Terracettes and active gelifluction terraces in the Drakensberg of the Province of the Eastern Cape, South Africa: a process study

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ABSTRACT

Terracettes and turf-banked terraces exist at Tiffindell Ski Resort in the Drakensberg of the Province of the Eastern Cape at altitudes between 2750 m and 2880 m on slopes of between 15°and 26°. Ice lenses and interstitial ice exist within turf-banked terraces in winter. During post-winter thaws, soil moisture reaches saturation in at least the upper part of the regolith in which turf-banked terraces occur. These terraces move downslope under the influence of gelifluction (which is essentially a combination of frost creep and solifluction). Terracettes appear to move as a result of frost creep, processes associated with needle ice, and slope wash. Both turf-banked terraces and terracettes are part of the periglacial environment and are active under present climatic conditions at Tiffindell.

Introduction

Lewis (1988a,b) has summarised the evidence for the existence of active periglacial phenomena in southern Africa and has stated that 'Solifluction terraces, polygons -sometimes merging into stripes- and thufur are known to be active' (Lewis,1988a,357). Boelhouwers and Meiklejohn (2002,48) agree that 'Turf-banked steps and small stone-banked lobes resulting from solifluction are...evidence for contemporary periglacial activity.' They comment that much of the literature on southern Africa 'is limited to descriptive inventories of features, their dimensions and qualitative observations; few process studies have been conducted' and plea for 'the collection of data relating to periglacial *processes* and accurate ground climate data' (Boelhouwers and Meiklejohn,2002, 48, 50).

The aim of the present paper is to show whether terracettes and turf-banked terraces are active at present in the Southern Drakensberg (that is, in the Drakensberg of the Province of the Eastern Cape) and, if so, to establish the processes responsible for their existence and the climatic and other conditions under which they occur.

Location and setting

Tiffindell Ski Resort (Figure 1) provides an ideal setting for the study of terracettes and turf-banked terraces. The Resort is located at 30°39'S, 27°55'30"E in the Eastern Cape Province of South Africa, adjacent to the border with Lesotho. The resort is on the western side of a valley that is cut into the western flank of Ben Macdhui. This peak, at 3001 m, is the highest point in the Drakensberg of the Eastern Cape. The ski lodge is at an altitude of 2720 m and the ski slopes are above the lodge. The Resort is about 22 km north of the village of Rhodes and about 50 km from the market town of Barkly East (Figure 2). The Resort is fenced and has a permanent labour force, which provides security for research personnel and for equipment and facilitates continuous recording of data. The resort also provides other logistical support, including accommodation for research personnel.

The rocks that underlie the resort and that outcrop in the cliffs above the ski slopes at 2850 m and, more prominently, above 2900 m, are basaltic lavas of the Drakensberg Formation (SACS, 1980). They are of Jurassic age. The bedrock between the cliffs and the ski lodge is mantled with regolith in which exist scattered terracettes and lobe-like turf-banked terraces at altitudes above 2750 m. Many of the terrace and terracette fronts curve over.

The plant species at Tiffindell indicate that the resort is transitional between the Sub-Alpine Belt (1830-2865 m) and the Alpine Belt (2866-3353 m) vegetation zones that Killick (1963) recognised in the KwaZulu-Natal Drakensberg (Rosen *et al.*,1999). The resort is therefore in an altitudinal zone that is known to be subject to frost action (Hill, 1992).

Landforms developed within the regolith at Tiffindell

A variety of landforms exist within the regolith at Tiffindell, ranging from features of limited magnitude, such as nubbins (Washburn,1973) or ‘cryptogamic soil buds’ (Perez,1996) and small non-sorted and sorted polygons (Washburn,1973; Ballantyne and Harris,1994), through terracettes and turf-banked terraces (Embleton and King,1975), to stone lobes (Lewis,1988b) with fronts that are over 1.3 m high and that are up to almost 17 m wide. Well developed thufa (Schunke and Zoltai,1988) also exist on the plateau above Tiffindell, at altitudes around 2900 m, although they are just outside the boundary of the Resort. Elongated thufa-like mounds exist within the Resort boundary at altitudes around 2770 m on an abandoned ski slope on gradients of 6-9°. Further thufa-like hummocks exist around 2650 m on a slope of less than 4° adjacent to dams below the Resort buildings, where there is a plentiful supply of moisture.

The most obvious features on the slopes above the ski lodge are terracettes, turf-banked terraces and stone-banked lobes. Measurements in 1995/6 of stone-banked lobes, and of clasts on their surfaces, indicated that they are presently inactive. By contrast, terracettes and turf-banked terraces, with their convex (curved-over) fronts, appear to be active under present climatic conditions and are the focus of this paper.

Terracettes

Location

Terracettes at Tiffindell (Figure 3) exist between 2750 m and 2870 m on the south facing slope to the east of the main ski run on a gradient of 23°. West of that ski run they exist between 2790 m and 2880 m on a south east facing slope with a gradient of 26° (Figure 4).

Morphology

The heights of the fronts of terracettes varies between 25 cm and 55 cm and many fronts are vertical or even bulbous. The average width of the treads of 25 terracettes measured in 1994-5 was 70 cm and the angles of the treads varied between 4° and 7°. Many terracette fronts are crescentic in plan and are aligned across, or virtually across, the slope.

Terracette treads at Tiffindell commonly support a grassy cover that ends at the riser of the next terracette on the upslope end of the tread. The dense root network of the grassy vegetation appears to bind the regolith to form a ‘scarp’ along the length of the terracette front. Terracette fronts have a mean length of 1.6 m.

Sedimentology

Analyses of sediments within terracettes shows that they consist of in excess of 60 % of fine sand and silt. According to Beskow (1935), such sediments are highly susceptible to frost action and subject to frost heave.

Movement of terracettes

Visual inspections during 1994-5 indicated that terracettes moved downslope. Unfortunately the restricted depth of regolith within terracettes and the amount of frost heave to which they were subjected during the study period made it impossible to record movement by conventional methods, such as the insertion into terracettes of measuring pins and/or flexible tubes (see the paragraphs on the measurement of movement of turf-banked terraces). No quantitative data is therefore available relating to terracette movement.

Erosional processes affecting terracettes

Needle ice was observed projecting from terracettes on many occasions during the studied winters of 1995/6. After most freeze-thaw cycles, ice needles projected from unvegetated portions of terracette fronts, where their presence was favoured by soil moisture from tread-drainage and from snow melt. Needles grew up to 7 cm long within individual freeze/thaw cycles. The needles contained sediments derived from the terracettes, which was deposited further downslope by gravity fall and other processes when the needle ice melted. In some cases columnar ice needles were separated from other needle ice bands by layers of fine organic and/or inorganic sediment. On one occasion in July 1996 three distinct layers of needle ice development were observed, at 0.5 cm, 0.7 cm and 5 cm distance from the ground surface from which the ice masses projected, separated from each other by fine sediments (cf. Outcalt,1969,1971). During periods of heavy rainfall in 1995 and 1996 surface wash was observed on terracette treads, moving sediment downslope.

Erosional processes related to needle ice appear to be important for the maintenance of terracettes at Tiffindell, causing movement of sediments from terracette fronts to terracette treads further downslope and influencing the steepness of terracette fronts. Similarly, slope wash is important in transporting debris across terracette treads towards terracette fronts. Frost heave and slope wash therefore contributes to the development and maintenance of terracettes.

Turf-banked terraces

Location

Turf-banked terraces at Tiffindell (Figure 5) are located to the east of the main ski run on a south facing slope with gradients between 15° and 26° at altitudes between 2765 m and 2855 m. They also occur to the west of the same ski run on a south east facing slope with gradients between 19° and 28° at altitudes between 2800 m and 2880 m (Figure 4). The terraces form isolated lobe-like features and tend to be confined to linear drainage-ways. Most of the terraces thus exist one below another wherever moisture appears to be channeled downslope.

Morphology

The fronts (‘risers’) of the terraces are crescentic in plan and vary in height from 0.4 m to 1.0 m, averaging 0.75 m. The risers are near vertical or even bulbous, curving-over near their summits. On average, 80 % of each riser is vegetated, whereas the treads tend to be devoid of or are very poorly vegetated. The plants that colonise the risers include the *Helichrysum* species and various grasses, including *Pentaschistis curvifolia, Themeda triandra* and *Harpechloa falx.* The abundant vegetation on the risers has led to the classification of these landforms as turf-banked terraces, a term that Lewis and Lass (1965) used for features of similar appearance in The Faeroes. The widths of eleven turf-banked terraces that were studied in detail in 1995/6 and that were selected to represent both south and south east facing terraces on either side (east and west) of the main ski run, varied from 0.79 m to 3.1 m and averaged 1.69 m.

The lengths of the treads of thirty turf-banked terraces that were measured in 1995/6 ranged from 0.7 m to 3.14 m and averaged 2.07 m. The angles at which treads sloped varied from 2° to 14°, but averaged 6.7°. The median angle was 7°. Treads are almost devoid of vegetation and are often poorly drained. They are subject to frost heave, that was particularly noticeable in the winter of 1996, when markers inserted into terrace treads were heaved by amounts of up to 19 mm. Frost heaving probably inhibits plant colonisation of treads and, combined with poor drainage, may explain why terrace treads are largely unvegetated.

Sedimentary characteristics

The nature of the sediments that comprise turf-banked terraces is indicated on Table 1, which is based on analyses of sediments collected from depths of 0.2 m within the eleven terraces noted above. The sediments consisted mainly of inorganic material that was derived from the basaltic lavas that exist upslope of the terraces.

Table 1: The sedimentary characteristics of turf-banked terraces at Tiffindell

The sedimentary characteristics tabulated on Table 1 indicate that the deposits from all eleven terraces sampled have similar particle size distributions: they are essentially silty sand with some gravel. According to the findings of Beskow (1935) the terraces consist predominantly of sediments that are frost susceptible. The measured Atterberg limits indicate that the sediments are non-plastic, with plasticity indices that do not exceed 14 %. Liquid limits range between 24 % and 28 %, with the higher values corresponding to the upper organic contents (see LOI column). Low plasticity reflects the paucity of clay in the sediments and indicates that the deposits are essentially cohesionless. They are thus likely to be sensitive to changes in water content and susceptible to loss of strength and to flowage when water contents exceed the Liquid Limits. According to the criteria of Harris (1981) the terraces would, on the basis of their composition, be susceptible to gelifluction if wet conditions existed during a thaw subsequent to the sediments being frozen.

Surface movement downslope

The bulbous (curved over) nature of the fronts of many turf-banked terraces at Tiffindell suggests that the terraces are moving downslope. In order to check this observation a series of triangular metal markers was placed on the treads of five terraces, selected so as to represent terraces on either side of the main ski run, in straight lines during June 1995. The triangular base of each marker was 3 mm thick, 150 mm long on each side, and had a 100 mm metal spike projecting downwards from each corner in order to prevent the marker from being dislodged by snowfall, excessive rain, or wind. A 300 mm long central upright metal rod (painted red) was used as an indicator when placing the markers in straight lines.

The markers were inserted into the terrace treads with their bottom edges flush with the surface of each of the selected terrace treads and approximately 20 cm from the front (downslope) edge of each tread. Metal stakes were driven into the ground on either side of the five selected terraces to form ‘permanent’ reference points. Nylon cord was attached to these stakes so as to form a straight line across each terrace tread. The triangular markers were inserted immediately in front of these cords, which acted as guides in aligning the markers and also aided subsequent measurement of the displacement of the markers.

When the original 45 markers were checked in November 1996 only four showed no visible surface movement. Six had been displaced by burrowing animals or, probably, humans. The remaining markers had moved downslope by between 4 and 58 mm (Figure 6). The average surficial downslope movement of all five terraces was 21.6 mm. The average surficial movement of each of the individual terraces is shown on Table 2.

Table 2: Surface downslope movement of turf-banked terraces at Tiffindell between June 1995 and November 1996

Upward displacement of terrace markers

None of the markers inserted in June 1995 had been noticeably displaced upwards by the end of that year. By November 1996 (when they were finally checked), several markers that had been inserted in bare (unvegetated) ground had been displaced upwards by up to 19 mm. The winter of 1996 was colder than that of 1995 (Table 3) with a much higher percentage of Ice Days (days when maximum and minimum temperatures were below 0°C; Table 4). This suggests that frost activity may have been more pronounced within the regolith during the winter of 1996 than in that of 1995,and that the markers had been subjected to frost heave. The lack of upward displacement of markers inserted in vegetated portions of terrace treads suggests that the vegetation insulated the ground, thereby reducing the penetration of frost into the regolith, so that the markers were not apparently affected by frost action.

Subsurface rates of terrace movement

i) Method

Subsurface rates of movement of terraces were measured between June 1995 and November 1996. Eleven flexible polyethylene tubes were inserted into six terrace treads to depths of between 930 mm and 970 mm. The terraces were selected to represent conditions on either side of the main ski run. Each tube was heat sealed at its bottom end prior to insertion into a hole, slightly larger than the tube, that had been made by hammering a metal augur into the respective terrace tread. A thin steel rod was inserted into each tube subsequent to placement of the tubes in their holes. The rods kept the tubes straight while regolith was repacked around the tubes. Once the latter operation was completed the steel rods were removed and the top of each polyethylene tube was heat sealed. The site of each tube was marked with a red pole.

In November 1996, after the tubes had been in place for two winter seasons, six tubes were excavated so as to provide measurements of subsurface movements of the respective terraces. Each excavation extended below the base of the respective tube and left the tube exposed along a vertical face. A vertical plumb line was then dropped from the surface to the bottom of the tube, which was assumed not to have moved since the time of installation. The horizontal distance from the plumb line to the leading edge of the tube was then measured in millimetres to indicate the displacement of the tube from the vertical at various levels.

Of the eleven tubes inserted in 1995, one had been interfered with and removed before November 1996, two were not located due to their surface markers being removed and two were left *in situ* as part of a long-term study of regolith movement at Tiffindell.

ii) Results

Of the six terraces examined, two showed no evidence of movement. At the other four terraces movement was greatest at and immediately adjacent to the surface, where it varied from 11 mm to 3 mm, but declined with depth. The greatest depth at which movement occurred was 130 mm, the other three tubes indicating movement to depths of 40 mm (two tubes) and 70 mm. The tubes that had moved displayed a concave downward shape.

There is obvious disparity between the rates of movement at and near the surface recorded by the tubes and by those indicated by metal markers placed on the surfaces of other terraces (Table 2). Of the five terraces on which the movement of metal markers was recorded, only one apparently moved slower than the fastest rate recorded by tube measurements. Whereas the fastest rate recorded by the metal markers was 44 mm, the fastest rate recorded by the tubes, (assuming that their bases did not move) was 11 mm. Despite these disparities it is evident that turf-banked terraces at Tiffindell actively move downslope under present conditions.

Excavation of a turf-banked terrace in winter and the existence of ice lenses and interstitial ice

Excavation of a turf-banked terrace at an altitude of 2820 m on 7 June 1996 revealed the existence of both ice lenses and interstitial ice (Figure 7). The uppermost 30 mm of the section was composed of roots and saturated sediments. Below this depth the ground was frozen. Four vein-like ice lenses, the greatest of which was 6 mm thick, existed between 30 mm and 120 mm below the surface. Interstitial ice also occurred. A 35 mm thick ice lens existed at a depth of 150 mm and below that was 170 mm of interstitial ice and essentially inorganic sediments. No ice was encountered below 355 mm. Since the section was excavated early in winter it is likely that frost would have penetrated further into the ground later in that season.

Frost heave

An excavation at an altitude of 2720 m in regolith adjacent to the main ski lodge during the winter of 1996, when frost heave of over 4 cm was recorded on a nearby turf-banked terrace tread at an altitude of 2794 m, revealed the presence of ice lenses up to 10 cm thick. It is thus apparent that ice lenses, and possibly other ice bodies, cause considerable frost heave at Tiffindell.

Climatic conditions

In order to ascertain the climatic conditions under which terracettes and turf-banked terraces exist, at least at Tiffindell, two MCS-120 electronic data loggers (MC Systems,1990a) to which temperature and soil moisture probes were attached, were installed in both groups of terracettes and turf-banked terraces that were studied, on either side of the main ski run. Air temperatures were recorded using unscreened MCS 151 series probes 1.2 m above the ground surfaces. Ground and regolith temperatures (at depths of 0.05 m and 0.2 m) were also recorded using similar probes (MC Systems,1990b). Soil moisture was recorded at depths of 0.05 m and 0.20 m below ground level using MCS 159 Nylon Soil Moisture sensors (MC Systems,1990c). One set of probes was attached to the data logger to the west of the main ski run (recording Station A, Figure 4), and two sets of probes (recording Stations B and C, Figure 4) were attached to the data logger to the east of the main ski run. Recording took place between 27 May 1995 and 15 September 1996 with the exception of February to April 1996 and of some limited periods when there were system failures. Station B, at 2788 m, yielded an almost continuous record of temperature and soil moisture conditions throughout the study period.

The extremes of air temperatures recorded at Station B were 26.2°C (14/1/1996) and -12.8°C (16/7/1996). Mean monthly air temperatures varied from 16.3°C (January 1996) to -3.1°C (July 1996). These means were calculated by totalling the maximum and minimum temperatures for each day and halving the result to produce daily means, and then totalling all daily means per month and dividing them by the number of days per month.

The daily range of air temperatures recorded at Station B for the winters of 1995 and 1996 (the months of June, July and August) is shown on Figure 8. The monthly averages for maximum and minimum air temperatures at the same Station are tabulated on Table 3. The winter of 1996 was markedly colder than that of 1995 with 20 Ice Days (when maximum and minimum temperatures were below 0°C) compared with four Ice Days in 1995, and 54 Freeze/Thaw Days (with oscillations of temperatures above and below 0°C) compared with 48 such days in 1995.

Table 3: Average air temperatures (°C) for the winter months of 1995 and 1996 at Station B, Tiffindell

The Mean Annual Air Temperature (MAAT) at Tiffindell, based on the records for Station B, may be of the order of 7.5°C, although seasonal variability, as evidenced on Table 3, and the short length of records at the Resort, renders an accurate statement presently impossible.

Table 4 shows the number of Frost Free, Freeze/Thaw, and Ice Days recorded at Station B during periods of 153 days in 1995 and 138 days in 1996 between May and September of each year.

Table 4: The number and percentage of Frost Free, Freeze/Thaw and Ice Days at Station B, Tiffindell, between May and September 1995 and the same months in 1996

Temperatures were markedly colder during the above months in 1996 than in the previous year. In 1995 substantial snow cover shielded the ground and regolith from prolonged penetration by frost, but air temperatures were also warmer that year than in 1996. In 1996 the ground and regolith at Station B (at least at depths of 0.05 m and 0.2 m) was frozen throughout almost all of July as well as the whole of August, although a rapid thaw took place in early September (Figure 9). The number and percentage of Freeze/Thaw Days was similar at air and ground levels in both years but was markedly less in 1996 within the regolith, which was predominantly frozen in that year.

Temperature investigations at Tiffindell, as evidenced by records from Station B, show that freeze/thaw cycles are common at the Resort. They occur on over 40 % of all days between May and September at air level (1.2 m above the ground surface) and at over 20 % of all days at ground level and at depths of up to 0.2 m within the regolith. No records exist of temperatures at greater depths. Landforms influenced by or even resultant from frost action may therefore be expected at Tiffindell and, presumably, at locations of similar altitude and aspect elsewhere in the Southern Drakensberg.

Soil moisture

Soil moisture, as already stated, was recorded automatically at Stations A-C at Tiffindell during parts of 1995 and 1996. Soil moisture levels for the winters of 1995 and 1996 are presented on Figure 10. Much of the winter precipitation at Tiffindell falls as snow, which normally melts within a few days, resulting in virtually continuous saturation of surface sediments producing high soil moisture percentages, as was the case in mid-August 1995.

During June and July 1995, in which approximately 50 freeze/thaw cycles occurred at air level (1.2 m above the ground) and slightly less at depths of 0.05 m and 0.2 m, soil moisture approximated 50 % at both depths below the surface. As soil moisture sensors record liquid moisture, it could be expected that a sensor in frozen or semi-frozen sediments would record values below 100 % moisture. From the beginning of August, when subsurface temperatures at 0.05 m and 0.2 m depth rose above 0°C, soil moisture percentages increased rapidly, initially at 0.05 m depth and subsequently at 0.2 m depth (Figures 9 and 10). The higher percentage of moisture in the upper layers of the regolith was partly due to snow cover and to moisture associated with its melting. Thawing of the upper regolith was evidenced by 100 % saturation of the regolith at 0.05 m depth. Trapping of ground water above still frozen or partially frozen ground was indicated by the 0.05 m level being typically 20 % more saturated during August than the 0.2 m level.

During the winter of 1996 (June/August) soil moisture levels were initially higher than in 1995, but fell rapidly at the depth of 0.05 m in the latter part of June as temperatures at that depth descended below 0°C. The reduction in soil moisture at a depth of 0.2 m was less rapid, reaching a minimum of just under 60 % in late July. As air and ground temperatures increased rapidly in late August so, too, did soil moisture levels, presumably as frozen ground thawed.

In both 1995 and 1996, as temperatures rose after the rigours of winter, soil moisture at the 0.05 m and 0.2 m depths reached 100 %. Under these saturated conditions the upper portion of the regolith, at least, would have been susceptible to soil flowage. Soil moisture levels declined below 100 % during the warmer post-winter seasons of 1995 and 1996. The high soil moisture levels, particularly towards the end of winter in both years recorded, and at the onset of winter in 1996, would have been conducive to ice formation within at least the upper regolith on those occasions when temperatures fell below freezing. Soil moisture at depths below 0.2 m has not been recorded at Tiffindell.

Discussion

i) Terracettes

Terracettes at Tiffindell exist within narrow altitudinal limits: 2750 m to 2880 m, which suggests that they are climatically sensitive landforms. They are associated with needle ice which, in the studied winters of 1995/6, was noted as being concentrated at terracette fronts. Needle ice raises sediments above the ground surface as ice crystals grow, but releases sediments to fall downslope by gravity as the ice needles melt. The sediments are then ready for reworking by other processes.

French (1996, 137) states that ‘Needle ice formation is particularly common wherever wet, silty frost-susceptible soils are present.’ The regolith within which terracettes exist at Tiffindell consists mainly of fine sand and silt and is therefore frost susceptible. Freeze/thaw cycles at ground level also occurred on over 20 % of all days from May to September in 1995 and 1996, the years for which records exist. The combination of fine sand and silt sediments, appreciable soil moisture and multiple freeze/thaw cycles thus renders the Tiffindell area highly susceptible to needle ice development especially since, as Grab (2001) has already shown from the Lesotho Drakensberg, needle ice can develop and melt within one freeze/thaw cycle as long as ground temperatures descend to or below -0.4° C.

The regolith at altitudes immediately below 2750 m at Tiffindell is not discernibly different from that in which terracettes occur between 2750-2880 m, neither is there any apparent difference in soil moisture or slope angles. There is thus no obvious reason for the lack of terracettes below 2750 m, except for temperatures, which are probably higher below 2750 m than above that altitude. At altitudes above 2880 m the regolith tends to be thinner and slope angles increase compared with conditions below that level. The lack of terracettes above 2880 m may be due to slope gradient and regolith factors, as well as to associated soil moisture and air, ground and sub-surface temperatures.

Heavy convection showers (such as are associated with the thunderstorms that are characteristic of Tiffindell during summer months), as well as surface saturation following thaws, provided surface runoff that, in 1995 and 1996, was seen to transport sediments downslope, across the treads of terracettes.

The combination of needle ice development and decay (which is usually a diurnal event in the colder months at Tiffindell), causes erosion particularly of terracette fronts, where moisture is most plentiful for needle ice development. The eroded material is subsequently moved downslope by surface wash and possibly by other processes. When the finer sediment is dry it may also be moved by aeolian processes.

Terracettes elsewhere in southern Africa have been studied in some detail in KwaZulu-Natal. The size of terracettes reported from that Province by Watson (1988) is considerably larger than those at Tiffindell and some of them may therefore be of different origins. Watson (1988) suggests that terracettes are initiated by a variety of processes: soil slippage, soil flow, soil creep. Garland (1987) suggests that shear failure and sheet wash erosion are important initiating processes. West (1951) postulated that they originate as a result of water-saturated soil slippage over underlying rock. De Villiers (1962) favoured shear failure. Granger (1976) suggested that vegetation changes due to an increase in the frequency of dry-season fires, as a result of human influence in the Drakensberg, affected rooting levels as grassland replaced deeper rooting (possibly fynbos) plants. This, in turn, caused slopes to exceed their angles of repose. As slopes adjusted to new rooting levels so, he suggested, terracettes developed due to soil creep. On a more global scale Clarke (1976) has also postulated that vegetation changes are important in terracette formation. The weight of animals on slopes has also been held responsible for terracette formation (Watson,1988) as, in Lesotho, has intensive grazing by domestic animals combined with frost (needle ice) action (Hastenrath and Wilkinson, 1973). Killick (1963) suggested that terracettes are polygenic features, formed by accumulation of debris upslope of grass tussocks as a result of slope wash, with erosion associated with needle ice steepening the down slope side of the debris accumulation. Harper (1969) supported Killick's suggestion. Troll (1944) suggested that terracettes in the Mont aux Sources area of KwaZulu-Natal resulted from water saturation of the regolith and/ or by frost action causing solifluction.

Rosen *et al.* (1999) have shown, through palynological analyses of organic-rich sediments from Tiffindell, that there has been little change in the vegetation at the resort since somewhat before 2700 radiocarbon years BP. The hypotheses of Granger (1976) and of Clarke (1976) are thus unlikely to apply at Tiffindell.

Tiffindell has not been grazed by appreciable numbers of animals for at least a decade, so animal treading is unlikely to contribute towards at least the maintenance, if not the initiation, of terracettes there.

The vegetation that grows along the top of terracette scarps at Tiffindell appears to exist there because scarp tops are better drained than the adjacent treads and are thus less susceptible to frost heave, which may damage or even break roots. There is no evidence that vegetation spread upslope from grass hummocks or that sediments accumulated upslope of such tussocks to form terracette treads. Killick's suggestion (1963), that grass tussocks were responsible for terracette initiation, has not been substantiated by observations at Tiffindell.

Watson (1988) states that, in the Cathedral Peak area of the KwaZulu-Natal uplands that she studied, the density of terracettes is greatest '... on the driest shallowest soils with the highest clay content'. Her findings thus contradict the suggestion of West (1951) relating to terracette formation in that the driest soils are unlikely to be water-saturated. The regolith in which terracettes occur at Tiffindell is moist, at least when post-winter thawing occurs. The regolith may then be susceptible to soil slippage although it is more likely that debris flows (Rapp and Nyberg, 1981) would occur under those conditions, rather than terracettes.

Summary

Terracettes at Tiffindell are apparently climatically sensitive landforms, owing their existence to essentially diurnal freeze/thaw cycles, the presence of sufficient moisture for needle ice development and to surface wash. They may thus, as frost sensitive landforms, be considered as elements of the periglacial landscape. The way in which terracettes originate, at least at Tiffindell, is unknown but is probably frost-related. The narrow altitudinal limits in which terracettes exist at Tiffindell is probably a reflection of micro-climatic and soil moisture conditions.

ii) Turf-banked terraces

Turf-banked terraces at Tiffindell occur between 2765 m and 2880 m. They exist at slightly lower altitudes on a south facing slope than on a south east facing slope. South facing slopes in the Drakensberg receive less insolation than south east facing slopes (Granger and Schulze, 1977). Comparison of temperature data from Stations A and B, on south east and south facing slopes respectively, confirms that at Tiffindell the south facing slope is colder than that which faces south east. There is no obvious difference in slope angles or in the regolith immediately above and below the altitudes at which turf-banked terraces occur at Tiffindell, which suggests that their absence below 2765 m is due to climatic or, as suggested below, soil moisture factors. Bedrock outcrops above the upper altitudinal limits of the turf-banked terrace zone so that, since these terraces are landforms developed in regolith, the bedrock outcrops form the upper limit of the turf-banked terrace zone.

Turf-banked terraces at Tiffindell tend to be confined to linear drainage-ways that are aligned basically up and down slope. This indicates that the terraces are moisture dependent landforms and that there is insufficient moisture at suitable sites elsewhere at Tiffindell for their existence.

The presence of ice lenses and of interstitial ice within a terrace that was excavated in winter, and the already presented evidence of frost heaving, suggests that frost action plays an important role in the existence of turf-banked terraces. The initiation and growth of ice lenses (and to a lesser extent of interstitial ice) is dependent upon an adequate supply of moisture. Hence the existence of terraces predominantly along drainage-ways, where moisture is more plentiful than elsewhere.

Freezing of moisture within the regolith is known to occur to depths of at least 355 mm in turf-banked terraces at Tiffindell. The resultant ice causes displacement of sediments, both vertically (by frost heave) and laterally. Down slope movement of sediments at Tiffindell has been recorded to depths of at least 130 mm in one turf-banked terrace and 70 mm in another. Downslope movement of the surfaces of turf-banked terraces of up to 58 mm was recorded over an 18 month period in 1995/6. At least part of such movement, as indicated by distortion of tubes inserted into terraces and later exhumed, was due to frost creep (see below).

The thawing of frozen ground within the regolith also appears to be important for the existence of turf-banked terraces at Tiffindell. As the ground thaws it apparently does so from the surface downwards. Soil moisture thus becomes concentrated between the ground surface and the top of the thawing regolith. As a consequence, during post-winter thaws soil moisture at 0.05 m and 0.2 m depths has been recorded as 100 %. (No measurements have been made at greater depths). Such saturation is conducive to movement of at least the upper portion of the regolith by processes such as flowage.

Tubes inserted in turf-banked terraces at Tiffindell in 1995 were subsequently bent by sediment movements so as to be concave downward. This is a feature associated with frost creep (Matsuoka, 1994), with creep and compressive shearing in soliflucting sediments (Benedict, 1970; Smith,1992) and with laminar flow associated with gelifluction. (French,1996). Gelifluction is '...the form of solifluction associated with either seasonal or perenially frozen ground' (French,1996,152).Deformation of the upper parts of tubes was also typical of deformation caused by flowage of solifluction sediments (Gorbunov and Seversky, 1999).

French (1996,152) maintains that 'Conditions suitable for gelifluction occur in areas where downward percolation of water...is limited by the frozen ground and where the melt of segregated ice lenses provides excess water which reduces internal friction and cohesion in the [regolith]. Gelifluction is essentially a process operating mainly during the thaw period.' This is precisely what appears to happen at Tiffindell. During winter the regolith, in which turf-banked terraces exist, freezes. During post-winter and other thaws the uppermost part of the regolith, above the frozen layer, becomes saturated with moisture and moves downslope in laminar fashion. Evidence of such movement is provided by the tubes that were inserted into turf-banked terraces at Tiffindell in 1995 and by the surface markers placed on terrace treads that year.

Gelifluction is known to occur in sediments that are matrix-supported, the matrix consisting of clay, silt or silty sand that generally has low liquid limits and plasticity (Harris, 1987; French,1996). The regolith in which turf-banked terraces exist at Tiffindell consists essentially of silty sand and has low liquid limits and low plasticity. These are suitable sediments for the development of gelifluction.

All the evidence thus far presented indicates that turf-banked terraces at Tiffindell are landforms of gelifluction and that they accord with the already quoted definition of that process by Lewkowicz (1988,335) as ‘solifluction associated with seasonally or perenially frozen ground’. Solifluction is sometimes considered to be the same as gelifluction and to involve the movement of thawed sediments over frozen ground (Matthews and Frenzel, 1993), frost creep (Ballantyne,1993), or even all soil-movement processes resulting from freezing and thawing (Graf, 1993). Such forms of ‘solifluction’ do not accord with the original definition of the term by Andersson (1906,95) as ‘the slow flowing from higher to lower ground of masses of waste saturated with water (this may come from snow-melting or rain)’.

Active solifluction (which may not necessarily be gelifluction), has been reported from the Drakensberg/Lesotho highlands by Hastenrath and Wilkinson (1973) from altitudes around 3200 m in Lesotho, as in the region of Mahlasela Hill near Ox Bow; by Dardis and Granger (1986) from about 3000-3200 m in the Nkosazana valley near Champagne Castle in KwaZulu-Natal; and by Lewis (1988a) from altitudes between 2800 m and 3000 m on the slopes of Ben MacDhui in the Tiffindell area of the Eastern Cape.

Active gelifluction, in the form of turf-banked lobes at about 3000 m, was reported by Dardis and Granger (1986) from the Nkosozana valley and by Boelhouwers (1994) from altitudes between 3140 m and 3300 m near Giant’s Castle in KwaZulu-Natal. Boelhouwers (1994,135) described ‘Thin stone banked sheets’ resulting from ‘active frost creep and gelifluction’. He referred to them as gelifluction sheets and stated that they are ‘some tens of metres in both width and length’, with ‘Small lobate fronts up to 0.5 m high’. He stated that they ‘result from active frost creep and gelifluction’. Boelhouwers (1994) stated that there was seasonal frost penetration to a depth of 0.2 m in the gelifluction sheets, although this statement appears to have been based on the ‘maximum depth of sorting’ in the sediments within the supposedly gelifluctional sheets, rather than on instrumental measurements.

None of the above authors presented measurements of rates of movement in the supposedly gelifluction deposits, nor details of temperatures above, at or below the surface of the regolith, or of soil moisture, except for Boelhouwer’s (1994,135) statement of ‘seasonal frost penetration to 0.2 m depth’. Neither have they provided details of the particle size, liquid limits or plasticity of the matrix within the deposits. The gelifluctional character of the landforms has thus been assumed from surface morphology and sediment stratigraphy rather than from process studies. Nevertheless Grab (1997) has presented instrumental measurements from the Mashai Valley in the Lesotho highlands region of the Drakensberg, adjacent to KwaZulu-Natal, that showed that mean monthly air temperatures at an altitude of about 2950 m were below freezing during the three winter months (June-August) of 1994. This suggests that gelifluction could occur, given the provision of suitable slope angles, sediments and soil moisture, in the high Drakensberg.

Summary

Unlike previous studies of supposedly gelifluctional features in the Drakensberg, this paper presents climatic, soil moisture, surface and sub-surface movement data that shows that turf-banked terraces at Tiffindell are active gelifluction terraces. The restricted altitudes within which the features exist at Tiffindell probably reflects the narrow altitudinal limits within which climatic and soil moisture conditions there are suitable for gelifluction.

Conclusion

Climatic, sediment, slope and soil moisture conditions at Tiffindell result in the presence of active turf-banked gelifluction terraces, particularly along drainage-ways, at altitudes between 2765 m and 2880 m. Active terracettes occur between 2750 m and 2880 m but on slopes that may have less soil moisture content than those in which turf-banked terraces exist. Terracettes apparently exist due to processes associated with needle ice, surface wash and possibly creep. They are located on slopes that appear to be too dry for the development of gelifluction.

Terracettes and turf-banked terraces at Tiffindell are both periglacial landforms, owing their existence at least partially to frost action on slopes of lesser and greater soil moisture content respectively. The claim of Lewis (1988b,105): 'that a limited range of periglacial phenomena [is] active at high levels in the [Drakensberg] at present', is therefore substantiated.

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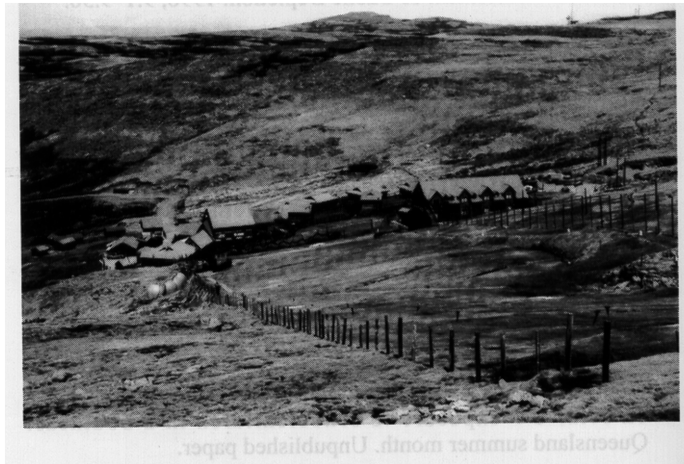

Figure 1: The main ski slope and buildings at Tiffindell Ski Resort, September 2001. The turf-banked terraces shown on Figure 5 are located to the left of the small valley beside the tanks shown alongside and mid-way down the ski slope. The terracettes shown on Figure 3 are located on the cleared slope near the row of fencing poles on the upper right of the photograph.

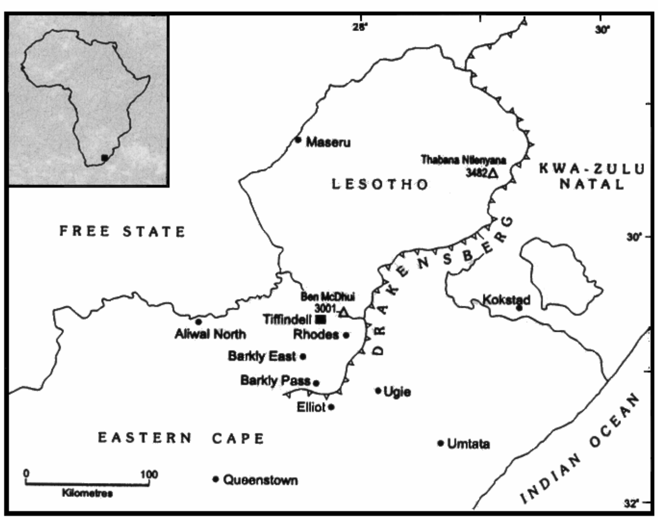

Figure 2: The location of Tiffindell Ski Resort in the Drakensberg of Eastern Cape Province, South Africa. Altitudes in metres.

Figure 3: Terracettes at Tiffindell formed on an area cleared in 1998 for a ski run and photographed in September 2001. The tape measure is 65 mm wide.

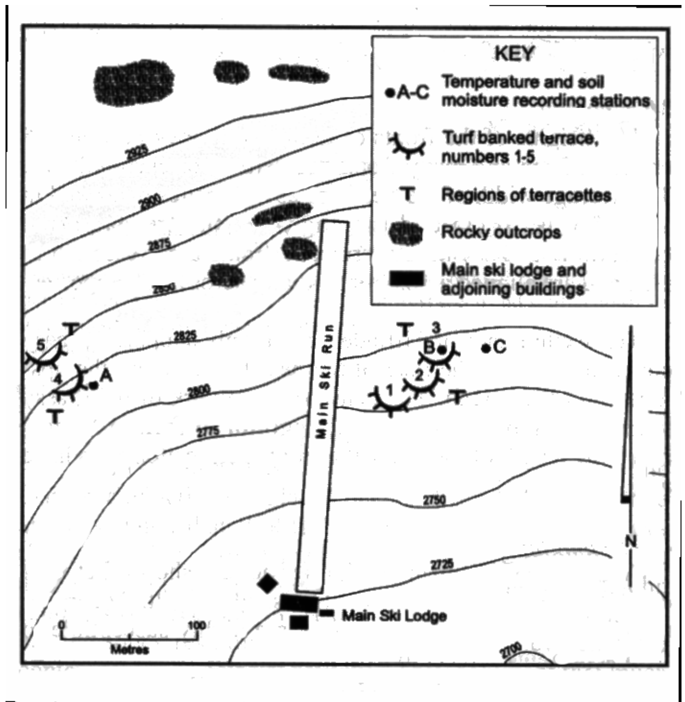

Figure 4: The location of turf-banked terraces (1-5), the movement of which has been measured (Table 2);of the general location of terracettes (T) and of temperature and soil moisture Stations (A-.C) at Tiffindell Ski Resort. Contours in metres. Only selected Resort buildings are shown.

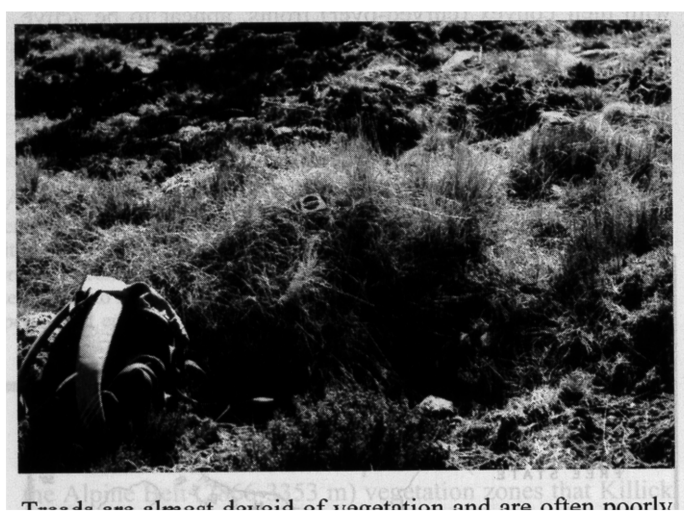

Figure 5:A turf-banked terrace showing the vegetated riser behind the rucksack, which rests on the tread of the next terrace downslope. Contrast the well vegetated terrace front with the sparsely vegetated terrace tread. The tape measure (on the terrace front) is 65 mm wide.

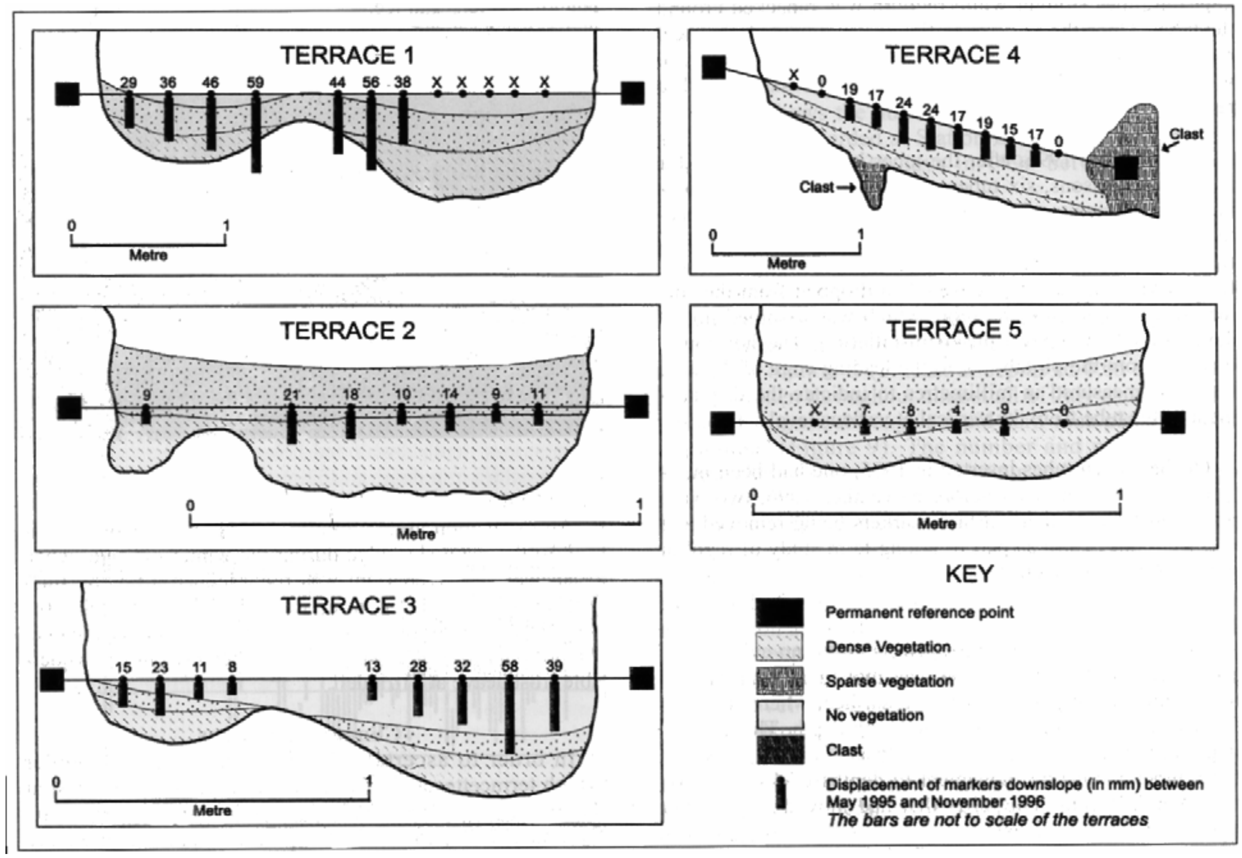

Figure 6: Surficial movements of turf-banked (gelifluction) terraces 1-5 (see Figure 4) between May 1995 and November 1996. Displacement of markers (denoted by black bars) is measured in millimetres as shown above each bar. The bars are not to the scale of the terraces. The bars indicate the amount rather than the direction of movement. The terraces were located at altitudes between 2770 m and 2835 m.

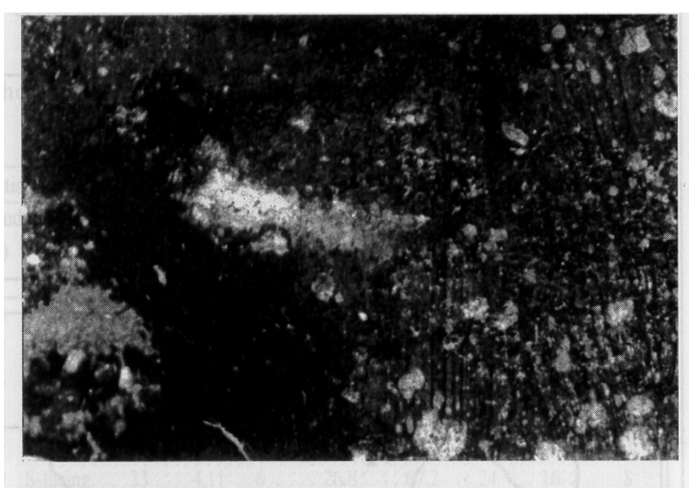

Figure 7: Thirty five millimetre thick ice lens within a turf-banked (gelifluction) terrace at a depth of 150-185 mm below the surface, exposed by excavation in June 1996. Notice the surrounding interstitial ice.

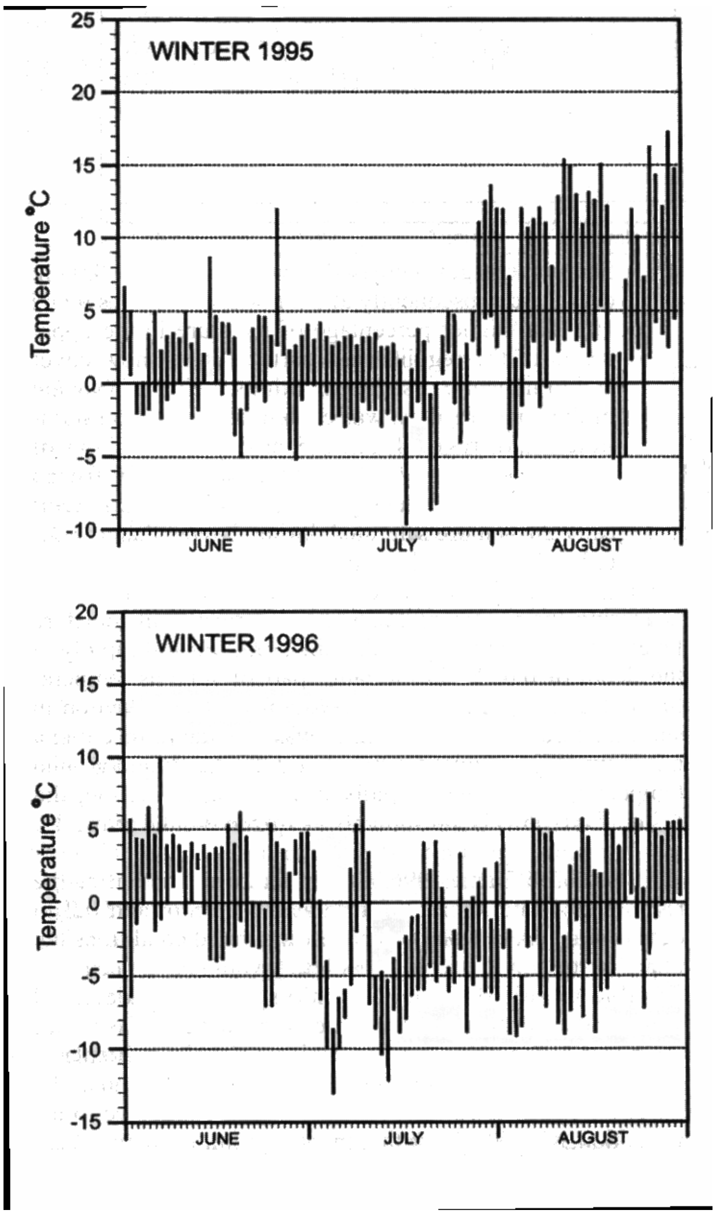

Figure 8: Daily range of air temperatures at Tiffindell during the winter months (June-August) of 1995 and 1996 at Station B, at an altitude of 2788 m.

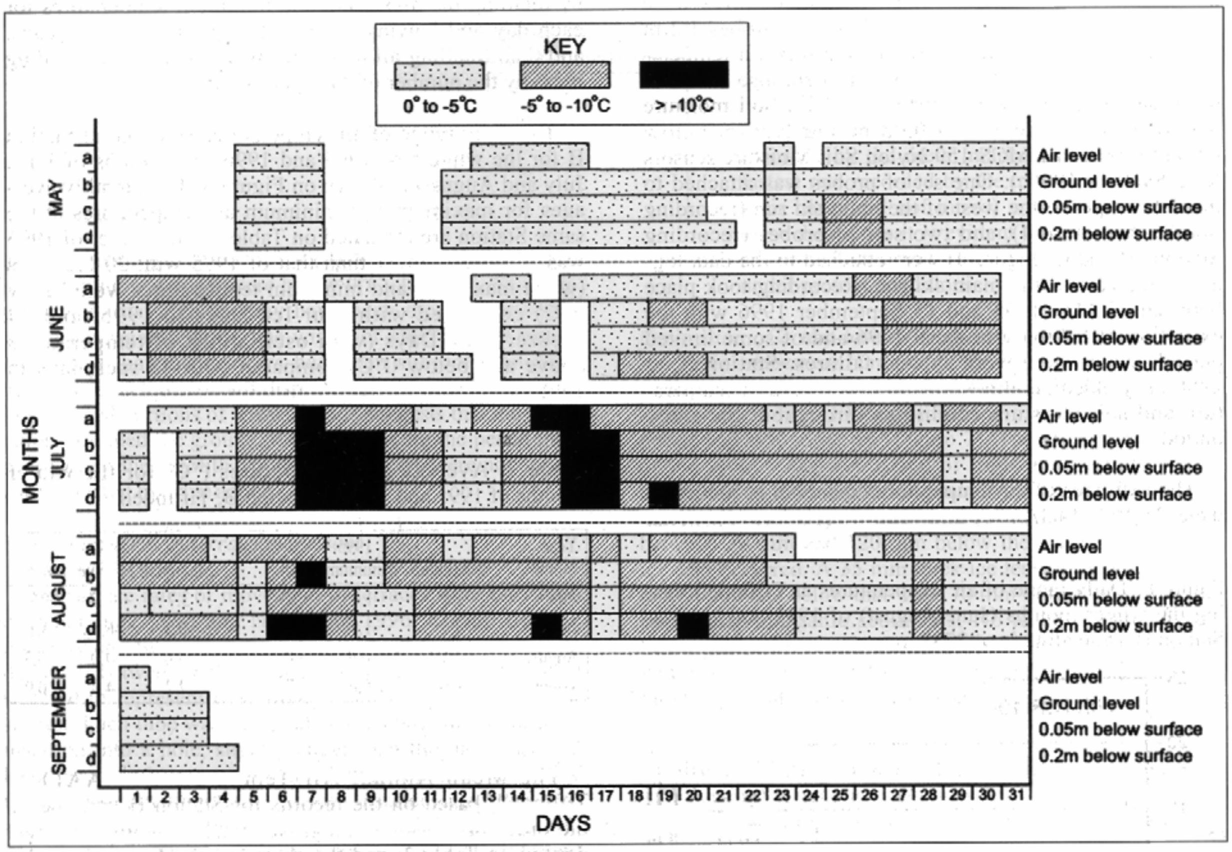

Figure 9: Duration and intensity of freezing at Tiffindell in the air; at ground level; at 0.05 m below the ground surface; at 0.2 m below the ground surface, at Station B (2788 m) during the winter of 1996.

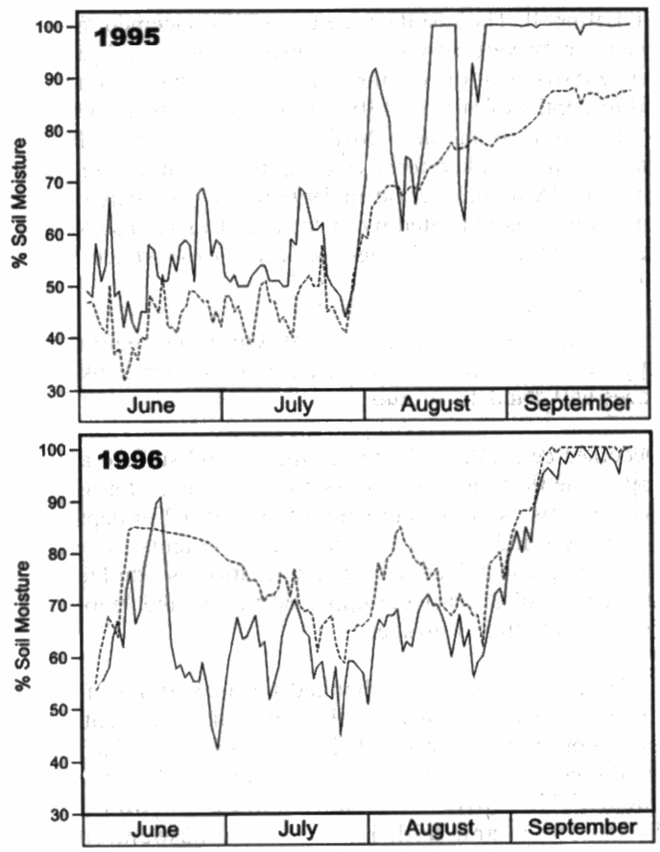

Figure 10: Daily percentages of soil moisture at 0.05 m (solid line) and at 0.02 m (dashed line) at Station B at Tiffindell at an altitude of 2788 m during the winters of 1995 and 1996.

TABLE 1: The sedimentary characteristics of turf-banked terraces at Tiffindell

Locational characteristics				Physical characteristics						
Terrace No.	Altitude (m)	Aspect	Gradient (Degrees)	LOI %	%Clay <0.002 mm	%Silt >0.002- >0.063 mm	%Sand+Gravel >0.063 mm	Liquid Limit %	Plastic Limit %	Plasticity Index %
1	2770	S-facing	20	4.91	5.9	31	63.1	25	11	14
2	2777	S-facing	23	4.3	6.3	27	66.7	24	15	9
3	2786	S-facing	22	6.2	4.4	39.4	56.2	26	19	7
4	2825	SE-facing	25	8.42	4.1	22.3	73.6	28	19	9
5	2835	SE-facing	21	6.11	8	24	68	26	15	11
6	2799	S-facing	23	4.11	6	26.8	67.2	24	16	8
7	2789	S-facing	22	6.53	4.2	40.8	55	27	20	7
8	2790	S-facing	22	5.96	4.1	36.5	59.4	26	15	11
.9	2813	SE-facing	24	4.16	5.4	31.6	63	24	16	8
10	2826	SE-facing	25	7.27	3.6	21.9	74.5	27	18	9
11	2834	SE-facing	21	4.86	7.1	23.5	69.4	25	15	10

LOI= Loss on ignition

TABLE 2: Surface downslope movement of turf-banked terraces at Tiffindell between June 1995 and November 1996

Terrace No.	Altitude (m)	Slope angle (°)on which terrace exists	Tread angle (°)	Overall (average) surface movement (mm) over18 months
1	2770	20	2	44
2	2777	23	4	13
3	2786	22	4	25
4	2825	25	7	19
5	2835	21	5	7

TABLE 3: Average air temperatures (°C) for the winter months of 1995 and 1996 at Station B, Tiffindell

Year	1995			1996		
Month	Maximum	Minimum	Mean	Maximum	Minimum	Mean
June	3.5	-1.0	1.25	3.7	-2.2	0.75
July	3.5	-1.9	1.6	-0.3	-6.0	-3.1
August	11.0	0.9	5.0	3.4	-4.0	0.3
Winter	6.0	-0.6	2.7	2.2	-4.0	0.9

TABLE 4: The number and percentage of Frost Free, Freeze/Thaw and Ice Days at Station B, Tiffindell, between May and September 1995 and the same months in 1996

Year	1995			1996		
Condition:	Frost Free	Freeze/Thaw	Ice Day	Frost Free	Freeze/Thaw	Ice Day
Air:	82 (53.3%)	62 (40.5%)	9 (6%)	39 (28%)	65 (47.5%)	34 (24.5%)
Ground:	95 (61.5%)	34 (22.5%)	24 (16%)	30 (22%)	34 (24.5%)	74 (53.5%)
-0.05 m:	98 (64%)	45 (29.5%)	10 (6.5%)	26 (19%)	34 (24.5%)	78 (56.5%)
-0.2 m:	92 (60%)	43 (28%)	18 (12%)	24 (17%)	32 (23.5%)	82 (59.5%)