Union and European Science Foundation project, funded under the Environnement and Climate Programma (1994-98) through contract No. ENV4-CT95-0074. We thank the national funding agencies and organisations in Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Sweden, Switzerland and the U.K. for financial support.

University of Milan, IGNAZIO EZIO TABACCO,
Department of Earth Sciences, ANDREA PASSERINI,
Via Cicognara 7,
20129 Milan, Italy

ENEA–PNRA, FILIPPO CORBELLI,
Via Anguillarese 301,
Sanata Maria di Galeria,
00060 Rome, Italy

Scott Polar Research Institute, MICHAEL GORMAN
University of Cambridge,
Lensfield Road,
Cambridge CB2 1ER, England

16 October 1997

REFERENCES

Bentley, C. R., K. C. Jezek, D. D. Blankenship, J. S. Lovell and D. G. Albert. 1979. Geophysical investigation of the Dome C area. *Antarct. J. U.S.*, **14**(5), 98–100.

Bogorodsky, V.V., C. R. Bentley and P. E. Gudmandsen. 1985. *Radioglaciology.* Dordrecht, etc., D. Reidel Publishing Co.

Brisset, L. and F. Rémy. 1996. Antarctic topography and kilometre-scale roughness derived from ERS-1 altimetry. *Ann. Glaciol.*, **23**, 374–381.

Cefalo, R., G. Manzoni and I. E. Tabacco. 1994. Elaborazioni dei rilievi cinematici GPS a Dome C e della traversa da Dome C a Dumont d'Urville. *In Workshop PNRA, 20–21 June 1994, Rome.* Rome, Progetto Nazionale di Ricerche Antartide, 35–42.

Cefalo, R., I. E. Tabacco and G. Manzoni. 1996. *Processing of kinematic GPS trajectories at Dome C (Antarctica) and altimetry interpretations.* Bologna, Distart Ed. Nautilus. (Reports on Surveying and Geodesy.)

Drewry, D. J., *ed.*. 1983. *Antarctica: glaciological and geophysical folio.* Cambridge, University of Cambridge. Scott Polar Research Institute.

Hempel, L. and F. Thyssen. 1993. Deep radio echo soundings in the vicinity of GRIP and GISP2 drill sites, Greenland. *Polarforschung*, **62**(1), 1992, 11–16.

Hodge, S. M., D. L. Wright, J. A. Bradley, R.W. Jacobel, N. Skou and B. Vaughn. 1990. Determination of the surface and bed topography in central Greenland. *J. Glaciol.*, **36**(122), 17–30.

Jacobel, R.W. and S. M. Hodge. 1995. Radar internal layers from the Greenland summit. *Geophys. Res. Lett.*, **22**(5), 587–590.

Jouzel, J., G. Orombelli and C. Lorius. 1996. European Project for Coring in Antarctica (EPICA). *Terra Antartica*, **3**(1), 49–54.

Paterson, W. S. B. 1981. *The physics of glaciers. Second edition.* Oxford, etc., Pergamon Press.

Robin, G. de Q. 1975. Velocity of radio waves in ice by means of a bore-hole interferometric technique. *J. Glaciol.*, **15**(73), 151–159.

Siegert, M. J., J. A. Dowdeswell, M. R. Gorman and N. F. McIntyre. 1996. An inventory of Antarctic sub-glacial lakes. *Antarct. Sci.*, **8**(3), 281–286.

Vincent, C. 1994. *Project Concordia, glaciology at Dôme C. Geodetic measurements at Dome Concordia.* Grenoble, Laboratoire de Glaciologie et Géophysique de l'Environnement. (Technical Report.)

SIR,

Comments on "Some comments on climatic reconstructions from ice cores drilled in areas of high melt" by Roy M. Koerner

Koerner (1997) presents an interpretation of ice-core data collected from the circumpolar Arctic. As a member of a Russian research team, I was involved in the coring and study of some of the ice cores referenced in his paper. The results of our research were published in the Russian scientific literature. This letter presents relevant data not included in Koerner (1997), and corrects a few inaccuracies. This additional information should contribute to a clearer understanding of the complexity of the ice-formation processes in glaciers subjected to intensive melting.

DATA

Lomonosovfonna. Three locations were studied along the ice divide on Lomonosovfonna. In the southern part of the plateau at 1025 m a.s.l., Zinger and Mikhalev (1967) determined the average accumulation rate to be 988 mm w.e. a^{-1} for the period 1957–64. The 201 m ice core was recovered in 1976 in the northwest part of the plateau at about 1080 m a.s.l.; results were published in Gordienko and others (1981). Because the thickness of the ice is unknown, the time-scale based on stable isotopes remains questionable. The firn–ice transition at the 1976 drilling site was in the depth range 27–32 m (Zagorodnov, 1985). In addition, a 135 m ice core was recovered in 1982 from a site (about 1000 m a.s.l.) approximately 10 km south of the 201 m core. This borehole was plumb from surface to bottom (Zagorodnov and others, 1984). Melt features comprised 34% of the glacier sequence, and the 1975–82 balance was 620 mm w.e. a^{-1}; for the period of 1962–82 the average balance was 658 mm w.e. a^{-1} (Zagorodnov and Samoylov, 1985). Note that Koerner (1997, table 1) gives the balance for the 1976 drilling site as 820 mm w.e. a^{-1}.

Austfonna. The elevation of the drilling site on the Austfonna summit was close to 750 m a.s.l. (Dowdeswell, 1986; Dowdeswell and others, 1986; Arkhipov and others, 1987; Dowdeswell and Drewry, 1989). The 566.7 m ice core was recovered from a plumb borehole. Mass-balance data for the drilling site are presented in Table 1. Assuming that the tritium peak at 14 m was from 1963 (Vaykmyae and Punning, 1989), the average (27 year) mass balance was 526 mm w.e. a^{-1}; without tritium data the average (5 year) balance was 598 mm w.e. a^{-1}. Both these values are lower than 794 mm w.e. a^{-1} given by Koerner (1997, table 1).

The melt scale for the Austfonna record appears to be incorrect and the curve given by Koerner (1997, corrected fig. 4) appears shifted. Using data from Tarussov (1992), and assuming that the profile was digitized from Zagorodnov and Arkhipov (1990) or from Kotlyakov and others (1990), with a net accumulation of 794 mm w.e. a^{-1} (Koerner, 1997, table 1), the Austfonna melt record presented by Koerner (1997) cannot be reproduced; melt values exceed the net accumulation. A similar problem exists in the Akademii Nauk melt record. The original percentage melt record was obtained from two ice cores, one drilled in 1985 (0–561 m) and the other in 1987 (250–761 m). These melt records are internally consistent. Using the melt percentage profile (Kotlyakov and others, 1990) and assuming annual net ac-

https://doi.org/10.3189/S0022143000002513 Published online by Cambridge University Press

Table 1. Mass balance at Austfonna summit

Year	*Balance* mm w.e. a^{-1}	*Comments*	*Source*
1987	640 *	10–12 measurements of snowpack thickness every 1 km of 118 km traverse; also 15 pits, 26 shallow cores before melting season; May	Sinkevich and Tarusov (1989)
1985	550	10–12 measurements of snowpack thickness every 1 km of 12 km traverse; also 10 pits, 8 shallow cores before and after melting season	Arkhipov and others (1987)
1963–85	860 (510)	Beta-radioactivity and tritium concentration in 32 m ice core	Vaykmyae and Punning (1989)
1958	~700*	Snow pit; mid-June	Schytt (1964)
1931	~600*	Snow pit; mid-July	Troitsky and others (1975)
1873	~500*	Snow pit; mid-June	Ahlmann (1933); Schytt (1964)

* Because summer–fall precipitation was not determined, 10% of the measured value was added to the values measured during spring and summer.

cumulation of 315 mm w.e. a^{-1}, again the values presented in Koerner (1997, corrected fig. 4) cannot be reproduced. In order to obtain the best approximation of original data, the melt values have to be multiplied by a factor of 1.22 and the curve has to be shifted down so that the last peak on the right equals 19 g cm^{-2} a^{-1}. In spite of these errors, the general trends and major elements of the profiles are consistent with the original data; therefore, it appears that inaccurate graphs were produced due to digitization of graphs that were originally published as rather small figures.

DISCUSSION

In some cases, representation of melt data in g cm^{-2} a^{-1} units could obscure details of the nature of the ice-formation process. Specifically, Austfonna, Vestfonna (Nordaustlandet) and Akademii Nauk ice cores have high (75–100%) concentrations of melt features (infiltration and infiltration–congelation ice in Shumskii's (1964) notation) in the upper 50–60 m. Below 350 m, the Austfonna ice core consists of 100% infiltration ice, which means that in the past the ice was formed under extensive melting conditions with a thin or no firn layer at the glacier surface. Similar conditions were described by Koerner and Paterson (1974) on Meighen Ice Cap, where the ice accumulation by melting and refreezing of snow was interrupted several times in the past, and there were several periods of negative mass balance associated with a warm climate. Zagorodnov (1985) reported that runoff from the infiltration–congelation zone (firn thickness <12 m) is possible when the concentration of infiltration ice exceeds 75%. Therefore, at high concentrations of infiltration ice, runoff is possible and accumulation can be less than precipitation. The presentation of melt as a fraction of the depth interval (which may or may not be equal to annual accumulation), as proposed by Koerner (1977), creates a universal parameter which does not depend on accumulation, and probably does not depend on the vertical deformation of ice layers with depth. It therefore can represent the climate history of glaciers subjected to melting.

The possibility of an ice cap building up to the thickness and temperature state of Austfonna during the late Holocene was studied using a numerical model (Larina and Zagorodnov, 1989b). Using a variable balance (0–500 mm w.e. a^{-1}), allowing runoff in earlier stages of glacier growth, and assuming surface temperatures ranging from 0° to −12°C (determined using an infiltration and infiltration–congelation ice-concentration–summer-temperature transfer function (Zagorodnov 1985)), a 560 m thick ice cap could form in 3000 years. Its growth begins once it attains a thickness of 50 m. The model suggests that the growth of the Austfonna ice cap was completed about 1000 years ago. Therefore, only the top section of the ice core (above 350–400 m) represents regional climatic changes, and the bottom section (400–566.7 m) records changes in surface elevation and local climate. The high dust content below 350 m in the Austfonna core (Zagorodnov and Arkhipov, 1990) supports the idea of snow/ice-free land on Nordaustlandet which could reflect warmer climate and/or lower precipitation. High concentrations (>75%) of melt features below 400 m also suggest the likelihood of negative mass balance creating gaps in the stratigraphic record. Domination of melt ice in the bottom (100% in the depth interval 170–200 m) of Vestfonna ice cap on Nordaustlandet (Zagorodnov, 1985) also supports our suggestion that there has been recent glacier regrowth subsequent to the Holocene thermal optimum.

Borehole temperatures indicate that the Little Ice Age was the coldest period recorded in Eurasian Arctic ice caps. At the very end of that period (110–130 years ago), Austfonna and Akademii Nauk near-surface temperatures (15 m depth) were 6–10°C colder than at present (Larina and Zagorodnov, 1989a, b). Similar changes were recently found in the Windy Dome (Franz Jozef Land) borehole (unpublished data, this author). In general, the new interpretation (Koerner, 1997) of Eurasian Arctic ice-core data is in agreement with our vision of the climate conditions and state of glaciation during the Holocene (Kotlyakov and others, 1990).

ACKNOWLEDGEMENTS

The author is grateful to E. Mosley-Thompson for the clear formulation of this paper.

Byrd Polar Research Center, V. S. ZAGORODNOV
The Ohio State University,
1090 Carmack Road, Columbus,
Ohio 43210, U.S.A.

2 January 1998

REFERENCES

Ahlmann, H.W:son, *ed.* 1933. Scientific results of the Swedish–Norwegian Arctic expedition in the summer of 1931. *Geogr. Ann.*, **15**.

Arkhipov, S. M. *and 11 others.* 1987. Soviet glaciological investigations on Austfonna, Nordaustlandet, Svalbard in 1984–1985. *Polar Geogr. Geol.*, **11** (1), 25–49.

Dowdeswell, J. A. 1986. Drainage-basin characteristics of Nordaustlandet ice caps, Svalbard. *J. Glaciol.*, **32** (110), 31–38.

Dowdeswell, J. A. and D. J. Drewry. 1989. The dynamics of Austfonna, Nordaustlandet, Svalbard: surface velocities, mass balance, and subglacial melt water. *Ann. Glaciol.*, **12**, 37–45.

Dowdeswell, J. A., D. J. Drewry, A. P. R. Cooper, M. R. Gorman, O. Liestøl and O. Orheim. 1986. Digital mapping of the Nordaustlandet ice caps from airborne geophysical investigations. *Ann. Glaciol.*, **8**, 51–58.

Koerner, R. M. 1997. Some comments on climatic reconstructions from ice cores drilled in areas of high melt. *J. Glaciol.*, **43**(143), 90–97; Erratum **43**(144), 375–376.

Koerner, R. M. and W. S. B. Paterson. 1974. Analysis of a core through the Meighen Ice Cap, Arctic Canada, and its paleoclimatic implications. *Quat. Res.*, **4**(3), 253–263.

Kotlyakov, V. M., V. S. Zagorodnov and V. I. Nikolaev. 1990. Drilling on ice caps in the Soviet Arctic and on Svalbard and prospects of ice core treatment. *In* Kotlyakov, V. M. and V. E. Sokolov, *eds. Arctic research: advances and prospects. Part 2.* Moscow, Nauka, 5–18.

Larina, T. B. and V. S. Zagorodnov. 1989a. Vliyaniye klimata na raspredeleniye temperatury v tsentral'noy oblasti pokrovnogo lednika [Influence of climate on the distribution of temperature in the central part of an ice sheet]. *Mater. Glyatsiol. Issled.* 65, 43–49.

Larina, T. B. and V. S. Zagorodnov. 1989b. Vliyaniye klimata na raspredeleniye temperatury vo l'du na ledorazdele Vostochnogo ledyanogo polya (Severo-Vostochnaya Zemlya) [The impact of climate on the diffusion of temperature in the ice on the ice divide of Austfonna (Nordaustlandet)]. *Mater. Glyatsiol. Issled.* 67, 185–190..

Schytt, V. 1964. Scientific results of the Swedish Glaciological Expedition to Nordaustlandet, Spitsbergen, 1957 and 1958. *Geogr. Ann.*, **46**(3), 243–281.

Shumskii, P. A. 1964. *Principles of structural glaciology.* New York, Dover Publications.

Sin'kevich, S. A. and A. V. Tarusov. 1989. Osobennosti akkumulyatsii snega na Vostochnom ledyanom pole (Shpitsbergen) [Peculiarities of snow accumulation on Austfonna (Svalbard)]. *Mater. Glyatsiol. Issled.* 67, 190–194.

Tarussov, A. 1992. The Arctic from Svalbard to Severnaya Zemlya: climatic reconstructions from ice cores. *In* Bradley, R. S. and P. D. Jones, *eds. Climate since A.D. 1500.* London and New York, Routledge, 505–516.

Troitskiy, L. S., Ye. M. Zinger, V. S. Koryakin, V. A. Markin and V. I. Mikhaliov. 1975. *Oledeneniye Shpitsbergena (Sval'barda) [Glaciation of Spitsbergen (Svalbard)].* Moscow, Nauka.

Vaykmyae, R. A. and Ya.-M. K. Punning. 1989. Stratifikatsiya lednikovykh kernov Shpitsbergena v tselyakh glyatsioklimaticheskikh rekonstruktsiy [Stratification of ice cores from Spitsbergen with a view to glacioclimatic reconstruction]. *Mater. Glyatsiol. Issled.* 67, 97–103.

Zagorodnov, V. S. 1985. Ldoobrazovaniye i glubinnoye stroyeniye lednikov [Ice formation and inner structure of glaciers]. *In* Kotlyakov, V. M., *ed. Glyatsiologiya Shpitsbergena [Glaciology of Spitsbergen].* Moscow, Nauka, 119–147. (Rezul'taty Issledovaniy po Mezhdunarodnym Geofizicheskim Proyektam.)

Zagorodnov, V. and S. Arkhipov. 1990. Studies of structure, composition and temperature regime of sheet glaciers of Svalbard and Severnaya Zemlya: methods and outcomes. *Bull. Glacier Res.* 8, 19–28.

Zagorodnov, V. S. and O. Yu. Samoylov. 1985. Godovoye stratifitsirovaniye lednikovykh tolshch v kholodnoy firnovoy zone [Annual stratification of glacier sequences in a cold firn zone]. *Mater. Glyatsiol. Issled.* 53, 160–163.

Zagorodnov, V. S., O. Yu. Samoylov, Yu. V. Raykovskiy, A. V. Tarusov, M. N. Kuznetsov and A. V. Sazonov. 1984. Glubinnoye stroyeniye lednikovogo plato Lomonosova na o. Zap. Shpitsbergen [Depth structure of the Lomonosov ice plateau, Spitsbergen]. *Mater. Glyatsiol. Issled.* 50, 119–126.

Zinger, Ye. M. and V. I. Mikhalev. 1967. Akkumulyatsiya snega na lednikakh Shpitsbergena [Snow accumulation on the Svalbard glaciers]. *Mater. Glyatsiol. Issled.* 13, 86–100.

SIR,

*Reply to the comments of V. S. Zagorodnov on "Some comments on climatic reconstructions from ice cores drilled in areas of high melt" by Roy M. Koerner**

Some of Dr Zagorodnov's criticisms arise from the problems I found utilizing the former Soviet Union (SU) publications. My organization at the time (Polar Continental Shelf Project of the Department of Energy, Mines and Resources, Canada) funded translation of some of the required papers. I should also have acknowledged the help of V. I. Nikolayev in providing a translation and discussion of Kotlyakov and others' (1991) paper. One thing I hope my paper did do was bring the extensive work of the SU to the attention of workers in the field of ice-core research. Dr Zagorodnov's additions and corrections are welcome.

However, my main point was to stress the problems of research in areas of high melt but, at the same time, point out that valuable information can still be extracted. Thus, my main conclusion, that there was a very early Holocene thermal maximum, remains unchanged and is supported by the comments and additional information Dr Zagorodnov presents. The thermal maximum removed many ice caps and caused major recession of others. Regrowth of the different ice caps and glaciers began at various times along the cooling curve of the second half of the Holocene.

Further work is presently being undertaken, some of it under the auspices of the International Geosphere–Biosphere Programme (IGBP), Past Global Changes (PAGES) and International Arctic Science Committee (IASC) programme ICAPP (Ice-core CircumArctic Paleoclimate Programme). All those who work on these ice caps feel sure that we need to examine cores from more than the Greenland ice sheet and Antarctica.

Terrain Sciences Division,
Geological Survey of Canada,
601 Booth Street, Ottawa,
Ontario K1A 0E8, Canada

ROY M. KOERNER

23 February 1998

REFERENCES

Koerner, R. M. 1997. Some comments on climatic reconstructions from ice cores drilled in areas of high melt. *J. Glaciol.*, **43**(143), 90–97; Erratum **43**(144), 375–376.

Kotlyakov, V. M., V. M. Nikolayev, I. M. Korotkov and O. L. Klementyev. 1991. Klimatostratigrafiya golotsena lednikovykh kupolov Severnoy Zemli [Climate-stratigraphy of Severnaya Zemlya ice dome in the Holocene]. *In* Khudyakov, G. I., *ed. Stratigrafiya i korreliatsiya chetvertichnykh otlozhenii Azii i Tikhookeanskogo regiona [Stratigraphy and correlation of Quaternary deposits of East Asia and the Pacific region].* Moscow, Nauka, 100–112.

* Through no fault of my own, figures on pages 92 and 93 of my paper were transposed. The *Journal* has published both pages as an erratum (Koerner, 1997). I have corrected reprints of the paper for distribution.

https://doi.org/10.3189/S0022143000002513 Published online by Cambridge University Press