Quaternary Periglacial Landforms in the Sani Pass Area, Southern Africa

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Preface

Contradictory evidence exists in published literature concerning the interpretation of palaeoenvironments from landforms in the High Drakensberg and Lesotho mountains. Consequently, a collaborative project was initiated to attempt to obtain consensus regarding the Quaternary palaeoenvironments in the Sani Pass area. The data represents ongoing research by the authors and students from the Universities of Pretoria, Western Cape, Northern British Columbia, Upsala and The Witwatersrand. The material published in this document was initially produced as a Field Guide for Post Conference Excursion B3 of the INQUA XV International Conference that was held in Durban, South Africa between 1 August 1999 and 11 August 1999 under the auspices of the Southern African Permafrost Group and the International Permafrost Association. The excursion took place between 12 August 1999 and 15 August 1999 and involved a vehicle journey from Durban to Sani Pass via the eastern part of the Free State Province in South Africa and via Buthe Buthe, Oxbow, Letseng-la-Draai and Mokhotlong in Lesotho. Periglacial blockstreams, solifluction deposits, possible cryoplanation features, valley asymmetry, valley head hollows, cutback development, micro-scale patterned ground and slope deposits formed the foci of observations and discussions in the Sani Pass area. References to the specific excursion programme have been omitted in this document to facilitate its use as a scientific document and as a field guide for researchers that intend to visit the study area.

Introduction

The highest and most extensive mountain range in southern Africa is the Drakensberg (Dutch name for “Mountains of the Dragon”), also known as Quathlamba (Zulu name for “a barrier of spears”). An escarpment of the Drakensberg that reaches altitudes of over 3300m, dominates the scenic beauty of the KwaZulu-Natal interior and forms a natural border between the High Drakensberg and Lesotho and the “Little Berg” in KwaZulu-Natal (Fig. 1). Direct access for vehicles between KwaZulu-Natal and the High Drakensberg and Lesotho is via Sani Pass (altitude 2874m).
The Sani Top mountain chalet that is the base for the fieldwork described in the following discussion is located near the upper Sani Pass border post (Lesotho) and overlooks the Main Escarpment. Four-wheel drive transport is required for the 8km long mountain pass that winds its way from the sandstone foothills into the Drakensberg Group amygdaloidal basalts (Fig. 2). The field sites described in this document are all in the vicinity of Sani Pass and are situated in the High Drakensberg and Lesotho.

Figure 2: The typical topographical expression of each unit in the geological succession in the Drakensberg (after Pickles, 1985).
Environmental Setting

The Main Escarpment

In southern Africa, the Main Escarpment (also known as the Great Escarpment or Drakensberg Escarpment in KwaZulu-Natal) extends approximately parallel to the coast from northern Namibia, south and east through the southern Cape and north through KwaZulu-Natal into Mpumalanga (Fig. 1). Maximum altitudes range from below 1500m in the quartzites of the west coast to above 3300m in basalts along the eastern coast where the escarpment watershed demarcates the national boundary between Lesotho and South Africa (KwaZulu-Natal province).

Several theories for the development of the Main Escarpment have been proposed (e.g. King, 1944; 1962; Ollier and Marker, 1985; Partridge and Maud, 1987; Birkenhauer, 1985). A common aspect of these theories is that the post-Gondwana landscape of southern Africa is characterised by several well-defined landscape cycles (Gilchrist, 1995). This is due to post Late Jurassic episodic tectonic or eustatic landscape rejuvenation around the margin of the continent. Erosion of the down-warped coastal margins and subsequent back-wearing of a scarp from approximately the position of the present coastline has given rise to the Escarpment as it exists today.

Notwithstanding the dissected highlands that exist above the oldest African surface (Late Jurassic/Early Tertiary to end of early Miocene; Partridge and Maud, 1987), several erosion surfaces have been suggested for the Little Berg region below the Drakensberg Escarpment (e.g. King, 1976), related to the episodic uplift. Although surfaces can be observed in the Little Berg below the Main Escarpment, problems occur when matching erosion surfaces across the Drakensberg (Partridge and Maud, 1987). Due to the nature of the underlying sandstones and basalts, it seems likely that the distinctly stepped landscape is a product of slopes retreating in equilibrium with their rock mass strength (see Moon and Selby, 1983).

The escarpment is characterised by numerous cutbacks and passes. The positioning of the drainage of the High Drakensberg and Lesotho and the cutbacks off the escarpment follow major joints and doleritic intrusions through the basalts (Dempster and Richard, 1973). Doleritic intrusions are common to many of the cutbacks. Evidence of the intrusion, characterised by close joint spacing and enhanced weathering at the basalt/dolerite contact, can be observed in the upper region of Sani Pass. Preferential weathering and enhanced surface erosion are suggested as the causes for the location of this and other cutbacks. Remnants of other doleritic intrusions can be observed lower in the pass.
Although down-wearing and back-wearing of the cutbacks is expected to be continuous, major incision occurred during and after an estimated 900m of uplift (in this region) during the Pliocene (Partridge, 1997). The Escarpment cutbacks appear to have been ideal sheltered sites for the accumulation of snow during the LGM (Last Glacial Maximum) (Grab, 1996a). The presence of niche glaciers and nival action in cutbacks north of Sani Pass has been suggested by Hall (1994) and Grab (1996a) based on the interpretation of evidence from depositional landforms found in the cutbacks. Hall (1994) suggested that melt-water from snow and ice contributed to the development of the deposits in the cutbacks. Similar deposits to those discussed by Hall (1994) and Sumner (1995) can be observed adjacent to the Mkhomazana River in the lower sections of Sani Pass.

Soils and Vegetation

The shallow soils of the High Drakensberg and Lesotho are mostly residual and colluvial in origin. Small amounts of alluvial material have contributed to the deeper soils in the wide valley-floors. Most of these soils lack a “B” horizon but are frequently underlain by a yellowish-brown cambic horizon at greater depths (Klug et al., 1989). Most of the miniature cryogenic features such as sorted and non-sorted patterned ground have developed in mollisols due to the abundance of fine material and soil moisture. Examination of the palaeosols could provide an important contribution to determining palaeoenvironments, such as those recently studied at Tlaeeng Pass (Hanvey and Marker, 1994). Palaeo-histosols have also been examined at a few sites in the Sani Pass region and dated between 13 490 and 2 310 $^{14}$C yrs BP (Marker, 1994).

Montane and alpine vegetation belts in the High Drakensberg have been described by Killick (1963). With increasing altitude, *Podocarpus* forests in the montane belt give way to what has been described as “miniature” and “cushion” plants of the alpine belt (van Zinderen Bakker, 1981). This alpine vegetation belt is characterized by climax heath communities, in particular woody species of *Erica* and *Helichrysum* (Killick, 1963). The stunted growth of the woody species encountered along the Escarpment can be attributed to the shallow soils and high wind speeds.

Climate

Sani Pass and its environs has a distinctly seasonal precipitation pattern; 70% falling between November and March and less than 10% falling between May and August (Tyson et al., 1976). The most important source of precipitation over the Drakensberg is in the form of orographic thunderstorms. Occasionally, cyclonic weather systems (cold fronts) may bring some precipitation, particularly during autumn, winter and early spring, when they may also deliver snowfalls. Maximum precipitation (about 1800 mm) along the main escarpment is said to occur at
altitudes between 2287m and 2927m (Killick, 1963). Killick (1963) argues that the decrease in vapour content above this altitude reduces precipitation. The Escarpment also produces a rain shadow to the western interior where a marked decrease in precipitation is encountered (Schulze, 1979) (Fig. 3).

![Graph showing rainfall vs altitude](image)

**Figure 3:** Rainfall : altitude relationship along transect from Bergville to Mothelsessane, Lesotho (after Schulze, 1979).

Estimates of the absolute maximum and absolute minimum temperatures for the Little Berg (altitude ± 2000m) are +35.0°C and -12.5°C respectively (Tyson et al., 1976). The higher peaks, above 3000m are thought to have a mean annual air temperature of about 7°C (Schulze, 1979). Meteorological stations the High Drakensberg and Lesotho are sparse and data are, therefore, difficult to interpret. However, recorded mean minimum temperatures at Letseng-la-Draai during June and July are lower than –6°C; daily minimum temperatures may fall to below –10°C between May and September (Table 1). The lowest known recorded temperature is -20.4°C at Letseng-la-Draai on the 12 June 1967 (Grab, 1997a). It is estimated that ground level freezing could occur at altitudes above 3000m on more than 160 days annually (Table 1).

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**Table 1:** Average recorded air temperature data (°C) for Letseng-la-Draai, altitude 3 050m, based on 10 years of data collection between 1983 and 1993 (after Grab, 1994).

**Present-day soil frost features**

A variety of contemporary miniature cryogenic landforms occur in the High Drakensberg and Lesotho (Boelhouwers, 1991) and several of these have been identified in the Sani Pass region (e.g. Boelhouwers and Hall, 1990; Grab, 1994). Some of the relict periglacial landforms
that occur in the Drakensberg are discussed later. Most of the microforms are the product of surficial diurnal freeze-thaw cycles or somewhat deeper (to 20cm depth) winter freeze. The most widespread features are soil stripes and miniature sorted circles and polygons that are commonly linked to needle ice development, all of which are frequently visible on the slopes and interfluve of Kotisephola pass in winter (Fig. 4).

Figure 4: Field sites in the Sani Pass area.

Owing to the abundance of soil moisture in the wetlands during winter, and the presence of deep clay rich sediments, thufur are prominent in the wetlands. Also observable, are the many small terrace fronts with exposed soil, referred to as turf exfoliation by Troll (1973). Although, these terraces have been ascribed to the erosive action of needle ice by Boelhouwers and Hall (1990), the cryogenic role in turf exfoliation is still poorly understood (Grab, 1997b). The occurrence of turf exfoliation will not be explored in this discussion, however, the role cryogenic activity is a potential avenue for investigation.

Terracettes are a particularly visible landform in the Sani Pass area, where turf exfoliation apparently plays a formative role. Although Gallart et al. (1993) argue that terracettes generally “belong to a family of periglacial forms” (p529), others (e.g. Vincent and Clarke, 1976) are not convinced of an “exclusive” periglacial origin. It appears that the terracettes in Lesotho are primarily the result of animal trampling and only slightly modified by cryo-geomorphic processes (Day, 1993; Grab, 1997b). Other features that may be of periglacial origin and have
been recorded in the High Drakensberg, but have yet to be found in the Sani Pass area, include stone-banked and turf-banked lobes.

**Sorted stripes**

Features referred to as “raked ground”, “striated soil” and needle ice stripes” (e.g. Troll, 1944; Hastenrath and Wilkinson, 1973; Hanvey and Marker, 1992) are common in the vicinity of Sani Pass and indeed elsewhere in High Drakensberg and Lesotho Mountains. These so-called needle ice stripes are common in open soil patches where there is sufficient soil moisture available; their formation is attributed to the growth and decay of needle ice (Troll, 1944; Hastenrath and Wilkinson, 1973; Hanvey and Marker, 1992). The stripes usually develop during April/May when diurnal soil freezing occurs but when there is still sufficient soil moisture available. As winter progresses and desiccation sets in at some localities, the soil stripes become less active and eventually form crumbly and “puffy” surfaces of disintegrating stripes. Wind deflation appears to eventually cause the stripes to disappear in July/August. With increased moisture during the spring months, stripes frequently re-develop and may become active again until early November. At the more moist sites, and during wetter years, stripes may be active throughout winter. Understanding of the physical processes of such stripe formation still appears to be poor. Troll (1958) suggested that nocturnal winds play an important role in stripe formation and thus may be referred to as “wind-striped frost-heaved soil”. However, recent observations have shown that the stripes are predominantly aligned in the direction of the early morning sun, orientated in an east-west direction, irrespective of slope aspect (Grab, 1997b).

Elsewhere in the High Drakensberg and Lesotho mountains (e.g. Mafadi, 3350m altitude, ±50km north of Sani Pass), sorted stripes are found that are ±3m long and sorted to a depth of 6.7cm, with mean a-axis clast sizes of 7.4cm; coarse stripe widths are ±12.6cm and fine stripe widths ±16.2cm (Grab, 1996b). These stripes appear to be restricted to high altitude slopes but, unlike the needle ice stripes, are perennial features. A number of possible mechanisms such as water induced rill development, needle ice activity, segregation ice development and thermal creep have been suggested as possible formative contributing factors (Grab, 1996b).

**Sorted circles and polygons**

Miniature sorted circles and polygons may be observed on the Kotisephola interfluve and along dry sections of the Mangaung streambed. These are usually represented by an accumulation of cobbles and gravel around centres of finer material, primarily the result of needle ice lifting material in the centres (Fig. 5). Mean centre dimensions for such miniature sorted patterns commonly range between 11.6cm and 16 cm. Despite altitudinal differences of 300 - 500
metres, there appears to be little variation in pattern size throughout the plateau region (Grab, 1997c).

Desiccation and thermal contraction cracking appear to be the primary mechanisms for such miniature pattern development at relatively dry sites on slopes and interfluves, while differential swelling and frost heaving are the likely operative processes within saturated stream gravel deposits (Grab, 1997c). Despite the low proportion (<5%) of clay/silt sediment size fractions, these miniature patterns may become fully developed over very short periods of five to six weeks (Grab, 1997c). Clearly, these miniature patterns are the product of a highly regular and frequent ground freeze-thaw cycle. Many of the patterns at lower altitudes and along drainage lines are destroyed by fluvial processes during the summer, while the better-preserved patterns on slopes at altitudes above 3200m sometimes host perennial patterns.

**Thufur**

Several studies have examined the morphological and ground freezing characteristics of thufur in the high Drakensberg (Boelhouwers and Hall, 1990; Grab, 1994; 1997d; 1998). Thufur distribution in the Drakensberg is primarily controlled by the spatial occurrence of moisture and they are predominantly located in wetland areas. Both active and relict features are found in the Sani Pass area. Boelhouwers and Hall (1990) found thufur with an average height of 16cm and average diameter of 70cm in Kotisephola pass.

Evidence for environmental alteration is seen in that up to 50% of thufur in some swarms show signs of disintegration. A variety of factors such as desiccation cracking,
solifluction, animal trampling and needle ice activity have been attributed to the turf exfoliation and rupture of thufur (Grab, 1994). It is suggested that ice rats (*Otomys sloggetti*) have a major impact on the disintegration of thufur; the recent mild years and relatively dry wetland conditions have apparently resulted in increased the ice rat populations. The ice rats usually build their tunnel exits into the sides of thufur for protection against predators. Further, as the thufur have developed within thick organic (sometimes peat) horizons, they offer insulation during the cold winter months. Observations from the Mashai Valley (from 1995 to 1998) have indicated that the burrowing activity of the ice rats has increased substantially in recent years and progresses from the wetland fringes towards the central parts of wetlands.

The precise age of the thufur in the Sani Pass area is not known; however, most of the wetlands are estimated to be between 2000 and 13 000 years old (Van Zinderen Bakker, 1955; Hanvey and Marker, 1994). Better developed thufur frequently occur towards the wetland centres, as opposed to the wetland periphery areas, and may have formed during wet cycles and degraded during drier times (Grab, 1998).

The thermal characteristics of thufur have been studied in the Mashai Valley, approximately 10km to the south of the Sani Flats (Grab, 1997d). Considerable thermal differentials are found between thufur apexes and their adjoining depressions (Fig. 6). The apexes may freeze to a depth of 20cm and remain frozen from early June to late August while the depression soils remain unfrozen from depths of 3-4cm. Micro-topography (e.g. thufur) is an important factor in controlling the development of small-scale landforms in marginal periglacial environments by creating “frozen pockets” in an otherwise predominantly unfrozen environment (Grab, 1997d).

![Figure 6: Comparison of apex and depression temperature trends for a thufa in the Mashai Valley, Lesotho](after Grab, 1997d).
Cryoplanation terraces/ transverse nivation hollows (?)

In the Sani Pass area, notably along the Kotisephola interfluve (Fig. 4), are distinct benches cut in the plateau basalts. Each has a vertical, weathered backwall with a tread composed of finer material close to the back wall (although there is some rockfall at the base of the face) and larger debris further away (Fig. 7, Fig. 8). In the photos, taken in September 1998, there can be seen to be remnants of snow against the backwall (in the protective shadow) and some ice on the face of the backwall (Fig. 7).

Figure 7: Basalt benches with scarp backwalls

Figure 8: Snow and ice may be seen along some of the scarp backwalls.
The benches create distinct steps in the landscape and appear to predominate on the southerly slopes, or at least to occur in greater numbers and as larger forms on these slopes. Whilst there, it is obvious that these forms are present, the question arises as to what they actually represent or are indicative of? Consideration of most forms in the high Drakensberg and in Lesotho has, inevitably, led to an association with periglacial conditions. Being able to observe that snow still resides against the backwall and that ice can be found on the weathered face tends to reinforce this association - if conditions are like this today then they should have been even more severe during the Glacials. That being so, then a circularity develops such that these forms then must be the product of periglacial conditions. Although this circularity of argument may well not be in error, it still leaves the question as to what do these forms represent?

Nivation has been long associated with landforms in the Drakensberg but, to date, no mention has ever been made of cryoplanation, although Harper (1969) does identify “basalt steps” that he considered to be the product of frost wedging. Cryoplanation is said to be a "... cryogenic process promoting the low-angled slopes and level bedrock surfaces typical of many periglacial regions" (French, 1996, p.181). The processes seen as causative for cryoplanation terraces, namely intense frost shattering, solifluction and, in some instances, slope wash are similar in makeup to those associated with nivation, although their relative contributions and rates of operation may differ. The end result of 'cryoplanation processes' is the development of a low-angled bedrock surface. A number of authors (e.g. Reger and Péwé, 1976) consider cryoplanation terraces to be associated with permafrost and for them to exhibit orientational preferences. Many authors (e.g. Boch and Krasnov, 1943; Demek, 1969; Reger, 1975) identify nivation as initiating cryoplanation and that, at some later stage, 'cryoplanation' takes over from 'nivation'. Certainly, along the Kotisephola interfluve above the block stream deposits (Fig. 4) a number of features that have all the visual attributes of cryoplanation terraces are observed (Fig. 7, Fig. 8). Further, these features are south-facing (note the so-called ‘nivation hollows’ identified by Marker & Whittington (1971) and Marker (1991, 1994, 1995b) are north-facing) and so certainly experience a cold micro-climate. Many of these benches are visible and there is an apparent preference for a south-facing orientation. On the interfluve between Kotisephola Pass and the Sani block streams major benches are apparent on the south-facing aspects. Thus, there would certainly appear to be a preference for the colder aspect where snow will prevail longer and temperatures will be lower for a longer period. The thought that these are simply ‘structural benches’ is a non sequitur, as there still needs to be a suite of processes, apparently aspect constrained, to exploit along the structure - the term describes only form and does not consider process. A view across the landscape shows that these benches are certainly a noticeable
feature and thus there needs be some explanation within the general framework of the landscape developmental sequence.

If ‘nivation’ were given some credence for the hollows, then the question would arise as to whether these forms are, in fact, ‘transverse nivation hollows’? Certainly, if it can be thought that snow could survive, despite the northerly aspect, in the hollows then it will certainly do so in the lee of these steps - as it does today in winter. Indeed, it may well be that the north-facing hollows are post-glacial (i.e. post cold period) features associated with chemical weathering along joints whilst these benches are, in fact, transverse nivation hollows. Such a judgement would make more sense when aspect is considered. A clear problem here is how to determine between a transverse ‘nivation hollow and a ‘cryoplanation terrace’? The whole issue of form, process and terminology in ‘nivation’ and ‘cryoplanation’ is fraught with problems, especially where ‘nivation’ is seen to initiate ‘cryoplanation’ and yet cryoplanation takes over at some unspecified point although the processes remain the same! In reality, there is actually nothing that can identify either these benches or the facing hollows as of nivation or cryoplanation origin. The whole issue of nivation and cryoplanation - the terminological, process and form problems - is discussed at length in Hall (1998). Here, as we walk across, we can look back to see the ‘nivation hollows’ and can clearly see the benches - the questions remain as to the origin(s) of both features, as to what they tell us about the palaeoclimate (if anything) and what their status is within the landscape development of this area. As significant as these questions are to Lesotho and its Quaternary history, so these questions need to be posed for all other areas where such forms are thought to exist.

Thus, we are left with an unanswered problem and all the more so if any argument is made for these to be cryoplanation terraces, for then that may imply permafrost (Reger and Péwé, 1976) and that, in turn, confounds consideration of glaciation or, perhaps, even nivation, as both require substantial snowfall for operation. If an argument can be made that these are transverse nivation hollows then, as they are significantly smaller than the north-facing hollows (considered to be nivation hollows), this may indicate that the latter are more likely a product of post-glacial weathering. Ultimately we are left with the problem of deducing process from form (for both nivation and cryoplanation forms imply specific processes and conditions) and this may simply be too dangerous. Further, this issue regarding the origin of these benches, and the hollows, symbolizes the larger problem of high Drakensberg-Lesotho (indeed southern Africa) Pleistocene conditions and landform development. What can we see that is unequivocal (if anything!) and from this what sort of scenario can we build regarding landform development and developmental processes for this region?
Periglacial blockstream and solifluction mantles

Location

A large blockstream is situated in a valley due east, and at about one hour walking distance, from the top of Kotisephola Pass (Fig. 4). The easiest access to this blockstream follows the Kotisephola interfluve to the head of the blockstream valley; alternatively, the site can be reached walking in from the Sani river bridge on the main Sani Pass-Mokhotlong road (Fig. 4).

Significance

The deposits in this valley are representative of those at many other high elevation sites in the Lesotho mountains. This blockstream was first referred to by Hastenrath and Wilkinson (1973), while Boelhouwers (1994) described relict allochthonous blockfields at Giant’s Castle, 30km north from this site, as indicators of gelification processes. Similar blockstream deposits are reported for the Western Cape Mountains (Boelhouwers, 1996, 1999), with openwork slope deposits also described for the higher regions of the Amatola mountains of the Eastern Cape (Marker, 1986). They must be distinguished from autochthonous blockfields, resulting from in situ weathering, which do not necessarily require a periglacial origin.

Allochthonous blockstreams in the Sani Pass area (Fig. 9) are suggested to have formed under severe seasonal freezing, but not necessarily permafrost (Boelhouwers, 1994). Such deep frost penetration also implies the presence of a limited snow-cover. None of these openwork block deposits have been absolutely dated, but are considered of Last Glacial age. In the Western Cape, they are most readily associated with severe periglacial conditions during the Last Glacial Maximum (Boelhouwers, 1999). As such, allochthonous blockstreams and blockfields of the summit areas of southern African mountains are considered the geomorphological manifestations of the most severe Quaternary periglacial conditions encountered.

Site descriptions

Along the watershed en route to the blockstream valley, cryogenic soil surface disturbance can be recognised in the form of needle-ice induced turf exfoliation, small turf-banked steps and micro-polygons. From the ridge crest there are excellent views into both the north- and south-facing valleys. The two south-facing valleys both contain openwork block accumulations in the central part of the valley-floor. Solifluction terraces can be seen along the valley-side and valley-head slopes. The last north-facing valley passed before reaching the blockstream valley contains a thick colluvial mantle that is currently being incised by fluvial erosion. The colluvial
mantles are considered the result of Pleistocene solifluction processes, creating dry valleys with subsequent fluvial incision in the Holocene.

Figure 9: Geomorphological map of the blockstream valley, based on 1:5000 aerial photo interpretation.

**Site 1. Head of the blockstream valley**

The saddle leading into the blockstream valley offers a good overview of the four small catchments, designated A-D in Figure 9, that converge in the central valley where the main blockstream is located. The catchment is distinctly asymmetrical with tributaries B, C and D feeding into the main valley from the north. Figure 9 represents a geomorphological sketch of the catchment. The upper slopes of the catchment comprise small rock scarps alternating with thin debris mantles that level out in downslope direction on the next rock ledge. Rock scarps on the south-facing slopes are less continuous than on the north-facing slopes and show mechanically induced fracturing. Rockfall-derived blocks spread over short distances between rock scarps. Downslope from this upper scarp-zone the north- and south-facing slopes develop notably different characteristics. The north-facing slope continues as a rectilinear rock slope with a thin debris veneer less than 1m thick. Occasional rockbands, less than 2m high, are exposed at the surface. Clast abundance is low. The south-facing tributaries are slightly concave in profile with deeper debris mantles that have a significantly higher clast content than the opposite slopes. Resistant basalt flows, although not necessarily exposed, create local breaks in slope above which wetlands are frequently present. Thufur are often well developed at such sites. As
indicated in Figure 9, deep solifluction mantles have accumulated in these tributaries. In the
downslope direction solifluction sheets form terraces with risers of 0.5m - 1.5m high and are
particularly well developed in catchment (D). Clast content also increases in the downslope
direction resulting in occasional openwork block deposits. Where located along preferred
drainage lines, openwork deposits may be in a slightly depressed location as a result of matrix
removal by suffosion. Lobate terrace fronts are often found where a local decline in slope angle
occurs, with thufur immediately downslope from such a front. Rock scarp disintegration with
localized displacement of blocky debris also results in small, isolated openwork block
accumulations.

The south-facing valley slopes are clearly much longer and wider than the north-facing
slopes, thus providing a much larger source area for debris production. Bedrock weathering at
the upper catchment scarps also appears more advanced on the south-facing slopes. These two
factors are suggested to largely explain the thicker debris mantles feeding into the central valley
from south-facing slopes with relatively little sediment input from the north-facing slopes. The
explanation for the distinct valley asymmetry in the High Drakensberg and Lesotho is discussed
elsewhere in this guide. Suffice to point out that the processes discussed here operated in an
already asymmetrical valley. Although process dynamics have been very different on opposite
slopes during debris production and emplacement of the landforms under discussion, valley
asymmetry is considered to pre-date these landforms.

**Site 2. The blockstream**

The large blockstream that occupies the central valley floor has a length of
approximately 1.1km and a maximum width of about 75m. This long, narrow openwork block
deposit is aligned along the central drainage of the main valley and is positioned at the terminal
end of the solifluction mantles from catchments A and B (Fig. 9). It extends downslope at a
gradient of 8°. Cross profiles in Figure 10 show the block deposit to have an irregular surface,
with its highest parts slightly raised above the surrounding valley-floor. The depressions and
channels beneath the level of the surrounding slope point at removal of material subsequent to
deposition. This provides an important indicator for the presence of a matrix during deposition of
the valley-floor deposits, with the blockstream being a residual deposit following washing out of
the matrix.

Block size (a-axis) data at various distances along the blockstream are summarized in
Table 2 and indicate minimal variation in block size composition over the entire length of the
blockstream. Fabrics of the ab-plane of clasts show well-developed bi- or trimodal clast orientation
distributions and are strong indicators that the block deposit is not the result of \textit{in situ} weathering but, rather, is of allochthonous origin (Fig. 11). The primary alignment of clasts at all sites, except at 500 m, is parallel to the local maximum slope gradient, which supports emplacement of the valley-floor deposits by means of slow mass movement. A secondary concentration of blocks with orientations at right angles to the primary mode is present at all sites reflecting imbricated and often steeply dipping clasts. These may result from local decelerating movement or block displacement by frost heave. A third peak, indicating a preferred north-south alignment, is found on the northern margin of the blockstream at 500, 700 and 900 metres. These sites are located at the confluence with catchments B and C and their more complex (random) fabrics are interpreted as a result of the pressures generated by downslope movement of the solifluction mantles from these catchments. Although difficult to substantiate due to the uniform lithologies in the area, the morphology of the deposits suggests that from 500m the block material from catchment B is incorporated into the blockstream.

![Blockstream Cross Profiles](image)

Figure 10: Cross profiles of the blockstream, viewed from its upper end (0m) in downslope direction. Location of the transects is given in Figure 12.
Figure 11: Location of the transects presented in Figure 10 and block orientation (ab-plane) plots. Each concentric circle in the fabric plot indicates a 10% frequency.

Table 2. Summary statistics of block a-axis measurements along the blockstream in downslope direction.

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>n</th>
<th>Minimum (cm)</th>
<th>Maximum (cm)</th>
<th>Average (cm)</th>
<th>Standard Deviation (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>75</td>
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<td>143</td>
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<tr>
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<td>50</td>
<td>25</td>
<td>112</td>
<td>60.2</td>
<td>24.0</td>
</tr>
</tbody>
</table>

**Origin of the blocks**

The boulders in the valley-floor blockstream are sub-rounded with pitted surfaces and weathering rinds less than 2 mm thick. In contrast, the blocks that comprise the smaller blockfields in the tributaries are distinctly angular and surface pits are largely absent. The rock scarps in the upper sections of the catchment have generally rounded faces, but highly fractured, angular rock scarps and tors dominate the south-facing slopes.
Based on the block shape and weathering characteristics, the clasts found in the small blockfields are clearly derived from the rock scarps found in the upper-catchment. The blocks found in the valley-floor blockstream are significantly more rounded and weathered than those in the tributaries and two possible sources for the blocky debris can be envisaged. Besides an origin from surrounding rock scarps, corestones derived from spheroidal weathering mantles in the valley-floor and surrounding slopes could provide significant volumes of rounded clasts. Observations in road cuttings in Sani Pass and Kotisephola Pass, however, indicate that the degree of rounding and advanced chemical decomposition found in these profiles exceeds the rounding, weathering rind thickness and loss of strength observed in blocks from the blockstream. Instead, the blocks found in the blockstream are considered the result of cryoclastic debris production at the scarps. The rounding and pitting is interpreted to be the result of subsurface weathering of the diamicton before subsequent washing out of the matrix.

**Site 3. Exposure in solifluction mantles**

Following the valley in downslope direction a small stream emerges in summer from the terminal end of the blockstream. After another ±500m (and further openwork material detached from the main body) one reaches the confluence of streams from catchments C and D with the main channel. Stream incision has resulted in exposure of the slope materials that blanket many of the valleys at these altitudes.

Headwall erosion of the central valley-floor deposits reveals a uniform, coarse, clast-supported diamicton at least 4m in thickness. The washing out of matrix by the stream results in further residual openwork deposits. Geomorphological mapping indicates that this material constitutes the terminal zone of the mass-wasting mantle from catchment C (Fig. 9).

Exposures in the slope materials from catchment D occur along its stream that runs over bedrock. At the confluence the material is 15-20m thick and composed of a massive granular loam. In the otherwise unstratified material, occasional thin layers contain a 10-30% abundance of small stones with a-axes up to 15cm. In the uppermost 0.4m larger boulders occur with a-axes up to 1.5m.

Three hundred metres upstream from the confluence the stream in catchment D cuts through a 3m thick deposit, including a stone-banked terrace, on its eastern bank. The stone-banked terrace reveals a 1.6m thick clast-supported diamicton at its 8m wide front. Clasts have a-axes up to 80cm and dip at 22° in upslope direction. Contact with the underlying material is
near horizontal on an 8° slope. The deposit rests on 1.5m of granular loam. At 0.9m below the surface a thin layer exists with 20% clast abundance that have a-axis lengths of up to 25cm. The feature is relict with soil development subsequent to deposition.

**Blockfield development**

The morphology of the openwork deposits, the clast fabrics and the low angled slopes on which they are found, resemble that of allochthonous blockstreams found at other mid-latitude environments, such as those in southeast Australia (Caine and Jennings, 1968), Tasmania (Caine, 1983) and the Appalachians (Potter and Moss, 1968). In all these cases an emplacement of the slope materials by slow mass wasting under periglacial conditions is proposed. Material fed from all four catchments into the central valley where most of the accumulation of blocky material took place. This accumulation took place as a diamicton with matrix present between the blocks as suggested by the weathering status of the blocks and the recessed cross profiles of the blockstream.

Movement mechanisms by slow mass flow require the build up of considerable pore pressure in the debris material. In the coarse materials at an 8° slope angle this is best explained with an impervious layer at the base which here is provided by bedrock. However, the coarse deposits drain readily even when assuming a matrix present between the blocks. Washburn (1980, p. 98) points out that sufficient hydrostatic head may be generated when a seasonally frozen surface layer impedes drainage. Such a mechanism has also been proposed by Caine (1983) for the movement of some blockfields in north-eastern Tasmania.

Frost creep would provide an additional mechanism of movement of the upper zone, operating in close association with solifluction. Although no estimate of soil frost penetration can be given, Fahey (1974) showed 30cm heave with seasonal frost to a depth of 2m in very wet soil. Under such optimal conditions this would result in 1.76cm/a (potential) creep on a 10° slope. Based on this mechanism alone, a clast from the upper catchment would travel about 1km to the blockstream in almost 57ka. This makes it very unlikely that frost creep is the only transport mechanism. However, the apparent concentration of blocky material in the upper sections of the exposures, with minimal presence of blocks lower down in the vertical profile, suggests that frost heave induced creep played some role in the movement of the material. This is further borne out by the localised, lateral sorting features present in the blockstream and blockfields.
Palaeoenvironmental implications

The blockstream and related deposits described here most likely developed under a seasonal frost environment, with no permafrost required. Solifluction mobilised a well-weathered regolith under conditions suitable for cryoclastic debris production at surrounding scarps. For significant segregation ice to develop sufficient moisture must have been present at the time of freeze up in autumn. Furthermore, sufficient water supply is a necessity for failure under high pore water conditions. On the other hand, to allow for a 1-2m deep seasonal freeze-up, snow-cover must be largely absent to avoid thermal insulation of the ground surface. Under present-day conditions summer precipitation generates seasonal wetlands in the central parts of the catchment and tributaries. As precipitation amounts decrease in autumn drainage from these wetlands continues, thus providing suitable conditions for the mechanisms outlined above to operate under the right temperature conditions. This suggests that precipitation patterns were not significantly different than at present. This is in agreement with estimates by Partridge (1997).

Concerning the age of the deposits, the regolith material in which the blockstreams and solifluction mantles have developed may date back to the Early Tertiary. The uniform weathering status and angularity of the blockfield material points at emplacement of the, now relict, openwork deposits in the Late Quaternary. Conditions for sufficiently severe seasonal frost would have prevailed only during the Last Glacial, and particularly the Last Glacial Maximum, and it is during this period that the main phase of solifluction and frost creep took place. The apparent dominance of solifluction processes throughout the High Drakensberg and Lesotho argues against widespread glaciation of the region during this period. Slope materials became largely stable in the Early Holocene with only surficial frost penetration occurring at present. The latter still generates frost creep and solifluction in the upper 0.4m of the soil. However, low sediment yields due to limited sediment supply and increased vegetation cover in the Holocene result in suffosion and the current phase of stream incision in the colluvial mantles.

Valley Asymmetry and Valley-head hollows in the Sani Pass Area.

Introduction

Two major features are illustrated to the south of Sani Pass, namely valley asymmetry and the valley-head hollows. The main focus is on an unnamed valley approximately 3km south of the Sani Top Chalet. This is typical of the High Drakensberg and Lesotho mountains as it is asymmetrical with a steeper south-facing slope than the north-facing slope (Fig. 4, Fig. 12). The north-facing slopes of the valley contain three large hollows that have been described as being either of glacial or nival origin (Marker & Whittington, 1971; Marker, 1991, 1994). Three sites are suggested for investigation:
• Site 1 (Fig. 13) is an ideal location for the observation of valley asymmetry, while providing a view of the hollows that will be discussed at Site 2.

• Site 2 (Fig. 13) is located at the base of a hollow (identified as Hollow B by Marker & Whittington (1971) and Marker (1994, 1995b) where the sedimentary sequence is visible in an erosion gully. The adjacent hollow to the west of Hollow B will be observed en route to Site 3 (Fig. 13).

• Site 3 was chosen as it represents a contemporary analogue from which the depositional environment of the hollows at Site 2 can be interpreted.

![Figure 12: Valley profile and sedimentary analysis for a valley approximately 3km south of Sani Pass, Lesotho.](image)

**Site 1: Description and Background**

As indicated above, the valley 3km to the south of Sani Pass is typical of the High Drakensberg and Lesotho mountains. Throughout the region, south-facing slopes have been found to be steeper than north-facing slopes (Meiklejohn, 1992). It has been previously argued that valley asymmetry in the High Drakensberg and Lesotho is the result of periglacial processes (Alexandré, 1962; Sparrow, 1964, 1971). Other research indicated that the observed asymmetry at lower altitudes is not necessarily the result of a periglacial environment (Garland, 1979; Boelhouwers, 1988). Meiklejohn (1992, 1994) used published material suggesting a periglacial
environment (e.g. Alexandré, 1962; Sparrow, 1964, 1971; Harper, 1969; Linton, 1969; Hastenrath, 1972; Lewis, 1988a, 1988b), to propose that cryogenic processes may have resulted in the observed asymmetry.

Figure 13: Rock Mass Strength Transects and major Lineaments at the study sites.

At Site 1 the average gradient of the south-facing slope is 20° while that of the north-facing slope is 15° (Fig. 12). The north-facing slope of the valley has poorly developed thin soils with very little horizon development; only a humic A-horizon can be identified except for the valley floor (position “a”, Fig. 12) where a red apedal B-horizon with clay illuviation is found. While the south-facing slope is also comprised of similar thin soils, two horizons can be identified where the soil layer is deeper. At location “x” (Fig. 12) a cutanic B-horizon, 70cm deep, is found beneath a 35cm thick A-horizon, while a thin yellow-brown apedal B-horizon is found at “y” (Fig. 13). Saprolite, 70 - 80cm thick, is found beneath a humic A-horizon, of 60 - 70cm, at locations marked “z” (Fig. 12), where the soils are deepest.

The presence of clay (Fig. 12) and saprolite, as well as cutanic and apedal B-horizons indicate that the basalt weathering is active on south-facing slopes. Weathering on the south-facing slopes is likely to be a response to the relatively high moisture conditions (Fig. 12). However, the high proportion of clay minerals and saprolite indicate that the south-facing environment is not conducive to the removal of weathering products. It follows that observations of the south-facing slope support the basic premise of Meiklejohn's (1994) model that south-facing slopes are geomorphologically less active than north-facing slopes.
Given that the valley floor stream channel is located so close to the base of the south-facing slope, it is apparent that the north-facing slope has undergone considerably more retreat than the opposite slope. If the north-facing slopes are more active, then it is surprising that the only evidence of products of mass wasting from the north-facing slopes is the accumulation of sediment at the base of the observed hollows. The implication of this observation is that the environment on the north-facing slope has produced weathered material that is easily removed. The susceptibility of the Drakensberg basalts to weathering by moisture-related processes (van Rooy and Nixon, 1990; van Rooy, 1992; van Rooy and van Schalkwyk, 1993) supports this, especially as the weathered material is generally comprised of fine, often clay-sized, particles. Further, given the finer size of the weathered product, it is unlikely that any accumulations will be found in fluvial systems downstream.

Site 1: Palaeoenvironmental Interpretation

Throughout the year, north-facing slopes receive more direct incoming solar radiation than south-facing slopes in areas south of the Tropic of Capricorn. Given that this will result in relatively high temperatures on north-facing slopes, chemical weathering processes will be faster here than on the south-facing slopes. The increased rate of weathering will, in turn, result in more weathering products being available for transport and thus potentially lead to faster denudation of the north-facing slope. This assumption is, however, based largely on the premise that moisture is available for the weathering to take place.

It is apparent, from ongoing field research, that both the north- and south-facing slopes are relatively inactive. Given that soil moisture content is higher on south-facing slopes than on north-facing slopes and that this is unlikely to have been different in the past, it would be logical to argue that weathering and erosion are enhanced on the south-facing slopes resulting in shallower south-facing slopes than north-facing slopes. However, the opposite is true and deep sedimentary profiles in the base of shallower north-facing slopes indicate that weathering and slope processes are more active on north-facing slopes. Two possible scenarios may explain this; first, the moisture regime on the north-facing slopes was more dynamic than on the opposite slope, thus resulting in a relatively high rate of weathering and increased debris production, together with high rates of debris removal. Alternatively, or simultaneously, the moisture on the south-facing slope was in a “non-mobile form”; this may indicate frozen slope conditions. A frozen south-facing slope would mean that the moisture regime was not dynamic and thus relatively inactive in terms of geomorphic activity. Climatic amelioration after the Last Glacial Maximum would have resulted in the south-facing slope becoming more geomorphologically active in terms of weathering, thus, contributing towards the formation of the soils observed on these slopes. It is
during this amelioration that weathered bedrock or residuals could be mobilised and result in the observed mass movement features (Fig. 12). The clay minerals, saprolite and clay-rich B soil horizons present on the south-facing slope are likely to be a function of the relatively high moisture contents found on this slope.

Site 2: Background

Three hollows in the valley 3km south of the Sani Top Chalet have previously been investigated by Marker & Whittington (1971) and Marker (1991, 1994, 1995b) and given a nival or glacial origin due to lee-side snow accumulations. In each of the three hollows, the basal sediments have been incised, providing an ideal location for description and investigations into their origin. The incision of the sediments in the hollows near Sani Pass is likely to have arisen as a result of increased runoff. This could either be due to the impact of overgrazing from cattle and sheep or from increased precipitation (i.e. during a wetter period) or a combination of both. Marker (1994, 1995b) has published data regarding material that has been dated from this site. The oldest dates are obtained from organic sedimentation at the base of the hollows are from 13 490 BP and possibly represent the rapid amelioration of temperature after the Last Glacial Maximum (Marker, 1994, 1995b).

The argument that the hollows were formed by nival or glacial processes is based on a model proposing that mid-latitude cyclones extended far north during the cold periods of the Pleistocene, resulting in high precipitation in the form of snow (Marker, 1991, 1994, 1995). This in itself is a difficult argument to conceptualise, considering that a pre-existing hollow would be required for snow accumulation, especially in the case of lee-side accumulation on a north-facing slope. The north-facing slope receives more incoming solar radiation than any other slope and snow accumulation would arguably melt first here and rather accumulate on south-facing slopes. In addition, evidence suggests that during the Last Glacial Maximum, precipitation was only 70% of present (Partridge, 1997), making large accumulations of snow on any slope highly improbable. In contrast, Grab and Hall (1997) have proposed that the hollows may be the result of bog-cirque development. If this were the case, then it would be expected that there would not be a sharp contact between sediments and basalt bedrock at the base of the hollows. Moist conditions for a prolonged period at the base of a hollow would result in considerable in situ weathering, especially as Drakensberg basalts are prone to breakdown through related moisture processes (van Rooy and Nixon, 1990; van Rooy, 1992; van Rooy and van Schalkwyk, 1993). In reality, the hollow sediments have a sharp contact with the bedrock. In situations where the hollow sediments have not been incised by fluvial action, relatively impermeable clay layers would prevent
substantial moisture seepage through to the bedrock, thus resulting in a protected rather than an active weathering environment.

**Site 2: Palaeoenvironmental interpretation**

The sediments at the base of the Sani hollows have been described in some detail (Marker & Whittington, 1971; Marker, 1991, 1994, 1995b). Those at Site 2 are investigated further. The sediments show a sharp contact with the bedrock, which can be clearly seen downstream from the described profile at Site 2. A profile shows successive organic peat accumulations, with alternating interstitial coarse fluvial and fine aeolian sedimentation (Fig. 14). The described section in hollow B has two peat layers, while in a gully in the adjacent hollow to the west, up to five peat layers were identified. Downstream from the described section at Site 2, is a layer of large (10-30cm diameter) clasts within the fluvial sediments in the sequence; this indicates an energetic fluvial regime. Occasionally a relatively impermeable clay-rich layer is located within granular fluvial sediments (Fig. 14). Evidence from cored samples indicates that another clay layer is situated beneath the visible section. The formation of ferricretes above the clay layers in the profile is an indication of a variable water table (Fig. 14).

The upper layer of peat is said to have formed during a warmer and wetter period between 9000 and 5000 BP (Marker, 1994, 1995b). In-between, alternating fluvial and aeolian deposition is said to represent a drier period that existed between 5000 BP and 1000 BP (Marker, 1994, 1995b). However, while this section may be relatively easy to interpret, the increase in the number of peat layers in the adjacent hollow to the west, indicate that the interpretation of the sediment in the hollows at Sani Pass may be more complex than initially suggested. Similar, but younger sediments have been described at Tlaeeng pass, approximately 110km north-west of this site (Marker, 1994, 1995).

Currently, no published data are available indicating that sediments in valley-heads and hollows in Lesotho are older than the Last Glacial Maximum. This either suggests that the area was protected or geomorphologically relatively inactive during the coldest part of the Pleistocene. The absence of datable material preceding the LGM may be the result of an inactive geomorphic environment, or an environment with limited vegetation cover. Alternatively, it is possible that increased precipitation during the relatively wet period immediately following the Last Glacial Maximum (Partridge, 1997) could have resulted in the removal of much of the material that accumulated during the colder period. Data suggesting that the Last Glacial Maximum was relatively dry and 6-10°C colder than present (e.g. Partridge, 1997) support the argument that this period was geomorphologically relatively inactive.
If, as it is argued above, the hollows at Sani and all the others identified by Marker (1994, 1995b) do not owe their formation to the action of snow or ice, then another hypothesis regarding their origin should be sought. The answer may lie in the underlying bedrock structure.
The rock mass strength technique (Selby, 1980; Moon and Selby, 1983, Moon, 1990) was utilized as it was thought that it may provide some evidence for the location of the Sani hollows. A hollow (Hollow C described by Marker, 1994), and the interfluve between two hollows were investigated (see Fig. 13 for the location of transects) using the rock mass strength technique (Fig. 15). It was found that while the entire north-facing slope was slightly over-steepened, there was relatively more over-steepening in the hollows than at the interfluves (Fig. 15, Fig. 16). This observation possibly indicates recent slope development and that the slopes will still undergo change. However, the observation made above, that the slopes are currently relatively inactive, does not support this hypothesis. The rock mass strength technique did not, however, prove to be entirely conclusive in this case and further transects are required before any conclusive derivations can be made. The only real difference found between hollows was that the joints in the hollows are more continuous and exhibit a more defined orientation.

Figure 15: Rock slope classification using rock mass strength and gradient of Hollow C back wall and the interfluve between Hollow B and C (as identified by Marker, 1994).

Figure 16: Profiles of Hollow C back wall and the interfluve between hollow B and C (as identified by Marker, 1994).
Joints, dolerite dykes, and kimberlite dykes in the Drakensberg volcanics show very strong orientations (Dempster and Richard, 1973). From fieldwork, aerial photographic analysis and digital terrain modelling, the positions of the main lineaments in the area of the hollows were plotted (Fig. 13). It is apparent that the basal layers of the hollows are exactly where these lineaments intersect (Fig. 13). Given that these are likely to be major joints, it is possible to postulate that these are avenues of easy moisture access and thus enhanced weathering. While this provides an answer for the location of the hollows, it does not indicate the specific processes responsible for the formation of the hollows.

**Site 3: Introduction**

A location approximately 1.5km south of the Sani Top Chalet was investigated as it locality potentially provides a suitable contemporary analogue for the formation of sediments located in hollows at Site 2 and elsewhere in the High Drakensberg and Lesotho mountains. The site comprises a relatively shallow valley containing a wetland fed by with a braided fluvial channel system. Material in the fluvial channels is course gravel similar to that is sections of the profile at Site 2.

**Site 3: Description and Interpretation**

A core of 3m was obtained from Site 3, which provided a comparison with the sediments at Site 2. The sedimentary sequence obtained from Site 3 (Table 3) follows a similar pattern to that at Site 2 and other hollows documented from the High Drakensberg and Lesotho, in that coarse fluvial sediments alternate with organic rich sediments.

The surface at Site 3 consists of course fluvially deposited material to a depth of 50cm. From 50 - 80cm organic rich sediments comprising a high proportion of clay and silt particles are found. It is proposed that these sediments would eventually form a peat layer. Between 80cm and 2.5m the sediments were similar to the surface sediments, with some evidence of ion oxidation and ferricrete mineralisation, similar to, but less dramatic than Site 2. At a depth of 2.5m a further organic rich layer of approximately 20cm was found above coarse fluvial sediments. The difference between this site and Site 2 is that the surface is comprised of coarse fluvial sediments deposited in an "outwash" area rather than an organic rich A horizon. Further, the organic O horizons have not fully developed into peat as in Site 2. In a dynamic system (as is the case at site 3) where there are braided stream channels, the cycle between an area being vegetated and then denuded of vegetation could be as short as a single season in a particular year. In this case, the coarse fluvial material may represent an active fluvial environment rather than a dry period. The layers of peat may thus represent more complex cycles than that proposed by Marker (1994,
1995). More rigorous dating of the sediments is required before any conclusions regarding climatic cycles can be made.

Table 3: Description of the Sedimentary Sequence at Site 3.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Depth</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 0.5cm</td>
<td>Coarse fluvial sediments</td>
</tr>
<tr>
<td>2</td>
<td>0.5 - 0.8cm</td>
<td>Fine, organic-rich sediments</td>
</tr>
<tr>
<td>3</td>
<td>0.8 - 1.8m</td>
<td>Coarse fluvial sediments</td>
</tr>
<tr>
<td>4</td>
<td>1.8 - 2.2m</td>
<td>Coarse fluvial sediments with ferricrete mineralisation</td>
</tr>
<tr>
<td>5</td>
<td>2.2 - 2.5m</td>
<td>Coarse fluvial sediments</td>
</tr>
<tr>
<td>6</td>
<td>2.5 - 2.7m</td>
<td>Fine, organic-rich sediments (more &quot;peat-like&quot; than layer 2 above)</td>
</tr>
<tr>
<td>7</td>
<td>2.7m -</td>
<td>Coarse fluvial sediments</td>
</tr>
</tbody>
</table>

Future research into valley forms in the High Drakensberg and Lesotho mountains

It is apparent that valley forms in the High Drakensberg and Lesotho mountains require further investigation, before they can be used as palaeoenvironmental indicators. Published data currently available provide more questions than answers and often consider isolated features out of context. There is thus a need for further research and possible locations for such investigation are the thick, valley-bottom sediments; an example of which can be seen in south-facing hollows to the north of the Sani Top Chalet. From aerial photographic analysis it is apparent that similar sediments are located throughout the High Drakensberg and Lesotho mountains. It is likely that snow would have accumulated here rather than in north-facing hollows. Future research should thus be directed towards these sediments as they may provide some evidence to the role of snow or ice in the landscape development in the high regions of southern Africa. Until more data are collected and analysed from a broader perspective than past and current research, no definite conclusions will be forthcoming.

Road sections in Sani Pass

Location

Exposures of the slope materials and underlying weathering mantles in the basalt in the pass are within 20 minute walking distance from the Sani Top chalet at 1.7km from the top of the pass.

Significance

The exposures in Sani Pass provide the only easily accessible sites to study the slope deposits and basalt weathering profiles in the cutbacks along the Drakensberg Escarpment. Discussion on the conditions in some of the cutbacks during the cold phases of the Pleistocene have centred around the origin of the extensive mass wasting deposits at the base of the cliffs (Sumner, 1995; Hall, 1995) as well as possible niche glaciation (Hall, 1994; Grab, 1996a). No
detailed sedimentological work has been carried out on the cutback deposits to date and no ages have been established. The sites described here are intended to stimulate further debate on these issues.

Site descriptions

The three road sections presented here cut through the steep debris mantles that alternate with rock scarps beneath the cliffs of the Main Escarpment. The slopes are orientated towards the east and southeast and have gradients around 32-34°, which must be close to the angle of internal friction of the debris. Sketches of the three exposures are presented in Figures 18, 19 and 20.

Site 1a (Fig. 17)

This section has been subdivided into five units separated by indistinct boundaries. The lowermost unit is comprised of a massive, matrix- to clast-supported diamicton with large clasts. Unit 2 makes up most of the section and contains a grey-yellow, crudely stratified, matrix-supported diamicton with occasional thin gravel lenses and scattered large clasts. Unit 3 is a massive clast-supported diamicton, truncated by a matrix-supported diamicton similar to unit two. The dark-grey colour in unit 4 represents, for local conditions, well-developed buried soil horizons. The uppermost unit represents a grey, massive, matrix-supported diamicton with current soil development.

Figure 17: Sketch diagram of road Section A in Sani Pass.
Site 1b (Fig. 18)

This exposure presents a longitudinal section through similar slope material as at site 1a. Units one and three are massive, grey yellow, diamictons with relative low clast abundance, separated by a layer with high clast content. Pockets of small clasts are present immediately upslope from large blocks in this unit. Unit four represents a buried soil horizon in loam with 20% abundance of small clasts. This unit is superceded by similar crudely stratified material of lower organic matter content. A decrease in clast content separates unit 5 from 6. Clasts contained in the material at this site show a distinct a-axis alignment parallel to the slope.

Figure 18: Sketch diagram of road Section B in Sani Pass.

Site 1c (Fig. 19)

This exposure further illustrates the uniform nature of the slope material contained at all three sites. Four units are distinguished in this 3m high exposure. Units 1 and 3 comprise the grey-yellow, crudely stratified, matrix-supported diamicton that dominates all three sections. Clast-supported diamictons create lenses that pinch out laterally (unit 2). These alternate with zones of distinctly low clast abundance. The uppermost unit comprises a pocket of large clasts near the surface.

Interpretation

Dominant in all sections are the matrix-supported diamictons with high percentages of gravelly loams as matrix. Since the deposits are relatively uniform, the units described indicate no major temporal succession in lithostratigraphic facies. Crude stratification is present in the form of lenses of clast-supported diamictons of several metres wide and long and 50cm thick that pinch
out both in lateral and longitudinal profiles (units 1a-3; 1b-2; 1c-2). These coarse lenses are interpreted as small debris flow deposits that redistribute material from upslope (Eyles et al., 1988; Nieuwenhuizen and van Steijn, 1990; Hinchliffe et al., 1998). The alternating zones of thin gravel lenses and layers of low clast abundance (units 1a-2, 4, 5; 1b-3, 5, 6; 1c-1) indicate sedimentation by surface wash, reworking unvegetated slope material, including fines from recently deposited debris flows, during rainstorms (Hinchliffe et al., 1998). The large clasts found scattered in the deposits are considered the result of rockfall, but make only a small percentage of the total debris mass. The buried soil horizon at sites 1a (unit 4) and 1b (unit 4) relates to a phase of reduced sediment deposition conducive to soil development.

Figure 19: Sketch diagram of road Section C in Sani Pass.

*Palaeoenvironmental significance*

The most outstanding characteristic in these deposits is the large percentage of matrix present in the material. The angularity of the clasts indicates that the bulk of the fines must come from sources other than post-depositional weathering of clasts in the debris mantle. Weathering profiles in the road sections of the pass indicate that a substantial amount of fines can be derived from in situ weathering profiles on the steep slopes beneath the escarpment. A significant percentage of fines must however have been derived from the cliffs themselves. The importance of fines production at cliffs and their contribution to talus slope development has also been stressed by Hétu (1992), Salt and Ballantyne (1997) and Hinchliffe et al., (1998). Considering the relative dominance of fines in the deposits it is suggested that chemical weathering processes have played an important, if not dominant role in cliff weathering. On the other hand, the
reworking of slope materials exposed here do not allow for statements to be made on the significance of mechanical weathering at the cliffs or any temporal variations in such activity.

Processes implied in the debris production and the subsequent deposition point towards environmental conditions not significantly different than at present. None of the lithostratigraphic characteristics found in the deposits point at significant periglacial activity at the time of deposition. However, the restriction of buried soil horizons to the upper section of the profiles indicates increased slope stability by a newly establishing vegetation cover. It is worth noting that the darker colour in the palaeosol at sites 1a and 1b, in comparison to the recent A-horizon, suggests climate conditions amenable to better conditions for soil development than at present. The entire sequence of material is considered of Holocene age, but absolute dating of the palaeosol may prove useful to estimate rates of material accumulation.

Conclusion

Information presented in this discussion has provided an insight into the landscape, formative geomorphic processes and problems of landscape interpretation in the Sani Pass area. It is evident that considerable research is still required before any conclusive statements can be reached for the formation of the landscape. Nevertheless, it is becoming increasingly apparent that evidence indicates that many of the superficial features in the vicinity of Sani Pass and indeed the whole of the High Drakensberg and Lesotho mountains point towards periglacial processes in a cool and relatively dry Last Glacial Maximum. However, the arguments and discrepancies that exist in landform and sedimentary interpretation have provided an ideal field laboratory for future research that will positively contribute towards an understand of palaeoenvironments in Lesotho and the High Drakensberg.

Acknowledgements

Marieta Botha, Awie Fourie, Steve Holness and Gerard van Weele are thanked for fieldwork that contributed greatly towards the production of this document. Awie Fourie, in particular is thanked for his assistance in interpreting valley and hollow sediments near Sani Pass. In addition, Hermien Bijker and Anita Böckheler are thanked for their valuable assistance in data collection.
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