Werenskiold Glacier (starting from 1957 to 1983, in scales of 1:5000 and 1:10,000) and located on the glacier, moraines and outwash plain, are presented in Table 3. Their coordinates were determined by geodetic works.

The glacier area and patricularly its snout, was divided with a reference to the Norwegian geodetic network. Four geodetic rows with nodes were planned. These rows were measured as early as in 1957 (by the geodesists Jerzy Fellmann, Samek Gąsienica and Cezary Lipert) and the needed mark benches were defined and plotted on the map in the scale of 1:5000 prepared in that time, covering the glacier area in three sheets.

Coordinates of these points were plotted onto the map in accordance with horizontal coordinates and have the altitudes H (Table 3), what enables a univocal comparison of the latter on the glacier and moraines.

Collected data of the ground geodetic measurements were mainly cal-

Table 3

Points determined by the geodetic surveys

Name	X	Y	H	Location, sheet no.
F 103	61797.4	105010.0	223.30	I
F 102	61709.7	105036.3	40.26	I
F104	61545.4	104618.4	20.56	I
W 100	61518.0	105602.3	43.82	I
F 15-W 18	61259.4	105389.7	98.60	I
F 16	61008.0	105441.3	73.67	I
W 17	60992.9	105213.5	63.45	I
F 19	60905.8	104961.9	81.70	I
W 19a	60884.3	105570.4	44.97	I
F 17-F-18	60871.2	106028.9	86.60	I
F 24	60756.8	104797.7	60.19	I
F 96-W 19	60754.3	105692.2	61.80	I
F 23	60752.7	104988.8	81.36	I
F 25	60706.1	104789.7	55.09	I
F 20-F 21 F 22 W 16	60705.0	104993.5	80.89	I
W 13	60650.0	106651.2	87.07	I
W 20	60572.2	106135.6	80.37	I
F 26-W 27	60530.3	104862.2	80.77	I
F 27-W 27	60425.4	104816.3	71.62	I
F1 F 28a W1	60419.2	106570.3	100.86	I
F 14	60526.0	106563.4	88.28	I
W 28	60418.4	106572.6	100.86	I
F 108	60391.1	103945.6	9.22	I
F 28 F 29 W 14	60315.8	104740.9	69.73	I
F 109	60309.5	103904.0	7.90	I
F 32	60049.6	104486.0	57.52	I
F 33	60012.1	104473.8	59.71	I
F 31	39974.7	104573.4	61.97	I
F 30 W 19	59965.2	104619.5	60.95	I
Point 7	59842.4	108908.5	245.80	I
Point 8	59768.3	108865.0	244.90	I
F 110	59759.0	103688.0	1.27	I
F 41 F 42	59697.1	104409.9	57.16	I
F 39 F 40	59676.3	104455.8	58.07	I
F 37 F 36	59658.7	104492.4	60.50	I
F 36	59646.4	104523.8	60.32	I
F 35 W 11	59630.1	104550.2	64.46	I
Point 5	59526.1	110128.6	334.60	II

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Name	X	Y	H	Location, sheet no.
W 31	59507.2	104014.1	1.62	I
Point 4	59479.1	110209.3	336.40	II
Point 6	59418.9	110119.3	329.80	II
W 32	59114.3	104220.7	1.55	I
W 78 W 9	58870.1	104597.5	27.89	I
F 34 W 12	58832.5	104591.8	67.55	I
W 8	58766.3	104948.1	34.93	I
F 113	58714.5	104200.5	1.45	
W 116a	58633.9	104390.3	—	I
W 6	58608.9	105685.9	73.94	I
Point 10	58592.8	107548.9	213.40	I
F 117	58541.6	104579.9	12.71	I
Point 11	58499.8	107608.6	220.30	I
Point 9	58479.4	107512.3	218.70	I
W 7	58391.4	105213.4	55.93	I
W 33	58339.2	104695.3	22.11	I
Point 2	58127.0	111334.3	384.70	II
Point 1	58115.1	111289.9	383.3	II
Point 12	58072.0	111295.1	388.0	II
Point 3	58012.3	111212.3	380.60	II
Point 13	57463.9	112686.4	587.7	II

culated after the return home. In consequence the following results were obtained:
— smoothing of angles at observation stands,
— coordinates of backwards incised points,
— values of measurement bases (14 bases and 5 base developments),
— recalculation of altitudes from trigonometric points of the Norwegian geodetic network to sites on the glacier,
— coordinates of the points established by additional measurements.

These geodetic measurements allowed to make the necessary ground stereoscopic photos of the glacier as well as to make calculations for their photogrammetric and instrumental elaboration.

Photogrammetric measurements

The ground stereophotogrammetric photos were done in the field by the author with a use of the Zeiss-Jena 1318 phototheodolite of a focal length f = 195.76 mm. A considerable help is acknowledged from the members of the Silesian University expedition, and particularly from the journalist Janusz Karkoszka.

Table 4

Bases and numbers of stereograms

Base No.	Size of the base in m	Number of made stereograms
b_1	271.77	11
b_2	297.71	
b_3	512.40	
b_4	71.25	7
b_5	110.21	
b_6	540.76	9
b_7	194.35	
b_8	69.83	1
b_9	104.17	4
b_{10}	216.14	
b_{11}	246.14	6
b_{12}	143.94	3
b_{13}	143.94	2
b_{14}	142.34	1
	Total	44

The ground photos were done for 14 bases (Table 4) from the normal and broken bases. The 2 m high staff, Zeiss made, was used for measuring the base values.

Construction of map sheets

The map of the Werenskiold Glacier area was limited by corners resulting from cartographic construction calculations with a use of the data from the Norwegian Polar Institute. In Spitsbergen the previous maps were prepared in the local system with an application of the Gauss-

Table 5

Geographical coordinates φ and λ as well as flat coordinates X, Y of map sheet corners of the Werenskiold Glacier

	15° 08' 33"		15° 12' 18"		15° 19' 00"		15° 23' 00"		15° 28' 27"		15° 33' 40"	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
77° 02' 30"									111875	55101		
77° 03' 20"					107923	56665						
77° 04' 22"	103585	58586										
77° 04' 30"											113515	58848
77° 05' 20"							109562	60398				
77° 06' 04"			105236	62312								

-Krüger conform cylindrical projection. 15°E has been assumed for the projection axis of the West Spitsbergen. Zero X of 8500 km from the equator and zero Y of 100 km eastwards from the meridian 15° have been assumed. In accordance with these assumptions the geographic and flat coordinates of the map of the Werenskiold Glacier were calculated (Table 5).

A convergence of meridians is considerable at this latitude, and thus the area of the projected sheets is different and as well as their shapes, the more so that the area of the whole glacier was supposed to be enclosed. Hence the size of the sheets amounts to about 2' for the latitude ζ and to about 10' for the longitude λ. The Werenskiold Glacier area has been covered within these limits by map sheets in the scale of 1:10,000.

Preparation of map sheets

Ground stereophotogrammetric photos were edited by the author and Janina Fedorowska with a use of 1318 stereoautograph Zeiss made. Two sheets of the map in the scale of 1:10,000 were prepared with basic contour lines of 2.5 m, except the glacier where they ran at every 5.0 m. Locally, especially at steep slopes of Jens Erikfjellet and Angellfjellet the contour lines at every 10 m were drawn. Contour lines were drawn generally in black, except the ones at every 10 m which were drawn in red. Streams and lakes were presented in blue and contour lines on the glacier in green. The maps were drawn on transparent, non-deformable tracing papers (each colour on a separate sheet). The masks for hydrography were also prepared.

Accuracy of photogrammetric measurements

While taking into consideration the values of calculated bases and distances with a reference to the picture presented on the map, one can assume the accuracy of the photogrammetric work, determined by the error of the Y coordinate (photographing direction). During the fieldworks the normal case and averted photographs were applied. No convergent and divergent photographs were made. The base of stereophotogrammetric photos was suitably selected, to obtain the base ratio not exceeding the values of 1:5 to 1:20 and the graphic accuracy of the elements suitable for the scale of 1:10,000.

Y coordinates within the photogrammetric system of the map were:

$$Y_1 = Y_2 = \frac{b\ f}{p};$$

The error of the Y coordinate after differentiation would be:

$$dY_1 = -\frac{Y_1}{b\ f_1}\ dp;$$

The error of the Y coordinate can be defined as the error of the function

$$Y = F\ (b,\ p,\ f)$$

where: b — length of the photogrammetric base,
p — longitudinal paralaxa value on the stereogram,
f — focal length.

Upon transforming the differential function in relation to its variables, we obtain the formula for the average error of the coordinate Y:

$$m_y = \frac{Y}{b\ f}\sqrt{f^2\ m_b^2 + Y^2\ m_p^2 + b^2\ m_f^2}$$

where: m_b, m_p, m_f are mean errors of b, p, f.

While substituting the suitable values of the Y coordinate and the other data, as of bases (Table 5), focal length f = 193.76 mm and mean errors of a determination of the stand of $m_b = \pm 0.05$ mm, $m_p = \pm 0.01$ mm, $m_f = \pm 0.005$ mm, we obtain the suitable values of the mean error m_f dependent on the base and the distance from the base.

Two extreme cases at b = 71.25 m and Y = 600 m and b = 312.40 m and Y = 6000 m are quoted as an example of illustration the accuracy of a photogrammetric elaboration of the maps. While substituting the above data b, Y and mean errors of the m_b, m_p and m_f, we obtain $m_y = 0.84$ m for the first case and $m_y = 1.17$ m for the second case. The graphic accuracy of the map in the given scale, equal 2 to 3 m respectively, is therefore fully ensured.

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Резюме

С 11 сентября по 7 октября 1983 г. на леднике Веренскъёльда проводились измерительные стереофотограмметрические наземные сьемки с использованием фототеодолита Цейсс-Иена 1318 с фокусным расстоянием f = 195,76 мм. На основании съемок на фотограмметрическом инструменте (стереометрограф Цейсс-Иена 1318) была разработана карта ледника в масштабе 1:10000 охватывающая двумя листами всю площадь ледника. Фотограмметрические измерения были проведены на желание проф.-д-ра Мариана Пулины, руководителя Региональной научной полярной экспедиции Силезского университета. Целью проведенных измерений было зарегистрирование состояния ледника, в частности его поверхности в передней части, которая подвергнулась отображению под действием до сих пор не наблюдаемой абляции. Открытые трещины поверхности ледника и другие морфологические и гляциологические изменения разрабатываются на составленной карте Силезским университетом.

Streszczenie

Zjawisko dużej ablacji Lodowca Werenskiolda niespotykane na przestrzeni czasu podczas długoletnich badań jego dynamiki spowodowało konieczność zarejestrowania zmian szczególnie powierzchniowych po stopieniu się jego warstw nalodziowych.

Na podstawie wykonanych na lodowcu w okresie jesiennym 1983 r. pomiarowych stereofotogrametrycznych zdjęć naziemnych w ramach Programu Badań Polarnych Polskiej Akademii Nauk MR.I.29 opracowano mapę w skali 1:10000 obejmującą dwoma arkuszami cały lodowiec. Mapa umożliwia porównanie obecnego i poprzednich stanów lodowca, ujętych również na podstawie pomiarów fotogrametrycznych wykonanych kilkakrotnie począwszy od 1957 r.