ROYAUME DE BELGIQUE

MINISTERE DES AFFAIRES ECONOMIQUES ET DE L'ENERGIE
ADMINISTRATION DES MINES - SERVICE GEOLOGIQUE DE BELGIQUE

13, rue Jenner - 1040 Bruxelles

MASS TRANSPORT MEASUREMENTS IN THE SOR-RONDANE DRONNING MAUD LAND ANTARCTICA

PRELIMINARY REPORT

by

T. VAN AUTENBOER and H. DECLEIR

PROFESSIONAL PAPER 1974 N° 6

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T. Van Autenboer* and H. Decleir**

CONTENTS

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1. *INTRODUCTION*

The first results of mass transport measurements in the Sør-Rondane, based upon gravimetric and topographic surveys by the 1959 and 1960 Belgian and 1965 Belgian-Dutch Antarctic Expeditions, have been presented in an earlier paper (VAN AUTENBOER and BLAIKLOCK, 1966). This survey was continued during the 1966 Belgian-Dutch Expedition : the already established movement markers were resurveyed and the gravimeter and movement observations extended to the remaining glaciers of the range (Kreitserisen, Hansenbreen, Gjelbreen and Byrdbreen).

These observations allow calculation of the discharge of all major glaciers in the Sør-Rondane and evaluation of the mass transport through a 220 km long section at right angles to the main flow from the polar plateau (between 21° 15' E and 26° 30' E). This regional contribution to the mass balance of the Antarctic ice sheet was the main purpose of the study.

Included in this report are the results of all oversnow gravity traverses[☆] in the Sør-Rondane, except for a long north-south profile from the coast to the mountains. In the interpretation of the latter, difficulties are experienced with the extrapolation of regional anomalies over long distances.

The velocity values reported here are a selection of the most representative data i.e. observations by the same surveyor covering the longest periods of observations.

At the Gunnestadbreen stakes, observations were repeated more frequently in the hope of establishing the existence or absence of seasonal variations of the rate of movement. Further analysis of these data is planned.

(☆) The already published 1959 and 1960 glacier profiles (VAN AUTENBOER and BLAIKLOCK, 1966) calculated with a slightly different and less accurate method, have been recalculated and the results are included in this report.

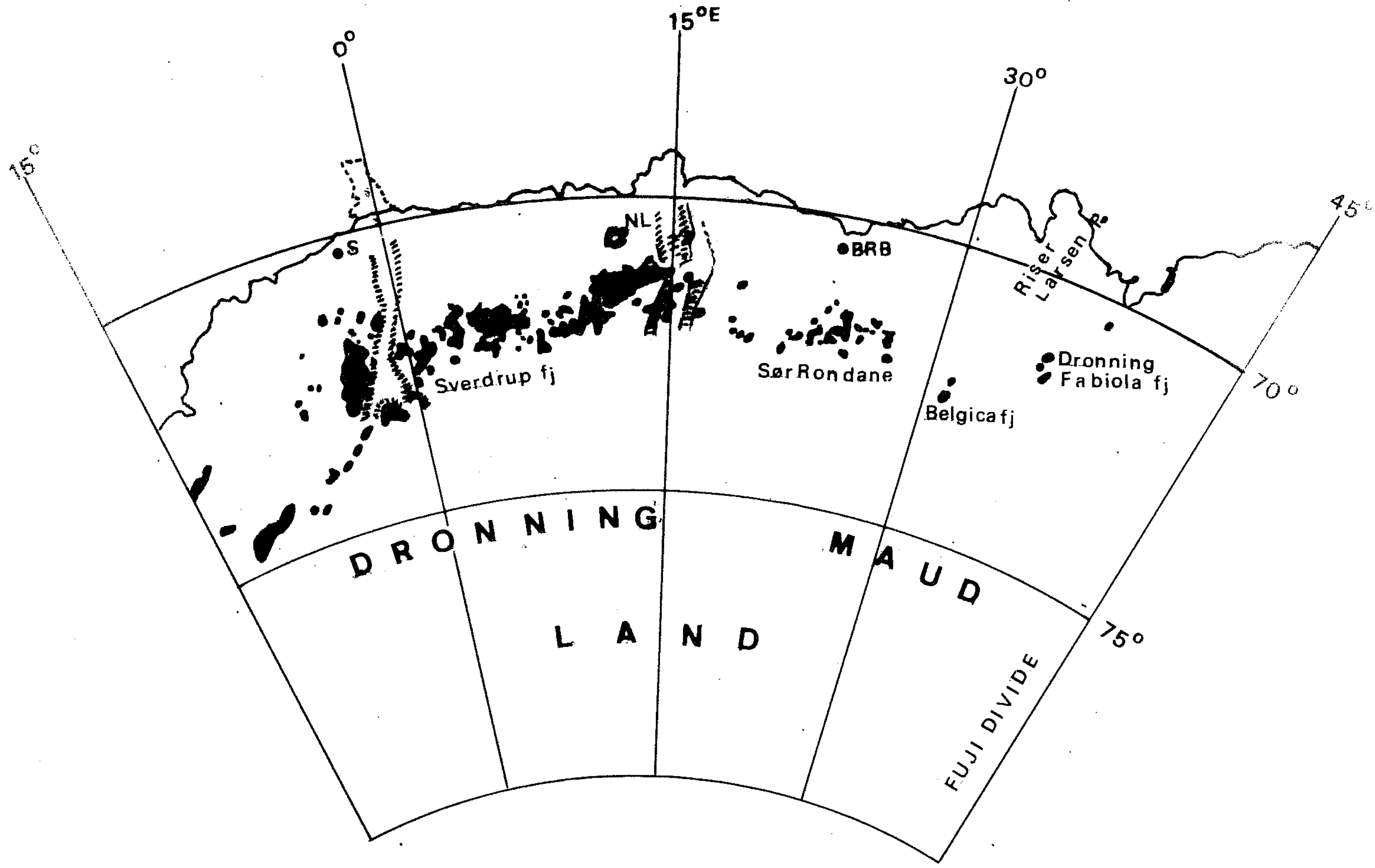

Fig.1. DRONNING MAUD LAND (compiled from different sources; S = SANAE station; NL = NOVO LAZAREVSKAYA; BRB = KING BAUDOUIN STATION). The ice streams near Sanae and Novo Lazarevskaya are schematically represented.

The 1959, 1960 and 1965 surveys were carried out by K.V. Blaiklock and T. Van Autenboer. The 1966 surveys were carried out by T. Van Autenboer and the surveyors E. Lallemand and J.P. De Winde. Further support in the field was received from G. Derom, J. Dubois and L. Goossens during the 1960 and from F. Gordts and J. ten Bosch during the 1966 expedition.

2. *THE SØR-RONDANE*

The Sør-Rondane forms a 250 km long, east-west wedge shaped mountain range some 200 km south of King Baudouin station (Fig. 1 / Fig. 3).
A map on a scale of 1:250.000, based upon US Navy air photographs (operation Highjump 1946-47) and published by Norsk Polarinstitutt in 1957, was originally used. A new series of 1:250.000 maps over this area, based upon Belgian field work[☆] and Norwegian oblique air photographs (1959-1960), is being prepared for publication by Norsk Polarinstitutt and was used in the preparation of this report.

The Sør-Rondane mountains, belonging to the precambrian platform of East Antarctica, have been studied during the 1958, 1959 and 1960 Belgian and 1965 and 1966 Belgian-Dutch Antarctic Expeditions. MICHOT (1962, 1963) studied the petrography of the metamorphic and igneous rocks of the eastern part of the range. VAN AUTENBOER and others (1964) and VAN AUTENBOER and LOY (in press) give a general synthesis of the geology and VAN AUTENBOER (1969) a 1:500.000 geologic map of the area.

Age measurements (mainly Rb/Sr on biotites) can be found in PICCIOTTO and others (1967) and U/Pb zircon ages in PASTEELS and MICHOT (1968). ZIJDERVELD (1968) published the results of palaeomagnetic measurements. An outline of the glacial geology and glacierization of the range can be found in VAN AUTENBOER (1964).

(☆) Geodetic and topographic work by K.V. Blaiklock during the 1959 and 1960 Belgian Antarctic Expeditions (unpublished).

3. *GRAVIMETRIC ICE THICKNESS DETERMINATIONS*

Gravimetric profiles were measured at right angles to the main direction of flow of the glaciers. A Worden Geodetic Gravimeter (Nr 453), checked on Belgian and international calibration bases, was used. The calibration curves, supplied by the manufacturers, were found satisfactory and were used for the computations. Transport was by dog sledge or by motor toboggan with the gravimeter suspended in a framework rigged on the back of the sledge.

The positions of the gravimeter stations were mainly determined by resection from the trigonometric stations (see movement observations). On some of the less important traverses it was also carried out by sledge meter measurements and aneroid altimetry between established positions. At the resected stations, vertical angles were measured to provide the altitude of the stations which was calculated by taking into account the combined curvature and refraction correction.

The ice thickness at each of the stations was computed from the gravimeter measurements using a method of which the first steps are similar to the one outlined by VAN AUTENBOER and BLAIKLOCK (1966).

(i) An initial two-dimensional model is calculated for the glacier assuming that the gravity anomaly at each station results from the replacement of an infinite slab of rock by a slab of ice of identical dimensions (MARTIN, 1948). The gravity anomaly, used in this calculation, is the difference between the value at the glaciological station and the value at the reference station on rock.
The gravity measurements at the glaciological stations are first reduced to the same altitude and latitude and corrected for the regional variation of gravity. The latter correction is calculated for this first step by linear interpolation of the difference between the gravity values observed at the reference stations on rock at both sides of the profile.

(ii) This model is then improved by computing the gravity effect of the calculated cross section at each of the stations. It has been shown by HUBBERT (1948) that to evaluate the gravity effect of a two dimensional body, the areal integral can be replaced by a line integral following the periphery of the body.
Replacing the cross section of the two dimensional body with a n-sided polygon, TALWANI and others (1959) adapted the line integral method for digital computers. The anomaly at each gravimeter station calculated by this method was compared with the observed anomaly as defined above. The difference between the two anomalies was then again converted into ice thickness with the infinite slab method, as outlined under (i), and the shape of the cross section (i.e. the ice depths) altered accordingly. This process was repeated until measured and calculated anomalies coincided.

(iii) The model as computed by (ii) indicated the existence of a negative value at the reference stations where the anomaly - per definition - was supposed to be equal to zero. These negative values represent the effect of the computed glacier model on the reference stations on rock. This indicates that there is a difference between the regional gravity gradient - or the gravity gradient when the glacier is replaced by rocks of the density of the country rock - and the gradient between the measured values on rock on both sides of the glacier.
In practice this means that the values at the reference stations have to be corrected for the negative effect of the glacier and that the gravity anomalies at each glaciological station have therefore to be recalculated. The final computing scheme included, at each step, a correction to the observed values at the reference stations for the negative effect of the glacier model, computed during the previous step. This iterative process converges rather rapidly towards a constant negative

value at the reference stations and results in a deepening of the glacial floor especially near the side walls.

The calculated ice depths of the surveyed glaciers are given in table I. The degree of adjustment of the physical model is indicated by the standard error between calculated and observed anomalies. This value is generally better than one tenth of a milligal after 10-20 steps of the iterative process. This indicates the accuracy of the mathematical fit between the model and the observed values. It does not however represent the accuracy of the calculated ice depths. These can be affected by unknown factors as local geologic or topographic anomalies, variations of the ice-rock density contrast (inclusion of morainic material within the ice), and the two-dimensional representation of a three-dimensional feature[☆].

The calculated model was fitted for as many points as had originally been measured on the glacier surface. The form of the subglacial valley is therefore very sensitive to small irregular variations of the gravity values at adjacent stations, which explains the rather angular subglacial relief found on some of the profiles. A smooth subglacial profile, generally associated with glacierized landforms, could have been obtained by reducing the number of points at which ice depths are calculated but without eliminating observational data (e.g. CORBATO, 1965). However this method is not better justified mathematically and has the serious drawback of eliminating information on possible irregularities in the subglacial relief such as the meridional ridges described below.
Fig. 2 gives an example of the calculation of the subglacial profile of Gunnestadbreen indicating the differences between ice depths calculated by the infinite slab method and the line integral method with (a) and without (b) the correction for the negative effect of the glacier on the reference values on rock.

(☆) It is planned to improve the model by introducing the effect of neighbouring glaciers.

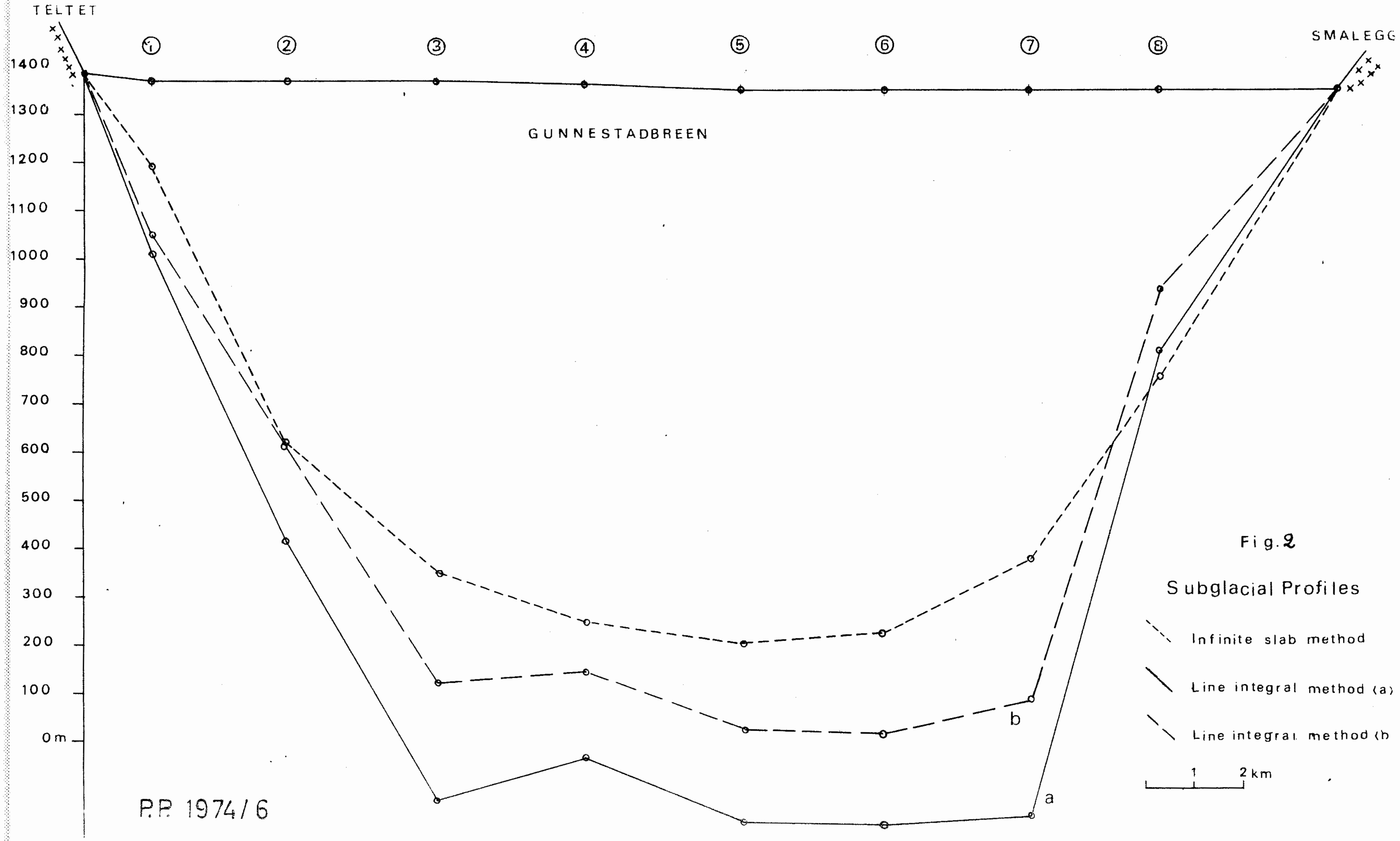

Fig. 2

Subglacial Profiles

TABLE 1 GRAVIMETRIC ICE THICKNESS DETERMINATIONS

- KREITSERISEN I (TAGGEN - TAGGEN JR)
- KREITSERISEN II (TAGGEN JR - LAGKOLLANE)
- HANSENBREEN (TANNGARDEN - LAGKOLLANE)
- HANSENBREEN (NILS LARSENPSELLET - BAMSEFJELLET)
- GLACIER between OTTO BORCHGREVINK - and NILS LARSENFJELLET
- GLACIER between TANNGARDEN and OTTO BORCHGREVINKFJELLA
- GLACIER between TANNGARDEN "1980" and PINVINANE
- GLACIER between TELTET and TANNGARDEN
- GLACIER between UTSTEINEN and TELTET
- GUNNESTADBREEN (TELTET - SMALEGGA)
- GILLOCKBREEN (SMALEGGA - ELLIS RIDGE) ≉
- JENNINGSBREEN (ELLIS RIDGE - BRATTNIPANE)
- DOTTEN - ROMNAESFJELLET (seal) ≉
- GJELLBREEN (AUSTKAMPANE - BRATTNIPANE)
- NIPEBREEN (MENIPA - AUSTKAMPANE)
- BYRDBREEN (FIDJELANDFJELLET - VESTHJELMEN)

≉ The gravity effect of the glacier on the reference value has not been taken into account for this profile.

Key to table

(1) Station number ; ≉ denotes reference station on rock
(2) Distance from reference point 1 in meters
(3) Ice thickness under reference level in meters
(4) Observed anomaly reduced to reference station in milligal
(5) Anomaly computed for adopted cross-section in milligal
(6) Total ice thickness in meters
(7) Elevation of station above reference level in meters
(8) Absolute elevation of bedrock above sealevel
(9) Standard error between (4) and (5) in milligal

A

KREITSERISEN I (TAGGEN - TAGGEN JR)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 *	0.0	0.0	-3.0112	-3.0112	0.0	0.0	1486.7998	0.0029
7 *	10100.0000	0.0002	-4.0224	-4.0226	0.0	120.7000	1607.4996	
6	7700.0000	639.2205	-43.2819	-43.2805	659.9204	20.7000	847.5793	
5	5800.0000	877.2732	-56.5833	-56.5868	883.1731	5.9000	609.5266	
4	4500.0000	961.5374	-58.6548	-58.6500	966.1372	4.6000	525.2625	
3	3200.0000	839.0107	-51.5905	-51.5926	847.8105	8.8000	647.7891	
2	1500.0000	225.9508	-23.4991	-23.4988	230.9508	5.0000	1260.8489	

KREITSERISEN II (TAGGEN JR - LAGKOLLANE)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 *	0.0	0.0	-7.6384	-7.6295	0.0	0.0	1510.0000	0.2066
10 *	14000.0000	0.0002	-7.1109	-7.1123	0.0	-23.0000	1487.0000	
9	12600.0000	564.9536	-40.0294	-40.0163	526.9536	-38.0000	945.0464	
8	11100.0000	825.5779	-55.3745	-55.4283	783.5779	-42.0000	684.4221	
7	9900.0000	925.8035	-60.4556	-60.3530	874.8035	-51.0000	584.1965	
6	8700.0000	656.7029	-62.5715	-62.7318	627.7029	-29.0000	853.2971	
5	7300.0000	1331.3127	-75.3900	-75.1692	1288.3127	-43.0000	178.6873	
4	5200.0000	1047.1104	-77.7231	-78.0688	1011.1104	-36.0000	462.8896	
3	4200.0000	1451.7395	-77.8474	-77.5030	1407.7395	-44.0000	58.2605	
2	2600.0000	879.5305	-61.9104	-62.0341	834.5305	-45.0000	630.4695	

HANSENBREEN (TANNGARDEN - LAGKOLLANE)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 *	0.0	0.0	-7.1434	-7.1357	0.0	0.0	1594.5000	0.2964
12 *	23200.0000	0.0002	-13.7547	-13.7389	0.0	-83.1000	1511.3998	
11	20260.0000	1449.5535	-83.2118	-83.4059	1357.4534	-92.1000	144.9465	
10	19120.0000	1658.5569	-88.9952	-88.3445	1591.6567	-66.9000	-64.0569	
9	18420.0000	1079.9331	-86.1489	-86.4760	988.2329	-91.7000	514.5669	
8	15520.0000	1113.5237	-88.0179	-87.9344	1065.2236	-48.3000	480.9763	
7	13630.0000	1453.6506	-99.6846	-99.7496	1391.1506	-62.5000	140.8494	
6	11500.0000	1786.0510	-108.4167	-108.4354	1702.2510	-83.8000	-191.5510	
5	9230.0000	1569.5054	-103.2016	-103.1009	1476.0054	-93.5000	24.9946	
4	7000.0000	1081.8584	-92.3165	-92.6555	983.5583	-98.3000	512.6416	
3	5850.0000	1671.7559	-91.6932	-91.2999	1566.9558	-104.8000	-77.2559	
2	3850.0000	936.4585	-71.3514	-71.4901	841.6584	-94.8000	658.0415	

HANSENBREEN (NILS LARSENFJELLET - BAMSEFJELLET)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 ★	0.0	0.0	-15.8632	-15.8676	0.0	0.0	1611.0000	0.0333
14 ★	23000.0000	0.0	-2.7774	-2.7776	0.0	58.0000	1669.0000	
13	21000.0000	30.4493	-7.0494	-7.0490	56.4493	26.0000	1580.5505	
12	19200.0000	211.0428	-22.8486	-22.8479	246.0428	35.0000	1399.9570	
11	17500.0000	444.7744	-44.6938	-44.6945	492.7744	48.0000	1166.2256	
10	15800.0000	1028.6301	-74.2720	-74.2632	1072.6301	44.0000	582.3699	
9	13950.0000	1502.5901	-95.8810	-95.8956	1537.5901	35.0000	108.4099	
8	12350.0000	1695.5615	-104.4256	-104.4122	1727.5615	32.0000	-84.5615	
7	10750.0000	1510.1816	-105.2984	-105.2722	1549.1816	39.0000	100.8184	
6	8950.0000	1371.9172	-106.6982	-106.7536	1416.9172	45.0000	239.0828	
5	7100.0000	1922.5930	-112.8235	-112.7483	1980.5930	58.0000	-311.5930	
4	5300.0000	1763.1934	-108.6984	-108.7213	1797.1934	34.0000	-152.1934	
3	3550.0000	1357.2046	-94.2954	-94.3055	1374.2046	17.0000	253.7954	
2	2200.0000	1181.8770	-77.2270	-77.2029	1192.8770	11.0000	429.1230	

OTTO BORCHGREVINKFJELLA - NILS LARSENFJELLET)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 ★	0.0	0.0	-1.9128	-1.9129	0.0	0.0	1645.0000	0.0472
4 ★	13400.0000	0.0002	-4.8262	-4.8366	0.0	-33.7000	1611.3000	
3	9000.0000	1181.6470	-66.5297	-66.4653	1236.9468	55.3000	463.3530	
2	5550.0000	695.4666	-50.1856	-50.2037	730.7664	35.3000	949.5334	

TANNGARDEN - OTTO BORCHGREVINKJELLA

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 ★	0.0	0.0	-3.7288	-3.7436	0.0	0.0	1595.0000	0.1037
3 ★	8300.0000	0.0002	-5.2805	-5.3010	0.0	49.7000	1644.7000	
2	4750.0000	1149.8315	-60.5621	-60.4584	1126.8315	-23.0000	445.1685	

TANNGARDEN - PINVINANE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 ★	0.0	0.0	-0.4293	-0.4293	0.0	0.0	1401.0000	0.0004
4 ★	6300.0000	0.0002	-0.4999	-0.4999	0.0	5.9000	1406.9000	
3	5050.0000	130.2641	-10.1147	-10.1149	139.3641	9.1000	1270.7358	
2	3450.0000	327.0198	-20.1076	-20.1072	325.9197	-1.1000	1073.9802	

TELTET - TANNGARDEN

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 A	0.0	0.0	-3.1148	-3.1178	0.0	0.0	1332.0000	0.0185
3 A	11000.0000	-0.0002	-2.4898	-2.4921	0.0	68.9000	1400.9000	
2	5000.0000	1039.8479	-58.9195	-58.9010	1038.8479	-1.0000	292.1521	

UTSTEINEN - TELTET

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 A	0.0	0.0	-4.3222	-4.3190	0.0	0.0	1339.0000	0.0646
4 A	7350.0000	0.0	-6.8121	-6.8219	0.0	46.0000	1385.0000	
3	4050.0000	1302.8562	-62.5862	-62.5125	1271.2561	-31.6000	36.1438	
2	3000.0000	789.7488	-54.5016	-54.5555	762.2488	-27.5000	549.2512	

GUNNESTADBREEN (TELTET - SMALEGGA)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 A	0.0	0.0	-13.0720	-13.0732	0.0	0.0	1385.0000	0.0558
10 A	13000.0000	0.0002	-10.2454	-10.2443	0.0	-36.0000	1349.0000	
9	11150.0000	581.0242	-56.9544	-56.9746	537.0242	-44.0000	803.9758	
8	9800.0000	1542.1582	-85.0476	-84.9858	1501.1582	-41.0000	-157.1582	
7	8300.0000	1559.3081	-96.6145	-96.6999	1521.3081	-38.0000	-174.3081	
6	6800.0000	1553.2102	-98.5918	-98.5165	1516.2102	-37.0000	-168.2102	
5	5200.0000	1421.2119	-95.5627	-95.6277	1398.2119	-23.0000	-36.2119	
4	3650.0000	1506.0361	-88.4967	-88.4430	1491.0361	-15.0000	-121.0361	
3	2100.0000	972.8945	-68.7923	-68.8163	956.8945	-16.0000	412.1055	
2	700.0000	367.8550	-37.7042	-37.6960	349.8550	-18.0000	1017.1450	

GILLOCKBREEN (SMALEGGA - ELLISRIDGE)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 A	0.0	0.0	0.0	-5.7925	0.0	0.0	1349.0000	0.1360
6 A	5200.0000	0.0	0.0	-19.2910	0.0	-23.3000	1326.0000	
5	5100.0000	571.4260	-26.4215	-26.2074	528.4260	-43.0000	777.5740	
4	4450.0000	446.4172	-39.2837	-39.4195	407.4172	-39.0000	902.5828	
3	3000.0000	1144.5613	-55.0696	-54.9786	1111.0613	-33.5000	204.4387	
2	1450.0000	555.0552	-40.1973	-40.2358	530.5552	-24.5000	793.9448	

JENNINGSBREEN (ELLISRIDGE - BRATTNIPANE)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 ⚝	0.0	0.0	-8.0798	-8.0788	0.0	0.0	1299.0000	0.0771
7 ⚝	8000.0000	0.0	-10.4220	-10.4114	0.0	7.8000	1306.8000	
6	6200.0000	892.6548	-59.3865	-59.4674	900.7546	8.1000	406.3452	
5	4750.0000	1440.8757	-74.9608	-74.8487	1445.9756	5.1000	-141.8757	
4	3100.0000	1097.2556	-69.0497	-69.1468	1100.8555	3.6000	201.7444	
3	1600.0000	712.6528	-49.6385	-49.6051	721.9526	9.3000	586.3472	
2	550.0000	194.4328	-24.4256	-24.4330	192.4328	-2.0000	1104.5671	

NUNATAK 1550 - SEAL (ROMNAESFJELLET)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 ⚝	0.0	0.0	0.0	-3.5236	0.0	0.0	1186.0000	0,0028
21 ⚝	32700.0000	-0.0002	0.0000	-7.6438	0.0	-244.0000	942.0000	
20	31150.0000	827.1609	-43.3363	-43.3341	565.1609	-262.0000	358.8391	
19	29500.0000	439.3831	-39.2415	-39.2438	182.3831	-257.0000	746.6169	
18	28000.0000	645.5442	-44.5879	-44.5861	399.5442	-246.0000	540.4558	
17	25050.0000	666.2314	-49.9300	-49.9321	450.2314	-216.0000	519.7686	
16	23400.0000	830.4829	-54.6627	-54.6594	634.4829	-196.0000	355.5171	
15	21850.0000	749.1101	-52.4287	-52.4317	562.1101	-187.0000	436.8899	
14	20400.0000	595.1021	-47.4456	-47.4432	420.1021	-175.0000	590.8979	
13	18800.0000	629.2871	-48.6369	-48.6405	486.2871	-143.0000	556.7129	
12	17350.0000	781.4543	-53.2642	-53.2588	648.4543	-133.0000	404.5457	
11	15800.0000	724.2483	-53.9199	-53.9258	602.2483	-122.0000	461.7517	
10	14600.0000	761.9143	-55.2804	-55.2767	651.9143	-110.0000	424.0857	
9	12650.0000	821.2075	-57.9191	-57.9205	729.2075	-92.0000	364.7925	
8	11100.0000	814.9231	-58.5047	-58.5043	733.9231	-81.0000	371.0769	
7	9350.0000	815.0103	-59.1173	-59.1177	746.0103	-69.0000	370.9897	
6	7850.0000	853.6560	-60.6236	-60.6236	796.6560	-57.0000	332.3440	
5	6150.0000	900.2375	-62.1574	-62.1559	852.2375	-48.0000	285.7625	
4	4550.0000	933.0166	-61.1540	-61.1568	886.0166	-47.0000	252.9834	
3	2900.0000	834.6265	-51.0609	-51.0587	782.6265	-52.0000	351.3735	
2	1350.0000	93.6727	-17.1332	-17.1336	72.6727	-21.0000	1092.3271	

DOTTEN - NUNATAK 1550

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 A	0.0	0.0	0.0	-16.2561	0.0	0.0	1366.0000	0,0392
10 A	15700.0000	-0.0002	0.0000	-4.6715	0.0	-180.0000	1186.0000	
9	14300.0000	427.6572	-30.4994	-30.5013	273.6572	-154.0000	938.3428	
8	12200.0000	600.2063	-45.0418	-45.0350	460.2063	-140.0000	765.7937	
7	10150.0000	742.6570	-59.6431	-59.6672	625.6570	-117.0000	623.3430	
6	8450.0000	1301.7583	-75.1383	-75.0975	1199.7583	-102.0000	64.2417	
5	5800.0000	1014.8682	-73.8382	-73.8868	918.8682	-96.0000	351.1318	
4	4000.0000	1131.6892	-71.8035	-71.7390	1045.6892	-86.0000	234.3108	
3	2500.0000	908.7905	-64.4426	-64.4948	822.7905	-86.0000	457.2095	
2	900.0000	871.6223	-49.5699	-49.5424	792.6223	-79.0000	494.3777	

GJELLBREEN (AUSTKAMPANE - BRATTNIPANE)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 A	0.0	0.0	-12.0797	-12.0904	0.0	0.0	1117.5000	0.0398
6 A	11300.0000	0.0002	-13.6357	-13.6516	0.0	61.5000	1179.0000	
5	9100.0000	1289.8398	-72.0982	-72.0321	1268.3398	-21.5000	-172.3398	
4	7200.0000	1250.0469	-81.5297	-81.5277	1237.5469	-12.5000	-132.5469	
3	4900.0000	1188.0601	-81.1660	-81.1570	1184.5601	-3.5000	-70.5601	
2	2500.0000	1295.3315	-72.8274	-72.7841	1277.8315	-17.5000	-177.8315	

NIPEBREEN (MENIPA-AUSTKAMPANE)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 A	0.0	0.0	-15.5359	-15.6236	0.0	0.0	1143.0000	0.3302
7 A	6000.0000	-0.0002	-15.5134	-15.5844	0.0	-25.5000	1117.5000	
6	5000.0000	915.6580	-52.2819	-52.0738	913.8579	-1.8000	227.3420	
5	3800.0000	1076.1658	-65.3857	-65.2585	1070.7156	-5.4500	66.8342	
4	2500.0000	1087.6179	-68.2228	-68.2686	1077.5979	-10.0200	55.3821	
3	1200.0000	1244.9558	-60.2058	-59.7950	1229.4558	-15.5000	-101.9558	
2	100.0000	0.0	-20.0849	-19.5237	-34.4000	-34.4000	1143.0000	

BYRDBREEN (FIDJELANDFJELLET - VESTHJELMEN)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1 A	0.0	0.0	-6.4503	-6.4506	0.0	0.0	982.0000	0.0018
11 A	23600.0000	0.0	-5.6700	-5.6702	0.0	33.0000	1015.0000	
10	21400.0000	694.5972	-45.5438	-45.5424	715.5972	21.0000	287.4028	
9	19200.0000	782.2415	-57.5500	-57.5513	803.2415	21.0000	199.7585	
8	16700.0000	1043.5115	-69.4476	-69.4448	1053.5115	10.0000	-61.5115	
7	14500.0000	1075.5107	-71.9137	-71.9155	1085.5107	10.0000	-93.5107	
6	11350.0000	902.4976	-63.9438	-63.9416	909.4976	7.0000	79.5024	
5	9500.0000	700.1016	-57.7070	-57.7084	699.1016	-1.0000	281.8984	
4	6500.0000	988.0388	-65.4931	-65.4908	979.0388	-9.0000	-6.0388	
3	4400.0000	955.1340	-63.1688	-63.1702	950.1340	-5.0000	26.8660	
2	2000.0000	699.4707	-46.8147	-46.8133	694.4707	-5.0000	282.5293	

4. *MOVEMENT OBSERVATIONS*

The positions of the stakes were determined by theodolite resection from the main triangulation scheme, estabished by K.V. Blaiklock during the 1959 and 1960 Belgian Antarctic Expedition. At each station two or more sets of horizontal angles were observed with Wild T2 or T3 theodolites. The angles were measured between as many clearly identified peaks as possible with well known grid coordinates. The movement was measured for periods ranging from 205 to 1509 days.
The 1959, 1960 and 1965 movement observations have been calculated with a semi-graphic method, an example of which is given by VAN AUTENBOER and BLAIKLOCK (1966).
The calculations of the grid coordinates from the 1966 observations were completely carried out by computer : an approximate position of the stake was first determined from two angles only. These provisional coordinates were then adjusted to give final values by fitting them to all observed rays using the method of least squares. When the standard error of the final result proved too big some observations were rejected after comparison of the observed directions with the computed ones. The whole process was then repeated until acceptable errors were obtained.
Example 1 gives an indication of the computer results and the errors affecting the measurements.
Table II gives the tabulated results.

Example 1

HANSENBREEN Stake nr. 2

Date of observation	20.04.66		16.11.66	
Number of rays	5		6	
	X	Y	X	Y
Approximate coordinates* in m	142 074.8	171 946.0	142 070.6	171 968.2
Final coordinates	142 073.8	171 945.6	142 068.1	171 966.7
Standard error	0.6	0.3	1.0	0.5
			ΔX	ΔY
Difference of coordinates in m			-5.8	+21.2
Standard error			1.2	0.6

	Magnitude	Azimuth
Resulting movement vector	21.9 m ± 0,6 m	345° ± 3°
Movement per day	10.4 cm day^{-1} ± 0.3 cm day^{-1}	345° ± 3°
Movement per year	38.1 m yr^{-1} ± 1.0 m yr^{-1}	345° ± 3°

* Origin of coordinates = Teltet

TABLE 2 ICE-FLOW MEASUREMENTS IN THE SØR-RONDANE 1959-66

- KREITSERISEN (I - II)
- HANSENBREEN
- GLACIER between UTSTEINEN and TELTET
- GUNNESTADBREEN
- GILLOCKBREEN
- JENNINGSBREEN
- PIEDMONT ZONE
- GJELLBREEN
- NIPEBREEN
- BYRDBREEN

Key to table

(1) Station number

(2) Period of observation

(3) Number of days

(4) Movement in $cm.day^{-1}$

(5) True azimuth of movement

(6) Movement in $m.year^{-1}$

KREITSERISEN

(1)	(2)	(3)	(4)	(5)	(6)
1	22.04.66 - 19.11.66	211	6.13	325	22.37
2	24.04.66 - 20.11.66	210	5.18	000	18.90
3	24.04.66 - 20.11.66	210	4.70	357	17.10
4	26.04.66 - 21.11.66	209	1.06	359	3.87
5	26.04.66 - 21.11.66	209	11.90	066	43.43
6	28.01.65 - 19.11.66	666	2.45	353	8.94
7	28.01.65 - 20.11.66	666	5.59	008	20.40

HANSENBREEN

1	19.04.66 - 14.11.66	209	10.29	336	37.56
2	20.04.66 - 16.11.66	210	10.44	345	38.10
3	20.04.66 - 16.11.66	210	8.20	345	29.93
4	20.04.66 - 19.11.66	213	9.99	278	36.46
5	27.01.65 - 24.11.66	667	19.35	344	34.27
6	27.01.65 - 16.11.66	667	7.90	341	28.83

GLACIER BETWEEN TELTET AND UTSTEINEN

1	22.12.60 - 28.12.65	1.498	0.24	030	0.87
2	22.12.60 - 28.12.65	1.498	0.26	038	0.95

GUNNESTADBREEN

(1)	(2)			(3)	(4)	(5)	(6)
1	21.12.60	-	28.01.65	1.499	0.37	006	1.35
2	21.12.60	-	28.01.65	1.499	2.45	015	8.94
3	21.12.60	-	27.01.65	1.498	3.28	024	11.97
4	20.12.60	-	27.01.65	1.499	2.77	029	10.11
5	20.12.60	-	26.01.65	1.498	2.57	028	9.38
6	20.12.60	-	26.01.65	1.498	2.55	026	9.30
7	20.12.60	-	25.01.65	1.497	1.75	023	6.38
8	20.12.60	-	25.01.65	1.497	0.63	023	2.30
9	13.04.60	-	27.12.60	258	3.70	040	13.50
10	13.04.60	-	27.12.60	258	4.00	040	14.60
10 A	11.05.66	-	02.12.66	205	1.72	037	6.28
10 B	11.05.66	-	02.12.66	205	0.80	020	2.92
11	08.04.59	-	26.12.60	628	8.09	006	29.53
12	08.04.59	-	26.12.60	628	10.48	009	38.25
13	08.04.59	-	26.12.60	628	1.52	022	5.55
14	08.04.59	-	26.12.60	628	2.56	025	9.34
15	08.04.59	-	12.04.60	370	1.07	009	3.90

GILLOCKBREEN

1	16.12.60	-	25.01.65	1.501	0.09	004	0.33
2	16.12.60	-	25.01.65	1.501	0.24	011	0.88
3	16.12.60	-	25.01.65	1.501	0.20	032	0.73

JENNINGSBREEN

1	03.03.60	-	17.12.60	289	0,10	270	0.36
2	17.12.60	-	25.01.65	1.500	0.11	339	0.40
3	24.02.60	-	17,12.60	297	0.10	000	0.36
4	17.12.60	-	24.01.65	1.499	0.19	308	0.69
5	17.03.60	-	01.12.60	259	0;10	300	0.36
6	01.01.60	-	24.01.65	1.484	0.09	343	0.33
7	01.01.60	-	25.01.65	1.485	0.09	344	0.33

PIEDMONT ZONE

(1)	(2)	(3)	(4)	(5)	(6)
6	21.04.60 - 16.01.61	270	1.90	028	6.93

GJELLBREEN

1	28.02.60 - 11.12.60	287	1.80	335	6.57
2	28.02.60 - 11.12.60	287	2.00	329	7.3
3	27.02.60 - 11.12.60	288	2.50	349	9.12
4	28.02.60 - 11.12.60	287	2.50	002	9.12
5	13.12.60 - 23.01.65	1.502	2.16	358	7.88
6	26.02.60 - 13.12.60	291	0.80	000	2.92
7	06.12.60 - 23.01.65	1.509	0.15	324	0.54
8	29.02.60 - 09.12.60	286	2.80	003	10.22
9	01.03.60 - 08.12.60	283	2.60	036	9.49

NIPEBREEN

1	23.01.65 - 23.12.66	699	1.55	291	5.65

BYRDREEN

1	02.04.66 - 14.12.66	256	4.81	000	17.56
2	31.03.66 - 14.12.66	258	4.55	007	16.60
3	01.04.66 - 14.12.66	257	5.13	333	18.72
4	01.04.66 - 14.12.66	257	10.71	224	39.09
5	03.04.66 - 14.12.66	255	9.24	010	33.72

5. ANNUAL DISCHARGE AND MASS FLUX

The annual discharge and the mass flux of the surveyed glaciers are represented in table III. The estimates are maximum ones seen that the measured surface velocities were applied to the corresponding vertical sections of the cross profiles without correction for the reduction of the velocity with depth. Data on which this reduction of velocity in thick outlet glaciers of the continental ice sheet could be based, are lacking*. Two boreholes reach bedrock underneath thick polar ice (Byrdstation, Antarctica and Camp Century, Greenland) but no differential movement has been recorded. No deep drillings have been made on outlet glaciers of the continental ice sheet. It seemed therefore best to calculate the maximum value of the discharge rather than to apply an arbitrary reduction (e.g. GJESSING, 1972).

Table III also gives an estimate of the total mass output and of the average mass flux through the 220 km long section between Taggen and Vesthjelmen. Included in the latter are estimated values for Kampbreen and for the local glacier between Utsteinen and Perlebandet. These are based upon an extrapolation of the very consistent mass flux of the measured local glaciers ($0.0003\ 10^{15}$ g km^{-1} yr^{-1}).

6. FLOW ANALYSIS

Fig. 3 represents the computed cross-sections and the observed movement vectors within the general pattern of ice flow in the Sør-Rondane area. The ice flow is schematized by flow lines, drawn as orthogonals to the surface contours and origi-

(*) PATERSON (1969) reviews the available information on the ratios of surface to glacier bed velocities. These data; restricted to 7 temperate, wet based, alpine glaciers of reduced thickness, show that sliding over bedrock comprises roughly half the surface movement. Large variations can occur over comparatively short distances (between two drill sites, distant by 1,5 km and situated on the same flow line on Athabasca glacier (Canada), the ratio varies from 0.75 to 0.10).

nating at equidistant points along an east-west line in 72° 40' S. The flow of the local glacier system has been indicated in addition to the flow lines which represent the main directions of the flow of the ice from the polar plateau. In the construction of the flow lines, use has been made of the above mentioned maps being prepared for publication by Norsk Polarinstitutt. It has been remarked that the surface contours of the ice are locally weak (S. HELLE, pers. comm.). A remarkably good correspondence however exists between the direction of the flow lines and the measured azimuths of the markers and even local anomalous directions are corroborated by the flow line analysis (e.g. Hansenbreen N° 4).
In addition attention was paid to the orientation of some supraglacial morainic deposits.

Table III

DISCHARGE AND MASS FLUX*

	Discharge in $km^3\ yr^{-1}$	Mass flux in $10^{15}g\ km^{-1}\ yr^{-1}$
Kreitserisen I	0.0412	0.003757
II	0.1521	0.009994
Hansenbreen	0.7400	0.029344
Teltet Utsteinen	0.0024	0.000300
Gunnestadbreen	0.1056	0.007475
Gillockbreen	0.0017	0.000304
Jenningsbreen	0.0025	0.000288
Gjellbreen	0.0745	0.006063
Nipebreen	0.0018	0.000268
Byrdbreen	0.4704	0.018339
TOTAL mass output**	1.5988	0.006686

(*) Mass flux : discharge per km of width of cross section.

(**) Total mass output through Sør-Rondane area between Taggen and Vesthjelmen. This figure includes the discharge of the glaciers given here and an estimated value for the local glaciers (Kampbreen and the local glacier between Utsteinen and Perlebandet). The latter values have been estimated using the very consistent mass flux values of the local glaciers.

7. *REGIONAL DESCRIPTION*

Hansenbreen, is the most important of the surveyed glaciers and its discharge (0.740 km^3 yr^{-1}) is as large as the combined mass transport of all other glaciers in the Sør-Rondane.
High surface velocities (up to 38 m yr^{-1}) and the greatest ice depths in the Sør-Rondane (1980 m with the floor of the glacier at -311 m) were measured on this glacier. The mass flux attains 0.0293 10^{15} g km^{-1} yr^{-1}, the highest value in the surveyed area.

Hansenbreen is situated immediately west of the apex of the wedge-shaped mountain area, which indicates that it is fed by a practically unobstructed flow of ice from the polar plateau. Its discharge might also be increased by the ice deflected to the west by the range.
A maximum depth of the floor of the subglacial valley (311 m below sea level) is measured on the southern profile ; on the northern one the glacier floor is situated close to sea level. The subglacial relief seems therefore to become shallower to the north which corresponds to the increase to the north of the divergence of the flow.

The subglacial topography of the glacier valley is not a simple one : there is evidence for the existence of subglacial longitudinal ridges - locally substantiated by the existence of heavily seracced and crevassed areas - which divide the glacier. This seems to indicate that Hansenbreen, as the other important drainage glaciers in the area, is in fact a composite glacier.

Byrdbreen, with a discharge of 0.470 km^3 yr^{-1} and a mass flux of 0.0183 10^{15} g km^{-1} yr^{-1} is, in importance, the second glacier in the range. In its northern part it is a composite glacier divided in two by a subglacial longitudinal ridge. The existence of this ridge indicated by the gravimeter measurements is substantiated by the presence upstream of nunataks (Krakken).

The greatest discharge takes place on the eastern side of the ridge where the highest surface velocities (up to 39 m yr^{-1}) and the greatest ice depths (up to 1085 m) are recorded. This part of Byrdbreen is directly fed by the ice flow from the polar plateau and has a weak and very regular surface gradient which explains the absence of crevasses.
The western side of the glacier (north of Bautaen) is shallower and the surface velocities are lower (from 17 to 19 m yr^{-1}). It results from the coalescence of several narrow and steep glaciers cutting their individual gorge through the mountains. These glaciers originate from the edge of the plateau. The general geography of the area apparently indicates that they could originate from a local ice dome to the south of Gunnar Isachsenfjellet rather than from the polar plateau.
The vast mamillated surfaces of Balchenfjella to the east of Balchenfjella have been taken as proof of the former greater importance of Byrdbreen and as an indication of the reduction of the plateau glacierization (VAN AUTENBOER, 1964).

Gunnestadbreen and Gjelbreen have several similarities : their discharge (respectively 0.106 and 0.074 km^3 yr^{-1}) and mass flux (0.0075 and 0.0061 10^{15} g km^{-1} yr^{-1}) are of the same order of magnitude as are their surface velocities and ice depths.
When passing through the mountains both glaciers cut a rather narrow gorge, the orientation of which deviates considerably from the general pattern of the ice flow.
When taking into account the mathematical method of calculating the ice depths, it is clear that both outlet glaciers have a subglacial profile which is strongly suggestive of a U-shaped valley.
Gunnastadbreen widens considerably north of Walnumfjellet and the velocity markers indicate a strong eastward component of the movement. In earlier papers (VAN AUTENBOER, 1964 ; VAN AUTENBOER and BLAIKLOCK, 1966) this has been interpreted as the compensation by this active glacier for the disappearance of former tributary glaciers on Walnumfjellet. The subglacial

profile between Romnaesfjellet and Dotten - obtained since - however indicates that the subglacial Gunnestadbreen valley deviates to the north-east. This means that the north-eastern direction observed at the markers of Gunnestadbreen indicate a general direction of flow rather than a local one. A comparison between the subglacial profiles of Gunnestadbreen on the Teltet-Smålegga line and its extension on the Romnaesfjellet-Dotten line indicates shallower subglacial relief to the north, which corresponds to the increasingly divergent flow in the piedmont area.

Kreitserisen I (west) is the plateau drainage glacier with the lowest mass flux rate (0.0038 10^{15} g km^{-1} yr^{-1}). The very low discharge is explained by the existence to the south of a buried highland of which the highest peaks pierce the ice cover as granitic nunataks (Tertene).

Kreitserisen II (east) has a mass flux which is of the same order of magnitude as Gunnestadbreen. This glacier appears to be fed by an unobstructed flow of ice from the polar plateau. The subglacial profile is complicated, showing as in the case of Hansenbreen, the existence of subglacial ridges which seem to indicate that this glacier is a composite one.

Gillock, Ellis and Jenningsbreen are emissaries of a small ($\sim$ 175 km^2) local ice dome. The latter is situated on the edge of the polar plateau, south of Walnumfjellet and reaches an elevation of 2500 m. Part of the ice flow from the dome joins Gunnestadbreen and Gjelbreen while the rest cascades down into the three above mentioned glaciers. They can therefore be considered as local glaciers, which is confirmed by their very low discharge and their mass flux values (0.0003 10^{15} g km^{-1} yr^{-1}) which are consistent with those of the other local glaciers. An indirect confirmation of this local origin could be seen in the composition of the hillocky morainic deposits on the east side of Jenningsbreen (SOUCHEZ, 1966).
Information on the surface elevations on the south side of the

mountains has only recently become available and these glaciers were considered as plateau drainage glaciers in earlier papers (VAN AUTENBOER, 1964 ; VAN AUTENBOER and BLAIKLOCK, 1966). The glacier smoothed surfaces of some isolated nunataks situated in the area south of Walnumfjellet and rising some 150 m above the present surface of the ice, had therefore been taken as a minimum indication of the lowering of the level of the plateau (VAN AUTENBOER, 1964). It now appears that these glaciated surfaces can be explained by the reduction in thickness of a local ice dome on the edge of the plateau. Information on the surface elevations on the edge of the plateau in the Sør-Rondane area is unfortunately still too scant to decide whether this conclusion can be generalized for other glaciated nunataks south of the range. There is as yet no glacial-geological evidence in the Sør-Rondane to establish the relationship between local and plateau glaciation. It also appears that it will be necessary to obtain further information on the extension and role of the local drainage systems before concluding to the significance of some of the observed glaciated surfaces.

Both Nipebreen and the glacier between Teltet and Utsteinen have their drainage area entirely situated on the northern slopes of the mountains. Discharge values are rather weak, seen that they are based on few measurements (1 movement observation for Nipebreen and 2 movement and gravimetric stations on the glacier between Teltet and Utsteinen).
Discharge value are very low. The mass flux values however show a remarkably good agreement with the other local glaciers.

8. DISCUSSION

8.1. Dronning Maud Land drainage system

The Sør-Rondane are part of the coastal mountains of Dronning Maud Land extending between 15° W and 30° E.
These mountain ranges follow the northern limit of a still poorly defined and largely unexplored drainage system (Dronning Maud Land Drainage system). The south-

eastern limit of this system apparently corresponds to the northern part of the East Antarctic Ice divide which in Dronning Maud Land trends from the south-south-east to the north-north-west and locally culminates at 3.700 m in the Fuji divide (77° 40' S and 42° E) (FUJIWARA and others, 1971). Russian authors (KAPITZA, 1967 ; IVASHUTINA, 1966) assumed that this part of the divide corresponds to the meridional trending, subglacial Vernadsky mountains(*) forming the northwards extension of the subglacial Gamburtsev mountains better documented in the Vostok - Pole of Inaccessibility area (EVANS and ROBIN, 1972). FUJIWARA and others (1971) however state that the results of the Japanese traverse crossing the Fuji Divide do not substantiate the deductions made by the Soviet authors.

To the south and to the west little is known about the limits of the drainage system. Mass transport measurements of Jutulstraumen, given elsewhere(**), make it however clear that there is some doubt about the outline of an ice divide ending near the coast east of the Greenwich meridian, as indicated on the widely used map of GIOVINETTO (1964).

Surface elevations on the South Pole-Queen Maud Land traverse (e.g. BEITZEL, 1971 ; PICCIOTTO and others, 1971) indicate that a large part of the continental ice sheet in Dronning Maud Land flows towards the Weddell sea and Filchner ice shelf. This indicates that an ice divide, situated in the unexplored area between the S.P.Q.M.L. traverse and the coastal mountains forms the southern limit of the basin feeding the outlet glaciers of eastern Dronning Maud Land. South of the Sør Rondane this divide might be situated quite close to the mountains as indicated by some isolated surface elevations in that area (G. De Rom, pers. comm.).

(*) Evidence for the northwards extension of this subglacial range (?) could be found in the Dronning Fabiolafjella, the Rüser Larsen peninsula and the submarine Gunnerus-ridge. The ice depths of the Soviet traverse are presented together with the seismic determinations of the first two legs of the S.P.Q.M.L. traverse in a fence diagram by BEITZEL (1971).

(**) Results of the 1968 Belgian geophysical traverse across Jutulstraumen to be published.

8.2. Sør-Rondane

It seems very likely that the relative proximity of this ice divide influences the flow and the mass transport through the range. The Sør-Rondane, as the other coastal mountains in Dronning Maud Land, are more or less perpendicular to the main flow of ice from the continental ice sheet on which they have a damming effect.

The general orientation of the ice flow in the Sør-Rondane area is from the south-east to the north-west. The damming of the ice flow by the range is clearly illustrated : only three main outlet glaciers - Gunnestadbreen, Gjelbreen and Byrdbreen - cut through the range. The direction of the flow of these glaciers - or of their tributaries in the case of Byrdbreen -clearly deviates from the general orientation of the ice flow. Maximum flow is measured in the unobstructed area to the west of the range where mass transport through Hansenbreen alone is larger than the combined output of all the other glaciers in the range.

The obstruction of the ice flow by the Sør-Rondane might also be the cause of the increased surface elevations to the south of the range and of the existence of an undisturbed, crevasse-free zone extending northwards from Romnaesfjellet to the coast.

This also seems related to a rather sheltered area immediately to the north of the range, between Hansenbreen and Gunnestadbreen. No outlet glaciers cut through this area, entirely covered by local glaciers, and which probably corresponds to a glacierized highland forming the subglacial extension of the Wideröefjellet and Vikinghögda massifs.

Information on the subglacial topography is restricted to a few gravimeter profiles and a couple of seismic depth determinations (DIETERLE and PETERSCHMITT, 1964). It is clear that the Sør-Rondane with the floor of the main glaciers below or close to sea level resemble an ice covered fjord landscape. There are furthermore indications (Hansenbreen and Romnaes to Dotten profiles) that the glacier valleys are deepest at the foot of the slopes rising to the plateau and become shallower to the north, underneath the progressively diverging flow. This local overdeepening is characteristic for fjord valleys (e.g. Sognefjord and Hardangerfjord in Norway, where rocky submarine thresholds are generally related to sounds or low lands where the ice could spread out and have less erosive effects (HOLTEDAHL, 1967)).

Russian authors (RAVICH and others, 1969 ; RAVICH and KAMENEV, pers. comm.) believe the ice flow in this range, as in other parts of the coastal mountains of Dronning Maud Land, to be completely controlled by tectonics : the major massifs of the mountains are delimited by vertical faults of mesozoic-cenozoic age forming horst and graben structures. Structural control of glacier flow in Dronning Maud Land is not to be excluded : the Jutulstraumen ice stream further west e.g. is situated on a down faulted block (ROOTS, 1969). In the Sør-Rondane however there is no geological or geophysical field information that points to the existence of a multitude of major faults*. The ice flow analysis adds no further information but certainly does not add weight to the postulated existence of these block faults.

There is no evident relationship between the flow lines and mass transport. Fig. 3 however shows a certain proportionality between the number of flow lines passing through a glacier and its measured mass transport. This relationship confirms the discharge measurements if we can assume a rather even distribution of the mass flow at the edge of the plateau.

The survey has allowed measurement of the mass transport of all major glaciers in the Sør-Rondane and from table III it can be concluded that there is a clear relationship between the mass flux values and the different types of glaciers under consideration.

The mass flux values of the local glaciers, including the

(*) The ridge west of Gjelbreen (a long and steep rectilinear scarp) might be the morphological expression of a north-south orientated vertical fault.

ones originating from a local ice dome near the edge of the plateau, are very consistent (0.0003 10^{15} g km^{-1} yr^{-1}). The mass flux values of the drainage glaciers on the other hand vary from 0.0038 10^{15} g km^{-1} yr^{-1} (Kreitserisen I) to 0.0293 10^{15} g km^{-1} yr^{-1} (Hansenbreen), highlighting the complexity of the drainage pattern in the area.

The mean mass flux through the Sør-Rondane taken as a whole (between Taggen and Vesthjelmen) is estimated at 0.0067 10^{15} g km^{-1} yr^{-1}. The mass flux values for the Sør-Rondane are very low when compared with those given by GIOVINETTO and others (1966) for the glaciers in the Trans-Antarctic mountains, the western part of the Ross Ice Shelf drainage system. These authors conclude to the following values :

0.25 10^{15} g km^{-1} yr^{-1} (glaciers with large drainage basins)
0.05 10^{15} g km^{-1} yr^{-1} (glaciers with small basins and cirque glaciers)
0.02 10^{15} g km^{-1} yr^{-1} (piedmont glaciers)

The highest mass flux value in the Sør-Rondane area (Hansenbreen : 0.0293 10^{15} g km^{-1} yr^{-1}) falls between the two lowest estimates of the Trans Antarctic mountains. The mean mass flux in the Sør-Rondane (0.0067 10^{15} g km^{-1} yr^{-1}) is consequently also appreciably lower than the one given for the Trans-Antarctic mountains (0.04 10^{15} g km^{-1} yr^{-1}).
It is especially low when compared with the mean mass flux for the periphery of the grounded ice sheet in Antarctica which is estimated as 0.09 10^{15} g km^{-1} yr^{-1}(GIOVINETTO, 1964 cited in GIOVINETTO and others, 1966).
The only other mass transport measurements in Dronning Maud Land are those of Jutulstraumen ice stream. The discharge of this 49 km wide glacier has been given elsewhere(☆) as 10,8 km^3 yr^{-1}, nearly 7 times the amount of ice flowing through the 220 km long section of the Sør-Rondane. The mass flux value for Jutulstraumen (0.2 10^{15} g km^{-1} yr^{-1}) on the other hand is

(☆) Results of the 1968 Belgian geophysical traverse across Jutulstraumen (to be published.)

close to that assigned to glaciers with a large drainage basin in the Trans-Antarctic mountains.

The comparison between the discharge of Jutulstraumen and of the Sør-Rondane confirms the view, already expressed by MELLOR (1959) that mass transport by ice streams, which occupy a small fraction of the drainage periphery are responsible for the removal of more ice from the continent than the sheet flow over the remaining length of coast. It also explains why only ice streams can still be recognized as individual geographic features within the coastal areas of high accumulation and why only the latter give rise to characteristic glacier tongues.

The low rate of discharge through the Sør-Rondane might mean that the outlet glaciers in this area are fed by a comparatively small drainage basin. This confirms the above made suggestion of the proximity of an ice divide to the south of the mountains. WILSON and CRARY (1961) have shown that the Skelton glacier - which has a discharge comparable to that of Hansenbreen - is mainly fed by a local accumulation area on the plateau side of the Trans-Antarctic mountains and not by the main flow of ice from the plateau. These authors also suggest that this situation, related to the lowering of the surface of the plateau, is typical of most of the glaciers on the west side of the Ross Ice Shelf as far south as the Beardmore glacier. A somewhat similar situation might exist behind the mountain ranges in Dronning Maud Land, with the flow from the plateau channeled into at least two glacier streams (Jutulstraumen[*] and the glacier stream east of Novolazarevskaya[**]) and with the other glaciers mainly draining a marginal section of the continental ice sheet.

(*) GJESSING (1972) gives mass transport data and velocity measurements for Jutulstraumen.

(**) For velocity measurements on glaciers in the vicinity of Novolazarevskaya Station, see KRUCHININ and others (1967).

9. *APPENDIX*

The movement of lateral bulges.

The bottom part of some dry local valleys in the Sør-Rondane appear well below the surface level of the still active glaciers to which they once contributed (Smalegga, Walnumfjellet, Jenningsbreen, Mefjell ...).
A lateral lobe of ice of the active glacier seems to advance into the dry glacial valleys thus compensating for the disappearance of the local ice supply (VAN AUTENBOER, 1964). During the 1966 Belgian-Dutch Antarctic Expedition detailed maps were made over some of these lateral bulges and the movement of three markers was measured on a lateral lobe of Gunnestadbreen at the mouth of a small local dry valley on Smalegga.
Fig. 7 shows the map of the Smalegga occurrence (illustration in VAN AUTENBOER, 1962). It indicates, as expected, a small movement of the marker stakes towards the dry local valley (stake 1 : 1.30 m yr^{-1} ; stake 2 : 0.32 m yr^{-1} ; stake 3 : 0.21 m yr^{-1}).

It also shows the structure of the lateral ice lobe and furnishes a suggestion for the local mass budget of the advancing ice lobe. The latter which has a denivellation of some 50 m is mainly composed of blue glacier ice. It ends on an arcuate melt area, which reaches a maximum width in its lowermost central part and overlies on hillocky shear moraine. The bottom part of the dry local valley is covered by a blue ice lake in which frost mounds - already described by VAN AUTENBOER (1962) - occur.
The "melt area" described here is in fact a zone of thin ice (1 to 2 thick in the lateral zone), with penitent like features immediately overlying the shear moraine.
In summer, in spite of the severity of the climate(*), melting of the ice takes place in contact with the morainic debris warmed up by the solar radiation. This melt water, probably percolating through the superficial parts of the moraine, feeds the lake in the dry glacial valley.

(*) The mean annual temperatures should be close to -25°C as read from the map of the average annual temperature (WEXLER and RUBIN, 1961).

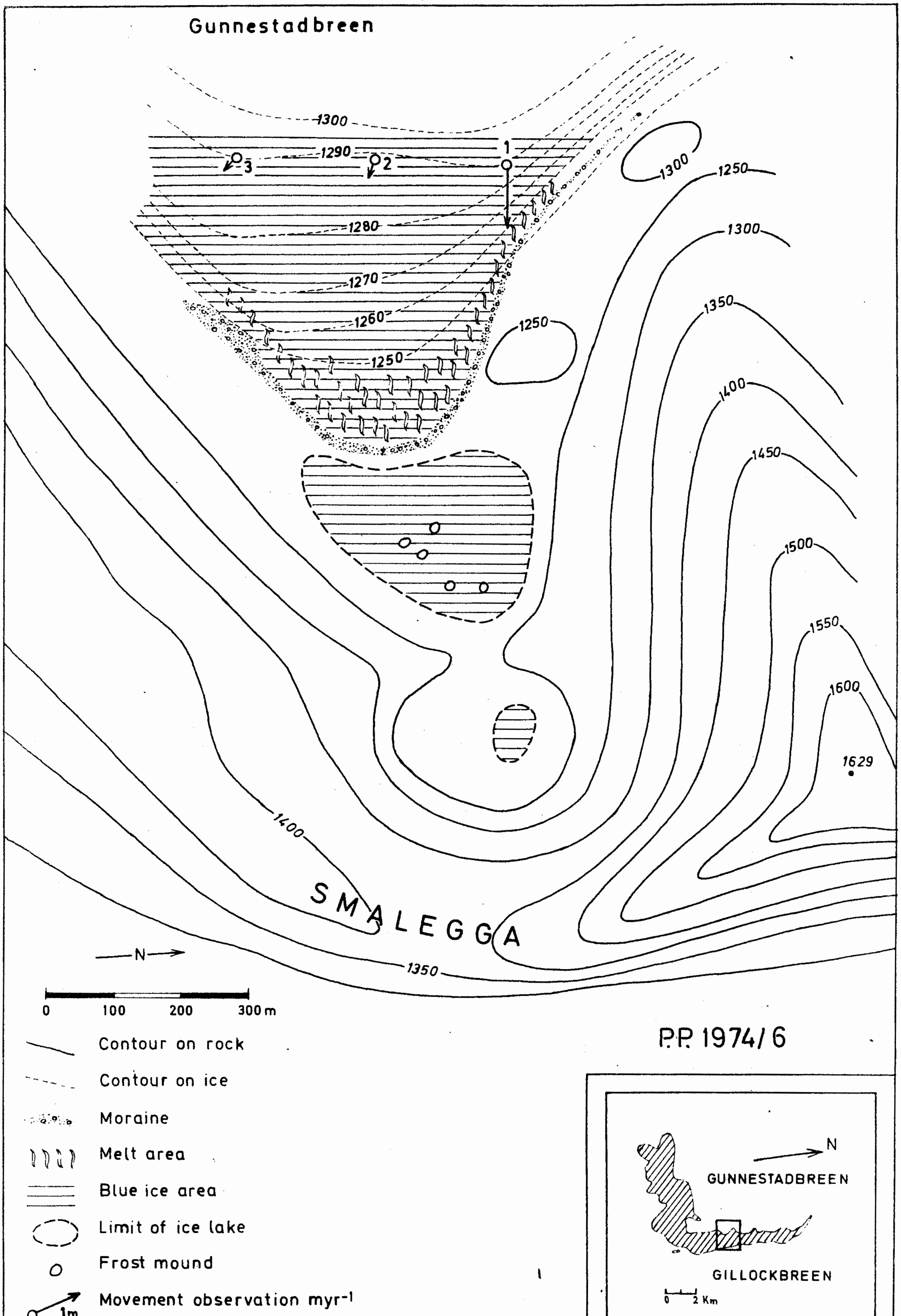
Gunnestadbreen
1300
1290
1280
1270
1260
1250
1
2
3
1300
1250
1300
1250
1350
1400
1450
1500
1550
1600
1629
1400
1350
SMALEGGA
N
0 100 200 300 m
Contour on rock
Contour on ice
Moraine
Melt area
Blue ice area
Limit of ice lake
Frost mound
Movement observation myr-1
1m
P.P. 1974/6
N
GUNNESTADBREEN
GILLOCKBREEN
0 2 Km

Fig: 7

The front of lateral bulge of Gunnestadbreen is apparently in equilibrium - at least no differences were observed between the situation in 1959 and in 1966 - or possibly retreating. It is to be noted that the other ice lobes of this type are in a similar position with regards to the dry valley. The advancing ice must therefore be compensated by the sublimation of the blue ice on the lateral bulge and on the ice lake and to a minor extent by evaporation of the melt water.

Sublimation measurements in the Sør Rondane[☆] make it appear likely that the mass transport of ice into the dry valley can be compensated by this form of ablation. The formation of the arcuate shear moraine as observed here also explains the existence of apparently inverted morainic arcs observed in some other dry valleys (e.g. Brattnipane). It now appears that these deposits did not originate from the local glaciers that once occupied these valleys but constitute shear moraines of the lateral bulges of the drainage glaciers which once penetrated in these valleys. The series of "inverted" arcs observed at Brattnipane seem to correspond to the successive positions of these lateral bulges.

These observations seem to indicate that the local deglaciation took place prior to the general lowering of the ice sheet. Detailed investigations of these morainic features might furnish useful information on the still poorly documented glacial geological history of the area.

(☆) Ablation measurements on blue ice fields in the Sør-Rondane were made during 1966 (VAN AUTENBOER, in preparation).
All stakes show a marked ablation with an average value estimated at 10 cm of ice per year and a maximum of 15 cm yr^{-1}. The major part of the ablation seems to take place in the December-January period while there are indications that little or no ablation takes place in the April to September period. This indicates that the energy needed for the sublimation is mainly furnished by solar radiation and not by the adiabatically warmed katabatic winds.
SCHYTT (1961) and LUNDE (1961) also record ablation measurements of the same order of magnitude in Western Dronning Maud Land.
Higher values (up to 50 cm yr^{-1}) have been reported from the dry valley area in Victoria Land (CALKIN and BULL, 1967 ; HENDERSON and others, 1966).

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