Geol. It. XCIII, 1972, 73-154.

Bruni, P.: Considerazioni tettoniche e paleogeografiche sulle serie dell' Appennino Bolognese tra le Valli dell' Idice e del Santerno. In: Mem. Soc. Geol. It. 12, 1973, 157-187.

Catizzone, M.: La carta del pericolo d'erosione. In: Riv. Agricoltura Subtropicale e Tropicale LXXVII (1), 1983, 123-138.

Cremonini, G. & Elmi, C.: Note illustrative della Carta Geologica d'Italia, Foglio 98 Vergato. Servizio Geologico d'Italia; Rome 1971.

Commissione Interministeriale per lo Studio della Sistemazione Idraulica e della Difesa del Suolo, III *Sottocommissione:* Guida alla classificazione delle frane ed ai primi interventi. Atti della Commissione; Rome 1971.

Damiani, A. U. & Panuzzi, I.: Carta di geomorphologia dinamica in funzione della pianificazione territoriale. In: Boll. Serv. Geol. It. XCIX, 1978, 77-84.

Dikau, R.: Experimentelle Untersuchungen zu Oberflächenabfluß und Bodenabtrag von Meßparzellen und landwirtschaftlichen Nutzflächen. Heidelberger Geogr. Arbeiten 81, Heidelberg 1986.

Gentz, P.: Geologische Untersuchungen im Raum Firenzuola, Passo della Raticosa und Passo della Futa. Unpublished dissertation, Freie Universität Berlin 1970.

Groscurth, J.: Zur Geologie der Randgebiete des westlichen Teils des Mugello-Beckens östlich der Prato-Sillaro-Linie. Inaugural-Dissertation, Freie Universität Berlin 1971.

Laatsch, W. & Grottenthaler, W.: Typen der Massenverlagerung in den Alpen und ihre Klassifikationen. In: Forstwiss. Centralbl. 91, 1972, 309-339.

Mäusbacher, R.: Die Verwendbarkeit der Geomorphologischen Karte 1:25 000 (GMK 25) der Bundesrepublik Deutschland für Nachbarwissenschaften und Planung, Beiträge zum GMK-Schwerpunktprogramm V. Berliner Geogr. Abh. 40, 1985.

Masini, R.: Perforazioni profonde nell' Appennino Tosco-Romagnolo. Rilievi e deduzioni sul problema delle argille scagliose. In: Boll. Soc. Geol. It. LXX (3), 1951, 565-587.

Merla, G.: Geologia dell' Appennino Settentrionale. In: Boll. Soc. Geol. It. LXX, 1951, 95-382.

Ministero Lavori Pubblici, Servizio Idrografico, Sezione Bologna: Annali Idrologici 1964-1974.

Panizza, M.: Proposita di legenda per carte della stabilità geomorfologica. In: Boll. Soc. Geol. It. 92, 1973, 303-309.

Reutter, K. J.: Die tektonischen Einheiten des Nord-Apennin. In: Ecl. Geol. Helvetiae 61, 1968, 183-224.

Richter, M.: Der Bauplan des Apennin. In: N. Jh. Geol. Paläont. Mh. 9, 1963, 509-518.

Rodolfi, G. & Zanchi, C.: Caratteristiche fondamentali e dinamica del paessaggio dell' Appennino toscoromagnolo. In: Annali dell' ISSDS XIV, 1983, 289-336.

Sanesi, G.: I suoli del bacino dei torrenti Diaterna e lineamenti pedologici del Mugello e dell' Alta Valle del Santerno (Firenze). P. F. Cons. Suolo, S. P. Din. Versanti, pubbl. n. 12. Firenze 1977.

Seiler, W.: Anwendung der „Grünen Legende" im semiariden Süditalien. In: Berliner Geogr. Abh. 35, 1982, 63-72.

Servizio Geologico D'Italia: Carta Geologica d' Italia, Foglio 98 Vergato 1:100 000, 1970.

Schmidt, R.-G.: Probleme der Erfassung und Quantifizierung von Ausmaß und Prozessen der aktuellen Bodenerosion auf Ackerflächen. Physiogeographica 1, Basel 1979.

Suter, K.: Die eiszeitliche Vergletscherung des Nordapennins. In: Vierteljahreszeitsch. Naturf. Gesell. Zürich 95, 1950, 224-241.

VARIATIONS OF MOUNT KENYA'S GLACIERS 1963-87

With 2 figures, 5 tables and 1 supplement (IX)

Stefan Hastenrath, Raouf Rostom and Robert A. Caukwell

Zusammenfassung: Veränderungen der Gletscher am Mount Kenya 1963-87

In dem vorliegenden Aufsatz wird eine Karte der Gletscher am Mount Kenya vorgestellt (Maßstab 1:5000, Stand: September 1987). Diese Karte beruht auf Bodenkontrollpunkten und photogrammetrischen Kontrollpunkten, auf einer luftgestützten Triangulation dieser Punkte und der stereo-photogrammetrischen Auswertung von Bildflügen. In Verbindung mit einer Kartierung aus dem Jahr 1963 dokumentiert die Karte die Veränderung der Gletscher am Mount Kenya während der letzten 25 Jahre.

1. Introduction

The glaciers of Mount Kenya have been the object of an ongoing field project aimed at problems of climate and cryosphere changes in the tropics (Hastenrath 1984). As part of this program, terminus positions were regularly measured for various glaciers. Fig. 1 and Tab. 1 offer an orientation on the ice extent in 1963 and the glaciers which disappeared earlier in this century. On the largest ice body, the Lewis Gla-

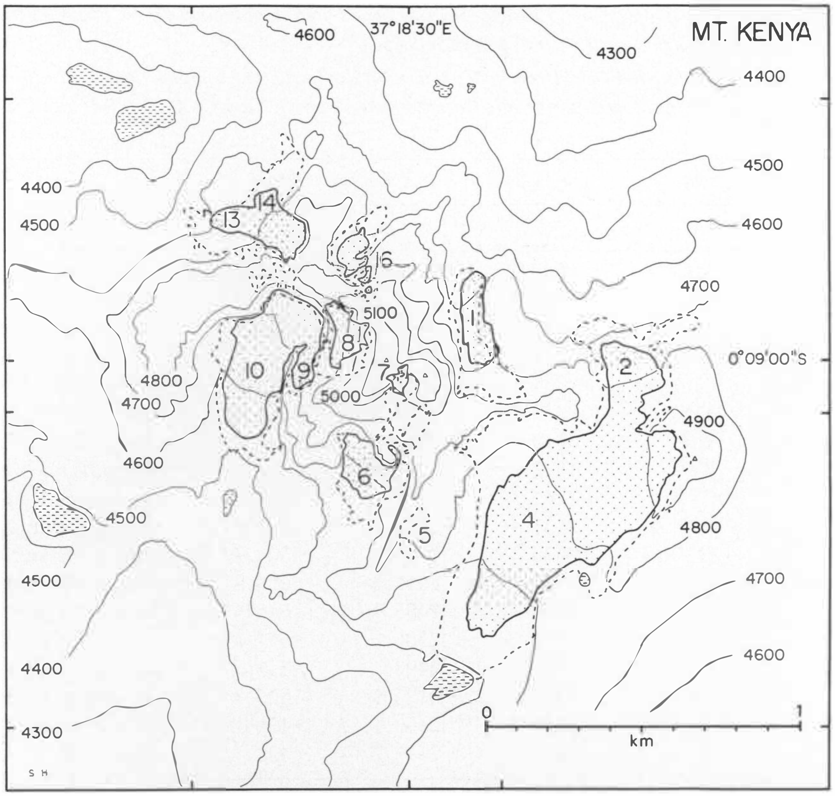


Fig. 1: Orientation map of the glaciers on Mount Kenya, January 1963 broken, September 1987 solid. Scale 1:25 000. Contours at 100 m intervals. Large numbers denote glaciers listed in Tab. 1

Orientierungskarte der Gletscher am Mount Kenya (gestrichelte Linie: Januar 1963, durchgezogene Linie: September 1987); Maßstab 1:25 000; Höhenlinien im 100 m-Abstand; die großen Zahlen bezeichnen die in Tab. 1 aufgelisteten Gletscher

cier, precipitation, net balance, and ice flow velocity were monitored continuously since 1978, and airborne mappings at scale 1:2500 were produced at four-year intervals since 1974, all published in this journal (Caukwell and Hastenrath 1977, 1982; Hastenrath and Caukwell 1979, 1987). Prior to the commencement of our field monitoring program, the ice extent on the entire mountain has only once been mapped in a way suitable for glaciological purposes, namely by E. Schneider (*Forschungsunternehmen Nepal-Himalaya* 1967), using terrestrial photogrammetry, at scale 1:5000, and for the January 1963 datum. It was long found desirable to re-map the glaciers of the entire mountain, in order to assess the ice changes since 1963, and so as to establish a documentation of the cryosphere status in the late 20th century. After the establishment of the appropriate ground control in the course of preceding years, aerial photography was flown on 3 September 1987. Following the sequence of our earlier mappings for

Tab. 1: Nomenclature of glaciers on Mount Kenya
Nomenklatur der Gletscher am Mount Kenya

1. Krapf	
2. Gregory	
(3. Kolbe	disappeared after 1926)
4. Lewis	
(5. Melhuish	disappeared after Feb 1978)
6. Darwin	
7. Diamond	
8. Forel	
9. Heim	
10. Tyndall	
(11. Barlow	disappeared after 1926)
(12. NW Pigott	disappeared)
13. Cesar	
14. Joseph	
(15. Peter	disappeared after 1926)
16. Northey	
(17. Arthur	disappeared)
(18. Mackinder	disappeared)

Tab. 2: Coordinates of ground survey stations (m). Triangles indicate points used in mapping, circles points plotted but not used, and brackets points not plotted in map. Code identifies points plotted in map

Koordinaten der Bodenbeobachtungsstationen (m). Dreiecke bezeichnen bei der Kartierung benutzte Punkte; Kreise eingetragene, aber bei der Kartierung nicht benutzte Punkte; nicht in der Karte eingetragene Punkte stehen in Klammern. Der Code identifiziert in der Karte eingetragene Punkte.

	name	*code*	*+ Y(N)*	*+ X(E)*	*height*	*mark*
A. Points established by present project						
△	Melhuish Cross	MC	1637.9	2743.9	4878.1	white cross
○	Thomson New	TN	2037.6	3166.1	4957.5	new aluminum stud
△	Thomson Cross	TC	2037.8	3165.5	4958.1	white cross
△	Two Tarn Cross	TTC	1521.2	1518.7	4519.1	white cross
	(Arthur's Seat Col)		2364.0	1619.8	4629.4	no ground mark
△	Molar Saddle	MS	3234.9	2327.8	4615.8	white cross and aluminium stud
△	Kami Boulder	KB	3015.8	2961.9	4448.5	white cross and aluminium stud
○	RHT	RHT	1818.9	2222.8	4512.9	red paint mark
△	Gregory	G	2261.3	3303.1	4693.5	aluminium stud, paint mark HK
△	Joseph	J	2757.8	2260.4	4609.0	aluminium stud, paint mark HK
△	Hausburg	H	2979.3	1708.8	4359.9	white cross and aluminium stud
○	Lewis Snout	LS	1306.7	2917.1	4623.5	aluminium stud
○	Darwin East	DE	1759.8	2498.6	4645.1	aluminium stud
○	Darwin Mid	DM	1766.7	2500.7	4647.1	aluminium stud
○	Darwin West	DW	1769.4	2493.0	4649.6	aluminium stud
○	Tyndall New	TYN	1929.3	2128.4	4505.9	aluminium stud
○	Tyndall 51	TY5	1842.7	2100.4	4486.3	aluminium stud, paint mark HK
○	Tyndall 108	TY8	1895.8	2117.7	4498.3	aluminium stud, paint mark HK
B. Points established by IGY Mount Kenya Expedition						
△	Arthur's Seat	AS	2404.8	1555.6	4665.6	white cross, bolt hole and stud
	(Bere)		1667.4	851.3	4540.6	cairn
	(Boulder)		1290.0	1171.6	4496.7	cairn
	(L1)		1508.0	3373.9	4823.1	not looked for
△	L2	L2	1450.4	3210.6	4797.2	white cross, metal plug
○	L3	L3	1791.8	2884.0	4792.7	white cross, metal plug
	(Little John)		1306.1	2577.7	4628.4	not looked for
△	Lenana	LE	1847.9	3622.1	4985.0	white cross, metal plug
○	Melhuish	ME	1630.6	2742.2	4876.5	metal plug
△	S3	S3	1206.3	2745.5	4600.6	white cross, metal plug
	(Thomson)		2031.0	3159.7	4955.1	not found
	(Tilman)		521.3	3116.5	4800.3	not looked for
	(Top Hut)		1361.4	3177.5	4809.4	not looked for
	(Shipton)		664.3	2069.6	4476.0	not looked for
○	Two Tarn	TT	1524.0	1524.0	4519.6	bolt hole, bolt lying near
△	Tyndall	TY	1771.1	1751.0	4551.3	bolt hole and white cross
△	S8	S8	1794.4	2086.0	4477.5	white cross and metal plug

the Lewis Glacier published in this journal, the resulting map is presented here along with the corresponding background documentation.

2. *Ground control*

Basic to the aero-photogrammetric mapping is a sound set of control points surveyed and marked in the terrain. Control points established by the IGY Mount Kenya Expedition (Charnley 1959) are useful to this end, but it was found necessary to establish numerous other points using electromagnetic distance measuring (EDM) equipment, and with a closure around the mountain. Tab. 2 lists the coordinates of points from the IGY Expedition and the present project. Fourteen of these points, identified in Tab. 2 by triangles, were used in the mapping, but the locations of other points are also plotted in the map.

3. *Air photography*

To obtain aerial photography for mapping all the glaciers on Mt. Kenya encounters problems that are not present when mapping only the Lewis Glacier. These are posed by the geographical position of the mountain and its altitude and include the seasons, the enormous differences in height falling on a single photograph, and the dead ground or blind spots created by the ridges and peaks masking some areas from the camera.

The watershed running approximately southwest to northeast through the summits from Arthur's Seat to Lenana divides "winter" from "summer". South of the watershed snow is retained in the April-May-June rainy season, and north of the line in the October-November-December rains. The snow cover obliterates the painted ground control crosses, and masks the line between glacier ice and adjoining seasonal snow fields. Thus to map the northern glaciers photography should be taken in the boreal summer, August or September, and to map the southern glaciers needs photography in the austral summer, February or March. Fortuitously in 1987 the April rains failed, leaving unseasonably little snow on the southern glaciers and exposing the control crosses, so that it was found possible to map the whole peak area from a single photographic sortie in September. By way of comparison it should be noted that SCHNEIDER's 1963 survey *(Forschungsunternehmen Nepal-Himalaya* 1967) was made in January, when the northern glaciers were in "winter" conditions surrounded by seasonal snowfields.

The ground altitude in a single photograph can differ by as much as 1000 m in the area of the central peaks, which means that the scale within a single photograph can vary from 1:8000 to 1:14 000 approximately. This, with the image displacement accompanying the scale changes, can cause difficulties in obtaining a stereoscopic model in the plotting instrument.

The problem of dead ground is also related to the steep peaks and ridges of the mountain that create the scale changes. One way to overcome the difficulty is to increase the flying height of the aircraft. This has two disadvantages; it reduces the scale of the photographs, and it pushes the aircraft even closer to its ceiling, when at 6300 m it es already suffering from the altitude and the turbulence surrounding the mountain.

The alternative solution is to increase the lateral overlap of the strips from 25 to 60 percent, and between successive photographs from 60 to 80 percent. This was the method adopted, and the best three runs out of ten photographs were chosen for the mapping.

Based on these considerations, the aerial photography was flown in the late morning of 3 September 1987 by Photomap (K) Ltd., at an average height of 1500 m above the average terrain level of 4800 m. The photographs were taken by a Wild 152 mm RC 10 camera, and are at an approximate average scale of 1:10 000 with 80 percent forelap and 60 percent sidelap. As shown in Fig. 2, these runs were flown in parallel strips, consisting of the frames nos. 3505–3512, 3484–3494, and 3544–3555. The frames used for aerial triangulation and mapping are from run 1 nos. 3506, 3508, 3500, and 3512, and from run 3 nos. 3544, 3548, 3552, and 3555.

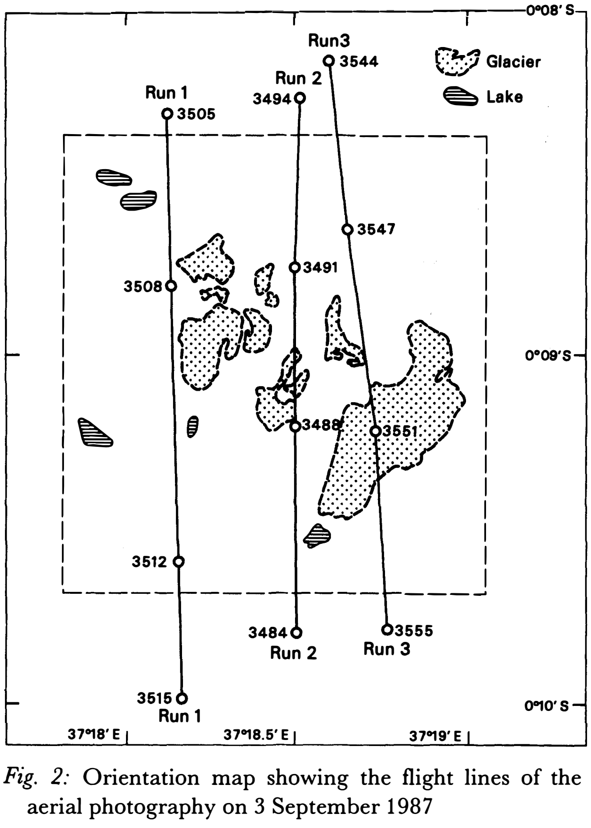


Fig. 2: Orientation map showing the flight lines of the aerial photography on 3 September 1987

Orientierungskarte mit den Flugstrecken der Bildflüge am 3. September 1987

4. *Aerial triangulation and stereographic plotting*

In addition to the 14 terrain control points indicated in Table 2 by triangles, a further 14 photogrammetric control points were identified in locations suitable for stereographic compilation. The locations of the 14 ground and the 14 stereographic control points were marked on the photographs, and diagrams were drawn of the photogrammetric control points to guard against misidentification. Approximate ground coordinates for the photogrammetric control points were obtained by planimetric intersection and using the existing maps (*Forschungsunternehmen Nepal-Himalaya* 1967; *Survey of Kenya* 1971). Of the 14 stereographic control points, 10 fall outside the area represented here. The remaining 4 are plotted in the map, along with the 14 ground control points, and another 12 points not used in the mapping.

In the aerial triangulation, the bundle method was chosen as most accurate. The Wild Autograph A 8 was used as mono-comparator to obtain the measured coordinates of the image points in the fiducial system. The left projector was calibrated by using a grid plate to transform the machine coordinates into grid coordinates based on a projective transformation. The residuals of the grid coordinates after transformation were of the order of ± 4 μm. The same transformation parameters were used to convert machine into image coordinates in the fiducial system. The maximum residuals were found to be of the order ± 10μm in the photo image coordinates.

All computations were run with a special program on the University of Nairobi mainframe ICL 2950 computer. The input consisted of the coordinates of all image points on all photographs in the fiducial system and the coordinates of the ground control points. However, the residuals on the control points Molar and Joseph (ref. Tab. 2) were found to be large, both in planimetry and height (for Molar μ(plan) = 23 m, μ(height) = 32 m); for Joseph μ(plan) = 44 m, μ(height) = 20 m). These discrepancies are believed to be due to misidentification on one or more adjacent frames. Accordingly, Molar and Joseph were excluded from the adjustment and the computations carried out again. As a result, residuals of the image coordinates were reduced to ± 10 μm, which conforms well with the initial accuracy.

Based on this aerial triangulation, the photogrammetric and ground control points were used for orientation of individual models. The stereo-photogrammetric plotting was performed at scale 1:5000 by using the Wild Autograph A 8 plotter at the University of Nairobi.

There appears to be a discrepancy between the geographical latitudes on the Survey of Kenya (1971) maps and the Schneider 1963 map (*Forschungsunternehmen Nepal-Himalaya* 1967).

Schneider based his map on the two triangulation stations, Arthur's Seat and Point Lenana using rectangular coordinates in the Imperial system of feet and decimals of a foot obtained from the IGY and converted to the metric system by the standard relationship 1 foot = 0.3048 meters.

Tab. 3: Characteristic parameters of Mount Kenya's glaciers, 1963
Charakteristische Kennziffern der Gletscher am Mount Kenya 1963

No.	Name	latitude S °	'	longitude E °	'	area [10^3 m^2]	mean width [m]	length [m]	orientation	highest elevation [m]	lowest elevation [m]
1	Krapf	0	09.02	37	18.60	47	90	450	N	4880	4600
2	Gregory	0	9.11	37	18.89	91	220	475	N	4920	4660
4	Lewis	0	9.37	37	18.71	351	450	1100	SW	4975	4680
5	Melhuish	0	9.38	37	18.49	9	30	220	S	4870	4760
6	Darwin	0	9.29	37	18.42	42	200	200	SW	5040	4620
7	Diamond	0	9.15	37	18.47	12	70	200	SW	5140	4790
8	Forel	0	9.07	37	18.39	25	250	150	W	5060	4850
9	Heim	0	9.10	37	18.32	18	230	100	W	4850	4725
10	Tyndall	0	9.13	37	18.21	108	230	550	S	4775	4500
13	Cesar	0	8.87	37	18.16	40	130	370	W	4800	4530
14	Joseph	0	8.78	37	18.27	25	100	400	W(N)	4775	4550
16	Northey	0	08.88	37	18.41	29	110	300	N	5040	4640
total						797					

The IGY triangulation was computed in plane rectangular coordinates on a local origin, with the scale established from a base line measured on the mountain and the orientation established from an astronomical azimuth taken from theodolite observations to the sun by J. B. ALEXANDER and R. A. CAUKWELL at station Tyndall (ref. Tab. 2) in 1958.

The local origin of the IGY coordinate grid is believed to be related to the Directorate of Colonial Surveys coordinates of the single station Bere (ref. Tab. 2), which was part of the control for the new topographic mapping of Kenya begun in 1950. No record appears to have been kept of the exact details of the relationship between IGY and DCS coordinates, and without this the relationship between northings and latitude and eastings and longitude cannot be precisely known.

5. *Glacier inventory for the September 1987 datum*

Our map is a contribution to the inventory of tropical glaciers. HASTENRATH (1984, p. 326–327) contains a compilation of Mount Kenya's glaciers based on information to the late 1970's, in accordance with the standards of the World Glacier Monitoring Service (*Temporary Technical Secretariat for World Glacier Inventory of UNESCO-UNEP-IUGG-IASH-ICSI,* 1977). Tab. 3 offers a summary for the 1963 status (Fig. 1), while Tab. 4 presents characteristic parameters for the September 1987 datum, as constructed from our map.

Comparison of Tab. 3 and 4 reveals a substantial shrinkage of the ice cover on Mount Kenya over the 1963–87 time span. One glacier, the Melhuish, has disappeared altogether. All other glaciers decreased in width and lenght. Overall, the termini retreated to higher elevations but the glaciers also shrank at their upper extremities.

6. *Area and volume changes during 1963–87*

The characteristic parameters of a glacier inventory listed in Tab. 3 and 4 can be relatively reliably retrieved from topographic maps containing accurately traced ice boundaries. By comparison, the estimation of volume changes is a more demanding task, because it hinges on the degree of internal consistency in vertical and horizontal control between successive mappings, for the various portions of the mountain.

In this regard, the potentials of the aerial photogrammetric method used here should be appreciated in reference to the terrestrial photogrammetry on which the 1963 map was based. The airborne is deemed superior to the terrestrial method in the planimetric, although not necessarily in the vertical control. The terrestrial method has particular shortcomings in narrow and steep valleys and canyons, where details in remote corners are laterally less well captured than from above. These shortcomings of the terrestrial photogrammetry concern the upper reaches of the Krapf, Darwin, and Joseph-Cesar glaciers in particular.

Tab. 4: Characteristic parameters of Mount Kenya's glaciers, 1987
Charakteristische Kennziffern der Gletscher am Mount Kenya 1987

No.	Name	area [10^3 m^2]	mean width [m]	length [m]	highest elevation [m]	lowest elevation [m]
1	Krapf	22	70	300	4800	4620
2	Gregory	51	150	420	4890	4713
4	Lewis	242	350	950	4962	4611
5	Melhuish	–	–	–	–	–
6	Darwin	23	170	200	4740	4640
7	Diamond	2	40	100	5120	4980
8	Forel	15	150	100	4950	4803
9	Heim	16	230	80	4800	4775
10	Tyndall	78	200	500	4775	4513
13	Cesar	24	100	300	4780	4580
14	Joseph	10	80	200	4775	4620
16	Northey	11	70	150	4930	4680
total		493				

In evaluating the 1963-87 changes of ice area and especially volume it was found essential to guard against the presumably inferior planimetric control of the terrestrial (1963) method and discrepancies in the vertical control. To this end, grid intersections of the two maps were registered for limited sub-areas of the peak region, namely domains containing, respectively, the Krapf, Gregory, Lewis, and Melhuish; the Darwin, Diamond, Forel, Heim, and Tyndall; and the Cesar, Joseph and Northey glaciers (Fig. 1). Within these three domains, the topography of the 1963 chart was graphically subtracted from that of the 1987 map, for the glacier areas as well as the surrounding rock terrain. This allowed one to adjust the height difference values for the glaciers in accordance with any non-zero differences abtained for the surrounding rock. The resulting difference fields were contour analyzed and total area and volume changes for each glacier obtained by planimetering. Results are summarized in Tab. 5.

The mismatch in surrounding rock topography varied between the glaciers and occurred of either sign. Thus, the difference in rock topography was near zero along the boundaries of the Gregory, and all but the lower portion of the Lewis Glacier, around the Melhuish, the Darwin, Tyndall, and Heim, and the lower portions of the Cesar and Joseph glaciers. Values around 10 m in absolute value were found along part of the boundary of the lower portion of the Lewis Glacier, while values in excess of -15 m occurred around the Diamond and Northey, and the upper part of the Cesar-Joseph glaciers. Considerable planimetric mismatch was found at the Diamond and especially at the Krapf Glacier. For the Krapf, in particular, this seems to be due to critical blind spots in the terrestrial photogrammetry. For the latter two glaciers, estimates of area and volume changes over the 1963-87 time span are therefore severely limited.

As the Lewis Glacier has been mapped regularly at 4 years intervals since 1974, likewise using aerial photogrammetry, it was possible to study the internal consistency between the sequence of 1:2500 mappings 1974-86 specific to the Lewis (ref. Section 1) with the present 1:5000 map based on an aerial triangulation of the same and additional control points encompassing the mountain as a whole. Adding to the volume difference over 1974-86 determined from the aforementioned sequence of four maps at scale 1:2500, the volume difference from the 1963 and 1974 maps, and the observed 1986-87 net balance integrated over the entire glacier, one obtains an estimate of the volume difference over the 1963-87 time span. This is nearly $1000 \times 10^3 m^3$ larger than the volume loss derived from the 1963 and 1987 mappings (Tab. 5). Given the area of Lewis Glacier (Tab. 4) this corresponds to a discrepancy of the average thickness in 1987 of the order of 3 m, rather larger than the tolerance in the graphical subtraction, and despite the reasonable agreement in the rock topography around the glacier. It appears that these discrepancies in ice topography may in part stem from the different treatment of the ensemble of all control points on the mountain in the aerial triangulation for the 1987 map, as compared to the Lewis-specific photogrammetry for the sequence of 1974-86 maps. The discrepancy in 1963-87 volume loss found for the Lewis should not be expected to be constant, or even of the same sign, all around the mountain. However, it may indicate the general magnitude of uncertainty in the estimates of volume loss presented in Tab. 5. By comparison, the concomitant changes in area are more comfortably determined. Note that during 1963-87 the ice-covered area decreased by some 40 percent, and the total volume loss over this time span was larger than the 1963 volume of the Lewis Glacier alone.

In sum, Tab. 3-5 indicate the proportions of the glacier shrinkage on Mount Kenya over the past quarter century. The quantitative assessment of recent ice volume and area changes for the entire mountain will serve as basis for modelling studies

Tab. 5: Area (10^3 m^2) and volume (10^3 m^3) decreases of Mount Kenya's glaciers during 1963-87

Flächen- (10^3 m^2) und Volumenverluste (10^3 m^3) der Gletscher am Mount Kenya 1963-87

glacier no.	name	△ area	△ volume
1	Krapf	26	625
2	Gregory	40	627
4	Lewis	109	3,554
5	Melhuish	9	81
6	Darwin	19	432
7	Diamond	10	126
8	Forel	10	380
9	Heim	1	277
10	Tyndall	31	1,829
13	Cesar	16	602
14	Joseph	16	371
15	Northey	18	500
total		305	9,144

aimed at inferring the climatic forcing. In the light of the growing concern about "greenhouse"-induced climatic change, and in the absence of a comparable sustained glacier field program elsewhere in the tropics, the observations at Mount Kenya appear particularly important in the global context.

7. *Glacier variations on Mount Kenya and in the global tropics*

The present assessment of the changes of Mount Kenya's glaciers over the past quarter century was based on airborne and terrestrial photogrammetric mappings at scale 1:5000. These should be viewed in perspective with endeavors in the other high mountain regions of the tropics. The documentation varies greatly in scale and temporal coverage. Only a brief overview is given here for recent decades, while reference is made to HASTENRATH (1981, 1984) for details, particularly on earlier epochs.

Concerning the other two glaciated mountains of East Africa, for the Ruwenzori maps at scale 1:25 000 have been published for the 1938 and 1955 epochs, and an inventory map at scale 1:100 000 has been produced for the mid 1970's conditions (HASTENRATH 1984). The glaciers of Kilimanjaro have been mapped in 1912 at scale 1:50 000 and in 1953 at scale 1:25 000, and the ice extent in the mid 1970's has been sketched at scale 1:50 000 (HASTENRATH 1984). Tape measurements of terminus variations with reference to surveyed terrain control points are being carried out only on Mount Kenya.

In the tropical Americas, glacier inventory maps have been produced for the Mexican volcanoes at scale 1:20 000 and with datum 1958–60, and for the Ecuadorian Andes the 1970's ice extent has been sketched at scale 1:100 000 (HASTENRATH 1981). For portions of the Peruvian Andes, inventory maps are being compiled at scale 1:25 000, and topographic mappings at scale 1:5000 and 1:2000 have been conducted for selected glaciers.

Turning to the third glaciated high mountain region in the equatorial zone, the glaciers of Mount Carstensz (Jaya) in New Guinea have been mapped at scale 1:20 000 in 1973 (HOPE et al. 1976). As with the Ruwenzori, no new glaciological information has come forth from this remote region since the early 1970's, for both mountains understandable from a host of terrain, logistical, and political problems.

The systematic monitoring of varying ice extent on the high mountains of the tropics merits particular attention in the context of global climate change. The present cursory review serves to illustrate the diverse status and prospects of glacier mapping in the various high mountain regions of the tropics. The existence of a 1:5000 map for 1963 was an important consideration for the recently completed re-mapping of Mount Kenya's glaciers. Maps at much coarser scale are less usefull for glaciological purposes, although even these have proven valuable in documenting cryosphere changes over half a century. On the East African scene, a mapping of Kilimanjaro's glaciers at a scale large enough for glaciological concerns is the most immediate challenge. The time also appears ripe for the purpose-bound aerial mapping of glaciers in certain mountain regions of the tropical Americas. For the chronically cloud-covered Ruwenzori and Mount Carstensz, finally, where mapping proper would face formidable logistical obstacles, suitably enhanced SPOT satellite imagery promises some exciting time-lapse glimpses.

8. *Concluding remarks*

The new map presented here documents the ice cover on Mount Kenya for the September 1987 datum. Conditions were optimal for this survey as the lower portions of glaciers on both the southeast and northwest sides of the mountain were then free of snow. The mapping was based on a set of ground control points especially established for this undertaking and purpose-flown air photography. Changes with respect to the only previous mapping suitable for glaciological purpose, for the January 1963 epoch (*Forschungsunternehmen Nepal-Himalaya* 1967), is of interest concerning long-term glacier and climate variations in the tropics. The comparison is limited by the differences in the mapping methods employed, such as aerial versus terrestrial photogrammetry, in large part different ground control points, and their treatment. On the whole, each of the two maps, 1963 and 1987, must stand in their own right, neither may be taken as absolute truth for the rock topography, although the aerial method is intrinsically superior in the planimetric control and in capturing certain blind spots. With these qualifications, the present in conjunction with the only comparable previous map has provided estimates of the area and volume losses of all glaciers on Mount Kenya over the past quarter century, and establishes a historical bench mark of the ice conditions on Mount Kenya near the end of the millennium.

Acknowledgments:

This study was supported by U.S. National Science Foundation Grant EAR-8620093. Wallis Hime was instrumental in surveying the ground control points, and Nayan Bhatt and John Omirah Miluwi also participated in the field work. Samuel W. Kimani performed the stereo-compilation. The research was authorized by the Office of the President, Republic of Kenya.

References

Caukwell, R. A., Hastenrath, S.: A new map of Lewis Glacier, Mount Kenya. In: Erdkunde 31, 1977, 85–87.
– : Variations of Lewis Glacier, Mount Kenya, 1978–82. In: Erdkunde 36, 1982, 299–303.
Charnley, F.: Some observations on the glaciers of Mount Kenya. In: Journal of Glaciology 3, 1959, 483–492.
Forschungsunternehmen Nepal-Himalaya: Mount Kenya 1:5000. Wien 1967.
Hastenrath, S: The glaciation of the Ecuadorian Andes. Rotterdam 1981.
– : The glaciers of equatorial East Africa. Dordrecht, Boston, Lancaster 1984.
Hastenrath, S., Caukwell, R. A.: Variations of Lewis Glacier, Mount Kenya, 1974–78. In: Erdkunde 33, 1979, 292–297.
– : Variations of Lewis Glacier, Mount Kenya, 1982–86. In: Erdkunde 41, 1987, 37–41.
Hope, G., Peterson, J. A., Radock, U., Allison, I.: The equatorial glaciers of New Guinea: results of the Australian Universities expeditions to Irian Jaya, 1971–73. Rotterdam 1976.
Survey of Kenya: Mount Kenya 1:25 000. SK 75 (DOS 302), Ed. 4-SK, Nairobi 1971.
Temporary Technical Secretariat for World Glacier Inventory of UNESCO-UNEP-IUGG-IASH-ICSI: Instructions for compilation and assemblage of data for a World Glacier Inventory. Zürich 1977.

MORPHOTEKTONISCHE ENTWICKLUNG VON KONTINENTRÄNDERN – EINE UNTERSUCHUNG AM BEISPIEL OSTAUSTRALIENS

Mit 2 Abbildungen

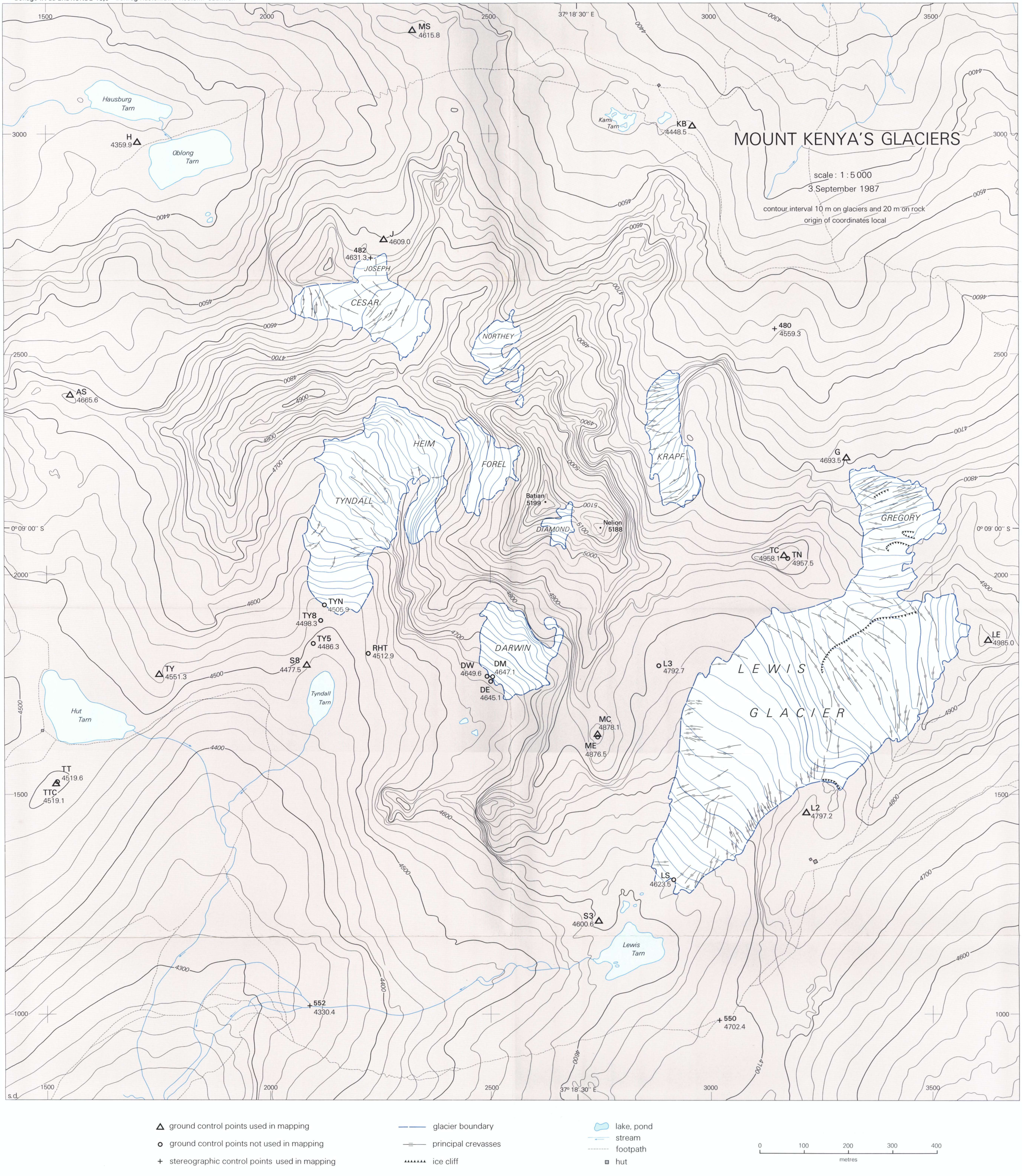
Jochen Kubiniok und Ernst Löffler

Summary: Morphotectonic development of continental margins – a study taking Eastern Australia as an example

Contrary to previous opinion, which considered the geomorphological development and in particular the uplift of the Eastern Australian Highlands as a relatively recent event (Kosciusko Uplift), new research indicates that the geomorphological history of the highlands dates back at least into the Cretaceous period. A review of the modern literature and the authors' own research show that the present landscape developed from a Mesozoic erosion surface of low relief through uplift of the continental margin. The Great Escarpment was formed by uplift of the continental margin and headward erosion. Variations in the morphology of the Great Escarpment and the old land surfaces are the result of differential uplift of the continental margin, which commenced in the upper Cretaceous in connection with the plate tectonic movement of the Australian continent and the final break up of Gondwana. The rate of uplift decreases from south to north and the age of uplift becomes progressively younger in the same direction.

1. *Einleitung*

Australien besitzt im Gegensatz zu anderen Kontinenten keine alpinotypen Hochgebirge. Die höchste Erhebung, Mount Kosciusko in Südostaustralien, erreicht nur eine Höhe von 2228 m. Die Oberflächenformen des Kontinents setzen sich vielmehr aus weitgespannten Rumpfflächen zusammen, die von markanten Inselbergen und Inselbergsystemen wie etwa Ayers Rock oder den Olgas überragt werden (Bremer 1967). Zu den Kontinenträndern steigt das Relief meist allmählich an, um dann relativ unvermittelt und steil zur Küstenregion abzufallen. Am deutlichsten ist dies entlang der Ostküste ausgeprägt, wo eine oft mehrere 100 m, vereinzelt bis 1000 m hohe Steilstufe – das „Great Escarpment" – das meist plateauartige Küstengebirge vom schmalen Küstentiefland trennt (Abb. 1). Die Küstenregion und das anschließende Hochland erstrecken sich hier über


MOUNT KENYA'S GLACIERS
scale : 1 : 5 000
3 September 1987
contour interval 10 m on glaciers and 20 m on rock
origin of coordinates local
37° 18' 30'' E
0° 09' 00'' S
Hausburg Tarn
Oblong Tarn
Kami Tarn
Hut Tarn
Tyndall Tarn
Lewis Tarn
JOSEPH
CESAR
NORTHEY
HEIM
FOREL
TYNDALL
KRAPF
DIAMOND
DARWIN
GREGORY
LEWIS GLACIER
Batian 5199
Nelion 5188
MS 4615.8
H 4359.9
KB 4448.5
J 4609.0
482 4631.3
480 4559.3
AS 4665.6
G 4693.5
TC 4958.1
TN 4957.5
TYN 4505.9
TY8 4498.3
TY5 4486.3
RHT 4512.9
S8 4477.5
TY 4551.3
DW 4649.6
DM 4647.1
DE 4645.1
L3 4792.7
LE 4985.0
MC 4878.1
ME 4876.5
TT 4519.6
TTC 4519.1
L2 4797.2
LS 4623.5
S3 4600.6
552 4330.4
550 4702.4
s.d.
ground control points used in mapping
ground control points not used in mapping
stereographic control points used in mapping
glacier boundary
principal crevasses
ice cliff
lake, pond
stream
footpath
hut
0 100 200 300 400
metres