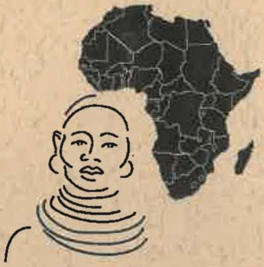
# CASE STUDIES
# IN THE GIANT'S CASTLE GAME RESERVE

Edited by Paul Sumner



SoSAG / SAAG / SAPG Field Guide for the International Conference on
*Environment and Development in Africa: an Agenda and Solutions for the 21st Century*
Post-Conference Excursion, Injasuti Valley, 4-6 July, 1997

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CASE STUDIES

## Preface

The KwaZulu Natal Drakensberg is an important natural and recreational resource in southern Africa. The area is of geomorphological, botanical and biological significance and includes the upper regions of the major catchments in KwaZulu Natal, thus providing water to the region and to regions of the Highveld. Tourism to the area is controlled by the Natal Parks Board and aside from the natural beauty the rock paintings are an important attraction and cultural inheritance. From a geomorphological perspective, the region provides important sites for investigations into periglacial activity, palaeoenvironmental studies and contemporary fluvial and slope processes.

Detailed geomorphological mapping and description of geomorphic processes operative in a region of the Giant's Castle Game Reserve has previously been undertaken (Boelhouwers, 1988; 1992) and utilised as a field guide to the area. These investigations highlighted the need for more detailed quantitative analysis of specific landforms. For these reasons this field guide will focus on three case studies conducted in the area. The participants will be introduced to two study sites in the Injasuti valley; firstly, Battle Cave, where long-term monitoring of the deterioration of rock art has been undertaken, and secondly a series of fluvial terraces which appear to provide some indication of palaeoenvironmental conditions in the upper region of the catchment. On route to these sites discussions will include issues relating to footpath erosion and a case study conducted in the region near the Main Camp.

The contributors trust that this field trip will stimulate further discussions on the general geomorphology and slope processes of the region and as such encourage further research in the area.

Paul Sumner

## Introduction

The KwaZulu/Natal Drakensberg is a part of the Main Escarpment which extends from the Eastern Cape through KwaZulu/Natal and into the Free State (Fig. 1). The Main Escarpment separates the coastal lowlands from the interior plateau of southern Africa and forms an enormous horseshoe-shaped step at distances ranging from 50km to 500km inland from the coast (King, 1982). Giants Castle Game Reserve is located in the central region of the KwaZulu Natal Drakensberg and consists of two camps; the Main Camp and the Injasuti Camp. The topography of the Reserve can be divided into three zones: the Little Berg, Escarpment and Lesotho Plateau (Fig. 2). Peaks on the escarpment reach up to above 3400m and the valley floors in the Little Berg extend down to 1500m. Two main tributaries drain the Reserve; the Bushman's River and the Injasuti River. These are tributaries drain to the northeast and in to the Tugela River catchment.

The history of the area prior to the turn of the century is poorly documented, but the area which is now the Reserve was mostly uninhabited with the Amahlubi tribe who have resided on the fringes of what is now the Reserve boundary. The 1849 'rebellion' by Chief Langalibalele of the Amahlubi prompted Major Durnford of the Natal Carbineers to establish, in the mid 1870's, a base near what is now the Main Camp (Pearse, 1987). Some of the passes including the Ka-Langalibalele Pass and Giant's pass were dynamited, ostensibly to prevent Langalibalele escaping into Lesotho with his cattle. Bushmen (San) are also known to have inhabited the area and have left numerous rock paintings, particularly in the Clarens Formation Sandstones.

The original homestead in Giant's Castle Game Reserve was built when the Reserve was established in 1903 and the Main Camp was subsequently developed closely upstream of it. During the first half of the 1900's cattle were farmed in the Game Reserve by Natal Parks Board staff and these were gradually phased out in the late 1960's and early 1970's. Horses were used extensively by the Reserve Management and may have numbered up to 80-100 at any one time in the late 60's, but were slowly reduced in numbers due to the increasing reliance on motorised transport. A number of jeep tracks were built in the early 1950's which provided access to the more remote areas of the Reserve and a link road was made to Loteni (south of Giant's). Most of the jeep tracks were progressively closed until the late 1970's and some rehabilitation of these tracks was attempted (Meiklejohn, *pers. commun*). There were a number of wattle woodlots located near the Main Camp and these were slowly removed after 1972. A burning programme was implemented when the Reserve was established and has been in operation since, on a biannual burn.

This field guide comprises an introduction to the environmental setting of Giant's Castle Game Reserve and three case studies conducted in the Reserve. These case studies include:

1) an assessment of the role of moisture on weathering of the rock art at Battle Cave in the Injasuti valley and preservation implications, by Ian Meiklejohn;
2) monitoring and assessment of footpath erosion near the Main Camp by Paul Sumner, and
3) an analysis of fluvial terraces in the Injasuti Valley by Sarah Currie.

For a detailed description and interpretation of the geomorphological features in Giant's Castle Game Reserve readers are referred to Boelhouwers (1988; 1992).

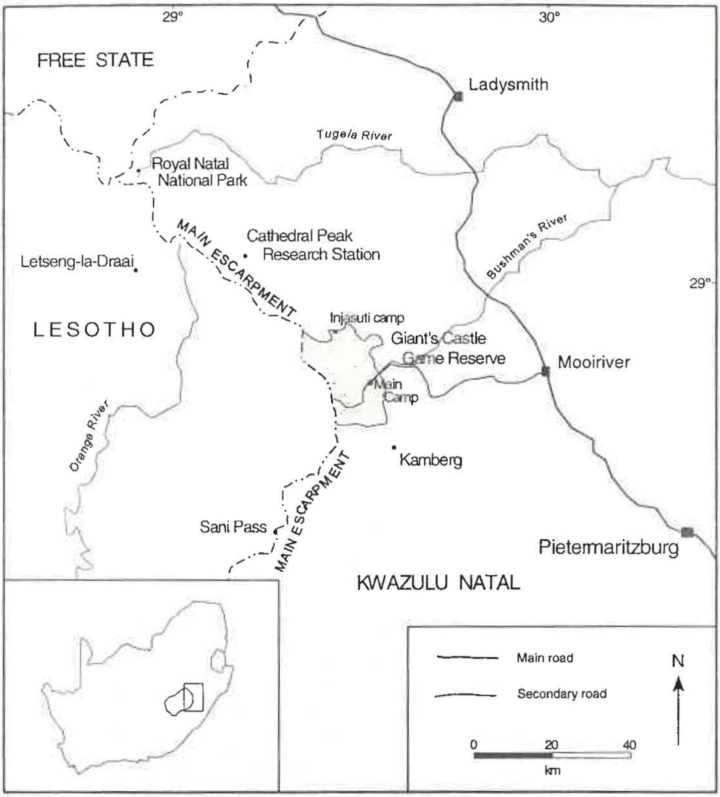

Figure 1. Location of Giant's Castle Game Reserve

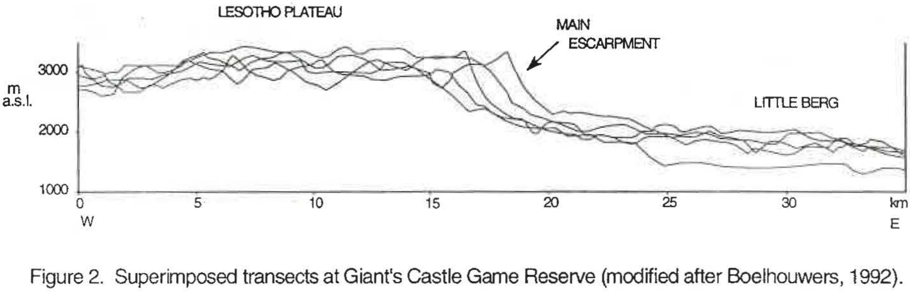

Figure 2. Superimposed transects at Giant's Castle Game Reserve (modified after Boelhouwers, 1992).

## Environmental Setting

### Geology

The stratigraphy of the Drakensberg is characterised by a concordant sequence of sedimentary strata which are overlain by basalts and intruded by a lattice of dolerite sills and dykes (Table 1, Figure 4). The Upper Beaufort Subgroup, exposed at between 1500m and 1590m in the Bushman's River valley floor, is the lowermost member of the Karoo Supergroup to outcrop in Giant's Castle Game Reserve (Boelhouwers, 1988). It consists of fine-grained to medium-grained yellowish feldspathic sandstones, alternating with thicker members of red or maroon coloured mudstones and blue-green shales. The Beaufort-Molteno stratigraphic contact is readily distinguished whereas the Molteno-Elliot and Elliot-Clarens contacts are gradational and therefore exact stratigraphic boundaries of the formations are difficult to define (Du Toit, 1954; Haughton, 1969; Eriksson, 1983).

| SUPERGROUP | GROUP | SUBGROUP / FORMATION | AGE |
|---|---|---|---|
| Karoo Supergroup | Drakensberg Group (volcanics) | | Upper Triassic - Lower Jurassic |
| | (No group name) | Clarens Formation | Upper Triassic |
| | | Elliot Formation | Upper Triassic |
| | | Molteno Formation | Middle Triassic |
| | Beaufort Group | Upper Beaufort Subgroup | Lower Triassic |
| | | Middle Beaufort Subgroup | Lower Triassic |
| | | Lower Beaufort Subgroup | Upper Permian |

Table 1. Stratigraphy and ages of the upper part of the Karoo Supergroup (modified after Eriksson, 1983).

The Molteno Formation is characterised by light-coloured, fine to course-grained sandstones which display argillaceous beds and lenses. These grade upwards into deposits of the Elliot Formation which display subordinate sandstone lenses set in massive red siltstones and mudstones. The Clarens Formation (previously known as the Cave Sandstone) overlies the Elliot Formation and consists of pale, fine sandstones with subordinate argillite layers and lenses (Du Toit, 1954; Eriksson, 1983). By comparison the contact of the Clarens Formation with the Drakensberg Basalts is quite distinct. Small lenses of volcanics are occasionally found within the Clarens Formation sandstones and low grade contact metamorphism has often affected the upper few metres of sandstone (Eriksson, 1983). The Clarens Formation constitutes the upper part of the majestic cliffs surrounding the Injasuti campsite. These are overlaid by basalts with the contact visible at the Lower Injasuti cave. The basalts consist of numerous individual lava flows, generally attaining a total thickness of over 1350m (King, 1982) and up to 1800m at Sani Pass (Dunlevey *et al.*, 1993). Secondary minerals of calcite, chalcedony, zeolite and analcime are common in amygdales (Brink, 1983) with a distinct zonal distribution (Dunlevey *et al.*, 1993). A summary of the lithologies of the upper stratigraphic sequences of the Karoo Supergroup is shown in Table 2 and the geological distribution of the Injasuti area is shown in Figure 3.

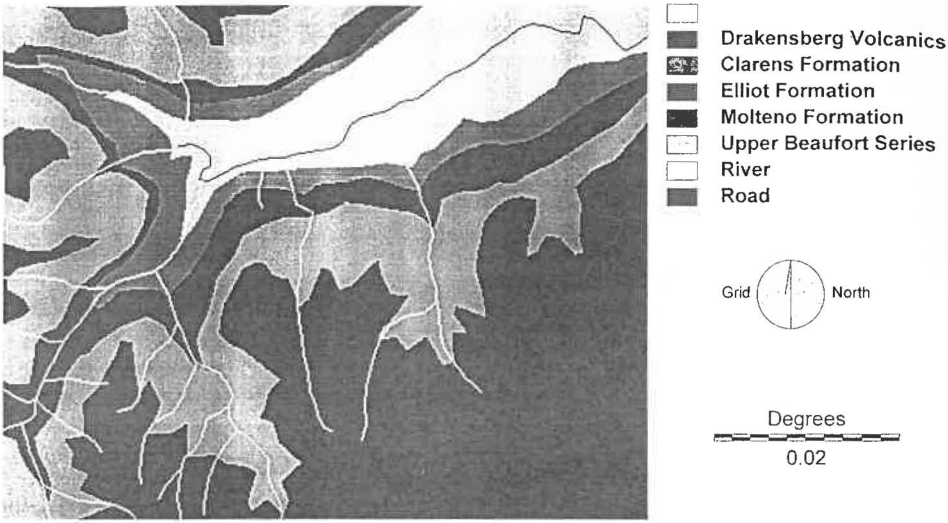

Figure 3. Geology of the Injasuti valley near Battle Cave.

| GROUP | FORMATION | LITHOLOGY | THICKNESS | ALTITUDE |
|---|---|---|---|---|
| Drakensberg | - | basalt | 1350m | >1880m |
| No group name | Clarens | sandstone | 120m | 1720 - 1880m |
|  | Elliot | red siltstone and mudstones/ sandstone lenses | 50 - 80m | 1630 - 1720m |
|  | Molteno | sandstones/mudstones/ shales | 7 - 20m | 1600m |

Table 2 Characteristics of the upper stratigraphic sequences of the Karoo Supergroup found in Giant's Castle Game Reserve (modified after Boelhouwers, 1992).

## Geomorphological evolution

The earliest interpretation of the Main Escarpment (the dominant feature of the Drakensberg) was that of a huge fault (Suess, 1904). Such interpretation was refuted by Penck (1908) who suggested it to be the product of scarp retreat. This theory was extended by Dixey's (1942) proposal of four erosion surfaces and the later recognition by Fair and King (1954) of three surfaces caused by cycles of erosion initiated by intermittent uplift since the Triassic, with parallel retreat of slopes. King (1976) later concluded that five datable surfaces exist. Five stages of uplift were identified, the late Pliocene stage of uplift hypothesised as giving rise to a rejuvenation of streams in the Little Berg (King, 1982). Not all researchers agreed with these earlier interpretations. King was criticised for a lack of empiricism and objectivity (Young, 1972; Le Roux, 1991). Problems emerged with the dating and correlating of surfaces over extensive areas (De Swart and Bennet, 1974; Summerfield, 1985) and Birkenhauer (1985) proposed structural control as the cause of the distinctly stepped topography. Simultaneously, a number of general problems associated with the application of denudation chronology in landscape interpretation emerged (Chorley *et al.*, 1984; Selby, 1985). Ollier and Marker (1985) alternatively suggest that the Escarpment was initiated by erosion on the downwarped continental margins to the base level of the newly emerging coastline. In response to the confusion of geomorphological interpretation a re-evaluation of the geomorphological history of the subcontinent was undertaken by Partridge and Maud (1987).

Partridge and Maud (1987) interpreted the mountainous regions above the Great Escarpment as being unrelated to particular phases of erosion, in contrast to King's reference to a Gondwana surface, although generally discrete phases of erosion can be identified. The oldest surface identified by Partridge and Maud (1987), the African surface, coincides generally with the African surface described by King (1967). Two surfaces of the post-African age were identified, and are referred to as the Post-African I and the more recent Post-African II surface. The relationship between surfaces and stages is hypothesised as being indicative of landform development by progressive backwearing and downwearing, where existing surfaces continue to develop at the expense of higher lying areas. However, more recently, Gilchrist (1995) suggests that these classical models of endogenic activity are deficient based on time scales required for relaxation at the macroscale and require revision based on more recent tectonic analyses.

Notwithstanding the work of Partridge and Maud (1987) and Gilchrist (1995) few broadly based studies of geomorphic evolution of the sub-continent have appeared in the last two decades. The recent focus within the geomorphology of the sub-continent has been on landscape development at the regional to local scale and on landscape processes that are active under present-day conditions or during the late Pleistocene and Holocene. The presence of periglacial activity on the Lesotho Plateau supports the contention that periglacial processes have played, and continue to play, a role in modifying the morphology of the high Drakensberg (Lewis, 1988; Boelhouwers, 1991; 1994; Hanvey and Marker, 1992; Meiklejohn, 1992; 1994; Grab, 1994). The cryogenic influence may have extended down the Main Escarpment in the last glacial in the form of niche glaciers (Hall, 1994) with some evidence of cryogenic processes at lower altitudes (Lewis, 1988).

By analysing the scarps of the Main Escarpment basalts near Royal Natal National Park, Moon and Selby (1983) contested the idea of strictly parallel retreat, citing evidence for the occurrence of strength equilibrium slopes. Findings by Munro-Perry (1990) on the Clarens Formation Sandstone show that slope retreat will occur only under the specific condition of a resistant caprock. In the absence of a caprock the slope will decline. Moon (1990) showed that the parallel retreat model is not a general model and will occur only where there is sufficient difference in resistance in the capping and the underlying strata. Although some research has been directed to mass movement and erosion (eg. Beckedahl, 1977; Boelhouwers, 1988, 1992; Sumner, 1993) the contribution of mass movement and erosion process to the landforming processes of the Drakensberg is as yet little understood.

## Climate

There is a scarcity of climatic data for the Drakensberg area due to the small number of weather monitoring stations. All Natal Parks Board camps keep records of total rainfall. There are, however, only three automated weather stations within the Natal Parks Board Drakensberg areas. One station is at the Cathedral Peak Research Station (1870m a.s.l.) and the other two are at the Main Camp in Giant's Castle Game Reserve (~1750m a.s.l.). The two stations in Giant's Castle Game Reserve are controlled respectively by the Natal Parks Board and the Weather Bureau. Both stations have been in operation intermittently since 1985. The most complete records come from the Cathedral Peak Research Station (some 45km northwest of Giants Castle Game Reserve Main Camp) whereas some high altitude data are available from above the Escarpment at Letseng-la-Draai (3050m) (Fig. 1).

### Temperature

Mean monthly temperatures above the Main Escarpment at Letseng-la-Draai (3050m) vary between -0.5°C in July and 11.1° C in January (Grab, 1994). Temperatures are higher in the Little Berg and mean monthly temperatures for Giant's Castle (1737m) range between 2°C in July to 15°C in January (Schulze, 1981). Mean monthly temperature data for the two stations are provided in Table 3.

Few observations have been made of valley temperature structure in the many valleys that are a feature of the Little Berg. Lapse rates measured in the Bushman's River valley in Giant's Castle Game Reserve indicated a temperature inversion under calm conditions in winter (Tyson *et al.*, 1976). These valley inversions are intensified by the drainage of cool air down-valley. After sunrise, however, with the receipt of direct solar radiation, inversions dissipate rapidly. In winter, conditions of clear skies, temperature inversions, dry air and the absence of wind, favour the development of frost. In the Little Berg frost may occur from May to September with a frequency in the order of 120 days per year (Tyson *et al.*, 1976).

### Precipitation

Rainfall amount and the associated kinetic energy vary spatially and seasonally in the Drakensberg. Total rainfall varies between about 1000mm in the Little Berg to 1800mm at the Escarpment (Tyson *et al.*, 1976). Precipitation in the summer months between November and March accounts for 70% while the winter months (May to August) contribute only 10% to the total annual precipitation (Tyson *et al.*, 1976). Most of the rain occurs in the form of thunderstorms with more than 100 rainfall-days being recorded on an annual basis in the Escarpment region (Schulze, 1974). Mean monthly rainfall totals and the number of rainfall days for Giant's Castle Game Reserve and at the Cathedral Peak Research Station are shown in Figure 4. Giant's Castle Game Reserve and Cathedral Peak have a similar number of rainfall days, although Cathedral Peak has a higher total rainfall.

|  | J | F | M | A | M | J | J | A | S | O | N | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L-l-D | 11.1 | 10 | 9.0 | 4.9 | 2.3 | -0.5 | 0.1 | 2.0 | 5.4 | 7.3 | 8.3 | 9.8 |
| G.C.G.R. | 15 | 12 | 13 | 7 | 7 | 2 | 3 | 4 | 8 | 10 | 10 | 12 |

Table 3. Mean monthly temperatures for Letseng-la-Draai (L-l-D) and Giant's Castle Game Reserve (G.C.G.R.) (modified after Schulze, 1981; Grab, 1994).

### Wind

The airflow of the Drakensberg is strongly influenced by the presence of the Main Escarpment and the deeply dissected terrain of the Little Berg (Fig. 2). Under clear, fine weather conditions, airflow patterns near the ground are completely dominated by topographically induced local winds (Tyson *et al.*, 1976). These are formed on a variety of scales by the solar heating of the ground during the day and radiation-cooling by night. Anabatic and katabatic winds may drain warm and cool air on slopes by day and night respectively (Tyson *et al.*, 1976).

Strong pressure gradients are usually associated with the passage of frontal systems. 'Berg Wind' conditions generally precede a cold front and wind velocities are high with generally low humidity (Killick, 1963; Hurry and van Heerden, 1981; Preston-Whyte and Tyson, 1988). Strong winds accompanying thunderstorms are known to occur but these seldom last for long periods (Killick, 1963). The geomorphic influence of strong winds is mostly unknown as little data are available to assess the influence of wind on soil movement. Although cited by Bainbridge (1979) as being an underestimated form of soil transport, Garland (1987) suggests that the conditions in the Drakensberg do not favour extensive wind erosion and deflation has been assumed to operate only on bare soils (Boelhouwers, 1988). The effects of burning on wind erosion have, however, not yet been fully investigated. Some tentative figures place soil loss associated with burning and high wind speeds up to peak values of 152 tons/ha near the Escarpment south of Kamberg (Sumner, 1992).

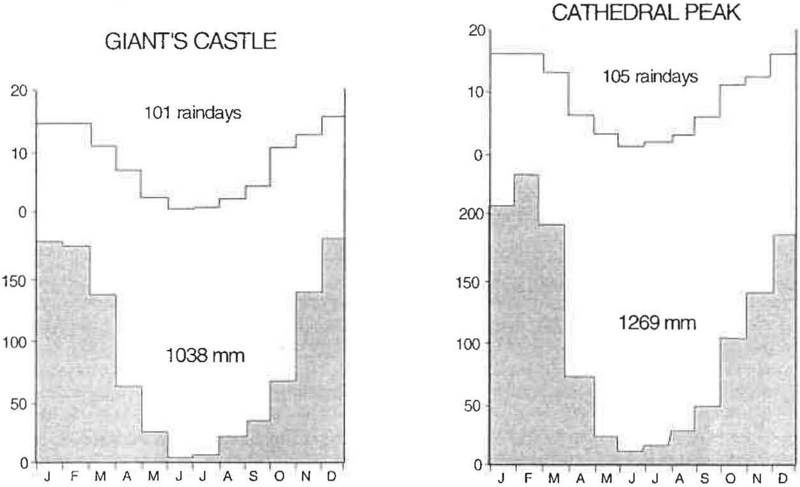

Figure 4 Monthly rainfall totals and number of raindays in Giant's Castle Game Reserve and at the Cathedral Peak Research Station (modified after Tyson *et al*, 1976)

## Soils

Although some small scale soil surveys of the Cathedral Peak area have been undertaken (Schulze, 1974; Granger, 1976) there has, as yet, been no comprehensive soil survey taken for the Natal Drakensberg. The Tugela Basin was mapped at a scale of 1:100 000 by Van der Eyk *et al.* (1969) but little attention was given to the soils of the Little Berg and Escarpment zones. The soils in the Little Berg have been described as ferrallitic, structureless and acid due to a high degree of leaching (Schulze, 1974; Granger, 1976; Boelhouwers, 1988). At Cathedral Peak the A horizon is rich in organic matter and is classified as orthic. The A horizon is best developed on moist, cool south-facing slopes, increasing in thickness downslope to a maximum of 25cm (Schulze, 1974; Granger, 1976). This trend has also been observed elsewhere in the Drakensberg, as exemplified by Humphrey (1983) who reported organic matter contents in the Kamberg area of 10.3% on north-facing slopes and increasing to 17.7% on south-facing slopes. The soil appears to be low in clay content in the vicinity of the Main Camp in Giant's Castle Game Reserve and samples indicate the texture class to be classified as that of loamy sand (U.S. Department of Agriculture texture classes cited in Strahler, 1975).

Five soil forms have been identified in Giant's Castle Game Reserve, namely Hutton, Griffin, Clovelly, Katspruit and Mispah Form (Van der Eyk *et al.*, 1969; Garland, 1987; Boelhouwers, 1988). The dominant soil forms found in Giant's Castle Game Reserve and their general location are listed in Table 4.

| FORM | DIAGNOSTIC HORIZONS | LOCATION |
|---|---|---|
| Hutton | orthic A / red apedal B | low gradient slopes |
| Griffin | orthic A / yellow-brown B / red apedal B | low gradient moist conditions on cooler slopes |
| Clovelly | orthic A / yellow-brown apedal B | steep and/or south-facing slopes |
| Katspruit | orthic A / firm gley | poorly drained valley floors and in narrow strips along streams |
| Mispah | orthic A over rock | dolerite outcrops and along scarp edges |

Table 4 Soil forms found in Giant's Castle Game Reserve (modified after Van der Eyk *et al.*, 1969; Garland, 1987; Boelhouwers, 1988).

## Vegetation

Two of the dominant factors which have influenced vegetation in the Drakensberg are altitude and the long history of controlled burning (Garland, 1987). Three altitudinal belts of vegetation were recognised by Killick (1963) as the Montane, Subalpine and Alpine belt. These belts have generally been used in later studies (Edwards, 1967; Schulze, 1974; Granger, 1976; Boelhouwers, 1988) and are shown in Table 2.5.

The montane belt supports the *Themeda-Trachypogon* sub-climax community. It is dominated by *Themeda trianda* and *Trachypogon spicatus* grassland and is interspersed with small communities of *Protea* savanna. Pockets of shrub and woodland with *Leucosidea sericea* and *Buddleja salvifolia* are found on rocky soils, in kloofs and on streambanks (Garland, 1987). The subalpine belt consists of *Themeda-Festuca* grassland where *Themeda trianda* is common, particularly on north-facing slopes, and *Festuca costata* is common on south-facing slopes. Subalpine fynbos exists along streams and steep slopes at the head of main streams where there is some measure of protection from fire. The greatest variety of species are found on south-facing slopes and are attributed to local moisture and climatic conditions (Granger, 1976). The alpine belt supports the *Danthonia-Festuca-Pentaschistis* association. Vegetation is characteristic of a harsh climate of wet summers and freezing of soils in winter (Boelhouwers, 1988). Sites protected from fire may support *Danthonia* tussock grassland and stands of alpine fynbos (Garland, 1987).

| VEGETAL BELT | ALTITUDE | LOCATION | CLIMAX COMMUNITY |
|---|---|---|---|
| Montane | 1280 - 1829m | Valley floors to lowest basalt cliffs | *Podocarpus latilolius* Forest |
| Subalpine | 1830 - 2865m | Edge of Little Berg to just below summit | *Passerina-Phillippa-Widringtonia* Fynbos |
| Alpine | 2866 - 3353m | Plateau and peak areas | *Erica Helichrysium* Heath |

Table 1.5 Vegetation belts and climax communities of the Drakensberg (after Killick, 1963).

# THE ROLE OF MOISTURE IN THE WEATHERING OF THE CLARENS FORMATION OF THE KWAZULU-NATAL DRAKENSBERG: IMPLICATIONS FOR THE PRESERVATION OF INDIGENOUS ROCK ART

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*The Clarens Formation in the KwaZulu-Natal Drakensberg, South Africa, contains some of the World's finest rock art. This heritage is fast disappearing as a result of natural weathering processes. In an attempt to elucidate the operative weathering processes, a range of micro-climatic, rock temperature, rock moisture, rock chemistry and rock property data were monitored. Results indicate that rock moisture regimes, and to a lesser extent rock temperature regimes, are crucial to the weathering of the Clarens Formation.*

*The major active weathering processes in the study area are: solution; chemical alteration of minerals; crystallisation pressures from precipitating salts and the hydration and dehydration of rock minerals, precipitates and clay minerals. Weathering enlarges the existing pores of the sandstone, so that moisture intake and movement are increased. A more dynamic moisture regime allows for increased rock weathering and acceleration of the rate of breakdown. Given the high micro-porosity of the Clarens formation (>80%), it is unlikely that rapid moisture changes will occur deep below the rock surface. The rock weathering processes that cause the deterioration of rock art, therefore, take place at, or close to, the rock surface.*

*While considerable international research towards preserving stone buildings has been undertaken, little has been achieved with respect to preserving rock art. The future existence of indigenous rock art in the KwaZulu-Natal Drakensberg depends on investigations aimed at the development of techniques for its preservation.*

## INTRODUCTION

A large part of the interior of southern Africa was occupied by the Bushman[1] people for at least 25 000 years until approximately 1870 (Rudner, 1989). These hunter-gatherers, although now extinct in much of southern Africa, have left behind a valuable heritage through their paintings and engravings. Clarens Formation sandstones contain the highest concentration of rock paintings in the world, amounting to approximately 80% of all southern African rock art (Ward, 1979; Rudner, 1989; Bachelor, 1990). Bushman paintings on the Clarens Formation in the KwaZulu-Natal Drakensberg (Fig. 1) are located on the walls of shallow shelters or, occasionally, on the lee sides of isolated boulders (Avery, 1974; Ward, 1979; Mazel 1983; Bachelor, 1990; Lewis-Williams and Dowson, 1992).

Unfortunately, this heritage is rapidly being lost through natural weathering processes. Earliest records of the deterioration of Bushman paintings in southern Africa are from the south-western parts of South Africa and date to the late Eighteenth Century, while the decay of rock art in the KwaZulu-Natal Drakensberg was first noticed in the late Nineteenth Century (Hoffman, 1971; Avery, 1974; van Rijssen, 1987; Rudner, 1989; Bachelor, 1990). Geomorphologists have themselves acknowledged that rock art is decaying; King (1942, p25), uses the deterioration of paintings to provide an "evaluation" of the relative weathering rates of the sandstones onto which they are painted.

The nature and rate of decay of rock art in southern Africa have previously been, and still are, a source of great concern to many researchers (Meiklejohn, 1994). However, although there has been a great deal written concerning the location, interpretation, restoration and archaeological importance of rock art in southern Africa, little has been achieved in determining the processes of deterioration or techniques for its preservation (Meiklejohn, 1994).

The general lack of understanding concerning specific mechanisms of rock weathering has been cited as a major reason for inadequate research into rock art preservation in southern Africa (Loubser, 1991). Much of the literature concerned with the deterioration of rock art as a result of rock weathering processes has been speculative, and few investigations into specific weathering processes have been undertaken (Meiklejohn, 1994). Even within the field of geomorphology, in which weathering processes are a major focus, there is little literature relating to rock weathering in southern Africa. While some research has been conducted into biological weathering and other selected weathering topics relating to the Clarens Formation (e.g. Eriksson, 1979; Cooks and Pretorius, 1987; Wessels and Schoeman, 1988; Cooks, 1983), this is not adequate for an understanding of the rock weathering processes that cause the deterioration of Bushman paintings. Therefore, a need arises for extensive research to evaluate the mechanisms causing the decay of rock art, not only on the Clarens Formation, but throughout southern Africa

This discussion reflects part of investigations carried out to determine and evaluate the contemporary weathering processes in the Clarens Formation at two sites in the Drakensberg Park of KwaZulu-Natal, South Africa. In so doing, this research provided a valuable contribution towards determining the causes of the deterioration of Bushman paintings and is a first step towards preservation of this valuable heritage. The two sites chosen were the Main Caves near the Giant's Castle Rest Camp and Battle Cave in the Injasuti valley (Fig. 1).

In developing a hypothesis for the weathering of the Clarens Formation in the study area it is necessary to consider that no single process can be isolated, and that rock breakdown results from an interdependent complex of mechanisms, which are mechanical, chemical and biological. This study focussed on aspects of physical and chemical weathering, as logistical constraints and a lack of expertise prevented adequate investigations into biological weathering processes. Despite the interdependence of weathering mechanisms, it was necessary to investigate the controlling factors separately. Research showed that rock temperature and rock moisture were potentially the most important environmental controls on weathering (Meiklejohn, 1994); for this reason they were identified as topics for investigation. Additionally, chemical analyses, rock property determination, rock strength determination and simulation experiments were valuable components of data collection.

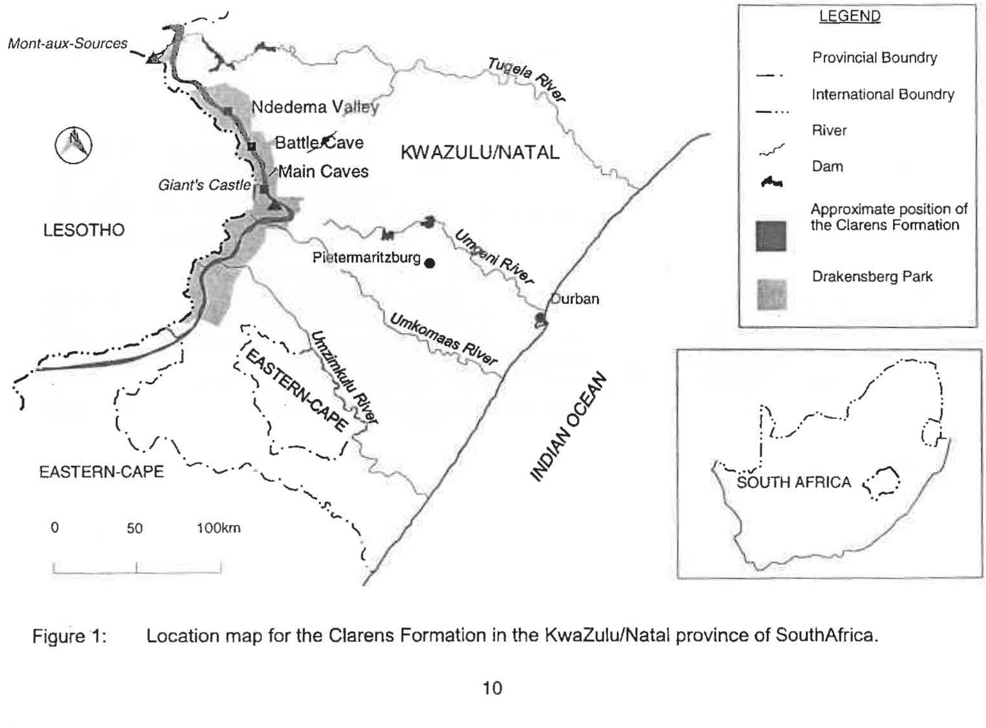

Figure 1: Location map for the Clarens Formation in the KwaZulu/Natal province of SouthAfrica.

## THE WEATHERING ENVIRONMENT AT TWO SITES IN THE KWAZULU-NATAL DRAKENSBERG

Initial discussions with interested parties, on the basis of climatic data, indicated the potential for so-called "freeze-thaw" weathering to be great in the study area. However, data shows that cryogenic processes are not contemporary at either of the study sites and for that matter are unlikely at any rock art site in the entire Clarens Formation. The lowest rock temperatures recorded were 4.5°C at the Main Caves and 6.6°C at Battle Cave, despite the fact that air temperatures often drop below zero. Further, the lack of moisture would prevent cryogenic weathering from being active. Rock moisture content is lowest during the winter months when the temperature regime would be most favourable for cryogenic processes. Thus, given that moisture is essential, it can be said with certainty that cryogenic weathering is not contemporary in the Clarens Formation of KwaZulu-Natal.

The role of thermal regimes in rock weathering is well documented (e.g. Blackwelder, 1933; Griggs, 1936; Peel, 1974; Rice, 1976; Aires-Barros, 1977; Ollier, 1984; Jenkins and Smith, 1990; Hall and Hall, 1991). It therefore stands to reason that thermal processes may contribute towards the deterioration of rock art. Field data show that daily rock temperature ranges are often in excess of 30°C. Further, recorded rates of rock temperature change on exposed rock faces of in excess $2°C.min^{-1}$ may be sufficient to induce cracks along grain boundaries (Richter and Simmons, 1974; Yatsu, 1988; Hall and Hall, 1991). There is thus a great potential for thermal stress fatigue to be active at exposed sites in the Clarens Formation. However, there was no evidence to suggest that micro-fracturing took place. Further, weathering is observed to be most active underneath rock shelters where neither the rate of temperature change nor temperature ranges are great.

It is thus apparent that thermal fatigue and other thermally controlled weathering processes on their own are not responsible for the breakdown of rock in the rock shelters. Rock weathering is most active in protected sites, underneath rock overhangs, where the rock temperature regime is the most stable, but where data indicate that the moisture regime is more conducive to rock weathering processes. It is thus possible that moisture changes rather than temperature changes, may be the major cause of rock weathering and rock art deterioration in the KwaZulu-Natal Drakensberg. In mudrock, which makes up part of the Clarens Formation, it has been found that atmospheric humidity changes are sufficient to result in weathering and may indeed cause more breakdown than temperature changes (Venter, 1981a, 1981b). While it has often been argued that moisture is the primary agent of rock art deterioration in the Drakensberg, few specific weathering mechanisms have been identified (Meiklejohn, 1994). In order to ascertain the active weathering processes at the study sites it is thus imperative that the rock moisture regime is determined. Rock properties, mineralogy and other influences on rock moisture should also be monitored. However, it must be said that despite the dominant role of moisture, rock temperature is still an important influence on all weathering mechanisms in the Clarens Formation, in that it will affect amongst others: the rate of chemical reactions, chemical equilibria, as well as evaporation and condensation cycles.

Two methods were used to determine rock moisture content. The actual rock moisture content was determined using a mass balance (measured as a percentage of the saturated mass of the rock sample), while the relative rock surface moisture content was determined using a "leaf-wetness sensor" connected to automated logging equipment (measured, using electrical conductivity, as a percentage of the moisture content when the *rock surface* was saturated). As with rock temperatures, there is more than one temporal rock moisture regime in the study area. There is a seasonal trend, with summer rock moisture content (% saturation) being higher than that in winter and a daily trend, both of which appear to be controlled by atmospheric humidity. Trends for actual rock moisture content and relative rock surface moisture were almost identical. The average correlation coefficient of monthly averages of rock moisture content, for rock samples monitored, with atmospheric moisture was as high as +0.83 for some samples, while that for percentage saturation of rock samples and rock surface moisture was as high as +0.92 (Fig. 2). Short term data showed similar trends in that relative rock surface moisture content are related to atmospheric moisture. The same is true for the relationship between actual rock moisture content and atmospheric water vapour content. The relationship between the ambient humidity and rock moisture content indicates an extremely rapid response of the latter to changes in atmospheric moisture (Fig. 3).

The above moisture data seem to imply that Clarens Formation sandstone is porous and permeable. However, findings from rock property determinations, using water and mercury porosimetry seem to indicate just the opposite. The average porosity of samples taken from the Clarens Formation is only between 6%-8%, which is less than half the average porosity of sandstones, which is 15% (Pettijohn, 1975). In considering this data and that which is to follow, it should be noted that rock property determinations were carried on

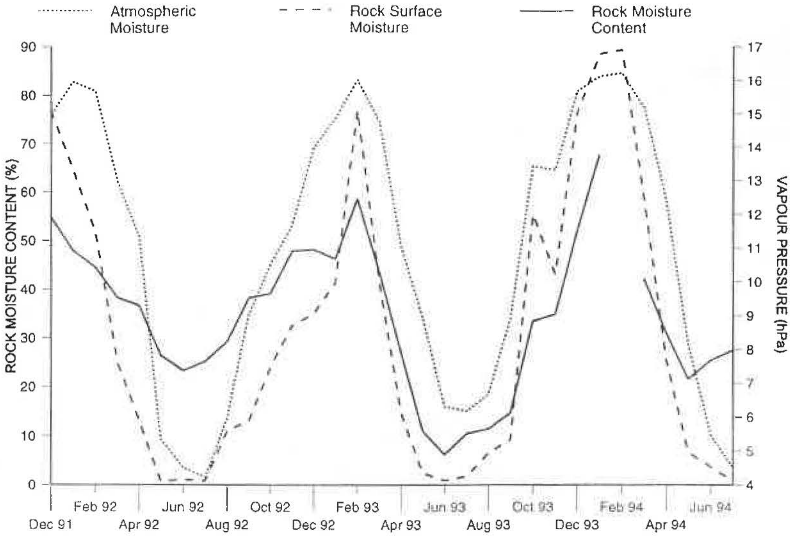

Figure 2: Rock moisture (% saturation), relative rock surface moisture and atmospheric moisture contents for the Main Caves study site. F

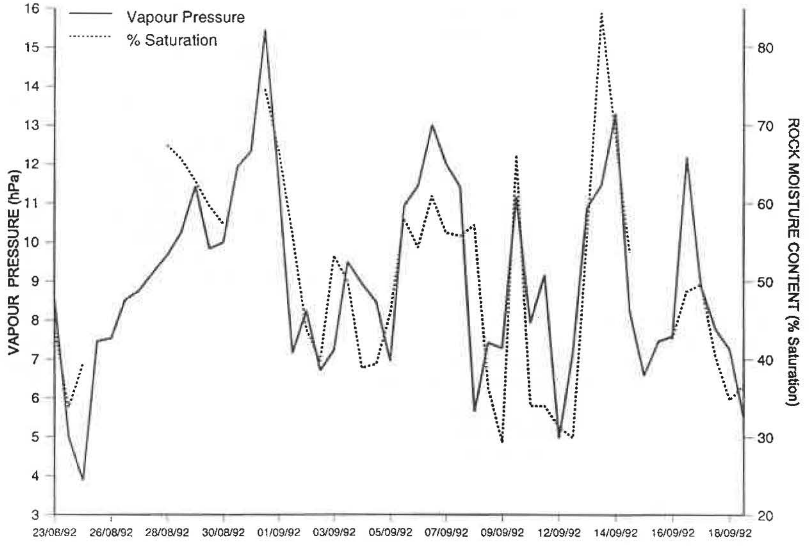

Figure 3: Graph of atmospheric moisture (vapour pressure) content and rock moisture content (% saturation) at an external face of the Main Caves study site.

already weathered rock and thus the values over exaggerate the actual values for the Clarens Formation. Further data indicates that the average micro-porosity (i.e. the % of pores with diameters of 1µm and less (Bousquie, 1979)), of the Clarens Formation is in excess of 85%. In fact, only the most weathered samples had micro-porosity values as low as 80% (Fig. 4). The least weathered sample had an infra-porosity (i.e. the % of pores with a radius of 0.01µm and less (Bousquie, 1979)) of approximately 67%. It is also evident that the average size of micro-pores increases as the degree of weathering of a sample increased. The least weathered sample, of those tested, had the largest range of pore sizes, while the more weathered samples had a smaller range. A further interesting observation is that the more weathered samples do not have any significant numbers of very small pores (e.g. infra-pores). This seems to indicate that in weathering the individual pores become larger as a rock weathers, rather than new pores forming.

The results obtained from porosimetry data are thus in apparent contradiction to earlier published material and earlier statements that the Clarens Formation sandstone is extremely porous and permeable. Given the transport regime proposed by Meng (1992) (Fig. 5), it is likely that there is little, or no, capillary movement of moisture in the Clarens Formation. Further, little moisture is likely to move through the pores of the rock as the pore size range of the samples analysed for this study are at the limits for this mode of movement. The movement of moisture in Clarens Formation sandstone is, thus, likely to be a complex of adsorption and absorption processes as well as gaseous and surface diffusion. However, the precise modes of moisture movement will depend on the pore architecture (Meng, 1992). Pores can be divided into coarse, medium and fine fractions, and their inter-connectivity will determine the mode of moisture movement (Meng, 1992). Although no precise modes of moisture movement are deduced, the indications are that in the Clarens Formation moisture does not move at the same rate and in the same manner as has previously been proposed (Fig. 6). What then of the gypsum precipitates that are often observed at rock art sites, especially at Battle Cave? Given that there is rock art that is painted on the surface of gypsum deposits, these are largely palaeo-precipitates. Further gypsum precipitates are only found at existing joints and discontinuities in the rock surface and are not found at the continuous massive surfaces. If it were possible to date these precipitates, they would be most useful for palaeoenvironmental studies, as they are indicative a wetter climate than the present one.

While it can be said that moisture does not move through the Clarens formation as much as previously thought, moisture movement *does* still take place. This was shown earlier in data regarding rock moisture content and also by relatively high water absorption capacities and saturation coefficients. So how then does this moisture enter the rock? Given the rapid changes of rock moisture content in response to atmospheric moisture changes (Fig. 3) and the pore structure of the Clarens Formation, it is likely that the changes occur at or very close to the rock surface. This is the area in contact with the outside atmosphere and is where pore sizes are largest and most conducive to moisture absorption and movement.

In order to determine the effect of the moisture regime on rock art the consequences of changes in rock moisture need to be considered. Potentially, a whole number of weathering mechanisms are influenced by rock moisture changes (Meiklejohn, 1994). When considered with other data (Meiklejohn, 1994) not presented in this discussion the contemporary weathering is likely to be due to granular disintegration as well as enlargement of pores and bedding planes. Larger pores and bedding planes will further result in a more dynamic weathering environment and accelerated weathering. As a whole, the weathering environment can be summarised as follows (Fig. 7):

- the mineralogy, rock structure, rock properties and especially the rock moisture and thermal regimes influence rock weathering processes;
- thermal stress fatigue, salt crystallisation, hydration and dehydration of rock minerals, clay minerals and precipitated salts, solution, hydrolysis and chemical alteration, are the potential rock weathering mechanisms;
- the rock weathering processes result in granular disintegration and the enlargement of pores and bedding planes;
- the existing weathering processes produce a more dynamic environment with respect to both the thermal and rock moisture regime results, thereby accelerating rock weathering processes.

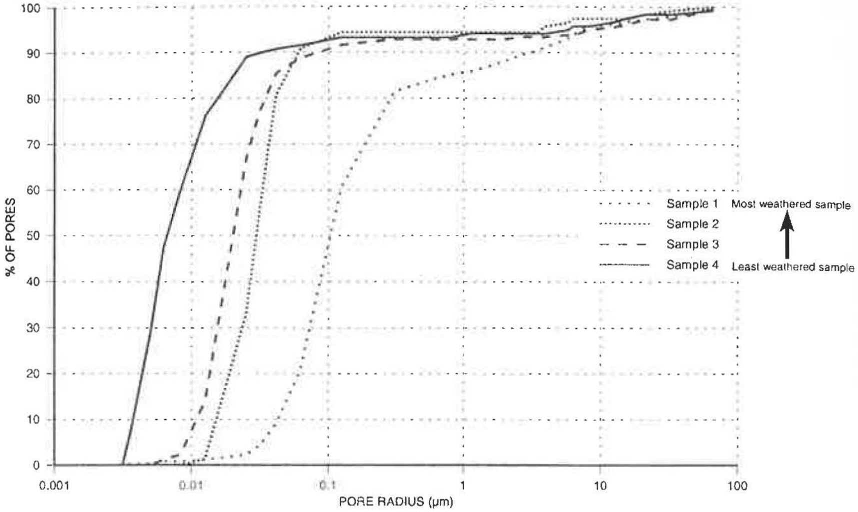

Figure 4: Graph of pore radius against the % of pores in each of the pore sizes monitored for four samples of varying degrees of weathering from the Main Caves study site, determined using mercury porosimetry.

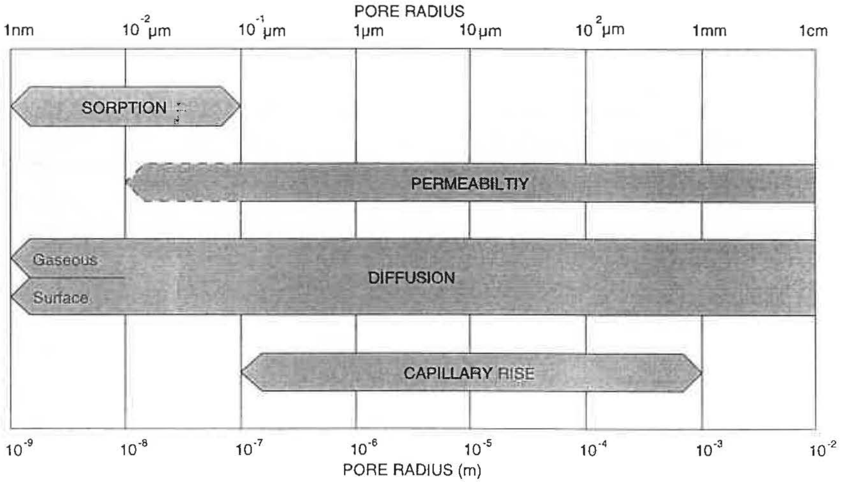

Figure 5: Diagram showing the relationship between the mode of moisture movement in a rock and pore size (after Meng, 1992).

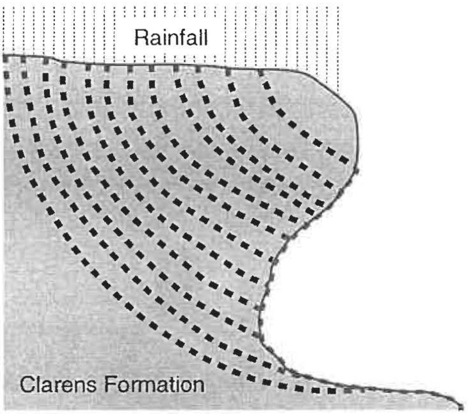

Figure 6: Pager's (1971) hypothesis for the movement of moisture through Clarens Formation sandstone (After Pager, 1971)

## IMPLICATIONS OF THE WEATHERING ENVIRONMENT FOR THE PRESERVATION OF ROCK ART

It is extremely significant that Bushman paintings are located at the rock surface and in the first few µm below the surface. The contemporary weathering environment discussed above is thus likely to be extremely damaging to this wonderful heritage. The deterioration is also likely to be accelerated along places where moisture is able to penetrate into the rock, for example along bedding planes.

How does the weathering environment then influence the preservation of rock art *in situ*? Obviously the primary aim of any preservation attempts would be to minimise the effect of the rock moisture regime. This can be achieved in two ways, first by altering the environment in which the rock art is found. The most extreme cases of this are seen in France, where caves and shelters are walled-in. It is unlikely that similar methods could be used in many Drakensberg shelters, for logistical, aesthetic and financial reasons. Cases where environmental alteration is effective, are when drip-lines are used to prevent precipitates from washing over and obliterating rock art (Fig. 8). However, drip-lines are insignificant when art in the Drakensberg is considered as a whole and altering the ambient environment is, in most cases, not a feasible solution to the problem of deteriorating rock art. Second, chemicals can be applied to the rock surface, and this may prove to be the only successful method.

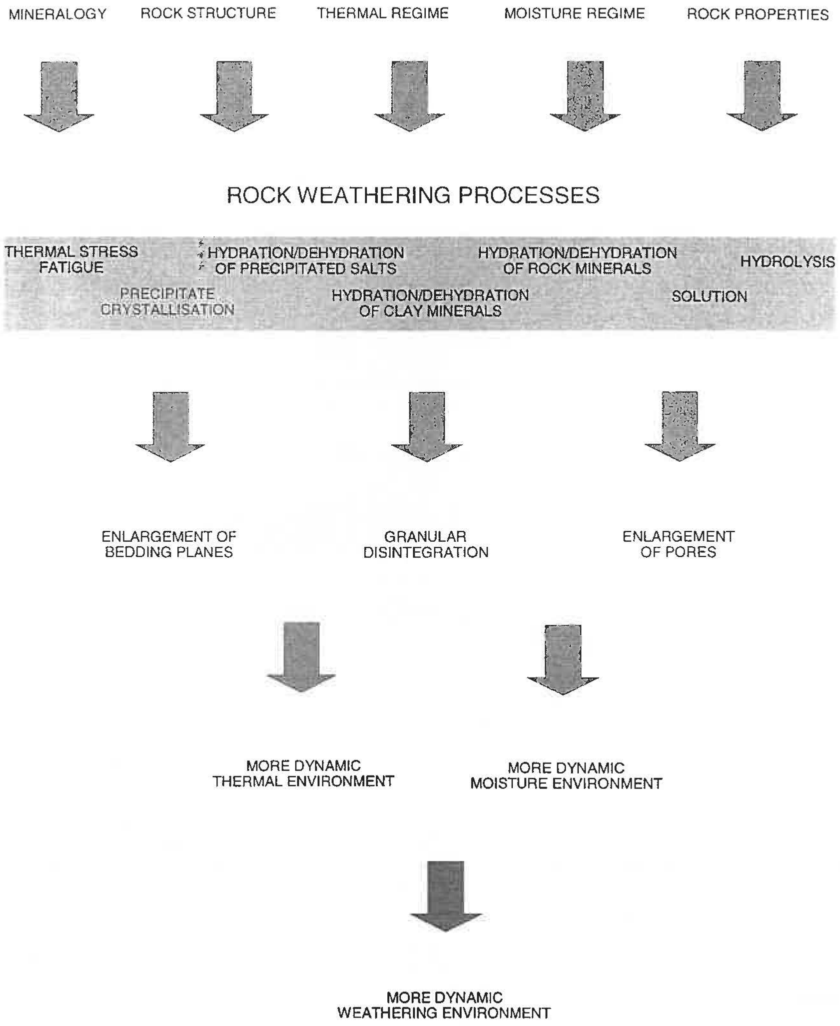

Figure 7: Flow diagram of the weathering processes causing the deterioration of indigenous rock art in the Clarens Formation of the KwaZulu/ Natal Drakensberg.

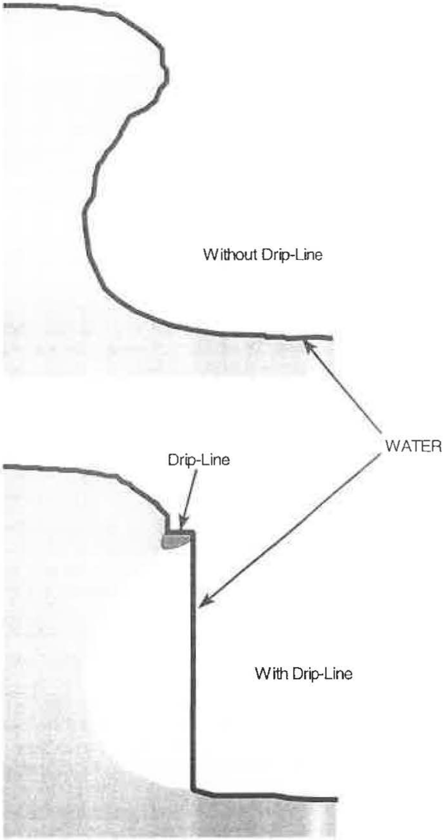

Figure 8: The effect of drip-lines, which prevent water from running over Bushman paintings.

Chemical treatments have previously been applied to many stone surfaces, primarily in the preservation of historical buildings in Europe (Meiklejohn, 1994). The most effective chemical preservatives are those which are hydrophobic, but have a minimal effect on the porosity and permeability (gaseous and liquid) of the parent material (Torraca, 1976; Valle *et al.*, 1985; Bachelor, 1990; Villegas and Vale, 1992; Wendler *et al.*, 1992; Brunet, pers. comm., 1993; Ozouf, pers. comm., 1993). The most effective chemicals that are used for the preserving of natural stone are the silanes, (National Building Research Institute, 1979; 1983; Fukuda *et al.*, 1984; Lewin and Wheeler, 1985; Rudner, 1989; Bachelor, 1990; Loubser, 1991). The permeability of the rock to water and gas is not altered significantly, so that both are able to escape from the rock, thereby preventing enhanced sub-surface weathering. Other chemical preservatives, on the other hand, (e.g.

silicone) often seal off a surface completely, thereby resulting in enhanced sub-surface weathering and ultimately causing the loss of the rock art (Brunet, pers. comm., 1993; Ozouf, pers. comm., 1993). However, while silanes may be effective on new building material their usefulness is limited when applied to already weathered material (Midgley, pers. comm., 1994; Swanepoel, pers. comm., 1994).

Despite the effectiveness of silanes in the treatment of stone materials, diagnostic and control methods of stone preservation are poorly developed (Pien, 1991). This situation influences the selection and the adjustment of interventions and the control of applications such that the incorrect treatment is often adopted (Pien, 1991). Some applications of chemical preservatives, rather than slowing weathering processes down, often result in enhanced sub-surface weathering; this applies particularly to acrylic treatments (Bachelor, 1990; Villegas and Vale, 1992; Wendler *et al.*, 1992). There is thus a fear amongst rock art enthusiasts that chemical applications may damage rock paintings rather than preserve them (Mazel, pers. comm., 1994).

## CONCLUSION

While it is recognised that rock art is fast disappearing as a result of rock weathering processes, primarily controlled by the rock moisture regime, little has been achieved with respect to its preservation. Further research is thus required to investigate specific methods of ensuring the survival of Bushman Paintings in the KwaZulu-Natal Drakensberg. It can be seen that considerable research is required before it will be possible to preserve rock art *in situ*. Until such time as an effective technique for the preservation of rock art has been developed, a management policy needs to be implemented, so that the deterioration of this valuable heritage can be minimised.

## ACKNOWLEDGEMENTS

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### Notes

[1] In this discussion the term "Bushman" and the collective term "Bushmen" are used to refer to the hunter-gatherer people who painted their art onto the walls of the Clarens Formation; all negative connotations which may be attached to these words are rejected. Bushmen may also be referred to as San, but this term too has negative connotations and is thus not used.

# Footpath erosion in Giant's Castle Game Reserve

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*The successful planning of new footpaths and the maintenance of existing footpaths requires an understanding of the mechanisms and controls of the erosion process. Very little research has been undertaken on footpaths in Southern Africa. Four path sections totalling 21 km of footpaths in the Giant's Castle Game Reserve, Natal Drakensberg, South Africa were surveyed in order to determine controls over the erosion process. Results from the survey show that a path width to maximum depth ratio value of 4.50 is the threshold for the initiation of multiple path development. Where mean path gradients are high the most important control on erosion is the path gradient. On low mean path gradients with high user intensities the orientation of the path to the slope is more important than the path gradient or cross-slope gradient. As total path use increases, the morphology of the paths become more correlated to the geomorphological and recreational forces exerted on them.*

## INTRODUCTION

The environmental impacts associated with the recreational use of protected areas poses ongoing management challenges. Overuse threatens both the character of the wilderness resource and detracts from the visitor experience. The erosion associated with footpaths is a leading concern, particularly where recreational pressure is on the increase.

Footpath erosion has long been recognised as a major problem in wilderness areas. Over the past three decades there have been several studies on the mechanisms and controls of erosion (Bayfield, 1973; Bryan, 1977; Weaver and Dale, 1978; Bratton *et al*, 1979; Quinn *et al*, 1980; Coleman, 1981; Garland, 1985; Garland *et al*, 1985; Starodubova, 1985; Tinsley and Fish, 1985; Garland, 1987; Jubenville and O'Sullivan, 1987; Garland, 1988; Auerswald and Sinowski, 1989; Lance *et al*, 1989). In comparison to the extensive literature available on erosion associated with agriculture and forestry, however, there has been little research on the erosion of footpaths.

Research on footpaths in southern Africa has been limited to a few studies (Garland, 1985, 1987, 1988, 1990; Garland *et al*, 1985) in the Natal Drakensberg. The Natal Drakensberg mountains are one of the major wilderness areas in southern Africa where access by foot is possible. It is a mountainous region where peaks reach up to 3000m. Trails in higher level ecosystems are often more susceptible to erosion (Ketchledge and Leonard, 1970, Bratton *et al*, 1979). Much of the Drakensberg has been proclaimed a wilderness area and management objectives tend towards the preservation of the wild mountain character, the conservation of the indigenous flora and fauna, and the provision of opportunities for wilderness recreation (Garland, 1990).

Coleman (1981) provides a simple framework for the understanding of the interaction of forces in defining the footpath morphology. The general model can be stated as:

| FORCES | + | RESISTANCE | = | FOOTPATH |
|---|---|---|---|---|
| (recreation/<br>geomorphological) | | (soil/vegetation) | | MORPHOLOGY |

This model is highly simplified and the various factors will interact to reinforce or counteract one another (Coleman, 1981). Most authors have concluded that the process of erosion cannot be attributed to any one factor and that a combination of both components of recreational factors and of geomorphological forces are responsible. In order to attempt to achieve a greater understanding of the various components of the phenomena, a study of footpaths in Giants Castle Game Reserve in the Natal Drakensberg has been conducted.

The Reserve is a well known area of the Drakensberg and attracts both chalet dwellers to the Main Camp and hikers who frequently use the two mountain huts. Most of the Reserve is traversed by a path commonly referred to as the "contour path" which lies between 2200 and 2400m, passing beneath the escarpment. There are a number of approach paths to the contour path and a number of passes up the escarpment which provide access to the Lesotho highlands (Fig. 1)

## METHODOLOGY

Four path sections (A-D, Fig. 1) totalling 21 km of footpaths were surveyed. These included two sections of the contour paths (Bannerman Hut contour path and Ka-Langalibalele Pass contour path) and two approach paths from the vicinity of the main camp (Bannerman Hut approach path and Giant's Ridge path). Survey point spacing was 100m, measured with a trundle wheel. At each site the footpath width was measured, and depth cross-sectioned at an interval of 5cm. In addition the following was recorded: vegetation type, path gradient and aspect, slope gradient above the path and slope aspect. The difference between the slope aspect and the path aspect gives the orientation of the path to the slope and ranges between 0° and 90° (Bratton *et al*, 1979; Tinsley and Fish, 1985). For short sections of some of the paths, secondary paths tend to develop running parallel to and in close proximity to the original path. These form as a result of hikers leaving the original path and walking next to it. At survey sites where secondary paths were observed, the widths and depths were recorded.

Although a current hiking register is kept at the Main Camp, past records are not available therefore user intensity of the footpaths could not be established. Further, it is observed that day hikers do not always complete the available forms. In order to determine the user intensity of the path sections surveyed, automated pedestrian counters were installed on the four path sections. These recorded the number of hikers using the paths over a two month period. While this does not provide representative user intensities over an extended period, relative user intensities for the four path sections can be determined. It is assumed that once a hiker has set out on the path the person will walk the full length of that section. There is also no record of the age of the paths and the manner in which they were constructed. This necessitates the assumption that the paths are of a similar age and that they were constructed in a similar manner.

The data from the survey have been analysed in order to establish relationships between the site specific variables and the footpath morphology. Simple statistical descriptions of the path sections are calculated. In order to assess possible relationships, correlation and multiple regression between dependents (width, depth and cross-sectional area) and independents (path gradient, path-slope orientation and cross-slope gradient) has been undertaken.

## RESULTS AND DISCUSSION

### General path section descriptions

Simple statistical descriptions of the four path sections are provided in Table 1. The mean cross-sectional area provides a good indication of the extent of soil loss on a path section. It is derived from the product of the width and the mean depth for each survey site. Where secondary paths were recorded the cross-sectional areas were considered individually and not as a total for that survey site. The number of secondary path sites was taken as the proportion of the total number of sites for that path section. User intensity is expressed as a proportion of the maximum user intensity recorded for the four paths, the Giant's Ridge path, which recorded 900 users over a two month period.

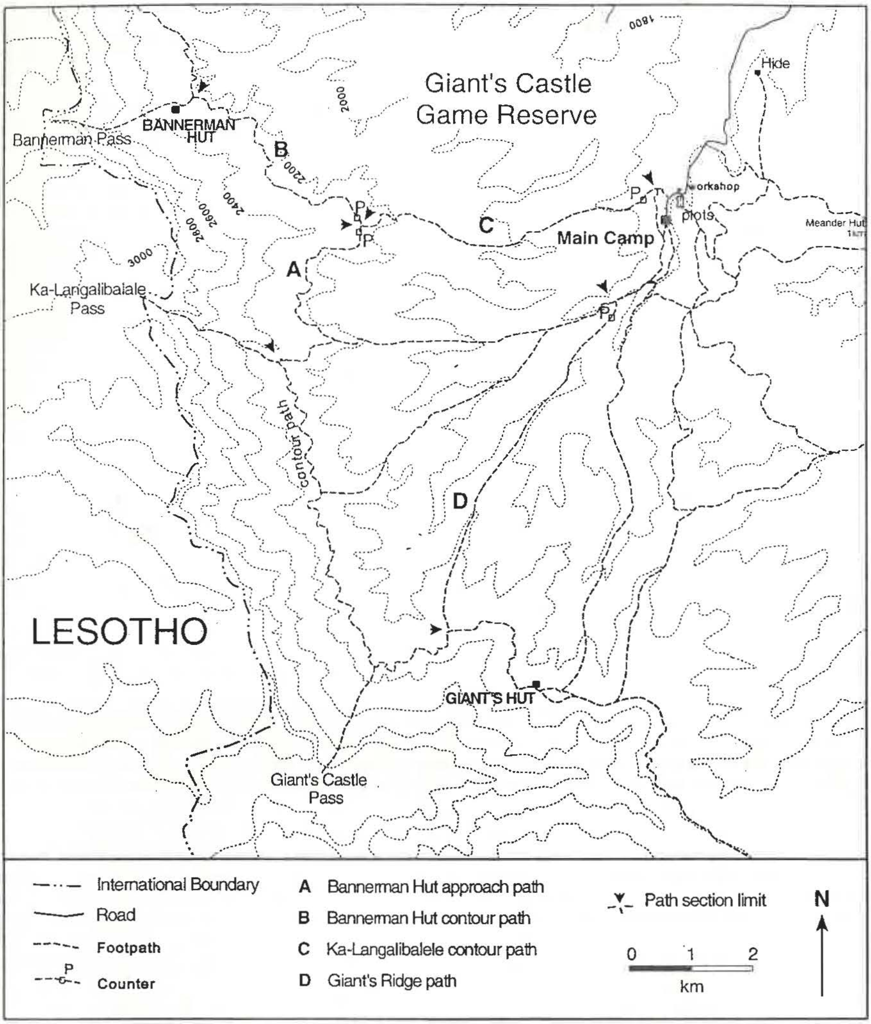

Figure 1. Footpaths in Giant's Castle Game Reserve

|  | Ka-Langalibalele pass contour path | Bannerman Hut contour path | Bannerman Hut approach path | Giants Ridge path |
|---|---|---|---|---|
| Path length (m) | 4605 | 4168 | 5491 | 6458 |
| No.of survey points | 46 | 41 | 55 | 65 |
| Mean width (cm) | 49 | 54 | 54 | 53 |
| Mean max depth (cm) | 11 | 14 | 12 | 13 |
| Mean cross-sectional area ($cm^2$) | 510 | 651 | 601 | 586 |
| Mean path gradient (°) | 2.8 | 3.2 | 5.9 | 5.3 |
| Mean cross-slope gradient (°) | 13.9 | 12.7 | 11.9 | 12.3 |
| No. of secondary path points (%) | 0 | 67 | 34 | 29 |
| Mean path - slope orientation (°) | 72 | 70 | 54 | 46 |
| User intensity (% max) | 20 | 42 | 81 | 100 |

Table 1: Surveyed path section characteristics

The two contour paths sections are noticeably different from each other in morphology and user intensity, although similar in path gradient, orientation and cross-slope gradient. The number of survey sites where secondary footpaths were recorded differs considerably. The Bannerman contour path section recorded 67% of the sites with secondary footpaths and on the Langalibalele contour path section none were recorded. The number of secondary path sections is a result of recreational forces and is generally controlled by hiker response to the path conditions (see discussion below).

The two approach paths (Bannerman Hut and Giants Ridge) appear comparable in all attributes, but differ from the two contour path sections. The cross-sectional areas of the approach paths, although similar to each another, are intermediate values for the four path sections. This suggests a situation where higher mean path gradients does not necessarily cause higher path cross-sectional areas. A detailed examination of the path sections is provided by analysis of the variables measured at each survey site. Results from this analysis are categorized broadly under the sections of Coleman's (1981) model.

## Forces of Resistance

The resistance to erosion is governed by soil and vegetation characteristics. Apedal upland soils dominate the area and these tend to be highly leached, with a good aggregate stability (Eyk *et al*, 1969). Grass types are predominantly *Themeda trianda* in the regions below approximately 2200m. Above 2200m a mixed grass type occurs including a predominance of *Diheteropogon filifolius, Festuca costata, Harpocloa flax, Koeleria capensis* and *Themeda trianda.* The two approach paths © and D, Fig. 1) lie predominantly within Themeda trianda and the sections of the contour path (A and B, Fig.1) lie predominantly in the mixed grass type. Variations in mean cross-sectional area (Table 1) show that the contour paths sections have both the highest and the lowest cross-sectional areas. This illustrates that variations in vegetation types do not explain variations in the condition of the paths. A similar situation appears to exits for any altitudinal variations of soil type.

## Recreational forces

The impact of walkers on the path surface is two fold. Firstly, it causes compaction of the soil and secondly, it causes soil deformation and smearing or shearing of the soil (Quinn *et al*, 1980) resulting in truncation of the soil horizons. Compaction may decrease porosity to such an extent that the paths become practically impermeable, favouring runoff (Starodubova, 1985). Bryan (1977) found that soil truncation is related to intensity of use. The relative importance of compaction and truncation by erosion on footpaths has not yet been fully investigated. Soil core samples taken from approach paths in the vicinity of the Main Camp indicate that compaction may account for as much as 20% of the cross-sectional area of a path on path gradients less than 5°.

Previous research has shown relationships to exist between path use and path morphology. Coleman (1981) found path erosion to increase with the square of the recreational pressure. Tinsley and Fish (1985) found that path width and visitor use were directly related to increased amounts of soil movement, but did not necessarily result in greater net erosion. The main factor influencing path width in some areas has been found to be the walking frequency (Weaver and Dale, 1978; Auerswald and Sinowski, 1989) and path width is shown to increase with the log of trail users (Dale and Weaver, 1974; Weaver and Dale, 1978). The magnitude of the path cross-sectional area may depend in part on the user intensity, particularly where path gradients are high (Table 1). This factor alone cannot, however, fully explain the path morphological characteristics in Giant's Castle Game Reserve.

The formation of a secondary path running parallel to, and in close proximity to, the original path generates a second drainage line. This has the potential to increase the rate and quantity of soil loss at any particular site. The mean cross-sectional area for the survey points which had secondary paths was found to be 2.79 times those survey points which had single paths. This indicates an almost three fold increase in the total soil loss at specific sites. The prevention of secondary path initiation should thus rate highly in path management objectives.

The controls on the formation of secondary paths are, however, poorly understood. Auerswald and Sinowski (1989) observed a distinct tendency toward extensive branching of paths with an increasing number of walkers. This was not quantified. Lance *et al* (1989) found a trend for secondary paths to form where paths ran through wet hollows, and less frequently, where the new paths were narrower and firmer underfoot. There also exists a greater tendency for walkers to leave the path coming downhill (Bayfield, 1973). These observations are not sufficient to explain the existence of multiple paths in Giant's Castle Game Reserve. Firstly the user intensities do not satisfactorily account for the relative number of secondary path sites on different path sections. Secondly the secondary path sites exist regardless of changes in soil moisture characteristics and thirdly, the tendency for walkers to leave the path when walking down hill does not explain the reason for leaving the path.

An important controlling factor over the development of multiple paths in the studied area appears to be the existence of a narrow, deep path. A narrow, deep path makes walking uncomfortable, and allows vegetation to hang over into the path. Walking is then particularly uncomfortable when the grass is wet. Such a situation may encourage hikers to leave the path and walk next to it thus creating a second path. Width to maximum depth ratios were calculated for each survey site and assigned into classes (Table 2). The number of observations in each class was then plotted (Fig. 2). Where secondary paths occurred the higher width to depth ratios of the sites are indicated in the multiple path series. A rocky tread also makes walking awkward or treacherous by giving a loose underfoot surface and increasing the potential for injury. This encourages hikers to leave the path and walk alongside. At only five of the surveyed sites where multiple paths were recorded the situation arose where the tread was recorded to be too rocky to allow stepping between rocks onto the path surface. These data are not included in the width to maximum depth analysis since a rocky tread may initiate the formation of a second path even if the path is not narrow and deep.

From figure 2 it is evident that a threshold exists at class 9 for the existence of multiple paths. This indicates that the probability of multiple path development increases below a width to maximum depth ratio of 4.50. It does not necessarily imply, however, that multiple paths will form below that value as it is evident that a proportion of the single path sites have width to depth ratios in this range. The potential for encouraging hikers to leave the established path does, however, increase below the threshold value.

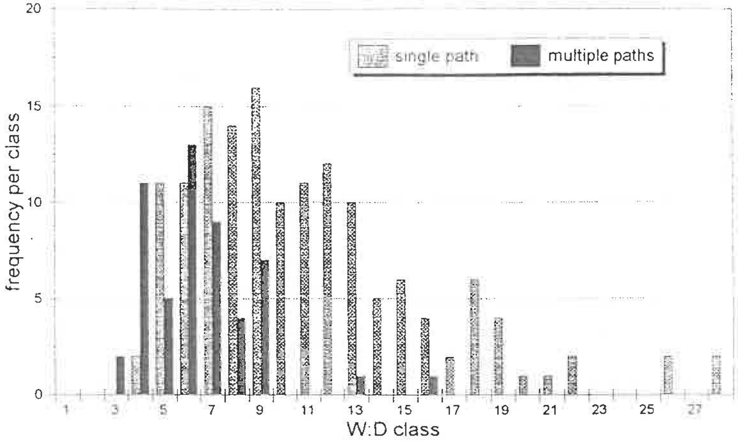

Figure 2. Occurrence frequency of width to maximum depth class ratios for single and multiple footpaths

| Class | Width to depth ratio | Class | Width to depth ratio |
|---|---|---|---|
| 1 | 0.00 - 0.50 | 11 | 5.01 - 5.50 |
| 2 | 0.51 - 1.00 | 12 | 5.51 - 6.00 |
| 3 | 1.01 - 1.50 | 13 | 6.01 - 6.50 |
| 4 | 1.51 - 2.00 | 14 | 6.51 - 7.00 |
| 5 | 2.01 - 2.50 | 15 | 7.01 - 7.50 |
| 6 | 2.51 - 3.00 | 16 | 7.51 - 8.00 |
| 7 | 3.01 - 3.50 | 17 | 8.01 - 8.50 |
| 8 | 3.51 - 4.00 | 18 | 8.51 - 9.00 |
| 9 | 4.01 - 4.50 | 19 | 9.01 - 9.50 |
| 10 | 4.51 - 5.00 | 20 | 9.51 - 10.00 |

Table 2: Class intervals for width to depth ratios

## Geomorphological forces

Correlations between variables for the four footpath sections are illustrated in Table 3 (all significant at 95% or better). Some correlations are to be expected. Since the two approach paths essentially guide hikers from low elevations to higher elevations, correlations are expected between path gradient and cross-slope gradient, but not for the contour paths sections. The contour path sections generally follow the contours but have short sections of changing altitude. Correlations between path width and depth for the path sections range from strong (Bannerman Hut contour path) to poor (Bannerman Hut approach path).

| | Ka-Langalibalele pass contour path | Bannerman Hut contour path | Bannerman Hut approach path | Giants Ridge path |
|---|---|---|---|---|
| Width / depth | 0.438 | 0.623 | 0.300 | 0.435 |
| Path gradient / cross-slope gradient | 0.151 | 0.022 | 0.342 | 0.424 |
| Orientation / cross-sectional area | -0.044 | -0.594 | -0.064 | 0.275 |
| Cross-slope gradient / cross-sectional area | 0.135 | 0.013 | 0.065 | 0.461 |
| Path gradient / cross-sectional area | 0.133 | 0.254 | 0.411 | 0.497 |
| Path gradient / width | 0.102 | 0.057 | 0.335 | 0.421 |
| Path gradient / depth | 0.136 | 0.300 | 0.418 | 0.630 |

Table 3: Correlation coefficients (r) for surveyed footpath attributes

Relationships between path width, depth, cross-sectional area and path gradient have been established by other authors. Trail depth depends on compaction and erosion and therefore on climate, vegetation type, soil and substrate type, slope and type of user (Dale and Weaver, 1974). Weaver and Dale (1978) found trail depths tended to be greater on slopes than on level sites. Auerswald and Sinowski (1989) found that path depth increased linearly with path steepness. Garland (1985) found a weak yet significant relationship between depth and path slope, depth and hill-slope, and depth and width. Trail width has been found to increase linearly with increasing path slope (Bayfield, 1973; Dale and Weaver, 1974). Coleman (1981) showed that the extent of path erosion was found to increase with the square root of the slope angle.

The survey data from Giant's Castle indicates that correlations exist between path gradient and the width, depth and cross-sectional area for the two approach paths (Table 3). No such relationships were found for the two sections of the contour path. Regression suggests, however, that the relationships are not strongly linear. The approach paths carry the highest number of users and have the highest mean path gradients (Table 1). This suggests that the recreational forces exerted by path users may be a contributing factor. The shearing action of hikers on soil and vegetation has the greatest effect on steeper slopes (Quinn *et al*, 1980) and this will contribute to the breakdown of the path tread and facilitate removal by runoff.

Bryan (1977) observed that topography was significantly related to trail orientation and that where paths follow the fall-line severe water erosion hazard exists, regardless of slope angle. Bratton *et al* (1979) found a significant negative correlation between orientation and erosion. The only path section in which there is a correlation between the path orientation and the cross-sectional area is the Bannerman Hut contour path section where the orientation of the path explained 59% of the variance. This path section shows a negative correlation and regression indicates that some linear relationship ($r^2 = 0.35$) exists (Table 3). This suggests that where path gradients are low, the cross-sectional area may be at least partially explained by the orientation of the path to the slope.

The Giant's Ridge path is the only path section where cross-slope gradient can explain some of the variation in cross-sectional area (Table 3). This path section has the lowest mean path - slope orientation (Table 1) indicating that the path is generally more orientated up the slope than the other path sections. The

Langalibalele contour path section shows very poor overall correlations and it is concluded that none of the independents measured can explain the variations in cross-sectional area, width or depth.

Bannerman Hut was closed for five weeks during the two month period when the user intensity of the path sections was measured. This suggests that the Bannerman Hut contour path section may well have a higher user intensity than the data indicates. The abundance of secondary paths on the Bannerman Hut contour path section in comparison to the Langalibalele Pass contour path section (Table 1) and the location of the path, providing easy access to Bannerman Hut, supports this. Thus it is possible that the Bannerman Hut contour path has a higher user intensity, possibly similar to the corresponding approach path.

Based on this assumption some important points emerge. The path construction and path age must play a role in determining the morphology of the paths. Although thresholds cannot be established here relative comparisons can be made. It is apparent that as the use of the path increases, and the extent of compaction and erosion increases, the control of path design and construction on morphometry decreases. This is a result of the paths becoming more in equilibrium with the forces exerted on them and is illustrated by the stronger correlations between independent and dependent variables for the higher-use footpaths. On higher mean path gradients (the two approach paths) the path morphometry is correlated to the path gradient. On lower mean path gradients with relatively high intensity of use (Bannerman Hut contour path) the orientation of the path to the slope is an important controlling factor. Where a path becomes more orientated to the direction of the slope then it appears that the cross-slope is important. Relationships and thresholds for these types of findings still need to be determined.

## CONCLUSION

In order to successfully plan new footpaths and to maintain existing footpaths, a knowledge of the processes operating on the footpaths is essential. There has, however, been a limited amount of research on the mechanisms and controls of the path erosion process, particularly in Southern Africa. Research thus far illustrates that the erosion process is a result of a complex interaction of the various components of the process. Most findings are site specific and cannot easily be extrapolated to other areas.

The existence of multiple paths can dramatically increase the total soil loss for a particular path section. Prevention of multiple path formation and the remediation of badly affected sites should thus rate highly in management objectives. The initiation of a secondary path is controlled primarily by the width to depth ratio. Findings show a threshold width to depth value of 4.50. Below this the probability of secondary path formation increases as hikers are encouraged to leave the existing path.

The findings from this survey do not conclusively explain variations in path morphometry, although some trends can be noted. Correlation coefficients show that when mean path gradients are high some of the morphological variance can be explained by path gradient. Where mean path gradients are lower and use is high then the orientation of the path to the slope best explains morphological variations (linear relationship). It appears that the influence of path construction on morphological correlations with orientation and gradient decreases with increasing path use.

## ACKNOWLEDGEMENTS

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This paper forms is extracted from a MSc dissertation and is submitted to *Geoökdynamik.*

# Fluvial terraces near Battle Cave in the Injasuti Valley, KwaZulu Natal Drakensberg

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*A river terrace complex in the Injasuti River Valley at Giant's Castle Game Reserve was investigated to establish the cause and sequence of depositional events. Lowering of the river gradient within the vicinity of the site and the change in direction of the river, from a westward direction to a northward direction, appears to have caused a decrease in velocity of the river, resulting in the deposition of the river load. Four terraces were identified within the complex. These appear to be the result of two catastrophic events, the earlier event being greater in magnitude than the more recent. The relative age of the river terraces is difficult to determine due to the absence of datable material. The presence of river terraces above the current stream level appears to indicate high magnitude fluvial events during a previously wetter period. Such river terrace complexes in the KwaZulu Natal Drakensberg have been little examined, but are potentially valuable in palaeoenvironmental reconstruction.*

## INTRODUCTION

The phenomenon of river terrace formation from alluvial derived material, particularly in mountain environments, has to a large extent been a neglected area of study in southern Africa. Apart from the recent work done by Hatting (1994a; 1994b) in the gravel terrace deposits of the Sunday's River Valley, very little research has been undertaken. Geomorphologists in southern Africa, are in a unique situation with regards pioneering work in this field.

In Europe and America, the knowledge of alluvial terrace formation is advanced. Although useful in helping to understand the theory and mechanisms of formation of river terraces in other areas of the world, this relates primarily to the European and American environment and extrapolations to southern African conditions are difficult. The mere concept of scale is unique in southern Africa particularly with regards the high intensity rainfalls and the corresponding high energy, high velocity river systems common to Natal.

This project investigates a river terrace complex in the Injasuti Valley in Giant's Castle Game Reserve. The project aims to determine why the terraces, of fluvial origin, were deposited at the location. Further the project attempts to assess the direction from which the material came from and determine sequence of depositional events.

## STUDY SITE

The study site is located in the northern region of Giant's Castle Game Reserve in the upper reaches of the Injasuti Valley. The river terrace complex investigated is located upstream from the Injasuti camp, a distance of approximately 7km. Figure 1 depicts the river terrace sites location (position A) within the reserve. The terrace complex is situated on the north west bank of the Injasuti River, at the confluence of the Mbovaneni Stream with the Injasuti River. Extending approximately 10m downstream of the confluence and 200m upstream of the confluence. Due to the high altitude and relief intensity in the high mountain drainage basin (Siegburg, 1994), erosion of the Injasuti River valley has resulted in the formation of cliffs and minor scarps of Clarens Sandstone. The morphology of the river valley differs dramatically upstream and downstream from the terraces (Fig. 2 and Fig. 3). The terrain above the terrace complex increases in altitude quite rapidly and is characterised by a very narrow v-shaped valley, while downstream, the descend in altitude is more gradual with a much wider U-shaped valley and a flat river bed being characteristic. As is common in mountain environments, the Injasuti River system is braided. A braided river is defined as one that consists of two or more channels divided by bars and islands (Miall, 1977). Evidence of braid bars and palaeochannels are apparent within the site at Injasuti. The site was chosen primarily due to its accessibility by path and close proximity to Battle Cave.

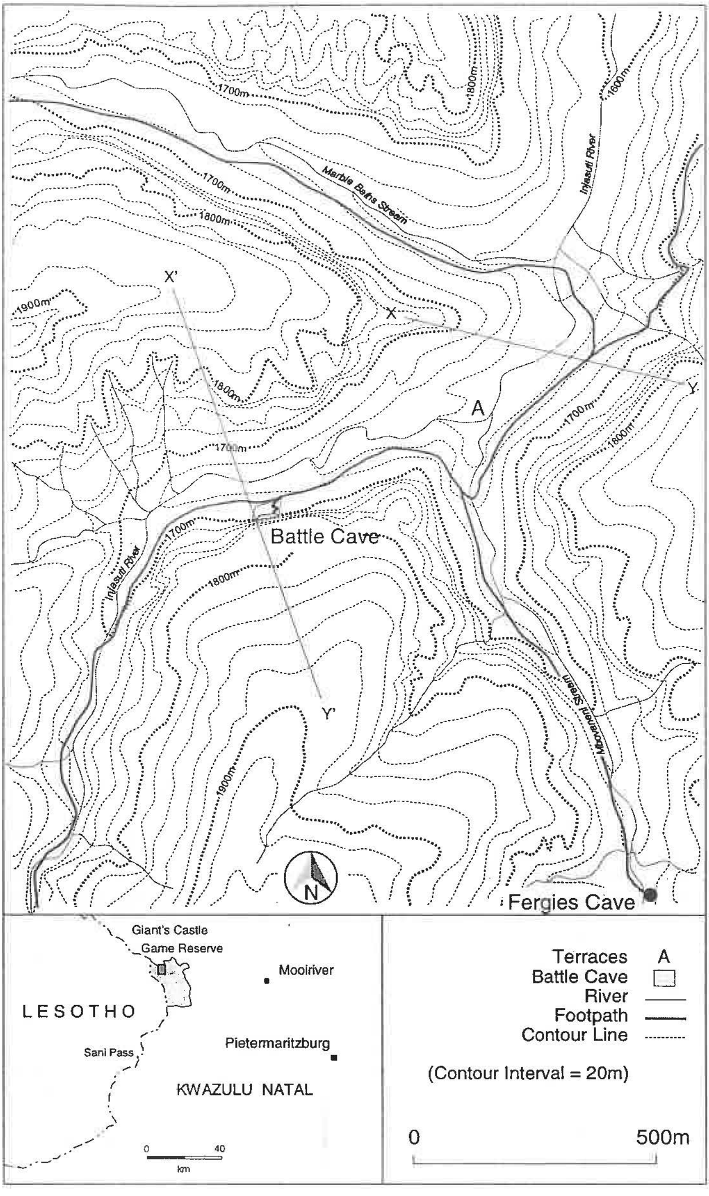

Figure 1. Position of terrace complex within Giant's Castle Game Reserve. (Modified after Meiklejohn, 1994)

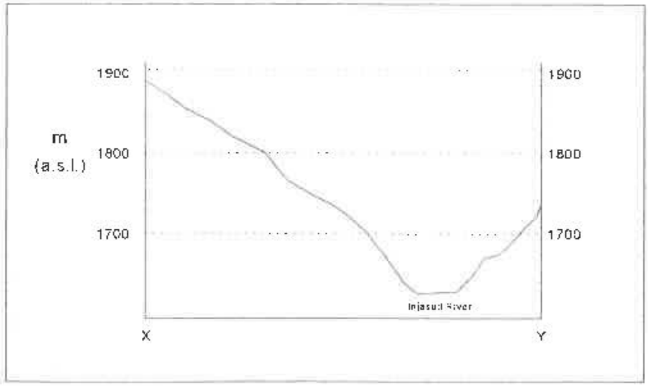

Figure 2. Downstream valley profile X - Y.

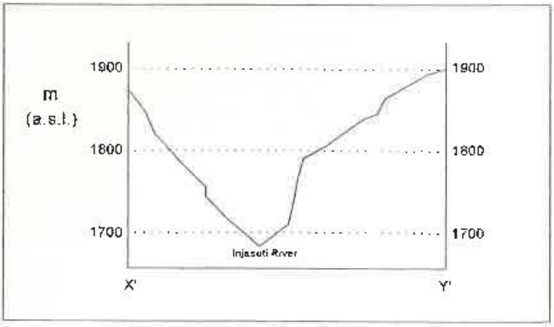

Figure 3. Upstream valley profile X' - Y'.

## METHODOLOGY

### Field analysis

#### Profiles

Methodology is divided into two stages, namely field analysis and laboratory analysis of samples taken from the terraces. In the field, morphology of the river terrace complex was determined by a series of profiles and theodolite readings. Three valley cross profiles and one river profile were measured with the use of an abney level and tape measure. Valley cross profiles were measured from the slope above the terraces, across the river onto the slope on the other side of the river, opposite the terraces. The cross sectional profiles were positioned to highlight the different terraces within the complex. A river profile was measured such that height above the present day river position could be determined. Height and morphology of the different terraces were determined with the use of a theodolite and measuring rod.

#### Fine sediment

Two soil samples from each identified terrace were taken for determination of particle size distribution. A total of eight samples were collected. A-horizon soil samples were taken from the lower terraces. This area of the terrace appeared to have been influenced by processes of pedogenesis and slope processes. Due to the hazardous nature of the exposures, the collection of A-horizon samples was not feasible. The remote nature of the site makes access of equipment such as ladders difficult.

#### Fabric Analysis

Fabric analysis is a description of the three-dimensional disposition of the individual grains, pebbles or boulders that make up a deposit. Measurement is by reference to the orientation or alignment of the particles and by analysis of their dip or plunge (Briggs, 1981). Although selection of site is important in any analysis, it is of particular importance with regards fabric analysis as an undisturbed sample is required.

Due to the fact that there is no standard method for sampling fabric analysis on terraces, a sampling plan had to be derived. As the terrace exposure is heterogeneous, the first requirement of the sampling plan was that the sampling site should be representative of the entire exposure without any form of personal bias. The second requirement was that a systematic sampling technique was formulated to ensure that errors were kept to a minimum and personal bias did not interfere with the measurements. These problems were overcome first, by the measurement of two sets of fabric analyses on each terrace, and secondly with the use of ropes hung vertically down the terrace face, a grid system whereby all clasts that intersected the rope were measured. Length, orientation, dip, rock type and roundness of the clasts along each transect were measured. Once again the two higher terraces posed a problem. Due to the unconsolidated nature of material, it was not feasible to measure fabric analysis in the upper two terraces. A visual investigation established that trends measured in the lower portions of the terraces were duplicated in the upper sections. Further measurements and determinations could not be established without the use of correct equipment such as ladders and scaffolding.

### Laboratory analysis

#### Fine sediment analysis

A description of the basic properties of geomorphological materials, such as particle size, is often the most important starting point for an explanation of geomorphological processes (McAllister, 1981). Particle size distribution refers to the relative proportions of the various soil sizes and is a fundamental property of geomorphological materials providing clues to their origin and behaviour.

As sediment removal from hillslopes is particle size selective (Parsons et al, 1991; Syvitski, 1991), the measurement of particle size analysis is one of the most important and useful techniques of sedimentary analysis (Briggs, 1977). Although there are a number of methods available to determine particle size analysis, ranging from the measurement of the primary axis of gravels and cobbles to the centrifugal particle size analysis of silts and clays, the simplest and most preferred method for determining particle size analysis of the sand component of soil is with the use of a vibrating sieve stack (Allen, 1981).

Here the sieves are stacked in descending order of aperture size. The sample dry weight recorded and the sample placed in the top sieve. The stack of sieves is then vibrated continually for 15 minutes at 50 Hz. The sieve sizes used ranged on phi units from -3 phi (8000μm) to 4 phi (63μm) and the fraction less than 4 phi collected in the tray at the base of the sieve stack. On the Wentworth grade scale, this constitutes the silt and clay fraction of the sediment (Briggs, 1977). The weight of the sediment, retained in each sieve, was calculated as a percentage of the original sample weight and plotted on a histogram (Allen, 1981). Cumulative percentages, from coarse to fine, were determined and plotted for further statistical descriptions of the sample.

## RESULTS

### Profiles

Figures 4, 5 and 6 illustrate the cross valley profiles. Four distinct terrace levels are confirmed by valley cross profile analysis of the Injasuti River. It is important to note that all the profiles are represented looking down the Injasuti Valley. Thus profiles were measured from the north river bank to the south bank. Each profile will be discussed below.

Figure 4 illustrates the first cross valley profile. The most significant feature on the diagram is terrace 1. The characteristic flat surface and steep flank features of river terraces are well represented in Figure 4. Situated furthest downstream, Terrace 1 is the highest of all the terraces studied. The terrace, measured from the palaeochannel (Y) at the base of the terrace to the crest of the terrace, is 12m high. Position X marks the location of the present day river channel. Braid bar deposits, situated on either side of the river, are made up of rounded clasts and boulders of Drakensberg basalt and Clarens sandstone. Void spaces between the rounded boulders are filled by finer sediment that has accumulated to form fine sediment deposits.

Figure 5 portrays terrace 1 in relation to terrace 2. The difference in height between terrace 1 and terrace 2 is minimized by the 'tapering off' of terrace 1 at its western most boundary. The change from the one terrace to the other is characterised by a difference in height between the two. This is explained by Davis (1970), who describes the different mechanisms by which river terraces are formed and the resulting terrace patterns formed by each mechanism. These will, however, be discussed in greater detail later. The present day stream position (X) is situated much closer to the terraces than in Figure 4. This can be attributed to the fact that the profile was measured above the confluence of the Injasuti River with the Mbovaneni Stream. The valley is therefore much narrower than downstream of the confluence. Position of the braid bars to the right of the stream may also affect the proximity of the stream to the terraces.

Figure 6, positioned slightly further upstream from the profile in Figure 5, illustrates the position of terrace 2, terrace 3 and terrace 4. The lower three terraces in this profile are all positioned parallel to the present day stream. Once again the characteristic flat upper surface and steep flanks are evident. The present day stream position (X) is now situated at the base of terrace 4. The present day stream position therefore has moved gradually away from the terraces with a move downstream. Terrace 4 is characteristically more defined than terrace 2 and terrace 3. This can be attributed to the fact that the higher terraces have undergone more erosion than terrace 4, due to the different ages of the terraces.

The downstream river profile (Fig. 7) depicts the change in height of the river within the study area. Over a 300m stretch, the river descends in height by almost 20m. The river profile therefore has a gradient of 3.95° within the vicinity of the study site. This is characteristic of a high energy stream in a mountain environment, as is the case with the Injasuti River in the Drakensberg.

From the above profile evaluation, a number of assumptions can be made. The first is that the highest terrace must be the oldest terrace due to its height above the rest of the terraces and above the present day river position. Each terrace is therefore a relict of a previous landscape. Secondly, the terraces must decrease in age with a decrease in height above the present day stream. Thus terrace 4 which is situated approximately 2.5m above the present stream position must be the youngest.

### Fine sediment analysis

Cumulative particle size analysis for the samples analysed showed similar trend for all the terraces. Particle size analysis for terrace 4 (Fig. 8), the lowest terrace in the complex, illustrates the differences between the two sediment samples taken from the terrace exposure, and the sample obtained from the pedogenetic layer that has formed on top of the terrace. Results show that sample 1 and sample 2 are very similar, while the A horizon sample is distinctly different. This trend is continued in terrace 3 (Fig. 9), terrace 2 (Fig. 10) and terrace 1 (Fig. 11).

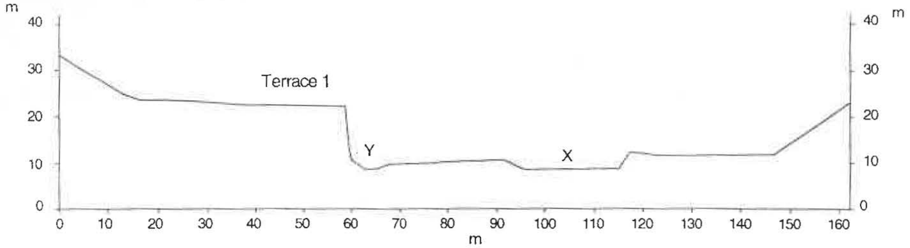

Figure 4. Valley cross profile illustrating terrace 1, present river channel (X) and palaeochannel (Y).

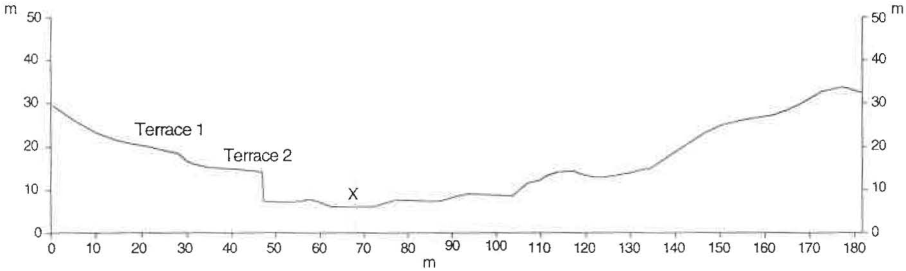

Figure 5. Valley cross profile illustrating terrace 1, terrace 2 and present river position (X).

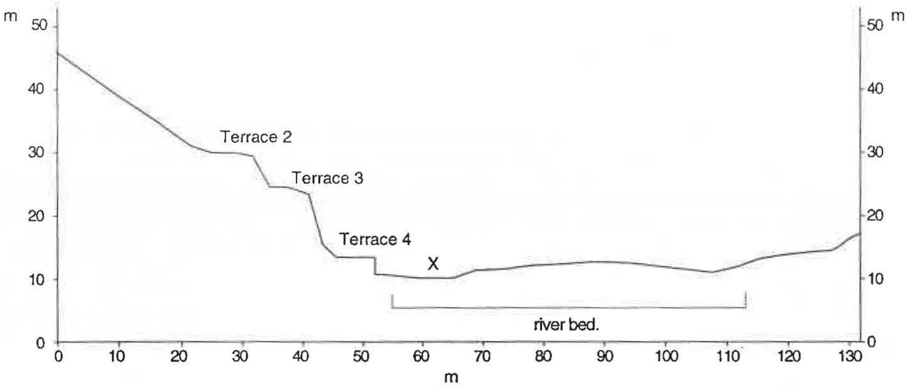

Figure 6. Valley cross profile illustrating terrace 2, terrace 3 and terrace 4. and present river channel

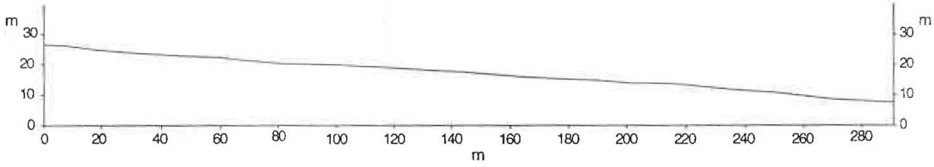

Figure 7. Downstream river profile.

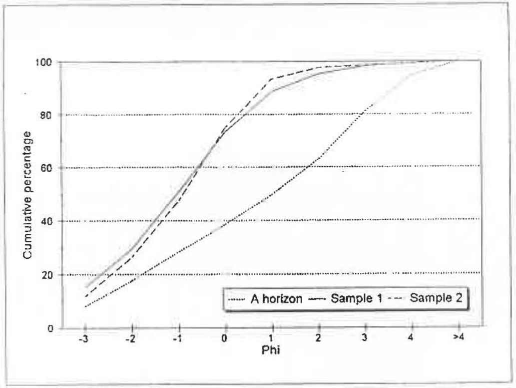

Figure 8. Cumulative particle size distribution for terrace 4

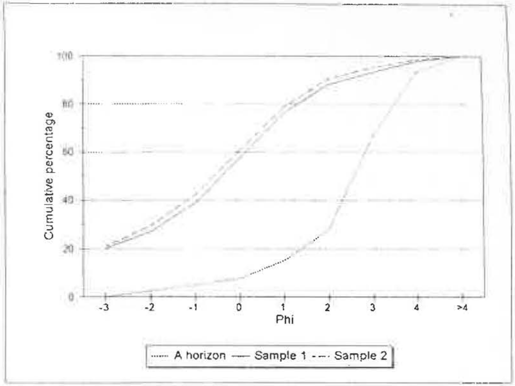

Figure 9. Cumulative particle size distribution for terrace 3

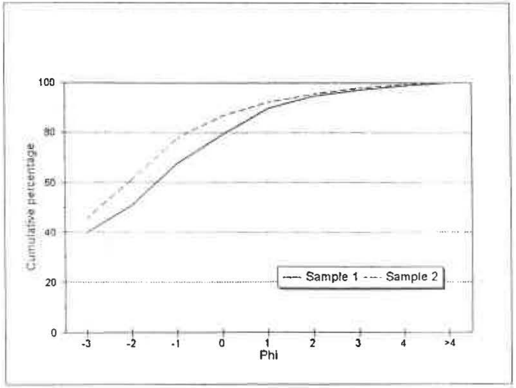

Figure 10. Cumulative particle size distribution for terrace 2

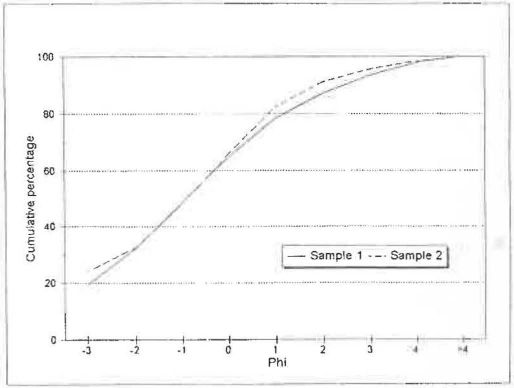

Figure 11. Cumulative particle size distribution for terrace 1

Due to the hazardous nature of the terrace exposures of terrace 2 and terrace 1, a sample of the A horizon was not obtained. Comparison between the two soil samples taken from each of the terraces, illustrate that samples within each of the two terraces are similar in nature. The slight differences that are apparent may possibly be due to the weathering of the exposed terrace surface.

Each of the samples from the different terraces were compared using the Kolmogorov-Smirnov test to determine whether the complete form of two distribution samples taken from each of the terraces are the same such that they can be considered to be the same population (Till, 1974). For all the soil samples at the respective terraces, the Null Hypothesis could be accepted at the 95% confidence limit. Consequently, the soil samples at each of the terraces are accepted to be from the same population. Comparison of the A-horizon samples from terrace 1 and terrace, using the Kolmogorov-Smirnov test, revealed that the Null Hypothesis is rejected at the 95% confidence. Therefore the samples are rejected as being from the same population.

This can however, be explained by the difference in time that the soil forming processes have been allowed to act on the respective terraces. If the assumption, that the terraces increase in age away from the present day stream level is correct, then pedogenesis must also increase with age away from the stream provided conditions are conducive to soil formation. That is that the terrace surface is not either under water, or is too alkaline or acidic to sustain soil formation.

### Clast analysis

Rose diagrams of orientation measurements from fabric analysis were drawn up in an attempt to determine trends that may exist between the terraces. All the rose diagram show a very tight collection of orientation values within a small quadrant of the rose diagram. This is significant as the direction from which the material came from can be established.

Results from terrace 1 (Fig. 12) and terrace 2 (Fig. 13) show very similar trends. Mean values derived from the von Mises distribution for terrace 1 and terrace 2 are very similar, 278,56° and 272.99° respectively (Table 1). Values obtained from terrace 3 (Fig. 15) and terrace 4 (Fig. 16) are also very similar, 310.31° and 307.53° respectively, however, the mean value of terrace 3 has been influenced by the position of the outlier between 55°and 65° (Fig.15). The outlier therefore has the effect of pulling the mean away from the area of most concentration towards the outlier. Due to the fact that the outlier is reflected in the other half of the rose diagram; ie it mirrors the position of the area of most concentration, the direction from which the material is derived, is still the same.

| | Mean (°) | Standard deviation |
|---|---|---|
| Terrace 1 | 278.56 | 52.86 |
| Terrace 2 | 272.99 | 38.94 |
| Terrace 3 | 310.31 | 45.77 |
| Terrace 4 | 307.53 | 45.92 |

Table 1. Mean values and standard deviations derived using von Mises' distribution.

Although the data obtained for fabric analysis is very similar, one noticeable difference between the respective sets of data, is the absence of sandstone clasts within the exposures of terrace 1, terrace 2 and terrace 3 and its presence in terrace 4. This is an important aspect as no basalt deposit is evident at the study site. The basalt thus it must have been transported from elsewhere and deposited in its present position. The most obvious suggestion is that material was derived from upstream within the Drakensberg basalt layer and is thus an allochthonous deposit.

Powers' roundness index assign the majority of the clasts measured to the well rounded category. That is between 0.7 and 1.0. No differences therefore appear to exist between the different terraces. Although both basalt and the Clarens sandstone tend to weather to rounded boulders, the similarities that exist between the present day stream boulders and rocks and the clasts incorporated in the terrace are very similar. Imbrication of clasts, dipping in an upstream direction, is evident throughout the entire terrace complex. Slope material would not tend to show the same degree of rounding or stacked imbricated nature, thus it can be deduced that the terraces are made up of fluvially derived material.

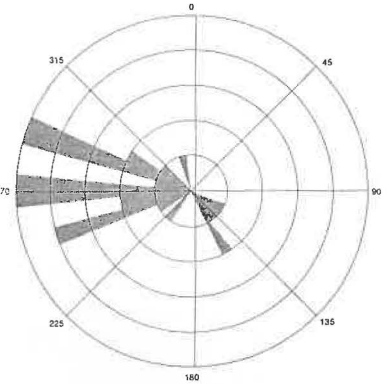

Figure 12. Terrace 1 fabric orientation

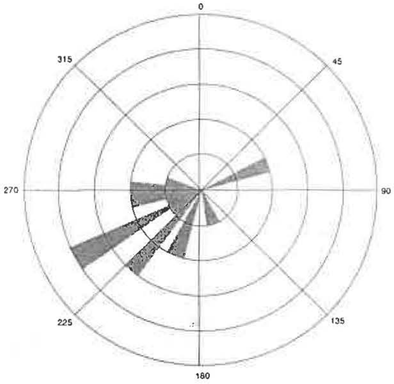

Figure 14. Terrace 3 fabric orientation

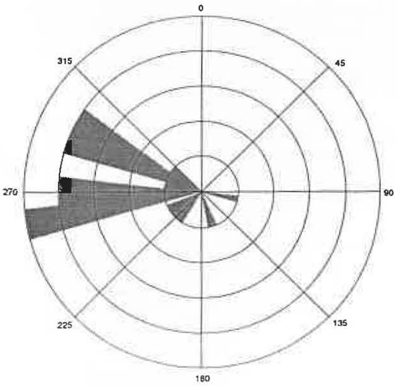

Figure 13. Terrace 2 fabric orientation

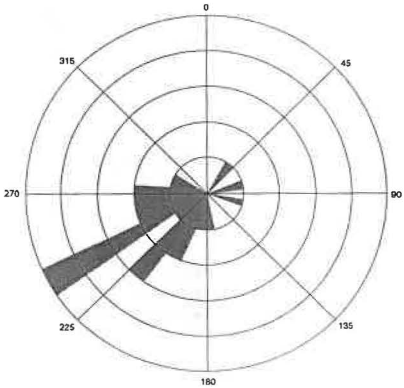

Figure 15. Terrace 4 fabric orientation

## DISCUSSION

From field investigation, a number of factors are revealed. The first is that the terrace complex is divided into four distinct terraces levels (Table 2). Secondly, the terraces appear to have been laid down as two separate events. The initial event, as a catastrophic event resulting in the deposition of approximately 12m of debris. Reworking of the debris by fluvial action and the incision of the river into the debris at a number of different levels, resulted in the formation of the upper three terraces. The second event, also catastrophic, but smaller in scale than the first (possibly similar in nature to the 1987 floods), resulted in the deposition of the debris that constitutes the lower most terrace. Further reworking and incision of the river within this debris resulted in the formation of terrace 4. A distinguishing feature regarding the terraces is they are all characterised by very low angled upper surfaces (approximately 0°-7°) and very steep flanks (approximately 80°- 90°). It is on these steep exposed profiles that fabric analysis was determined.

| | Height above present-day stream level (m) |
|---|---|
| Terrace 1 | 12 |
| Terrace 2 | 8 |
| Terrace 3 | 5.5 |
| Terrace 4 | 2.5 |

Table 2. Terrace heights above the present day stream level.

Although four distinct terrace heights are evident above the present day stream position, questions regarding the age, origin, position of the debris in relation to the rest of the river valley and energy of the water transporting the sediment are not answered by the results above. While no conclusive answers can be assign to these questions, some ideas can be formulated based on investigation and interpretation visual field analysis.

Sedimentological investigation of the different terrace exposures show that terrace 1, terrace 2 and terrace 3 differ from terrace 4. Terrace 1, terrace 2 and terrace 3 appear to have occurred as a single depositional event as no apparent boundary exists with a decrease in height between the respective terraces. In contrast to this, a distinct boundary exists between terrace 3 and terrace 4. Visual investigation of Terrace 4 reveal a predominantly clast-supported terrace 4, while the other three terraces are more matrix supported. The upper three terraces also exhibit distinct lenses of fine sediment. This can be explained by backwater environments within a stream whereby fine sediment is deposited in quieter water environments. Such an environment can be characterised by a diminishing volume a stream (Davis, 1970).

The exclusive presence of basalt clasts in the upper three terraces is an indicator as to the origin of the material deposited. Approximate distance to the nearest available basalt at river level is 3km. However, similar terraces are located beyond the basalt-sandstone contact. Therefore the possibility exists that the material has moved further than 3km. For material to be moved this substantial distance, three criteria are required. First, that there is sufficient water to move such a large quantity of debris, originally in excess of 12m in height; secondly that material of that quantity is available for transportation, and thirdly that the river has the energy to move the entire mass and subsequently cut back and erode into the material deposited. The effects that different velocities of water have on sediment was studied by Millar (1970). Results show that when water is travelling at a velocity of 0.91ms$^{-1}$ or 3.29 kmh$^{-1}$, it is capable of moving slippery angular stones the size of an egg. For clasts measured in the terrace complex, to be moved, the water must have been travelling at extremely high velocities. Unfortunately no means for determining the actual flow velocities based on the size of the debris is available. Le Roux (1994) has formulated a computer-based technique to determine sediment transport vectors from grain-size parameters. Although this is still in the experimental stages of development and further testing is still required to determine its validity and usefulness. All three of the above mentioned criteria must however have be feasible, primarily due to the presence of the terraces today. Witness accounts of the floods in 1987, substantiate the capabilities of the river at peak flow periods

(Christianson, 1994).

From valley profiles undertaken above, below and at the depositional site (Fig. 2 and Fig. 3), a number of differences arise that could explain the position of the terraces in relation to the entire river valley. The downstream valley profile represents a distinctly wider valley than the upstream valley profile. River gradients measured immediately below the complex decreased dramatically thus resulting a flattening of the river valley. At the position of the confluence of the Injasuti river with the Mbovaneni Stream, the river also changes direction from an easterly flowing direction, to a north flowing direction (Fig. 1). This would act as resistance therefore resulting in a decrease in water velocity. The upstream valley profile depicted the opposite. Namely a very narrow V-shaped valley with a high river gradient. The position of the terraces may therefore be explained by the sudden decrease in river gradient (Harvey *et al*, 1987). Deposition would therefore result as a consequence of the sudden reduction in potential energy of the river caused by a decrease in gradient as well as a change in river direction . Thus resulting in the deposition of the material the river was carrying.

The formation of the different terrace levels within the initial deposition event can be explained by the wandering nature of the river system within the valley floor (Davis, 1970). The river will wander around freely as long as it is working on unconsolidated material. When an obstruction is encountered however, the stream will tend to swing away. Thus resulting in the formation of a cusp. Obstructions can take the from an encountered ledge, bedrock or a sufficiently large enough boulder that the river is incapable of removing. The Injasuti site therefore appears to have been formed as a result of a waning or diminishing of stream volume coupled by a wandering of the river within the river valley floor. Resulting in the incomplete terrace destruction of a three-swing cusp.

Deposition of the lowermost terrace must have occurred sometime after the first deposition event, due to the presence of sandstone boulders within the terrace exposure. The catastrophic event resulting in the deposition must have been smaller, due to the 2.5m height of the terrace, compared to approximately 12m of the first event. The time period between the two events is unable to be determined due to the lack of organic material ($C_{14}$) within the different terraces exposures. Lichenology is another possible dating technique, however this is a relatively new technique and is very expensive to determine.

## CONCLUSION

River terraces are relict features of a previous landscape. In the Injasuti River valley, a number of different sites of terraces have been identified at a number of different levels. Focussing on the site near Battle Cave (Fig. 1), profile analysis indicates the presence of four distinct terrace surfaces.. Heights of the terraces are 2.5m, 5.5m, 8m and 12m above the present day river position. Powers' rounding index indicate that the material incorporated within the different terraces is fluvial in nature due to the high roundness values (0.7-1.0). Orientation evaluation from rose diagrams and von Mises' distribution show the material to be derived from the same direction, that is from a westerly direction. Therefore the material is derived from upstream of the Injasuti River.

The positioning of the terraces appears to be as a result of the change in river gradient above and below the terrace complex. This coupled with the change in direction of the river from a predominantly westward flowing river to a northward flowing river appears to have caused a decrease in velocity of the river, thus resulting in deposition of the material being carried by the river.

The presence of Clarens Sandstone clasts within the lowermost terrace and its absence in the upper three terraces gives rise to the idea that deposition of the alluvial material occurred in two phases. This is substantiate by the distinct contact that is evident between terrace 4 and terrace 3. Between the upper three terraces however, no contact between the different terrace surfaces is evident.

Age determination of the different terraces was not able to be established due to the lack of organic material within the terraces. Due to the isolated nature of the site, the use of heavy duty machinery was not a feasible option. In the future, age may be able to be determined through the process of lichenomety. The determination of age is an important aspect of the project as palaeoclimatic regimes of southern Africa may thus be established. At present very little work in southern Africa has been undertaken to reconstruct palaeoclimatic regimes. For the terraces to be present at such heights above the present day stream level, a much wetter environment must have been experienced. Hypotheses for this include those by Hall (1994) and Hanvey *et al* (1994). Hanvey et al (1994) argue for a wetter period between 5000 B.P and 1000 B.P based on the marked change in sedimentation from clastic inorganic to largely organic sediment. Hall (1994) hypotheses a much wetter period as a result of the melting of niche glaciers within the cutback regions of the Drakensberg. If the hypothesis is correct, the meltwaters could operate as the medium of high velocity water that is required to move the volume of alluvial material a distance of over 3km. These are however, at present much disputed hypotheses (eg. Sumner, 1995). Only through intense research will answers be found and a reconstruction of palaeoclimatic regimes be established. Until then only hypotheses and assumptions can be made.

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