Polarforschung 60 (2): 73–77, 1990 (erschienen 1992)

1. Cenozoic Glaciation of the Rennick Glacier Area, the Everett Range and Yule Bay Area, North Victoria Land, Antarctica

By Frederik M.van der Wateren* & Anja L.L.M. Verbers**

During GANOVEX VI (1990/91) we have investigated a large part of the drainage area of the Rennick Glacier, the Everett Range and Yule Bay area (Fig. 1). Data gathered during GANOVEX IV and V (HÖFLE 1989, VAN DER WATEREN & VERBERS 1990) show that this part of the Transantarctic Mountains has been covered by the East Antarctic ice sheet during the Late Pliocene. Our investigations concentrate on the relation between Cenozoic mountain uplift and the glacial history of the area.

The results from glacial geologic research during GANOVEX V and GANOVEX VI (VAN DER WATEREN & VERBERS 1990, 1991, JORDAN & VAN DER WATEREN in press) support our view that the methods we employ may be beneficial to models of ice sheet volume variation due to climatic change as well as to tectonic models of the Transantarctic Mountains.

We expect that our work may give a better indication of the latest high uplift rates in the area than can be gained by fission track analysis alone. On the other hand we expect to set limits to the amount of ice surface lowering since the Late Pliocene.

Two alternative scenarios have been proposed explaining the overriding of the Transantarctic Mountains. One, more or less ignoring tectonic uplift, postulates ice thickness fluctuation of the East Antarctic ice sheet in the order of 1000 m or more, several times during the Tertiary (e.g. MAYEWSKI 1975, MAYEWSKI & GOLDTHWAIT 1985, DENTON et al. 1984, 1986). They assume that the ice sheet has become thinner by that amount since the Late Tertiary, with minor fluctuations during the Pleistocene and Holocene.

The other explains the apparent ice thinning by rapid differential block uplift in the order of 1,000 to 3,000 m since the Late Pliocene, drastically changing the drainage of the East Antarctic ice sheet in the area of the Transantarctic Mountains (BRADY & MCKELVEY 1983, WEBB et al. 1984, 1986, MCKELVEY et al. 1991). The latter authors report as evidence the occurrence of meltwater deposits, fossil wood, leaves and palynomorphs at high elevations (ASKIN & MARKGRAF 1986, WEBB & HARWOOD 1987, WEBB et al. 1987).

The second scenario requires much smaller climate induced thickness variations. It also implies that uplift of the Transantarctic Mountains is episodic in character, with much higher rates during the last 6 Ma than is evident from available fission track data. Late Pliocene drainage directions (HÖFLE et al. 1989) and subglacial topography (WEBB et al. 1984) indicate that a separate ice sheet developed in North Victoria Land quite independent of the greater East Antarctic ice sheet.

The main objective of our programme is a comparison of the glacial history of blocks in the Transantarctic Mountains which have undergone different amounts of tectonic uplift, combined with ^{10}Be dating of summit plateaus and various lower (and supposedly younger) glacial landforms. In North Victoria Land, we selected four fieldwork areas arranged along a profile crossing the Rennick Graben (Fig. 1) which we assumed had undergone different amounts of uplift.

* Dr. Frederik M. van der Wateren, Geological Survey of The Netherlands, Postbus 157, NL-2000 AD Haarlem, The Netherlands.
** Drs. Anja L.L.M. Verbers, University of Amsterdam, The Netherlands, present address: Bundesanstalt für Geowissenschaften und Rohstoffe, Stilleweg 2, D-W-3000 Federal Republic of Germany.

We have sampled granites for fission track dating, to determine uplift rates. We have taken quartz samples from striated bedrock for ^{10}Be dating, to determine exposure ages of deglaciated surfaces according to NISHIIZUMI et al. 1986. In addition, we have collected till, rock and algae samples for SEM, X-ray diffraction, microfossil, grain size, heavy minerals and soil chemical analyses and ^{14}C dating. Geological mapping (GANOVEX V) and structural studies in North Victoria Land (ROLAND & TESSENSOHN 1987) have shown that the area had undergone a considerable amount of post-Jurassic differential block movement. The main structural element is the Rennick Graben (approximately coinciding with the Rennick Glacier), flanked by shoulders which today are still clearly expressed as high mountain ranges. A younger uplift phase connected with Ross Sea margin faulting and volcanic activity has tilted the North Victoria Land block towards the NNW (Fig. 1). Fission track data presented by FITZGERALD & GLEADOW (1988) provide evidence that this phase, still continuing today, has started 50 Ma ago.

The graben shoulders on both sides of the Rennick Glacier show evidence of Late Tertiary ice overriding (MAYEWSKI et al. 1979, DENTON et al. 1984, 1986, HÖFLE 1987, 1989, VAN DER WATEREN & VERBERS 1990). The morphology shows remnants of a glacially eroded plateau and terrace landscape. This is not only true of the tablelands sculptured in flatlying Ferrar Dolerites and Kirkpatrick Basalts, e.g. the Mesa Range, but also of the metasediment terranes and granite intrusions throughout North Victoria Land, e.g. the Everett Range and the Daniels Range (Fig. 1).

Summit plateaus up to 3200 m in altitude have striated and streamlined bedrock surfaces recording ice flow directions completely independent of recent ice drainage. Quartz samples from these plateaus yield exposure ages ranging from 2.7 Ma (Mesa Range, 3200 m) to 4 Ma (Roberts Butte, Outback Nunataks, 2800 m). Terraces and mountain ridges at lower levels have become icefree between 1 and 1.4 Ma (BREMER et al. 1991). The present drainage pattern of cirque and valley glaciers and large ice streams cuts into the plateau and terrace landscape and seems to be younger than this.

The Late Cenozoic glacial history of North Victoria Land in our view can be divided into two main phases. During the Pliocene the North Victoria Land ice sheet covered a peneplain, the remnants of which are now found at altitudes between 2,500 and 3,200 m. The striation and erratic dispersal patterns on the highest surfaces (Fig. 1) indicate that the centre of the Pliocene ice mass in North Victoria Land lay in the mountain ranges southeast of the Rennick Graben. This area has undergone the highest amount of uplift, according to FITZGERALD & GLEADOW (1988) up to 10 km in 50 Ma, and even today is part of the ice divide between the Pacific and Ross Sea drainage areas.

During the Early Pleistocene the ice began to cut valleys into this peneplain. Isolated terraces at altitudes between 1,000 and 2,500 m are the remaining traces of the early part of this erosion phase. Ice radar investigations (THIERBACH this volume) show that the bottoms of the largest outlet glaciers are up to 900 m beneath their surfaces, suggesting that between 1,500 and 2,500 m of valley erosion has occurred during the last 1 to 1.5 Ma. Presently, the Rennick Glacier drains Talos Dome (DREWRY 1983), a local ice centre of the East Antarctic icesheet, located more than 250 km to the west of the Pliocene ice centre.

We believe that apart from the morphology, several arguments are in favour of the sequence we present here. Firstly, the erratic composition of tills depends on the relative position of the glacial terrace or moraine in which it occurs. This applies to many areas in North Victoria Land as well as to the area south of the David Glacier (VERBERS & VAN DER WATEREN this vol.). Tills at higher levels commonly have lower percentages of, or even are devoid of, basement rocks. This may partly be due to a higher degree of weathering at increasing altitude and exposure age (HÖFLE 1989), but even the most resistant basement rocks are absent in the tills covering the highest plateaus and terraces.

Secondly, intensity of weathering, number of ventifacts and intensity of patina on erratics and striated bedrock increase with the level of the moraines and terraces. This argument is weakened by the observation in North Victoria Land that weathering degree is much more dependent of rock type, distance from the sea and exposition than exposure age. It appears to be a rather ambiguous age criterion and must be used only for local correlation, whereas elsewhere along the Transantarctic Mountains it seems to work satisfactorily (e.g. CAMPBELL & CLARIDGE 1987, MAYEWSKI 1975, DENTON et al. 1984).

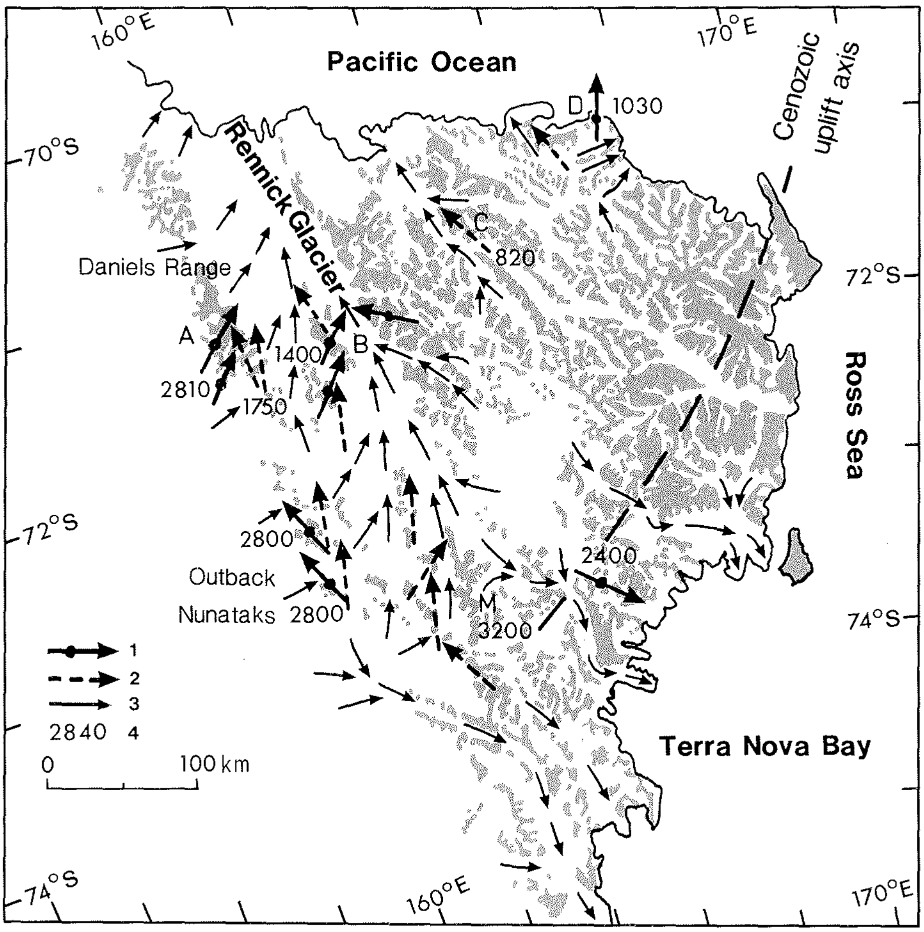

Fig. 1: Research area, A = Daniels Range (Thompson Spur, Schroeder Spur), B = Morozumi Range, C = Everett Range, D = Yule Bay area, M = Mesa Range.
Fossil and recent ice flow directions indicated by arrows; 1 = Pliocene striations, 2 = Early Pleistocene striations, 3 = present ice drainage, 4 = altitude of striations.
Data sources: DENTON et al. (1986), Lanterman Range and Lichen Hills; HÖFLE (1989), Outback Nunataks; HÖFLE et al. (1989) Mountaineer Range. Other data from field work during GANOVEX V and VI. Pliocene ice centre appears to have lain near the Mesa Range (M). From the Pliocene onward, ice flow directions increasingly conform to present ice drainage.

Abb. 1: Untersuchungsgebiet. A = Daniels Range (Thompson Spur, Schroeder Spur), B = Morozumi Range, C = Everett Range, D = Yule Bay Gebiet, M = Mesa Range. Pfeile = fossile und rezente Eisstromrichtungen, 1 = Pliozäne Eiskritzungen, 2 = Altpleistozäne Kritzungen 3 = Heutiges Eisfließ-System, 4 = Höhenlage der gemessenen Kritzungen.
Daten-Quellen: Lanterman Range und Lichen Hills, DENTON et al. (1986); Outback Nunataks, HÖFLE (1989); Mountaineer Range, HÖFLE et al. (1989); übrige Gebiete: eigene Aufnahmen bei GANOVEX V und VI. Im Pliozän scheint das Eiszentrum in der Nähe der Mesa Range (M) gelegen zu haben. Danach gehen die Fließrichtungen schrittweise in das heutige System über.

Thirdly, the steep valley sides and cirque headwalls (even icefree cirques) show lower degrees of weathering than the plateaus and terraces which they cut into. Cirque headwalls commonly start below the level of the terraces, which in their turn lie below the level of the summit plateaus (Fig. 2). In some places, e.g. the Everett Range and the Morozumi Range, this may give the false impression of a trimline such as DENTON et al. (1986) believe to have found over large areas of North Victoria Land. Our impression is that this line marks the boundary between bedrock surfaces deglaciated during the Late Pliocene and Early Pleistocene and those eroded and deglaciated more recently.

According to ROLAND & TESSENSOHN (1987) the Rennick Valley has been a depression since Early Mesozoic

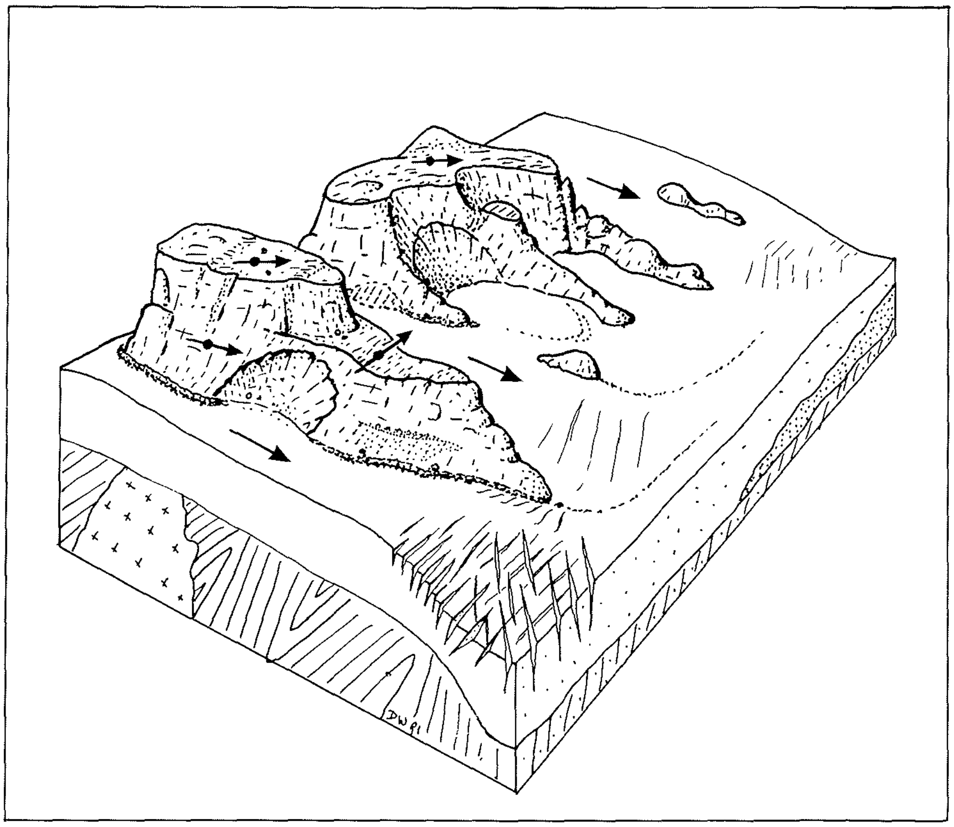

Fig. 2: Schematized block diagram of deglaciated nunataks in North Victoria Land. Striated plateaus, between 2,500 and 3,200 m in altitude, flanking the Rennick graben, are remnants of an uplifted peneplain. Ice flow directions on the plateaus have been dated from 2.7 to 4 Ma. Terraces and striated ridges, between 500 and 1,000 m lower than the summit plateaus have been exposure dated between 1 and 1.4 Ma. Present day outlet glaciers between the nunataks flow from the Polar Plateau into the large ice stream to the right of the block diagram (e.g. Rennick or Lillie Glacier). Elevated ice-cored moraines bordering the glaciers are an indication of their recent negative mass balances.

Abb. 2: Schematisches Blockdiagramm von heute eisfreien Nunatakkern in Nord Victoria Land. Gekritzte Hochplateaus um 2.500-3.200 m an den Flanken des Rennickgrabens sind Erosionsreste einer gehobenen Rumpffläche. Für Eisfließ-Richtungen auf dieser Fläche sind Alter von 2,7-4 Ma bestimmt worden.
Terrassen und gekritzte Bergrücken 500-1.000 m unterhalb dieser Plateaufläche sind nach ^{10}Be-Bestimmungen seit 1,4-1 Ma eisfrei. Heute fließt das Eis vom Polarplateau zwischen den Nunatakkern durch, um dann in die großen Eisströme (z. B. RennickGletscher) einzuschwenken, die im Diagramm rechts dargestellt sind. Hochgelegene Eiskern-Moränen an den Flanken der Gletscher sind Hinweise auf eine junge negative Massenbilanz.

time. The oldest ice flow directions we have found curve towards the Rennick Glacier (Fig. 1), confirming the existence of the depression during the Pliocene. The following radical change in ice drainage in our view has been caused by reactivation of the Mesozoic tension system and subsequent relative downward movement of the Rennick Graben.

We conclude that differential uplift of the Transantarctic Mountains, in connection with the Cenozoic rifting in the Ross Sea, have forced the ice drainage to change from a more or less radial to a linear flow pattern. Thus, ice level lowering, as suggested by MAYEWSKI et al. (1979), DENTON et al (1984, 1986), HÖFLE (1989) and HÖFLE et al. (1989) rather is the result of the uplift of crustal blocks flanking the Rennick Graben and the young Ross Sea rift. This would imply that there is no need to assume a Tertiary East Antarctic ice sheet that was ever much thicker than the present one.

Finally, laboratory analysis of our samples must prove the validity of our hypothesis. Differential block movement in North Victoria Land (FITZGERALD & GLEADOW 1988) is expected to express itself in different deglaciation histories and fossil drainage patterns for the various terranes. We expect to find trends in the heavy mineral composition and weathering degree from the higher, supposedly older, to the lower moraines, as well as in the exposure age versus altitude profiles in terrains with different uplift histories.

ACKNOWLEDGMENTS

We wish to thank the Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, and Dr. F. Tessensohn in particular, for our invitation to participate in GANOVEX VI and the excellent cooperation during the expedition. ^{10}Be analyses are performed by Prof. Dr. U. Herpers and Dr. K. Bremer of the radiochemical laboratory, Köln University; Dr. H.J. Hofmann and Prof. Dr. W. Wölfli, ETH Hönggerberg, Zürich. For fission track analyses we collaborate with a team led by Prof. Dr. M Olesch, Bremen University. Our research is supported by the Foundation for Ocean Research (SOZ), The Netherlands.

References

Askin, R.A. & Markgraf, V. (1986): Palynomorphs from the Sirius Formation, Dominion Range, Antarctica.- Antarctic J. US 21(5): 34-35.

Brady, H. & McKelvey, B. (1983): Some aspects of the Cenozoic glaciation of southern Victoria Land, Antarctica.- J. Glaciol. 29: 343-349.

Bremer, K., Herpers, U., Delisle, G., Höfle, H.-C., Wateren, F.M. van der, Hoffmann, H.J. & Wölfli, W. (1991): ^{10}Be-content of quartz grains collected in North Victoria land and the glacial history of the Frontier Mountain range in Antarctica.- Meteoritics 26(4): 323-324.

Campbell, I.B. & Claridge, G.G.C. (1987): Antarctica: soils, weathering and environment.- Developments in Soils Science 16. Amsterdam. Elsevier Publishers.

Denton, G., Bockheim, J.G., Wilson, S.C. & Schlüchter, C. (1986): Late Cenozoic history of Rennick Glacier and Talos Dome, Northern Victoria Land, Antarctica. In: Stump, E. (ed.), Geological investigations in Northern Victoria Land.- Antarctic Research Series 46: 339-375, AGU, Washington D.C..

Drewry, D.J. (1983): Antarctica: glaciological and geophysical folio.- Cambridge University Press, 9 map sheets, Cambridge.

Fitzgerald, P.G. & Gleadow, A.J.W. (1988): Fission-track geochronology, tectonics and structure of the Transantarctic Mountains in Northern Victoria Land, Antarctica.- Chem. Geology 73: 169-198.

GANOVEX Team (1987): Explanatory notes of the geological maps 1:500,000 of North Victoria Land, Antarctica.- Geol. Jb. B66: 7-79.

Höfle, H.-C. (1987): Glacial geology in the Outback Nunatak area, west of North Victoria Land, Antarctica.- In: van der Meer, J.J.M. (ed.), Tills and glaciotectonics, 253-257, Balkema, Rotterdam.

Höfle, H.-C. (1989): The glacial history of the Outback Nunataks area in western North Victoria Land.- Geol. Jb. E38: 335-355.

Höfle, H.-C., Olesch M. & Schubert, W. (1989): A study of glacial erratics in the Mountaineer Range as evidence for a large ice sheet in North Victoria Land.- Geol. Jb. E38: 357-368.

Jordan, H. & Wateren, F.M. van der (in press): The lakes of Litell Rocks: consequences for the deglaciation of the Rennick valley. Geol. Jb. E.

Mayewski, P.A. (1975): Glacial geology and Late Cenozoic History of the Transantarctic Mountains, Antarctica.- Inst. Polar Stud., Rep. 56, 168 pp., Columbus.

Mayewski, P.A., Attig, J.W. & Drewry, D.J. (1979): Pattern of ice lowering for Rennick Glacier, Northern Victoria Land, Antarctica.- J. Glaciol. 22(86): 53-65.

Mayewski, P.A. & Goldthwait, R.P. (1985): Glacial events in the Transantarctic Mountains: a record of the East Antarctic ice sheet.- In: Turner, M.D. & Splettstoesser, J.F. (eds.), Geology of the Central Transantarctic Mountains.- Antarct. Res. Ser. 36: 275-324, AGU, Washington D.C..

McKelvey, B.C., Webb, P.-N., Harwood, D.M. & Mabin, M.C.G. (1991): The Dominion Range Sirius Group - a record of the Late Pliocene - Early Pleistocene Beardmore Glacier.- In: Thomson, M.R.A., Crame, J.A. & Thomson, J.W. (eds.), Geological Evolution of Antarctica, 675-682, Cambridge University Press.

Nishiizumi I, K., Lal, D., Klein, J., Middleton, R. & Arnold, J.R. (1986): Production of ^{10}Be and ^{26}Al by cosmic rays in terrestrial quartz in situ and implications for erosion rates.- Nature 319: 134-136.

Roland, N.W. & Tessensohn, F. (1987): Rennick faulting - an early phase of Ross Sea rifiting.- Geol. Jb. B66: 203-229.

Stuiver, M., Denton, G.H, Hughes, T.J. & Fastook, J.L. (1981): History of the marine ice sheet in West Antarctica during the last glaciation: a working hypothesis. In: Denton, G.H. & Hughes, T.J. (eds.), The last great ice sheets, 319-436, John Wiley & Sons, New York.

Wateren, F.M. van der & Verbers, A.L.L.M. (1990): Glacial geology of North Victoria Land, Antarctica: Results of GANOVEX VI, 1990/91.-Circumpolar J. 5: 23-36.

Wateren, F.M. van der & Verbers, A.L.L.M. (1991): Tertiäre und quartäre Vereisungen in Nord-Victoria-Land, Antarctica: Ergebnisse von GANOVEX VI. (Abstract).- In: Programm 16. Internationale Polartagung, Göttingen, 10.-13. April 1991, Deutsche Gesellschaft für Polarforschung.

Webb, P.-N. & Harwood, D.M. (1987): Terrestrial flora of the Sirius Formation: its significance for Late Cenozoic glacial history.- Antarct J. US 22 (4): 7-11.

Webb, P.-N. & Harwood, D.M., McKelvey, B.C., Mercer, J.H. & Stott, L.D. (1984): Cenozoic Marine sedimentation and ice volume variation on the East Antarctic craton.- Geology 12: 287-291.

Webb, P.-N., Leckie, R.M. & Ward, B.L. (1986): Foraminifera (Late Oligocene).- In: Barrett, P.J. (ed.), Antarctic Cenozoic history from the MSSTS-1 drillhole, McMurdo Sound.- DSIR Bulletin 237: 115-125, Wellington.

Webb, P.-N., McKelvey, B.C., Harwood, D.M., Mabin, M.C.G. & Mercer, J.J. (1987): Sirius Formation of the Beardmore Glacier region.- Antarct. J. US 22 (1/2): 8-13.