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Radio-Echo Sounding Investigations of Western Dronning Maud Land and North-Eastern Coats Land, East Antarctica

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Summary: During two Antarctic field seasons, western Dronning Maud Land and eastern Coats Land were covered by airborne radio-echo sounding surveys, conducted in combination with magnetic and gravity measurements along the 50 NW-SE-directed tracks, totalling about 11 200 km and spaced 20 km apart. The data were collected in analogue form and then processed to compile ice surface, ice thickness and bedrock topography maps in 1 : 2 500 000 scale which gave a new and/or more detailed information on the region than previous compilations. The maps show that western Dronning Maud Land is dominated by a large mountainous area with altitudes up to 2800 m including rock outcrops of Annandagstoppane, Borgmassivet, Kirwanveggen and Heimefrontfjella. Upland terrains of Vestfjella and Mannefallknausane have an isolated position and are surrounded by a plain with bedrock depressions of 600 m deep below sea level. A narrow strip of north-eastern Coats Land studied by radio-echo soundings exhibits a smooth subice relief with altitudes close to sea level. The structural style of bedrock topography was mostly determined by extensional tectonics.

Zusammenfassung: Während zwei antarktischer Feldsaisons sind das westliche Dronning-Maud-Land und das östliche Coats-Land mit Radioecholot-Vermessungen in Kombination mit magnetischen und gravimetrischen Messungen entlang von 50 NW-SE-ausgerichteten Profilen mit einer Gesamtlänge von 11 200 km und Abständen von 20 km überdeckt worden. Die Daten wurden in analoger Form registriert und anschließend prozessiert, um Karten zur Eisoberfläche, Eisdicke und Grundgebirgstopografie (1 : 2 500 000) zusammenzustellen, die neue und/oder detailliertere Informationen als bisher über die Region liefern. Die Karten zeigen, dass das westliche Dronning-Maud-Land von einem großen gebirgigen Gebiet mit Höhen bis zu 2800 m, einschließlich der Gesteinsaufschlüsse von Annandagstoppane, Borgmassivet, Kirwanveggen und Heimefrontfjella, dominiert ist. Die hochliegenden Gebiete der Vestfjella und Mannefallknausane liegen isoliert und sind von einer Ebene mit Grundgebirgsdepressionen von 600 m Tiefe unter dem Meerespiegelniveau umgeben. Ein schmaler Streifen des nordöstlichen Coats-Land, das mit Radioecholotmessungen untersucht wurde, weist ein glattes Relief unter dem Eis mit Höhen nahe des Meerespiegelniveaus auf. Der strukturelle Stil der Grundgebirgstopografie wurde überwiegend durch Extensionstektonik bestimmt.

INTRODUCTION

During austral seasons of 1986/87 and 1988/89 the Polar Marine Geological Research Expedition (PMGRE) carried out airborne Radio-Echo Sounding (RES) measurements in combination with gravity and magnetic observations over western Dronning Maud Land (WDML) and north-eastern Coats Land (NECL). The study has been aimed to get information on ice surface elevation, ice thickness and bedrock topography of this region, to map an ice sheet grounding line, and to recognize the features critical for geological and tectonic interpretation. The surveys covered the mountain region hidden under the thick ice sheet and inshore plain occupied by narrow ice shelves (Fig.1).

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Previous ice-thickness investigations in this region were sparse and irregular. First informations have been obtained from seismic over-ice measurements during the joint Norwegian-British-Swedish Antarctic Expedition in 1949-1952, which crossed Ritscher Hochland and the Ekström Ice Shelf by one profile (ROBIN 1958).

During the four austral seasons from 1971/72 to 1974/75 the South African National Antarctic Expedition carried out over-snow RES investigations in WDML using a 35-MHz Scott Polar Research Institute Mark II radio-echo sounder with a dynamic range of 155 dB housed in the Geophysical Caboose (SCHAEFER 1973, VAN ZYL 1973, WOLMARANS 1982). Ice-thickness data along several traverses were collected in the area of Ahlmannryggen and Borgmassivet to the east of 5° 30' W (i.e. mostly apart from the PMGRE's investigations).

In the 1985/86 season WDML was surveyed by Münster University (Germany) with airborne technique over flight tracks totalling 6100 km (HOPPE & THYSSEN 1988). The tracks represented mainly an irregular network with variable space intervals (10-60 km) and covered a triangle area between the Ekström Ice Shelf, Vestfjella and Heimefrontfjella. A 35-MHz radar with the overall dynamic range of 150 dB was used for the measurements. In about 25 % of data the ice-bottom-reflection signals were too weak to be detected and so large gaps in ice thickness information occurred. As a result of this study, bedrock and ice surface elevation maps have been compiled. The RES measurements revealed broad areas below sea-level seaward of Heimefrontfjella and Ritscher Hochland and suggested the existence of a subglacial plateau connecting Borgmassivet and Vestfjella and NE-SW-trending graben-like structures with a bottom more than 600 m below sea level, situated between this plateau and Heimefrontfjella. Simultaneously with RES study, over-snow seismic reflection experiment was conducted along three profiles and at 18 stations north of Heimefrontfjella (HUNGELING & THYSSEN 1991). The observations confirm a graben-like structure in the bedrock topography and outlined a deep crustal framework below this.

ACQUISITION TECHNIQUES AND DATA PROCESSING

The RES studies were carried out with a 60-MHz MPI-60 radio-echo sounder with a dynamic range of 180 dB and a pulse width of 750 ns. The ice thickness was sampled at 15 KHz, which provided virtually continuos reading of information. RES data were recorded in analogue form on a

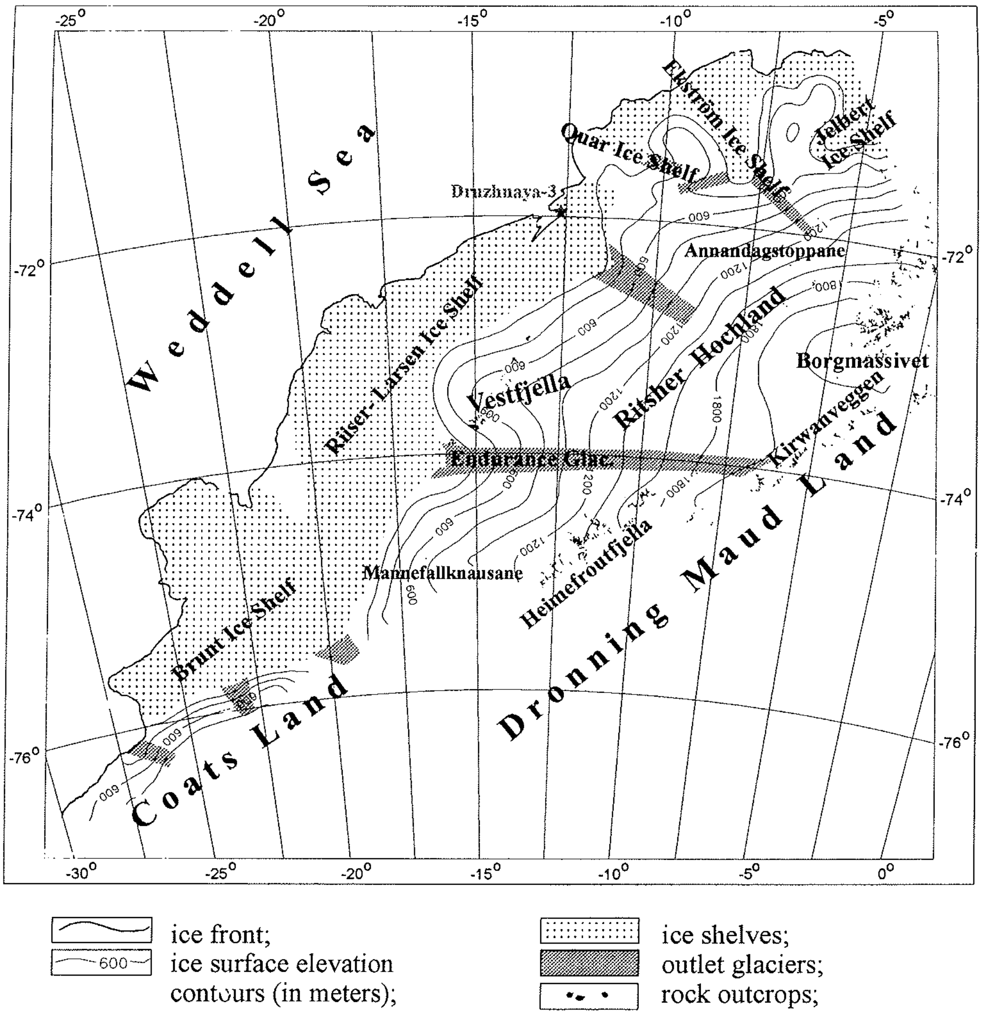

Fig. 1: Ice surface morphology with outlined ice shelves and major outlet glaciers.

Abb. 1: Morphologie der Eisoberfläche mit hervorgehobenen Eischelfen und größeren Ausflussgletschern.

35-mm film. Equipment was mounted in a middle-range IL-14 aircraft which refuelled at the Russian base Druzhnaya-3, situated at the ice coast (Fig. 1). The data were collected over a regular, NW-SE-oriented network, with a line spacing of 20 km crossed by several tie-lines (Fig. 2). The navigation system was different at each season and included DISS-013 Doppler units supplemented by camera techniques in 1986/87 (WDML) and satellite GPS in 1988/89 (NECL) allowing to have a position accuracy of the order of 1000-1500 m and 450 m, respectively. Flights were conducted at a constant altitude due to gravity measurements, which demanded to minimize the vertical acceleration, and accounted for 2200 and 3000 m during the first season and 2000 m during the second one. The aircraft altitudes were fixed by a BS-6 stringed barometer that provided the accuracy of about 20 m.

The ice surface elevation was determined by a combination of baro- and radio-altimeter data. A total thickness of ice was obtained in about 75 % of measurements and in the remaining 25 % the ice-bottom-reflection signals were not recorded because of probably either small electromagnetic coefficients at an ice-bottom interface and/or signal fading (mostly in areas with great ice thickness). An electromagnetic wave velocity in ice of 168 m/ms was used for the calculations of the ice thickness. The accuracy of ice thickness measurements is estimated at 5-7 % of complete thickness and appears to be not more than 70-80 m for the thickest ice. At the stage of data processing analogue RES data were digitized along profiles with a 5 seconds (about 300 m) flight interval and were included into a database together with data on aircraft spatial position and altitude.

To compile the maps, RES data were adjusted and interpolated into a 5 km grid using a minimum curvature technique. Before contouring, the integrated grid was filtered by a running mean method (radius of 7.5 km). SURFER software for Windows-6.0 (Golden Software Inc.) was applied for data gridding and map compilation. Ice surface, ice thickness and bedrock topography maps of 1 : 2 500 000 scale were compiled as the result of data processing.

MAIN RESULTS

Ice Morphology

Most of WDML is covered by ice and only scarce bedrock crops out as mountain chains and/or groups of nunataks. The Ice Surface Elevation Map (see enclosure) shows two areas with principally different structure: one is the floating ice shelves and another is the grounded ice sheet. The former is characterised by the very flat surface varying in elevation from 40-50 m to 150-200 m whereas the latter exhibits relatively steep slope (with surface gradients of about 7-10 m/km or 25′-

35′) raising toward the south-east from first hundred meters up to 2300 m (Figs. 2, 3 and 4). Only two ice tongues (peninsulas of the grounded ice) between the Riiser-Larsen Ice Shelf and the Jelbart Ice Shelf on the north and the wide valley between Borgmassivet and Kirwanveggen on the south-east show a smooth ice sheet topography forming dome-like structures (Fig. 4, lines M-23a and M-19).

The position of an ice-sheet grounding line (inner ice shelf boundaries) was determined using both surface elevation data (by a strong decrease in ice surface gradients; Figs. 3 and 4) and ice-bottom radio-wave reflections (by change of reflection pattern from grounded to floating ice; Fig. 5). Not everywhere a grounding line is recognized and mapped in details owing to a complicated structure and nature of ice bottom, but in places RES data allow to correct it in comparison with previously published maps (DREWRY 1983, JOHNSON et al. 1983). New position of the grounding line is specifically evidenced for the area to the south of Vestfjella where previously declared narrow gulf of the Riiser Larsen Ice Shelf (DREWRY 1983, JOHNSON 1983), is not supported by our study. North of Vestfjella the grounding line has an approximate position because there ice-bottom reflections are poor due to wide zone of crevasses.

The ice sheet of WDML and NECL is crossed by several outlet glaciers which commonly represent structural valleys in the ice surface and form gulfs of ice shelves at the mouths (Fig. 1). Largest of them is the Endurance Glacier situated between Vestfjella and Heimefrontfjella and draining more than 25 % of the studied region.

The thickness of ice shelves ranges from 100 m along the barrier to 500-700 m near the grounding line to be approximately 300 m in average. The grounded ice sheet shows a much greater variations in thickness. In mountain areas it is reduced to 0 m within the bedrock outcrops but increases up to 1600 m and more in the intermontane valleys and foreland (see Ice Thickness Map).

Bedrock Morphology

The bedrock surface is dominated by the complexly-structured mountain area highly risen above sea level and is represented by outcrops of Borgmassivet, Annandagstoppane, Kirwanveggen and Heimefrontfjella (see Bedrock Topography Map). Borgmassivet and Annandagstoppane show a rugged relief with maximum elevation up to 2800 m above sea level (Fig. 4, line M-19). Toward the south-west and north the mountains are generally lower and less rugged but still dissected by deep valleys (Fig. 4, lines M-15a and M-23a). All this terrain is a part of more spacious morphostructure known as Ritscher Hochland which stretches further eastward, beyond the region studied and is separated from Kirwanveggen by a deeply-incised valley with steep slopes of about 1000 m in amplitude. The valley is traced along the northern foot of Heimefrontfjella representing a graben-like structure of 30-50 km wide and more than 150 km long (see Bedrock Topography Map). This structure was previously described by HOPPE & THYSSEN (1988) and HUNGELING & THYSSEN (1991), who outlined it using both RES and seismic data and reported depths to the graben bottom of up to 800 m below sea level.

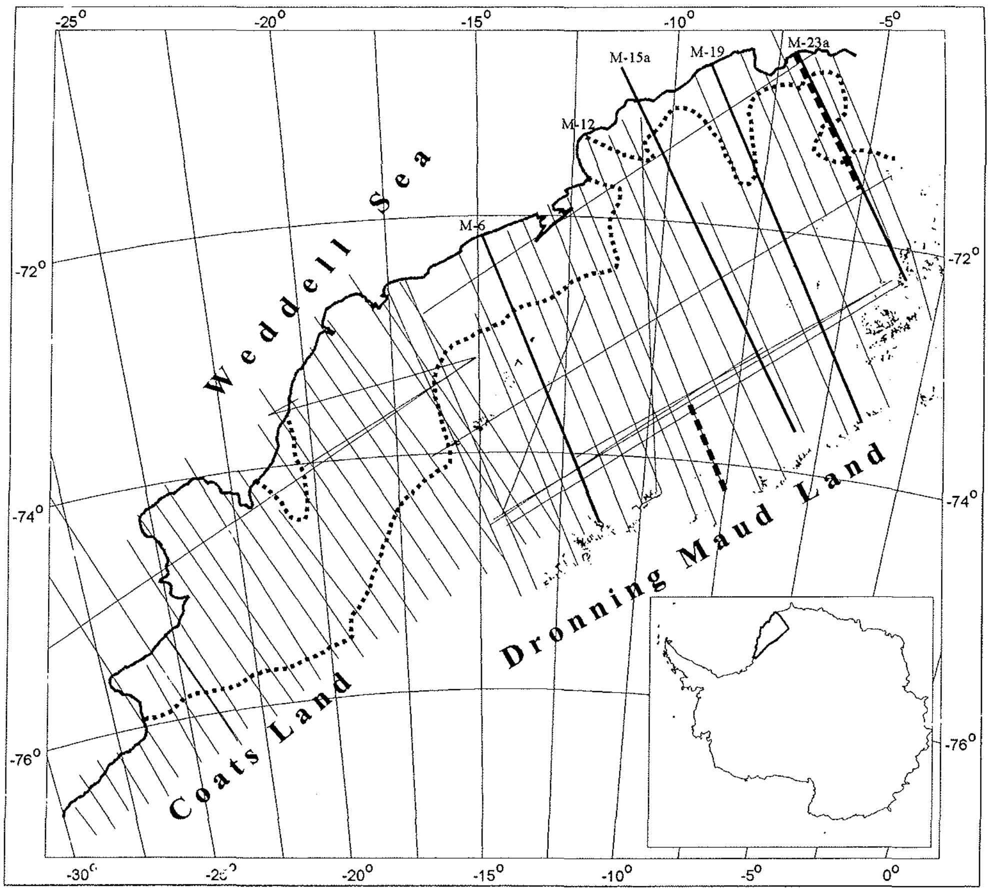

Fig. 2: Flight lines completed in the 1986/87 and 1987/88 seasons. Heavy lines show RES crossections displayed in Fig. 4; heavy broken lines are RES records displayed in Fig. 5.

Abb. 2: Flugprofile, die in den Saisons 1986/87 und 1987/88 vervollständigt wurden. Fette Linien zeigen RES (Radioecholot)-Querschnitte, abgebildet in Abb. 4; fette gestrichelte Linien sind RES-Aufnahmen, abgebildet in Abb. 5.

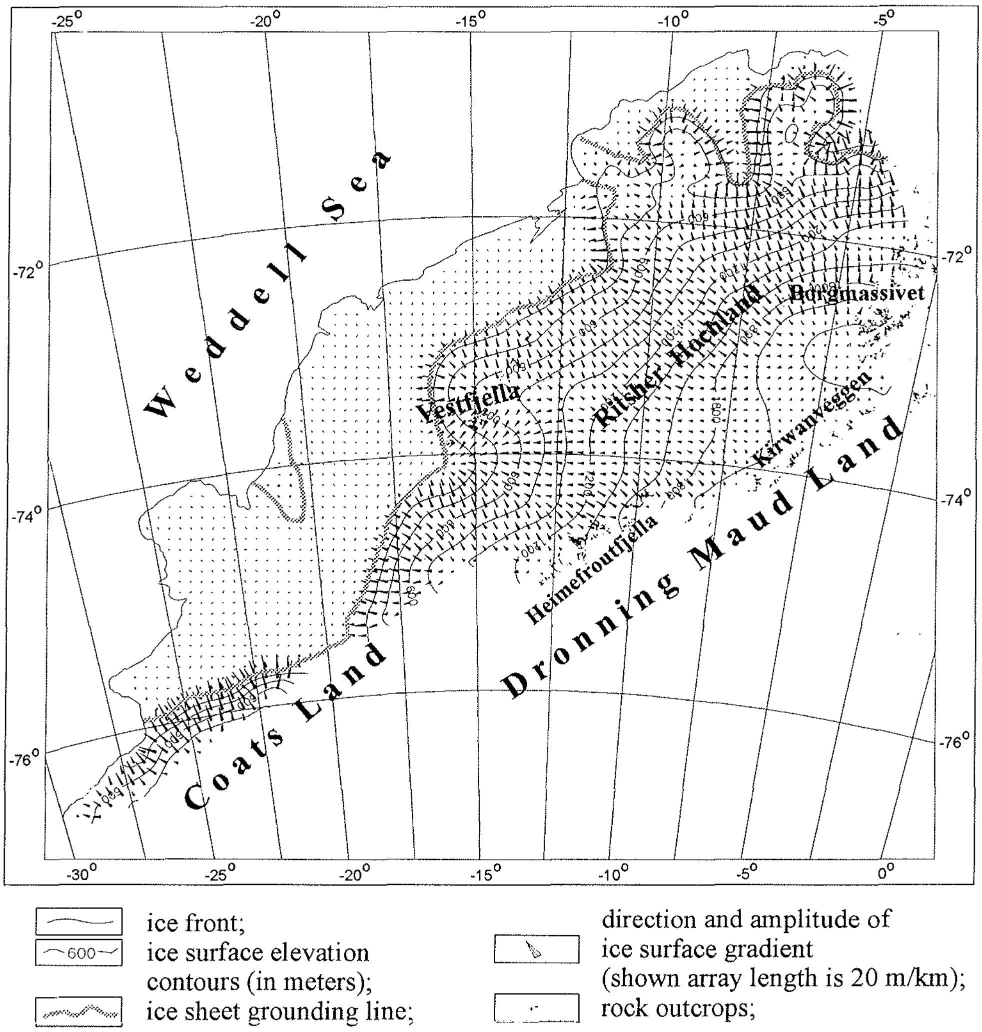

Fig. 3: Gradients of ice surface.

Abb. 3: Gradienten der Eisoberfläche.

Our RES data allow to recognize the bottom of the graben only in places, if the bedrock surface is not deeper than 600 m, since the subice-reflection signals are lost at greater ice thickness (during the map compilation individual data obtained within the graben were interpolated to get continuous generalized contours). The elongated ridge and another graben stated by HOPPE & THYSSEN (1988) to the north (between 74 °S and 73.5 °S) are not confirmed by our survey which maps here rather isometric hills (200-400 m high) against the wide area lying below see level (see Bedrock Topography Map).

A deep, rounded and almost closed depression is outlined to the north-west of Heimefrontfjella merging with the aforecited graben at its foot. The bedrock surface descends here down to 700 m below see level (see Bedrock Topography Map and Fig. 4, line M-6) and only narrow neck between south-eastern Vestfjella and Mannefallknausane connects this depression with the spacious coastal plaine. Vestfjella framing the depression on the west show a more complicated structure than are suggested from the SW-NE-trending chain of outcrops. The southern nunataks of Vestfjella form an insulated bedrock high which is separated from the north by a narrow trench. The northern nunataks, in turn, represent the part of an elongated subice ridge, striking eastward and showing altitudes of between 100 and 300 m above sea level (see Bedrock Topography Map and Fig. 4). Our data do not show a connection of this ridge with Ritscher Hochland as was suggested by HOPPE & THYSSEN (1988). Mannefallknausane appears to represent the easternmost height of WDML mountainous system which gives way to a low country of NECL. The relief of NECL is represented by gentle-wavy surface lying predominantly below sea level. The only positive structure here is a hill situated in the south-western edge of the survey area. The bedrock topography of WDML and NECL is governed by two principal trends running parallel and normal to the continental margin. They are expressed by mountain valleys, escarpments, bedrock depressions and slope configuration which generally form a tabular pattern of the regional relief (Fig. 5).

The isostatically adjusted map (Fig. 6), calculated under the assumption that the Antarctic ice sheet would melt and 60 m of global sea level rise would occur, show that all previously insulated mountaineous terrains form a single system above sea level with highly-rugged relief and altitudes of more than 1600 m. In the south-eastern part of WDML it is cut by a wide and deep north-west-trending graben with a bottom from 200 m to 400 m below sea level. The map reveals a fjord-lake configuration of the coast-line which exhibits many pronounced marine bays penetrating inland.

Seismic data available from WDML (HUNGELING & THYSSEN 1991, LEITCHENKOV & MASOLOV 1997) suggest that bedrock

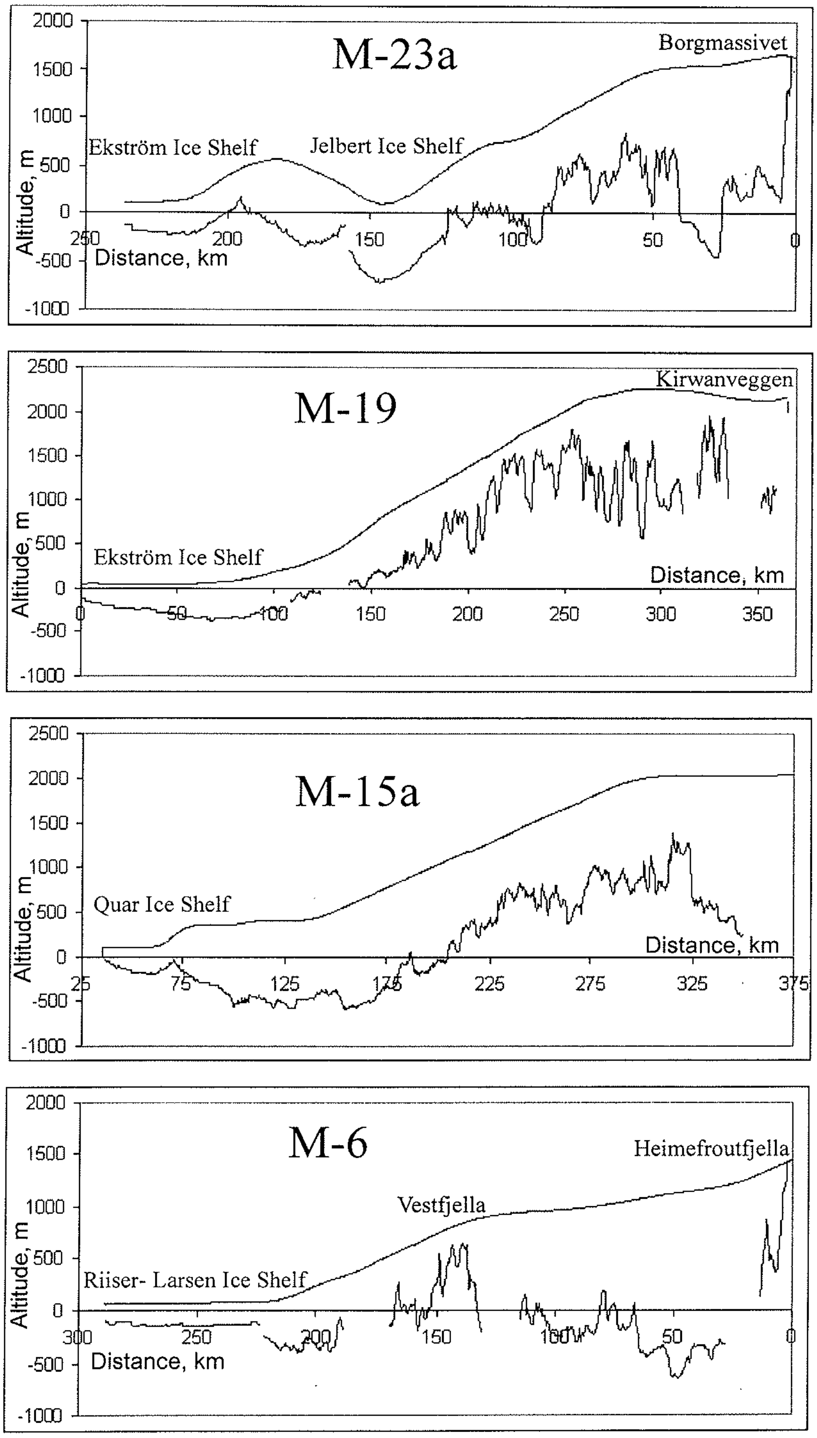

Fig. 4: Digitized RES data along the lines crossing western Dronning Maud Land in different bedrock topography terrains. See Fig. 2 for location of lines.

Abb. 4: Digitalisierte RES-Daten entlang der Profile, die das westliche Dronning Maud Land mit Gebieten unterschiedlicher Grundgebirgstopografie kreuzen. Siehe Abb. 2 für Lage der Profile.

depressions and coastal plain of WDML are composed presumably of Late Paleozoic (Permian) and Mesozoic to Cenozoic sedimentary rocks, whereas the mountain terrains (according to geological data) are dominated by Precambrian assemblages of the East Antarctic Craton covered in places by Permian deposits and Jurassic flood basalts (TINGEY 1991). The main phase of crustal uplift and mountains formation is presumed to have been related to the emplacement of the mantle plume beneath central Gondwanaland and subsequent rifting along WDML margin (LEITCHENKOV & MASOLOV 1996, JACOBS et al. 1996). The morphostructural style of the studied region was thus determined by a magnitude and trend of extensional stress which acted in a NW-SE direction. This has led to the formation of NE-SW-striking ranges (horsts) and depressions (grabens) crossed by transverse valleys interpreted as faults and/or fracture zones. The principal fracture zone system appears to be responsible for the pronounced change in contours outlining the main mountain area of WDML (Ritscher Hochland - Kirwanveggen – Heimefrontfjella) which occurs in the vicinity 10 °E longitude. Seaward, this zone breaks considerably the continental margin and bounds the Explora Escarpment (LEITCHENKOV & MASOLOV 1987).

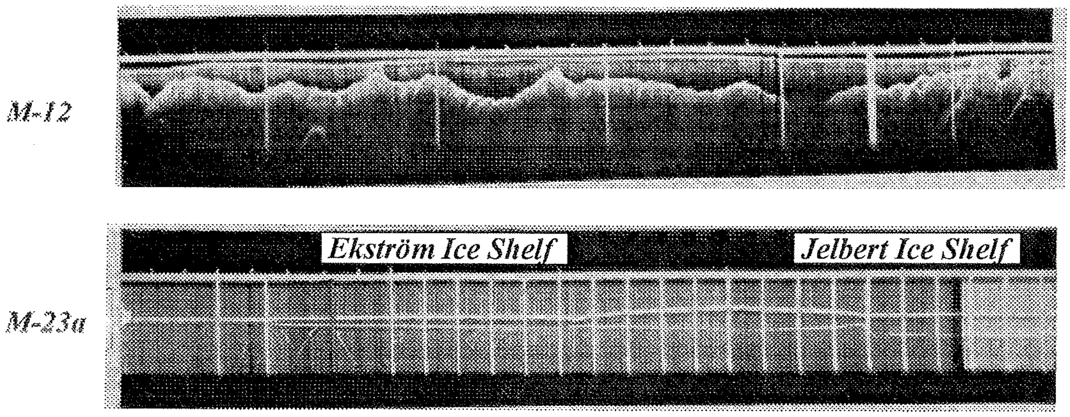

Fig. 5: Digitized RES lines across the mountain region and ice shelves. See Fig. 2 for location of lines.

Abb. 5: Digitalisierte RES-Profile entlang der Gebirgsregion und der Eisschelfe. Siehe Abb. 2 für Lage der Profile.

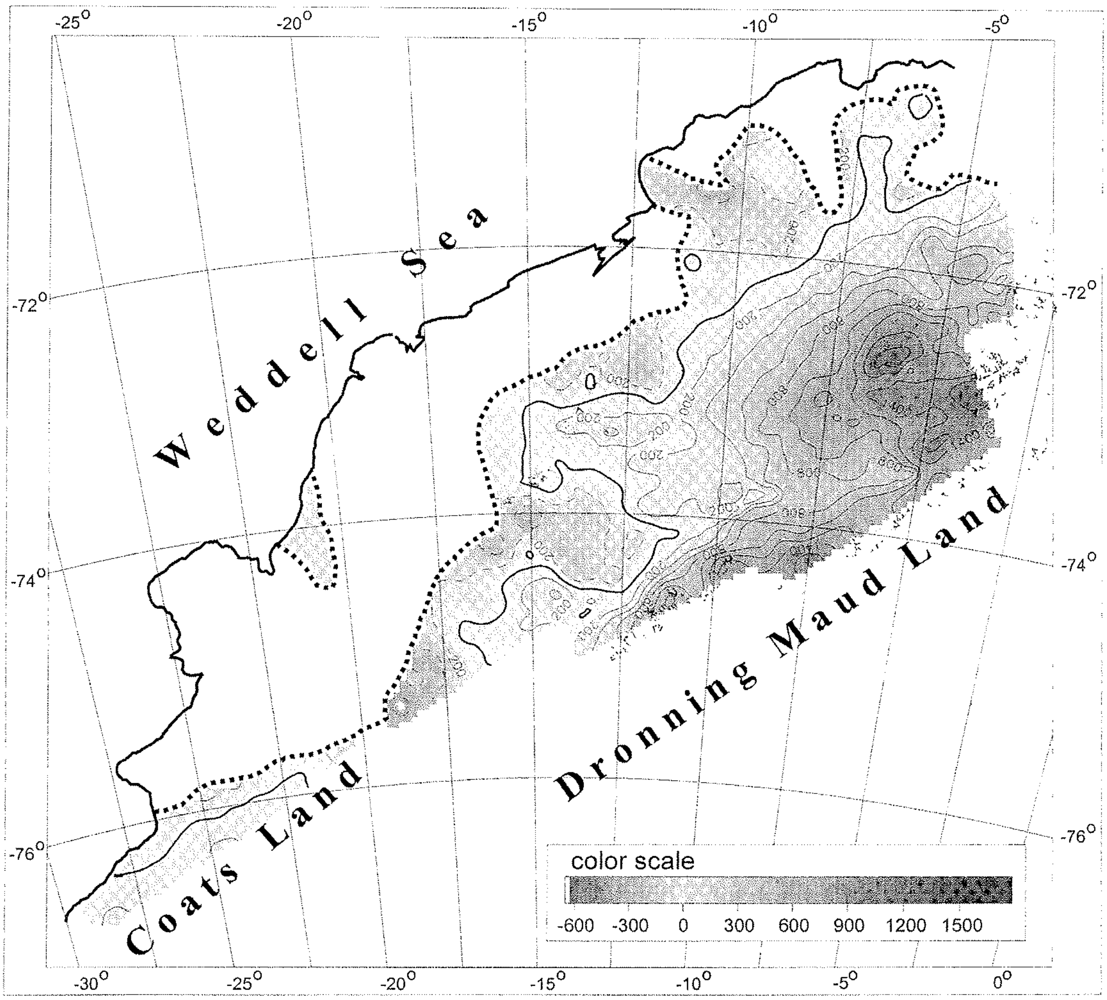

Fig. 6: Bedrock elevation after isostatic rebound. Bedrock topography contours are shown in metres (solid isolines are values of bedrock relief above sea level and at sea level (thicker isoline); dashed isolines are values of bedrock relief below see level). A window of 150 km in length was used to adjust the central point of the window.

Abb. 6: Grundgebirgshöhen nach dem isostatischen Ausgleich. Konturen der Grundgebirgstopografie in [m]; durchgehende Isolinien zeigen Werte vom Grundgebirgsrelief über dem Meeresspiegel und auf dem Meeresspiegel (fette Isolinie); gestrichelte Isolinien zeigen Werte vom Grundgebirgsrelief unter dem Meeresspiegel. Ein Fenster von 150 km Länge wurde benutzt, um den zentralen Punkt des Fensters zu justieren.

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References

Drewry, D.J. (1983): Antarctica: glaciological and geophysical folio.- Scott Polar Research Institute, University of Cambridge.

Hoppe, H. & Thyssen, F. (1988): Ice thickness bedrock elevation in the western Neuschwabenland and Berkner Island, Antarctica.- Ann. Glaciol. 11: 42-45.

Hungeling, A. & Thyssen, F. (1991): Reflection seismic measurements in western Neuschwabenland.- In: M.R.A. THOMSON, J.A. CRAME & J.W. THOMSON (eds.), Geological Evolution of Antarctica, 73-76.

Jacobs, J., Kaul, N. & Weber, K. (1996): The history of denudation and resedimentation at the continental margin of western Dronning Maud Land, Antarctica, during break-up of Gondwana.- In: B. STOREY, E. KING & R. LIVERMORE (eds.), Weddell Sea Tectonics and Gondwana Break-up.- Geol. Soc. London Spec. Publ. 108: 191-199.

Johnson, G.L, Vanney, J.-R., Drewry, D.J & Robin, G.de Q. (1983): General Bathymetric Chart of the Oceans (GEBCO), Antarctica, 5th edition, Ottawa.

Leitchenkov, G.L. & Masolov, V.N. (1997): Tectonic and magmatic history of the Weddell Sea region.- In: C.A. RICCI (ed.), Antarctic Region: Geological Evolution and Processes, Terra Antartica Publ., 461-466.

Robin, G. de Q. (1958): Glaciology III. Seismic shooting and related investigations.- Norwegian-British-Swedish Antarctic Expedition 1948-52, Scientific Results 5: 3-134.

Schaefer, T.G. (1973): Radio Echo Sounding in western Dronning Maud Land, 1971.- S. Afr. Journ. Ant. Res. 3: 45-52.

Tingey, R.J. (ed.) (1991): The Geology of Antarctica.- Clarendon Press, Oxford, pp. 680.

Van Zyl, R.B. (1973): Radio-echo sounding in western Dronning Maud Land, 1972. – S. Afr. Journ. Ant. Res. 3: 53-59.

Wolmarans, L.G. (1982): Subglacial morphology of the Ahlmannryggen and Borgmassivet, western Dronning Maud Land.- In: C. CRADDOCK (ed.), Antarctic Geoscience, Univ. Wisconsin Press, Madison, 963-968.