Cosmogenic ^{10}Be ages of the Saglek Moraines, Torngat Mountains, Labrador

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ABSTRACT

Cosmogenic ^{10}Be ages on boulders from the Saglek Moraines of the Torngat Mountains, Labrador, suggest that the moraines were deposited in their type area 13.4 ± 1.5 ka. The ^{10}Be ages on boulders from similar moraines in a valley system 100 km north of the type area yield a mean age of 12.0 ± 2.1 ^{10}Be ka. These data support the hypothesis that the Saglek Moraines were deposited by a regional system of outlet glaciers that drained the Laurentide Ice Sheet and left extensive areas of the Torngat Mountains ice free as nunataks. Weighted mean ages for erratic boulders and bedrock 5–50 m higher in elevation than the Saglek Moraines at both field areas are indistinguishable at 1σ from the weighted mean ages of moraines in each area. These data either indicate that thicker late Wisconsinan ice receded to the level of the Saglek Moraines at 12–13 ^{10}Be ka, or that the Saglek ice margin represents the maximum late Wisconsinan extent, but the ice margin fluctuated sufficiently to create a vertical zone of ~50 m with essentially the same exposure history.

Keywords: Quaternary, cosmogenic dating, chronology, Saglek Moraines.

INTRODUCTION

Weathering zones, defined as units of the land surface that are identified by distinct weathering features, have been widely used to interpret successively limited glaciations in mountainous terrain (Ives, 1978; Nesje, 1989). The weathering zone concept was first introduced to North America from observations in the Torngat Mountains, Labrador (Lieber, 1861). Subsequent work identified weathering zones along much of the eastern Canadian seaboard, where they have provided a fundamental framework for interpreting Pleistocene glacial histories (Pheasant and Andrews, 1972; Ives, 1978).

Ives (1976) defined the Saglek Moraines as those moraines occurring at the uppermost limit of the lowest (Saglek) weathering zone in the Torngat Mountains, and interpreted them as representing the maximum limit reached by outlet glaciers draining the Laurentide Ice Sheet during the last (i.e., Wisconsinan) glaciation. Clark (1988) defined the Saglek alloformation as a drift unit occurring throughout much of the Torngat Mountains that is distinguished from older deposits on the basis of well-preserved glacial morphology and poorly developed soils. These observations indicate that the Saglek weathering zone, as originally defined (Løken, 1962; Andrews, 1963), represents an ice limit rather than a change in basal-ice thermal regime. The Saglek Moraines thus place an important constraint on the thickness of the Laurentide Ice Sheet in this region at the time of their deposition (Ives, 1978; Clark, 1988).

Despite the significance of the Saglek Moraines to the glacial history of the eastern margin of the Laurentide Ice Sheet, their age remains poorly known. A basal radiocarbon age of 18,210 ± 1200 yr B.P. (GX-6362) on laminated glaciolacustrine sediments from a lake dammed by a Saglek Moraines segment (Short, 1981) provided the first evidence that the moraines were deposited during the late Wisconsinan. Because the sediments include reworked pollen, however, the radiocarbon age provides only a maximum age for moraine deposition. An accelerator mass spectrometry (AMS) radiocarbon age of 7950 ± 100 yr B.P. (AA-1825) on postglacial sediments immediately above glaciolacustrine sediments in the same core provides only a minimum age of deglaciation (Clark et al., 1989). Similarly, the age of marine limit on the northern Labrador coast, which indicates deglaciation of fiord heads between 9000 and 10,000 ^{14}C yr B.P. (Clark and Fitzhugh, 1991), is also considered a minimum age for deglaciation from the moraines.

The existing dating control on the Saglek Moraines is thus unable to establish whether they represent an ice limit at the Last Glacial Maximum 21,000 calendar (cal) yr B.P. or at some later time. Here we report ^{10}Be exposure ages for boulders from the Saglek Moraines as well as from boulders and bedrock immediately distal to the Saglek Moraines that further constrain the timing of glaciation in the Torngat Mountains. Because our data come from two widely separated areas, we also provide a test of the hypothesis that the Saglek Moraines are correlative throughout the mountains (Clark, 1988), and thus represent a regionally coherent ice surface.

SAMPLING

We collected samples from two areas: near Nakvak Lake (58°38.9′N, 63°43.9′W) and ~100 km north near an unnamed lake (59°18.2′N, 64°22.8′W) (Fig. 1). The first area corresponds to the type area of the Saglek Moraines (Ives, 1976), and has been a key area in defining weathering zones in the Torngat Mountains (Ives, 1958, 1978). We sampled six boulders from a prominent Saglek Moraines segment ~4 km north of Nakvak Lake, and one boulder (NK96-13) on a moraine ridge immediately below the Saglek Moraines (Fig. 2A). We also sampled four boulders and three bedrock surfaces (including one tor) immediately above (maximum 20 m vertical) the Saglek Moraines.

The second field area is ~18 km west of Kangalaksiorvik Fiord (Fig. 1). Clark (1988, Fig. 8) mapped deposits of the Saglek alloformation in this area, including moraines marking the upper or distal limit of the unit, which are thus considered correlative with the Saglek Moraines. We sampled three boulders from a lateral moraine immediately west of an unnamed lake, and two boulders from a prominent terminal moraine ~4 km south of the lake (Fig. 2B). Both moraines were deposited by a distributary lobe of ice that flowed south from the main outlet glacier draining into Kangalaksiorvik Fiord. We also sampled four boulders and one bedrock surface (TM96-18) that are 45–55 m higher than the lateral moraine, and one boulder (TM96-4) that is east of the lake and ~80 m higher than the lateral moraine.

COSMOGENIC ^{10}Be ANALYSES

Samples and chemical blanks were prepared for AMS analysis of ^{10}Be following Licciardi (2000). The ^{10}Be concentrations were determined at the Tandem Accelerator Facility in Gif-sur-Yvette, France (Raisbeck et al., 1994),

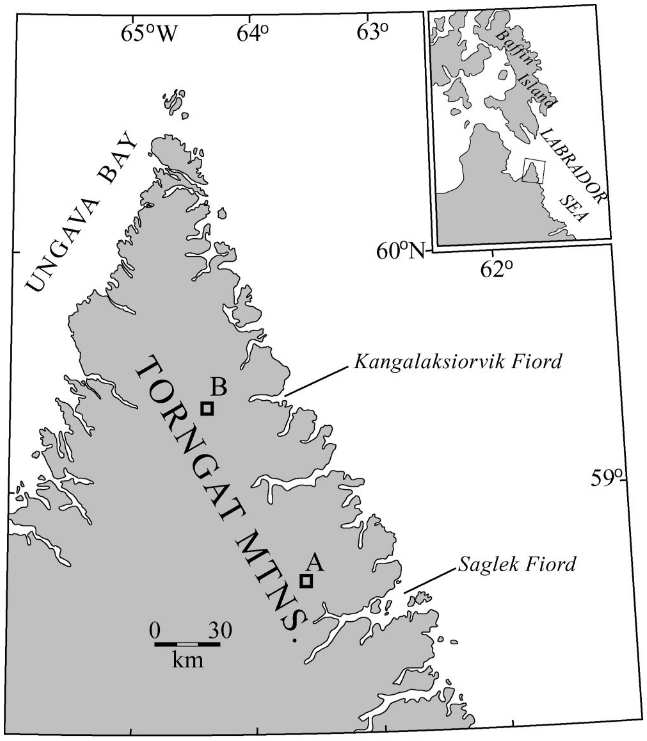

Figure 1. Location of study areas in Torngat Mountains. Nakvak Lake north of Saglek Fiord is identified by area marked A. Unnamed lake west of Kangalaksiorvik Fiord is identified by area marked B.

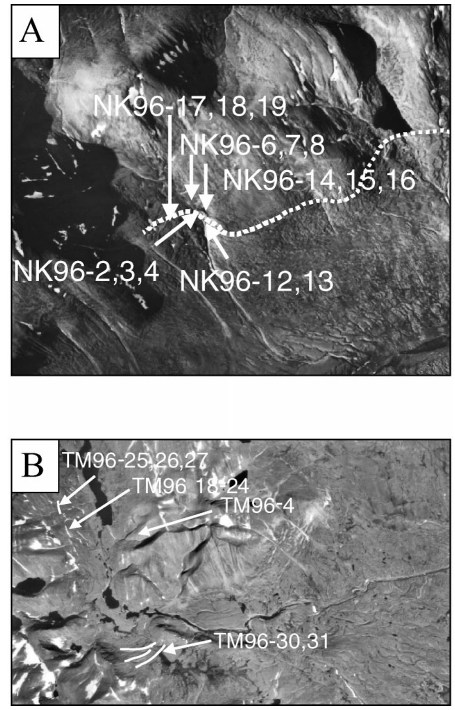

Figure 2. A: Air photo (scale = 1:75,000) of Nakvak Lake field area. Dotted white line marks upper limit of Saglek weathering zone as marked by near-continuous Saglek Moraines. Sample localities are identified. B: Air photo (scale = 1:80,000) of unnamed lake field area west of Kangalaksiorvik Fiord. Solid white lines identify Sagle Moraines. Sample localities identified.

using the National Institute of Standards and Technology (NIST) ^{10}Be standard (SRM 4325). Uncertainties (1σ) are based on counting statistics, an additional conservative 5% uncertainty based on long-term measurements of standards, and uncertainty in blank corrections. The three uncertainties were combined in quadrature. The procedural blank was 1.56 $\pm$ 0.96 $\times$ 10^5 atoms ^{10}Be (n = 11). We calculated exposure ages using the production rate estimates and scaling similar to that described by Stone (2000) in order to be consistent with recent work. We assume total production rate of 5.1 at $g^{-1}yr^{-1}$ ^{10}Be at sea level and high latitude; we also assumed 97.4% production by neutrons, and 2.6% by muons. Muon and neutron production are scaled separately, using scaling from Lal (1991) for neutrons. Latitudinal variation in muon production is scaled as for neutrons; altitudinal variation is scaled assuming an exponential dependence on atmospheric pressure, with an attenuation factor of 247 g/cm^2 (Nishiizumi et al., 1989). We use the standard relationship between atmospheric pressure and altitude adopted by Lal (1991). We decreased the calculated production rates by a factor of 0.875 (Middleton et al., 1993) in age calculations to account for the apparent difference between the certified ^{10}Be/^{9}Be ratio for the NIST ^{10}Be standard (SRM 4325) used in Gif-sur-Yvette and the ICN Biomedicals standard used to compile production rates. We corrected for sample thickness assuming exponential depth dependence and an attenuation factor of 150 g/cm^2 (Brown et al., 1992; Brook, 1994). Uncertainty associated with thickness corrections is negligible. Several samples required corrections for shielding by surrounding topography, following the methods of Dunne et al. (1999). Some boulders exhibit evidence of weathering and erosion, but most boulders preserve original polish or striations, particularly on resistant quartz veins; we thus apply no corrections for erosion. Snow cover at the field localities is unknown and we do not correct the ages for snow cover. To minimize the impact of snow cover, we sampled only boulders from exposed positions. With a few exceptions, all boulders were at least 1 m above the surrounding bedrock or moraine surface. Uncertainties in ages are the propagated analytical uncertainties only. We compare exposure ages to calendar ages in the following discussion, recognizing that uncertainties in production rate calibration and scaling (~10%) affect the accuracy of these comparisons.

RESULTS

Exposure ages of the six boulders on the Saglek Moraines segment north of Nakvak Lake range from 11.9 $\pm$ 1.0 to 19.5 $\pm$ 5.7 ^{10}Be ka (Fig. 3; Table 1). The boulder from the moraine immediately below the Saglek Moraines has an age of 13.9 $\pm$ 1.8 ^{10}Be ka (Fig. 3; Table 1). The uncertainty-weighted mean age of for these samples is 13.4 $\pm$ 1.5 ^{10}Be ka (n = 7) for the time of deposition of the Saglek Moraines in their type area.

At the unnamed lake west of Kangalaksiorvik Fiord, boulder ages from the Saglek Moraines range from 8.6 $\pm$ 1.0 to 15.7 $\pm$ 1.7 ^{10}Be ka (Fig. 3; Table 1). The ages from the lateral moraine are indistinguishable from the ages from the terminal moraine (Fig. 3; Table 1), and we include them to derive an uncertainty-weighted mean age of 12.0 $\pm$ 2.1 ^{10}Be ka (n = 6) for the deposition of the Saglek Moraines in this region.

Weighted mean ages for erratic boulders and bedrock 5–50 m higher in elevation than the Saglek Moraines at both field areas are indistinguishable at 1σ from the weighted mean ages of moraines in each area. Excluding two apparent outliers (NK96-15, NK96-16), the age range for samples distal to the Saglek Moraines near Nakvak Lake is 10.6 $\pm$ 2.0 to 17.7 $\pm$ 2.5 ^{10}Be ka (Fig. 3; Table 1), yielding an uncertainty-weighted mean age of 12.4 $\pm$ 1.4 ^{10}Be ka (n = 6). We interpret the two outliers, one on a boulder (31.4 $\pm$ 3.2 ^{10}Be ka) and one on a tor (28.0 $\pm$ 2.7 ^{10}Be ka), to reflect inherited ^{10}Be from prior exposure. The presence of the tor with an old exposure age (NK96-16) adjacent to bedrock surfaces with substantially younger exposure ages (NK96-8, NK96-14B) suggests highly variable rates of glacial erosion on local (tens of meters) scales.

Boulders sampled above the limit of the Saglek Moraines at the unnamed lake have an age range of 9.1 $\pm$ 1.8 to 12.8 $\pm$ 2.0 ^{10}Be ka (Fig. 3; Table 1). One bedrock sample (TM96-18) is anomalously old (37.5 $\pm$ 2.8 ^{10}Be ka);

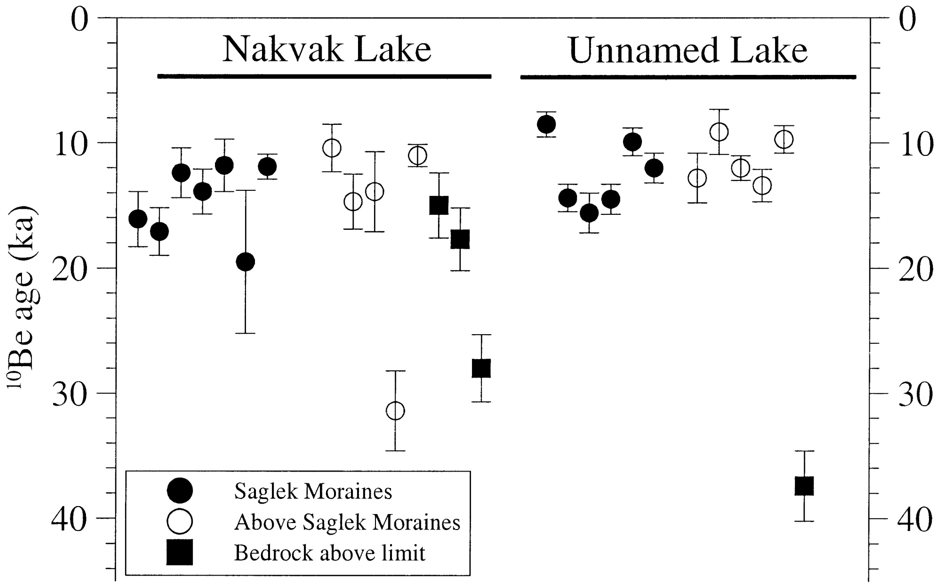

Figure 3. ^{10}Be ages from two field areas.

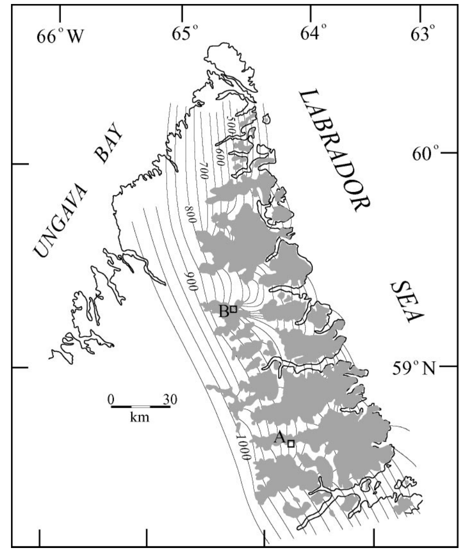

Figure 4. Reconstructed ice surface at time of deposition of Saglek Moraines. Reconstruction is based on assumption that moraines marking upper limit of lowest weathering zone correlate with each other; our ^{10}Be results from two widely separated areas (labeled A and B) support this assumption.

we attribute this to inherited ^{10}Be from prior exposure. The age of the boulder from east of the lake (TM96-4) is indistinguishable from ages of boulders west of the lake that are above the Saglek Moraines, and we include it to derive an uncertainty-weighted mean age 11.4 ± 1.7 ^{10}Be ka (n = 5) for these boulders.

DISCUSSION

Our results provide the first direct dating of the Saglek Moraines, and indicate that the moraines were deposited ca. 12–13 ^{10}Be ka. Although our sampling protocols were designed to minimize potential geological uncertainties derived from prior exposure, erosion, postdepositional movement, and burial, some of the observed age scatter in our data may be attributed to these phenomena. Nevertheless, our results clearly demonstrate that the Saglek Moraines are considerably younger than the Last Glacial Maximum. Moreover, our new data from two widely separated field areas provide the first independent test of the hypothesis (Clark, 1988) that moraines marking the upper limit of the lowest weathering zone are correlative throughout the Torngat Mountains and thus represent a regionally coherent ice surface.

Because ice sheets usually completely override the underlying topography, opportunities to reconstruct their former surfaces from ice-marginal deposits are rare. When such surfaces can be reconstructed, they provide important constraints on physically based ice sheet models and on Earth models that invert relative sea-level data to reconstruct ice thickness. We have reconstructed the former ice surface in the Torngat Mountains associated with deposition of the Saglek Moraines (Fig. 4). The reconstruction shows a regional ice surface sloping down to the east-northeast, with a maximum ice surface elevation of ~1000 m at the modern drainage divide. To the west the Laurentide Ice Sheet completely overrode the terrain descending to Ungava Bay. To the east the ice became confined to the main valleys of the Torngat Mountains and drained the ice sheet as outlet glaciers, leaving large areas of the mountains ice free as nunataks (Fig. 4). The outlet glaciers may then have flowed onto the adjacent continental shelf, coalescing as low-gradient piedmont glaciers and depositing

TABLE 1. ^{10}Be DATA FROM THE TORNGAT MOUNTAINS, LABRADOR

Sample ID	Quartz (g)	Thickness (cm)	Topography correction	Altitude (m)	^{10}Be (10^5 at g^{-1})	Production rate (g^{-1} yr^{-1})	Age (^{10}Be ka)
Nakvak Lake samples at upper limit of Saglek weathering level							
NK96-2	20.34	3.2	1.00	670	1.33	9.73	16.2 ± 2.2
NK96-3	32.14	1.0	1.00	675	1.45	9.78	17.1 ± 1.9
NK96-4	19.83	1.0	1.00	675	1.05	9.78	12.4 ± 2.0
NK96-13	32.47	2.8	1.00	640	1.12	9.48	13.9 ± 1.8
NK96-17	21.43	1.0	1.00	655	0.98	9.61	11.9 ± 2.1
NK96-18	30.21	2.7	0.99	670	1.61	9.73	19.5 ± 5.7
NK96-19	28.62	1.0	1.00	665	1.00	9.69	11.9 ± 1.0
							13.4 ± 1.5*
Nakvak Lake samples above upper limit of Saglek weathering level							
NK96-6 (1)	19.42	1.0	0.57	685	0.52	9.86	10.6 ± 2.0
NK96-6 (2)	34.35	1.0	0.57	685	0.73	9.86	15.0 ± 2.3
NK96-7	27.97	1.0	0.98	690	1.17	9.91	13.9 ± 3.2
NK98-8	20.71	3.0	1.00	690	1.49	9.91	17.7 ± 2.5
NK96-14A	35.26	1.0	1.00	675	0.94	9.78	11.1 ± 1.0
NK96-14B	20.07	3.4	1.00	675	1.25	9.78	15.1 ± 2.6
NK96-15	31.25	1.0	1.00	690	2.68	9.91	31.4 ± 3.2
NK96-16	30.31	2.5	1.00	675	2.33	9.78	28.1 ± 2.7
							12.4 ± 1.4*
Unnamed lake samples at upper limit of Saglek weathering level							
TM96-25	26.29	3.8	1.00	600	0.66	9.15	8.6 ± 1.0
TM96-26	29.50	3.0	1.00	600	0.77	9.15	10.0 ± 1.1
TM96-27 (1)	19.50	1.0	1.00	600	1.23	9.15	15.7 ± 1.7
TM96-27 (2)	48.13	1.0	1.00	600	1.14	9.15	14.4 ± 1.1
TM96-30	33.99	4.1	1.00	410	0.77	7.69	12.0 ± 1.2
TM96-31	47.55	1.0	0.93	410	0.77	7.69	14.6 ± 1.2
							12.0 ± 2.1*
Unnamed lake samples above upper limit of Saglek weathering level							
TM96-4	33.18	5.0	1.00	680	1.05	9.82	12.8 ± 2.0
TM96-18	30.42	1.0	1.00	655	3.09	9.61	37.5 ± 2.8
TM96-19	32.15	1.0	1.00	655	1.00	9.61	12.0 ± 1.0
TM96-22	31.61	3.8	1.00	650	1.10	9.56	13.4 ± 1.3
TM96-23	27.50	2.7	1.00	650	0.79	9.56	9.8 ± 1.1
TM96-24	31.30	1.0	1.00	645	0.75	9.52	9.1 ±1.8
							11.4 ± 1.7*

*Weighted mean age.

a regional till sheet (Clark and Josenhans, 1986).

Our cosmogenic ^{10}Be ages of the time of deposition of the Saglek Moraines are consistent with our understanding of regional deglaciation. Insofar as our ^{10}Be ages indicate the age of moraine abandonment, our results agree, within uncertainties, with a minimum age of deglaciation of the continental shelf east of Nakvak Lake of 11 ^{14}C ka (ca. 12.8 cal ka) (Hall et al., 1999). The age of marine limit indicates subsequent deglaciation of fiord mouths by 9–10 ^{14}C ka (10.5–11.5 cal ka) (Clark and Fitzhugh, 1991).

Our data are less clear with respect to whether the Saglek Moraines represent maximum ice extent in the Torngat Mountains during the late Wisconsinan. Same-aged boulders and rock surfaces immediately distal to the Saglek Moraines may indicate that the moraines represent a brief recessional phase subsequent to a phase of thicker ice. According to this hypothesis, the clear distinction between geomorphic and weathering characteristics of drift above and below the Saglek Moraines (Clark, 1988) would suggest that this earlier ice was predominantly cold based, largely preserving an older glacial landscape, and only became warm based when the ice had receded to the level of the Saglek Moraines. The presence of a rock surface with inherited ^{10}Be 55 m above the Saglek Moraines near the unnamed lake (TM96–18) indicates minimal glacial erosion. However, we are not aware of any well-defined ice-marginal deposits marking a limit higher than the Saglek level. The break between the next two higher weathering zones (the Koroksoak and Komaktorvik zones; Ives, 1978) is characterized by a change from largely weathered drift to frost-riven bedrock, but interpreting the glaciological significance of this change remains uncertain.

A second hypothesis is that ice thickness may have been greatest during the late Wisconsinan ca. 12–13 ^{10}Be ka, but the ice margin fluctuated sufficiently to create a vertical zone ~50 m high with essentially the same exposure history. Accordingly, our data do not constrain the age of the next older glaciation, although weathering characteristics (Clark, 1988) indicate it is pre–late Wisconsinan. Further cosmogenic sampling along vertical transects is required to test these two hypotheses.

According to some climate model simulations, the Labrador sector of the Laurentide Ice Sheet was particularly sensitive to the abrupt changes in North Atlantic sea-surface temperatures that characterized the last deglaciation (Fawcett et al., 1997; Hostetler et al., 1999). The uncertainty in our ages, however, precludes definitive correlation of the Saglek Moraines with the associated millennial-scale climate events. We thus propose two hypotheses to explain the formation of the moraines; the moraines may represent a response to increased snow accumulation associated with the Bølling-Allerød warm interval (14,600–12,900 yr B.P.), or they represent a response to cooler temperatures during the Younger Dryas cold interval (12,900–11,500 yr B.P.). If they are Younger Dryas in age, the Saglek Moraines may be associated with a major northward readvance of ice through Ungava Bay during Heinrich event 0 (Andrews et al., 1995). Higher resolution dating of the moraines will be required to test these hypotheses.

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