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CLIMATIC ICE CORE STUDIES AT LEWIS GLACIER, MOUNT KENYA*

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With 5 figures

ABSTRACT

Two ice cores of 11 and 13 m were retrieved in February 1978 on Lewis Glacier, Mount Kenya, as part of a multi-annual field study aimed at climate reconstruction. Oxygen isotope ratios show comparatively little variation with depth. Variations of microparticle concentration and of total β activity are approximately concomitant, values being smallest in snow layers, and largest in ice horizons. The latter mainly reflect the two ablation seasons per year. The microparticle and β profiles thus offer some prospect for a chronology and possibly for a net balance series. However, in contrast to our work on the high Quelccaya Ice Cap in Peru, percolation on Lewis Glacier below 5000 m is substantial, and hampers the interpretation of profiles. The summit ice fields of Kilimanjaro are regarded as the most nearly suitable site for climatic ice core studies in equatorial East Africa.

ZUSAMMENFASSUNG

Im Rahmen eines mehrjährigen, auf Klima-Rekonstruktion ausgerichteten Feldprojekts auf dem Lewisgletscher am Mont Kenya wurden im Februar 1978 zwei Eiskerne von 11 und 13 m Länge entnommen. Quotienten der Sauerstoffisotope zeigen vergleichsweise wenig Änderung mit der Tiefe. Die Konzentration der Mikro-Partikel und die Gesamt-Beta-Aktivität ändern sich ungefähr gleichläufig, und zwar so, daß die geringsten Werte in Schneeschichten und die größten in Eishorizonten angetroffen werden. Letztere spiegeln hauptsächlich die beiden jährlichen Ablationsperioden wieder. Die Mikropartikel- und Beta-Profile stellen also eine Chronologie der Eisschichten und möglicherweise sogar Zeitreihen der Massenbilanz in Aussicht. Im Gegensatz zu unseren Arbeiten auf der hohen Quelccaya-Eiskappe in Peru ist indessen am Lewisgletscher unterhalb 5000 m das Einsickern von Schmelzwasser beträchtlich, was die Interpretation der Profile erschwert. Die Eisfelder des Kilimandscharo-Gipfels scheinen der am ehesten geeignete Ort für Eiskernstudien im äquatorialen Ostafrika.

1. INTRODUCTION

Tropical glaciers are extremely sensitive albeit complex indicators of climatic variations. As a basis for the study of glacier-climate relationships a multi-annual field program is being conducted by the Meteorology Department of the University of Wisconsin on Lewis Glacier, Mount Kenya. The Lewis was chosen because it is easily accessible; its catchment area is well defined; and most importantly, historical documentation on secular changes is unequalled in the tropics, as it includes various mappings (Troll and Wien 1949; Charnley 1959; Forschungsunternehmen Nepal-Himalaya 1967; Caukwell and Hastenrath 1977; Hastenrath and Caukwell 1979) and numerous photographs since the turn of the century (Hastenrath 1975).

Project components include readings at a network of net balance stakes installed on the glacier; monitoring of ice movement and changes in surface topography by repeated surveys of these poles; stratigraphic studies in ice pits dug at strategic locations; regular precipitation measurements; repeated airborne mappings of the glacier; ice thickness determinations by the seismic and gravimetric techniques;

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and numerical modelling of ice dynamics and glacier-climate relationships (Hastenrath 1975; Caukwell and Hastenrath 1977; Hastenrath and Caukwell 1979; Hastenrath and Kruss 1980; Bhatt et al. 1982).

In February 1978 ice cores were retrieved for an alternative approach to climate reconstruction through the analysis of oxygen isotope, total β activity, and microparticle content. Further samples were obtained in January 1980 from a pit in the same general location. The background provided by the overall project, and in particular the stratigraphic control available from pits, net balance, and precipitation measurements, are considered fundamental to the interpretation of ice cores. Results shall be discussed here in the context of our earlier ice core experience at the Quelccaya Ice Cap in Peru (Thompson et al. 1979; Thompson 1980).

2. SAMPLING

Among the pits dug in February—March 1978 are two on the flat col between the Lewis and Gregory Glaciers around 4,870 m (Fig. 1). The more northerly of these, pit I, extended to 2.5 m, from where a SIPRE drill provided a core to a total depth of 13.4 m. Pit II, some 40 m further South was dug to 2.1 m, and an ice core was drilled to a total depth of 11.4 m. At site I drilling was unusual, in that voids were encountered between 8.3 and 8.6 m and between 9.4 and 12.9 m depth. The core at site II is continuous.

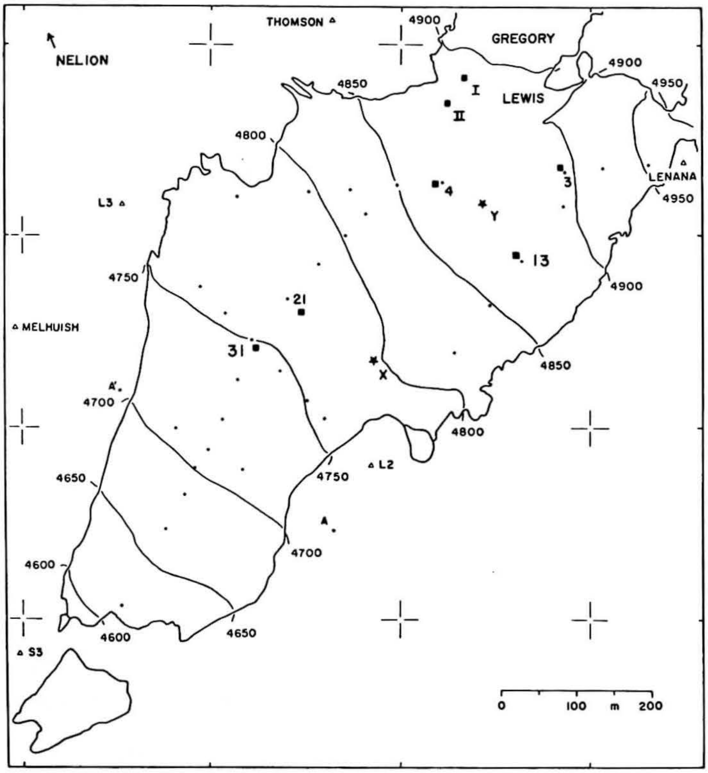


Fig. 1: Orientation map. Rectangles denote sites of snow pits 3, 4, 13, 21, 31, and of ice cores I and II; and dots refer to the network of net balance stakes. Asterisks denote drill sites by University of East Anglia expeditions in August 1975 (X) and July 1977 (Y).

519 samples were cut, melted, and placed in clean containers while in the field. In the process, each core was split in half. One half was analyzed for oxygen isotope and total β activity at the Geophysical Isotope Laboratory in Copenhagen, and the other for microparticles at the Ohio State University under Class 100 clean room conditions (Thompson 1977).

In December 1978 a pit was excavated to 3.8 m in the same general area, for study of stratigraphy and density profile. In December 1979 to January 1980, another pit was dug to 3.1 m, and 16 samples were retrieved for isotope and microparticle analysis. Further pit studies were performed at four other sites during each of the 1977/78, 1978/79 and 1979/80 expeditions (Fig. 1). The location of net balance stakes is also shown in Fig. 1, as are the approximate drill locations of the University of East Anglia expeditions in July—August of 1975 and 1977 (Davies et al. 1977a, b; pers. comm. 1978—79).

3. PROFILE DESCRIPTION

Commensurate with elevation and latitude, annual mean air temperature is around 0° C, with an annual range of the order of 2° C as in most regions of the inner tropics. Temperature at the surface is below freezing during the night and early morning; however, firn temperatures increase to 0° C at 0.5 m depth, thus indicating that the ice is temperate. Fig. 2 illustrates a rapid increase of density with depth, presumably resulting from percolation.

Results for sites I and II are shown in Figs. 3 and 4, respectively. Fig. 5 illustrates the pit profile obtained in the same area in January 1980. Both cores (Figs. 3 and 4) contain well developed ice horizons and visually detectable dirt bands. Throughout the cores large particle concentrations occur simultaneously with high β radioactivity. $\delta\,^{18}O$ ratios exhibit a range of 5.4‰ at the surface, but this is smoothed out below 1 m presumably due to meltwater percolation.

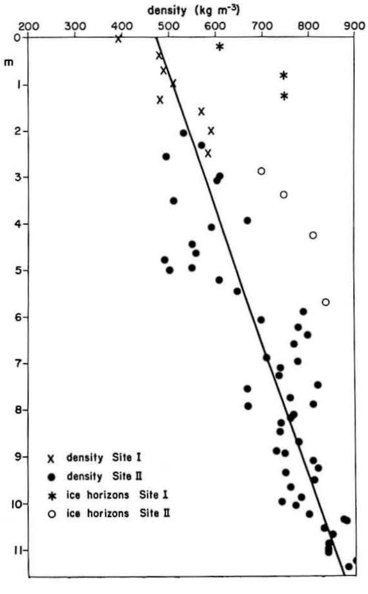


Fig. 2: Density profile. Crosses and asterisks refer to site I, dots and circles to site II, asterisks and circles denoting ice horizons.

For core I (Fig. 3) a hiatus is indicated at 6 m by a 45 degree tilting of the strata, as well as by the voids at 8.3—8.6 m and 9.4—12.9 m. Most remarkable is the large range of $\delta\ ^{18}O$ in the ice downward from 8.6 m, below the first void. As at the surface, the less negative $\delta\ ^{18}O$ values are associated with high particle concentrations. Open crevasses could allow snowfall to become trapped at greater depth, thus contributing to the irregularity of the $\delta\ ^{18}O$ profile. Although no crevasses were noted near the sampling site, some mobility in crack formation and closure cannot be ruled out even in this location of gentle topography. Based upon the aforementioned interruptions and irregularities, core I appears little suited for the reconstruction of a continuous climatic time series.

Ice core II (Fig. 4) differs remarkably from core I, despite their close proximity. Microparticle concentrations and total β activity are particularly large in the upper few m, but greatly decrease with depth, broadly parallel with increasingly larger negative $\delta\ ^{18}O$ values. The decrease with depth of visually apparent impurities in the Lewis Glacier has been noted earlier (Hastenrath 1975). The microparticle profile in Fig. 4 (A) is consistent with the cleaning of snow by percolation as reported for temperate glaciers (Glen et al. 1977). Whether the comparatively high radioactivity

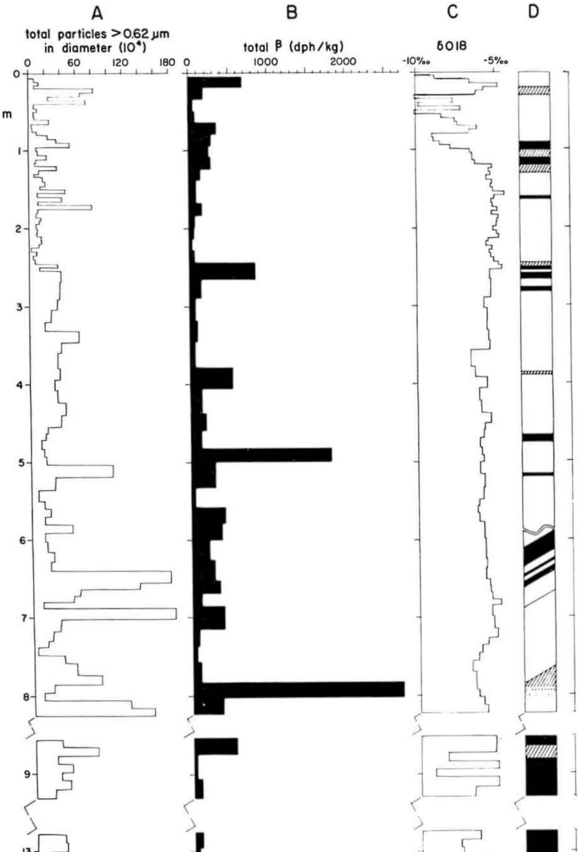


Fig. 3: Core profile at site I.
A. concentration of microparticles $> 0.62\ \mu m$ in diameter per $500\ \mu l$ of sample.
B. gross β activity in dph/kg, shaded.
C. oxygen isotope ratios, $\delta^{18}O$, unshaded.
D. ice core stratigraphy: ice horizons solid lines, and visually dirtier layers hatched.

in the top few m is related to the presence of algae, as suggested by the pink color of samples from the wall of pit II, is open to speculation.

The change toward more negative δ ^{18}O values with depth in core II (Fig. 4) contrasts with conditions observed in most temperate glaciers (Sharp et al 1960; Ambach et al. 1972; Thompson et al. 1979; Thompson 1980). Refreezing of the melt and rain water percolating into cold underlying snow or firn is a viable mechanism for homogenization and less negative δ ^{18}O values in temperate glaciers (Sharp et al. 1960). It is thought that rain and snow precipitated in the warmer season possesses less negative δ ^{18}O values. Temperature records from the Kenya highlands exhibit little variation over the recent past, and precipitation on the col between the Lewis and Gregory Glaciers is as a rule in solid form. Thus an explanation in other terms must be sought for the δ ^{18}O of core II (Fig. 4).

The Meren Glacier in New Guinea (Hope et al. 1976, pp. 39—49) also shows a change towards more negative δ ^{18}O values with depth. Hope et al. consider that most of the snowfall is associated with cyclonic activity, whereas daily convective clouds bring mainly rain. Assuming the air in convective systems is depleted in heavy isotopes, the percolation of rain water would yield more negative δ ^{18}O values at depth. However, neither the snow nor rain was analyzed isotopically, leaving this explanation open to speculation.

Fig. 4: Core profile at site II. Symbols as for fig. 3. In addition, mass content of layers in 10^2 kg m^{-2} is indicated to the right of column D. Gap at 195—407 cm is due to lack of sampling bottles.

Table 1: Summary of oxygen isotope and microparticle data from four tropical glaciers
A. Summit of Quelccaya Ice Cap, Peru, 13° 56′ S, 70° 50′ W, 5650 m (source: Thompson et al. 1979);
B. Meren Glacier, Mount Carstensz, Indonesia, 0° 9′ S, 37° 19′ E, 4870 m (source: Hope et al. 1976, p. 54—58);
C. Lewis Glacier, 0° 9′ S, 37° 19′ E, 4870 m;
D. Kilimanjaro, 3° 00′ S, 37° 20′ E, 5895 m (source: Gonfiantini 1970).

	Quelccaya	Meren	Lewis	Kilimanjaro
mean air temp (°C)	− 3	+ 0.5	− 0.5	
mean $\delta^{18}O$ near sfc ($^0/_{00}$)	−21.0	−15.5	− 7.8	−3.7 at 4600 m to −6.8 at 5700 m
mean $\delta^{18}O$ all samples ($^0/_{00}$)	−19.4	−15.7	− 6.0	
$\delta^{18}O$ max	−11.0	−12.7	− 4.8	
$\delta^{18}O$ min	−33.0	−17.2	−10.2	
$\delta^{18}O$ range	22.0 most negative in warm season	4.5	5.4	
concentration of particles $> 0.62\,\mu m$ (10^8 per liter)	2		8	

Table 1 summarizes the oxygen isotope and microparticle data from four glacier sites in the tropics. No simple relation is apparent between $\delta\,^{18}O$ ratios and mean surface air temperature. Values from Mt. Kenya and Kilimanjaro are of similar magnitude, reflecting their vicinity and similar climatic environments. The largest range is found on Quelccaya in the Peruvian Andes. The high particle concentrations at Lewis Glacier reflect the proximity of exposed rock massifs to the core sites. By contrast, particle concentrations are low at the Quelccaya summit, which is the highest point in the area, and distant from surfaces not covered by ice.

4. RELATION TO REGIONAL PRECIPITATION CONDITIONS

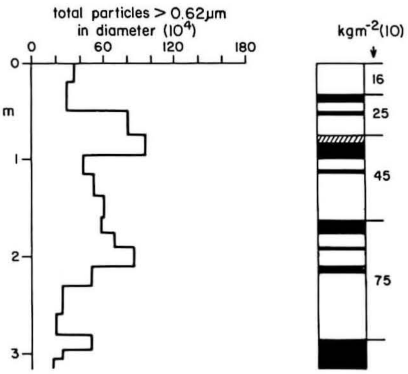
Stratigraphic control by snow pit and net balance studies is fundamental to the chronology and climatic interpretation of ice cores. These are provided for the last few years by our field program at Mount Kenya.

Table 2: Monthly precipitation totals in upper Teleki Valley at 4200 m below Lewis Glacier, average of years 1978—80, in mm

J	F	M	A	M	J	J	A	S	O	N	D	Year
40	45	91	108	111	28	21	22	54	96	117	53	786

Table 2 illustrates the annual precipitation regime. The mean annual total at Lewis Glacier is of the order of 800 mm. The annual march of precipitation in Central Kenya is characterized by two rainy seasons occurring about March—June and September—December. These are accumulation seasons on Mount Kenya. Precipitation activity and cloudiness is at a minimum during January—February and July—August, the ablation seasons on the mountain. Generally, the two ablation seasons are reflected in the pit profiles by pronounced ice horizons, and the accumulation seasons by more extended layers consisting predominantly of firn.

Fig. 5: Pit dug in general area of cores I and II in December 1979—January 1980. Symbols as for fig. 4.



Approximately monthly readings are made at net balance station 3 near pit 3, and at net balance station 13 near pit 13. For the area of ice cores I and II, stake readings indicate the net balance for the interval January 1979—January 1980, thus providing a time control on pit stratigraphy.

Figs. 3—5 indicate that the ice horizons, which may represent the two ablation seasons of the year, tend to be characterized by both high concentration of microparticles and large total β activity. By contrast, the relation of $\delta\ ^{18}O$ to the seasonality of net balance is not apparent. It seems desirable to extend the comparison of ice cores versus net balance and precipitation conditions beyond the most recent years of our monitoring program on Lewis Glacier. To that end, precipitation index series were constructed for a group of long-term stations in Central Kenya, but these can only serve to a limited extent as proxies for the precipitation and net balance conditions at Lewis Glacier itself.

5. CONCLUSIONS

At this stage it is suggested that the major ice horizons in Figs. 3—5 mark primarily the twice-annual ablation seasons. In view of temperatures near 0° C and the concomitant melting and percolation effects, however, it is considered that ice horizons may originate through mechanisms other than surface ablation. Conditions are conceivably complicated further by more complex topography in other portions of the glacier. Furthermore, annual net balance can become negative for nearly all portions of the glacier, as we measured during March 1979 to March 1980, and March to July 1980, so that stratigraphic chronology is destroyed. On site concurrent monitoring of precipitation, net balance, pit profiles, and sampling for various laboratory analyses, over a series of years may elucidate this problem complex. If in fact the concomitant maxima of microparticle concentration and total β activity mark the horizons of the twice-annual ablation seasons, then this would open the prospect for a net balance chronology from ice cores, similar to our exploits at Quelccaya. However, the Lewis is at much lower elevation, and ice lenses may *inter alia* originate from the refreezing of percolated meltwater.

These results in conjunction with our previous report (Thompson et al. 1979; Thompson 1981) exemplify the potential of climate reconstruction from ice cores in the tropics. The Quelccaya Ice Cap meets simultaneously the following important conditions: a) high elevation (low temperature, no percolation); b) gentle topography (minimum effect of flow dynamics on stratigraphy); c) location in outer tropics (some seasonality). Elsewhere in the tropics conditions are less favorable for ice coring. The concurrent study of modern net balance and stratigraphy is always imperative. The summit ice fields of Kilimanjaro are the obvious choice for further climatic ice core studies in Equatorial East Africa.

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