FOSSIL PERIGLACIAL DEPOSITS IN THE SEMIEN HIGHLANDS, ETHIOPIA

With 3 figures and 6 photos

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Zusammenfassung: Fossile periglaziale Vorkommen im Hochland von Semien, Äthiopien

Fossile Vorkommen von kantigem Basaltschutt finden sich zwischen ca. 3000 m und 3600 m im Mai Shaha Tal des Hochlandes von Semien, Äthiopien (13° N, 38° E). Ihre Mächtigkeit nimmt bergauf zu und sie liegen unter dunklem steinfreien Lehm. Kantiger Schutt wird heutzutage über ca. 4250 m gebildet. Die alten Vorkommen sind wahrscheinlich periglazialen Ursprungs; dies bedeutet 4°–8° C tiefere Temperaturen, aber nicht notwendigerweise höhere Niederschläge als gegenwärtig. Der obere Teil des Schutts hat sehr wahrscheinlich spätpleistozänes Alter. Die Verwechslung zwischen diesen fossilen Hangsedimenten und alten zerschnittenen Moränen mögen frühere Bearbeiter veranlaßt haben, die ehemalige Ausdehnung der Vergletscherung im Hochland von Semien zu überschätzen.

Wir besitzen gute Beschreibungen von a k t i v e n periglazialen Phänomenen am Mount Kenya, Mount Kilimandscharo und dem Hochland von Semien (HASTENRATH 1973; 1974), aber es gibt bemerkenswerterweise nur wenige Berichte von f o s s i l e n periglazialen Merkmalen im innertropischen Afrika. Das offensichtliche Fehlen von pleistozänen periglazialen Vorkommen könnte bedeuten, daß die Bedingungen nicht geeignet waren für deren Entwicklung, oder aber daß sie sich entwickelten und inzwischen abgetragen, begraben oder durch die Vegetation verborgen sind. Möglicherweise existieren sie und sind nur noch nicht erkannt bzw. als etwas anderes interpretiert worden. In dieser Arbeit beschreiben wir die unserer Meinung nach fossilen periglazialen Schuttvorkommen in einer Höhe von 3000–3600 m im Semien-Hochland von Äthiopien. Der Schutt reicht bis 1000 m unter die jetzige untere Grenze der aktiven Frostverwitterung und Blockbildung und ist bedeckt von einem dunklen Lehmboden jüngeren Alters.

Geology and geomorphology of the Semien Highlands

The Semien massif is an eroded shield volcano of Miocene age or younger (MOHR, 1968, p. 11; JONES, 1976) superimposed upon sub-horizontal Trap Series lavas and the underlying sedimentary rocks and Precambrian basement of the Ethiopian Plateau. The massif is roughly circular, with a diameter of about 100 km. Its main peak, Ras Dashan, is 4,543 m high (WERDECKER, 1967), making it the fourth highest mountain in Africa. The total thickness of volcanic rocks in the Semien is about 3,000 m. The Semien lavas are flow basalts, often highly weathered. Agglomerates and massive basalts occur in the summit regions. The basalt flows are 0.5 m to 5 m thick, and dip gently outwards at 1°–10° from the region of the highest summits, which may represent the eroded remnants of the original crater rim (Fig. 1).

The Semien is a region of vast relief, encircled on its northern and eastern sides by the Takezze River.

Headward erosion by the Takezze tributaries has created the magnificent escarpments which border the massif (Photo 1). Slopes on the escarpments are usually stepped, and range from a few degrees to vertical; hillslopes of 30° or more are common.

The original crater rim of Semien, now deeply dissected and very ill-defined, has been completely cut away on its southern side by the Mai Shaha river (Fig. 1). This river occupies a prominent gorge over 10 km wide and 1,500 m deep at its northern end. The sides of the gorge are drained by a series of parallel tributaries which enter the river almost at right angles (Fig. 1). It is along the margins of some of these tributaries that the deposits described below were seen during brief visits in December 1971 and April 1975.

Equivocal extent of glaciation in the Semien Highlands

As the highest of three known glaciated massifs in Ethiopia, the Semien has long attracted the attention of glacial geologists (MINUCCI, 1938; NILSSON, 1940; HÖVERMANN, 1954; HASTENRATH, 1974), despite the fact that moraines on the Arussi Mountains over 650 km to the south are both better defined and more abundant (POTTER, 1976). Certain earlier workers, notably NILSSON (1940) and HÖVERMANN (1954), have tended to over-emphasize the importance of glaciation in the Semien massif, and to neglect or misinterpret the nonglacial cold climate deposits. As a result, estimates of the former extent of glaciation are highly variable.

Deduced Pleistocene snowlines in the Semien range from 4,100–4,300 m (MINUCCI, 1938) and 3,500–4,100 m (NILSSON, 1940) to as low as 3,000 m (HÖVERMANN, 1954). HASTENRATH (1974) has recently argued for a late Pleistocene snowline of 4,200–4,300 m, which we consider a conservative and reasonable estimate, based as it is upon mapped cirque floor levels rather than upon dubious deposits of „moraine". Both we and HASTENRATH used altimeter readings to supplement WERDECKER's (1967) excellent contour map, upon which Figure 1 is based.

NILSSON (1940) and HÖVERMANN (1954) both referred to older „moraines" visible at low elevations (2,700–3,000 m) in tributary valleys of the Mai Shaha. The term „angular rubble" is preferable to the term „moraine", and is non-genetic. An alternative interpretation is that the angular rubble is a fossil periglacial deposit, laid down during one or more colder and perhaps seasonally wetter periods, and is not true glacial moraine at all. However, as SPARKS and WEST (1972, p. 101) point out, sediments deposited under
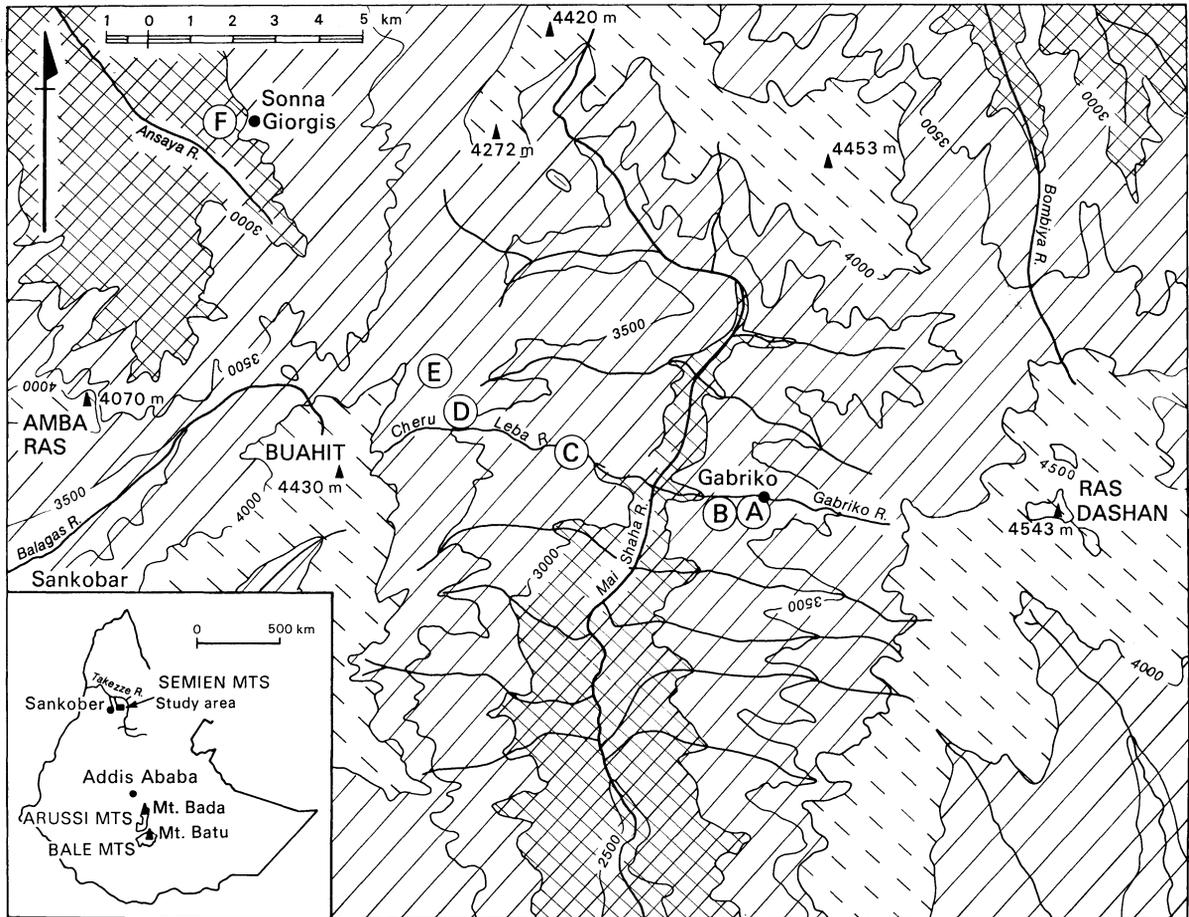
Fig. 1: Location map showing Semien Highlands, Ethiopia

periglacial conditions may range from „unbedded, unsorted material, difficult to distinguish from till, to fairly well-sorted and bedded material which is virtually a stream deposit". In addition, block accumulations or concentrations are not *per se* evidence of former periglacial conditions, and angular blocks may form by processes other than frost-riving (CAINE, 1967; WASHBURN, 1973, p. 193). Before discussing the possible periglacial origin of the rubble, we will briefly consider some of its characteristics.

Nature and distribution of the angular rubble

Exposures of angular basalt rubble are common along the slopes of the Mai Shaha valley (Fig. 1 and Photos 2 and 3). The observed lower limit was c. 3,000–3,100 m in both the Cheru Leba and Gabriko river valleys (Fig. 2). The less well-defined upper limit was 3,400–3,600 m on the col north of upper Cheru Leba. The observed lower limit is thus some 1,200 m below the inferred late Pleistocene snowline at 4,200–4,300 m in the region (HASTENRATH, 1974).

The angular rubble is quite distinct both from the rounded river gravels visible in the bed and banks of the Mai Shaha and its tributaries, and from the overlying dark loams cultivated by the highland farmers. The rubble usually rests directly on basalt ranging from fresh to strongly grussified. Above the rubble there is almost always a surface layer of dark greyish-brown, relatively stone-free clay or loam, with a moderate to strong polyhedral soil structure. On very steep slopes such as those in the Ansaya River gorge below section F (Fig. 1), it is not possible to distinguish fossil angular rubble from modern active talus. Consequently, the following discussion applies only to the buried and inactive rubble of the Mai Shaha valley.

In gulley section A immediately west of Gabriko village (Fig. 1), the rubble consists of two distinct beds, each about 3 m thick, separated by up to 3 m of brown clayey coarse sand generally devoid of angular rock fragments (Fig. 3 and Photos 4 and 5). The lower rubble unit has an iron-stained, strongly indurated matrix; it may be far older than the upper rubble, which has a porous, earthy fabric.
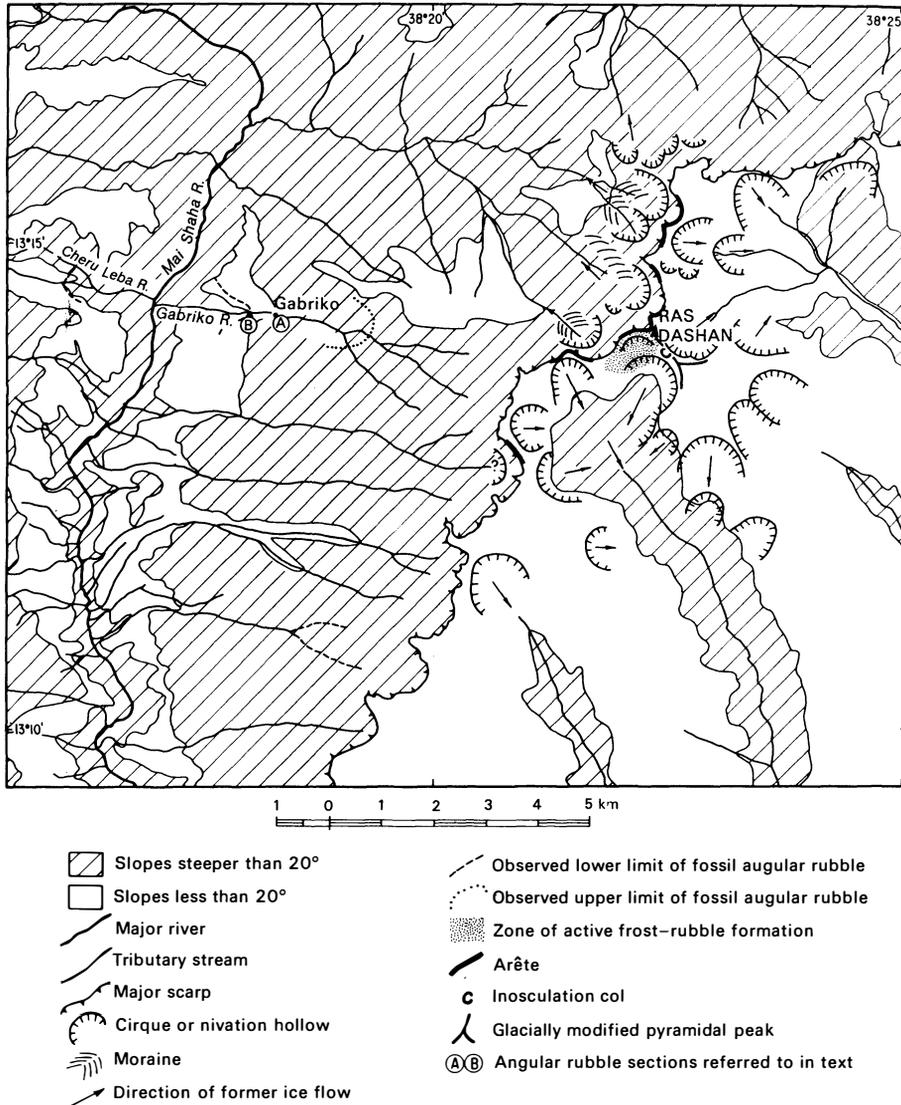
Fig. 2: Geomorphic map of Ras Dashan summit region, Semien Highlands. (Based upon WERDECKER, 1966; HASTENRATH, 1974; field observations in 1971 and 1974; and airphoto interpretation.)

In addition to the features noted above, we may note certain other characteristics of the angular rubble:

(1) The rubble consists of angular to sub-angular, very poorly sorted and unweathered basalt, comprising blocks up to 0.4 m long, as well as 1–5 mm platy fragments and granules.

(2) Matrix texture ranges from gritty loam to clayey sand, with hues lighter than the overlying dark surface clays.

(3) The rubble seems to become thicker and more widespread with increasing elevation.

(4) In several sections the long axes of the larger fragments show a rough downslope alignment.

(5) An upward-coarsening sequence is discernible in a few sections, with fine particles near the base and progressively coarser ones towards the top.

(6) The angular rubble is often several metres thick on bedrock slopes of 10°–15°, whereas presently active scree and angular colluvium is generally rare at these elevations except on slopes steeper than 20°–30°.

(7) The rubble often forms part of a fill beneath gently sloping colluvial-alluvial benches which are now being dissected by small tributaries of the Mai Shaha (Photo 6).

Periglacial origin of the angular rubble?

BÜDEL (1954, p. 147) claimed a late Pleistocene earthflow – solifluctional origin for the Semien rubble down to an elevation of 2,700–2,600 m, and considered that the climate was both cooler and wetter at that

Photo 1: Escarpment north of Sankober, Semien Highlands. Note horizontal lava flows.

Photo 2: Buried angular rubble in the Gabriko river valley

Photo 3: Buried angular rubble in the Cheru Leba valley

time. More recently KULS and SEMMEL (1965) have questioned this „pluvial solifluction" interpretation, asserting that stone-layers at 2,500–3,000 m elevation in Gojjam Province are forming *in situ* by differential weathering of the basalt bedrock, without the agency of freezing and thawing.

Our problem is to select which process, or combination of processes, can adequately account for a l l of the observed properties of the angular rubble in the high

Semien. At the present time, the main geomorphic processes along the lower slopes (3,000–3,600 m) are slope-wash, soil creep, and gully erosion, with minor debris avalanches and occasional landslips on the steeper slopes. No mudflows were seen. The climate is seasonally-wet, with a mean annual precipitation of about 1,600 mm (SCHALLER and KULS, 1972, p. 78 and Fig. 3). Snow is rare on the summits even during the June–September rainy season, but may occur at any time of the year. In December 1971 isolated snow-patches were noted at c. 4,000 m immediately west of Buahit (Fig.1).

The temperature is cold enough for minor soil frost phenomena to occur above 3,700 m (HASTENRATH, 1974). Like HASTENRATH, we noted a variety of freeze-thaw features above c. 4,300 m on Ras Dashan, including stone-banked terraces, stone stripes and polygons, fine-earth polygons, recently frost-riven boulders, and fields of unstable, angular basalt blocks. Neither we, BÜDEL, nor HASTENRATH found any evidence of present-day bedrock frost-riving, or of movement of the resulting angular debris, below c. 4,250–4,300 m, which was also the upper limit of tussock grass.

The characteristics of the angular rubble listed earlier are consonant with a periglacial origin. Periglacial solifluction produces deposits characterized by lack of sorting, angularity, downslope orientation of the long axes, a porous and often fine-textured matrix, and a local provenance (EMBLETON and KING, 1968, p. 513; DAVIES, 1969, pp. 32–35; FLINT, 1971, pp. 275–277; WASHBURN, 1973, pp. 189–193).

From their observed properties we consider that the buried rubble deposits in the Mai Shaha valley are: (a) transported (properties 4, 5, and 7); (b) relict (properties 2, 6, and 7); and (c) the result of mass-movement under colder than present conditions (properties 1 and 3). The angular rubble is neither glacial moraine nor river alluvium. It is not formed by weathering *in situ*. It presupposes two processes: (i) initial disintegration of the bedrock upslope; and (ii) its subsequent downslope transport under gravity. The rubble is buried beneath a surface layer of dark loamy soil, and is clearly a fossil hillslope deposit resulting from widespread mass-movement. We will discuss each process in turn.

Sections A/B, C, D and F are surmounted by slopes of 18°, 27°, 18° and 34° which rise up to 3,750 m, 3,300 m, 3,625 m, and 3,100 m respectively. We noted earlier that extensive frost-shattering of bedrock in this area occurs today only above c. 4,250–4,300 m, which is between 1,150 m and 1,500 m above the hilltops adjacent to these five sections. We concur with WASHBURN (1973, p. 193) that „widespread accumulations of truly angular blocks are certainly reasonable evidence of former frost wedging if located in an environment where such blocks are not accumulating today", while noting the need for additional evidence.

It could be objected that the rubble is not of local provenance, as assumed in the above argument, but is

Photo 4: Angular rubble in section A, near Gabriko village

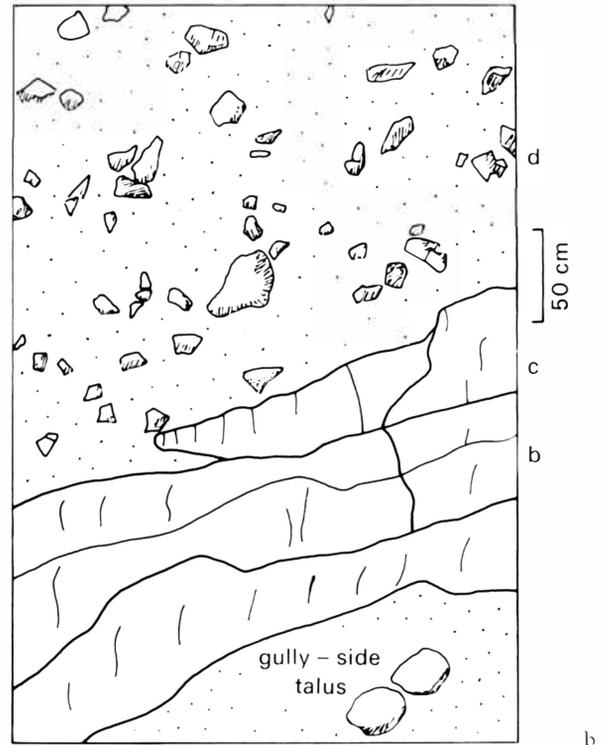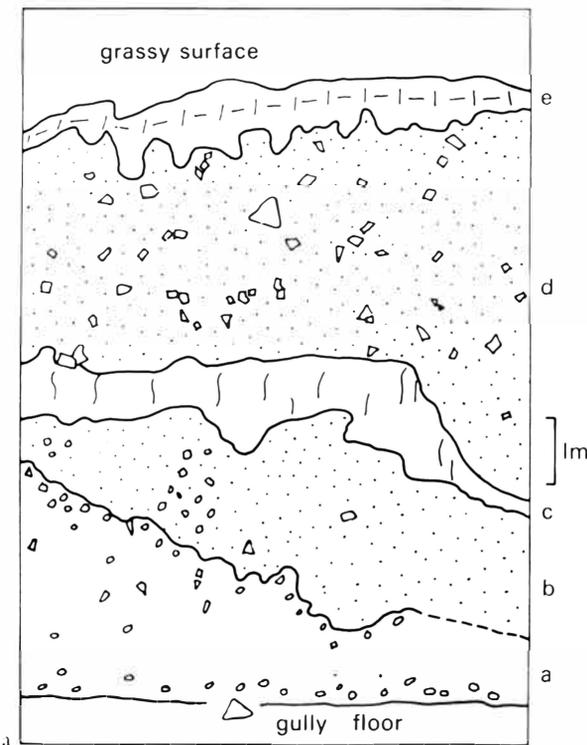Photo 5: Detail of angular rubble in section A

Fig. 3: Angular rubble in section A, near Gabriko village (Compare Fig. 3 a with Photo 4 and Fig. 3 b with Photo 5)
Key: a, d angular basalt blocks in clayey sand matrix; c, e dark loam or stone-free clayey sand; b gritty brown sand, occasional basalt blocks

a product of mudflows, which need not be periglacial (TRICART, 1963, p. 116). Against the mudflow hypothesis is the coherence of the bedrock, the absence of lobe forms, the upward thickening of the rubble, the crude stratification evident at sections A, B and C (Photos 4 and 5), and the downslope orientation of blocks in some sections. Movement by slow seasonal creep (gelifluction or solifluction) seems more in keeping with

Photo 6: Junction of Gabriko river and the Mai Shaha.
Note stepped relief related to horizontal lava flows, and
rugged topography.

properties 4 to 7, and it is perhaps worth noting that
an upward-coarsening sequence is characteristic of
many dolerite-derived periglacial solifluction mantles in
Australia (DAVIES, 1969, p. 46). That the rubble often

grades laterally into colluvial-alluvial benches now in
process of dissection is not surprising, since solifluction
and gullying tend to be mutually antagonistic proces-
ses in high mountains (DAVIES, 1969, p. 35).

Granted that freezing temperatures were needed to
shatter bedrock at elevations between 3,100 m and
3,750 m, and that gelifraction is now active only above
c. 4,250–4,300 m, what temperature lowering was in-
volved? The estimated mean lapse rate for the East
African highlands, including Ethiopia, is 0.6° C/100 m
(BROWN and COCHEMÉ, 1973), which compares well
with earlier estimates of 0.55–0.65° C/100 m for Ethi-
opia (FANTOLI, 1966); 0.65° C/100 m for Kenya (East
African Met. Dept., 1959, cited by BROWN and CO-
CHEMÉ, 1973); and 0.65° C/100 m for Ruwenzori (OS-
MASTON, 1965). Assuming a lapse rate of 0.6° C/100 m,
a possible temperature lowering of between 4° C and
8° C seems plausible. Such an estimate is in good accord
with estimates of late Pleistocene temperature lowering
elsewhere in East Africa, based upon last glacial snow-
lines (FLINT, 1959) and pollen data (VAN ZINDEREN
BAKKER and COETZEE, 1972).

What caused the frost-riven rubble to move down-
slope? The interstitial fines in the fossil detritus (Pho-
to 5) imply some disaggregation of the basalt either
before, during, or after the frost-riving of the coarse
blocks. For the matrix to have moved, it must have
been relatively wet, at least seasonally. Seasonal thaw-
ing of a frozen matrix is one possibility; another is
waterlogging by seasonally intense rainfall. It seems
likely that there was little or no plant cover. Lower
temperatures would reduce soil moisture loss by reduc-
ing surface evaporation, so that the soil may have been
wet without any overall increase in precipitation.
Whether wet or dry, the climate was certainly cooler
than now at the time the angular rubble was accumu-
lating.

That the climate was relatively dry immediately
before the deposition of the younger of the two angu-
lar rubble layers in section A is suggested by the absence
of clay from both the rubble matrix and the gritty
sand bed beneath the younger rubble (Fig. 3 and
Photos 4 and 5). Chemical weathering was sufficient
to allow bedrock disaggregation, but inadequate for
much clay formation. The comparatively high clay
content of the surface soil layer indicates that chemical
weathering of the basalt became more active after the
deposition of the uppermost angular rubble, probably
as a result of higher temperatures and more effective
leaching.

Although on present evidence we favour a perigla-
cial solifluction origin for the angular rubble, we do
not rule out the possibility that s o m e of the material
may be r e w o r k e d glacial moraine, nor that some
of it may have been deposited by more rapid forms of
mass-movement than solifluction. We do not regard
the rubble as moraine, nor as due mainly to mudflows.

Age of the angular rubble

The age of the angular rubble is uncertain, but is most probably late Pleistocene. Movement of the rubble took place at some stage after a phase of bedrock weathering, and before a renewed interval of weathering during which the dark colluvial loams were formed. The dark loam or clay is probably Holocene in age, and dark Holocene clays are common further south in the upper-middle Awash valley (TAIEB, 1974, p. 87; CLARK and WILLIAMS, in press). There are at least two generations of rubble, the younger of which may be uppermost Pleistocene in age. Until dateable organic samples are found, we tentatively favour a late Pleistocene/late glacial age for the younger rubble layer in this part of the Semien. It is perhaps no coincidence that, until c. 12,000 yr B.P., the Blue Nile was depositing coarse sands and gravels in the central Sudan, and thereafter began to deposit dark clays (WILLIAMS and ADAMSON, 1973). Likewise, in the Afar lakes fed by surface and subsurface flow from the Ethiopian highlands, there is evidence of widespread very late Pleistocene aridity, with lake levels high after 12,000 yr B.P. (DELIBRIAS, GASSE and ROGNON, 1973; GASSE, 1975).

We further consider that many of the „older" low-lying „glacial" deposits in the Ethiopian uplands may be fossil slope deposits formed by mass-movement of frost-shattered debris. A detailed re-appraisal of such deposits seems in order.

Acknowledgements

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