Journal of Glaciology, Vol. 25, No. 93, 1980

LATE QUATERNARY ROCK GLACIERS, MOUNT KENYA, KENYA

By W. C. Mahaney

(Department of Geography, York University, Toronto, Ontario M3J 2R7, Canada)

Abstract. Rock glaciers in Teleki Valley on Mount Kenya exist above 4 000 m below steep valley walls where they are supplied with debris from avalanche couloirs. These valley-side rock glaciers consist of three or four lobes of rubble bounded by transverse furrows resulting from differential movement. No ice cores were observed in these rubble sheets, but "drunken forest" stands of *Senecio keniodendron* indicate the probable presence of interstitial ice resulting either from the metamorphism of snow buried under rockfall and slide-rock debris, or from freezing of water beneath the rock mantle. A geological survey of Mount Kenya in 1976 revealed that rock glaciers are anomalous in the Mount Kenya Afroalpine zone above 3 300 m. Analysis of weathering rinds indicates that several rock-glacier lobes were built up over a short interval of time at or near the end of the last glacial maximum (Würm). Oversteepened fronts on the westernmost lobes may have resulted from re-activation coinciding with the advance of glaciers during late Holocene time (< 1 000 B.P.). Soils mantle 20% of the rock-glacier surface and have morphological characteristics comparable with soils forming on moraines of late Würm age in upper Teleki, Hausberg, and Mackinder Valleys.

Résumé. *Glaciers rocheux de la fin du quaternaire, Mont Kenya, Kenya.* Dans la Teleki Valley du Mount Kenya des glaciers rocheux existent au dessus de 4 000 m sous des flancs de vallées très abrupts où ils sont nourris en sédiments par des couloirs d'avalanches. Ces glaciers rocheux de vallées latérales consistent en trois ou quatre lobes de blocailles limitées par des failles transversales résultant de mouvements différentiels. On n'a pas observé de coeurs de glace dans ces couvertures de blocailles, mais des stations de "forêt ivre" de *Senecio keniodendron* indiquent la présence probable de glace interstitielle résultant soit de la transformation de la neige enfouie sous les chutes de blocs et les glissements de terrains, soit du regel de l'eau sous le manteau de rochers. Une reconnaissance géologique du Mount Kenya en 1976 a révélé que les glaciers rocheux sont anormaux dans la zone Afroalpine du Mount Kenya au dessus de 3 300 m. L'analyse des datations d'écorces indiquent que plusieurs lobes de glaciers rocheux ont été construits en un court intervalle de temps au moment ou près de la fin du dernier maximum glaciaire (Würm). Les fronts surabrupts des lobes occidentaux peuvent résulter de la ré-activation coïncidant avec l'avance des glaciers lors de la dernière période holocène (moins de 1 000 ans avant le présent). Des sols recouvrent 20% de la surface des glaciers rocheux et ont des caractéristiques morphologiques comparables aux sols en formation sur les moraines de la fin du Würm dans les hautes vallées du Teleki, de Hausberg et de Mackinder.

Zusammenfassung. *Blockgletscher aus dem späten Quartär am Mt Kenya, Kenya.* Im Teleki Valley am Mt Kenya gibt es über 4 000 m Höhe unter steilen Talwänden Blockgletscher, die aus Lawinenrinnen mit Schutt versorgt werden. Diese Blockgletscher am Talrand bestehen aus drei oder vier Schuttloben, die von Querfurchen, erzeugt durch differentielle Bewegung, begrenzt sind. Eiskerne konnten in diesen Schuttdecken nicht gefunden werden, doch deuten Stellen von "drunken forest" mit *Senecio keniodendron* auf das Vorhandensein von Zwischeneisschichten hin, die entweder aus der Umwandlung von Schnee, der unter Felsstürzen und Hangschutt begraben wurde, oder durch Gefrieren von Wasser unter dem Schuttmantel entstanden sind. Eine geologische Erkundung des Mt Kenya im Jahre 1976 ergab, dass Blockgletscher in der afroalpinen Zone des Mt Kenya über 3 300 m ungewöhnlich sind. Die Analyse von Verwitterungsrinden weist darauf hin, dass Blockgletscherloben in einem kurzen Zeitintervall während oder nahe am Ende des letzten Gletscherhochstandes (Würm) entstanden. Übersteilte Fronten der westlichen Loben können sich bei einer Reaktivierung gebildet haben, die mit dem Gletschervorstoss im späten Holozän (weniger als 1 000 Jahre vor der Gegenwart) zusammenfiel. Bodenbildungen überdecken 20% der Oberfläche der Blockgletscher; morphologisch sind sie mit Böden vergleichbar, die sich auf Moränen der späten Würm-Zeit im oberen Teleki, im Hausberg, und im Mackinder Valleys gebildet haben.

Introduction

Investigation of three rock glaciers on Mount Kenya developed out of a study of Quaternary stratigraphy and soil morphogenesis. Rock glaciers of the valley-side type (Outcalt and Benedict, 1965) are found in Teleki Valley (Naro Moru River) above 4 000 m on Mount Kenya (Fig. 1). Avalanche couloirs deliver trachyte-tuff agglomerate and porphyritic phonolite debris across 30° talus slopes into the three rock-glacier systems. In this paper the origin and age of the rock glaciers are discussed.

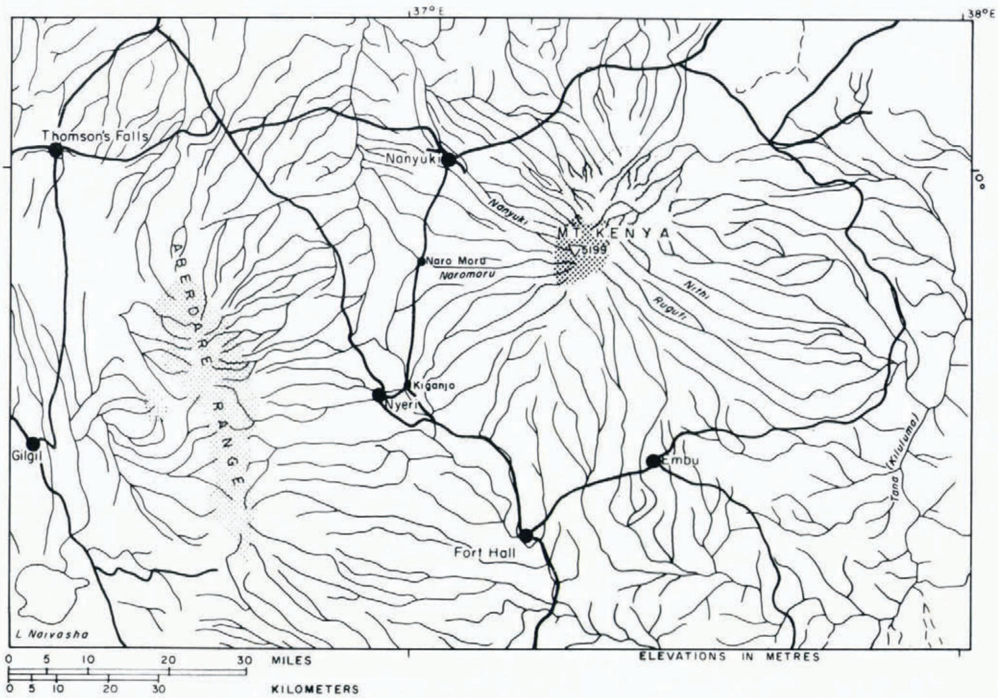

Fig. 1. Map of Mount Kenya showing Naro Moru drainage basin.

Field area

Mount Kenya is a prominent strato-volcano of late Pliocene/early Pleistocene age, located approximately 200 km north of Nairobi, and rising to 5 185 m above the high plateau of Kenya (Fig. 1) (Baker, 1967). Twelve glaciers are found above 4 600 m; prominent moraines, outwash trains, alluvial fans, talus cones, and rock glaciers of late Pleistocene/early Holocene age mantle the flanks of the mountain.

Vegetation in the vicinity of the rock glaciers has been described by Hedberg (1964) as belonging to the Upper Alpine group consisting of giant groundsel (*Senecio keniodendron*), *Helichrysum*, *Carex* sedge and *Agrostis* grass, *Carduus platyphyllus* and *Lobelia telekii*.

Climatic data for Teleki Valley are incomplete but Hedberg (1964) estimated the mean monthly temperature for August to be 3.1–3.6°C. Generalized isohyets for 1961 (Coetzee, 1967) approximate precipitation to be 108 cm. The wettest slopes are on the south-east flank of the mountain where precipitation reaches 375 cm.

Teleki Valley rock glaciers

Lobate-shaped rock glaciers in Teleki Valley consist of poorly sorted and angular debris, principally composed of porphyritic phonolite, agglomerate, and trachytic porphyry derived from nearby bedrock and moraine sources.

No interstitial ice was observed in the three rock-glacier systems but minimum temperatures taken at the base of a 78 cm open soil pit (site TV1, Fig. 2) averaged −4.1°C ($n = 5$, in August 1976). The lack of interstitial ice is more the rule than the exception according to numerous workers (White, 1976). These three systems have numerous concave depressions behind the outer lobe, a number of lateral, and a few longitudinal furrows and "drunken stands" of *S. keniodendron* and *L. telekii* (Fig. 3), suggesting that previous ice had melted out.

At least three lobes that are generally wider than they are long have developed below avalanche talus on the north side of the valley. The thicknesses of the rock glaciers are estimated at 100–150 m, and two of the outermost lobes appear to be re-activated (Fig. 2). However, the lobes on all three systems have

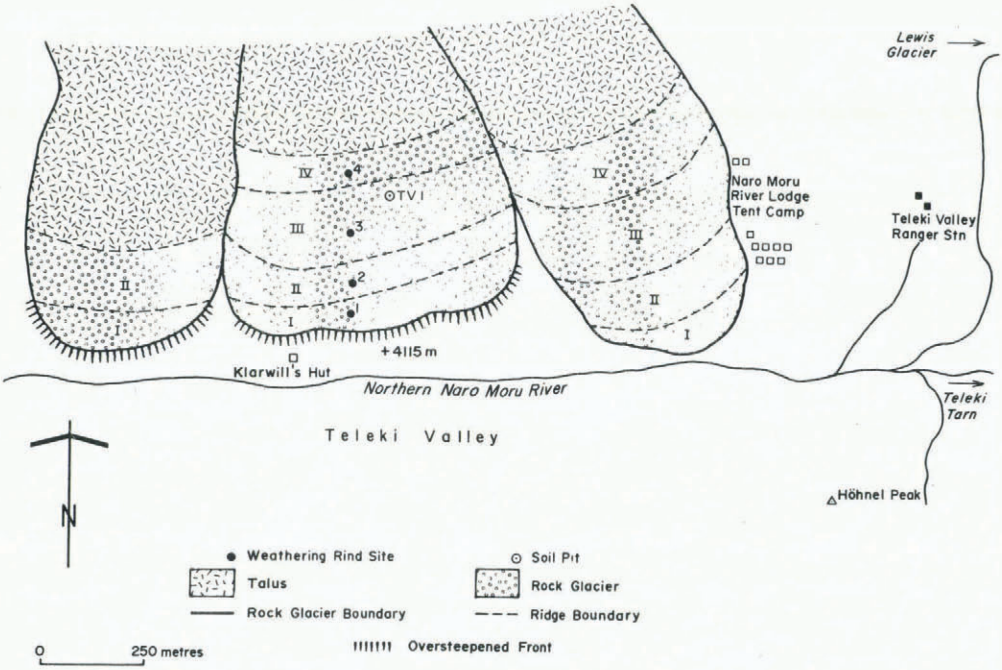

Fig. 2. Map showing distribution of rock glaciers in Teleki Valley at approximately 4 100 m. Late Pleistocene/early Holocene soil profile (TV1) is on the third lobe of the middle system. Soils mantle approximately 20% of surface; remaining 80% is an open network of boulders.

Fig. 3. Talus with Lobelia telekii *and* Senecio keniodendron *sparsely distributed on stones feeding into the middle rock-glacier system.*

c. 80% lichen cover (e.g. *Rhizocarpon geographicum*, *Lecanora* spp.?, *Umbilicaria haumania*, *Umbilicaria africana* and *Usnea*), suggesting that movement is exceedingly slow. Isolated boulders and large blocks were found in front of the two re-activated fronts (Fig. 2).

Weathering criteria

The degree of weathering increases from lobe IV to lobe I as shown in Table I.

The data indicate that the several lobes have similar ages and correlate closely with late glacial moraines described by Mahaney (in press).

TABLE I. WEATHERING CRITERIA USED TO DIFFERENTIATE ROCK-GLACIER LOBES

*Weathering criteria**	*Rock glacier lobes* I	II	III	IV
Average weathering rind	6	5	5	4
Average weathering pit depth	11	11	10	10

* Observations of 100 stones at each locality. Measurements taken to the nearest millimetre.

SOIL DEVELOPMENT

A discontinuous distribution of fine sediment supports a moderately developed Inceptisol as well as numerous grasses and sedges. A thin 1–3 cm mat of partly decayed black organic material (10YR 1/1, 2/1 m) overlies a pedon (TV1 soil profile) with the following horizonation:

Horizon	*Depth* cm	*Description**
A11	0–10	Brownish black (10YR 2/2 m; 10YR 3/2 d) pebbly sandy loam, granular structure, friable moist consistency, plastic and slightly sticky, pH 4.80
A12	10–18	Brownish black (10YR 2/3 m) and grayish yellow brown (10YR 4/2 d) pebbly sandy loam, granular structure, firm moist consistency, plastic and slightly sticky, pH 4.65
B2ir	18–58	Dark brown (10YR 3/4 m) and brown (4/4 m) and dull yellow-orange (10YR 6/3 d), cobbles and pebbly coarse sandy loam, massive to weak blocky structure, loose moist consistency, non-plastic and non-sticky, pH 5.60
IICox	58–78	Brown (10YR 4/4 m) dark olive-brown (2.5Y 3/3), and grayish yellow-brown (10YR 6/2 d) cobbles and pebbly coarse loamy sand, massive structure, loose to very friable moist consistency, slightly plastic and non-sticky, pH 5.90
D	78+	Deposit consists of an open network of boulders of phonolite, trachytic phonolite and basaltic tuff

* Soil-horizon nomenclature follows the U.S. Bureau of Plant Industry, Soils and Agricultural Engineering. Division of Soil Survey (1951), U.S. Soil Conservation Service (1960), and Birkeland (1974). (m, moist; d, dry colors.)

Particle-size determinations indicate that two parent materials are present (e.g. rock-glacier debris and loess). The data are shown in Table II.

The upward-fining sequence where silt is higher in the solum and lower in the sub-soil compares closely with soils on nearby end moraines of late Würm age (Mahaney, 1979) in Teleki, Mackinder, and Liki North Valleys, and with late-glacial soils in the Rocky Mountains (Mahaney, 1974). The higher clay and silt quantities in the solum of this soil further substantiate the observations of Zeuner (1949), who described aeolian materials in soils on the mountain.

No clay minerals were detected in the <2 μm grade-size material. However, rock-forming minerals in the fine clay-grade size include plagioclase and quartz. Feldspars exist in trace quantities throughout the soil, while quartz ranges from moderately abundant (>50% on diffractograms) in the A11, A12, and IICox horizons to traces in the B2ir horizon. The absence of clay minerals is noteworthy, especially since they occur in other nearby late-glacial soil systems (Mahaney, in press).

Table II. Particle-size distribution* for the soil horizons in profile TV1

	Sand 2 mm–63 μm	*Silt* 63–4 μm	*Clay* <4 μm
A11	69.2	14.3	16.5
A12	70.0	14.0	16.0
B2ir	72.3	17.2	10.5
IICox	83.0	11.0	6.0

* Data are given in weight % of soil mineral matter; coarse particle sizes determined by dry sieving; fine particle sizes by hydrometer.

The analysis by X-ray diffractometry of primary minerals in the silt-sized fractions (63–4 μm) indicates that quartz is nil in the solum, increasing to small amounts (30–50% based on peak height above background radiation) in the C horizon. Feldspar is found in trace amounts in the upper solum and increases to small and moderate amounts in the B and C horizons. The data correlate closely with mineral assemblages found in nearby soils forming on late glacial moraine systems and suggest that common rock-forming minerals weather quickly in soils above the timber line.

Conclusion

Three massive valley-side rock glaciers are found in Teleki Valley just above the 4 000 m contour. Numerous criteria including transverse furrows, steep re-activated fronts, and "drunken stands" of giant groundsel and lobelia attest to differential movement, but no interstitial ice cores were observed in the field. Rainfall and temperature regimes are marginally sufficient to support the growth of ice in the rock lobes. Soil and weathering criteria suggest a late-glacial age for the rock glaciers, while re-activation as indicated by steep fronts may have coincided with the advent of glacial advance in the late Holocene (<1 000 years B.P.).

Acknowledgements

I thank Barry D. Fahey (Guelph University) and Sidney E. White (Ohio State University) for critical reviews of this paper. W. Ahlborn, B. Blatherwick, R. Blatherwick, G. Carr, L. Gowland, D. Halvorson, L. M. Mahaney, and students in my mountain geomorphology course (1976) assisted with the field work. P. M. Snyder, F. W. Woodley, and the Mount Kenya Ranger Force provided invaluable assistance and support, as did W. and D. Curry of Naro Moru River Lodge. G. Berssenbrugge, L. Gowland, and M. Bardecki assisted with the laboratory analyses. Research was supported by grants from the National Geographic Society and York University.

MS. received 14 June 1979

REFERENCES

Baker, B. H. 1967. Geology of the Mount Kenya area. *Kenya. Geological Survey. Report* No. 79.
Birkeland, P. W. 1974. *Pedology, weathering, and geomorphological research.* New York, Oxford University Press.
Coetzee, J. A. 1967. *Pollen analytical studies in East and southern Africa.* Cape Town, A. A. Balkema. (Palaeoecology of Africa and of the Surrounding Islands and Antarctica, Vol. 3.)
Hedberg, O. 1964. Features of Afroalpine plant ecology. *Acta Phytogeographica Suecica*, 49.
Mahaney, W. C. 1974. Soil stratigraphy and genesis of neoglacial deposits in the Arapaho and Henderson cirques, central Colorado Front Range. (*In* Mahaney, W. C., *ed. Quaternary environments: proceedings of a symposium. First York University Symposium on Quaternary Research, 1974.* Toronto, York University, Atkinson College, p. 197–240.)

Mahaney, W. C. 1979. *Reconnaissance Quaternary stratigraphy of Mt. Kenya.* Cape Town, A. A. Balkema. (Palaeoecology of Africa and of the Surrounding Islands and Antarctica, Vol. 10.)

Outcalt, S. I., *and* Benedict, J. B. 1965. Photo-interpretation of two types of rock glacier in the Colorado Front Range, U.S.A. *Journal of Glaciology*, Vol. 5, No. 42, p. 849–56.

U.S. Bureau of Plant Industry, Soils and Agricultural Engineering. Division of Soil Survey. 1951. Soil survey manual, by Soil Survey staff. *U.S. Dept. of Agriculture. Agriculture Handbook* 18.

U.S. Soil Conservation Service. 1960. *Soil classification: a comprehensive system,* [*prepared by*] *Soil Survey staff. 7th approximation.* Washington, D.C., U.S. Government Printing Office.

White, S. E. 1976. Rock glaciers and block fields, review and new data. *Quaternary Research*, Vol. 6, No. 1, p. 77–97.

Zeuner, F. E. 1949. Frost soils on Mount Kenya and the relation of frost soils to aeolian deposits. *Journal of Soil Science*, Vol. 1, No. 1, p. 20–30.

https://doi.org/10.3189/S0022143000015331 Published online by Cambridge University Press