

The Development of a Spatial Database for Research into Cryogenic Processes and Landforms in Southern Africa

Stephanie de Villiers

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ABSTRACT

Title of dissertation : The development of a spatial database for research into cryogenic processes and landforms in southern Africa

by

Stephanie de Villiers

Promoter : Dr. K.I. Meiklejohn

Co-promoter : Mr. P.D. Sumner

Department : Geography

Degree : Magister Artium

The first publication on southern African geocryology in 1944 resulted in a recognition of the potential of cryogenic phenomena in establishing long-term climatic records in the region, leading to a substantial increase in publications and research. Cryogenic studies are concerned with the way frost-induced processes have modified, and continue to modify, the mountain regions of the subcontinent. However, problems exist in interpreting relict forms, while supportive evidence for glacial and periglacial hypotheses are lacking. Insufficient data regarding Quaternary cryogenic activity have resulted in contradicting qualitative interpretations of the palaeoclimate and poor spatial and temporal resolution.

It is apparent that there is a need for a more rigorous approach in southern African cryogenic studies as well as a better understanding of relict phenomena and the palaeoenvironment. For this purpose a database that acts as a supplementary source and a tool for GIS-based analysis, was compiled. In addition, several glossaries and indices were constructed. The main glossary is a first effort at explaining past terminology usage and providing a terminology basis specifically for current research in southern Africa.

Through database manipulation, the spatial distribution of past and present cryogenic phenomena as found in southern Africa, was mapped and it was found that cryogenic features and processes cluster along the Main Escarpment and the Western Cape Mountains. It is not clear if this is the actual situation or whether it represents a bias in the areas investigated.

Further, likely regions for glacial ice development and survival and regions for periglacial activity were determined. The extent of relict and contemporary cryogenic activity was also verified. Evaluation of available data indicates that the extent of the cryogenic palaeoenvironment did not differ considerably from the current one.

An improved understanding of the spatial distribution of both relict and current cryogenic phenomena was achieved. The database represents a contribution towards the reconstruction of the southern African Quaternary environment and supplements current knowledge on the subject. While not necessarily providing solutions to current research problems, the database, combined with the glossaries and indices, will be invaluable in future research and modelling of the Quaternary in southern Africa.

UITTREKSEL

Titel van die verhandeling : Die ontwikkeling van 'n ruimtelike databasis vir navorsing oor Suider Afrikaanse kriogeniese prosesse en landvorms

deur

Stephanie de Villiers

Promotor : Dr. K.I. Meiklejohn

Medepromoter : Mnr. P.D. Sumner

Departement : Geografie

Graad : Magister Artium

Die belangrikheid van kriogeniese verskynsels in die vasstelling van langtermyn klimaatsrekords vir Suider Afrika is reeds met die eerste publikasie daaroor in 1944 gevestig. Die gevolg was 'n aansienlike toename in die aantal publikasies en navorsing oor die onderwerp. Die prosesse verantwoordelik vir die vorming van die bergagtige gebiede van die suidelike kontinent word vervat in kriogeniese studies oor die gebied. Die interpretasie van relieke verskynsels is egter problematies weens die tekort aan voldoende bewys vir glasiale en periglasiale hipoteses. Ontoereikende inligting oor Kwarternêre kriogeniese aktiwiteit en die paleo-omgewing lei tot verskeie teenstrydige kwalitatiewe interpretasies en groot leemtes in die tyd-ruimtelike resoluksie van verskynsels.

Dit is duidelik dat daar 'n behoefte bestaan vir 'n meer noukeurige benadering tot die bestudering van Suider Afrikaanse kriogeniese aktiwiteit, asook 'n beter begrip van die paleo-omgewing en relieke verskynsels. Vir hierdie doel is 'n databasis ontwikkel wat ook dien as 'n aanvullende inligtingsbron en 'n instrument in GIS-gebaseerde analise. Verskeie woordelyste en indekse is opgestel as bykomende hulpmiddels. Die hoofwoordelys vorm die basis vir die gebruik van terminologie in huidige en toekomstige navorsing en help mee tot die ontwikkeling van 'n eiesoortige terminologie vir Suider-Afrikaanse kriogeniese navorsing.

Die ruimtelike verspreiding van kriogeniese verskynsels in Suider Afrika is deur middel van databasis manipulasie gekarteer, en dit is bevind dat kriogeniese vorms en prosesse langs die Groot Eskarp en die Wes-Kaap berge voorkom. Dit is nie duidelik of beskrywings die werklike situasie reflekteer nie en tot watter mate dit deur bestaande hipoteses en menslike faktore beïnvloed is nie. Moontlike gebiede vir glasiale ysvorming en gebiede vir periglasiale aktiwiteit is in die studie vasgestel en die strekking van relieke en kontemporêre kriogeniese aktiwiteit is ondersoek. Evaluasie van beskikbare data dui daarop dat die strekking van die kriogeniese paleo-omgewing nie drasties verskil van dié van die huidige nie.

In die studie is 'n beter begrip van die ruimtelike verspreiding van relieke en huidige kriogeniese verskynsels verkry. Die databasis vorm 'n bydrae tot die herkonstruksie van die Suider Afrikaanse Kwarternêre omgewing en is aanvullend tot die bestaande kennis van die onderwerp. Die databasis, in kombinasie met sy woordelyste en indekse, verskaf kan gebruik word as verwysingsbron vir toekomstige Kwarternêre navorsing en modelering in Suider Afrika.

“In the beginning was the Word, and the Word was with God, and the Word was God. All things were made by him; and without him was not anything made that was made. In him was life; and the life was the light of men. And the light shineth in darkness; and the darkness comprehended it not” (John 1: 1-5),

“... the invisible things of him from the creation of the world are clearly seen, being understood by the things that are made, even his eternal power and Godhead ...” (Rom. 1: 20),

“... the heavens and the earth, which are now, by the same word are kept in store, reserved unto fire against the day of judgement and perdition of ungodly men. But, beloved, be not ignorant of this one thing, that one day is with the Lord as a thousand years, and a thousand years as one day” (2 Pet. 3: 7-8)

PREFACE

On the use of the term "cryogenic"

Cryogenic processes are thermophysical, physico-chemical and physico-mechanical processes occurring in freezing, frozen and thawing earth materials. Specific processes of cryogenic action include water migration during freezing and thawing of the ground, frost heave, heat and mass (moisture) exchange, regelation and gelifluction (Poppe & Brown, 1976, cited by Van Everdingen, 1998). This is a very specific definition of what constitute cryogenic processes. For the purposes of this study the term "cryogenic" is used as a generic term to include both periglacial and glacial features and processes. It must be kept in mind, however, that the term may fall short in including or describing certain features and processes, e.g. terracettes and solifluction.

On other terminology usage

The reader may refer to The Terminology Glossary (Appendix C) for terminology usage throughout the study.

CHAPTER 1

Background, setting and research problem

1.1 Introduction

Over the last decade (1989-1999) there has been an increase in the number of studies of both past and current geocryological activities and landforms in southern Africa (Grab, 1998, 1999). These studies are concerned with the way particular cryogenic processes have modified, and continue to modify, the high summit regions of the subcontinent. Following Troll's (1944) paper on southern African geocryology, the importance of cryogenic studies in southern Africa was realised, leading to a substantial increase in publications after 1960 (Fig. 1.1).

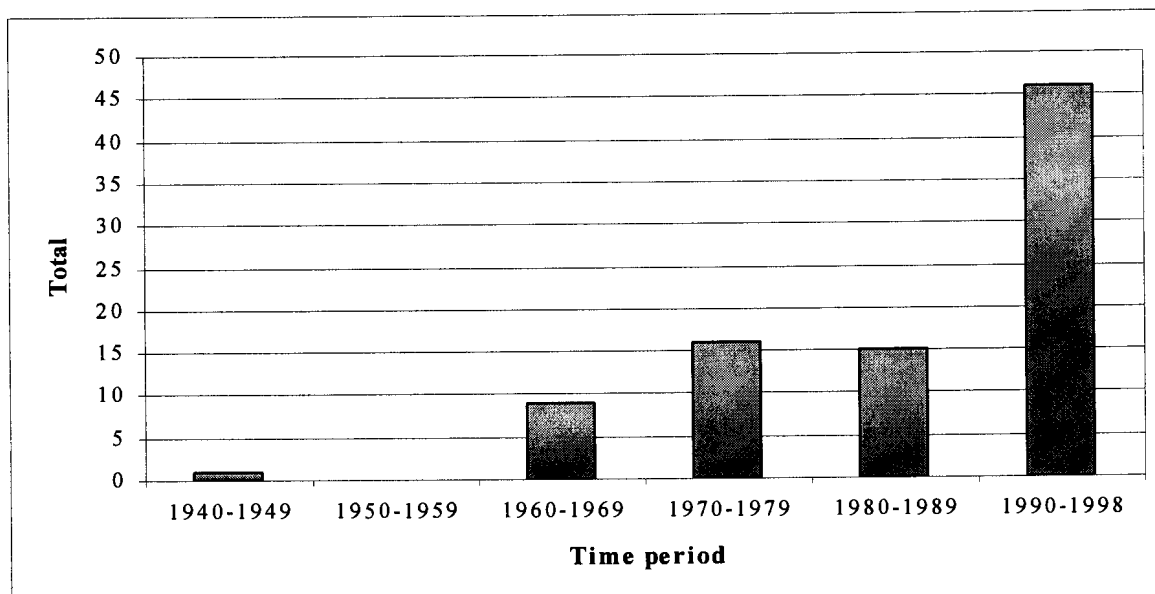


Figure 1.1: Cryogenic research publications in southern Africa between 1940 and 1998.

While contemporary activity is useful in the broader context of current environmental and earth science, palaeoenvironmental studies are important for the reconstruction of past climates. Superficial features are widespread throughout southern Africa (Grab, 1997a) and when sufficiently well preserved (Dewey, 1988), are used by researchers to establish:

- Pleistocene palaeoclimatic sequences (e.g. Sparrow, 1971),
- temperature fluctuations of the Quaternary (e.g. Hall, 1991a; Boelhouwers, 1994),
- the intensity and specific conditions of past climates (e.g. Marker, 1994a; Grab, 1999), and
- the reconstruction of a Pleistocene snowline elevation for the subcontinent (e.g. Hastenrath, 1972; Fitzpatrick, 1978).

Cryogenic research can thus be viewed within the broader context of climate change studies where assessing the past ultimately helps researchers to predict future trends. Climate has always been a major determinant of human activities, but over the last two centuries the activities of humankind have increasingly become a determinant of climate on global scale (Tyson, 1993; February, 1994a). Therefore, it has become important to understand the processes involved in climatic change and the nature of the changes taking place to forecast future events (Tyson, 1993), and in refining General Circulation Models currently used to predict atmospheric responses to global warming (Partridge, 1990; Partridge *et al.*, 1990; Hecht, 1997). Despite current research, there is a need to develop other methods of establishing longer climatic records than presently at our disposal (February, 1994a), and this involves many disciplines, e.g. biology, biogeography, climatology, pedology, palynology, botany, zoology and geomorphology (Partridge *et al.*, 1990; Grab, 1997a). Geomorphology is important in this context as the landscape responds to climatic fluctuations by generating processes which, in turn, produce products deposited as recognisable superficial forms (Dewey, 1988). It is logical to assume that landscapes react even more rapidly to extreme climatic oscillations, such as that of the Last Glacial Maximum (LGM).

1.2 The research problem

Because of a general lack of knowledge of palaeoclimates in southern Africa, more information relating climatic and geomorphic conditions during the Quaternary is required (Hall, 1991a, 1994; Le Roux, 1991; Marker, 1991a). In this regard research has focussed on cryogenic geomorphology in the high summit areas of southern Africa to establish the extent of contemporary and relict features in these regions (Sumner & Meiklejohn, 2000).

However, problems exist in interpreting surviving relict forms (Grab, 1996a). A number of superficial cryogenic features have been recognised and attributed to either Pleistocene glaciation or periglacial activity (e.g. Linton, 1969; Borchert & Sanger, 1981; Lewis, 1987;

Marker, 1992; Lewis & Hanvey, 1993; Grab, 1996a). However, supportive evidence for a glacial hypothesis is insufficient and Pleistocene periglacial activity is subject to considerable debate (e.g. Le Roux 1990, 1991; Marker, 1990a, 1991b; Hall, 1991a, 1994; Sumner, 1995). The arguments and difficulties currently facing southern African glacial and periglacial research will be discussed in Chapter 2, but are summarised as follows:

- Despite the relatively large body of research, the significance of many relict landforms remains difficult to interpret.
- The spatial extent of specific features and their associative processes are unknown.
- There is insufficient data regarding cryogenic activity during the Quaternary, which has resulted in contradicting qualitative interpretations of the palaeoclimate.
- The origin of relict landforms has seldom been interpreted within a larger palaeo-environmental context.
- There is an apparent lack of rigour in palaeocryogenic research.
- Spatial and temporal resolution of Quaternary cryogenic activity is poor.

Certain specific problems associated with cryogenic research in southern Africa can be identified and summarised as follows:

- Many relict landforms have been identified and are believed to be indicators of cold past conditions, while the significance of these features is difficult to interpret. This is mainly because the intensity and spatial distribution of past processes, whether glacial, periglacial or otherwise, are unknown.
- There are no conclusive data that suggest glacial conditions in the Drakensberg/Lesotho Mountains and along the Great Escarpment during the Quaternary.
- The spatial and temporal extent of both palaeoglacial and palaeoperiglacial activity has not previously been described.
- The uncertainty surrounding southern African cryogenic studies can be coupled to poor spatial and temporal resolution of data, contradictory quantitative and qualitative interpretations, and to a lesser extent, a lack of simple self-evident terminology for southern African conditions (see Chapter 2).

- There is a need to explain the origin of landforms ascribed to periglacial and glacial environments within a larger, sound theoretical framework and to shift from a single-cause perspective to an interactive perspective (see Chapter 3).

It is evident that there is a need for a more rigorous approach in southern African cryogenic studies (as also noted by Hall, 1992), as well as better understanding of relict features and processes and the palaeoenvironment in which they have developed. An objective data source of existing knowledge of the Quaternary in southern Africa will facilitate this process of understanding by providing a comprehensive overview of the current situation from which the scientific community can identify areas for future research.

1.3 Aims and objectives

The general aim of the study will be to expand on current knowledge of relict features and processes, thereby facilitating the reconstruction of the Pleistocene environment by means of a reliable data source for future verification. Specific aims and objectives are:

- to provide an objective data source to challenge specific research problems, thus adding to existing Quaternary knowledge;
- to gain a better understanding of the intensity and spatial distribution of relict features and processes, and ultimately contribute towards a reconstruction of the southern African Quaternary palaeoenvironment.

In addition, the study aims to create avenues for future research that will contribute towards a better understanding of the processes produced by climate change. Precipitation, snowline elevation and altitudinal zonation for relict features of the Pleistocene in southern Africa are important issues that need further research.

It is appropriate to focus attention on past episodes of climatic change as analogues for likely future changes (Partridge, 1990; Partridge *et al.*, 1990; February, 1994a, 1994b). In the face of human induced global climate changes, it is imperative to establish longer climatic data records. Given the dependence of cryogenic activity on the climate, it is reasonable to assume that periglacial and glacial research will provide an important avenue for Quaternary studies in southern Africa.

1.4 Study area

The study area, as defined by the literature, comprises the High Drakensberg, Lesotho Mountains, the Great Escarpment, the Eastern Cape Mountains, and the Western Cape Mountains (Fig. 1.2). These areas represent the highest elevations in southern Africa and hold the key in assessment of large-scale altitudinal zonation. Mountain environments react sensitively to climatic changes, which manifests itself in a variety of phenomena (Hastenrath & Wilkinson, 1973; see Chapter 2).

The different parts of the study area each display its own characteristic lithology, climate and temperature regimes. The dominant lithology of the Drakensberg and Lesotho Mountains is basalt, which overlies sandstones and forms part of the Karoo Sequence (Fig. 1.3, 1.4 and Table 1.1; SACS¹, 1980; Moon & Dardis, 1988). The basalts are particularly prone to chemical weathering (Van Rooy & Nixon, 1990; Hall, 1992; Van Rooy, 1992; Van Rooy & Van Schalkwyk, 1993). Prominent dolerite dykes are a familiar sight and the drainage pattern is complex and deeply incised (Nicol, 1973; SACS, 1980; Boelhouwers, 1991a; Marker, 1991b; Meiklejohn, 1994; Grab, 1996a). The dominant lithology of the Eastern Cape Mountains is quartzite with several resistant dolerite dykes and sills, such as those comprising Elandsberg, Hogsback, Katberg and Gaika's Kop (SACS, 1980; Moon & Dardis, 1988; Meadows & Meadows, 1988). The Western Cape Mountains consist of the Tafelberg Group sandstones, with subordinate shales, quartzites and conglomerates (SACS, 1980; Moon & Dardis, 1988).

Lesotho, the Kwa-Zulu Natal Drakensberg Escarpment and parts of the Western Cape Mountains receive the highest annual rainfall for the study area, approximately 1 800 to 3 300mm p.a. (Fig. 1.5). The High Drakensberg and Lesotho Mountains are located in a summer rainfall area with cold and dry winters and mild and wet summers (Schulze, 1965; Schmitz & Rooyani, 1987; Hanvey & Marker, 1992; Grab, 1996b). Snow sometimes accumulates on the high slopes and cutbacks during colder months (Marker, 1991b; Hanvey & Marker, 1992; Grab, 1996a). The Eastern Cape climate is relatively moist with an all-year precipitation regime and average annual totals in excess of 1 000mm (Fig. 1.5). Snow may fall in winter on peaks above 900m (Meadows & Meadows, 1988). The Western Cape Mountains receive winter precipitation with totals exceeding 2 000mm (Fig. 1.5). The whole of the study area is subject to regular frost occurrences between April and September (Schulze, 1965; Meadows & Meadows, 1988; Grab, 1996b, 1997a).

¹ South African Committee for Stratigraphy.

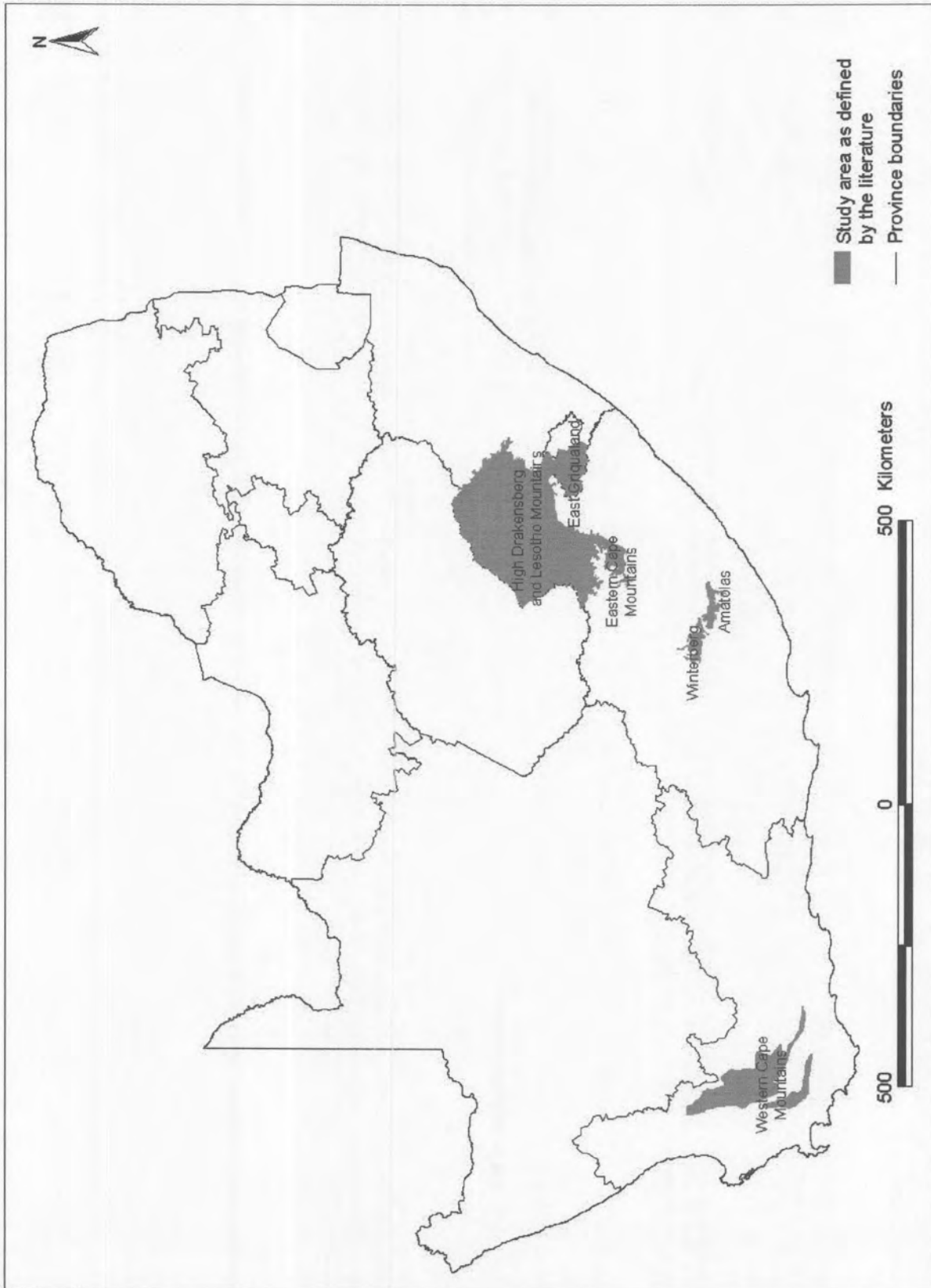


Figure 1.2: The study area(s) as defined by the literature.

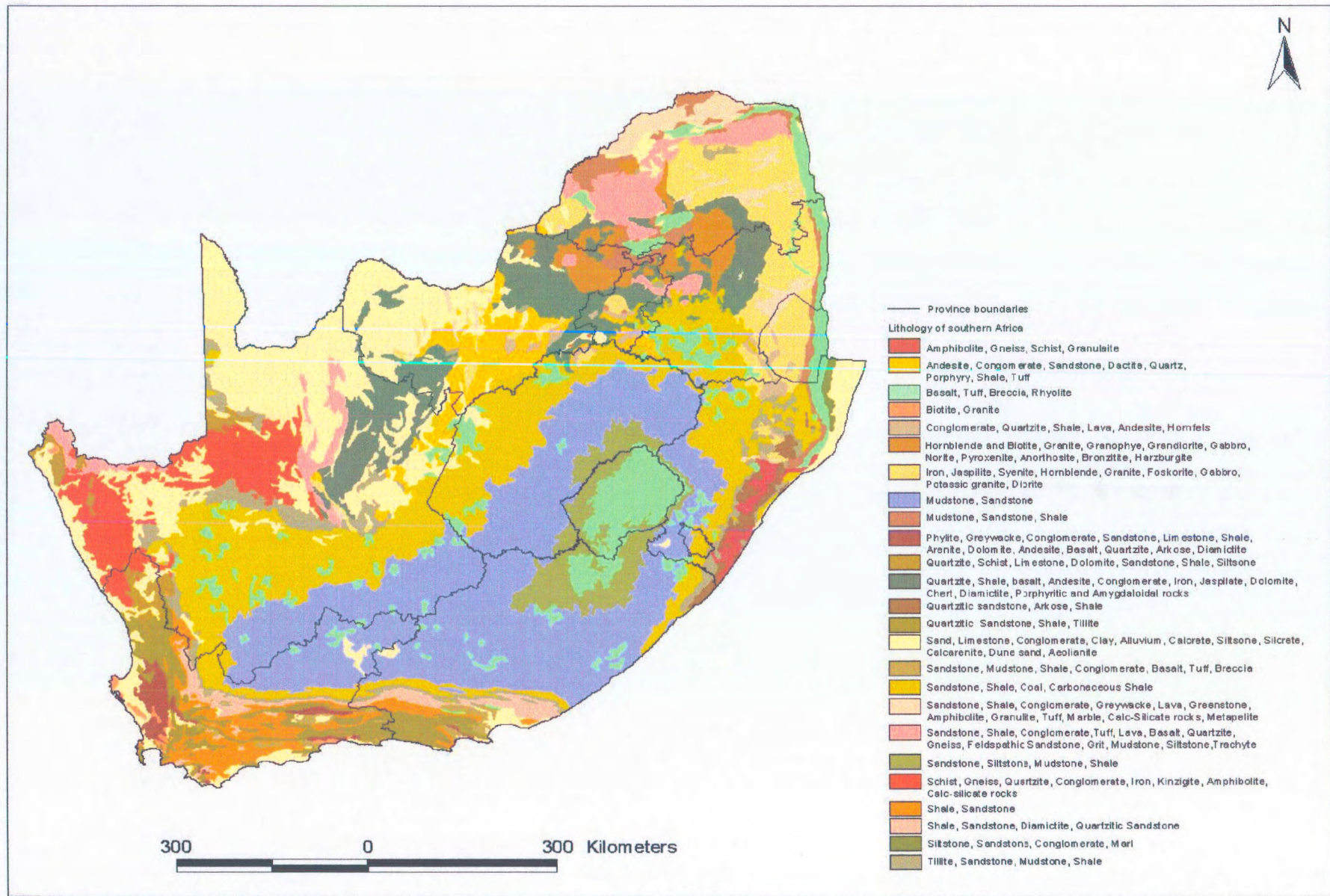


Figure 1.3: Lithology of southern Africa (Enpat).

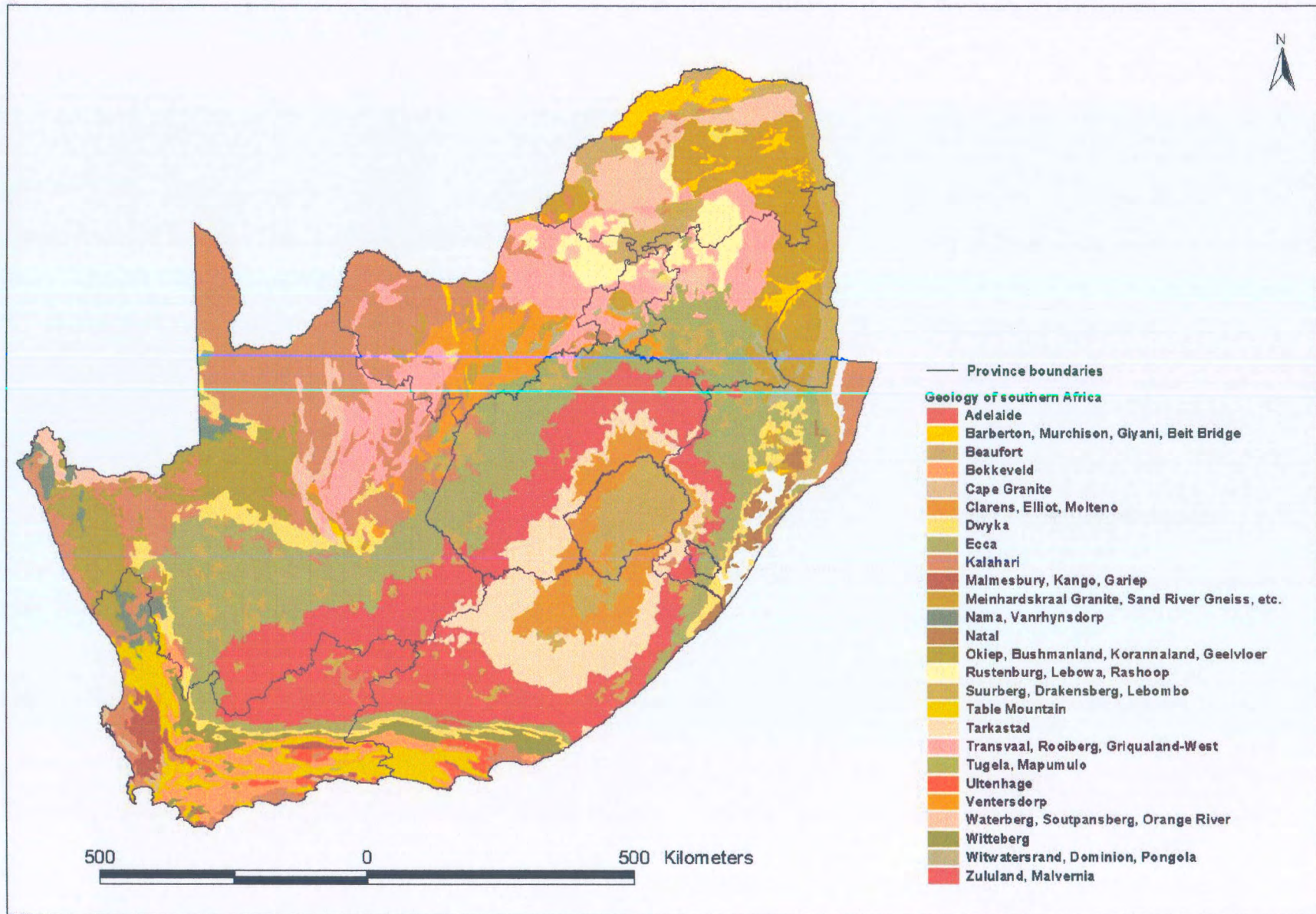


Figure 1.4: Geology of southern Africa (Enpat).

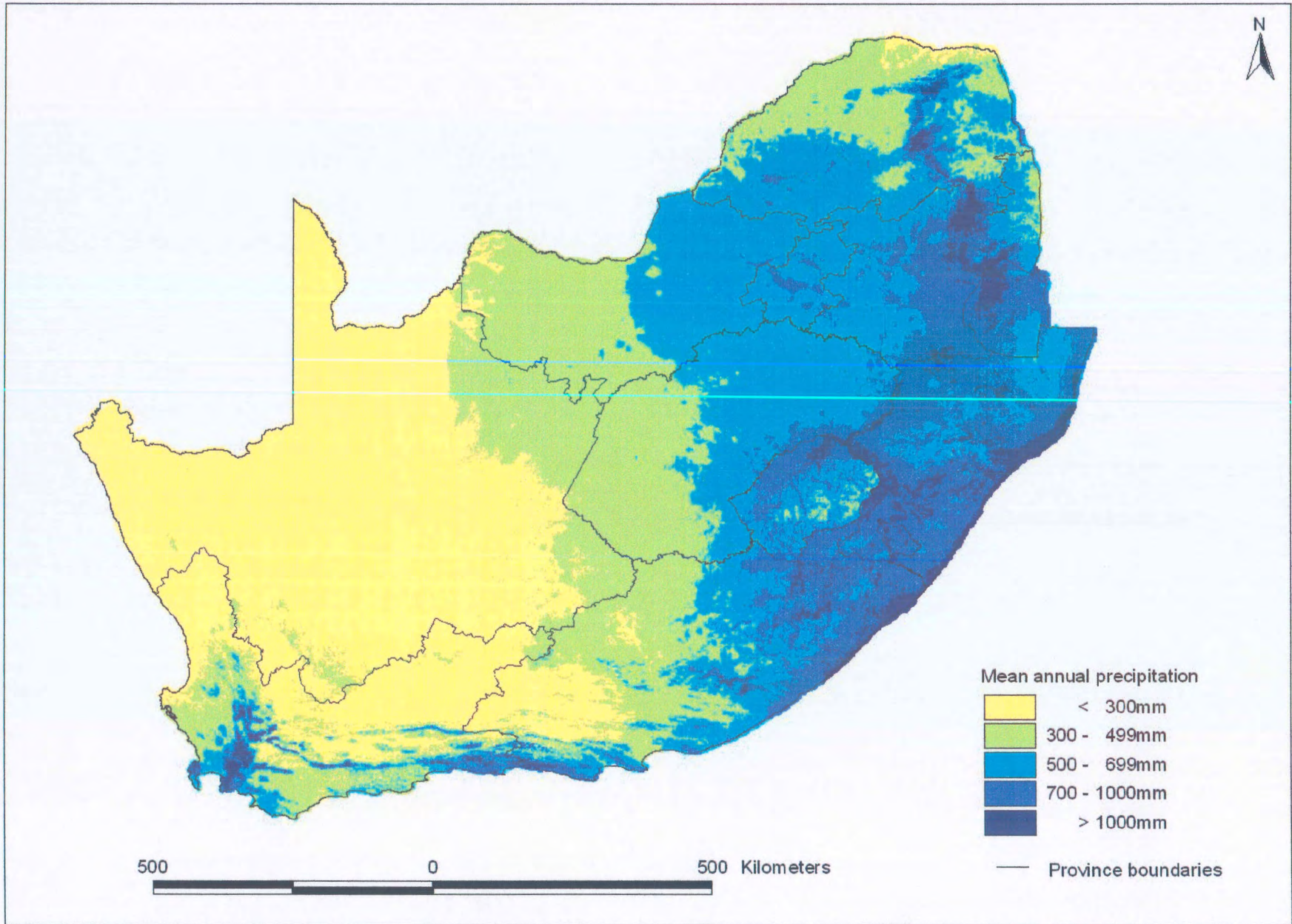


Figure 1.5: Mean annual precipitation for southern Africa (Schulze, 1998).

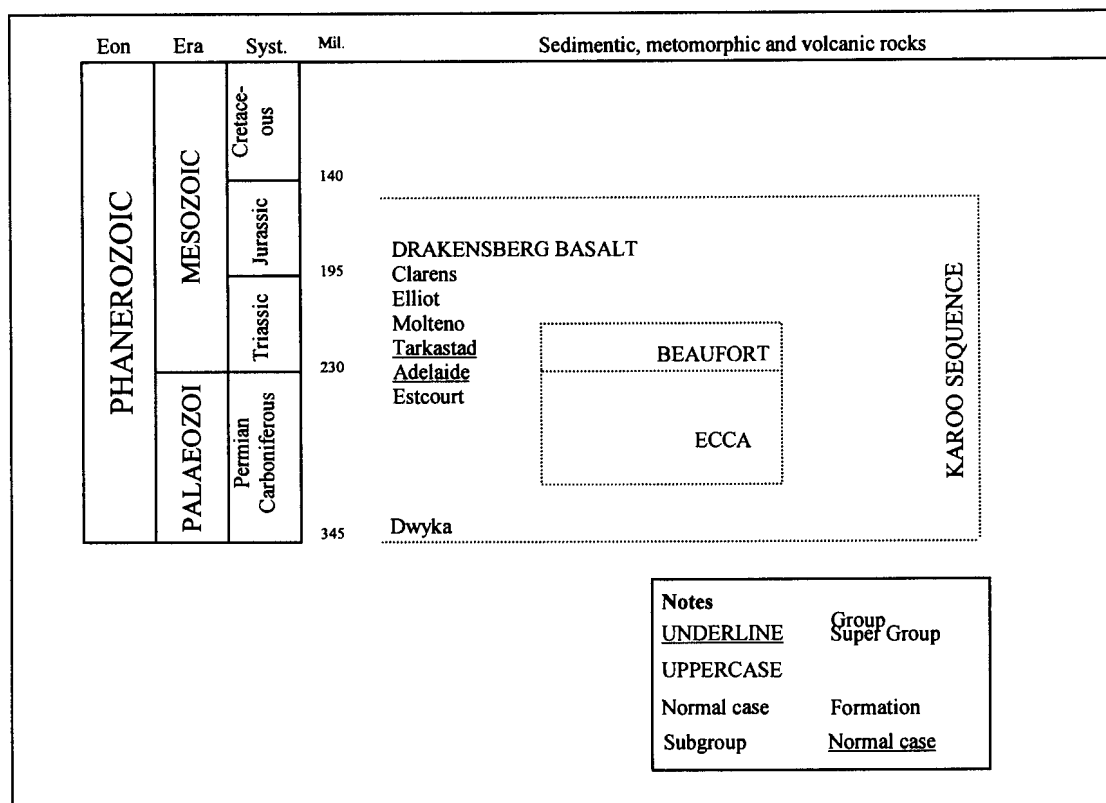


Table 1.1: Part of the geological time scale of southern Africa (after Wellington, 1955; King, 1963; SACS, 1980).

Mean annual air temperatures (MAAT) for the High Drakensberg and Lesotho Mountains as well as the Eastern Cape Mountains are relatively low, ranging between 1° and 12°C (Fig. 1.6). Along the main Escarpment and elevations above 2 800m, a MAAT of between 1° and 4°C occur (Backéus, 1989; Grab, 1996a, 1997a). The Western Cape Mountains have higher MAAT of between 10° and 20°C (Fig. 1.6).

Southern African mountain areas currently experience a *sub-periglacial* climate (Lewis, 1987; Meiklejohn, 1992; Boelhouwers, 1991b, 1995a; Hanvey & Marker, 1992; Marker, 1992, 1994b, 1995a). Seasonal frost action, generating micro-periglacial forms, prevails at altitudes above 1 900m a.s.l. (Boelhouwers, 1988; Marker, 1992; Hanvey & Marker, 1992), but cryogenic action is limited somewhat during dry periods in winter (Marker, 1992). The resultant cryogenic features are located along or adjacent to the Lesotho/Natal Drakensberg and Eastern Cape Escarpments (Lewis, 1987). No current permafrost has been recorded in southern Africa (Marker, 1995a; Lewis, 1996a).

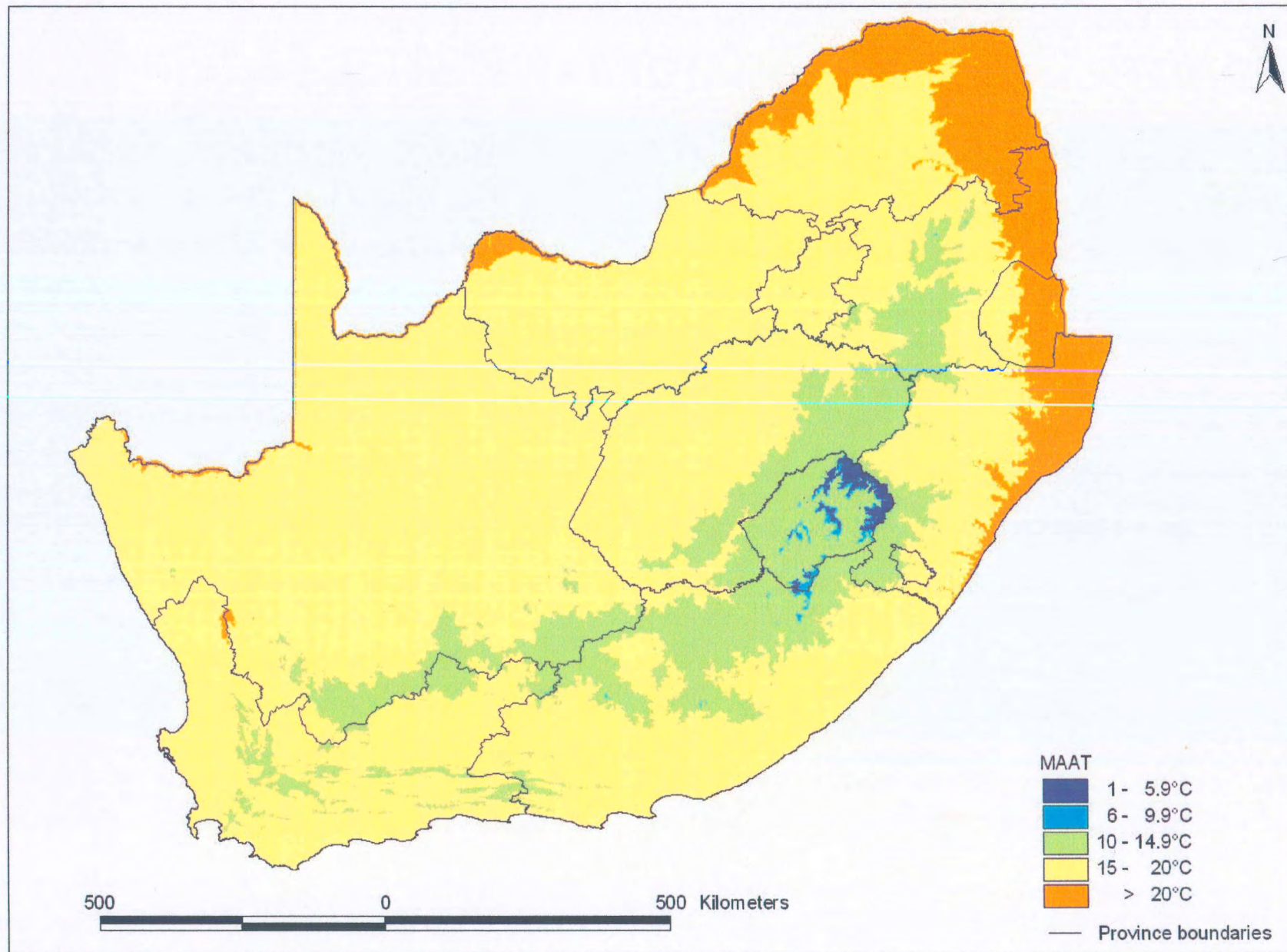


Figure 1.6: Mean annual air temperatures for southern Africa (Schulze, 1998).

To accomplish the study aims and objectives aforementioned, a database system approach within a geographical information system (GIS) framework was chosen (Chapter 3). Such a system can arrange and classify data and is a reliable and objective aid in problem solving. Through GIS-based analysis techniques it is hoped to achieve a better understanding of palaeocryological processes and potentially calculate prevailing moisture conditions, the Pleistocene snowline elevation and altitudinal zonation for relict periglacial features in southern Africa. The spatial database will serve as an information source for future research. Specific problems and hypotheses within current research will be addressed through the database and GIS-techniques in Chapter 5.

CHAPTER 2

Cryogenic research in southern Africa: geomorphic evidence and problems experienced within the discipline

This chapter is a review of studies in the high summit regions of southern Africa focusing on the main debates and problems. Research can roughly be divided into two groups (Fig. 2.1), namely research about present-day cryogenic features and processes, and studies of relict cryogenic processes and forms. Little is known of the formative processes of relict forms in southern Africa, and existing theories, hypotheses and views are apparently contradictory. These will be discussed in detail below.

2.1 The southern African cryogenic landscape in world context

Present glacial landscapes are landscapes covered with, or consisting of, glaciers or glacial ice that are remnants of the Last Glacial Maximum (LGM) (Sugden & John, 1976; Van der Meer, 1997; Ahnert, 1998). Glacial landscapes are subject to active glaciation and glacial processes recognisable in a variety of phenomena (Goudie *et al.*, 1985; Clark, 1998). Current glaciers are usually in transit and inclined to erode the underlying and surrounding topography (Van der Meer, 1997; Clark, 1998). There are several types of present-day glaciers and icecaps, normally categorised according to size (Table 2.1). The largest glaciers today are those covering Greenland and Antarctica.

The geological history of the earth has known several ice ages that included a number of glacials and interglacials. The last ice age, which ended about 14 000B.P. (Broecker & Denton, 1989; Marker, 1994b, 1995a; 1998; Hanvey & Marker, 1994; Lewis, 1996b; Partridge, 1997 etc.) saw large sections of the Northern Hemisphere covered in extensive ice sheets (Embleton & King, 1975; Lewis, 1996b; Van der Meer, 1997; Ahnert, 1998 etc.). Southern Africa experienced at least seven glaciations of which the greatest one was the Permo-Carboniferous Dwyka glaciation that occurred 300 million B.P. (Table 1.1; Du Toit, 1922; Truswell, 1977; SACS, 1980; Lewis, 1996b). Some researchers argue for at least one Pleistocene glaciation on the highest mountains, since southern Africa experienced periods of depressed temperatures apparently more or less concurrent with Northern Hemisphere temperature shifts (Harper, 1969; Hanvey & Marker, 1994; Marker, 1998).

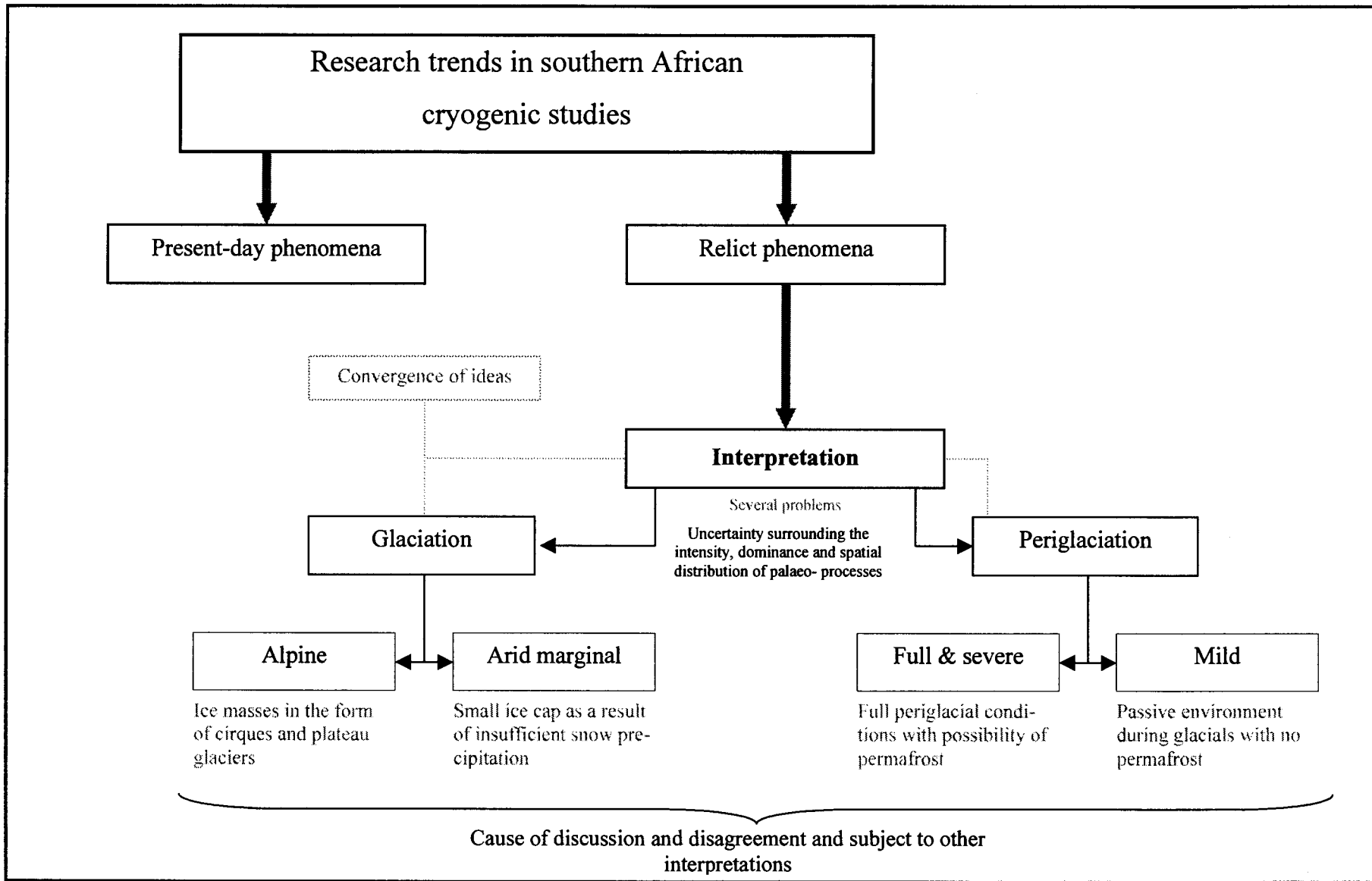


Figure 2.1: Cryogenic research in southern Africa.

Type of glacier	General description
Ice sheets	A continuous mass of ice and snow of considerable thickness and covering large areas of rock or water. Ice sheets occupy most of the continent of Antarctica and Greenland at present and are not influenced by underlying topography.
Icecaps	A dome-shaped glacier, smaller than an ice sheet, covering high altitude areas. Icecaps are not influenced by the underlying topography.
Valley glaciers	A glacier that occupies an existing valley. Valley glaciers are widespread in the Rocky Mountains, Himalayas and Alps.
Alpine glacier	A valley glacier formed in an amphitheatre among mountain summits descending a mountain valley and ending by melting or spreading out into a piedmont glacier.
Outlet glacier	A valley glacier originating from the margin of an icecap or ice sheet.
Cirque glacier	Cirque glaciers form in mountains in hollows called <i>cirques</i> .
Névé field	A névé field is not much more than a snow patch in which the snow has scarcely been turned to ice (névé). Usually there is not much movement in such ice patches.
Other	
Volcano glaciers	Aprons of glaciers on and around isolated volcanoes, e.g. Andes Mountains, Rocky Mountains.
Regenerated glaciers	Found below very steep slopes. A glacier at the edge of a precipice may discharge large blocks of ice which fall down. At the bottom of the precipice the ice blocks freeze back together again and the glacier flows further. These glaciers are found in all high mountain regions on earth.
Piedmont glaciers	Piedmont glaciers are found especially in arctic regions and also called ice tongues. Piedmont glaciers begin life as part of an icecap. These glaciers are long and thin and lie in shallow valleys.

Table 2.1: A summary of the types of glaciers found in current glacial landscapes (after Van der Meer, 1997; Clark, 1998).

Current periglacial environments are characterised by cryogenic conditions, processes and landforms (Fig. 2.2) associated with cold, nonglacial environments (Dylik, 1964; French, 1976, 1996; Washburn, 1979), regardless of their proximity to a glacier (Washburn, 1979; French, 1996). Most (but not all) periglacial environments are characterised by permafrost, and are dominated by frost action (Dylik, 1964; French, 1976, 1996; Washburn, 1979; Goudie *et al.*, 1985; Clowes & Comfort, 1987; Thorn, 1991). Periglacial environments are prevalent in high altitudinal and tundra regions, but may be encountered below the tree line and in alpine regions of temperate latitudes, such as the High Drakensberg and Lesotho Mountains (French, 1996). Frost action and/or permafrost are the most important indicators of a periglacial environment (Embleton & King, 1975; French, 1976, 1996), but permafrost is not a necessary attribute of periglacial regions (Thorn, 1991). Other processes not restricted to, but important on account of their high frequency in periglacial regions, are ice segregation, seasonal frost action, frost (cryogenic) weathering, and rapid mass movements (Embleton & King, 1975; Goudie *et al.*, 1985; French, 1996).

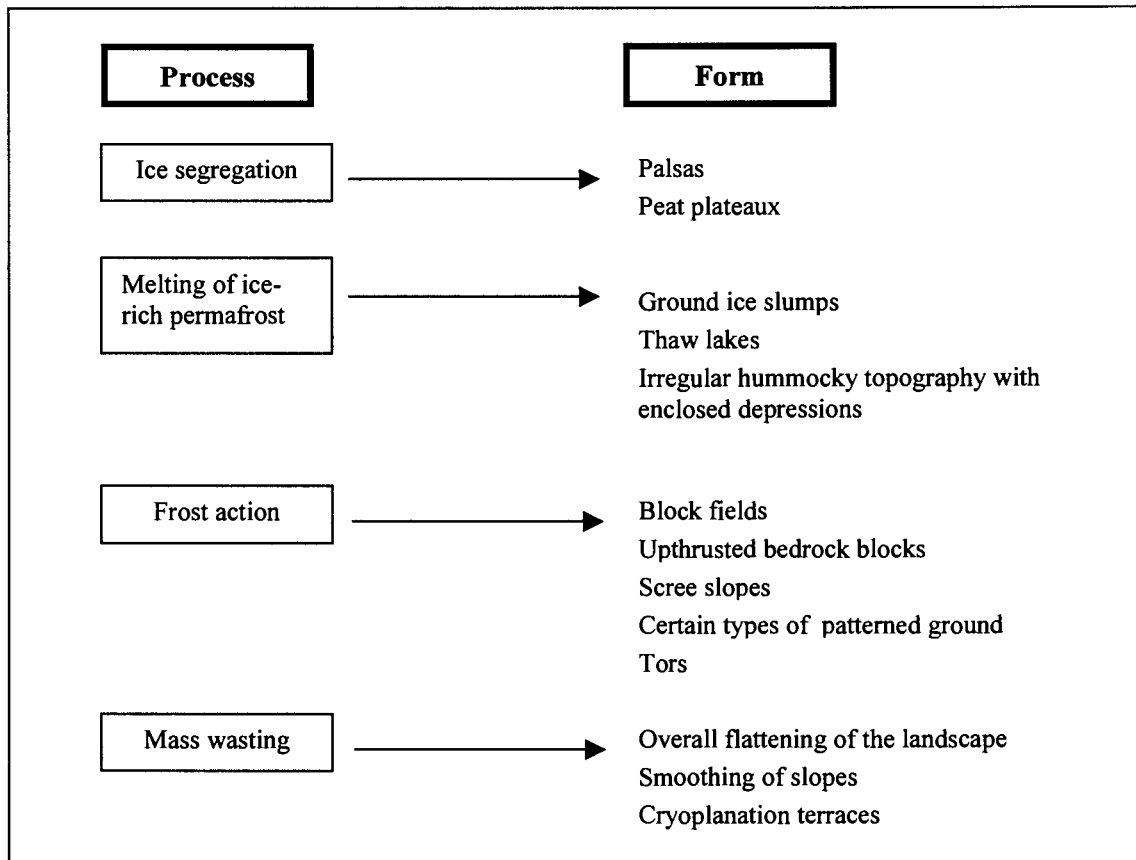


Figure 2.2: A summary of aggradational features commonly found, but not exclusive to, periglacial environments (after Goudie *et al.*, 1985).

2.2 Present-day periglacial phenomena in southern Africa

The High Drakensberg and Lesotho Mountains consist of the highest elevations of the Great Escarpment of southern Africa and separate the high interior from the low coastal regions (King, 1963; Hastenrath & Wilkinson, 1973; Boelhouwers, 1991a). The mountains reach heights of 3 000m (King, 1972; Watson, 1988) and reacts most sensitively to climatic change (Hastenrath & Wilkinson, 1973). Present-day high mountain areas on the subcontinent display a *sub-periglacial* nature (Lewis, 1987; Meiklejohn, 1992; Boelhouwers, 1991b, 1995a; Hanvey & Marker, 1992; Marker, 1992, 1994b, 1995a) despite their relatively low altitude and latitude (Hastenrath, 1972; Lewis, 1987; Marker, 1992, 1998), and have also been classified as:

- Marginal montane periglacial (Lewis, 1987; Boelhouwers, 1991a).
- Borderline periglacial (Boelhouwers, 1991b; Hall, 1994).
- Marginal frost action environment (Boelhouwers, 1994, 1995a; Grab, 1997a, 1997b).

For the purposes of this study the term *sub-periglacial* will be used. Sub-periglacial features cluster along or adjacent to the Drakensberg Escarpment of Lesotho, Kwa-Zulu Natal, the Eastern and the Western Cape, but may be more widespread than is generally assumed (Lewis, 1987). In northern Lesotho it appears that the sub-periglacial zone exists above 2 900m a.s.l. (Hanvey & Marker, 1992), lowering down to about 2 800m at 30°30'S (Boelhouwers & Hall, 1990), 1 900m a.s.l. in the Northeast Cape, 1 800m a.s.l. on the Matroosberg, and at 1 700m a.s.l. on the Waaihoek Mountains in the Western Cape (Boelhouwers, 1991b). The lower limit of the present-day sub-periglacial zone shows a decline in altitude with higher latitude (Marker, 1995a). Knowledge of periglacial environments in southern Africa, however, is still very much in its infancy (Hall, 1992; Grab, 1994), and the exact extent of the modern periglacial environment remains to be established (Lewis, 1987; Meiklejohn, 1992; Grab, 1997a). Little is known about the spatial and temporal variations of these sub-periglacial phenomena and of variability of local environmental controls other than climate (Boelhouwers, 1991a; Grab, 1997a).

It is interesting to note that active periglacial processes occur at lower altitudes (1 000 to 1 500m a.s.l. lower than in other periglacial regions of the world), in areas that receive strong insolation and have mean annual temperatures (MAAT) of between +4°C and +7°C, at least 6°C higher than postulated for a sub-periglacial zone (Boelhouwers, 1991a; Hanvey & Marker, 1992). Hanvey & Marker (1992) contribute this to the reduction of vegetation cover by fire and overgrazing, which, in turn, promotes frost action. Of course this observation warrants further discussion, but at this stage it is beyond the scope of the present study. It is more important, however, to realise that the existence of active periglacial microforms demonstrates that conditions at present are favourable for the formation of marginal periglacial phenomena (Boelhouwers, 1991a; Hanvey & Marker, 1992). Phenomena that have been studied and classified as current periglacial in origin are summarised in Table 2.2 and Table 2.3.

PRESENT-DAY PERIGLACIAL FEATURES			
Category	Type of feature	Author	
Patterned ground	Sorted circles	Dardis & Granger (1986) Boelhouwers (1991a; 1994; 1995b)	
	Nonsorted circles	Harper (1969) Hastenrath & Wilkinson (1973) Borchert & Sanger (1981) Boelhouwers (1991a)	
	Thufur (nonsorted circles)	Harper (1969) Hastenrath (1972) Hastenrath & Wilkinson (1973) Lewis (1987; 1996b) Boelhouwers (1991a) Hanvey & Marker (1992) Grab (1994; 1997b)	
	Sorted nets	Hastenrath & Wilkinson (1973) Boelhouwers (1991a)	
	Sorted polygons	Harper (1969) Hastenrath & Wilkinson (1973) Lewis (1987) Boelhouwers (1991a; 1995b) Hanvey & Marker (1992)	
	Nonsorted polygons	Harper (1969) Hastenrath (1972) Lewis (1987; 1996b) Hanvey & Marker (1992)	
	Nonsorted stripes	Lewis (1987) Boelhouwers (1991a; 1994; 1995b)	
	Sorted step	Borchert & Sanger (1981)	
	Nonsorted step	Boelhouwers (1991a; 1995b)	
	Sorting (gravel)	Hastenrath (1972)	
	Snow and ice features	Ground ice	Dardis & Granger (1986) Hanvey & Marker (1992)
		Ice-wedges	Harper (1969)
Needle ice		Hastenrath (1972) Hastenrath & Wilkinson (1973) Lewis (1987) Sanger (1988) Hanvey & Marker (1992)	
Segregation ice		Grab (1996b)	
Turf exfoliation		Hastenrath (1972)	
Solifluction features		Solifluctional overforming or smoothing	Hastenrath & Wilkinson (1973)
	Stone-banked terraces	Dardis & Granger (1986) Boelhouwers (1991b; 1994; 1995b) Lewis (1996a)	
Other features	Dislocation of stones	Borchert & Sanger (1981)	
	Slip scars	Harper (1969)	
	Terracettes	Harper (1969) Hastenrath (1972) Hastenrath & Wilkinson (1973) Dardis & Granger (1986) Verster & Van Rooyen (1988) Watson (1988) Boelhouwers (1991a; 1991b) Boelhouwers & Hall (1990) Hanvey & Marker (1992)	

Table 2.2: Present-day periglacial features in southern Africa.

PRESENT-DAY PERIGLACIAL PROCESSES		
Category	Type of process	Author
Freeze-thaw	Freeze-thaw	Harper (1969) Hanvey & Marker (1992)
	Periglacial processes	Hastenrath (1972) Borchert & Sanger (1981) Hanvey & Marker (1992)
	Ground freeze	Boelhouwers (1995b) Grab (1997b)
Frost and cryogenic action	Frost heave	Hastenrath (1972) Dardis & Granger (1986) Hanvey & Marker (1992)
	Frost action	Harper (1969) Hastenrath (1972) Hastenrath & Wilkinson (1973) Lewis (1987; 1996b) Grab (1994)
	Frost wedging	Harper (1969) Hastenrath & Wilkinson (1973) Borchert & Sanger (1981)
	Frost creep	Hanvey & Marker (1992) Boelhouwers (1994; 1995b)
	Frost shattering	Hanvey & Marker (1992)
	Frost creep	Boelhouwers (1991a)
	Cryoturbation	Borchert & Sanger (1981)
Gelifluction	Gelifluction	Dardis & Granger (1986) Hanvey & Marker (1992) Boelhouwers (1994) Lewis (1996a)
Solifluction	Solifluction	Hastenrath (1972) Hastenrath & Wilkinson (1973) Borchert & Sanger (1981) Sanger (1988) Boelhouwers (1991a; 1995b)
	Solifluctional smoothing	Hastenrath & Wilkinson (1973)
Soil and mass movement	Mass movement	Hastenrath (1972) Verster & Van Rooyen (1988)
	Surface creep	Sanger (1988)
	Soil creep	Borchert & Sanger (1981) Verster & Van Rooyen (1988) Boelhouwers (1991a)
	Sheet-wash	Watson (1988)
Other processes	Contraction	Hanvey & Marker (1992)
	Solution	Verster & Van Rooyen (1988)
	Desiccation	Hanvey & Marker (1992)

Table 2.3: Present-day periglacial processes in southern Africa.

2.3 Relict phenomena in southern Africa

The High Drakensberg and Lesotho Mountains also display a wide range of relict features (Fig. 2.1; Tables 2.4 and 2.5) of which most are believed to have formed during the LGM between 16 000 and 30 000B.P. (Lewis, 1996b). However, there are features older than 30 000B.P. (Lewis, & Dardis, 1985; Marker, 1992, 1994b; Lewis, 1996b), possibly deposited during the Quaternary cold phases before the LGM (Tyson *et al.*, 1976; Partridge, 1997). During the LGM temperatures were probably 5° to 6°C colder than today^{1,2}, and experienced several colder and warmer periods with a glacial maximum between ±14 000 and 21 000B.P. (Van Zinderen Bakker, 1963, 1964, 1966; Hastenrath, 1972; Deacon *et al.*, 1984; Vogel, 1985; Partridge *et al.*, 1990; Marker, 1991b, 1995a, 1998; Meiklejohn, 1992; Hanvey & Marker, 1992; Partridge, 1997). During the Quaternary cold spells, and especially the LGM, cryogenic processes must have been more widespread and severe on the subcontinent (Meiklejohn, 1992). It is generally accepted that the physical environment was thus changed, apparent from ample evidence that has been accumulated from a variety of palaeoecological sources, although the nature and extent of the Late Quaternary and Early Holocene environmental change remains unclear for most of the subcontinent (Dewey, 1988). If one considers that global temperatures were colder 18 000B.P. than present and large areas of the world in middle and high latitudes were inundated by glacial ice (Lewis, 1996b), this theory seems viable.

The LGM ended suddenly and simultaneously in both hemispheres at ±14 000B.P. with a rapid amelioration in annual temperatures (Broecker & Denton, 1989; Marker, 1995b; Hanvey & Marker, 1994). During the early southern African Holocene (5 000 to 8 000B.P.) warmer and wetter conditions followed (Partridge *et al.*, 1990; Marker, 1994b; Partridge, 1997). After 5 000B.P. little variation in temperature is identified, and from 2 000 to 1 000B.P. wetter conditions again dominated, as illustrated in Table 2.6 (Tyson, 1993; February, 1994a; Hanvey & Marker, 1994; Marker, 1994b, 1995a, 1998; Partridge, 1997).

¹ Van Zinderen Bakker (1964; 1976), Harper (1969) and Vogel (1983) have extrapolated a 5.5°C to 9°C late-Pleistocene temperature drop for the highlands of Lesotho. Talma *et al.* (1974) extrapolated an 8°C to 9.5°C drop for the Wolkberg caves at 19 800B.P. Grab (1996a) and Talma (1989) calculated temperature drops of 7.5° at 33°30'S and 5°C at 24°15'S for the period between 16 000 and 20 000B.P. However, the most conservative estimate is usually accepted and cited as between 5° and 6°C (Sparrow, 1971; Deacon *et al.*, 1984; Hanvey & Marker, 1992; Marker, 1992 etc.).

² The reconstruction of a temperature decrease of higher altitudes is only possible under the assumption of a constant lapse rate (6.5°C km⁻¹) (Hastenrath, 1972).

RELICT FEATURES		
Category	Type of feature	Author
Large hollows and associated features	Hollows reminiscent of nivation cirques	Harper (1969) Marker & Whittington (1971) Sparrow (1971)
	Cirque-like hollows	Sparrow (1964) Dyer & Marker (1979)
	Cirques	Sparrow (1967a) Harper (1969) Hastenrath (1972) Borchert & Sanger (1981) Sanger (1988)
	Erosional hollows	Hastenrath & Wilkinson (1973) Nicol (1973) Marker (1989; 1991a) Lewis & Hanvey (1991) Marker (1990a, 1990b) Hanvey & Marker (1994)
	Protalus rampart	Marker (1989) Lewis (1994; 1996a)
	Trough-like valleys	Lewis (1996b)
	Trough's end	Lewis (1996b)
	Glacial features	Avalanche deposits
Glacial deposits		Sanger (1988)
Glacial pavements		Sanger (1988)
Glacial polished surfaces		Harper (1969) Borchert & Sanger (1981) Sanger (1988) Marker (1989)
Hanging valleys		Lewis (1996b)
Pinnacles		Borchert & Sanger (1981)
Aretes		Sparrow (1967b) Sanger (1988)
Glacial striations		Borchert & Sanger (1981) Lewis (1996b)
Cutbacks		Hall (1994) Grab (1996a)
Glaciers Cirque glaciers		Borchert & Sanger (1981) Sanger (1988)
Valley glaciers		Sanger (1988)
Plateau glaciers		Sanger (1988)
Moraines Cirque or terminal moraine Kame moraine Kame-terrace deposit Moraine		Lewis (1996b) Lewis (1996b) Lewis (1996b) Sparrow (1967a) Borchert & Sanger (1981) Sanger (1988)
Fluvio-glacial deposits		Sanger (1988) Lewis (1996b)
Truncated spurs		Lewis (1996b)
Accumulations of coarse debris	Blockfields	Linton (1969) Sparrow (1971) Borchert & Sanger (1981) Sanger (1988)
	Blockstreams	Hagedorn (1984) Lewis (1996b)

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Accumulations of coarse debris- cont.	Screes	Sparrow (1967a) Marker (1986)
	Debris lobe & ridges	Sparrow (1967a) Nicol (1973) Lewis & Hanvey (1991) Grab (1996a)
	Rock glacier	Lewis & Hanvey (1993) Lewis (1996b)
Relict patterned ground	Sorted stripes	Boelhouwers (1994) Grab (1996b)
Snow and ice features	Fossilised permafrost layers	Fitzpatrick (1978)
	Ice-stripped areas	Sparrow (1967a)
	Ice-wedge casts	Lewis & Dardis (1985) Lewis (1996b)
	Ice-shattered ridges	Sparrow (1967a)
	Cryoplanation terraces	Hagedorn (1984)
Gelifluction features	Gelifluction sheets	Boelhouwers (1994)
	Head	Nicol (1973) Lewis & Dardis (1985) Lewis (1987)
Solifluction features	Geliflual deposits	Linton (1969)
	Solifluction lobes	Sparrow (1971) Marker (1989; 1992)
	Solifluction terraces	Harper (1969)
	Solifluctional mantles	Hastenrath (1972)
	Stone-banked lobe	Boelhouwers (1991a; 1991b; 1994)
	Solifluctional overforming	Hastenrath (1972)
Other features	Basalt steps	Harper (1969)
	Frozen ground phenomena	Borchert & Sanger (1981)
	Valley asymmetry	Sparrow (1964; 1967a) Harper (1969) Marker (1989) Meiklejohn (1992)
	Planation surfaces	Sanger (1988)
	Relict terracettes	Marker (1989)
	Grezes litees	Lewis & Dardis (1985) Lewis & Hanvey (1988)

Table 2.4: The most important cryogenic relict features of southern Africa.

RELICT PROCESSES		
Category	Type of process	Author
Geliflual and gelifluction	Geliflual action	Linton (1969)
Snow and ice processes	Perennial snowbed growth	Nicol (1973) Dyer & Marker (1979) Lewis (1994)
	Nivation	Dyer & Marker (1979) Marker (1990b) Hall (1994) Lewis (1994)
Glacial processes	Glacial meltwaters	Nicol (1973) Hall (1994)
	Glaciation Glaciation Marginal (arid) glaciation Niche glaciation	Borchert & Sanger (1981) Marker (1991a; 1998) Hall (1994) Grab (1996a)
Frost and cryogenic action	Frost wedging	Harper (1969)
	Frost climate	Borchert & Sanger (1981)
	Cryogenic action	Hanvey & Marker (1994)
	Frost action	Nicol (1973)
Solifluction	Solifluction	Hanvey & Marker (1994)
Other processes	Inversion of the weathering profile	Linton (1969)

Table 2.5: Important processes thought to have modified the high summit areas of southern Africa.

Ages	Palaeoclimates as compared to the present
Before the LGM	Cold, but warmer than preceding cryogenic period.
24 000– 13 500B.P.	The LGM Sever cold prevailed.
13 500– 9 000B.P.	Temperature amelioration. This period of warmer and wetter conditions and temperature increase started suddenly and concurrently in both hemispheres.
9 000– 5 000B.P.	Early Holocene, which experienced drier conditions.
5 000– 3 000B.P.	Wetter and warmer conditions.
3 000– 2 400B.P.	Wetter conditions.
2 400B.P.– 900A.D.	Warmer and wetter conditions.
900– 1300A.D.	Warmer conditions, but with much variability. The highest temperatures are recorded for the 10 th and 11 th centuries. Between 600 and 900 AD temperature were variable, whilst between 250 and 600AD it was warmer. Between 100 and 200AD cooler conditions prevailed.
1300– 1850A.D. (650B.P.)	The Little Ice Age. Major instability and variability in temperatures are recorded. 1300 to 1500 was the coldest phase with an increase in temperatures between 1500 and 1675.
1850A.D. – present (100B.P.)	The Post Little Ice Age, which is the period of recovery and amelioration. However, anthropogenically induced temperature increases owing to greenhouse gases and global warming may be superimposed.

Table 2.6: A synopsis of Late Quaternary and early Holocene climatic changes in southern Africa (after Marker, 1995b; February, 1994a and Tyson, 1993).

Southern Africa had several climatic oscillations during the Quaternary and, with the possibility of a 5° to 6°C drop in MAAT and the existence of relict landforms, past conditions were probably cold enough for widespread cryogenic activity, particularly during the LGM (Hanvey & Marker, 1992). However, the subcontinental dimensions of southern Africa makes it unlikely for a uniform climate to have existed (Sparrow, 1971; Butzer, 1973; Grab, 1996a). Uncertainty stems from disputes over the intensity, dominance and spatial distribution of past processes (Boelhouwers, 1988). To explain what may have happened thousands of years ago, and to understand the processes responsible for the creation of relict forms, two opinions emerge in the literature, namely that of a *glacial origin*, and that of a *periglacial origin* for relict phenomena (Fig. 2.1), while many earth scientists in southern Africa remain sceptical about either (Le Roux, 1991, Tyson, 1986, Deacon & Lancaster, 1988 etc.).

2.3.1 *A glacial origin for relict phenomena*

Some researchers believe that southern Africa experienced some form of glaciation during the Pleistocene (e.g. Sparrow, 1964; Dyer & Marker, 1979; Borchert & Sanger, 1981; Lewis, 1987; 1996a; Hall, 1994; Grab, 1996a, etc.). Several factors are taken into account that may prove, or disprove, glaciation on the subcontinent but supporting evidence for glaciation remains unclear. Two views on Pleistocene glaciation in southern Africa have been proposed, namely an *alpine glaciation* and, alternatively, an arid *marginal glaciation* (Fig. 2.1).

2.3.1.1 An alpine glaciation

By an alpine glaciation (Fig. 2.1) it is presumed that the mountain areas of southern Africa were covered by ice masses (in the form of plateau glaciers), feeding several shorter valley glaciers (Borchert & Sanger, 1981; Maud & Partridge, 1987; Sanger, 1988; Hall, 1994; Lewis, 1996b) that would have formed at insolation-protected sites (Hall, 1991a; Le Roux, 1991; Marker, 1991a; Grab, 1996a). The ice would have eroded the plateau summits and the Escarpment edge (Grab, 1996a). Along the Escarpment sidewalls pre-existing drainage lines would have been enlarged, forming funnel-shaped hollows and cirques (Grab, 1996a). Several relict features are said to support this theory, amongst others glacial striations, moraines, kame moraines, cirques, and glacially polished surfaces (Borchert & Sanger, 1981; Lewis, 1996b).

It is maintained that if the subcontinent did experience a substantial drop in temperature during the LGM (Partridge, 1997), then it is likely that the higher mountains experienced mean annual temperatures of between -1°C and -3°C (Grab, 1996a). It is also proposed that

the Antarctic polar fronts would have been displaced further north which probably increased the possibility of more winter precipitation during this time in the form of heavier snowfalls (Van Zinderen Bakker, 1975; Howard, 1985; Tyson, 1986; Marker, 1990b, 1992; Hanvey & Marker, 1992; Grab, 1996a). It is then likely that conditions during the late Pleistocene could have been favourable for localised development of glacial ice, with glaciation on the subcontinent corresponding with evidence for glaciation on Mount Kosciusko, Australia ($\pm 20\ 000$ to $15\ 000$ years B.P.) and Mount Elgon, Uganda / Kenya ($\pm 20\ 000$ to $17\ 000$ years B.P.) during the late Pleistocene (Grab, 1996a). After the LGM temperatures ameliorated such that much of the snow and ice would have melted over a short period of time (Vogel, 1985), resulting in an increase of surface water and runoff (Grab, 1996a). Meltwaters would have incised the glacial deposits, forming shallow gullies in pre-existing debris (Hall, 1994), and eventually transporting debris downstream (Grab, 1996a). Following this wetter phase the mountain areas became subject to periglacial activity (Sparrow, 1971).

However, conclusive evidence to confirm Pleistocene alpine glaciation remains elusive. This is mainly because of the apparent difficulty of recognising such landforms (Lewis & Hanvey, 1993; Hanvey & Marker, 1994; Lewis, 1996b). They are, for the most part, poorly preserved, partly due to the kind of material in which they are found, and partly to recent strong weathering and denudation, resulting mostly from intensive precipitation (Borchert & Sänger, 1981; Grab, 1999). Therefore, an alternative approach has been suggested that might offer better insights into the possible Pleistocene glacial history of the subcontinent, namely *arid marginal glaciation*.

2.3.1.2 Arid marginal glaciation

An arid marginal or arid continental glaciation (Fig. 2.1) is defined as the consequence of insufficient snow precipitation (Marker, 1991b), and implies that glaciation could have taken place in the form of a small icecap restricted to the highest elevations (Dyer & Marker, 1979). Ice development would have been marginal and ineffective (Marker, 1992, 1994b), the affected areas characterised by arid continental glacial conditions, marked cirque orientation and low cirque density (Marker, 1991b, 1994b) with glacial ice thinly spread and moving very slowly (Marker, 1998).

Two periods of extreme cold (glacials) are suggested for southern Africa (Harper, 1969; Lewis & Dardis, 1985; Lewis, 1996b). The first (the *Older Stadial*) occurred prior to

40 000B.P. (Marker, 1994b) with a snowline calculated at 3 350m (30°S) and 3 200m (31°S) with an estimated 9°C drop in temperature (Harper, 1969; Talma *et al.*, 1974; Lewis, 1996b). The second and less severe phase (the *Younger Stadial*) experienced a drop of $\pm 5^\circ$ to 6°C 16 000 to 20 000B.P. with a snowline at 3 770m (30°S) and 3 650m a.s.l. (31°S) (Harper, 1969; Deacon & Lancaster, 1988). During the Older Stadial some form of glaciation might have taken place on the subcontinent, covering the highest parts of Lesotho with a thin icecap (Maud & Partridge, 1987). It might be that a similar glaciation took place during the Younger Stadial. However, supporting evidence of proxy data for a cold period with an estimated 9°C prior to the LGM remains elusive.

The theory of arid marginal glaciation is used to explain the origin of certain cirque-like forms that have been noted in the Great Escarpment by Marker (1991b), who proposed that the characteristics and distribution of the hollows were in accordance with an origin under marginal glaciation. As a result, the hollows would display certain characteristics (Derbyshire & Evans, 1976), such as marked aspect, strong orientation towards the leeward side of ridges, a flatness index of glacial proportions, and a correlation between hollow density and precipitation.

Findings showed that 72.3% of the hollows studied were orientated towards the north, irrespective of topographic ridge alignment (Marker, 1991b). The orientation is believed to be consistent with leeward snow accumulation at times of lower temperatures, strong southerly winds and greater cloudiness. Marker (1991a, 1998) concluded that much of the ice must have been thin, if one is to accept these hollows as a measurement of effective glaciation, and that conditions for cirque glaciation were most favourable along the Escarpment where higher altitudes and greater precipitation were available (Marker, 1991b, 1998).

At present annual snowfall and precipitation are highly variable, and it is likely to have been the same in the past (Sparrow, 1971). During the Quaternary, however, existing synoptic conditions probably were displaced northwards (Howard, 1985), causing more frequent winter precipitation and lower freezing levels. It is proposed that the Escarpment zone and the Lesotho plateau were only marginally glaciated (Marker, 1991b, 1998).

2.3.2 Other views

The general view is that southern Africa was never glaciated (Tyson, 1986; Deacon & Lancaster, 1988; Preston-Whyte & Tyson, 1988), mainly because no direct evidence of

glaciation or permanent ice has been found (Van Zinderen Bakker, 1976; Marker, 1994a; Grab, 1996a). It is difficult to verify whether or not an icecap did exist in the absence of evidence of glacial abrasion. It may be that the Lesotho Highlands, for example, was an accumulation zone where no sediments, striations or other glacial evidence were generated. Features that may have been formed by glacial abrasion could have disappeared as a result of chemical weathering and fluvial action (Boelhouwers & Hall, 1990). It is argued that if estimated temperature drops and increased snowfall are acceptable, a small icecap could have formed and cirques could have developed to the leeward side of ridges on the Lesotho plateau and along the Escarpment (Marker, 1991b, 1998; Lewis, 1996b).

2.3.3 Periglacial origin relict phenomena

At present, active periglacial microforms prove that the climate is cold enough for periglacial processes to take place (Hanvey & Marker, 1992). The presence of a sub-periglacial zone lends credence to the opinion that the southern African mountain environment was modified by periglacial action during Quaternary glacials (Hanvey & Marker, 1992; Hanvey, 1990; Marker, 1994b, 1998³). Superficial relict periglacial deposits are found throughout the High Drakensberg and Lesotho Mountains and have been used to establish a Pleistocene palaeoclimatic sequence (Sparrow, 1971; Hastenrath & Wilkinson, 1973; Grab, 1999). The existence of relict periglacial landforms has led to the contention that the mountains were subject to much greater winter snowfall at times of Quaternary temperature depressions (Marker, 1990b, 1992, 1994b, 1998; Hanvey & Marker, 1992) and that at least two former phases of periglacial activity preceded the present phase of periglacial activity (Lewis, 1987; Marker, 1994b). These features are inactive under present climatic conditions, and gave rise to two palaeoperiglacial theories (Fig. 2.1):

- *Full periglacial conditions*, including the possibility of permafrost (Fitzpatrick, 1978; Lewis & Dardis, 1985; Marker, 1989; Lewis & Hanvey, 1993; Lewis, 1994) that caused cryogenic imprints recognisable in landforms (Troll, 1944; Ellenberger, 1960; Alexandré, 1962; Harper, 1969).
- A periglacial phase of *mild intensity* and *relatively short duration*, excluding the possibility of permafrost (Marker, 1995a).

³ Some authors referenced in this discussion support both the glacial and periglacial arguments.

2.3.3.1 Full or severe periglacial activity

It has been mentioned earlier that temperatures were depressed by at least 5°C between 16 000 and 20 000B.P. (Talma *et al.*, 1974). In view of these findings it is hypothesised that if a sub-periglacial zone can exist above 3 000m altitude at present, it will only be logical that full (or more severe) periglacial conditions occurred at high altitudes during the Quaternary cold periods (Fig. 2.1) (Lewis & Dardis, 1985; Hanvey & Marker, 1992; Marker, 1992, 1994b, 1995a). The mere recognition of relict periglacial landforms indicates that past conditions were suitably cold for widespread periglacial activity (Sparrow, 1971; Hanvey & Marker, 1992). It is supposed that certain features identified in the field could only have occurred under severe climatic periglacial conditions (Marker, 1989, 1990a, 1994a, 1998). A relatively thin snow cover may have survived the summer months on shaded slopes and formed snow or ice patches in hollows and depressions (Marker, 1989). Marker (1989) suggests that snow patches probably allowed the ground to freeze solid in winter resulting in nivation by freezing and thawing. According to Marker (1987) the Pleistocene southern African landscape may well have resembled the present sub-polar regions of Marion Island (46,5°S) or Northern Norway (60°N) in certain aspects.

Marker (1995a) found that relict cryogenic landforms of southern Africa can be separated into two regions, namely the eastern Great Escarpment and the Western Cape. Despite low altitudes and latitude, the higher summits of these regions project into the current sub-periglacial zone (Lewis, 1987; Boelhouwers, 1991b, 1995a; Hanvey & Marker, 1992; Marker, 1992, 1994b, 1995a, etc.). Most identified relict landforms require increased snowfall (Hanvey & Marker, 1992; Marker, 1995a); however, it is not certain what the moisture conditions during the Quaternary were (Marker, 1992). Furthermore, it is not easy to confirm cryogenic evidence, since southern Africa has neither a present-day glaciation nor an existing snowline (Marker, 1995a). The lower altitudes, at which some of the proposed periglacial features are found, may perhaps be a function of increased continentality at times of sea level recession and may date from earlier periods of extreme cold (Marker, 1995a), such as the Older Stadial discussed earlier.

2.3.3.2 Mild periglacial activity

For other researchers the theory of severe palaeoperiglacial phases in southern Africa does not satisfactorily answer the many questions surrounding the subject, especially where conclusive evidence is absent. In light of the various problems presented by this theory, it has been

proposed that, due to considerable temperature and precipitation variations during the Pleistocene, periglacial activity of mild intensity and short duration (Fig. 2.1) existed (Sparrow, 1971; Nicol, 1973; Hall, *pers. comm.*). It is accepted that conditions were cold enough for some form of periglacial activity to have taken place and that periglacial phases were concurrent with the commencement of cooler conditions in the rest of the world (Linton, 1969; Sparrow, 1971). The intensity of periglacial conditions during interstadials and stadials, however, probably resembled those of the present-day periglacial environment (Hall, *pers. comm.*; for an overview see Partridge, 1997).

2.3.4 A convergence of ideas

During the Pleistocene glacials and interglacials the subcontinent experienced temperature and precipitation oscillations comparable to and concurrent with those in the Northern Hemisphere (Linton, 1969; Sparrow, 1971; Partridge, 1997). Glacial and periglacial conditions might have co-existed (Linton, 1969; Marker, 1989; Lewis & Hanvey, 1993), or one could have been more dominant at times than the other. It is therefore important that a periglacial or a glacial origin of phenomena not be treated in isolation of each other (Fig. 2.1). The following issues still need further verification:

- The amount of moisture available for the formation of relict landforms (Marker, 1992).
- The exact Pleistocene drop in temperature for the mountain regions (Meiklejohn, 1992).
- An LGM snowline elevation to establish the extent and nature of glacial activity if Pleistocene glaciation did take place (Marker, 1995a).
- The extent of a former periglacial activity (Lewis & Dardis, 1985).

On macro-scale other difficulties arise. It is not yet known, for example, what effect the northward migration of the Antarctic polar ice had on the local climate or sea currents, or what the effect of increased continentality was (Van Zinderen Bakker, 1976; Marker, 1989, 1995a). The climate might have been only marginally suitable for snowbed or ice survival at times, thus restricting it to protected and shaded sites, or moist at other times, resulting in heavy snowfalls (Lewis, 1994). It has been suggested that glacial ice disappeared very quickly due to the sudden onslaught of warmer temperatures during the temperature amelioration after the LGM. Any glacial phenomena that may have remained would have been eroded away by fluvial and/or chemical action (Boelhouwers & Hall, 1990).

The relict landscape and its features apparently are products of more than one Pleistocene glacial period (Linton, 1969). There is no doubt that relict processes were more extensive and enhanced (Meiklejohn, 1994), as is evidenced by the widespread nature of these landforms (Linton, 1969; Marker, 1990b; Hanvey & Marker, 1992). With an estimated 5° to 6°C drop in temperature, it is possible that snow remained for longer periods (Marker, 1989) and enhanced cryoturbation, frost action, solifluction and gelifluction processes occurred (Marker, 1990b; Meiklejohn, 1992, 1994). Yet, it should be realised that if the mountainous areas were indeed glaciated, the formation of certain periglacial features (such as ice wedges) would have been highly unlikely (Hall, 1991a; Le Roux, 1991; Marker, 1991a). If the mountains were not glaciated, these regions may be true periglacial environments (as opposed to pro- or paraglacial; French, 1996), areas that have not been glaciated but subjected to cold-based processes without the provision of debris by glaciers (Hall, 1991a; Le Roux, 1991; Marker, 1991a).

2.4 Current research problems

It was mentioned elsewhere that there are several problems embedded in the study of cryogenic landscapes within southern African context. The hypotheses discussed above only serve to draw attention to the difficulties experienced in current research. It is imperative for researchers to take note of these problems since many of them in fact offer new avenues of research. The main problem currently facing cryogenic research in southern Africa is undoubtedly the scarcity of useable data.

2.4.1 Data

Sufficient data, as well as self-evident terminology and interpretation, is missing in contemporary cryogenic research in southern Africa (Hall, 1992; Grab, 1999). Hypotheses on Pleistocene conditions for the subcontinent lack supportive field data (Marker & Whittington, 1971; Hall, 1988a; Meadows & Meadows, 1988; Hanvey & Marker, 1992; Grab, 1994, 1996b), inhibiting the formulation of definite conclusions. Further, knowledge of Quaternary conditions is very limited (Partridge, 1990; Hall, 1991a; Le Roux, 1991; Marker, 1991a; Hanvey & Marker, 1994; Hall, 1994; Meiklejohn, 1994). Some data are inaccurate because of too few sampling sites (Hastenrath, 1972; Butzer, 1973; Hall, 1992; Boelhouwers, 1994). The scarcity of literature is mainly due to the very small number of workers on the subject

(Hall, 1988a, 1991b; Le Roux, 1991; Marker, 1991a)⁴. As far as terminology is concerned, for thufur alone six different terms exist (e.g. Schunke & Zoltai, 1988; Harris, 1988; Gerrard, 1992). Some regard one or two terms synonymous, while others distinguish between them. Terracettes also have a wide range of terminology in international literature (Watson, 1988), and so do numerous other features (Grab, 1999). A number of terms are outdated or obsolete, e.g. *congele-solifluction* (solifluction) and *confraction* (frost shattering) (Linton, 1969; Borchert & Sanger, 1981; Kearey, 1996). The lack of knowledge, data inaccuracy, inconsistency in field techniques, and problematic classification, result in many qualitative and contradictory presumptions being made (Butzer, 1973; Hall, 1988a, 1991b; 1992; Meadows & Meadows, 1988). Many plea that great care be taken in arriving at any judgement (Sumner, 1995; Hall, 1992, 1994) and for further testing of hypotheses in southern African context (Boelhouwers, 1991a; Grab, 1996a, 1999).

2.4.2 Feature anomalies

Feature anomalies are landforms that are found at altitudes and unexpected places anomalous to regular findings of relict features. One such feature was recognised by Marker (1990c) in Golden Gate Highlands National Park. Linton (1969) identified others:

Phenomenon	Location	Altitude a.s.l.
Gelifluction deposit	Port Alfred	445 m
Rubble drift (gelifluction)	Camps Bay, Cape Peninsula	sea level
Residual blocks from gelifluction sludges	Gydo Pass, north of Ceres	1 100m
Striped block fields	15 km south of Pretoria	1 500m
Inversion of weathering profile (gelifluction)	Magaliesburg	1 200m

Linton (1969) reached the conclusion that these residuals belong to an older phase of cryoturbation and raised the possibility of more than one glacial period in southern Africa (e.g. Harper, 1969; Lewis & Dardis, 1985; Deacon & Lancaster, 1988; Marker, 1994b; Lewis, 1996b). According to Meiklejohn (1992) and Marker (1995a), preceding cold periods were extreme and it may explain the existence of relict cryogenic features at low altitudes. These

⁴ Current literature on cryogenic studies in southern Africa has been supplemented greatly by a number of new publications for the period 1999 – 2000, e.g. Grab (1999), Meiklejohn *et al.* (1999), Sumner & Meiklejohn (2000), etc.

examples signify an age (or ages) of more severe climatic conditions in southern Africa, which allowed the formation of phenomena at lower altitudes, or on slopes that are currently not conducive towards cryogenic processes.

2.4.3 Climatic, altitudinal and latitudinal design

The climate and precipitation of southern Africa are controlled by the subcontinent's geographic location and its altitude above sea level (Marker, 1998). Southern Africa extends from $\pm 20^{\circ}00'S$ to $34^{\circ}30'S$ latitude and reaches a maximum altitude of 3 482m in Lesotho (Marker, 1995a, 1998). The subcontinent is both low altitude and low latitude (Hastenrath, 1972; Marker, 1992, 1995a, 1998); this fact hampers a clear assessment of Pleistocene conditions in southern Africa (Hastenrath, 1972). At present no modern glacial activity exists (Hastenrath & Wilkinson, 1973; Boelhouwers, 1994; Marker, 1995a; Grab, 1996a). Because there is no modern glaciation, the palaeoclimatic implications of relict phenomena are poorly understood (Hastenrath, 1972; Hastenrath & Wilkinson, 1973; Marker, 1992).

Southern Africa further has no modern snowline (Boelhouwers, 1994; Marker, 1995a), which is a drawback in periglacial studies and altitudinal zonation of past climates. High mountain environments react most sensitively to climatic change (Hastenrath, 1972; Hastenrath & Wilkinson, 1973) and a snowline can be seen as the manifestation of a complicated climatic balance. In places where a permanent snowline is present, geomorphic evidence can be interpreted with confidence. During winter months, the mountain areas of the subcontinent experience roughly eight snowfalls per annum, but snow only remains a few days (Borchert & Sanger, 1981; Grab, 1997b). The absence of a modern snowline and of non-permanent snow is contributed mostly to strong prevailing winds, mild conditions and high insolation (Hastenrath & Wilkinson, 1973).

2.4.4 Dating of phenomena

Datable material from study sites in southern Africa is limited (Sparrow, 1971; Marker, 1995a, 1998), causing several features to remain undated (Grab, 1994; Marker, 1994a; Lewis, 1994, etc.). The absence of datable matter can be attributed to certain factors such as aridity (Meadows & Meadows, 1988), and rapid fluvial incision (Hanvey & Marker, 1994). Thus, many studies that contribute to the palaeoclimatic record in southern Africa can give nothing more than a relative dating (Sparrow, 1971), keeping palaeoenvironmental reconstruction in a preliminary stage (Hanvey & Lewis, 1990).

2.4.5 *The onset of the Holocene and subsequent temperature amelioration*

When the LGM ended simultaneously in both hemispheres after 14 000B.P., annual temperatures in southern Africa rapidly increased (Hanvey & Marker, 1994; Marker, 1994b, 1995a, 1998; Lewis, 1996b; Partridge, 1997). The climate grew warmer and extensive glacial retreat occurred (Table 2.6). It is believed that, along with the glacial ice, remnant features of glacial and/or periglacial activity, vanished (Grab, 1996a; Lewis, 1996b). Basalt weathers very quickly and during the temperature amelioration following the LGM weathering mechanisms, e.g. chemical weathering, must have been greatly enhanced. Features that might have helped researchers understand past events, have simply disappeared, diminished or changed such that they remain unrecognised (Grab, 1999).

2.4.6 *Other issues in southern African cryogenic studies*

There are more unresolved issues in southern African cryogenic studies that can be added to the difficulties aforementioned. Currently, these issues prevent acceptable appraisal of palaeo-processes and their extent:

- Most phenomena, e.g. patterned ground, can be *polygenetic* in origin and not necessarily related to periglacial or glacial conditions (Hanvey & Marker, 1992).
- Some phenomena *are not clearly defined* or well developed (Boelhouwers, 1995a), making it difficult to correctly classify them.
- The *lower tree line* in southern Africa is attributed to the absence of boreal species and to a long history of fire and heavy grazing. The tree line position is critical in defining effective frost processes in cold environments (Marker, 1992).
- *Biological activity*, particularly endolithic and chasmolithic bacteria and lichens, may exert an influence on freeze-thaw weathering and other cryogenic mechanisms (Hall, 1988a, 1988b).
- *Past moisture regimes are difficult to project* from modern periglacial forms (Hanvey & Marker, 1992), especially those found in the High Drakensberg and Lesotho Mountain.

- Most southern African studies attempt to classify fossil phenomena through the use of *high latitudinal and altitudinal models*. These models can not readily be applied on the southern African environment due to the many difficulties already discussed (Hall, 1994; Sumner, 1995). Models based on periglacial phenomena also fail to define the current sub-periglacial environment (Boelhouwers, 1991a; 1995a).
- Actual cryogenic landforms in the High Drakensberg and Lesotho Mountains are generally *small in size* and of *seasonal occurrence* (Lewis, 1987; Grab, 1996b, 1997a), casting doubt on their proposed origins.
- Marker & Hanvey (1994) note that many hollows have been *truncated by the Great Escarpment recession* and that fluvial incision has modified hollow floor gradients (Marker, 1994b, 1998). It is not known what influence the Escarpment recession exerts (or exerted) on other cryogenic phenomena.
- There is no evidence for the present or former existence of *permafrost* in southern Africa. This is ascribed to climatic conditions that are unfavourable for permafrost development (Lewis, 1996a). Permafrost is generally accepted as an important diagnostic indicator in periglacial environments (Embleton & King, 1975; Goudie *et al.*, 1985).

The identified problems and difficulties prompted further study by way of comparison between local features and those of other cryogenic environments, thereby attempting to classify relict phenomena (e.g. Marker, 1990b). Existing models and theories for the Northern Hemisphere have also been applied to create models for the southern African cryogenic environment, e.g. a model for valley asymmetry in southern Africa (Fig. 2.3; Meiklejohn, 1992, 1994), and the identification of two classes of erosional hollow (Fig. 2.4; Marker, 1995a). Given the need to describe the southern African palaeoclimate, it is important to understand the environment in its entirety and to engage other disciplines and techniques to supplement current cryogenic research, e.g. a vegetation cover model for the southern African Pleistocene climate (Fig. 2.5; Van Zinderen Bakker, 1976). Unfortunately, models of this nature are not unique in southern African context and do not solve the problems encountered in cryogenic research. In an attempt to elucidate critical issues in southern African periglacial and glacial research, a database comprising cryogenic literature for the subcontinent, was

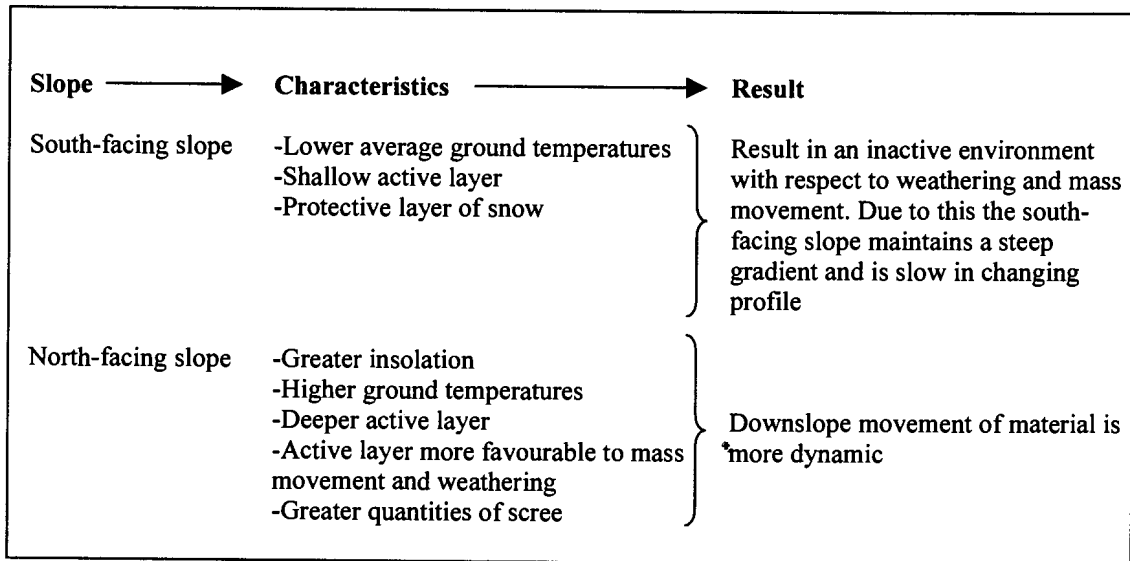


Figure 2.3: Contrasting processes on south- and north-facing slopes due to differing insolation receipts (after Meiklejohn, 1994).

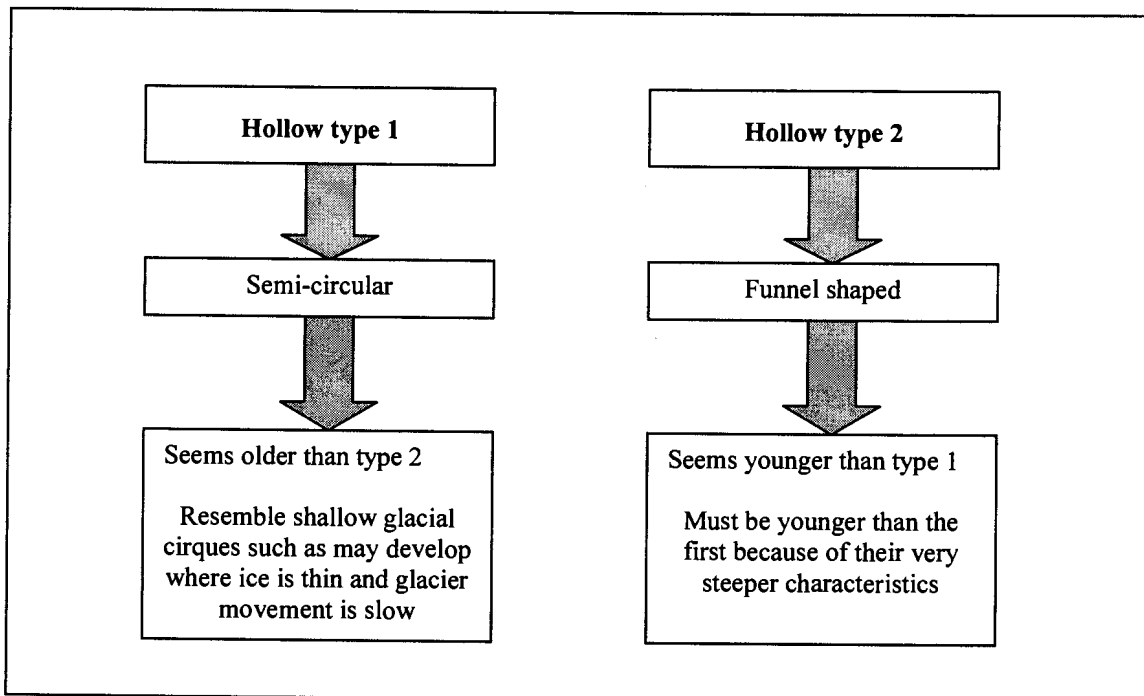


Figure 2.4: Two classes of erosional hollow as proposed by Marker (1995a).

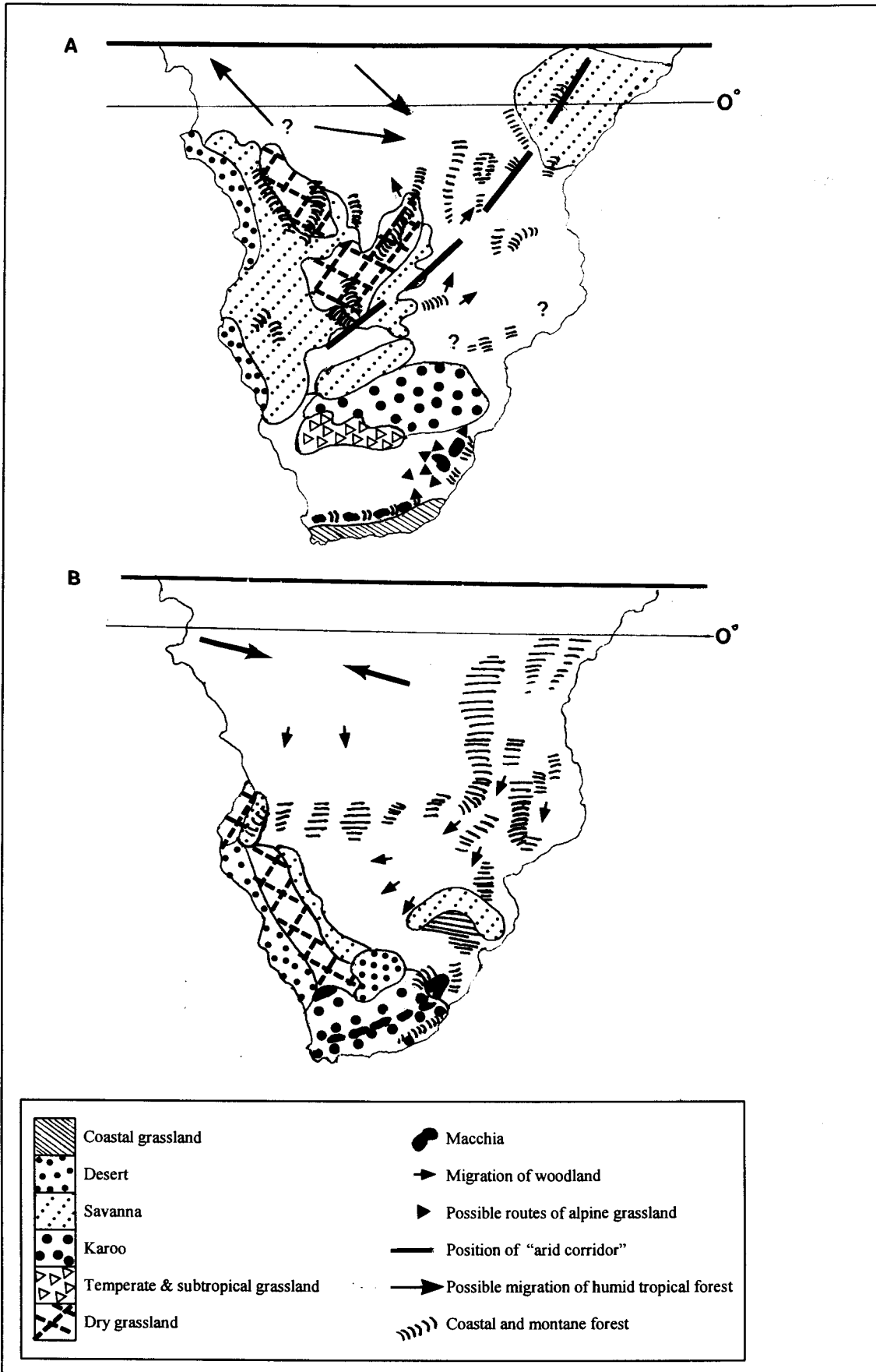


Figure 2.5: Vegetation patterns during a glacial maximum (A) and during an interglacial (B) (after Van Zinderen Bakker, 1976).

assembled. Within a GIS-system the database can be used to arrange and classify data for in-depth analysis, thus acting as a reliable and objective aid in problem solving. The spatial database will further serve as an information source for future research.

2.6 Conclusions

In this chapter different views expressed in southern African literature are presented. It was recognised that the modern environment is subject to sub-periglacial activity, but that the exact spatial extent thereof is still not certain. The mountain environment of southern Africa was exposed to widespread cryogenic activity and had experienced several temperature oscillations and depressions during the Pleistocene. In classifying cryogenic remnants of the Pleistocene, substantial controversy is evident, especially concerning the intensity, dominance and spatial distribution of past processes. Two main views were identified, namely a glacial and a periglacial origin for relict phenomena. Those who believe that glaciation took place proposed either an alpine or an arid marginal glaciation for the mountain areas of southern Africa. Those who maintain a periglacial view, either support full periglacial activity, or periods of mild periglacial action, excluding the possibility of permafrost. Both views take into account that all phenomena identified thus far require (and indicate) periods of enhanced snow cover. It was further shown that either activities should not be isolated and treated separately.

The uncertainty surrounding the classification of phenomena was indicated to be a function of several problems encountered in current research. The main problems were identified as those of data inconsistencies, phenomenon anomalies, the geographic location and climate of the subcontinent, difficulty in dating, terminology, and the effect of the temperature amelioration after the LGM on the local landscape. The need for a reliable data source in the form of a GIS-database was discussed.

CHAPTER 3

Research methodology: database components and development

3.1 Introduction

In Chapters 1 and 2 it was indicated that the significance of many relict landforms remains difficult to understand and that the exact extent of these features, as well as their associative processes, are unknown. It is evident that southern African knowledge of the Quaternary and palaeocryogenic action is insufficient, leading to contradictory quantitative and qualitative interpretations. There is a need to explain the origin of Pleistocene relict landforms within a larger framework and for a more rigorous approach towards palaeoenvironmental studies. Therefore, the aims and objectives are to gain a better understanding of relict features and processes, to establish or reconstruct the palaeoenvironment and its extent, to provide an objective data source, and supplement existing knowledge of the Quaternary.

To achieve these aims and objectives, the construction of a database system that assembles, arranges and classifies data on a less predisposed foundation was chosen. The purpose of Chapter 3 is to explain every step in the development of such a system, to reveal its advantages and to demonstrate how the database will be utilised in realising the aims and objectives of the study.

3.2 The advantages of a database system approach

Combined with the current explosion in computer technology, a database system approach offers a number of advantages to the researcher (Davies, 1996). It is not difficult to realise the potential such a system may have for current cryogenic research in southern Africa:

- Quick access to data and fast, inexpensive mapping. A database is convenient; data are very accessible with little problems in data retrieval. Existing software packages are specialised and user specific. Programmes, e.g. ArcView®, and supplementary datasets, e.g. Enpat, are created specifically for geographical use and contain most of the information needed by geographers. From the database southern African cryogenic data can easily be accessed and calculated for analysis, thus acting as both data source and data analyser.

- Modern computer programmes are able to do a wide variety of querying and the researcher will be able to do overlays and create reports at the same time within one system. This basically means that several options exist that make complex analyses of southern African cryogenic data combined with other sources in the form of spatial data, possible.
- The database will standardise the information it contains. This is necessary to secure consistent results free of the inconsistencies in southern African cryogenic data due to qualitative interpretations.
- An existing database and good software saves time and money since everything is done within one system.
- Data can be entered, upgraded, corrected and deleted. A database system is very flexible and will allow the researcher to upgrade or correct southern African cryogenic data within the database.

However, to maintain a database, regular data upgrading is necessary (Goodchild & Kemp, 1991). The next discussion will endeavour to curb this problem by presenting basic guidelines to aid researchers in the process of regular upgrading. Furthermore, definite and specific information is needed for a working database. This implies that before adding new information to the database, the researcher must first spend time in reading and interpreting the data according to the conditions and definitions stipulated for the database. The researcher must also be knowledgeable in database management and software, implying that time be set aside for training. Nevertheless, it is believed that a database system and complementing software will help clarify problems experienced in southern African cryogenic studies by utilising specialised operations such as digital mapping and mathematical analysis. The database must be as complete as possible with the definite possibility of upgrading and accessibility of information, and database operations and information contained within the structure must be easy to understand.

3.3 Development of a GIS-database for cryogenic studies in southern Africa

Database development involves several stages (Fig. 3.1), namely the input of *spatial data*, the input of *attribute data* and *linkage* between the two (Goodchild & Kemp, 1991). Digital spatial data were obtained from the Department of Environmental Affairs and Tourism, Surveyor General, Department of Land Affairs, Centre for Environmental Studies (University of Pretoria), Council for Geoscience, and the Computing Centre for Water Research (CCWR). The spatial data contain dataset information about southern African geology and lithology, vegetation patterns, mean annual, monthly and seasonal air temperatures and precipitation, international and national boundaries, and infrastructure.

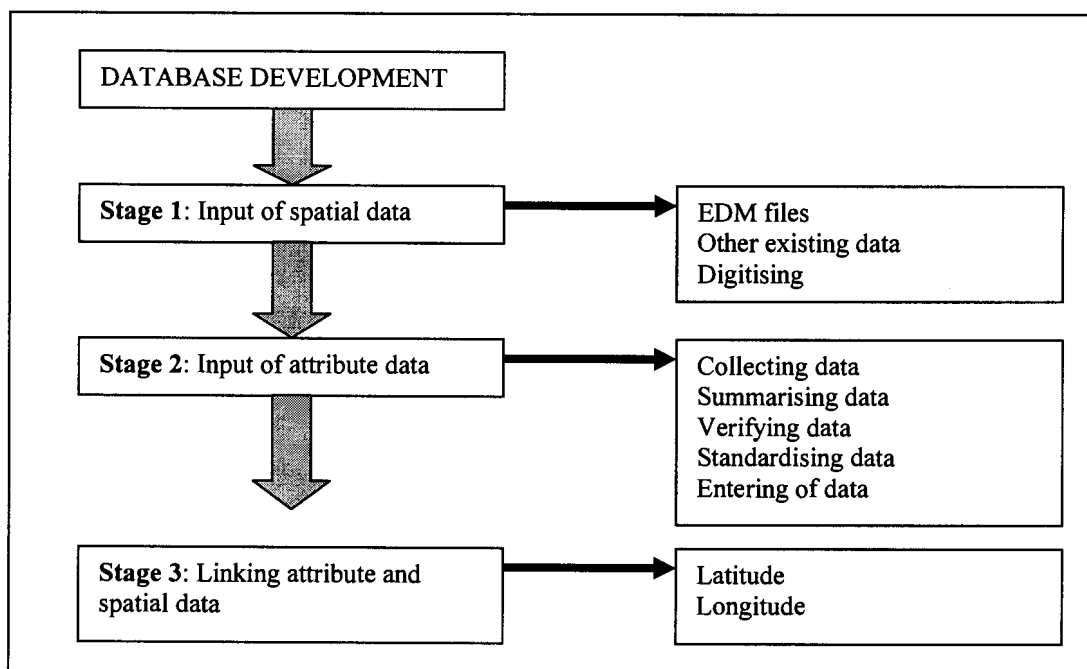


Figure 3.1: Stages in database development (after Goodchild & Kemp, 1991).

Attribute data were obtained from known relevant publications and unpublished sources. The information was summarised according to a summary list with the main points of interest (Fig. 3.2). Each entry received a reference number followed by the author(s) name(s), year of publication and specific information from research papers, theses or honours papers. Summaries were kept as true as possible to the original facts and entered into the database columns created in a database programme (Microsoft® Access™). New columns were added if required. The information summaries were compared with each other and with international literature to verify consistency in the use of cryogenic terminology. Background information indices regarding database terminology and data were subsequently constructed as a standar-

Reference:	_____	
Author(s):	_____	Year of publication: _____
Feature:	_____	
Age:	_____	Activity: _____
Altitude a.s.l.:	_____	
Causative:	_____	
Climate:	_____	
Consistency:	_____	
Count:	_____	
Dimensions:	Width:	_____
	Diameter:	_____
	Length:	_____
	Height:	_____
	Depth:	_____
	Slope angle:	_____
	Size:	_____
	Slope:	_____
	Form:	_____
Hypothesis:	_____	
Location:	Latitude:	_____
	Longitude:	_____
	Name of place:	_____
Other char.:	_____	

Figure 3.2: An example of a summary list used in the categorising of data.

disation measure. Additional information concerning specific cryogenic phenomena mentioned in the database as identified and contemplated by e.g. Sparrow (1974), Le Roux (1990), Hall (1988a, 1991a), Thorn (1991), Sumner (1995), French (1996), Grab & Hall (1996), Shakesby (1997), Grab (1999), Sumner & De Villiers (*in prep.*), were included. These two stages in the development of the database will be discussed further in Chapter 4.

Spatial and attribute data were linked by location (latitude and longitude). The database was imported in table format into ArcView[®] GIS. A more user-friendly database was created in Microsoft[®] Access[™]. In ArcView[®] GIS the database were fully employed by overlaying database attribute data on spatial data. Through simple map calculations and overlays the desired results were obtained and will be discussed in Chapter 5. The database and information are available on CD-ROM (Appendix A). The next discussion will consider the database components.

3.3.1 *Main components of the database*

Database components (Appendix B) were derived directly from the information summaries. Microsoft® Access™ automatically allocates a unique identification number for each data entry. When an entry is deleted, its identification number is never again allocated. This will allow the researcher to be sure of an entry's location in the database. It is desired that any given entry will contain as much information as possible, although it is not anticipated that all data columns will be filled. The following components were ascertained from the information summaries:

3.3.1.1 Information source

Research is acknowledged by stating the name(s) of the author(s) and the year of publication. A complete reference list of papers, theses, honours papers and personal correspondence is issued with the database on CD-ROM (Appendix A: Cryogenic Processes and Landforms Spatial Database for Southern Africa).

3.3.1.2 Identification of the phenomenon

This section is divided into the identification of the phenomenon and the processes involved in its formation (standardised version, Appendix C), and the author(s) own classification(s) (author's version). In the first component, the phenomenon and its associated processes are identified according to Appendix C. In the second part the author(s) classification(s) is (are) given to prevent possible misunderstandings.

3.3.1.3 Geographic location and processes involved in the phenomenon's formation

This category consists of the geographic location of the phenomenon, that is latitude, longitude, name of the place and altitude above sea level by which the distribution of a phenomenon can be determined. Different locations for the same phenomenon are treated as separate entries.

3.3.1.4 Geomorphic characteristics of the phenomenon

The geomorphic characteristics of a phenomenon indicate its mode of formation, whether produced under glacial or past- and present-day periglacial conditions (according to the research at hand). Closely linked with geomorphic characteristics is phenomenon activity.

Three activity levels are differentiated, namely glacial relicts, periglacial relicts and current periglacial phenomena. Of the latter most are seasonally active (mainly in winter, May to August or September), but others may be classified as currently active (phenomena active at the time of observation) or currently inactive (phenomena inactive at the time of observation, but showing distinct signs of ongoing activity).

3.3.1.5 Specific characteristics

- *Age*: sometimes it is possible to calculate a relative date for a phenomenon or at least estimate its age as before, during or after the Last Glacial Maximum (LGM). These options are provided for in the database.
- *Count* designates the number of phenomena encountered at the time of research. However, it is not possible to indicate a number for certain features, e.g. needle ice, or processes, e.g. frost action.
- *Vegetation*: in this section it is confirmed whether a phenomenon is covered with or display a fringe of vegetation (such as seen among screes).
- *Sorting* (Fig. 3.3) is the measure of the standard deviation of particles and relates to the way in which material is differentially removed by geomorphic agencies, such as wind and water (Kearey, 1996). Sorting is seen particularly among patterned ground phenomena (e.g. Harper, 1969; Hastenrath & Wilkinson, 1973; Dardis & Granger, 1986; Boelhouwers, 199a, 1994, 1995b).
- *Stratification* (Fig. 3.3) implies one layer of materials covering another layer of materials (Kearey, 1996).
- *Grading* comprises units that exhibit a vertical gradation in mean grain size (Goudie *et al.*, 1985). Normally a fining-upward sequence is present, but an inverse grading that displays an upward-coarsening sequence, may occur (Goudie *et al.*, 1985). In the database, this data column was allocated a drop-down option list.
- *Soils*: material composed of mineral particles and organic remains overlaying bedrock and usually supporting vegetation (Goudie *et al.*, 1985). If a phenomenon harbours a palaeosol (an ancient or relict soil or soil horizon), it is regarded as a soil. In the database soil names are entered, or, in the absence of specific identification, classified, e.g. *modern soils* or *subsoils*.

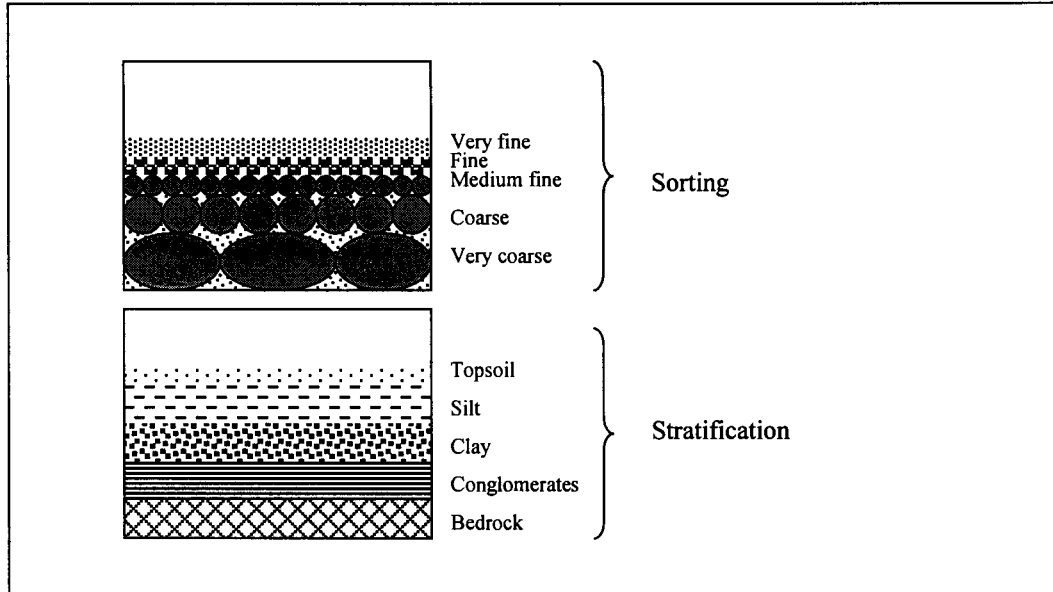


Figure 3.3: The difference between sorting and stratification.

- *Matrix and matrix supported material*: matrix is fine-grained material that separates clasts in a sedimentary rock or in which larger bodies are set (Kearey, 1996). The material it supports is called matrix-supported material. Both concepts are treated separately in the database.
- *Clasts and clast supported material*: a clast is a coarse particle of rock produced by weathering and erosion, usually larger than 4mm in diameter. Clast sizes include pebbles, cobbles and boulders (Goudie *et al.*, 1985; Kearey, 1996). Material that is clast-supported usually lacks matrix materials. These concepts are treated separately in the database.
- *Gradient* or angle of a phenomenon is its inclination in relationship to the body on which it is located, measured in degrees. Mostly a phenomenon inclines at the same angle as that of the slope or body on which it lies (Table 3.1 & Fig. 3.4).
- *Orientation* or aspect is the phenomenon's position in relation to the main points of the compass. In the database, orientation is treated as a definite compass direction (Fig. 3.4 & Fig. 3.6).
- *Slope* refers to the actual slope on which the phenomenon is located which faces a certain compass direction.
- *Slope angle* refers to the slope's inclination in degrees (Fig. 3.4).
- *Dimensions*: that is the width, length, height, depth and diameter of the phenomenon (Fig. 3.5).

Direction	Exact demarcation	Generalised demarcation	Compass direction
N	348.76° - 11.25°	348° - 10°	0°
NNE	11.26° - 33.75°	11° - 32°	22.5°
NE	33.76° - 56.25°	33° - 55°	45°
ENE	56.26° - 78.75°	56° - 77°	67.5°
E	78.76° - 101.25°	78° - 100°	90°
ESE	101.26° - 123.75°	101° - 122°	112.5°
SE	123.76° - 146.25°	123° - 145°	135°
SSE	146.26° - 168.75°	146° - 167°	157.5°
S	168.76° - 191.25°	168° - 190°	180°
SSW	191.26° - 213.75°	191° - 212°	202.5°
SW	213.76° - 236.25°	213° - 235°	225°
WSW	236.26° - 258.75°	236° - 257°	247.5°
W	258.76° - 281.25°	258° - 280°	270°
NNW	281.26° - 303.75°	281° - 302°	292.5°
NW	303.76° - 326.25°	303° - 325°	315°
NNW	326.26° - 348.75°	326° - 347°	337.5°

Table 3.1: Compass direction ranges.

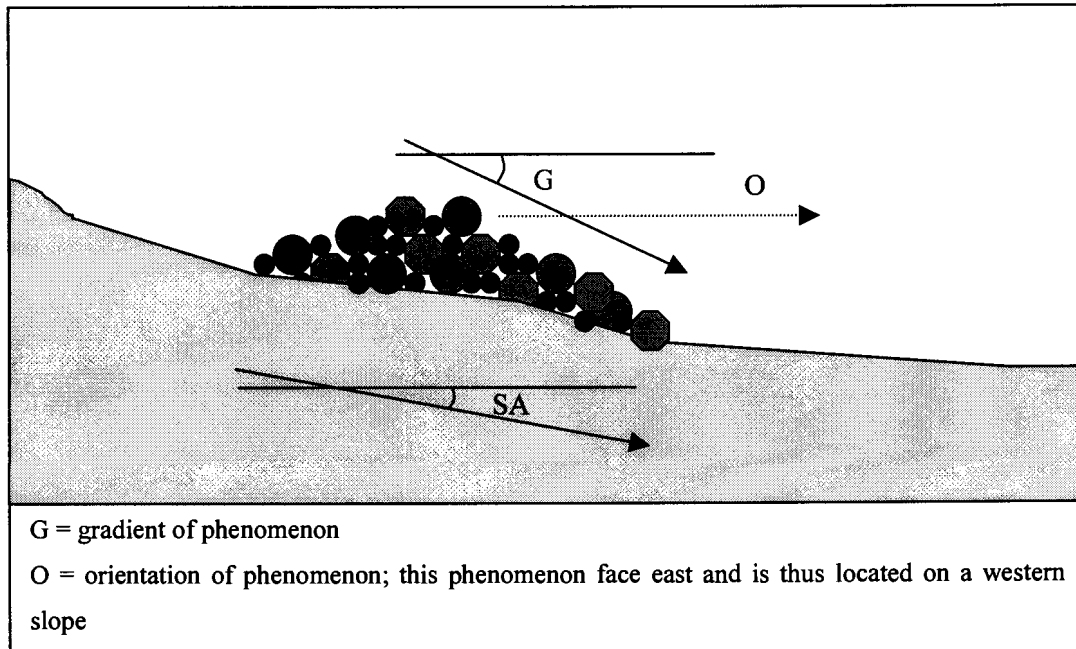


Figure 3.4: The differences between gradient, orientation and slope angle.

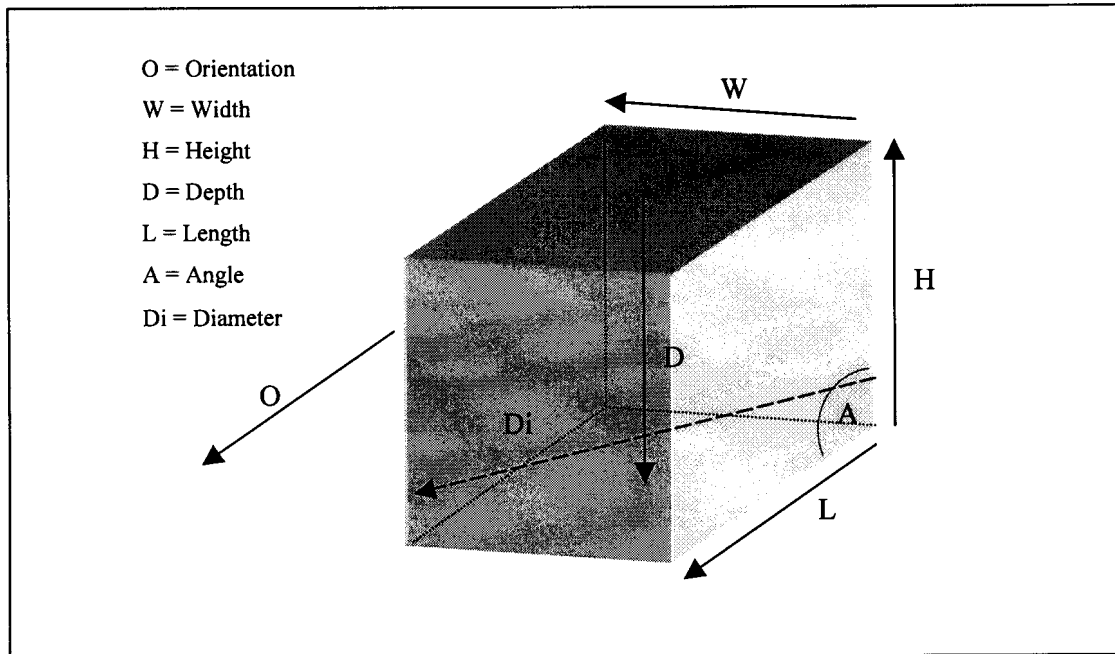


Figure 3.5: The dimensions of a three-dimensional figure.

Dimensional measurements differ from phenomenon to phenomenon. For terracettes and other step-like features, height is measured at their raised fronts, and for hollow-like features at their backwalls. Depth is applicable to features of which the distance can be measured from their “surfaces” to their bases. The measurement unit in the database (and later map analysis) is in metres.

3.3.1.6 Other characteristics

In the literature many interesting facts are discussed that can not be included in the data columns referred to above, but may be incorporated into this special category. The first subcategory encompasses other phenomena in the near vicinity of the phenomenon under discussion, e.g. tor-like features observed in close vicinity of cutbacks (Grab, 1996a). The second subcategory deals with any interesting fact or characteristic of the phenomenon, e.g. thufur “form in areas of abundant soil moisture” and “thufur break-up normally occur on the northern side of the mound” (Hastenrath, 1972).

3.3.2 *Problems encountered during the development of the GIS-database*

During database compilation, unforeseen difficulties came to the fore. One of the biggest problems is incomplete information. Many of the earlier papers give only a broad overview of phenomena. Sometimes the same phenomenon with the same characteristics is repeated

several times, differing only in location. Because of the lack of supportive data, there are incomplete data entries in the database. One of the research aims is to provide point data locality for each phenomenon. This goal can not be achieved if data were combined to give an overall or more representative picture. The same applies for generalisation of areas where no definite latitude or longitude is given for a feature. It is important in both cases that if point data are desired, phenomena must be indicated geographically separate from each other. The problem was partially overcome by allocating a polygon (representing that specific area) to a data entry; nevertheless, the convenience of point data locality is sacrificed.

It was also found that most features and processes were not clearly defined. The way in which data are presented is sometimes confusing and a certain degree of classification becomes necessary. For this problem, a glossary of terminology and a basic reference framework were compiled (see Chapter 4).

3.4 Realising the aims and objectives of the study through database manipulation

The purpose of the Cryogenic Features and Processes Database for Southern Africa is to realise the aims and objectives of the study and to comprehend the significance of relict and present-day features and processes through specialised operations. Regarding the conditions stipulated for the database earlier in the discussion, it is certain that the database will provide an objective data source and supplement existing knowledge of the Quaternary in southern Africa. Other important prerequisites, namely database efficacy, workability and user friendliness, are tested in Chapter 5.

A further aim of the database, combined with programme accessories such as Enpat for ArcView[®], is to enable researchers to create maps, interactive views and reports to assist them in future cryogenic studies in southern African. The database is a dynamic and flexible system and a valuable GIS-tool in decision making with a range of functions, outputs and operations (Davies, 1996). GIS uses geographically referenced data as well as non-spatial data, and includes operations that support spatial analysis (Goodchild & Kemp, 1991). The database is the focus of the GIS-system and embodies spatial and attribute data needed for data analysis.

The database can be manipulated to produce maps by isolating selected database elements (Eastman, 1992). A GIS-system is capable of data input and verification, data storage and database management, data output and presentation, data transformation, and interaction with the researcher (Burrough & McDonnell, 1997). It is evident that a GIS-system is dynamic, putting the latest technology and advanced information systems at the disposal of the researcher (Davis, 1996).

3.4.1 Factors affecting the reliability of spatial and attribute data

Different factors can influence the reliability of spatial and attribute data (Goodchild & Kemp, 1991; Burrough & McDonnell, 1997), especially where southern African cryogenic research is concerned. These factors not only limit the reliability of the data, but also its usefulness, credibility and efficiency:

- *Age of data*: The researcher is forced to use existing published data and in the case of the Cryogenic Features and Processes Database for Southern Africa, some information is rather old, but regarded indispensable for research.
- *Aerial coverage*: It is desirable that the whole of a study area should have a uniform information cover. If this is not possible, the researcher must be satisfied with partial levels of information. To make coverage more complete and uniform, supplementary data must be obtained or detailed data must be generalised to match less detailed data.
- *Map scale and resolution*: Most geographic resource data have been generated and stored in the form of thematic maps. It is only recently with the development of digital information system that it has been possible to have the original field observation available for further processing. In the southern African context not much has been done for cryogenic studies in the form digital mapping, implying that resolution and scale must be chosen discretely.
- *Density of observations* involves ground truth and sampling density upon which observations and data-sets are based. Some data in current cryogenic literature are seriously deficient in supportive ground truth data, which unavoidably affect data quality.

These factors affect the database system in one way or the other. However, it is hoped that the Cryogenic Features and Processes Database for Southern Africa will stimulate new research that will diminish these factors significantly.

3.4.2 Different outputs and operations

The Cryogenic Features and Processes Database for Southern Africa can be employed in different ways and through GIS-based programmes, e.g. ArcView[®], to aid further cryogenic research. ArcView[®] is a vector and raster based GIS-system and is used to visualise attribute

data for this study. The various advantages and disadvantages of raster and vector formats are outlined in Tables 3.2 and 3.3. Data can be recalled and organised to the researcher's specifications by utilising overlays, queries, map calculations, etc. By overlaying one coverage over another a multi-feature or multiple-theme coverage can be produced (Davis, 1996). Stored information can be viewed by location or by attributes through queries (Eastman, 1992). Query options, according to Goodchild & Kemp (1991), include:

- Simple recall of data.
- Showing a specified object (show me object X).
- Specifying an object (what is this object?).
- Summarising attributes of objects within a distance.
- Summarising attributes of objects within a region.
- Recommending the best route.
- Showing all objects satisfying pre-set or specified criteria.

After manipulating the data and acquiring the desired results, the outcome can be presented in text, graphic or digital format (Goodchild & Kemp, 1991). A GIS-system combined with a database offers an assortment of options for data manipulation and is one of the best methods for solving geographic problems and questions.

3.5 Conclusion

In this chapter each step in the development of the Cryogenic Features and Processes Database for Southern Africa was explained. The advantages of a GIS-based database were revealed and it was demonstrated how the database can be utilised in realising the aims and objectives of this study. Through database compilation, utilisation of GIS-techniques, data modelling and data representation, it is hoped that a better understanding of relict features and processes will be gained. By importing known Quaternary data into the database-GIS setting the reconstruction of the palaeoenvironment and its extent is possible and the insights gained from database modelling will enable prediction of future climatic events. Lastly, the database is a more reliable and objective data source and will supplement existing knowledge of the Quaternary in more than one way.

RASTER FORMAT	
Advantages	<ul style="list-style-type: none"> • Simple data structure: a grid with a single number in each cell. • Easy to understand and use, even for beginners. • Easy analysis. • Remote sensing imagery is obtained in raster. • Modelling which uses raster numbers, use the creation of a generalised data file or a set of universal procedures to accomplish a certain GIS task.
Disadvantage	<ul style="list-style-type: none"> • Spatial inaccuracies. • “Implies” truth (an implicit structure). • Relatively low resolution. • Raster systems can have very large data sets. • The general public does not usually understand raster imagery.

Table 3.2: Advantages and disadvantages of raster format (after Davies, 1996).

VECTOR FORMAT	
Advantages	<ul style="list-style-type: none"> • It is more map-like. • High resolution. • High spatial accuracy. • Vector data can be topological. • Takes less storage space and offer better storage capabilities than raster formats. • The general public usually understands what is shown on vector maps.
Disadvantages	<ul style="list-style-type: none"> • May be more difficult to manage than raster formats. • Require more powerful, high-tech machines. • More expensive.

Table 3.3: Advantages and disadvantages of vector format (after Davies, 1996).

CHAPTER 4

A discussion of database terminology and data problems encountered in the literature

In Chapter 3 the importance of background information indices regarding database terminology as part of the study methodology was mentioned. Besides the need for glossaries and indices, additional information concerning specific database features and processes prompted closer inspection. The following discussion will look at the preparation of supplementary information glossaries and will examine the difficulties regarding specific phenomena in the database.

4.1 Database terminology

Terminology usage in southern African cryogenic research is not consistent or self-evident (e.g. Hall, 1992; Grab, 1999; Chapter 2). This problem was partly overcome by compiling a glossary of terms and definitions for standardising purposes. International terminology definitions were collected in an effort to add more meaning to the often casual usage of terminology in southern African cryogenic studies (Hall, 1992). Periglacial terminology and definitions were obtained from the International Permafrost Association's Global Geocryological Database (Van Everdingen, 1998). Glacial and other geomorphological terminology were quoted from *The Encyclopaedic Dictionary of Physical Geography* (Goudie *et al.*, 1985), *Earth* (Press & Siever, 1986), *Dictionary of Geography* (Clark, 1998), and *The New Penguin Dictionary of Geology* (Kearey, 1996). Where necessary, definitions were inferred from southern African papers and personal communication. The Terminology Glossary is summarised in Appendix C.

Four supplementary reference tables and lists were added to the Terminology Glossary and comprise of a *Features and Processes Table* (Appendix D), a *General Features and Processes Reference Index* (Appendix E), a *Geographic Location Reference Index* (Appendix F), and an *English/Afrikaans Terminology Index* (Appendix G). To demonstrate the function of the indices, the feature *solifluction terrace* is considered as an example. When searching

through the Terminology Glossary (Appendix C) for “solifluction terrace”, the following definition will be found:

Solifluction terrace:

A low step, or bench, with a straight or lobate front, the latter reflecting local differences in the rate of solifluction movement. A solifluction terrace may have bare mineral soil on the upslope part and ‘folded-under’ organic matter in both the seasonally thawed ground and the frozen ground. Those covered with a vegetation mat are called turf-banked (solifluction) terraces; those that are stony are called stone-banked (solifluction) terraces (Van Everdingen, 1998).

For most terminology more than one definition is given. Synonyms, southern African papers, and a short synopsis of southern African examples for “solifluction terrace” are included in the Terminology Glossary:

Solifluction terrace:

Synonyms: solifluction bench, solifluction step, garland terrace (obsolete)

Papers: Harper (1969); Lewis (1996a)

Synopsis: active & relict; 2600-2744m.a.s.l.; vegetated; unconsolidated grey, orange & red sediments, modern soils & a palaeosol; 0.5-10m wide; 1m long; 1-20cm high; 6.1-12.2m deep

The other indices (Appendix D, E, F and G) are shorter specialised versions of the Terminology Glossary (Appendix C) and focus specifically on southern African cryogenic phenomena. The Features and Processes Table (Appendix D) was designed to standardise database term usage and rule out unnecessary synonyms or obsolete terminology, e.g.

Solifluction terrace:

Category:

Solifluction features

Term in database:

Solifluction terrace

Sub-categories:

Turf-banked terrace

Stone-banked terrace

Term recognised by the IPA¹:

Solifluction terrace

¹ International Permafrost Association.

Synonyms recognised by the IPA: *Solifluction bench*
Synonyms not recommended by the IPA: *Soliflual garland terrace*

The General Features and Processes Reference Index (Appendix E) functions as an extension of the Terminology Glossary (Appendix C) and incorporates southern African occurrences in particular, e.g.

Solifluction terrace:

Writers: *Harper (1969); Lewis (1996a)*
Activity: *Active & relict features*
Altitude above sea-level: *2 600 – 2 744m*
Vegetation: *Yes*
Sorted/nonsorted: *-*
Soils and sediments: *Unconsolidated grey, orange & red sediments, modern soils & a palaeosol.*
Matrix: *-*
Width: *0.5-10m*
Length: *1m*
Height: *1-20cm*
Depth: *6.1-12.2m*

The Geographic Location Reference Index (Appendix F) is a quick reference guide to the geographic location of features and processes in southern Africa, e.g.

Solifluction terrace:

Location	Province/region	Latitude	Longitude
<i>Ben MacDhui</i>	<i>Eastern Cape</i>	<i>30°38'44"</i>	<i>27°56'32"</i>
<i>Brandwag</i>	<i>Free State</i>	<i>28°34'05"</i>	<i>28°34'36"</i>
<i>Cathedral Cave valley</i>	<i>Kwa-Zulu Natal</i>	<i>29°01'30"</i>	<i>29°15'00"</i>
<i>Ribbok Valley</i>	<i>Free State</i>	<i>28°32'22"</i>	<i>28°36'19"</i>
<i>Tiffendell Ski Resort</i>	<i>Eastern Cape</i>	<i>30°40'22"</i>	<i>27°56'53"</i>

The English/Afrikaans Terminology Index (Appendix G) acts as a quick reference list regarding database terminology, synonyms, obsoletes and suggested Afrikaans terminology, e.g.

Solifluction terrace:

<i>Terminology</i>	<i>Preferred usage</i>	<i>Afrikaans</i>
<i>Garland terrace</i>	<u><i>Solifluction terrace</i></u>	<i>Bodemvloeiterras</i>
<i>Solifluction bench</i>	<u><i>Solifluction terrace</i></u>	<i>Bodemvloeiterras</i>
<u><i>Solifluction terrace</i></u>	<u><i>Solifluction terrace</i></u>	<i>Bodemvloeiterras</i>

The main objective behind the compilation of the glossaries and indices is to standardise terminology specifically for the development and functionality of the database. In addition, the indices were compiled according to the features and processes observed in southern Africa, thus lacking other significant periglacial and glacial phenomena found in the rest of world. The reader is therefore explicitly reminded that the database is primarily an aid for researchers inquiring into cold southern African environmental phenomena.

It is further realised that the southern African cryogenic environment may be unique in its own respect and that international terminology and definitions may not be applicable or suitable in southern African context. However, since no significant original vocabulary explicitly for southern African cryogenic features and processes has been put forward, and seeing that internationally accepted terminology is widely used by researchers, the Terminology Glossary (Appendix C) and supplementary indices must be accepted as a basis for database terminology. In the words of Thorn (1991:4), “terminology issues are an important facet of the inherent conflict in science between the need for meaningful generalisation and the need for precision ... it behoves every scientist to be clear-minded. Clarity of thought is dependent upon the small artefacts of the process (i.e. words) as well as the grandiose (i.e., overarching theory).”

4.2 Inconsistencies encountered in the literature

Because of the great uncertainty in southern African cryogenic studies many interpretation inconsistencies exist that have not been addressed or clarified. Southern African cryogenic geomorphology is going through a phase of acceptance (Hall, 1991a), and knowledge of the cryogenic environment is still in its early stages (Hall, 1992). Nonetheless, the problems and different views emphasised below reflect the likely *polygenetic* origin of most so-called

periglacial or glacial features (Thorn, 1991). Some of the irregularities may not necessarily affect database efficiency, but cast a poor light on database reliability. It is important to be aware of these conflicts for the following reasons:

- There are problems within current southern African cryogenic data that are often not addressed. Most of these problems, as will be revealed later on, are still under discussion internationally.
- Unconfirmed arguments and ideas influence database objectivity. Current cryogenic data interpretation are used to explain and lay the foundation for either glacial or periglacial arguments for the palaeoclimate of southern Africa. However, most proposed hypotheses and follow-up arguments have not been verified and lack back-up research and contributions from other disciplines.
- Criticism on proposed ideas is seldom constructive and rarely contributes towards the discussion.
- Due to the scarcity of cryogenic data in southern Africa, database reliability is compromised in that it is reliant on a small assortment of unverified research.

The primary intention of the following discussion is to focus attention on some irregularities and the arguments and criticism surrounding it, and not to assess database credibility.

4.2.1 Southern African erosional hollows

Southern African erosional hollows are the most debated phenomena in current cryogenic literature. Marker (1989, 1990c, 1991b, 1992, 1998) undoubtedly contributed greatly towards research concerning these much-disputed features. Erosional hollows are believed to be the products of Quaternary cold periods in southern Africa and are described as valley-type features found in the upper regions of the High Drakensberg and Lesotho Mountains resembling shallow cirques (Marker, 1989, 1990c, 1991b; Sparrow, 1971, 1973, 1974). Erosional hollows are sometimes referred to as amphitheatre-shaped hollows, cirque-like hollows and nivation cirques (Sparrow, 1964; Marker & Whittington, 1971; Hastenrath, 1972; Nicol, 1973; Hastenrath & Wilkinson, 1973; Dyer & Marker, 1979; Marker, 1989, 1990c, 1991b; Hanvey & Marker, 1994). Erosional hollows are frequent along the Great Escarpment.

4.2.1.1 The Golden Gate erosional hollows

Marker (1989) found that periglacial processes and nivation formed the Golden Gate erosional hollows, and that the characteristic niche-shape of some of these features indicates an origin under snow-patch conditions (Marker, 1990a). The contention is that the shape of the hollows was enhanced by the distinct geology of the region (resistant basalt over sandstone), but that if they were solely structural in origin they should occur on all aspects and at any elevation (Marker, 1990a). The hollows occur seemingly only on south-facing slopes and above 1 700m a.s.l. (Marker, 1990a).

Where form and shape is concerned, however, one cannot necessarily infer causes from outcomes. In addition, the hypothesis of periglacial conditions during the Pleistocene may be disputed on account of the probable aridity of the eastern Free State (and most of the subcontinent for that matter) during the Last Glacial Maximum (LGM) (Le Roux, 1990). The characteristic niche-shape hollows along south-facing slopes can form because of lithological differences, notably in basalt, which tends to be unhomogeneous (Le Roux, 1990; Van Rooy & Nixon, 1990; Van Rooy, 1992; Van Rooy & Van Schalkwyk, 1993). Different mechanisms other than nivation may have been operative in the formation of the hollows.

4.2.1.2 The High Drakensberg and Lesotho Mountains erosional hollows

Both nivation and cirque glaciation have been proposed to explain the origin of the Lesotho erosional hollows (see Chapter 2). The hollows are regarded as cold climatic features because of their strong pole-facing orientation, and are associated with other pole-facing asymmetrical slope forms and periglacial features (Sparrow, 1973). These hypotheses, however, have not yet been proven (Grab & Hall, 1996). Researchers should also note the following issues raised by Sparrow (1973), Hall (1991c), Le Roux (1991b) and Hall & Grab (1996):

- The Lesotho erosional hollows may imply a different suite of evolutionary and palaeoenvironmental events in the landscape.
- The term “nivation” has its own set of problems (see later discussion) and lacks an acceptable operating definition.
- The idea of large quantities of Pleistocene snow drifting into leeward positions seems unlikely when compared to contemporary snow drifting, which is insignificant.
- It is proposed that the hollows are of nivational/glacial origin. Erosional hollows appear to be restricted to regions above 3 000m a.s.l. and are mostly north-facing. But, if

snowfall were enhanced and remained for longer periods, it is just as valid to presume that cirques would rather have developed a preferred south-facing aspect.

- Snow-patches may accumulate in pre-existing hollows, but are unlikely to have produced the hollow itself. It is evident that the Lesotho erosional hollows developed over a long period, but it is difficult to contribute hollow formation to glacial/periglacial processes when unequivocal evidence is absent.
- It is difficult to interpret past conditions from geomorphological evidence alone. This makes it essential to support any argument in favour of former cold conditions by evidence from other disciplines.
- *Pre-existing* hollows for cirque formation and *time* for cirque development, growth and decline need more consideration.

The distinct structural disposition of the High Drakensberg and Lesotho Mountains, its superficial geomorphological impact yet unknown, may play a significant part in the natural formation and control of erosional hollows and niches (Meiklejohn, *et al.*, 1999).

An alternative approach is presented by Hall & Grab (1996) suggesting that the Lesotho erosional hollows are reminiscent of *bog cirques* as seen in north-eastern Mongolia (Dzulynski & Pekala, 1980). The regions in which bog cirques occur, display similar climatic conditions to those found in southern Africa, amongst others summer rainfall and winter drought, low mean annual air temperatures, a scarcity of snow, and intense diurnal and seasonal freeze-thaw cycles. According to Hall & Grab (1996) the Lesotho erosional hollows exhibit many prominent bog cirque characteristics:

- Hollow morphometry, like bog cirques, resembles that of nivation hollows and are prominent features of the landscape.
- Hollows are irregularly spaced, have arcuate rock benches and basin-like depressions.
- Hollows develop preferentially on the sun-exposed (north-facing) slopes.
- Hollow floors are boggy and host peat-forming vegetation.
- Hollows commonly merge into trough-like summit surfaces at high elevations.

Hall & Grab (1996) decided that the nival/glacial hypotheses for north-facing hollows harbour too many problems. They call for a revision of high altitude palaeoenvironmental theory and

unequivocal evidence. Sparrow (1973) documented the same hollow characteristics as found by Marker (e.g. 1989, 1991b, 1992) and Dyer & Marker (1979). However, Sparrow (1973) perceived that the hollows are relatively shallow and display prominent head fans at their bases, both of which tend to rule out an origin by ice processes. According to Sparrow (1973), glacial evidence is lacking for the High Drakensberg and Lesotho Mountains and former cold-climate conditions may not have been either intense or necessarily long in duration to produce glacial phenomena. Thus, Sparrow (1974) argues for a non-glacial hollow developmental sequence for southern African erosional hollows.

Sparrow (1974) found that the erosional hollows form through a sequence where asymmetrical slope forms evolve either through a dry succession or a wet succession into cirques (Fig. 4.1). Dry succession landforms have a developmental sequence of their own but may graduate into the wet succession. Wet succession landforms are restricted in distance to the eastern and south-eastern parts below the main Escarpment (Sparrow, 1974). The transitional stage between dry and wet successions can evidently be seen in the strongly denticulated cliffs, pinnacles and large shallow hollow development (Sparrow, 1974).

The origin of southern African erosional hollows remains nonetheless unresolved. More research and testing of hypothesis are needed to prove or disprove current ideas on the matter. Erosional hollows are not the only cryogenic features needing further investigation as will be shown presently.

4.2.2 Valley asymmetry

Valley asymmetry is another large-scale phenomenon observed in southern Africa. The strongest manifestations occur in Lesotho and adjacent areas (Sparrow, 1964, 1967a, 1969; Boelhouwers, 1988; Marker, 1989; Meiklejohn, 1992; Grab, 1999; Meiklejohn *et al.*, 1999). In the High Drakensberg and Lesotho Mountains south-facing slopes are consistently steeper than north-facing slopes and attributed mainly to periglacial and snow processes (Meiklejohn, 1992; Grab, 1999). However, asymmetric valleys can form under almost all climatic conditions (Le Roux, 1990) and are not necessarily indicators of periglacial activity (Meiklejohn, 1994). Garland (1979), Boelhouwers (1988) and Grab (1999) pointed out that differential operation of non-periglacial processes on north- and south-facing valley sides, might account for valley asymmetry in the Drakensberg. Garland (1979) and Boelhouwers (1988) proposed that the valley-side with the highest denudation rates will develop the

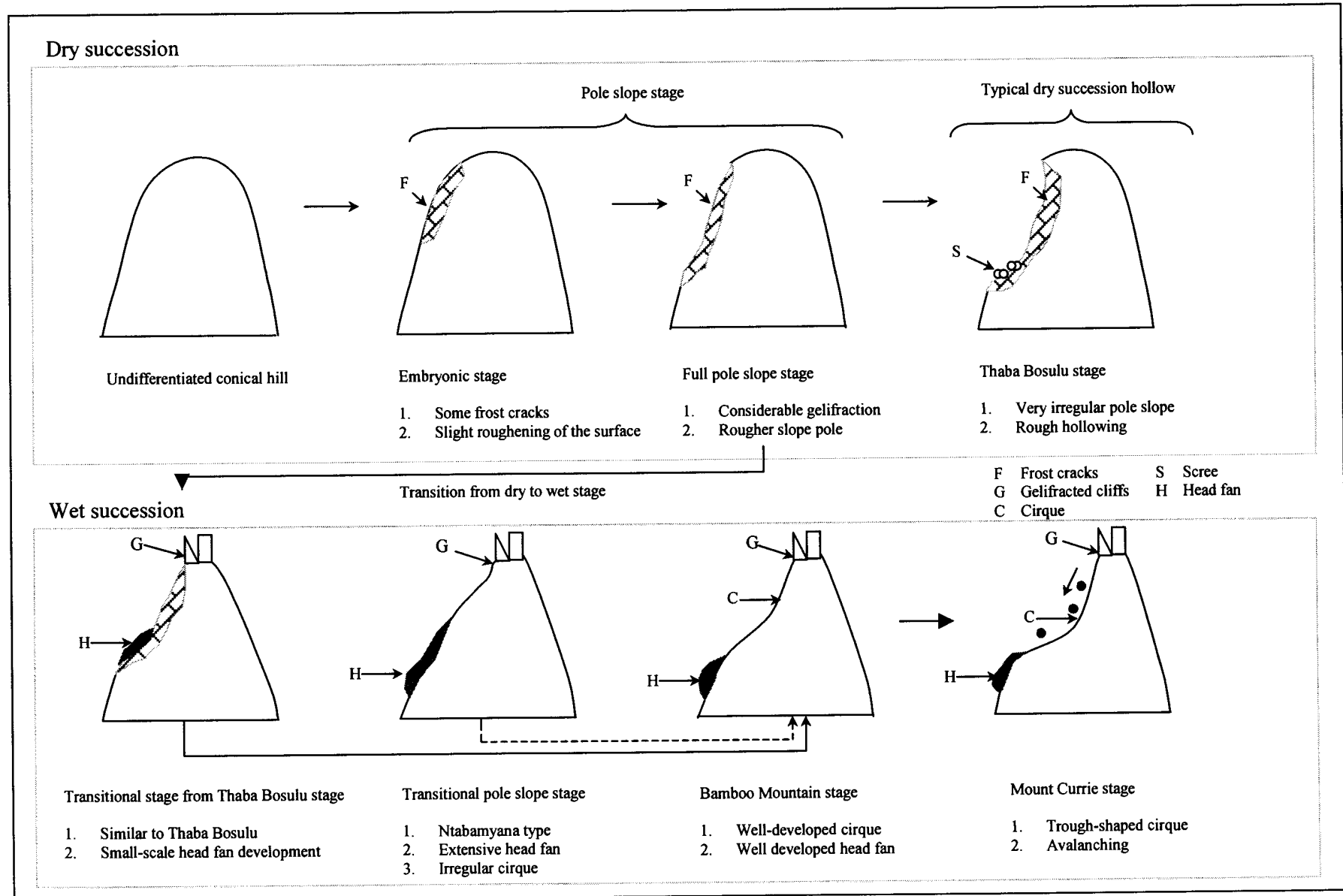


Figure 4.1: Suggested developmental sequence of non-glacial cirques (after Sparrow, 1974)

shallowest gradient, i.e. the north-facing slope, and that over time valley asymmetry will originate through the dominance of non-periglacial processes. Boelhouwers (1988) concludes that the observed valley asymmetry is the result of differing intensities of various weathering and erosion processes on opposite valley sides. No aspect of valley form in and of itself appears to be sufficient to establish a periglacial environment, and to emphasise asymmetry in and of itself cannot be considered diagnostic (Thorn, 1991; French, 1996).

4.2.3 River terraces

Marker (1989) reported a double terrace along the Little Caledon River consisting of rubble lobes evidently moved downslope by solifluction (Marker, 1989). Current drainage through the deposits do not affect the alleged solifluction material and at least five solifluction diamictons, fining upwards and showing fluvial sorting, are visible (Marker, 1989, 1990a). These unsorted sediments need not necessarily be solifluction material. During the present climate unsorted slope material creeps downslope very slowly, but during heavy rainfalls debris slides are common (Le Roux, 1990). The deposits could have accumulated during an arid phase of the LGM when the Little Caledon River might not have been able to move the unsorted sediment delivered by infrequent heavy rains (Le Roux, 1990). Thorn (1991) noticed that there are many fluvial situations in cold climates lacking diagnostic landforms that might establish a periglacial environment.

4.2.4 Large scattered boulders

Large scattered boulders are a regular phenomenon on slopes of the High Drakensberg and Lesotho Mountains. The distribution is widespread but seemingly always above 1 500m a.s.l. (Marker, 1989, 1990a). Some had slid down in a matrix of mud and boulders evidently caused by solifluction (Marker, 1989). According to Le Roux (1990) it must first be considered, before attributing the transportation and formation of the boulders to specific geomorphic events, that boulders can roll downslope from a scarp or cliff on to their present locations and can move downslope slowly in and on other debris and soil aided by gravitation and heaving. Boulders may even move due to the lubricating effects of water and the shear pressure of the debris packet above the boulder (Le Roux, 1991). Moreover, the large scattered boulders observed on the subcontinent are common tropical climate and tropical desert features. The observation that boulders are only found above 1 550m a.s.l. is accounted for by the fact that

rock material of sufficient strength coupled with massivity and thickness does not occur below that elevation (Le Roux, 1990).

4.2.5 Basalt and angular clasts

Basalt is a dark igneous rock characterised by small grain sizes and containing almost equal proportions of plagioclase feldspar and calcium rich pyroxene (Mottana *et al.*, 1995; Clark, 1998). Most angular clasts in the High Drakensberg and Lesotho Mountains are contributed to freeze-thaw mechanisms (e.g. Hanvey & Marker, 1992). In a laboratory test conducted by Haskins & Bell (1995) it was shown that all the basalts tested (olivine, amygdaloidal, moderately amygdaloidal and non-amygdaloidal) had a relatively high resistance to cyclic freezing and thawing, but not to repeated wetting and drying. Basalts are much more prone to chemical weathering (Hall, 1992). In cold climates basalts and sandstones can produce angular or rounded clasts (Hall, 1992). Rounded clasts are usually found where a greater amount of water and high rock temperatures are present to produce chemical weathering (Hall, 1992). It is more likely southern African basalts produce rounded or angular clasts not necessarily due to cryogenic processes, but rather to chemical weathering and the availability of water and high temperatures (Hall, 1992). Angular clasts can also result from thermal fatigue and have no unique association with frost action (Hall, 1992).

4.2.6 Cutbacks

Cutbacks are narrow, steep-sided valleys or passes cut into the slopes of a mountain. According to Grab (1996a) they are ravines or steep, narrow valley heads. Cutbacks are commonly found in the High Drakensberg and Lesotho Mountains. Hall (1994) observed that these cutbacks have channel systems with closing borders at their lower ends consisting of rounded, cobble to boulder-sized debris. Hall (1994) envisaged large volumes of water discharging the deposits and rounding boulders during transport. The possibility of debris flows and precipitation were ruled out in favour of meltwater from an ablating ice body (Hall, 1994). Hall (1994) concluded that there was a glacial ice cover on the High Drakensberg and Lesotho Mountains that melted during the onset of the Holocene, pouring down the cutbacks and forming the deposits. It is suggested that nival processes are responsible for the origin of the cutbacks. However, basalt is predisposed to rounded clasts and in cold climates with high rock temperatures and wet conditions, weather to rounded clasts (Sarracino & Prasad, 1988;

Hall, 1992; Sumner, 1995). Basalt can already be highly rounded by weathering prior to movement (Hall, 1992). Rounded basalts are frequent on the Escarpment where no fluvial action or clast movement is taking place (Sumner, 1995). Sumner (1995) argued that nival processes couldn't fully explain the origin of the cutbacks or the large debris deposits.

4.2.7 Protalus ramparts

A protalus rampart is an accumulation of coarse angular rock debris resembling a moraine and consisting of material that has slipped down from perennial banks of snow, lying parallel to the slope that produced it (French, 1996; Shakesby, 1997; Clark, 1998). A feature resembling a protalus rampart was found in Bokspuit, Eastern Cape by Lewis (1994) and measured according to the criteria given by Ballantyne & Kirkbride (1986). The rampart is approximately 1km long and 17m high, consisting of a connected series of arcuate debris accumulations. Lewis (1994) assumed that the feature is a protalus rampart caused by snowbed growth during the LGM. Shakesby (1997), though, is of the opinion that the differences are more noteworthy than the similarities between this feature and a true protalus rampart:

- Only the relationship between the Bokspuit rampart width and thickness is similar to the findings of Ballantyne & Kirkbride (1986).
- The relationship between the protalus rampart at Bokspuit's size indices and crest-talus distance was a negative relationship, unlike the positive one found by Ballantyne & Kirkbride (1986).
- All of the Bokspuit rampart size indices lie outside the range of the British examples given by Ballantyne & Kirkbride (1986).

Shakesby (1997) likewise questions other "protalus" ramparts identified in southern Africa (e.g. Nicol, 1973; Lewis, 1987, 1994; Marker, 1989, 1990c) and resolved that they probably had alternative origins.

4.2.8 Scree deposits

Intense frost action together with periglacial slope-wash is generally believed to be the formative processes behind scree (French, 1996). Scree deposits are familiar features in the

High Drakensberg and Lesotho Mountains and especially in the Eastern Cape. They have been extensively researched by Marker (1986) and attributed to nivational and frost action processes in a cold palaeoperiglacial environment. However, subsequent research by Sumner & De Villiers (*in prep.*) has shed more light on the nature of these screes and concluded that, although there is a strong indication that cold processes were responsible for their formation, the screes can not be ascribed to any specific cold environment scenario. It was further suggested that the features were deposited over a long period pre-dating the Last Glacial Maximum (LGM) (Sumner & De Villiers, *in prep.*). French (1996) cautions that screes may possess a wide range of textural characteristics related to local bedrock conditions. Screes may also be formed by other processes totally unrelated to periglacial conditions, e.g. debris flows (French, 1996) and may therefore not be a reliable diagnostic indicator for past periglacial climates.

4.2.9 Discussion of Harper (1969) and Linton (1969)'s findings

It is essential to support any argument in favour of former cold conditions by interdisciplinary evidence (Sparrow, 1973). Both Harper (1969) and Linton (1969) failed to produce empirically tested evidence (Sparrow, 1973). Harper (1969) and Linton (1969) reported on such diverse features and processes as basalt steps, patterned ground, erosional hollows, frost wedging, glacial polish, ice-wedges, slip scars, valley asymmetry, etc. Butzer (1973) suggested that Linton's (1969) striped blockfields near Pretoria (see Chapter 2) might actually be typical sheet-wash, creep and occasional mudflow deposits of a more colluvial nature. A more likely explanation is that the deposits are karstic or even litho-structural in origin (Butzer, 1973). The inverted weathering profile near Magaliesburg (Linton, 1969) are, according to Butzer (1973), not uncommon to the foot slope sectors of the High Veld wherever colluvial agencies have been prominent. Butzer (1973) altogether disregarded Linton's (1969) cryonival and geliflual interpretation of Western Cape features (Appendix A) and the possibility of cold climatic conditions in the northern parts of the subcontinent.

4.2.10 Comments on process terminology usage in southern African cryogenic research

It has been shown thus far that some southern African cryogenic researchers inevitably step into pitfalls because of qualitative presumptions and a lack of evidence and empirical quantitative research. Thorn (1991) specifies problems experienced world wide with certain

processes that southern African researchers should take note of, especially where terminology usage is concerned. Earlier it was revealed that southern Africa is a borderline or sub-periglacial region (Chapter 2) and that little is known about the features and processes abounding there. It is difficult to discern what combinations of processes have been operative in the recent past (Hall, 1992), particularly in marginal areas (i.e. sub-periglacial regions). Therefore, considerable caution must be taken when classifying and interpreting southern African phenomena, otherwise a completely misleading picture may emerge (Hall, 1992). Thorn (1991) further comments on the terminology usage of frost wedging, frost heaving and nivation in southern African cryogenic research.

4.2.10.1 Frost wedging

Frost wedging, in the broadest sense, is weathering by freezing and thawing, yet it is not known exactly how this process works and what the main protagonists are (Thorn, 1991). Although the term is widely accepted in periglacial studies, it lacks detailed theory (Thorn, 1991). In this regard, Walder & Hallet (1985) did develop a theoretical framework, but warned that there are too many unresolved problems, e.g. the likelihood of frost wedging as a multi-component process, of which not much is known (Thorn, 1991). Frost wedging is believed to produce angular fragments, but this has already been shown as not entirely true as angularity is largely dependent on the lithology and several other mechanisms (Hall, 1992). A revision of the use of “frost wedging” is called for since this term is used too readily in southern African cryogenic literature (e.g. Harper, 1969; Borchert & Sanger, 1981).

4.2.10.2 Frost heave

Hastenrath (1972) mentions the presence of frost heave processes in the High Drakensberg and Lesotho Mountains. Frost heave of soil is produced by two primary mechanisms, namely a 9% expansion of volume during the phase change from liquid to ice, and a much more complex as well as a potentially much larger effect produced by the migration of unfrozen soil moisture to the freezing front, usually producing segregation ice. The assumption is the presence of an attractive force towards the solid-liquid interface, but there is no definitive explanation of such a force, although evidence for it does exist (Thorn, 1991). Another assumption is the presence of a *disjoining* force that separates the faces of a growing ice

crystal from solids. Theoretical explanation of the formative processes of segregation ice, nevertheless, has remained difficult (Thorn, 1991).

4.2.10.3 Nivation

Matthes (1900) introduced the term nivation, defining it as the process of névé occupying a valley and changing its form from a V-shaped to a U-shaped (Thorn, 1988). Mechanical weathering, chemical weathering and mechanical transport are only a few of the processes that may be involved in nivation (Thorn, 1988). However, the term embraces many component concepts and is not defined operationally (Hall, 1991a; Thorn, 1991). According to Thorn (1978, 1991), the term “nivation” must be abandoned in favour of uncomplicated terminology and critical analysis (Grab & Hall, 1996). It is evident that southern African researchers use the term too quickly without prior knowledge of the many difficulties surrounding it (e.g. Sparrow, 1967a; Harper, 1969; Nicol, 1973; Dyer & Marker, 1979; Borchert & Sänger, 1981; Lewis & Hanvey, 1988; Marker, 1986; Hanvey & Lewis, 1991; Hall, 1994).

4.2.11 *Freeze-thaw weathering*

Freeze-thaw weathering, also called gelifraction (Sparrow, 1964; Hastenrath, 1972; Hastenrath & Wilkinson, 1973; Nicol, 1973), is a form of weathering in periglacial areas where the temperature stays close to freezing point, below which frost breaks up the rock and above which the ice melts, so that water flows and carries away the rock fragments (Clark, 1998). Many workers attribute their findings to freeze-thaw weathering (e.g. Sparrow, 1964; Hastenrath, 1972; Hastenrath & Wilkinson, 1973; Nicol, 1973; Marker, 1989), but findings continue to be unsubstantiated and qualitative with respect to the role of freeze-thaw weathering in nivation and of its role in the developmental sequence of hollow to cirque (Hall, 1988a; 1991b). Freeze-thaw weathering, is a very complex process (Hall, 1991b) and constitutes a range of potential means by which it can take place (Fig. 4.2). Hall (1988a) remarked that although the High Drakensberg and Lesotho Mountains experience cold for part of the year and are substantially elevated above sea level, one can not justifiably say that the process of freeze-thaw weathering takes place.

Freeze-thaw weathering is a complex phenomenon and has been researched extensively. For further reading on the matter the following publications are recommended: Clark & Small (1982), Hall (1988a, 1988b, 1991a) and Matsuoka (1990).

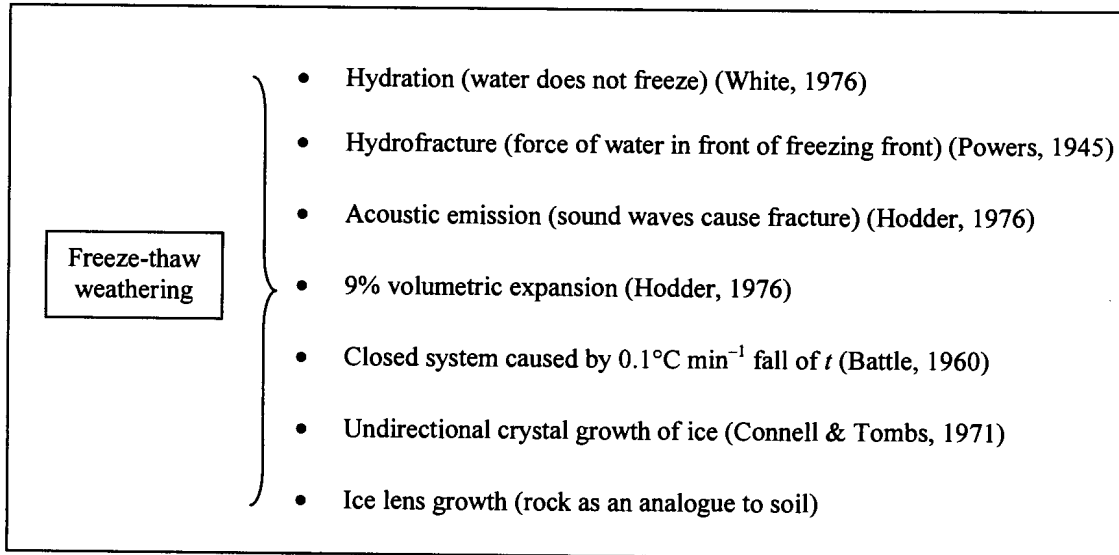


Figure 4.2: Some of the various mechanisms that constitute freeze-thaw weathering (after Hall, 1991b).

4.2.12 Frost action features

Frost action is frequently claimed as an important indicator of palaeocryogenic, and in particular periglacial, environments (French, 1996). Frost action has been cited as the cause of several southern African cryogenic features by Sparrow (1967a), Harper (1969), Hastenrath (1972), Hastenrath & Wilkinson (1973), Borchert & Sanger (1981), Hanvey *et al.* (1986), Lewis & Hanvey (1988), Lewis (1989, 1996a), Hanvey & Lewis (1991), and Grab (1994). The recognition and interpretation of evidence regarding frost action, however, is sometimes difficult, mostly because of the presence of contemporary frost action (French, 1996). According to French (1996), a relict feature's frost action significance is dependent on the evaluation of the susceptibility of the underlying bedrock to frost action, moisture, vegetation, and local conditions. Furthermore, features that are generally held as indicators of frost action palaeoenvironments, e.g. tors, blockfields, cryoplanation terraces, grezes litees and head, may have been formed under non-periglacial circumstances (French, 1996). Few of these features provide unequivocal proof of palaeoperiglacial conditions and only where a number of different features occur together or in association with one another, a frost action environment may be assumed (French, 1996).

4.2.12.1 Blockfields

Southern African blockfields have been documented by Linton (1969), Sparrow (1971), Borchert & Sänger (1981), Sänger (1988) and Boelhouwers (1994). Blockfields are apparently indicators of intense frost wedging (French, 1996). However, before considering blockfields as relict cryogenic features, it must first be proven that the deposits are not being formed under present-day climatic conditions or that the current rate of weathering is insufficient to explain them (French, 1996). It is also possible that blockfields, especially in southern African context, may have formed over a long period of time (French, 1996), in which case it is difficult to pinpoint one specific geomorphic event. French (1996) warns that these features are of limited use in Pleistocene periglacial reconstruction (French, 1996).

4.2.12.2 Tors and cryoplanation terraces

Sparrow (1967a), Hagedorn (1984), and Dardis & Granger (1986) identified tors and cryoplanation terraces on the subcontinent and ascribed them to gelifluction, nivation and frost creep. French (1996) suggests that a variety of processes and environmental conditions may produce essentially the same landform, and periglacial conditions merely represent one set. With regards to cryoplanation terraces, no processes thus far demonstrate that these phenomena form under prevailing cold climate conditions (French, 1996). French (1996) concludes that it is more appropriate to stress the role of mass wasting than frost action in the periglacial interpretation of tors and cryoplanation terraces. In terms of southern Africa cryogenic research it is questioned whether these ambiguous features should be considered in palaeoenvironmental reconstruction.

4.2.12.3 Gelifluction head deposits

Gelifluction head deposits (or more commonly referred to as “head”), are composed of predominantly poorly sorted and poorly stratified angular debris (French, 1996). Gelifluction head deposits are regarded as indicative of Pleistocene solifluction and frost creep in particular (French, 1996). Their direct interpretation in terms of frost action is difficult; the problem lies in the inability to distinguish between solifluctional (implying seasonal frost) and gelifluctional (implying permafrost) induced head deposits (French 1996). Although gelifluction head deposits have been documented by Nicol (1973), there is too much

uncertainty concerning the present-day as well as the palaeocryogenic environment to even consider gelifluction head deposits as an indicator of periglacial conditions.

4.3 Conclusion

The glossaries discussed in this chapter are seen as a means to standardise available cryogenic data as part of the development of the Cryogenic Processes and Landforms Spatial Database for Southern Africa (Appendix A). It was further recognised that the reliability of database information is dependent on more research and new data. Therefore several areas of concern were discussed as an attempt to focus attention on possible areas of research. The most important factor to consider is that, although the identification of distinct forms is essential in understanding the environment and the processes responsible for its evolution, form is only a means to an end and should not be the centre of inquiry. The only forms worthy of detailed attention should be those whose explanation adds something to existing knowledge of the landscape (Thorn, 1991). This is true for most environments of the world, and is applicable to the southern African cryogenic scene.

This concludes the developmental stage of the Cryogenic Processes and Landforms Spatial Database for Southern Africa. In the Chapter 5 the database will be implemented to evaluate certain issues in cryogenic research that have been discussed earlier.

CHAPTER 5

Preliminary data analysis through database manipulation

Chapter 5 focuses on preliminary data analyses (based on Schulze, 1998) through manipulation of the Cryogenic Processes and Landforms Spatial Database for Southern Africa (Appendix A) to evaluate database efficiency and feasibility. Key areas tested are (i) accessibility to data, (ii) data and database manipulation, and (iii) overall user friendliness in context of current debates in southern African cryogenic literature. The relevant requirements for an effective database were stipulated in Chapter 3:

- Quick access to data.
- Easy manipulation for overlaying, querying and map calculation.
- Reasonable generalisation of data.
- The possibility of entering new data and of upgrading, correcting and deleting existing data.

The purpose of this study is not to give a definitive analysis of southern African cryogenic data, but to provide a tool for future investigation and an objective data source to challenge specific research problems, thus adding to existing Quaternary knowledge. Ultimately the aim is to gain a better understanding of the intensity and spatial distribution of relict features and processes, and contribute towards reconstructing the southern African Quaternary environment.

5.1 Data analysis

The present situation of both relict and active cryogenic features and processes distribution can be constructed by projecting database attribute data onto spatial grid data. For this purpose a topographic map of southern Africa (Fig. 5.1) was used unto which glacial, relict periglacial and current periglacial phenomena were projected (Fig 5.2). Three focus areas for cryogenic features and processes manifested from the projection. The first are areas immediately adjacent to and in the near vicinity of the Lesotho/Kwa-Zulu Natal Drakensberg (above the Escarpment) (Region 1, Fig. 5.2; Fig. 1.2). The second are areas below the Escarpment comprising the Eastern Cape Drakensberg near the Lesotho border and a small extension towards the south-southwest (Region 2, Fig. 5.2). The third focus point is in the

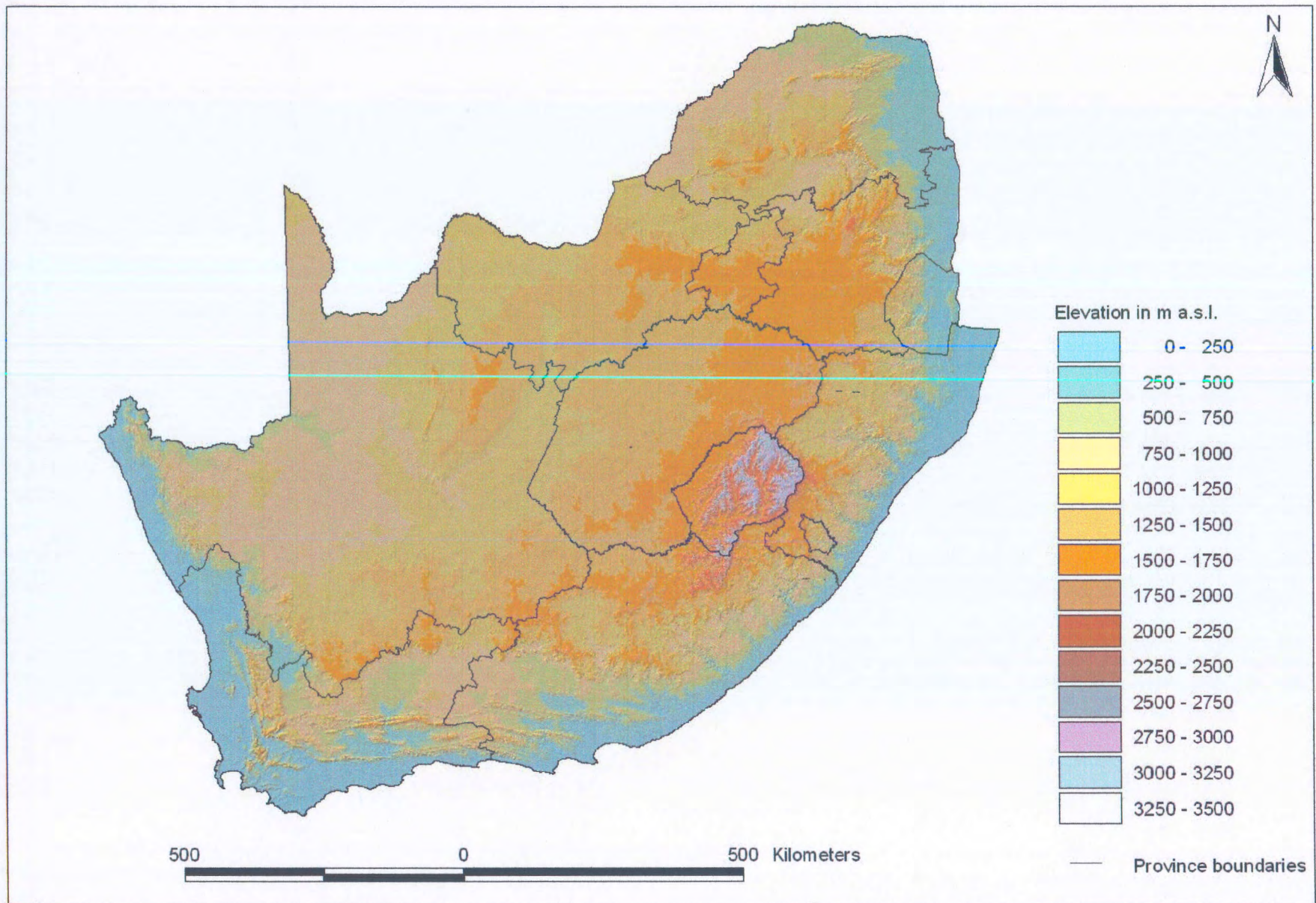


Figure 5.1: Topographic map of southern Africa.

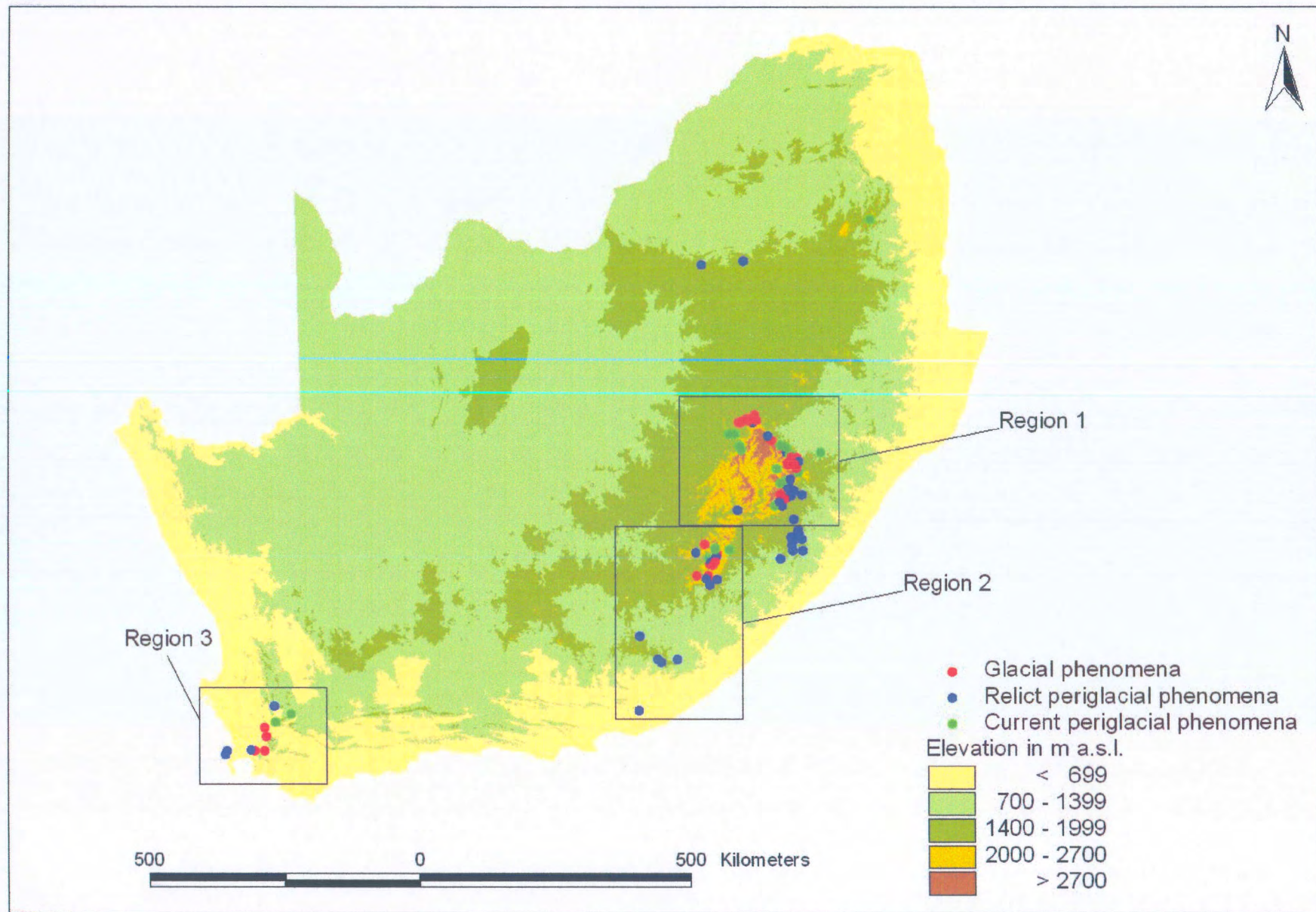


Figure 5.2: Proposed relict and current cryogenic phenomena and the main cryogenic regions.

Western Cape Mountains (Region 3, Fig. 5.2). Fig. 5.2 and Fig. 5.3 show that most features and processes occur at elevations above 1 200m a.s.l. along the major mountain ranges of southern Africa, especially at the Great Escarpment and Eastern Cape Drakensberg. With closer inspection, however, it appears that these areas are located primarily on basalts (Region 1), dolerites and sandstones (Region 2), and quartzites (Region 3; SACS, 1980; Dardis & Moon, 1988) and in regions that receive above 700mm annual precipitation (see later analysis). Clearly more in depth analysis is needed to comprehend the true nature of the distribution of cryogenic phenomena in southern Africa. Therefore the following themes will receive closer inspection:

- The current periglacial environment
- The periglacial palaeoenvironment
- The glacial environment

Each theme will be analysed by following a basic structure of inquiry:

- What are the general and specific conditions stipulated for a periglacial or glacial environment?
- What are the general and specific conditions of the southern African periglacial or glacial environment as documented by researchers?
- Which of those conditions will be examined in data analysis?

5.1.1 Current (sub-) periglacial environment

A periglacial environment is dominated by frost action features and processes and is not restricted to areas peripheral to glaciers, either in time or space (French, 1976, 1996). Periglacial regions display cold, non-glacial conditions and permafrost-related processes, although permafrost is not a necessary requirement for periglacial environments (French, 1976, 1996). Diagnostic criteria for all periglacial environments are freezing and thawing of the ground and/or the presence of perennially frozen ground (French, 1976, 1996). According to French (1976, 1996), the boundary conditions for periglacial domains are where mean annual air temperatures (MAAT) are less than +3°C, -2°C in areas where frost action dominates, or -2°C to +3°C in areas in which frost action processes occur, but do not dominate (Table 5.1).

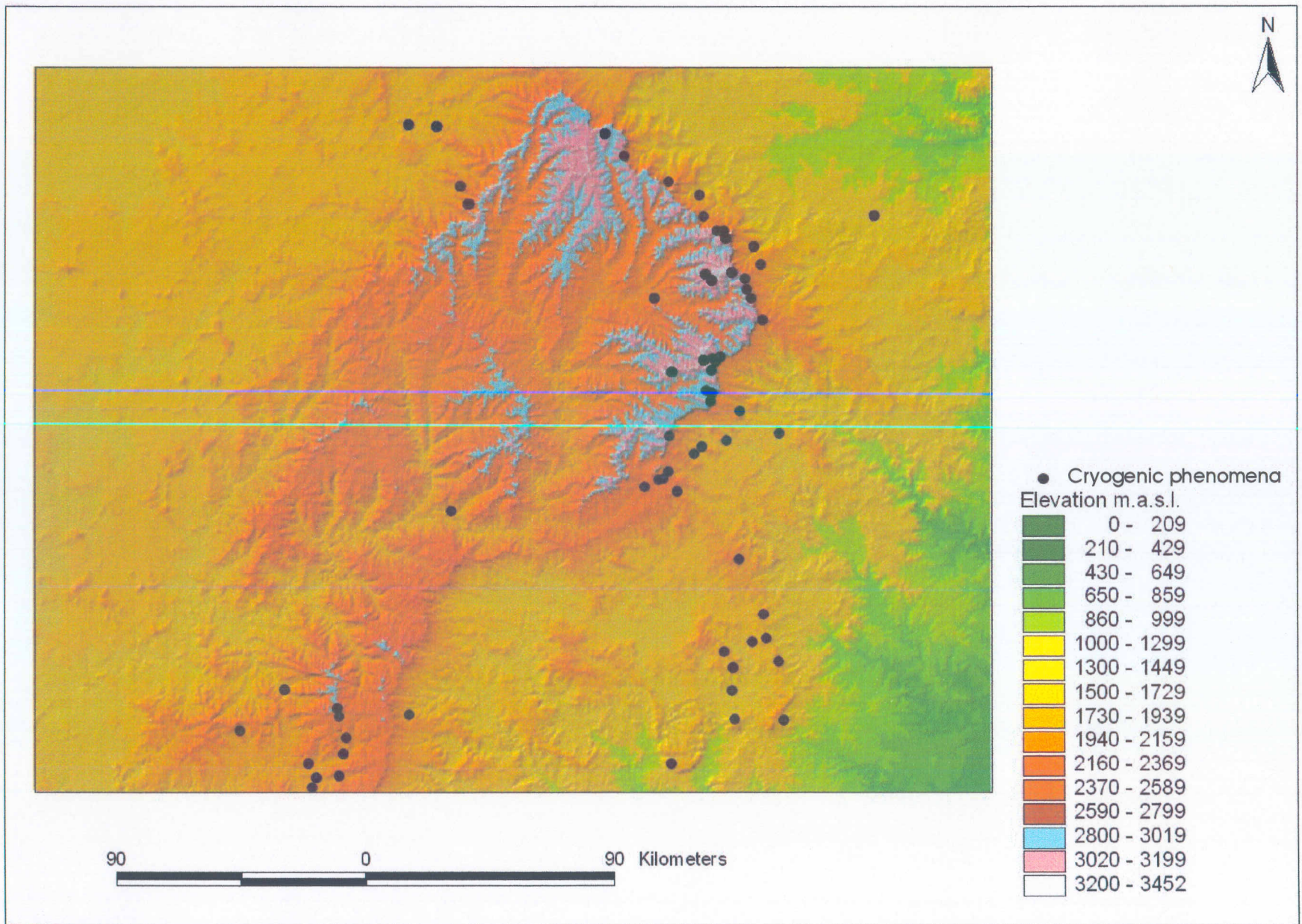


Figure 5.3: The main body of cryogenic features and processes are located at the Great Escarpment and Eastern Cape Drakensberg.

Periglacial climate	General	Description					Example
		Diurnal pattern	Seasonal pattern	Mean annual rainfall	MAAT		
					Range	°C	
High arctic	Polar latitudes	Weak	Strong	93 - 298mm	25 - 36	-8 to -14	Spitsbergen (78°N)
Continental	Subarctic latitudes	Weak	Strong	247 - 343mm	45 - 62	-5 to -10	Central Siberia (62°N)
Alpine	Middle latitudes Mountain environments	Well-developed	Well-developed	1 638 - 1 021mm	15 - 22	-3 to -7	Alps (47°N)
Qinghai-Xizang (Tibet) Plateau	High elevations (4 200 - 4 800m a.s.l.) Low latitude	Well-developed	Well-developed	345mm	23	-6	Fenghuo Shan (34°N)
Climates of low annual temperature range in azonal locations							
Island	Subarctic latitudes	-	-	365mm	8	0	Jan Mayen (71°N)
Mountain	Low latitudes	-	-	1 309mm	7	2	Andean summits (16°S)

Table 5.1: Classification of periglacial climates and environments based on elevation, insolation and temperature (after French, 1996).

5.1.1.1 Requirements for analysis

It was established that the following characteristics are distinctive of a present-day periglacial environment:

- Frost action and permafrost-related processes.
- Regular freezing and thawing of the ground.
- Perennially frozen ground.
- Not restricted to glaciated areas.
- MAAT between -2° and +3°C.

Compared to French's (1976, 1996) conditions for periglacial environments, the current southern African cryogenic environment display the following characteristics:

- Cryogenic phenomena occur at elevations above 1 200m a.s.l. (Marker, 1995a).
- Current cryogenic features and processes cluster along the main Escarpment of Lesotho, the Eastern Cape, and the Western Cape (Marker, 1995a).
- The current cryogenic environment displays a decline in altitude with lower latitude (Marker, 1995a).

- The current cryogenic environment extends from +1 700m a.s.l. in the Waaihoek Mountains, Western Cape, to +1 800m a.s.l. (southwestern Cape), +1 900m a.s.l. (north-eastern Cape) and +2 900m a.s.l. in northern Lesotho (Marker, 1995a).
- MAAT for the current cryogenic environment is between +4° and +7°C (Boelhouwers, 1991a; Hanvey & Marker, 1992).

Each characteristic is considered in the data analysis. Specific topics that need verification are the following:

- Whether the southern African environment is a marginal montane periglacial (Lewis, 1987; Boelhouwers, 1991a), borderline periglacial (Boelhouwers, 1991b; Hall, 1994), or a marginal frost action environment (Boelhouwers, 1994, 1995a; Grab, 1997a, 1997b).
- Whether cryogenic (sub-periglacial) features cluster along or adjacent to the Drakensberg Escarpment of Lesotho, Kwa-Zulu Natal, the Eastern Cape and the Western Cape (Marker, 1995a).
- The extent of the cryogenic (sub-periglacial) zone as proposed by Marker (1995a).
- Whether there is a decline in altitude with higher latitude (Marker, 1995a) for the present-day cryogenic (sub-periglacial) zone
- Whether the exact extent of the modern cryogenic (sub-periglacial) environment can be established (Lewis, 1987; Meiklejohn, 1992; Grab, 1997a).

The structure and procedure of the data analysis is reviewed in Table 5.2. Note that only processes, e.g. frost action, solifluction etc., are considered for analysis.

5.1.1.2 Discussion

After classifying current MAAT to fit French' (1976, 1996) requirements for a periglacial climate and projecting current frost action- and freeze-thaw related processes onto this, only a few areas along the Lesotho/Kwa-Zulu Natal Escarpment were identified as "periglacial" (Fig. 5.4). The regions below the Escarpment and the Western Cape-region (Region 2 and 3, Fig. 5.2) did not surface after calculation. Realising that most of these features and processes are probably seasonal rather than annual occurrences, a map was calculated to fit a seasonal cold pattern. The same periglacial requirements set by French (1976, 1996) were used to calculate seasonal "periglacial" regions for the subcontinent from mean annual minimum air temperatures (MAMAT). It was shown that larger areas that may be labelled as "seasonal periglacial" emerged from the calculation (Fig. 5.5). Parts of Region 2 (Fig. 5.2) are included

Analysis (A)	Map
A1 Current MAAT of southern Africa	
A2 Current frost action processes, permafrost-related processes, freezing and thawing of the ground in southern Africa.	
A3 Current MAAT and frost action processes, permafrost-related processes, freezing and thawing of the ground in southern Africa.	A1 + A2
A4 Current periglacial regions of southern Africa that meet the periglacial MAAT requirement of -2° to +3°C.	A3 + A4 = Fig 5.4
A5 Mean annual minimum air temperatures (MAMAT) of southern Africa.	
A6 Current periglacial regions of southern Africa that meet the periglacial MAMAT requirement of -2° to +3°C.	A2 + A5 + A6 = Fig. 5.5
A7 Mean annual precipitation (MAP) for southern Africa.	
A8 MAP for southern Africa and current periglacial regions that meet the periglacial MAAT requirement of -2° to +3°C.	A2 + A7 + A8 = Fig. 5.6

Table 5.2: Analysis structure for examining present sub-periglacial regions in southern Africa.

into this new definition and a few scattered areas to the south and south south-west surfaced (Fig. 5.5). Region 3 (Fig. 5.2) did not figure in this calculation.

Only air temperature was used in calculations. Another factor that needs consideration, especially where the Western Cape region (Region 3, Fig. 5.2) is concerned, is precipitation. The subcontinent receives its highest precipitation along the Western Cape Mountains, the Eastern Drakensberg, Mpumalanga and in the Northern Province along the Escarpment (Fig. 5.6). It is in these regions, except for those regions in the latter two provinces, that current cryogenic (sub-periglacial) phenomena cluster. MAAT calculations do not verify the existence of cryogenic (sub-periglacial) processes in the Western Cape Mountains.

From the findings it is suggested that the southern African environment is a cold environment where marginal frost action processes (Boelhouwers, 1994, 1995a; Grab, 1997a, 1997b) are prevalent. It is, however, not a periglacial environment (Fig. 5.4) in the strict sense of French's (1976, 1996) definition and it is not recommended that the term "sub-periglacial" be used to describe the environment unless defined according to recognised periglacial regions in

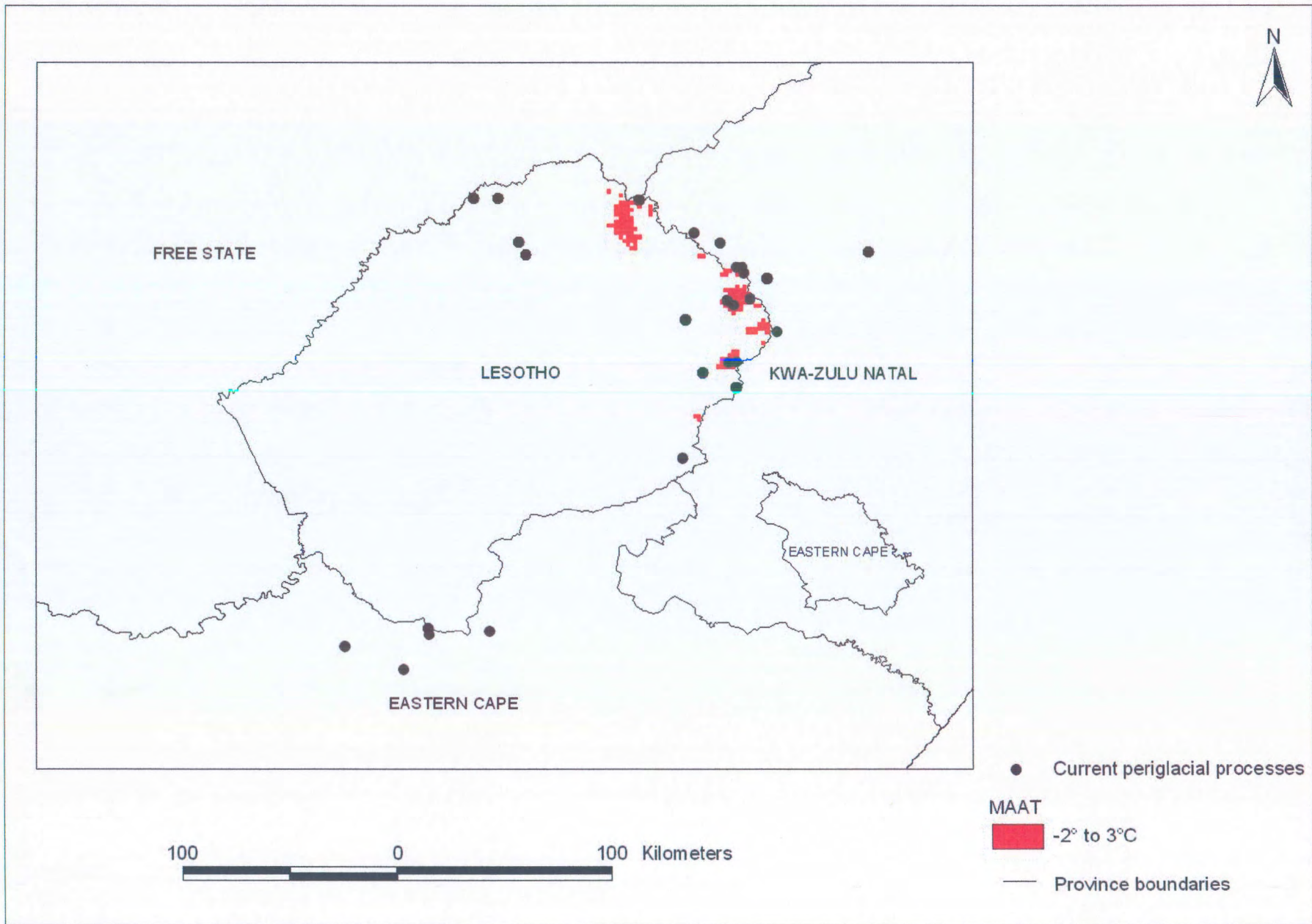


Figure 5.4: Regions that may be classified as current periglacial.

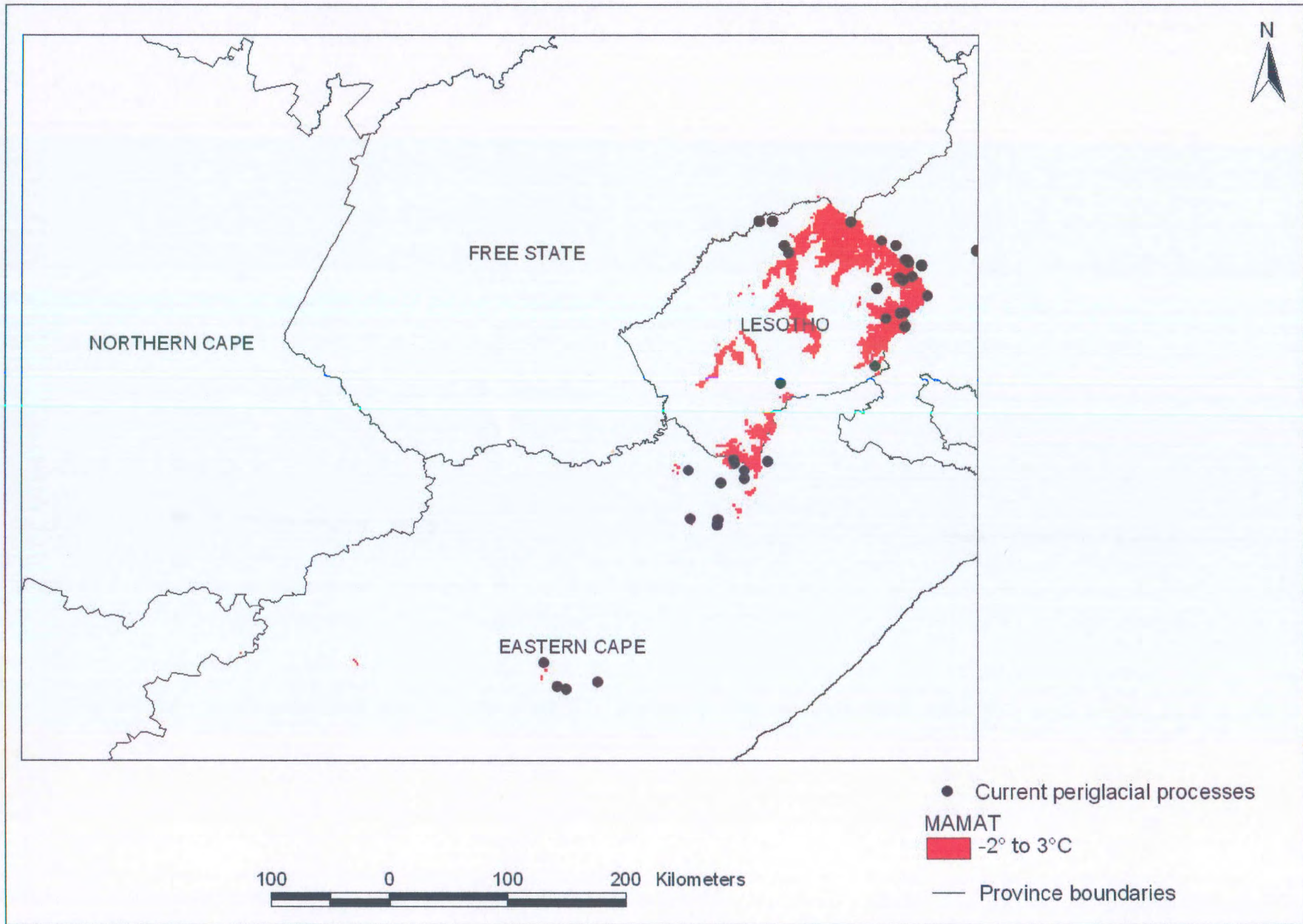


Figure 5.5: Current periglacial regions calculated on mean annual minimum air temperatures.

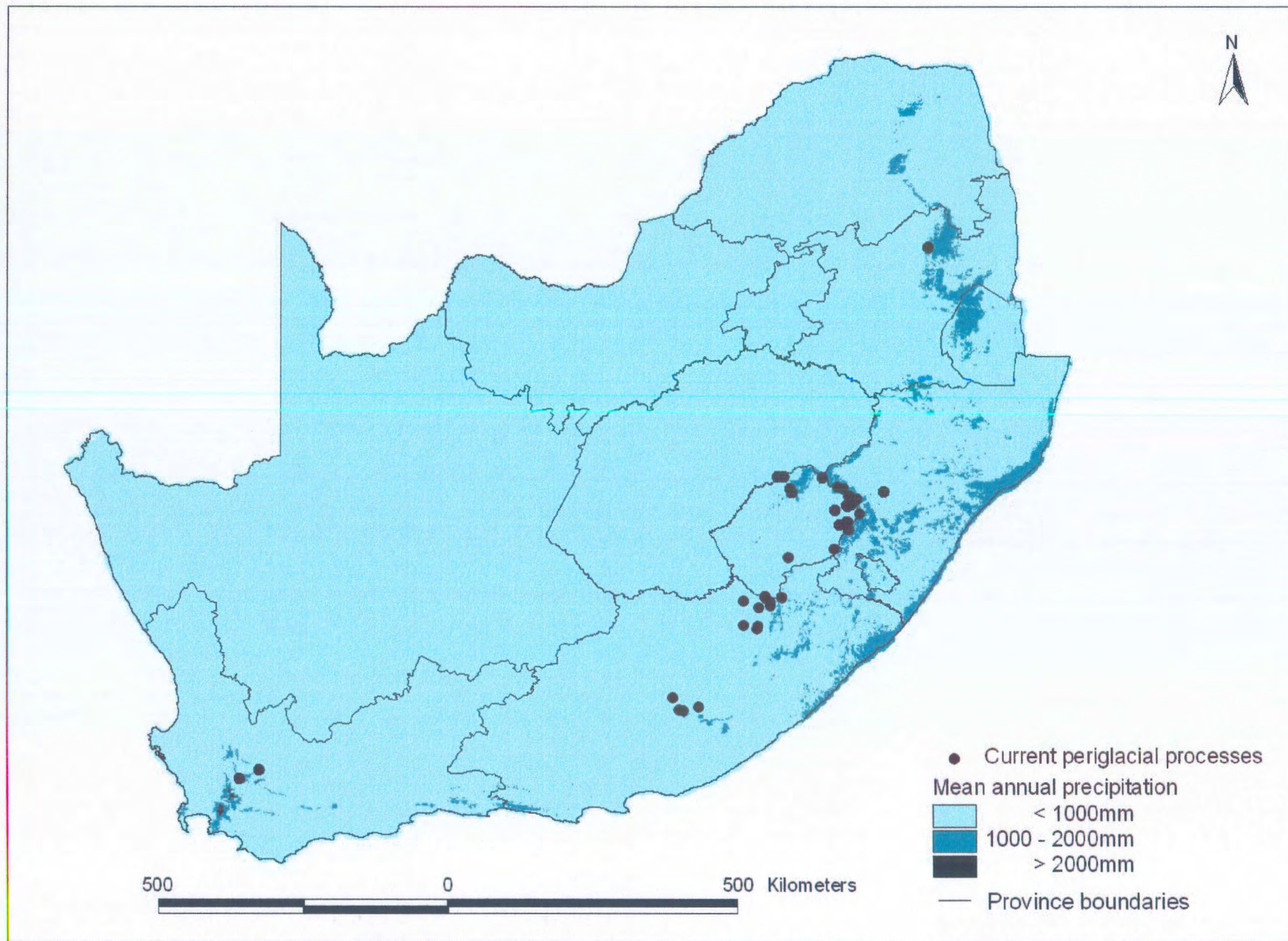


Figure 5.6: Current periglacial phenomena extrapolated on mean annual precipitation.

the rest of the world. The use of “marginal montane periglacial” (Lewis, 1987; Boelhouwers, 1991a) and “borderline periglacial” (Boelhouwers, 1991b; Hall, 1994) as terminology describing the southern African cryogenic situation, are not recommended, as it is not clear what the specific implications of these descriptions are. Calculations for Fig. 5.4, 5.5 and 5.6 did show that current cryogenic phenomena cluster along or adjacent to the Drakensberg Escarpment of Lesotho, Kwa-Zulu Natal, the Eastern Cape and the Western Cape as argued by Marker (1995a). It appears that phenomena occur in specific zones as suggested by Marker (1995a), namely above the Escarpment, directly below the Escarpment in the vicinity of the Eastern Cape at +1 900m a.s.l., and in the Western Cape at +1 700m a.s.l. (Fig. 5.2). The lower limit of the present-day cryogenic environment definitely shows a decline in altitude with higher latitude (Fig. 5.2) as proposed by Marker (1995a), although it is suggested that lithology play an important role in the spatial location and distribution of current (and relict) cryogenic features and processes.

There is little doubt that other factors other than precipitation and air temperatures, e.g. lithology, moisture factor for specific regions, vegetation patterns, and microclimate have to be considered to understand the full consequence of current cryogenic phenomena distribution in southern Africa as Fig. 5.4, 5.5 and 5.6 only give a general idea of the current periglacial situation from which only general conclusions can be drawn. It should also be considered that, given the occurrence of periglacial phenomena on the subcontinent (however marginal), the conditions stipulated for periglacial environments by French (1976, 1996) may be unsuitable for southern African. It may be more appropriate to find specific criteria that will be representative of the southern African cryogenic context.

5.1.2 Periglacial palaeoenvironment

When comparing periglacial palaeoenvironments with those of today, it must be kept in mind that there probably were differences in solar and snow cover conditions (French, 1976, 1996). French (1996) suggests that the contrast between summer and winter was less marked in both the Northern and Southern Hemispheres, that more freeze-thaw cycles occurred than at present, and that pronounced snow cover would have inhibited permafrost formation, but supported deep seasonal frost (French, 1976, 1996). Other factors may have played a greater role than today, e.g. global atmospheric circulation patterns, wind action and greater fluvial activity (French, 1976, 1996).

Many features are used as evidence for periglacial processes in southern Africa. However, French (1996:235) cautions that the recognition of relict phenomena requires careful investigation because "... few provide unequivocal proof of periglacial conditions and only

where several different features occur together or in association is one justified in assuming a frost-action environment." To gain a better understanding of the southern African relict cryogenic environment, the requirements as stipulated by French (1976, 1996) for current periglacial environments will be used in the next set of calculations.

5.1.2.1 Requirements for analysis

It was established that the following characteristics are distinctive of a periglacial palaeo-environment adjacent or not adjacent to glaciers:

- Palaeoperiglacial environments were most likely dominated by frost action processes like those of today.
- Permafrost-related processes were probably dominant.
- Freezing and thawing of the ground were probably regular occurrences.
- Palaeoperiglacial environments probably displayed perennially frozen ground.
- MAAT between -2° and $+3^{\circ}\text{C}$ where frost action occurred.

Compared to French's (1976, 1996) conditions for periglacial environments, the southern African cryogenic palaeoenvironment display the following characteristics:

- It is assumed that cryogenic features and processes were more widespread compared to those of today (Meiklejohn, 1992; Marker, 1995a).
- It is assumed that cryogenic phenomena occurred at lower altitudes (Lewis & Hanvey, 1993; Marker, 1995a).
- It is assumed that snow cover for the subcontinent was enhanced (e.g. Marker, 1990b, 1992, 1994b, 1998; Hanvey & Marker, 1992).
- Most phenomena are believed to have formed during the LGM (e.g. Lewis & Dardis, 1985; Lewis, 1996b; Marker, 1992, 1994b).
- A drop of between 5° and 10°C are suggested for the subcontinent during the LGM (e.g. Van Zinderen Bakker, 1963, 1964, 1986; Hastenrath, 1972; Talma *et al.*, 1974; Deacon *et al.*, 1984; Vogel, 1985; Talma, 1989; Partridge *et al.*, 1990; Marker, 1991b, 1995a, 1998; Meiklejohn, 1992; Hanvey & Marker, 1992; Grab, 1996a; Partridge, 1997).

Each characteristic is considered in the data analysis. More specific topics that need verification are as follows:

- Whether conditions on the subcontinent were suitably cold for widespread periglacial activity (Sparrow, 1971; Hanvey & Marker, 1992).
- Whether full periglacial conditions including permafrost (Fitzpatrick, 1978; Lewis & Dardis, 1985; Marker, 1989; Lewis & Hanvey, 1993; Lewis, 1994), or mild periglacial activity, excluding permafrost (Marker, 1995a), occurred.
- Whether ground freeze, nivation, and other freeze-thaw processes were active during the LGM (Marker, 1989).
- If relict landforms project into the two regions suggested by Marker (1995a).

The structure and procedure of the data analysis is reviewed in Table 5.3. Note that only processes, e.g. frost action, solifluction etc., are used for analysis. For the purpose of this analysis the 5° to 10°C drop in MAAT proposed for the LGM will be considered with a midway average point of 7°C as determined from the literature (Van Zinderen Bakker 1964, 1976; Harper, 1969; Sparrow, 1971; Talma *et al.* 1974; Vogel, 1983; Deacon *et al.*, 1984; Talma, 1989, Hanvey & Marker, 1992; Marker, 1992; Grab, 1996a, etc.).

Analysis (A)	Map
A1 Current MAAT of southern Africa minus 7°C for the LGM.	
A2 Relict frost action processes, permafrost-related processes, freezing and thawing of the ground in southern Africa during the Pleistocene.	
A3 Palaeoperiglacial regions of southern Africa that meet the periglacial MAAT requirement of -2° to +3°C.	A1 + A2 + A3 = Fig. 5.7
A4 Current MAMAT of southern Africa.	
A5 Palaeoperiglacial regions of southern Africa that meet the periglacial MAMAT requirement of -2° to +3°C.	A2 + A4 + A5 = Fig. 5.8

Table 5.3: Analysis structure for examining palaeoperiglacial regions in southern Africa.

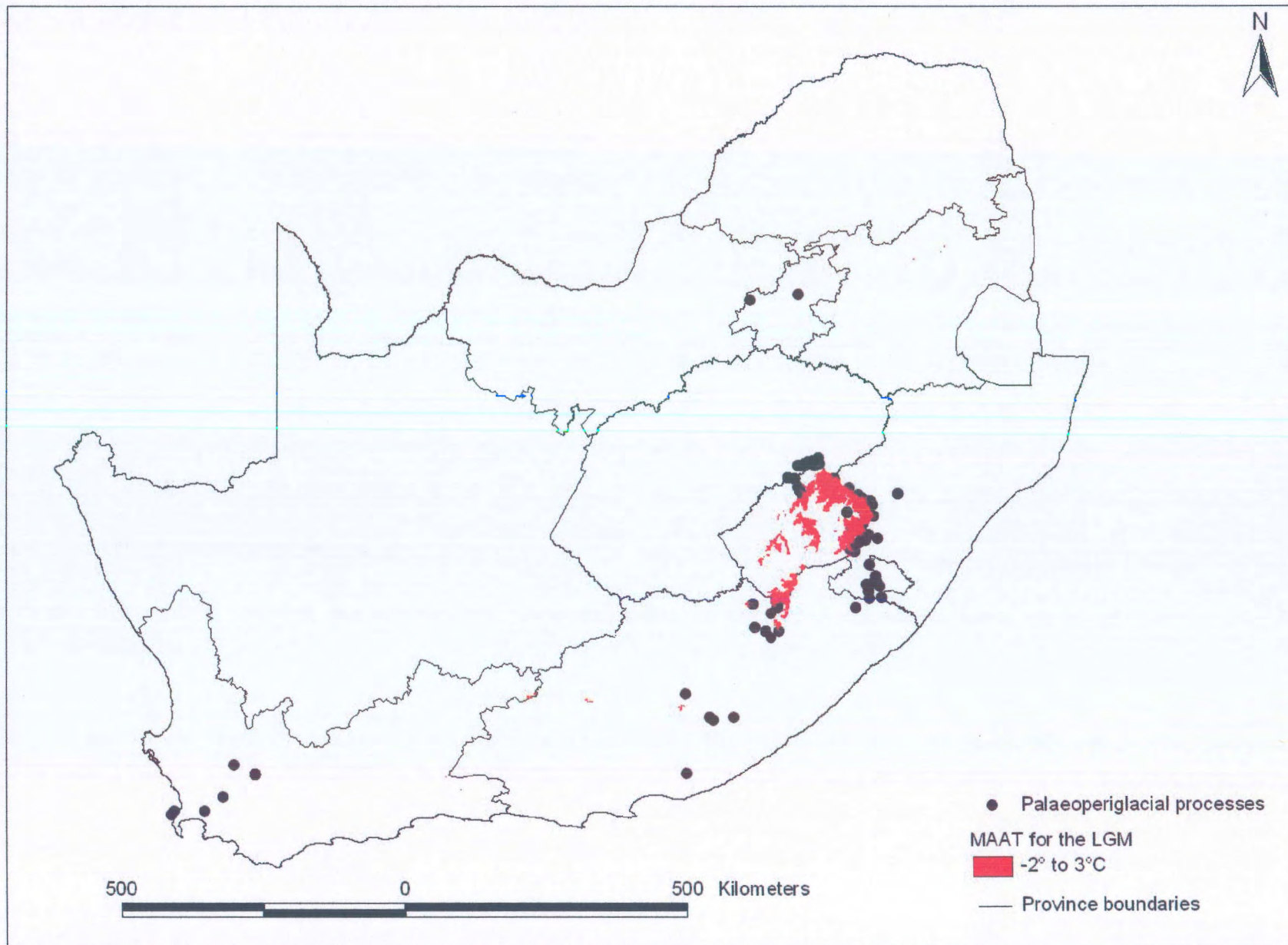


Figure 5.7: Possible periglacial regions for the Last Glacial Maximum based on 7°C drop in temperature.

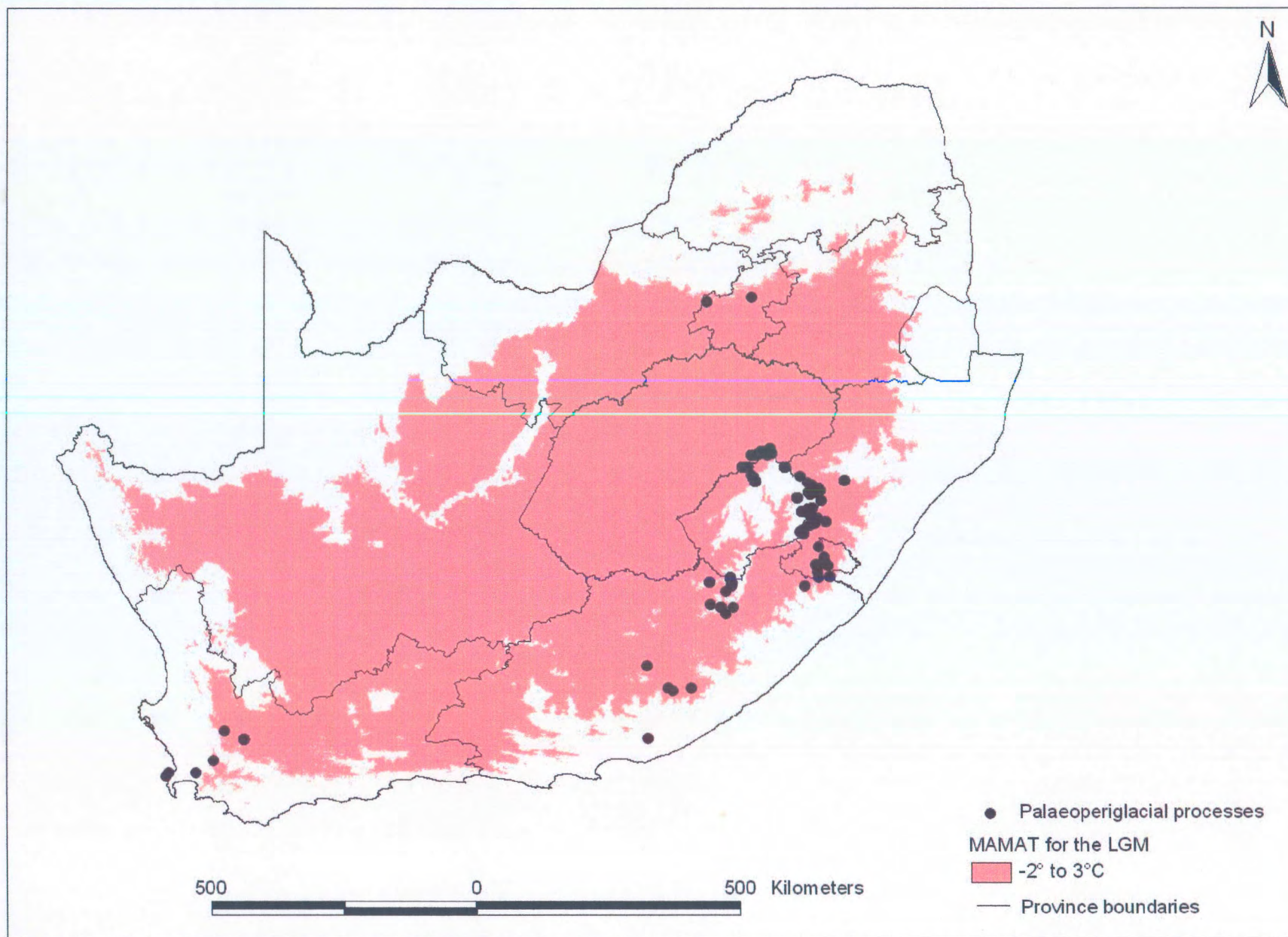


Figure 5.8: Possible periglacial regions for the LGM calculated on mean annual minimum air temperatures based on a 7°C drop in temperature.

5.1.2.2 Discussion

Fig. 5.7 revealed possible sites for periglacial activity during the LGM similar to those displayed in Fig. 5.5. Region 3 (Fig. 5.2) did not emerge from calculations. The seasonal palaeoperiglacial zone proved greatly enlarged after projecting MAMAT for the LGM (Fig. 5.8) and Region 3 (Fig. 5.2) finally surfaced. This suggests that temperature is not the only factor to consider in explaining the existence of relict forms in the Western Cape, and, like the current cryogenic environment, precipitation, lithology, vegetation cover, specific moisture factors, microclimatic differences etc. all may have had a significant impact yet unknown on the development and preservation of palaeocryogenic features and processes.

An environment with periglacial activity of mild intensity and relatively short duration, excluding permafrost as suggested by Marker (1995a), but more widespread than current cryogenic activity, is envisaged for southern Africa for the LGM. If MAAT values alone are considered, the LGM cryogenic environment is slightly enlarged, comparing with MAMAT calculations for the contemporary cryogenic environment (Fig. 5.5), but still excluding the Western Cape (Region 3, Fig. 5.2).

From Fig. 5.7 and 5.8 it is evident that conditions may have been suitable for widespread cryogenic (periglacial) activity on the subcontinent. Surviving landforms appear to project into the regions proposed by Marker (1995a), although a small extension of the Eastern Cape-region towards the Amatola Mountains is visible. The distribution and zonation for relict “periglacial” phenomena is comparable to that of contemporary phenomena (Fig. 5.2). This again implies that other factors such as precipitation and lithology need to be considered for a clearer understanding of relict cryogenic activity. Unlike the projections for the current cryogenic environment, precipitation values for the LGM could not be calculated since data are scarce and need intensive research and modelling beyond the scope of this study.

However, it cannot be said with absolute certainty from these map projections that a periglacial environment in the strict sense of French’s (1976, 1996) classification existed. Although there are strong indications that frost action processes did take place (as displayed by the current cryogenic environment and the survival of various relict features that display a periglacial nature), more detailed analysis is needed incorporating other relevant factors as previously referred to. Again the possibility that periglacial conditions stipulated by French (1976, 1996) may be unsuitable for southern Africa should be considered and criteria should be revised to ensure a more representative presentation of the southern African cryogenic environment in future analyses.

5.1.3 Glacial palaeoenvironment

Many southern African features are attributed to glacial activity during the Quaternary cold periods (e.g. Borchert & Sänger, 1981; Lewis & Dardis, 1985; Sänger, 1988; Marker, 1989, 1990b; Hall, 1994; Grab, 1996a; Lewis, 1996b). Still, it is not certain if southern African palaeoclimates were favourable towards, or could support, glacial activity (e.g. Hall, 1994; Sumner 1995). To attempt glacial modelling, a closer look at the characteristics of glacial environments is necessary.

The most important factor in the formation of glacial ice is that more snow must fall in winter than melts in summer (Ahnart, 1998). Very cold winters are not necessary (Ahnart, 1998). Glaciers form in a matter of decades, and large ice sheets, e.g. the Greenland ice sheet, form within 200 years under favourable conditions (Sugden & John, 1976; Ahnart, 1998). Glacier formation is furthermore a function of precipitation, temperature, solar radiation, latitude, and distance from the ocean (Sugden & John, 1976). Thus, glaciation of continents or highland regions is controlled by the complex interaction of several variables (Fig. 5.9; Sugden & John, 1976).

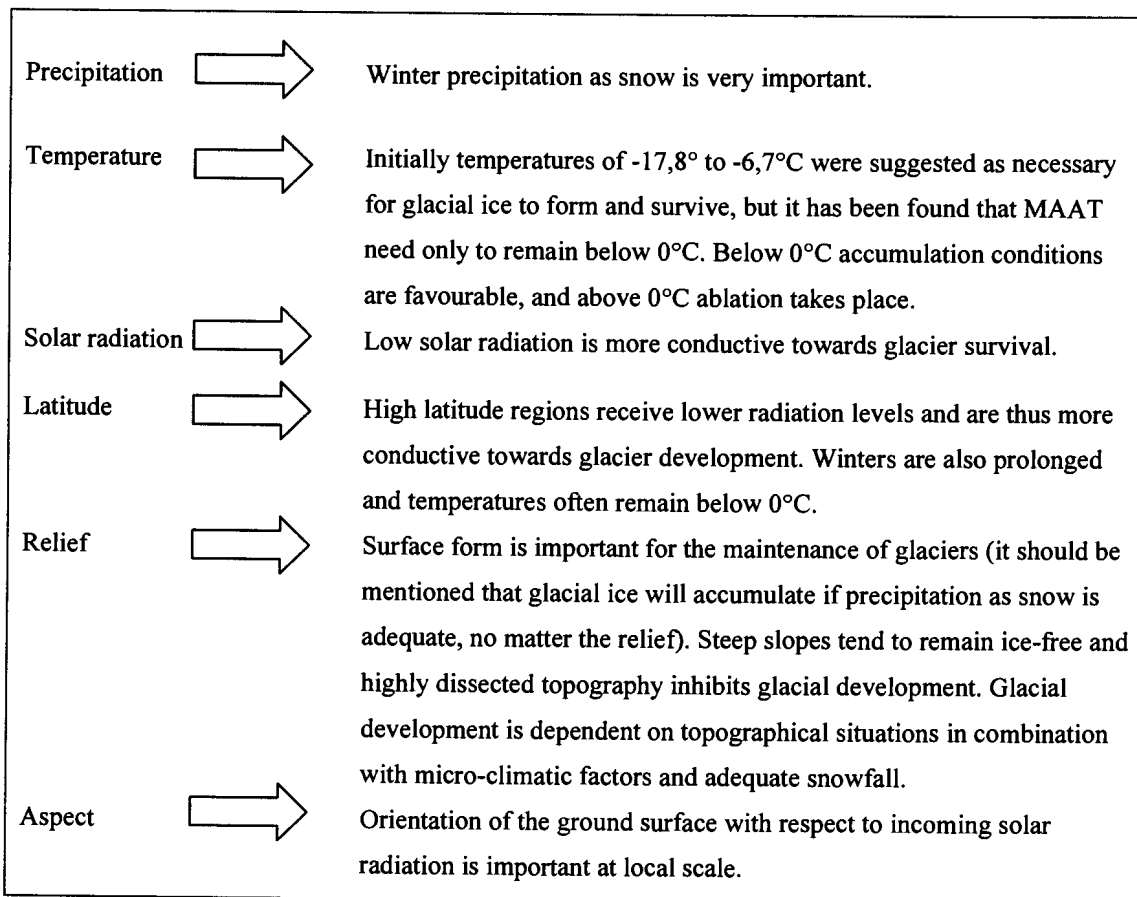


Figure 5.9: Factors in glacial development (after Sugden & John, 1976).

Southern African mountain regions are mostly high enough to reach +2 100m a.s.l. limit for glacial development (Sugden & John, 1976) in most areas (Fig. 5.2), but the other factors summarised in Fig. 5.9 remain to be established for the subcontinent. At this stage only one aspect, namely air temperature, will be used in the following analysis.

5.1.3.1 Requirements for analysis

It was established that the following characteristics are distinctive of a glacial environment and the formation of glacial ice:

- Winter precipitation as snow.
- A surplus of snow surviving summer heat into the next year.
- Very cold winters are not necessary.
- Low solar radiation is more conducive towards glacier survival.
- Prolonged winters during which mean temperatures often remain below 0°C, are favourable conditions for glacier survival.
- Surface relief must be favourable towards glacial ice accumulation.
- The orientation of the ground surface with respect to incoming solar radiation is an important factor at local scale.

Compared to Sugden & John (1976) and Ahnert (1998)'s conditions for glacial environments, the southern African cryogenic palaeoenvironment display the following characteristics:

- Glacial ice is thought to have accumulated in the mountain areas of southern Africa at insolation-protected sites (Hall, 1991b; Marker, 1991b; Grab, 1996a).
- The glaciers would have enlarged pre-existing drainage lines, forming funnel-shaped hollows and cirques (Grab, 1996a).
- It is believed that snow precipitation was greater (Van Zinderen Bakker, 1975; Tyson, 1986; Marker, 1990b, 1992; Hanvey & Marker, 1992; Grab, 1996a etc.).
- A drop of between 5° and 10°C are suggested for the subcontinent during the LGM (e.g. Van Zinderen Bakker, 1963, 1964, 1986; Hastenrath, 1972; Talma *et al.*, 1974; Deacon *et al.*, 1984; Vogel, 1985; Talma, 1989; Partridge *et al.*, 1990; Marker, 1991b, 1995a, 1998; Meiklejohn, 1992; Hanvey & Marker, 1992; Grab, 1996a; Partridge, 1997).

Each characteristic is considered in the data analysis. More specific topics that need verification are the following:

- View 1: an *alpine glaciation* where ice masses in the form of plateau glaciers, feeding several shorter valley glaciers as suggested by Borchert & Sanger (1981), Maud & Partridge (1987), Sanger (1988), Hall (1994), and Lewis (1996b).
- View 2: an arid *marginal glaciation* in the form of a small ice cap restricted to the highest elevations and ice development marginal and ineffective (Dyer & Marker, 1979; Marker, 1992, 1994b).
- It is argued that the higher mountains experienced MAAT of between -1°C and -3°C (Grab, 1996a), which would have been favourable conditions for glaciation.
- Grab (1996a) argued that glacial ice development was localised.

The structure and procedure of the data analysis is reviewed in Table 5.4. For the purpose of this analysis the 5° to 10°C drop in MAAT for the LGM will be considered with a midway point of 7°C (see 5.1.2.1).

Analysis (A)	Map
A1 Current MAAT of southern Africa minus 7°C for the LGM.	
A2 Glacial features and processes.	A 1 + A 2
A3 Palaeoglacial regions of southern Africa that meet the glacial MAAT requirement of 0°C .	A 1 + A 2 + A 3 = Fig. 5.10
A4 Current MAAT of southern Africa minus 7°C for the LGM to show minimum temperatures values (5 classes) and also possible sites for glaciation.	A 1 + A 3 – A 2 = Fig. 5.11

Table 5.4: Analysis structure for examining palaeoglacial regions in southern Africa.

5.1.3.2 Discussion

Areas where glaciation could have taken place and that display MAAT of less than 0°C , were identified as the Great Escarpment of Lesotho/Kwa-Zulu Natal (Region 1, Fig. 5.2), the Eastern Cape below the Escarpment (Region 2, Fig. 5.2) and a smaller region on the border of the Free State and Lesotho at Golden Gate Highlands National Park (Fig. 5.10). Once again

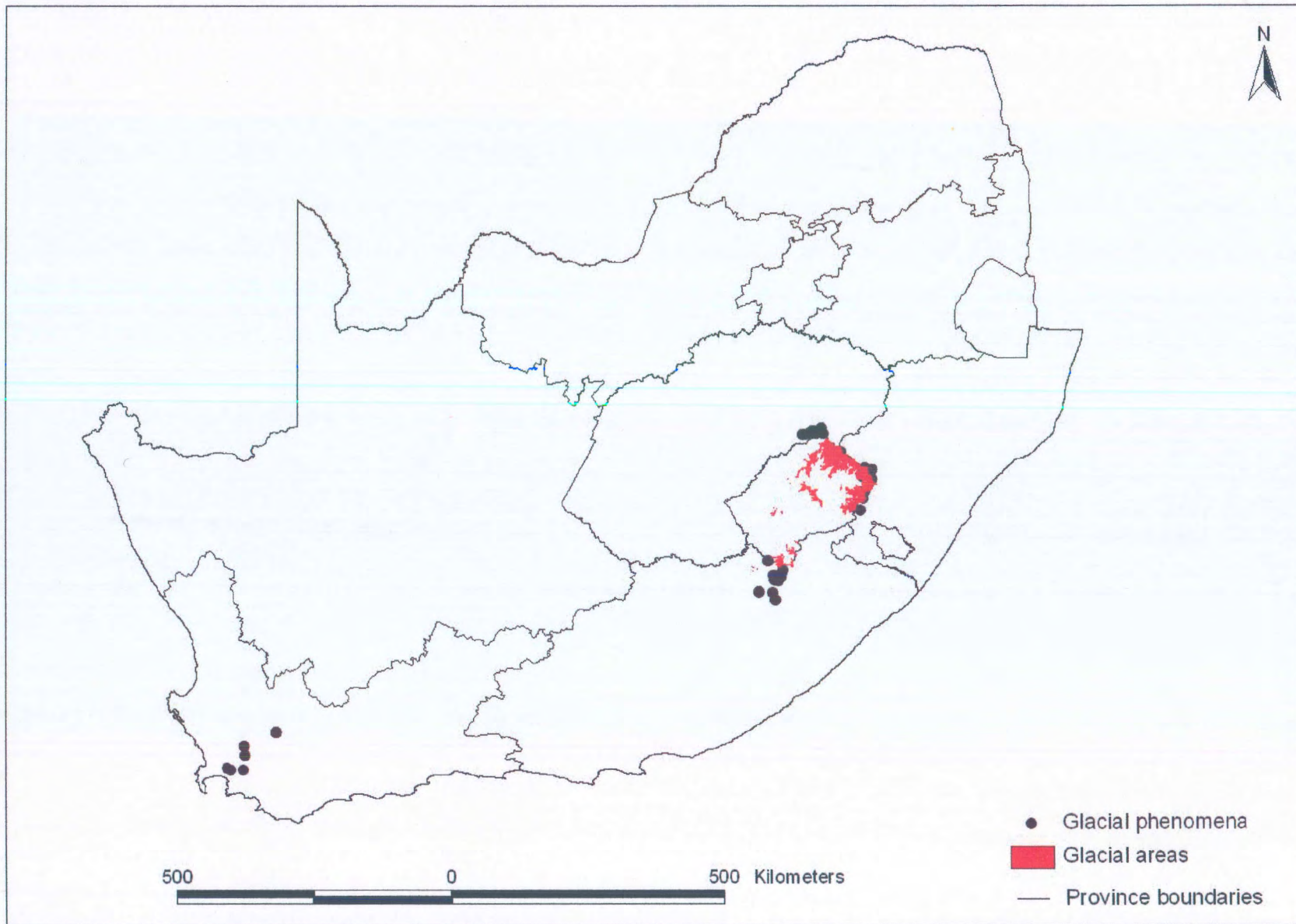


Figure 5.10: Possible regions for a Last Glacial Maximum glaciation.

the Western Cape (Region 3, Fig. 5.2) did not figure as a glacial region. By projecting the various glacial features and processes onto Fig. 5.10, it became apparent that glacial phenomena also cluster into the three distinctive regions identified in Fig. 5.2. The Golden Gate-extension may be classified under Region 1 (Fig. 2.5).

The general view is that southern Africa was not glaciated during the LGM or the other glacials of the Pleistocene (e.g. Tyson, 1986; Deacon & Lancaster, 1988; Preston-Whyte & Tyson, 1988). It is difficult to speculate on the nature and intensity of glacial ice formation in the absence of supported evidence of glacial abrasion. The *alpine glaciation* claim of Borchert & Sänger (1981), Maud & Partridge (1987), Sänger (1988), Hall (1994) and Lewis (1996b), is therefore rejected. The arid *marginal glaciation* argument (Dyer & Marker, 1979; Marker, 1992, 1994b) will not be considered since more information and further testing is needed before a conclusion can be reached. From the findings, it is suggested here that there was a possibility of glacial ice development, but not glaciation on a large scale. If this assumption proves to be correct, then southern African did not experience a LGM-glaciation *per se* and cannot be classified as a glaciated environment. However, the need for further evidence, detailed analysis and research is stressed and viewed as important in understanding the true nature of the palaeoenvironment of South Africa and Lesotho.

For this analysis only temperature was used as a diagnostic indicator for a glacial environment. The other factors listed in Fig. 5.9 were not considered since these need more thorough research and modelling beyond the scope of this study. Calculations, nonetheless, support the opinion that the higher mountains probably experienced MAAT of between -1°C and -3°C (Fig. 5.11), that favourable conditions for glaciation possibly existed (Fig. 5.10 & 5.11), and glacial ice development was most likely localised as argued by Grab (1996a).

5.2 Conclusions

Chapter 5 focused on preliminary data analyses through database manipulation to evaluate database efficiency and feasibility. Key areas tested were data accessibility, data and database manipulation, and overall user friendliness. Further, the purpose of this section was not to give a definitive analysis of southern African cryogenic data, but to evaluate the database in terms of its usefulness in context of current debates in southern African cryogenic literature. The database was put to use successfully in the analyses and reconstruction of the southern African cryogenic environment and offers great potential for more intensive future investigation of cryogenic data.

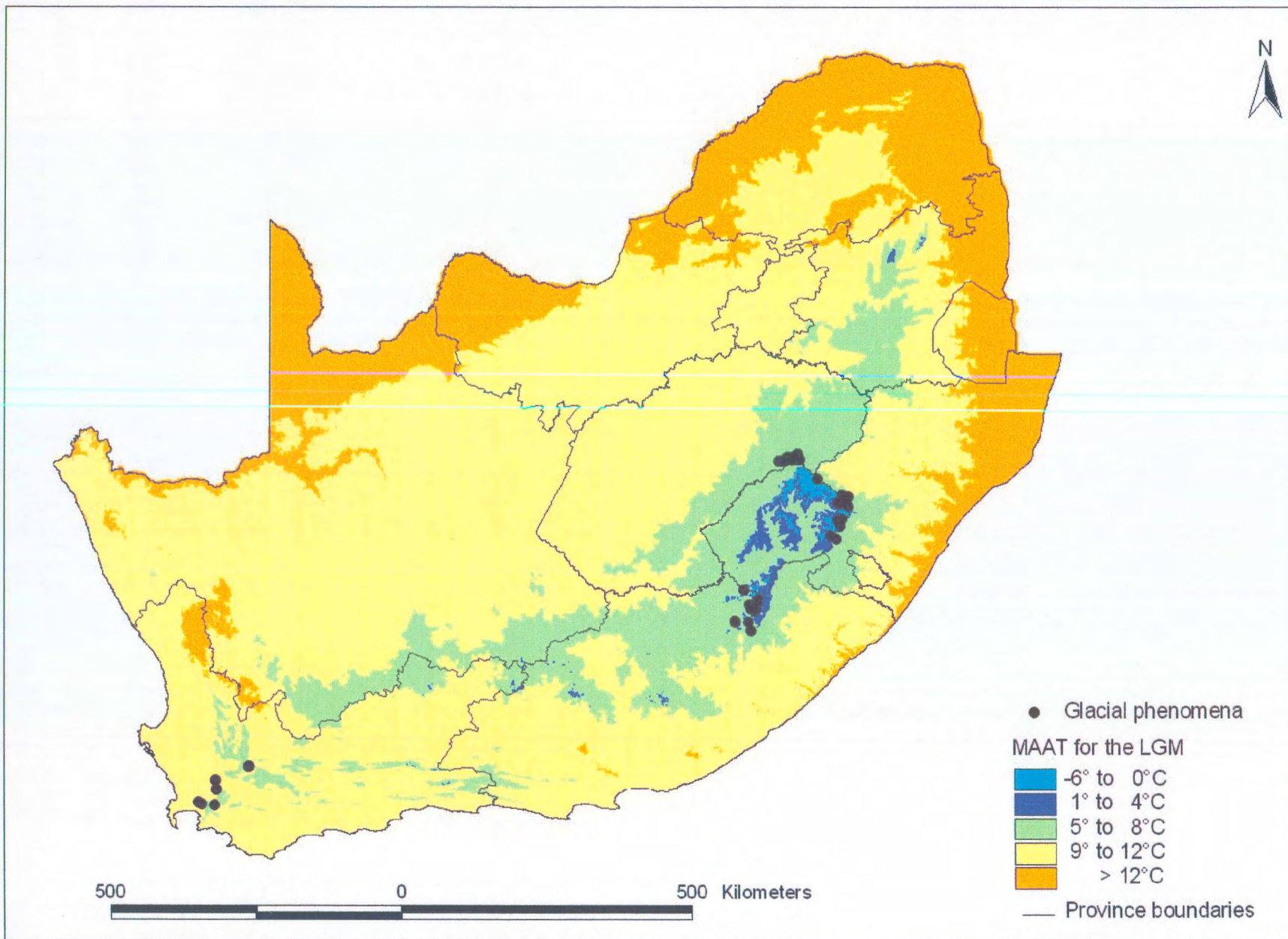


Figure 5.11: Possible temperature regime for the Last Glacial Maximum.

It must be pointed out that the database is a first attempt at assembling and classifying southern African data and is still in a preliminary stage. For example, at this stage the database will not adequately deal with geographical features with unique formative regimes or infer feature-process links unless, of course, broken up into several smaller units or expanded into a complex information centre. Nevertheless, it was shown that the database functions well and that the requirements stipulated in Chapter 3 for this study were met.

CHAPTER 6

Conclusions and recommendations

Cryogenic research is a growing field in southern African geomorphology. A diversity of features and processes have been identified and attributed to either glacial or periglacial origin. Most phenomena are believed to be products of the Last Glacial Maximum (LGM), thus indicating periods of climatic shifts during the Pleistocene. At present the subcontinent displays active cryogenic processes manifesting in a variety of features. It is believed that the contemporary cryogenic landscape is a remnant of a colder Pleistocene palaeoenvironment. However, there is uncertainty pertaining to the significance of relict cryogenic phenomena. This is because the intensity, dominance and spatial distribution of past processes are subject to considerable debate. Further, there is no conclusive data suggesting a Pleistocene glaciation, and evidence indicating periglacial activity is apparently not conclusive. Due to the absence of a modern snowline for the subcontinent, a palaeo-snowline can not be established and hence no clear interpretation of surviving features is possible along this line. Therefore, southern African cryogenic research is inconclusive.

It is evident that there is a need for a fresh approach to the problem. In addition, it is apparent that the origin of these cryogenic landforms should be explained within a larger, theoretical framework, incorporating other disciplines, e.g. biology, biogeography, zoology etc., and should aspire towards an interactive perspective (Chapter 2). This study represents an attempt to develop such an approach and to clarify some of the questions currently facing researchers. The research problem was established (Chapter 1) and investigated by

- determining the nature of cryogenic research and the problems facing it (Chapter 2);
- summarising data and compiling a database system that acts as (i) a data source, (ii) an aid in research, (iii) a basis for digital mapping, calculations and projections, and (iv) a possible medium for future modelling of climatic trends (Chapter 3);
- by compiling comprehensive glossaries as standardising measures for the database and as support in future research (Chapter 4).

Other objectives of this study was to expand on current cryogenic knowledge, to facilitate the reconstruction of the Pleistocene environment and, at the same time, provide a reliable data source. The aims and objectives (Chapter 1) were realised in the compilation and utilisation of

the Cryogenic Processes and Landforms Spatial Database for Southern Africa (Appendix A). The database proved to be an excellent tool by which research issues can be challenged. As a data source, the database reduces the problem of poor spatial and temporal resolution of data. Through database manipulation, the spatial distribution of both past and present cryogenic phenomena was attempted. In this preliminary analyses it was possible to determine and map

- the extent of both relict and contemporary cryogenic activity, which demonstrated that the actual cryogenic palaeoenvironment probably did not differ much from the current one (Fig. 5.4 and 5.5);
- areas where mean annual air temperatures (MAAT) possible were sufficiently cold for periglacial activity (Fig. 5.7 and 5.8);
- and likely regions where glacial ice could have developed and survived (Fig. 5.10) during the Last Glacial Maximum.

In addition to the establishment of a cryogenic database, several glossaries and indices (Appendices C, D, E, F and G) were compiled as logical extensions of the project. The main glossary (Appendix C) is a first effort at explaining past terminology usage and providing a terminology basis for current research. The database, combined with the glossaries and indices, will be invaluable in future research and modelling. In short, the following results were obtained in this study:

- A better understanding of the spatial distribution of both relict and current cryogenic phenomena were achieved. It is believed that the dominance and intensity of especially relict processes will be possible through further specialised modelling.
- The database supplements current knowledge on the subject and will contribute towards the reconstruction of the southern African Quaternary environment.
- The database acts as a data source on which further research can be based. It is flexible, reliable and a very convenient tool in GIS-based problem solving.

It is clear from findings (Chapter 5) that the Cryogenic Processes and Landforms Spatial Database for Southern Africa can be applied in such a way as to successfully clarify complex problems, e.g. snowline elevation and possible Pleistocene glacial extent. For further enquiry into the possibilities of periglacial and glacial environments in southern Africa, it is recommended that the database be refined to create a more dynamic problem solving GIS-instrument.

In conclusion, a number of research opportunities were identified in the study. It was perceived that, to understand the full implication of the existence of the current cryogenic environment, factors other than MAAT should be considered in further database modelling, e.g. the role of lithology and geology, micro-climatic factors, precipitation, insolation, vegetation, etc. Future analyses and outcomes should be evaluated against other research findings, e.g. by Lewis (1987) and Marker (1995a). Furthermore, the database should be critically assessed and refined for a more representative picture of the southern African cryogenic environment through future GIS-modelling and analyses. Regarding the possibility of a periglacial palaeoenvironment, a number of issues should be addressed:

- Seasonal contrasts and global atmospheric circulation patterns during the LGM and how these affected the southern African climate.
- The moisture factor during the LGM. Many argue that the subcontinent experienced dry conditions (e.g. Van Zinderen Bakker, 1976; Partridge, 1990, 1997, etc.) due to changing weather patterns. This should be investigated more closely.
- The exact drop in temperature for the LGM.
- The Western Cape (Region 3, Fig. 5.2) should be considered as a unique and site-specific cryogenic environment and its significance relating to past and present climatic conditions should be studied. Other factors, e.g. precipitation, vegetation and lithology, are believed to be key elements in the formation of cryogenic phenomena observed there and need to be correlated with the MAAT values in this study (Chapter 5).

The possibility of a glacial palaeoenvironment needs more intensive research than was undertaken in this study (Chapter 5). The factors influencing glacial development as listed in Fig. 5.8 must be considered if a true picture of the LGM situation is to be gained.

This project is a first effort towards a better understanding of cryogenic phenomena by utilising GIS-based techniques. It is hoped that this study will contribute towards further research into the reconstruction of palaeoclimatic events and the construction of future climatic trends in southern Africa.

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¹ CD-ROM available from the National Snow and Ice Data Centre, University of Colorado at Boulder. nsidc@kryos.colorado.edu

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APPENDIX A
Cryogenic Processes and Landforms Spatial
Database for Southern Africa

INSTALLATION

1. Insert CD in CD drive.
2. Go to Windows Explorer. Choose the CD-drive that will typically display **000808-1448 (D)**.
3. To install ArcExplorer, click on **Aeclient.exe**. If ArcExplorer is already installed, this action is not necessary. Projects may also be viewed in ArcView.
4. In Windows Explorer, on the CD-directory, there is a **INFO.txt** file with information regarding the compilation and contents of the CD.



APPENDIX B
Database Components

Appendix B: Database Components

Categories	Subcategories	Database column abbreviation	Full name	Explanation
1. ID		ID	ID	Automatic identification number of entry
2. Information source		Researcher	Author	Author(s) of publication
		Year	Year	Year of publication of paper
3. Identification of the phenomenon		Phenomenon	Phenomenon	Phenomenon identified in the paper according to Appendix C
		Cause1	Cause 1	First cause of phenomenon according to Appendix C
		Cause2	Cause 2	Second cause of phenomenon according to Appendix C
		Cause3	Cause 3	Third cause of phenomenon according to Appendix C
		Cause4	Cause 4	Fourth cause of phenomenon according to Appendix C
		Respheno	Author's phenomenon	Terminology used by author(s) to describe phenomenon
		Rescause1	Author's cause 1	Terminology used by author(s) to describe cause 1
		Rescause2	Author's cause 2	Terminology used by author(s) to describe cause 2
		Rescause3	Author's cause 3	Terminology used by author(s) to describe cause 3
		Rescause4	Author's cause 4	Terminology used by author(s) to describe cause 4
		Rescause5	Author's cause 5	Terminology used by author(s) to describe cause 5
		Rescause6	Author's cause 6	Terminology used by author(s) to describe cause 6
4. Geomorphic characteristics		Geomorphic characteristics	Geomorphic characteristics	Type of geomorphic characteristic which describes formation of phenomenon best, i.e. Glacial, Present-day periglacial or Past periglacial
		Activity	Activity	The activity level of a phenomenon, i.e. Relict, Currently active, Currently inactive, Seasonally active
5. Location	5.1 Latitude and longitude	Latitude (S)	Latitude (S)	Latitudinal location of phenomenon
		Latdeg	Latitude degrees	Latitude of phenomenon: degrees
		Latmin	Latitude minutes	Latitude of phenomenon: minutes
		Latsec	Latitude seconds	Latitude of phenomenon: seconds
		Newlat	New latitude	Latitude calculations used in ArcView®
		Newlat2	New latitude 2	Latitude calculations used in ArcView®
		Longitude (E)	Longitude (E)	Longitudinal location of phenomenon

Categories	Subcategories	Database column abbreviation	Full name	Explanation
5. Location (cont.)	5.1 Latitude and longitude (cont.)	Londeg	Longitude degrees	Longitude of phenomenon: degrees
		Lonmin	Longitude minutes	Longitude of phenomenon: minutes
		Lonsec	Longitude seconds	Longitude of phenomenon: seconds
		Newlon	New longitude	Longitude calculations used in ArcView®
		Newlon2	New longitude 2	Longitude calculations used in ArcView®
		Location	Location	Exact name of place where phenomenon was located
		Location1	Location 1	Name of place where phenomenon was located
		Loccation11	Location 11	Name of place where phenomenon was located (control measure)
		Loccation2	Location 2	Name of place where phenomenon was located
	5.2 Altitude	Altitude	Altitude above sea level	Average altitude at which phenomenon was encountered; altitude = (minimum altitude + maximum altitude)/2
		Altitudemin	Altitude minimum	Minimum altitude of phenomenon
		Altitudemax	Altitude maximum	Maximum altitude of phenomenon
	6. Specific characteristics	6.1. Age and count	Age	Age
Agemin			Age minimum	Minimum age of phenomenon
Agemax			Age maximum	Maximum age of phenomenon
Estimate			Estimate	Estimated age of phenomenon, i.e. Before the LGM, During the LGM, After the LGM, During the Holocene/Present
Count			Count	Number of phenomena encountered
6.2 Vegetation		Vegetated	Vegetated	Phenomenon vegetated
		Vegfringe	Vegetation fringe	The phenomenon display a vegetation fringe
6.3 Sorting and stratification		Sorting occur	Sorting occur	Sorting occur within/on/under the phenomenon
		Stratification occur	Stratification occur	Stratification occur within/on/under the phenomenon
		Sorting	Sorting	In what way is the phenomenon sorted? Gradual, Horizontal, Vertical, Well sorted, Poorly sorted
		Grading	Grading	To what degree is the phenomenon graded checked against the sorting? Very fine, Fine, Fine to coarse, Medium, Medium to coarse, Coarse, Very coarse, Medium to fine, Coarse to fine, Coarse to medium

Categories	Subcategories	Database column abbreviation	Full name	Explanation
6. Specific characteristics (cont.)	6.4 Soils	Soil	Soils	Some form of soil is present within/on/under the phenomenon. Soils include palaeosols
		Sediment	Sediments	Some form of sediment is present within/on/under the phenomenon.
		S1	Soil or sediment 1	First soil or sediment as listed in Soils
		Sthick1min	Soil or sediment thickness 1 minimum	First soil or sediment thickness minimum
		Sthick1max	Soil or sediment thickness 1 maximum	First soil or sediment thickness maximum
		S1%	Soil or sediment 1 percentage	Percentage of first soil or sediment present
		S2	Soil or sediment 2	Second soil as listed in Soil or Sediment
		Sthick2min	Soil or sediment thickness 2 minimum	Second soil or sediment thickness minimum
		Sthick2max	Soil or sediment thickness 2 maximum	Second soil or sediment thickness maximum
		S2%	Soil or sediment 2 percentage	Percentage of second soil or sediment present
		S3	Soil or sediment 3	Third soil or sediment as listed in Soils or Sediment
		Sthick3min	Soil or sediment thickness 3 minimum	Third soil or sediment thickness minimum
		Sthick3max	Soil or sediment thickness 3 maximum	Third soil or sediment thickness maximum
		S3%	Soil or sediment 3 percentage	Percentage of third soil or sediment present
		Scolour	Soil or sediment colour	Colour of soil or sediment of phenomenon i.e. brown, brown to dark, dark
	Squality	Soil or sediment quality	Quality of soil or sediment of phenomenon i.e. humic, heavy	
	6.5 Matrix and clasts	Matrixsupported	Matrix supported	Phenomenon material is matrix supported or there is a form of matrix present
		Clastsupported	Clast supported	Phenomenon material is clast supported or there is a form of clast present
		Matrix	Matrix	Matrix of phenomenon i.e. silt, clay
		Matrix1	Matrix 1	First matrix as listed in Matrix
		Matrix1char	Matrix 1 characteristics	Characteristics of first matrix type as listed in Matrix
		Matrixcont1min%	Matrix contents 1 minimum percentage	Minimum percentage matrix content of phenomenon
		Matrixcont1max%	Matrix contents 1 maximum percentage	Maximum percentage matrix content of phenomenon
		Matrix1thickness	Matrix 1 thickness	Average thickness of first matrix of phenomenon = (matrixdim1min + matrixdim1max)/2

Categories	Subcategories	Database column abbreviation	Full name	Explanation
6. Specific characteristics (cont.)	6.5 Matrix and clasts (cont.)	Matrixdim1min	Matrix dimensions 1 minimum	Dimensions of first matrix of phenomenon: minimum
		Matrixdim1max	Matrix dimensions 1 maximum	Dimensions of first matrix of phenomenon: maximum
		Matrix2	Matrix 2	Second matrix as listed in Matrix
		Matrix3	Matrix 3	Third matrix as listed in Matrix
		Matrix4	Matrix 4	Fourth matrix as listed in Matrix
		Matrixmat1	Matrix material 1	First matrix supported material as listed in Matrixsuppmat
		Ms/mdim1min	Matrix supported material dimensions 1 minimum	First matrix supported material dimensions (minimum)
		Ms/mdim1max	Matrix supported material dimensions 1 maximum	First matrix supported material dimensions (maximum)
		Matrixs/m1profile1	Matrix supported material 1 profile 1	First profile of first matrix supported material
		Matrixs/m1profile2	Matrix supported material 1 profile 2	Second profile of first matrix supported material
		Matrixs/m1profile3	Matrix supported material 1 profile 3	Third profile of first matrix supported material
		Matrixmat2	Matrix material 2	Second matrix supported material as listed in Matrixsuppmat
		Matrixmat3	Matrix material 3	Third matrix supported material as listed in Matrixsuppmat
		6.6 Gradients	Phen:overgrad	Phenomenon overall gradient
	Gradient1		Gradient 1	First gradient at which phenomenon inclines
	Gradient2		Gradient 2	Second gradient at which phenomenon inclines
	Gradient3		Gradient 3	Third gradient at which phenomenon inclines
	Gradient4		Gradient 4	Fourth gradient at which phenomenon inclines
	Slopeangle1		Slope angle 1	Average angle at which slope inclines (1) = (slopeangle1min + slopeangle1max)/2
	Slopeang1min		Slope angle 1 minimum	Minimum slope angle
	Slopeang1max		Slope angle 1 maximum	Maximum slope angle
	Slopeangle2		Slope angle 2	Average angle at which slope inclines (2) = (slopeangle2min + slopeangle2max)/2
	Slopeang2min		Slope angle 2 minimum	Minimum slope angle
Slopeang2max	Slope angle 2 maximum	Maximum slope angle		

Categories	Subcategories	Database column abbreviation	Full name	Explanation
6. Specific characteristics (cont.)	6.6 Gradients (cont.)	Slopeangle:other	Slope angle: other	Other interpretations of slope angle
		Orientation	Orientation	Average compass orientation of phenomenon = (orientation1 + orientation2 ...)/x
		Orientation1	Orientation 1	First orientation of phenomenon
		Orientdeg1	Orientation degrees 1	First orientation of phenomenon in degrees (see Fig. 3.4)
		O1%	Orientation 1 percentage	Percentage of phenomenon orientated in direction
		Orientation2	Orientation 2	Second orientation of phenomenon
		Orientdeg2	Orientation degrees 2	Second orientation of phenomenon in degrees (see Fig. 3.4)
		O2%	Orientation 2 percentage	Percentage of phenomenon orientated in direction
		Orientation3	Orientation 3	Third orientation of phenomenon
		Orientdeg3	Orientation degrees 3	Third orientation of phenomenon in degrees (see Fig. 3.4)
		O%3	Orientation 3 percentage	Percentage of phenomenon orientated in direction
		Aligndescr	Alignment description	Description of type of alignment
		Alignment1	Alignment 1	First alignment (degrees)
		Align1%	Alignment 1 percentage	Percentage of phenomena aligned in first direction
		Alignment2	Alignment 2	Second alignment (degrees)
		Align2%	Alignment 2 percentage	Percentage of phenomena aligned in second direction
		Slope	Slope	General slope face phenomenon is encountered on (i.e. on generally eastern slope (E))
		Slope1	Slope 1	First slope phenomenon is located on
		Slope2	Slope 2	Second slope phenomenon is located on
		6.7 Dimensions	Width:length	Width:length ratio
	W/Lmin		Width:length ratio minimum	Minimum width:length ratio of phenomenon (i.e.1:2)
	W/Lmax		Width:length ratio maximum	Maximum width:length ratio of phenomenon (i.e.1:2)
	Width		Width	Average width of phenomenon = (widthmin + widthmax)/2
	Widthmin		Width minimum	Minimum width of phenomenon

Categories	Subcategories	Database column abbreviation	Full name	Explanation
6. Specific characteristics (cont.)	6.7 Dimensions (cont.)	Widthmax	Width maximum	Maximum width of phenomenon
		Length	Length	Average width of phenomenon = $(lengthmin + lengthmax)/2$
		Lengthmin	Length minimum	Minimum length of phenomenon
		Lengthmax	Length maximum	Maximum length of phenomenon
		Height	Height	Average width of phenomenon = $(heightmin + heightmax)/2$
		Heightmin	Height minimum	Minimum height of phenomenon
		Heightmax	Height maximum	Maximum height of phenomenon
		Depth/thickness	Depth/thickness	Average width of phenomenon = $(depthmin + depthmax)/2$
		Depthmin	Depth minimum	Minimum depth of phenomenon
		Depthmax	Depth maximum	Maximum depth of phenomenon
		Diameter	Diameter	Average width of phenomenon = $(diammin + diammax)/2$
		Diammin	Diameter minimum	Minimum diameter of phenomenon
		Diammax	Diameter maximum	Maximum diameter of phenomenon
		6.8 Phenomenon profile	Profile	Profile
	Other1		Other 1	First other constituent of phenomenon as listed in Other
	Other1 Dim min		Other 1 dimensions minimum	First other constituent's minimum dimensions
	Other1 Dim max		Other 1 dimensions maximum	First other constituent's maximum dimensions
	Other1: profile		Other 1: profile	First other constituent's profile
	Other2		Other 2	Second other constituent of phenomenon as listed in Other
	Other2 Dim min		Other 2 dimensions minimum	Second other constituent's minimum dimensions
	Other2 Dim max		Other 2 dimensions maximum	Second other constituent's maximum dimensions
	Other2: profile		Other 2: profile	Second other constituent's profile
	Other3		Other 3	Third other constituent of phenomenon as listed in Other
	Other3 Dim min		Other 3 dimensions minimum	Third other constituent's minimum dimensions
	Other3 Dim max		Other 3 dimensions maximum	Third other constituent's maximum dimensions

Categories	Subcategories	Database column abbreviation	Full name	Explanation
6. Specific characteristics (cont.)	6.8 Phenomenon profile (cont.)	Other3: profile	Other 3: profile	Third other constituent's profile
		Other4	Other 4	Fourth other constituent of phenomenon as listed in Other
		Other4 Dim min	Other 4 dimensions minimum	Fourth other constituent's minimum dimensions
		Other4 Dim max	Other 4 dimensions maximum	Fourth other constituent's maximum dimensions
		Other4: profile	Other4: profile	Fourth other constituent's profile
		Other5	Other 5	Fifth other constituent of phenomenon as listed in Other
		Other5 Dim min	Other 5 dimensions minimum	Fifth other constituent's minimum dimensions
		Other5 Dim max	Other 5 dimensions maximum	Fifth other constituent's maximum dimensions
		Other5: profile	Other 5: profile	Fifth other constituent's profile
		Note1	Note1	First other characteristic and interesting fact of phenomenon
		Note2	Note2	Second other characteristic and interesting fact of phenomenon
		Note3	Note3	Third other characteristic and interesting fact of phenomenon
		Note4	Note4	Fourth other characteristic and interesting fact of phenomenon
		Note5	Note5	Fifth other characteristic and interesting fact of phenomenon
		Note6	Note6	Sixth other characteristic and interesting fact of phenomenon
		Note7	Note7	Seventh other characteristic and interesting fact of phenomenon
		Note8	Note8	Eighth other characteristic and interesting fact of phenomenon
		Note9	Note 9	Ninth other characteristic and interesting fact of phenomenon
		Note10	Note 10	Tenth other characteristic and interesting fact of phenomenon
		Note11	Note 11	Eleventh other characteristic and interesting fact of phenomenon
Note12	Note 12	Twelfth other characteristic and interesting fact of phenomenon		

APPENDIX C
The Terminology Glossary

The Terminology Glossary

Note: Definitions were taken from the International Permafrost Association (IPA) definition glossary and supplemented by definitions from (i) Goudie *et al.* (1985), (ii) Press & Siever (1986), (iii) Clark (1998) and (iv) Kearey (1996). South African literature was incorporated in some cases. An asterisk (*) stands for not recommended usage of terminology (according to the IPA and other sources). The list of authors at the end of each definition is only listed if they actually called the process or feature by name.

Abbreviations

A	Activity of phenomenon, i.e. whether it is still active or not
AASL	Altitude above sea level
D	Depth range of a phenomenon
Di	Diameter of phenomenon
H	Height range of a phenomenon
L	Length range of a phenomenon
M	The type of matrix present in a matrix supported phenomenon
Publications	Southern African publications of the phenomenon
SN	Sorted, nonsorted or stratified
SS	Soils and sediments present within, under or in the vicinity of the phenomenon in question
Strat	Stratified
Synonyms	Different terminology by which phenomenon is known
Synopsis	A broad description southern African cryogenic phenomena
V	Vegetated
W	Width range of a phenomenon
#	The writer's own definition extracted from other base definitions.

- Arête** A sharp narrow steep-sided mountain ridge, especially one formed when two cirques have been developed back-to-back and combined to form a ridge (Clark, 1998).
- Synonym:* under certain circumstances, sharp ridge
- Publications:* Sparrow (1964, 1967b); Sanger (1988); with non-specific reference Hastenrath (1972)
- Synopsis:* A relict
- Avalanche (-ing)** Originally the term was applied to a large mass of snow mixed with earth, stones and ice loosened from a mountainside and falling swiftly by gravity to the valley below. Now it is usually restricted and applied to a fall of a mass of snow, ice and firn, being qualified if used to cover similar movements of other materials, e.g. rock avalanche (better termed as landslide), sand avalanche (plinth). Avalanches are an obvious and important mechanism of mass wasting in mountainous parts of the earth; they are also highly significant on subaqueous continental margins and deltas as well as in extraterrestrial environments, like on Mars. Avalanches occur when the shear stresses on a potential surface of sliding exceed the shear strength on the same plane. Failure is sometimes associated with increased shear stress in response to slope steepening or loading to reduced shear strength within the material and sometimes a combination of the two (Goudie *et al.*, 1985; Clark, 1998).
- Publications:* Sparrow (1967a); Grab (1996a)
- Synopsis:* A relict; AASL 3200-3300m; SS humic
- Avalanche deposit#** Debris structures left behind by avalanche activity. See Avalanche (-ing).
- Publications:* Lewis & Dardis (1985)
- Synopsis:* A relict; M sand; D 1,5 – 1,8m
- Basalt step** Basalt outcrop on the contours of a mountainside that look like a step. Basalt steps are believed to be derived from frost wedging. Basalt steps form where the basalt flows are most resistant to chemical weathering and the soil the thinnest (Harper, 1969).
- Publications:* Harper (1969)
- Synopsis:* A relict; AASL 3230-3325m; SS chemically weathered modern soils & subsoils; H 1.8-6.1m
- Blockfield** A superficial layer of angular shattered rocks on top of a flat-topped mountain or a high plateau, sometimes on lowland, formed by *in situ* shattering by frost of a bedrock surface in either modern or Pleistocene periglacial environments (French, 1976, 1996; Washburn, 1979). They may surround features such as tors and nunataks and other landforms subjected to severe periglacial processes (Goudie *et al.*, 1985; Kearey, 1996; Clark, 1998).

...Blockfield-cont.

- Synonyms:* stone field , blockmeer*, felsenmeer*, boulder field*, rock-block field*, rock river*, rock stream*
- Publications:* Linton (1969); Sparrow (1971); Borchert & Sanger (1981); Sanger (1988); Marker (1992); Boelhouwers (1994); Grab (1996b)
- Synopsis:* A relict; AASL 1500-3260m; W 30m; L 25m; D 1-7m
- Blockstream** Lines of boulders, generally angular, formed by *in situ* shattering by frost of a bedrock surface. They may surround features such as tors and nunataks and other landforms subjected to severe periglacial processes (Goudie *et al.*, 1985).
- Publications:* Hastenrath & Wilkinson (1973); Hagedorn (1984); Lewis (1996a)
- Synopsis:* A relict; W 10-30m; L 100m; H 4-8m
- Boulder** Any large, detached, generally rounded mass of rock, larger than a cobble, especially one transported by ice, river or sea, from its original home, but also in some cases one weathered by frost shattering or exfoliation *in situ*, specifically 200 to 265mm in diameter (Kearey, 1996; Clark, 1998).
- Boulder bed[#]** A layer of boulders, separated from the overlying and underlying layers by a defined boundary.
- Publications:* Sparrow (1967a); Grab (1996a)
- Synopsis:* A relict; AASL 1675-3355m; L 100m; H 1-5m; Di 1m
- Channel system** A system of running water, cut into debris or bedrock, that serve to drain excess water away from an area (Clark, 1998).
- Publications:* Hall (1994)
- Synopsis:* A relict; AASL 2100m; W 100m; L 1km; H 10m
- Cirque** A hollow, open downstream but bounded upstream by an arcuate, cliffed headwall, with a gently sloping floor or rock basin (Goudie *et al.*, 1985). Cirques resemble steep-walled amphitheatres or horse-shaped basins at the head of a mountain valley (sometimes containing a small lake), resulting from frost and glacial action. At the meeting of two cirques a knife-edge or arête is formed (Press & Siever, 1986; Kearey, 1996; Clark, 1998). The cirque floor is eroded by glacier sliding while the backwall is attacked by basal sapping and subaerial rock weathering. Cirques are common in formerly glaciated uplands. They were originally thought to have been formed during the waxing and waning of sheet glaciations, but few were occupied by active glaciers during ice sheet withdrawal. Instead it seems likely that they represent several stages during the last few million years when marginal glaciation affected mid-latitude uplands. Most mid-latitude cirques show a preferred orientation towards the north-east in the Northern Hemisphere reflecting mainly the effect of shade in protecting the glacier from the sun, but also the effect of wind-drifted snow accumulated by predominantly westerly winds. Preferred orientation is less

...Cirque-cont.

important in polar and tropical mountains. Cirque altitude is an indication of former snow lines and it is common for basin altitudes to increase with distance from the coast. The main controls on their morphology remain unclear, but it seems that they tend to become more enclosed and deeper with time (Goudie *et al.*, 1985).

Synonyms: corrie, cwm, trough's end

Publications: Sparrow (1967a, 1967b); Harper (1969); Borchert & Sanger (1981); Sanger (1988)

Synopsis: A relict; AASL 1675-3355m; SS chemically weathered, gritty modern soils & subsoils; W 15,25m

Cirque-like hollow:

Publications: Sparrow (1964); Dyer & Marker (1979)

Synopsis: A relict; AASL 2607-3204m; SS peat; W 621-1166.7m; L 486-1071.4m; H 93-280m; D 96-230m

- Cirque glacier** A short-tongued small glacier which fills a separate, rounded basin glacially eroded on a mountainside (Clark, 1998).
Publications: Borchert & Sanger (1981); Sanger (1988)
Synopsis: A relict; AASL 1900m
- Cirque-like hollow** See Cirque
- Clast** A coarse sediment particle, commonly a rock fragment or mineral grain produced by the disintegration of a larger mass, by volcanic explosion, weathering and/or erosion, usually larger than 4mm in diameter; clast sizes include pebbles, cobbles and boulders (Goudie *et al.*, 1985; Kearey, 1996; Clark, 1998).
Publications: as cryogenic phenomenon, Hanvey & Marker (1992); others mention clasts as part of phenomena.
Synopsis: A active; AASL 3275m
- Compacted soil** The pressing together of soil particles (e.g. by torrential rain, or by heavy mechanical equipment) so that the voids between them are reduced, with consequent loss of air, to the detriment of soil fertility (Clark, 1998).
Publications: as part of permafrost layers, Fitzpatrick (1978)
Synopsis: A relict; SS orthic & humic, yellow, brown, grey & black magwa, clovelly & silt-loam
- Contraction** The decrease in length of a line during deformation (Kearey, 1996).
Publications: Dyer & Marker (1979)
Synopsis: A relict; AASL 2870-3070m

- Corrie sheet** see Glacier
- Cryogenic process (action)** Thermophysical, physico-chemical and physico-mechanical processes occurring in freezing, frozen and thawing earth materials. Specific processes of cryogenic action include water migration during freezing and thawing of the ground, frost heave, heat and mass (moisture) exchange, regelation and gelifluction (Poppe & Brown, 1976).
Publications: Meiklejohn (1992); Boelhouwers (1994); Hanvey & Marker (1994); Marker (1995b)
Synopsis: A relict, active; AASL 1850-3250m; SS humic, massive & organic peat, silt, gravels, modern soils & palaeosols
- Cryoplanation** The process through which cryoplanation terraces form. Cryoplanation occurs most frequently in periglacial areas of moderate aridity underlain by permafrost, under conditions of intense frost wedging associated with snow banks (Van Everdingen, 1998).
- Cryoplanation terrace** A step-like or table-like bench cut in bedrock in cold climate regions. Cryoplanation terraces may occur as both hillside benches or bevelled summit surfaces and often lack structural control. They are thought to form under conditions of intense frost wedging associated with snow banks. Cryoplanation terraces are more frequently reported from periglacial areas of moderate aridity. As these areas are usually underlain by permafrost, cryoplanation terraces are regarded by some as diagnostic landforms of permafrost terrain (Eakin, 1916; Demek, 1969; French, 1976; Reger & Péwé, 1976; Washburn, 1979).
Publications: Hagedorn, 1984
Synopsis: A relict; AASL 1800-2370m; W 0.7-2km; L 2km; H 2m
- Cryoturbation** Singular meaning: a collective term used to describe all soil movements due to frost action. Plural meaning: irregular structures formed in earth materials by deep frost penetration and frost action processes, and characterised by folded, broken and dislocated beds and lenses of unconsolidated deposits, included organic horizons and even bedrock. Cryoturbation encompasses frost heave, thaw settlement and all differential movements, including expansion and contraction due to temperature changes and the growth and disappearance of ground ice bodies, whether perennial or seasonal. Low temperatures alone are not enough to produce cryoturbation; the water-ice phase change is necessary. Cryoturbation is an important process in the development of patterned ground (French, 1976, 1996; Washburn, 1979; Kearey, 1996). The process is especially active in the zone above permafrost which is subject to seasonal freezing and thawing- the active layer (Goudie *et al.*, 1985).
Synonyms: singular meaning: spew frost*, congeliturbation*, frost churning*, frost stirring*, geliturbation; plural meaning: cryoturbates

...Cryoturbation-cont.

- Publications:* Borchert & Sanger (1981); Lewis & Dardis (1985)
Synopsis: A relict, active; AASL 3200-3377m; SS subsoils
Cryoturbation features
Publications: Borchert & Sanger (1981)
Synopsis: A active; AASL 1900m
- Cryoturbation features** see Cryoturbation
- Cutback[#]** A narrow, steep-sided valley or pass cut into the slopes of a mountain. According to Grab (1996a) they are ravines or steep, narrow valley heads. They are commonly found in the High Drakensberg and Lesotho Mountains. Some cutbacks contain deposits and are bounded by high summits. Others display large rock niches or hollows on the south-facing aspects.
Publications: Hall (1994); Grab (1996a)
Synopsis: A relict; AASL 2968-3377m
- Debris** An accumulation of rock waste consisting of rocks, sand and/or clay, moved from their place of origin and redeposited (Clark, 1998).
Debris deposit
Publications: Lewis (1996a)
Synopsis: A Relict; AASL; 1930m; L 400m
- Debris deposit** see Debris
- Debris fan** An accumulation of rock waste consisting of rocks, sand and/or clay, moved from their place of origin and redeposited (Clark, 1998) in a fan-like shape.
Publications: Lewis & Hanvey (1991)
Synopsis: A relict; AASL 1407-1648m; SN yes; SS fine black sand, palaeosols; M sand, gravel; H 20-22m
- Debris flow** The downslope flow of debris mixed with a minor yet significant amount of water (Innes, 1984).
Publications: Hanvey *et al.* (1986); Lewis & Hanvey (1988); Hall (1994)
Synopsis: A relict; AASL 1900m
- Debris mantle** The accumulation of loose rock debris, consisting of weathered rock and soil, lying on the older solid bedrock (Clark, 1998).
Publications: Boelhouwers (1991b)
Synopsis: A active; AASL 1800m; SN nonsorted; M diamicton

- Debris ridge** A long, narrow, steep-sided rise in the land consisting of rock waste (rocks, sand and/or clay) (Clark, 1998).
Publications: Lewis & Hanvey (1993); Grab (1996a)
Synopsis: A relict; AASL 3200-3250m; SS humic; L 18,4-747,35m
- Desiccation** Shrinkage during subaerial drying in fine-grained soil and mud material that form cracks (Kearey, 1996; Van Everdingen, 1998).
Publications: Hanvey & Marker (1992)
Synopsis: A relict; AASL 2870-3070m; SS peat
Desiccation polygon
Publications: Hanvey & Marker (1992)
Synopsis: A active; AASL 3275m; Di 15cm-1m
- Desiccation polygon** see Desiccation
- Diamicton** A term used to distinguish unconsolidated rocks (Flint *et al.*, 1960). Distinction can be made through the lithofacies code (Eyles *et al.*, 1983).
- Earth hummock** A hummock having a core of silty and clayey mineral soil which may show evidence of cryoturbation. Earth hummocks are a type of nonsorted circle commonly found in the zone of continuous permafrost. They develop in materials of a high silt and clay content and/or of high ice content. Earth hummocks found outside the southern limit of present-day permafrost are believed to have formed during a previous period of cooler climate when the area was underlain by permafrost (Tarnocai & Zoltai, 1978; Washburn, 1979; Goudie *et al.*, 1985). The rounded hummocks form an irregular net-like pattern as the result of frost heaving (Kearey, 1996).
Synonyms: mud hummock, earth mound*, tundra hummock*
- Emplacement[#]** An intrusion of material by slow flow into an envelope of pre-existing material. It is not certain if this pertains to solifluction or gelifluction.
Publications: Marker (1992)
Synopsis: A active; AASL 2300-2800m
- Erosion** The process of weathering away of the land surface by natural agents (running water, ice, wave action etc.) and the transport of the rock debris that results. This process excludes mass movement and is not synonymous with denudation (Press & Siever, 1986; Clark, 1998).
Publications: Harper (1969); Marker & Whittington (1971); Meiklejohn (1992); Hanvey & Marker (1994)
Synopsis: A relict; AASL 1500-3325m; SS chemically weathered modern soils & subsoils

- Erosional hollow[#]** A term used in southern African context to describe certain valley-type features found in the upper regions of the High Drakensberg and Lesotho Mountains that resemble shallow cirques (also refer to Marker 1989, 1990c, 1991a; Sparrow, 1971, 1973, 1974).
- Synonyms:* amphitheatre-shaped hollow, cirque-like hollow, hollow, nivation cirque
- Publications:* Sparrow (1964; 1971); Harper (1969); Marker & Whittington (1971); Hastenrath (1972); Hastenrath & Wilkinson (1973); Nicol (1973); Dyer & Marker (1979); Borchert & Sanger (1981); Lewis & Hanvey (1988); Marker (1989, 1990c, 1991a); Hanvey & Marker (1994)
- Synopsis:* A relict; AASL 1600-3355m; SS yellow to dark peats, gravels, clays, topped with unconsolidated & oxidised modern soils; **M** gravels & clasts; **W** 400m-2,5km; **L** 400m-2,25km; **H** 21-293m; **D** 93m-1,207km
- Flark** A wetland comprising accumulations of semi-decomposed plant matter, particularly mosses (that form acid peat), arising from precipitation rather than groundwater (Kearey, 1996). Also a marsh or an area of muddy ground (Goudie *et al.*, 1985).
- Publications:* Backeus (1989)
- Synopsis:* A seasonal; AASL 3200-3300m; **V** yes; SS humified, amorphous peat; **L** 15m; **D** 20-60cm
- Fluvial** Adjective: of or pertaining to a river. Second meaning: Found or living in a river. It is usual to apply fluvial to the action of the river (flow and erosive activity), and fluviate to the deposits lay down by the river, or to the flora and fauna of a river (Kearey, 1996; Clark, 1998).
- Synonym:* fluviate
- Publications:* Lewis & Dardis (1985); Lewis & Hanvey (1991); Meiklejohn (1992)
- Synopsis:* A relict; active; AASL 1675-3355m
- Fluvio-glacial** The activity of rivers fed by glacial meltwater. The main characteristics of such streams are the highly variable discharge and the high sediment loads. Discharge varies markedly on a wide variety of time scales. Variations over a matter of seconds or minutes relate to the sudden release or closure of basal water pockets as a result of glacier sliding. Fluctuations over a matter of days reflect prevailing weather patterns, whereas a strong seasonal summer flow reflects the effect of glacier in storing winter precipitation only to release it in the ablation season. The muddy colour of meltwater streams reflects their high suspended sediment loads and measurements as high as 3 800mg⁻¹ have been measured. In addition the bed load is high and may amount to 90% of the suspended sediment load. Fluvio-glacial landforms may reflect prodigious feats of erosion and sedimentation. Formerly glaciated areas, particularly in mid-latitudes, contain abundant erosional

...Fluvio-glacial-cont.

evidence in the form of deeply incised meltwater channels and giant potholes, sub-glacial channels, courses such as eskers and kames and extensive areas of pro-glacial outwash and lake deposits (glacio-lacustrine) (Goudie *et al.*, 1985; Kearey, 1996; Clark, 1998).

Synonym: glacialfluvio, glacial-fluvio

Publications: Hall (1994); Grab (1996a); Lewis (1996b)

Synopsis: A relict; AASL 2000-200m; SS sand, clay, palaeosols; W 100m; L 100m-3km; H 1-20m

Fluvio-glacial meltwater:

Publications: Hanvey *et al.* (1986)

Synopsis: A relict; AASL 2225-2340m; SS massive & structured sand, clay & silt; M massive

**Fluvio-glacial
deposit(-ion)**

The laying down of stratified drift by meltwater, especially in an outwash apron, a varve or a pro-glacial lake. Stratified drift consists of rounded, washed and sorted sand and gravel, unlike till, which is angular or subangular and not sorted (Clark, 1998).

Publications: Sanger (1988), Hall (1994); Grab (1996a); Lewis (1996b)

Synopsis: A relict; AASL 2000-3200; SS sand, clay, palaeosol; W 100m; L 100m-3km; H 1-20m

**Fluvio-glacial
meltwater**

see Fluvio-glacial

Freeze-thaw

A form of weathering in periglacial areas where the temperature hovers around freezing point, below which frost breaks up the rock and above which the ice melts, so that water flows and carries away the rock fragments (Clark, 1998).

Synonym: gelifraction*

Publications: Harper (1969); Marker & Whittington (1971); Sparrow (1971); Fitzpatrick (1978); Hanvey & Marker (1992)

Synopsis: A active; AASL 1788-3295m

**Freezing
(of ground)**

The changing of phase from water to ice in soil or rock. The temperature at which ground freezing starts may be lower than 0°C because of freezing-point depression (Van Everdingen, 1998).

Publications: Boelhouwers (1995a); see Frozen ground

Synopsis: A active; AASL 1407-3355m; SS organic peat, light black fine sand, palaeosols & modern soils; M gravels

Frost action

The process of alternate freezing and thawing of moisture in soil, rock and other materials, and the resulting effects on materials and on structures placed on, or in, the ground. Frost action in soils describes the detrimental processes of frost heave that occurs in the ground during the freezing period, and thaw weakening (followed by thaw settlement) that occurs as the seasonally frozen ground thaws. Although it normally refers to seasonal freezing and thawing processes and effects, the term “frost action” has also been used to describe the long-term heaving that occurs when soils are subjected continuously to a freezing temperature over a long period of time. Frost action contributes to the mechanical weathering (i.e., disintegration or breakdown) of soil and rock materials, by frost wedging, cryoturbation activity, and to the development of cryotexture and cryogenic fabric in soils (Hennion, 1955; Washburn, 1979; Johnston, 1981). The term “frost action” is sometimes used to include a wider range of frost-related processes, such as frost heaving, frost creep, thermal contraction cracking and frost weathering (Goudie *et al.*, 1985).

Synonyms: gelifraction, also frost wedging, frost riving

Publications: Sparrow (1967a); Harper (1969); Hastenrath (1972); Hastenrath & Wilkinson (1973); Fitzpatrick (1978); Borchert & Sanger (1981); Hanvey *et al.* (1986); Marker (1989); Lewis (1987; 1996b); Lewis & Hanvey (1988); Hanvey & Lewis (1991); Grab (1994)

Synopsis: A relict, active; AASL 1582-3355m; SS humic, massive, organic & homogeneous black, brown & grey silt, loam, clay & sand

Frost climate:

Publications: Borchert & Sanger (1981)

Synopsis: A relict; AASL 1900m

Frost climate

see Frost action

Frost creep

The net downslope displacement that occurs when a soil, during a freeze-thaw cycle, expands normal to the ground surface/slope and settles in a nearly vertical direction upon thawing (Benedict, 1970; Washburn, 1979). Although frost creep is commonly associated with gelifluction, it is a separate process. Movement associated with frost creep decreases from the surface downwards and depends upon frequency of freeze-thaw cycles, angle of slope, moisture available for heave, and frost susceptibility of soil (Goudie *et al.*, 1985).

Publications: Lewis & Dardis (1985); Dardis & Granger (1986); Hanvey & Marker (1992); Boelhouwers (1991a, 1994, 1995a)

Synopsis: A active; AASL 1800-3260m; M mud

Frost heave

The upward or outward movement of the ground surface (or objects on, or in, the ground)

...Frost heave-cont.

caused by the formation of ice in the soil. Frost action in fine-grained soils increases the volume of the soil by freezing of *in situ* pore water and also by drawing water to the freezing front where ice lenses form (ice segregation). Soils that have undergone substantial heaving may consist of alternate layers of ice-saturated soil and relatively clear ice lenses. The lenses are formed normal to the direction of heat flow and when freezing penetrates from the ground surface (which may be horizontal, sloping or vertical), they form parallel to that surface. Frost heave can occur seasonally or continuously if freezing of the ground proceeds without interruption over a period of years (ground temperatures below 0°C). Differential, or non-uniform, frost heaving is one of the main detrimental aspects of the frost action process and reflects the heterogeneous nature of most soils, or variations in heat removal rate and groundwater supply over short distances. Depending on the degree of restraint, large freezing pressures (up to 1 MPa) can be developed as the ground freezes. These can be transmitted to a foundation, structure or other object placed on the ground surface, or embedded or buried in the ground, as basal (i.e., vertical) forces acting on their underside, or through adfreezing of the soil to the sides of the foundation, structure or object (Penner, 1968, 1976; Washburn, 1979; Linell and Lobacz, 1980; Chamberlain, 1981; Johnston, 1981; Kearey, 1996). Frost heaving is usually associated with the active layer above permafrost or with seasonally frozen ground. Frost heaving processes include the upheaving of bedrock blocks, tilting of stones, formation of needle ice, and the sorting and migration of soil particles (Goudie *et al.*, 1985).

Synonym: frost thrust*

Publications: Hastenrath (1972); Dardis & Granger (1985); Lewis (1987); Hanvey & Marker (1992); Boelhouwers (1995a); Grab (1996b)

Synopsis: A active; AASL 3200m

Frost shattering

The mechanical disintegration of rock by the pressure of the freezing of water in pores and along grain boundaries. Frost shattering is the process of grain loosening and rock disintegration by the freezing pressure of water in films of varying thickness on the surfaces of individual mineral grains. Freezing of the water drawn between the grains by various particle surface forces exerts sufficient differential pressure to loosen and separate the grains (Van Everdingen, 1998). More commonly, the term applies to the complex of weathering processes, both physical and chemical which operate, either independently or in combination, in cold non-glacial environments. The most important physical weathering process is frost wedging which characteristically produces angular fragments of varying sizes. Porous and well-bedded sedimentary rocks, such as shales, sandstones and limestones are especially susceptible to frost weathering or shattering. Features attributed to frost weathering or shattering include extensive areas of angular bedrock fragments

...Frost shattering-cont.

(block fields and block slopes) and irregular bedrock outcrops (tors; Goudie *et al.*, 1985; Kearey, 1996).

Synonyms: congelifraction, frost splitting, frost weathering

Publications: Harper (1969); Hagedorn (1984); Sanger (1988); Marker (1989); Hanvey & Marker (1992); Lewis & Hanvey (1993)

Synopsis: **A** active; AASL 3200m

Frost sorting

The differential movement of soil particles of different size ranges as a result of frost action. Frost sorting often accompanies cryoturbation (Washburn, 1979).

Publications: Boelhouwers (1994)

Synopsis: **A** relict; AASL 3140-3260m; **SN** sorting

Frost wedging

Frost wedging is the mechanical disintegration, splitting or break-up of rock by the pressure of the freezing of water in cracks, crevices, pores, joints or bedding planes (Washburn, 1979; Kearey, 1996).

Synonyms: congelifraction, frost bursting, frost prying, frost riving, frost cracking, also frost splitting, gelifraction

Publications: Sparrow (1967a); Harper (1969); Hastenrath & Wilkinson (1973); Borchert & Sanger (1981)

Synopsis: **A** active, relict; AASL 1900-2530m; **SS** modern subsoils

Frozen ground

Soil or rock in which part or all of the pore water has turned into ice. Perennially and seasonally frozen ground can vary from being partially to extensively frozen depending on the extent of the phase change. It may be described as hard frozen ground, plastic frozen ground, or dry frozen ground, depending on the pore ice and unfrozen water contents and its compressibility under load. Hard-frozen soils are firmly cemented by ice, are subject to brittle failure, and exhibit practically no consolidation under load. Plastic-frozen soils are cemented by ice but have viscous properties due to their high unfrozen water content and therefore will compress under load. Dry-, or friable-frozen, soils have a very low total water content and are not cemented by ice; their compressibility is the same as for unfrozen soils having the same composition, total water content and density (U.S.S.R., 1969, 1973; Van Everdingen, 1976).

Publications: Harper (1969); Borchert & Sanger (1981); Lewis & Dardis (1985); Dardis & Granger (1986); Lewis (1987); Boelhouwers (1995a)

Synopsis: **A** active; AASL 2744-3200m; **SN** sorted; **SS** clay & a palaeosol; **M** mud, diamicton

Frozen ground phenomena

Publications: Borchert & Sanger (1981)

Synopsis: **A** relict; AASL 1900m

- Frozen ground phenomena** see Frozen ground
- Geliflual action¹** The fast movement of water saturated debris over a frozen substrate. This process differs from gelifluction in that it consists of more water and moves very quickly (Meiklejohn, 1999 *pers. comm.*)
- Publications:* Linton (1969)
- Synopsis:* A relict; AASL 445-2000; SS red, brown & grey modern soils & gravel; M brown earth, sand & grits
- Geliflual apron:*
- Publications:* Linton (1969)
- Synopsis:* A relict; AASL 445-2000; V yes; SS red, brown & grey modern soils & gravel; M brown earth, sand & grits; D 1-8m
- Geliflual deposit*
- Publications:* Linton (1969)
- Synopsis:* A relict; AASL 445; V yes; SS grey-buff modern soils & gravel; M rusty coloured chips; D 8m
- Geliflual apron** see Geliflual action
- Geliflual deposit** see Geliflual action
- Gelifluction** The slow downslope flow of unfrozen earth materials on a frozen substrate in periglacial environments. Gelifluction is a type of solifluction implying the presence of either seasonal frost or permafrost (Washburn, 1979). Suitable conditions for gelifluction occur in areas where downward percolation of water through the soil is limited by the permafrost table, where the melt of segregated ice lenses provides excess water in the soil and areas beneath or below late-lying snowbanks. Rates of movement, (between 0.5 and 10.0cm per year), usually decrease with depth. Frost creep is usually measured as a component of gelifluction. As with solifluction, features related to gelifluction include sheets, stripes and lobes (Goudie *et al.*, 1985; Kearey, 1996; Clark, 1998).
- Publications:* Linton (1969); Lewis & Dardis (1985); Dardis & Granger (1986); Lewis (1987; 1996b); Hanvey & Marker (1992); Boelhouwers (1994)
- Synopsis:* A relict, active; AASL 445-3260m; SS palaeosol; M mud & chips
- Gelisolifluction:*
- Publications:* Hagedorn (1984)
- Synopsis:* A relict; AASL 1700-2370

¹ The term and process of *geliflual action*, is not recognised by the IPA.

- Gelifluction apron** A fan-like deposit at the base of a slope, produced by gelifluction (compare with *solifluction apron*) (Van Everdingen, 1998).
- Gelifluction deposit** Deposits left by gelifluction action in the form of aprons, sheets, lobes and/or terraces (Van Everdingen, 1998).
Publications: Lewis & Dardis (1985); Lewis (1987)
Synopsis: A relict; AASL 445-2000m; SN some sorted; M chips, mud, sand; D 30cm-8m
- Gelifluction (head) deposit** A gelifluction slope deposit accumulation which form through various periglacial mass movement processes induced by seasonal thawing of the active layer, indicating the (former) presence of permafrost (Embleton & King, 1975).
Synonym: head
Publications: Nicol (1973); Lewis (1996b)
Synopsis: A relict; AASL 1841-2000m; V yes; SN stratified; SS grits, sand, gravels & a palaeosol; D 15m
- Gelifluction lobe** An isolated, tongue-shaped gelifluction feature, formed by more rapid gelifluction on certain sections of a slope showing variations in gradient (compare with *solifluction lobe*).
- Gelifluction sheet** A broad deposit of nonsorted, water-saturated, locally derived materials that is moving or has moved downslope. Sorted and/or nonsorted stripes might be associated with gelifluction sheets (compare with *solifluction sheet*).
Synonym: gelifluction mantle
Publications: Boelhouwers (1994)
Synopsis: A relict; AASL 3140-3260m; SN sorted; W 10m; L <20m; H <50m
- Gelifluction terrace** A low step, or bench, with a straight or lobate front, the latter reflecting local differences in the rate of gelifluction movement. A gelifluction terrace may have bare mineral soil on the upslope part and 'folded-under' organic matter in both the seasonally thawed ground and the frozen ground (compare with *solifluction terrace*).
Synonyms: gelifluction bench, gelifluction step
- Gelisolifluction** see Gelifluction
- Glacial** Adjective: a landscape occupied by glaciers. In this usage the term is similar to *glacierised*, an alternative which has not found general favour. The term *glaciated* describes a landscape that has been covered by glaciers, but normally in the past (Kearey, 1996). Noun: those occasions during the

...Glacial-cont.

Ice Ages when ice sheets were expanded and average global climates were colder and drier than during intervening *interglacials*. During many of the 17 or so Pleistocene glacials ice sheets covered Canada, northern USA, northern Europe, Britain north of London and north-western Siberia. The existing ice sheets of Greenland and Antarctica expanded offshore while mountain glaciers throughout the world extended into lower altitudes. Sea ice extended further towards the equator as global ocean temperatures fell. Atmospheric and oceanic circulation was modified. It seems likely that the globe as a whole was drier with sub-tropical deserts extending their equator margins and the equatorial rain forest being restricted to discrete islands by the spread of savannah conditions. Mid-latitude areas in the northern hemisphere saw increased wind action with extensive loess deposits in Europe, China and North America (Goudie *et al.*, 1985).

Publications: Sänger (1988); Hanvey & Lewis (1990); Marker (1991b); Lewis & Hanvey (1993)

Synopsis: A relict; AASL 1850-2135m; SS sand, clay, mud & silt

Glacial phenomena:

Publications: Harper (1969); Borchert & Sänger (1981); Sänger (1988); (Hanvey & Lewis (1990); Marker (1991b); Lewis & Hanvey (1993); Hall (1994); Grab (1996a); Lewis (1996b)

Synopsis: A relict; AASL 1820-3377m; V yes; SN stratified; SS peat, silt, clay, sand & a palaeosol; M sand, gravel & mud

Glaciation:

Publications: Grab (1996a)

Synopsis: A relict; AASL 3200-3300m

Glacial erosion

Erosion by glacier ice by the process of frost shattering, meltwater flow and plucking to form features such as arêtes, cirques, fjords, hanging valleys, horns, know-and-lochan topography and roches moutonnées (Kearey, 1996).

Publications: Harper (1969); Borchert & Sänger (1981); Lewis & Hanvey (1993); Lewis (1996b)

Synopsis: A relict; AASL 1820-2350m; SS chemically weathered, koalinised & organic modern soils, subsoils & palaeosol; M sand, silt & gravel

Glacial pavement

Rock surfaces, especially the floor of the glacier (Van der Merwe & De Villiers, 1978), that has been scratched and polished by the movement of debris-laden ice across it (Lewis, 1996a).

Publications: Sänger (1988)

Synopsis: A relict

- Glacial phenomena** see Glacial
- Glacial polish** A smooth surface developed on bedrock as the result of glacial abrasion (Press & Siever, 1986).
Publications: Harper (1969); Borchert & Sanger (1981); Sanger (1988)
Synopsis: A relict; AASL 1900-2350m; SS chemically weathered modern top- & subsoil
- Glacial striation** Scratches etched onto a rock surface by the passage over it of another rock of equal or greater hardness. Striations are characteristic of erosion by glaciers but may also occur beneath snow patches and on coasts affected by sea ice. Glacial striations are generally up to a few millimetres in width and rarely more than a metre in length. Larger striations grade into grooves. Striations are best displayed on rock surfaces which face up-ice, mainly because pressure melting in these locations forces the rock tools against the bedrock (Goudie *et al.*, 1985; Press & Siever, 1986; Kearey, 1996; Lewis, 1996a; Clark, 1998).
Synonyms: striae, striations, glacial scratches
Publications: Borchert & Sanger (1981); Sanger (1988); Lewis (1996b)
Synopsis: A relict; AASL 1900-2500m
- Glacier** A mass of ice and superficial snow that persists throughout the year and flows downhill under its own weight. The size range is from 100m to 10 000km (Press & Siever, 1986). Originally the term indicated a river of ice moving down a valley (valley glacier, alpine glacier or mountain glacier; Clark, 1998).
Publications: with specific reference to glacier as a feature, Borchert & Sanger (1981)
Synopsis: A relict; AASL 1900m; SS *in situ* koalinised granit soil; M sand
Corrie sheet (cirque glacier):
Publications: Borchert & Sanger (1981)
Synopsis: A relict; AASL 1900m
Plateau glacier:
Publications: Sanger (1988)
Synopsis: A relict
Valley glacier:
Publications: Sanger (1988)
Synopsis: A relict

- Glaciation** see Glacial
- Grèzes litées** Bedded screes of angular rock fragments or rhythmically stratified slope deposit (Dylik, 1960) associated with cold climates and frost shattering. The inclination of the layers parallels that of the slopes, and, in contrast to ordinary gravitational debris slides, the deposits show a striking predominance of fines in their distal parts. Snow patches may play a role in their formation and down-wash is an important process. The rhythmic nature of the sediments suggests that under cold conditions the following process occurs: first, freezing of rocks on a cliff face causes disintegration, and the coarse debris this released slides downward over frozen subsoil; second, the following phase of thaw causes a mantle of half fluid material rich in fines to spread over the stony layer (Goudie *et al.*, 1985; Kearey, 1996).
- Synonym:* stratified scree
- Publications:* Lewis & Dardis (1985); Lewis & Hanvey (1988)
- Synopsis:* A relict; SN sorted; M mud, sand & silt
- Ground freeze** See Frozen ground and Freezing (of ground)
- Ground ice** A general term referring to all types of ice contained in freezing and frozen ground. Ground ice occurs in pores, cavities, voids or other openings in soil or rock and includes massive ice. It generally excludes buried ice, except in Russian usage. Ground ice may be epigenetic/syngenetic, contempo-raneous/relict, aggrading/degrading, perennial/seasonal. It may occur as lenses, wedges, veins, sheets, seams, irregular masses, or as individual crystals or coatings on mineral or organic particles. Perennial ground ice can only occur within permafrost bodies (Mackay, 1972; Pollard & French, 1980; Clark, 1998).
- Publications:* Hanvey & Marker (1992)
- Synopsis:* A active; AASL 3275m
- Hanging valley** A tributary valley whose floor is discordant with the floor of the main valley high up on the valley wall. Hanging valleys are a hallmark of glacial erosion in mountains (Goudie *et al.*, 1985). The tributary enters a larger glacial valley above its base from which a waterfall may descend, and is commonly found where the main valley has been deepened by a glacier that has since disappeared (Press & Siever, 1986; Kearey, 1996; Lewis, 1996a; Clark, 1998).
- Synonym:* U-shaped valley
- Publications:* Lewis (1996b)
- Synopsis:* A relict; AASL 2000m
- Hogsback** A long ridge of rock, dipping steeply on both sides that is the exposure of hard rock strata

...Hogsback-cont.

which has been tilted until the originally horizontal beds are almost vertical and display two steep, equally inclined slopes (Goudie *et al.*, 1985). The strata are subject to slower erosion (Press & Siever, 1986). A hogsback differs from a cuesta in that both slopes of the ridge are steep and more nearly equal (Kearey, 1996; Clark, 1998).

Synonym: hogback, hog back, hog's back

Publications: Borchert & Sanger (1981)

Synopsis: A relict; AASL 1900m

Ice

Normally the solid form of water formed by (a) the freezing of water, (b) the condensation of atmospheric water vapour directly into ice crystals, (c) the sublimation of solid ice crystals directly from water vapour in the air, or (d) the compaction of snow. Ice derived from the freezing of water involves, amongst others, ground ice that forms a significant component of permafrost landscapes and the freezing of water within a snow packs to form ice lenses, or in the case of a glacier, superimposed ice. Repeated freezing and thawing is also an efficient means of weathering and can cause rapid rock breakdown. The compaction of snow to form glacier ice involves a number of metamorphic processes whose overall effect is to increase the crystal size and eliminate air passages. Snow which survived a summer melt season and begun this process of transformation is known as firn. When consolidation has proceeded sufficiently far to isolate the air into separate bubbles the firn becomes glacier ice (Goudie *et al.*, 1985).

Ice-stripped area:

Publications: Sparrow (1967a)

Synopsis: A relict; AASL 1675-3355m

Ice-shattered ridge:

Publications: Sparrow (1967a)

Synopsis: A relict; AASL 1675-3355m

Ice-stripped area see Ice

Ice-shattered ridge see Ice

Ice-wedge A massive, generally wedge-shaped body with its apex pointing downward, composed of foliated or vertically banded, commonly white, ice. Ice wedge size varies from less than 10cm to more than 3m in width at the top, commonly tapering to a feather edge at a depth of 1m to more than 10m. Some ice wedges may extend downward as much as 25m and may have shapes dissimilar to wedges. Epigenetic ice-wedges are characteristically wedge-shaped, whereas syngenetic ice wedges are generally wedge-shaped but with more

...Ice-wedge-cont.

irregular sides. Ice-wedges are formed in thermal contraction cracks in which hoarfrost forms and into which water from melting snow penetrates in the spring. Repeated annual contraction cracking of the ice in the wedge, followed by freezing of water in the crack, gradually increases the width (and possibly the depth) of the wedge and causes vertical banding of the ice mass. The surface expression of ice wedges is generally a network of polygons. Ice wedges growing as a result of repeated (but not necessarily annual) winter cracking are called active ice wedges, in areas of continuous permafrost when developed in mineral soil. Inactive ice wedges can be stable and remain for many centuries without changing (Dostovalov & Popov, 1966; Lachenbruch, 1966; Mackay & Black, 1973; French, 1976; Washburn, 1979; French *et al.*, 1982; Mackay & Matthews, 1983; Goudie *et al.*, 1985).

Publications: Harper (1969); Lewis (1996a)

Synopsis: **A** active; **AASL** 3050m; **SS** modern soil & subsoil; **W** 5cm-10m; **D** 61cm

Ice-wedge cast

A filling of sediment in the space formerly occupied by an ice wedge. An ice-wedge cast is a wedge of secondary filling. When the permafrost thawed, the ice wedge melted and the enclosing and overlying sediments collapsed into the resulting trough. An ice-wedge cast is one of the few acceptable criteria indicating the earlier presence of permafrost. The term "fossil ice-wedge" is not recommended because ice is no longer present (Washburn, 1979, 1980).

Synonyms: pseudomorph*, fossil ice wedge*

Publications: Lewis & Dardis (1985); Lewis (1996a)

Synopsis: **A** relict; **AASL** 1850m; **SS** fine sediments & a palaeosol; **W** 20-40cm; **D** 1-1,8m

Inversion of the weathering profile

The reversal of the normal or expected order of position (Clark, 1998), in this case of the weathering profile.

Publications: Linton (1969)

Synopsis: **A** relict; **AASL** 1200m; **SS** sand, grits

Kame

An imprecise, unspecific term applied to any ridge or mound of poorly sorted water-laid materials (glacial sands and gravels) associated with former fluvio-glacial activity (Goudie *et al.*, 1985; Clark, 1998).

- Kame moraine** An irregular, undulating mound of bedded sands and gravels deposited unevenly along the front of a stationary or decaying ice sheet (Press & Siever, 1986; Kearey, 1996).
Synonyms: esker, kame
Publications: Lewis (1996b)
Synopsis: A relict; AASL 2km; W 100m
- Kame terrace** A terrace formed between a hillside and a glacier (in a glacial trough) by fluvio-glacial activity. The landform is commonly associated with the former presence of stagnant ice downwasting in valleys (Goudie *et al.*, 1985; Kearey, 1996; Clark, 1998). These terraces consist of sediments deposited by streams that flow beside and parallel to a glacier, or fluvio-glacial sediments. The deposits display characteristics of fluvial deposition in that the constituent sediments tend to be rounded and are water-laid (Lewis, 1996a).
Publications: Lewis (1996b)
Synopsis: A relict; AASL 2000m; SS sand, gravel & a palaeosol; L 3km; H 20m
- Lacustrine deposit** Of or pertaining to a lake, hence applied, e.g. to deposits laid down in a lake; or to terraces on lake margins left when the area of the lake diminishes (Kearey, 1996; Clark, 1998).
Synonym: lacustral deposits
Publications: Hanvey & Lewis (1990)
Synopsis: A relict; AASL 1850m; SN stratified; SS massive, organic & laminated silt, gavel & sandstone; M mud & sand; L 60m; H 16m
- Mass movement (displacement)** Hillslope failure or the downhill movement of soil or fractured rock under the force of gravity (Press & Siever, 1986). Failures may be in circular, plane, wedge, toppling or settling modes (Goudie *et al.*, 1985). Flow processes include solifluction, soil creep, debris avalanches, earth flows and mudflows. Slide processes include rock falls, rockslides, planar slumps and rotational slumps. Additional there are frost heave, freeze-thaw and cambering movements (Kearey, 1996).
Synonyms: mass wasting, and under certain circumstances: downslope sludging of individual stones, mass flow, slow mass movement
Publications: Hastenrath (1972); Boelhouwers (1991b; 1994); Marker (1992); Meiklejohn (1992)
Synopsis: A active; AASL 3200m; SS subsoil; S yes
Slope weathering:
Publications: Hanvey & Marker (1994)
Synopsis: AASL 3000-3250m; SS brown to dark gravel, peat, silt & a palaeosol

Moraine

An accumulation of unstratified debris, especially boulders and coarse material, directly carried down and deposited by a glacier or ice sheet. The term applies both to the material (till) and to the feature produced. One group of moraines exists on the surfaces of glaciers and includes lateral moraines which form through the accumulation of the valley-side material on either side of the glaciers and medial moraines which form from the junction of lateral moraines as two glaciers meet. In the ablation areas of glaciers such moraines can form prominent upstanding ridges where the debris has protected the underlying ice from melting. The material in lateral and medial moraines is characteristically angular rockfall debris and undergoes minimum modification during transport. The second group occurs at the edge of existing glaciers or in areas formerly covered by glaciers. These include uniform till sheets, streamlined and transverse features. Active glaciers, which end on land, build up moraines at the ice margin. The size of the moraine depends on the period that the margin lies in the same location and also on the amount of rock debris transported to the edge of the glacier. The debris may be deposited as ground moraine when the ice melts or as a terminal or end moraine. The term applies both to the material and to the feature produced. Moraines are used to delimit the former extent of glaciers and can be dated. Problems have arisen in recent years however because many moraines are found to have been built up by successive glacier advances over long time spans. (Goudie *et al.*, 1985; Press & Siever, 1986; Kearey, 1996; Clark, 1998).

Publications: Sparrow (1967a); Borchert & Sänger (1981); Sänger (1988); Lewis (1996b)

Synopsis: A relict; AASL 1675-2515m

Moraine sheet:

Publications: Borchert & Sänger (1981)

Synopsis: A relict; AASL 1900m

Moraine sheet

see Moraine

Needle ice

A small-scale heave phenomenon produced by freezing and associated ice segregation at or just beneath the ground surface. Needle ice forms during nights when there is extensive radiative cooling, causing ice segregation in the surface layer of the soil. The needles can form under stones, soil peds, moss or other surface vegetation and are best developed in alpine areas with maritime temperate climates where wet silty or organic soils are present. They can also form on coarse-grained, porous volcanic ejectamenta (Krumme, 1935; Mackay & Matthews, 1974; Washburn, 1979). The needles, which can range in length from a few millimetres to several centimetres, may lift small pebbles or soil particles. The growth of needle ice is usually associated with diurnal freezing and thawing. It is widespread and particularly common in locations in mid-latitudes where the frequency of

...Needle ice-cont.

freeze-thaw is greatest. Needle ice frequently occurs in oriented stripes, and both wind direction and sun have been suggested as explanations for the pattern; it is not clear whether orientated needle ice patterns are primarily a shadow effect developed by thawing or a freezing effect. Thawing and collapse of needle ice is thought significant for frost sorting, frost creep, the differential downslope movement of fine and coarse material, and the origin of certain micro-patterned ground forms. The importance of needle ice as a disruptive agent has probably been underestimated, especially in exposing soil to wind and water in periglacial regions. In other areas it may be responsible for damage to plant materials when freezing causes vertical mechanical stress within the root zone (Goudie *et al.*, 1985).

Synonym: pipkrake

Publications: Hastenrath (1972); Hastenrath & Wilkinson (1973); Lewis (1987); Sanger (1988); Verster & Van Rooyen (1988); Marker (1989); Boelhouwers (1991a); Hanvey & Marker (1992); Grab (1996b)

Synopsis: A active; AASL 1800-3410m; H 5cm

Needle ice activity Patterns formed in the ground by the growth and decline of needle ice.

Synonyms: raked patterns*, raked ground*, striated soil*, needle ice stripes

Publications: Hastenrath & Wilkinson (1973); Lewis (1987); Sanger (1988); Marker (1989); Boelhouwers (1991a); Hanvey & Marker (1992); Grab (1996b)

Synopsis: A active; AASL 1800-3410m; H 5cm

Surface creep

Publications: Sanger (1988)

Synopsis: A active

Net A form of patterned ground (see Patterned ground)

Publications: Hastenrath & Wilkinson (1973); Boelhouwers (1991a)

Synopsis: A active; AASL 1181-3200m; SN sorted (see Sorted net); W 5-20cm

Niche (hollow) A small recess or shelf in a rock face (Clark, 1998; also refer to Grab, 1996b).

Publications: Marker (1991b); Grab (1996a)

Synopsis: A relict; AASL 3295-3377m

- Niche glacier** A small cirque glacier, lying in a funnel-shaped hollow high in a steep mountain slope (Clark, 1998).
Publications: Hall (1994)
Synopsis: A relict
- Nivation** A general term for the localised erosion of a hillside by frost action, mass wasting and the sheet flow or rill work of meltwater at the edges of, and beneath, lingering snow patches (however, in contrast to those produced by glacier ice). The theory is that nivation produce nivation hollows and niches, which, as they grow in depth, trap more snow and thereby enhance the process of deepening. The disintegration of the rock brought about by freeze-thaw and chemical weathering (sometimes termed snow patch erosion), may eventually lead to the formation of a nivation cirque. Topographic and climatic controls strongly influence the distribution and orientation of nivation hollows. The most favoured locations are on hillsides protected from the sun and with an ample supply of drifted snow. In mid-latitudes these factors favour a north-eastern orientation in the Northern Hemisphere and south-eastern orientation in the Southern Hemisphere (Goudie *et al.*, 1985; Kearey, 1996; Clark, 1998).
Publications: Sparrow (1967a); Harper (1969); Nicol (1973); Dyer & Marker (1979); Borchert & Sanger (1981); Lewis & Hanvey (1988); Marker (1986, 1989, 1990b); Hanvey & Lewis (1991); Hall (1994); Lewis (1994, 1996b)
Synopsis: A relict; AASL 1675-3355m; SS sand & modern soil; M silt, clay
- Nivation niche** A semi-circular steep-sided depression formed by nivation (Harper, 1969).
Publications: Harper (1969); Marker (1989)
Synopsis: A relict; AASL 1800-2837m; V yes
- Nonsorted circle** A patterned ground form that is equidimensional in several directions, with a dominantly circular outline that lacks a border of stones. Nonsorted circles characteristically have margins of vegetation; they occur singly or in groups; their diameter is commonly between 0.5 and 3.0m. Their central areas tend to be slightly dome-shaped and may be cracked into small, nonsorted polygons. In places, the long axes of stones and sand particles tend toward vertical. The term covers both mud circles, developed in fine-grained materials, and stony earth circles, developed in gravelly materials (Washburn, 1979).
Synonym: tundra hummock*
Publications: Harper (1969); Hastenrath & Wilkinson (1973); Borchert & Sanger (1981); Boelhouwers (1991a)
Synopsis: A active; AASL 1181-3354m; SN nonsorted; V mostly; SS gritty modern soils & subsoils; W 40cm; Di 20-60cm

- Nonsorted net** A type of patterned ground with cells that are equidimensional in several directions, neither dominantly circular nor polygonal, and lacking borders of stones. Nonsorted nets occur on nearly horizontal surfaces. Diameters of individual cells range from 0.5m to 10m. Where vegetation is sparse, it is generally concentrated in furrows bordering the individual cells of the net, emphasising the pattern (Washburn, 1979).
- Nonsorted polygon** A nonsorted polygon is a patterned ground form that is equidimensional in several directions, with a dominantly polygonal outline that lacks a border of stones. Nonsorted polygons commonly occur in extensive patterns, most frequently on nearly horizontal surfaces (although small forms have been found on slopes up to 27°; large ones have been found on slopes as steep as 31° in polar regions). Micro-scale polygons range in size from 5cm to 1m; macro-scale polygons may be more than 100m in diameter. Where vegetation is sparse, it is generally concentrated in furrows along the borders between the polygons, emphasising the pattern. The mineral soil can be well-sorted fines, sand, gravel, or a mixture (Washburn, 1979).
- Publications:* Harper (1969); Hastenrath (1972); Lewis (1987, 1996b); Hanvey & Marker (1992)
- Synopsis:* A active; AASL 2900-3354m; SN nonsorted; SS gritty modern soil; W 6-20cm
- Nonsorted step** A patterned ground feature with a step-like form and a downslope border of vegetation embanking an area of relatively bare ground upslope. Nonsorted steps are only found on slopes commonly ranging from 5° to 15°; their downslope border forms a low riser fronting a tread whose slope is less than the general slope. Nonsorted steps are assumed to be derived from nonsorted nets or hummocks or nonsorted polygons, rather than to develop independently (Washburn, 1979).
- Nonsorted stripe** A form of patterned ground with a striped and nonsorted appearance, due to parallel strips of vegetation-covered ground and intervening strips of relatively bare ground, oriented down the steepest available slope. Nonsorted stripes, both large and small, occur on slopes of 5° to 6°, downslope from nonsorted polygons or nonsorted nets. In some places the vegetated and non-vegetated strips are equally wide; in other places vegetated strips of 0.3 to 0.6m are spaced from 3 to 4.5m apart. They can be several hundred metres long (Washburn, 1956).
- Palaeosol** An ancient, fossil or relict soil or soil horizon in the sedimentary rock record, formed on a past landscape, documented for both the Precambrian and Phanerozoic (Goudie *et al.*, 1985; Press & Siever, 1986; Kearey, 1996).
- Synonyms:* ancient soil, fossil soil, relict soil
- Publications:* Harper (1969); Lewis & Hanvey (1991, 1993); Hanvey & Marker (1994); Marker (1995b); Lewis (1996a)
- Synopsis:* A relict; AASL 1407-3175m; V yes; SS brown soils; D 40cm-2.5m

...Patterned ground-cont.

Patterned ground A general term for any ground surface exhibiting a discernibly ordered, more or less symmetrical, morphological pattern of ground and, where present, vegetation. Some patterned ground features are not confined to permafrost regions but they are best developed in regions of present or past intensive frost action. A descriptive classification of patterned ground includes such features as nonsorted and sorted circles, nets, polygons, steps and stripes, and solifluction features. In permafrost regions, the most ubiquitous macro-form is the ice-wedge polygon, and a common microform is the nonsorted circle. The latter includes mud boils, mud hummocks, frost boils, stony earth circles, earth hummocks, turf hummocks, thufa and tundra hummocks. Nonsorted circles are not all of the same origin. Mud and earth hummocks and frost boils, involve cryoturbation activity and differential heave of frost-susceptible materials. Mud boils involve hydraulic pressures and diapiric displacements of water-saturated sediments. The genesis of many types of patterned ground phenomena is not clearly understood. Patterned ground also occurs in peatland in the form of string fens and other peatland features (Washburn, 1956, 1979; Mackay & MacKay, 1976; Stanek, 1977; Tarnocai & Zoltai, 1978; Shilts, 1978; Mackay, 1980; Stanek & Worley, 1983; Goudie *et al.*, 1985; Kearey, 1996).

Publications: Harper (1969); Hastenrath (1972); Hastenrath & Wilkinson (1973); Borchert & Sanger (1981); Dardis & Granger (1986); Lewis (1987, 1996b); Boelhouwers (1991a, 1994, 1995a); Hanvey & Marker (1992); Grab (1996b)

Synopsis: A active & relict; AASL 1181-3210m; SN sorted & nonsorted; SS chemically weathered & gritty modern soils, subsoils, clays, silts, sands & gravels; W 6cm-2m; L 1cm-10m; Di 15cm-6m

Pebble A small stone, naturally rounded by the action of water or wind, diameter between that of gravel and cobble. There is some confusion over precise size, but a pebble is commonly defined as having a diameter between 10 and 50mm (Clark, 1998).

Publications: concerning pebbles modified by glacial action: Sanger (1988)

Synopsis: A relict

Periglacial process A process commonly associated with a periglacial environment, e.g. freeze-thaw, solifluction, gelifluction, cryoturbation etc.

Publications: Sparrow (1964); Hastenrath (1972); Borchert & Sanger (1981); Hagedorn (1984), Lewis & Hanvey (1988); Marker (1989); Hanvey & Marker (1992); Lewis (1996a)

Synopsis: A active & relict; AASL 1700-3200m; SS subsoils

Periglacial slope-wash:

Publications: Lewis & Hanvey (1988)

Synopsis: A relict; M sand & silt

Periglacial slope-wash

see Periglacial process

Permafrost

Ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years. Permafrost is synonymous with perennially cryotic ground: it is defined on the basis of temperature. It is not necessarily frozen, because the freezing point of the included water may be depressed several degrees below 0°C; moisture in the form of water or ice may or may not be present. Whereas all perennially frozen ground is permafrost, not all permafrost is perennially frozen. Permafrost should not be regarded as permanent, because natural or man-made changes in the climate or terrain may cause the temperature of the ground to rise above 0°C. Permafrost includes perennial ground ice, but not glacier ice or icings, or bodies of surface water with temperatures perennially below 0°C; it does include man-made perennially frozen ground around or below chilled pipelines, hockey arenas, etc. Russian usage requires the continuous existence of temperatures below 0°C for at least three years, and also the presence of at least some ice (Muller, 1943; Van Everdingen, 1976; Kudryavtsev, 1978). A differentiation is made between cryotic (below 0°C) and non-cryotic (above 0°C) ground. The former is subdivided into unfrozen, partially frozen, and frozen, depending upon the amount of unfrozen water present. The upper boundary of permafrost is known as the permafrost table, and the near-surface layer which is subject to seasonal thaw is called the active layer. The depth at which annual temperature fluctuations are minimised is termed the depth of the zero annual amplitude; this usually varies between 10 to 20m depending on climate and terrain factors such as amplitude of annual surface temperature variation snow cover, and effective thermal diffusivity of the soil and rock (Goudie *et al.*, 1985).

Synonyms: perennially frozen ground, perennially cryotic ground, biennially frozen ground*, climafrost*, cryic layer*, permanently frozen ground*

Publications: as causative, Boelhouwers (1994)

Permafrost process:

Publications: Lewis (1996a)

Synopsis: A relict; AASL 1930m

Permafrost layer:

Publications: Fitzpatrick (1978); Lewis (1996a)

Synopsis: A relict; AASL 2500m; SN stratified; SS humic & orthic yellow, black & brown magwa, clovelly & silt

Permafrost layer

see Permafrost

- Permafrost process** see Permafrost
- Pinnacle** A rock wall weathered into tower-like features thought to be indicative of strong frost action (see Borchert & Sänger, 1981; Goudie *et al.*, 1985).
Synonym: gendarme
Publications: Borchert & Sänger (1981)
Synopsis: A relict; AASL 1900m
- Plateau glacier** see Glacier
- Polygon** Closed, multi-sided, roughly equidimensional patterned-ground features, bounded by more or less straight sides; some of the sides may be irregular. Macro-scale polygons, typically 15m to 30m across, result from thermal contraction cracking of the ground and form random or oriented polygonal patterns. They occur in both mineral terrain and peatland. Ice-wedge polygons are common in poorly drained areas and may be either high-centred or low-centred. Sand-wedge polygons occur where wedges of primary mineral infill underlie the polygon boundaries. Some polygons may be formed by seasonal frost cracking in areas of deep seasonal frost. Micro-scale polygonal patterns, usually less than 2m in diameter, are normally caused by desiccation cracking (Rapp & Clark, 1971; Washburn, 1979; Clark, 1998).
Synonyms: frost polygon, frost-crack polygon, depressed-centre polygon*, fissure polygon*, raised-centre polygon*, Taimyr polygon*, tundra polygon*
Publications: Harper (1969); Hastenrath (1972); Hastenrath & Wilkinson (1973); Lewis (1987; 1996b); Hanvey & Marker (1992); Boelhouwers (1991a; 1995a)
Synopsis: A active & relict; AASL 2550-3355m; SN sorted & nonsorted; SS chemically weathered, gritty modern soils & subsoils; W 4-20cm; Di 15-60cm
- Pothole** Applied loosely to any deep hole, vertical cave system or underground cave, in limestone country, hence the term potholing for carving or exploring underground caverns etc. In studies of erosion, a more or less circular hole worn in rocks by whirling stones, as in the bedrock of the channel of an eddying swift stream (Press & Siever, 1986; Clark, 1998).
Publications: Sänger (1988)
Synopsis: A relict
- Protalus rampart** A ridge or ramp of accumulated coarse angular rock debris, resembling a moraine, consisting of material that has slipped down from perennial banks of snow, and lying parallel to the slope that produced it (Shakesby, 1997; Clark, 1998).
Synonym: pronival rampart, snow slope detritus*, snowbank accumulation*, snowbank

...Protalus rampart-cont.

deposit*, winter-talus ridge*, nival moraine*, nivation moraine*, and under certain circumstances, debris lobe

Publications: Nicol (1973); Marker (1989, 1990b); Lewis (1994, 1996b)

Synopsis: A relict; AASL 1800-2837m; V yes; W 52-83m; L 217m-1.5km; H 8.5-104m; D 8-16m; Di 27-69m

River terrace

A part of former floodplain of a river, left on the side of a river valley as the stream cut down its bed and now appearing as a generally flat, step-like strip on the side of the valley, at a level higher than that of the present channel. Such a terrace is usually built up of gravel, coarse sand and alluvium deposited by the river when it was flowing at the level of the terrace. Thus the terrace represents a part of the valley floor at that time, and may not be perfectly flat. The term is applied to a rock bench as well as to a gravel-covered terrace (Clark, 1998).

Publications: Marker (1989); Lewis & Hanvey (1991)

Synopsis: A relict; AASL 1407-2837m; SN nonsorted; SS sand, gravel; D 15-35m

Rochés moutonnées

Glacially moulded outcrops of rock that are asymmetric in cross-section, with a gently ascending striated and polished up-flow side and a steep and ice-plucked down-flow side (Lewis, 1996a).

Publications: in describing tors in the High Drakensberg and Lesotho Mountains: Grab (1996a)

Synopsis: A relict; AASL 2968-3377m

Rockglacier

A mass of rock fragments and finer material, on a slope, that contains either interstitial ice or an ice core and shows evidence of past or present movement. Rockglaciers do not form where there is insufficient moisture to form the interstitial ice that permits movement of the mass. There are two main theories of origin: that the rock debris has ice mixed in the spaces between the rock (the interstitial ice model), or that the debris is a thick covering in a thin, probably decaying true glacier (the glacier ice model). One major feature is that rockglaciers usually exhibit slow movement, often less than a metre per year, but it has also been noted that active rockglaciers may move at speeds up to 50m per year and possess steep fronts with slope angles greater than the angle of repose. Rockglaciers are said to be inactive when the main body ceases to move and most rock glaciers have transverse ridges and furrows on their surface (Capps, 1910; White, 1976; Washburn, 1979; Goudie *et al.*, 1985; Press & Siever, 1986).

Publications: Lewis & Hanvey (1993); Lewis (1996a)

Synopsis: A relict; SN sorted; SS organic, containing palaeosols; M sand, silts, clays; W 30-250m; L 200-550m; H 4-30m

- Scree** First meaning: A slope consisting of an accumulation of loose angular rock debris of any size and commonly formed by frost action from the parent rock, lying at a uniform angle (commonly of 35°) at or near the foot of a steep cliff, rock-buttress, mountain etc. Second meaning: The angular rock debris itself. Third meaning: A synonym for talus, angler of repose, mass movement. repose slope (Clark, 1998). The scree may be metres to hundreds of metres in height (Goudie *et al.*, 1985; Press & Siever, 1986; Kearey, 1996).
- Synonym*: talus
- Publications*: Sparrow (1967a); Marker (1986, 1992); Lewis (1994); Sumner & De Villiers (*in prep.*)
- Synopsis*: A relict; AASL 1582-3355m; V yes; W 37-75m; L 100-235m; H 1-3m
- Segregation ice** Ice in discrete layers or ice lenses, formed by ice segregation. Segregated ice can range in thickness from hairline to more than 10m. It commonly occurs in alternating layers of ice and soil (Taber, 1929; Mackay, 1966; Penner, 1972).
- Synonyms*: segregated ice, ice gneiss*, sirloin ice*, Taber ice*
- Publications*: Boelhouwers (1994); Grab (1996b)
- Synopsis*: A active; AASL 3140-3410m
- Sheet-wash** A flow of rainwater that covers the entire ground surface with a thin film and is not concentrated into streams (Press & Siever, 1986). Overland flow on all but the smoothest surfaces and on all natural hillsides, breaks into threads of high velocity separated by areas of slower and shallower flow. Sediment entrainment by the flow occurs only within the more rapid threads. In the sheet-wash areas between, sediment detached or dislodged by rain-splash will be transported farther than in the absence of flow, so that sheet-wash has a small influence on sediment transport even though it cannot initiate erosion (Goudie *et al.*, 1985; Press & Siever, 1986; Kearey, 1996).
- Synonym*: sheet-flow
- Publications*: Lewis & Dardis (1985); Watson (1988)
- Synopsis*: A active & relict; V yes; SN sorting; SS acid leached & weathered hutton, griffen & mispah-glenrosa; M mud & sand
- Slope weathering** see Mass movement (displacement)

- Snow patch** A relatively small area of snow cover remaining after the main snowmelt period. Such areas commonly represent remnants of snowdrifts (Van Everdingen, 1998) and initiate processes associated with nivation (Goudie *et al.*, 1985).
- Snow patch conditions:*
- Publications:* Sparrow (1967, 1973); Nicol (1973); Dyer & Marker (1979); Marker (1990); Lewis (1994)
- Synopsis:* A relict; AASL 1675-3355m; SS peat
- Snow patch meltwater*
- Publications:* Marker (1989)
- Synopsis:* A relict AASL 1800-2837m
- Snow patch conditions** see Snow patch
- Snow patch meltwater** see Snow patch
- Soil creep** The imperceptible downhill flow of soil under the force of gravity. It is a shear flow with velocity decreasing downward and occurs even on gentle slopes (Press & Siever, 1986).
- Synonym:* soil flow
- Publications:* Borchert & Sanger (1981); Verster & Van Rooyen (1988); Boelhouwers (1991a, 1991b); Lewis & Hanvey (1991)
- Synopsis:* A active & relict; AASL 1407-2249m; SS clovelly, silt, griffen, hutton, sand, clay & palaeosol; M sand
- Solifluction** Solifluction is defined as the slow downslope flow of saturated unfrozen earth materials. The presence of a frozen substrate, or even freezing and thawing, is not implied in the original definition (slow flowing from higher to lower ground of waste saturated with water). However, one component of solifluction can be the creep of frozen ground. Rates of flow vary widely. The term is commonly applied to processes operating in both seasonal frost and permafrost areas (Andersson, 1906; Washburn, 1979). In contrast to gelifluction, solifluction does not require permafrost for its occurrence, but modern use of the term does imply the existence of cold climate conditions. It is a form of mass wasting faster than soil creep (0.5 to 5.0cm year⁻¹). Features produced by solifluction include uniform sheets of locally derived materials, tongue-shaped lobes, and alternating stripes of coarse and fine sediment. When associated with the active layer the term gelifluction should be used (Goudie *et al.*, 1985). Formerly solifluction was considered to be synonymous with soil creep (Clark, 1998).

...Solifluction-cont.

Synonym: solifluxion*

Publications: Sparrow (1967, 1971); Harper (1969); Hastenrath (1972); Hastenrath & Wilkinson (1973); Nicol (1973); Borchert & Sanger (1981); Sanger (1988); Marker (1989, 1992); Lewis & Hanvey (1991); Boelhouwers (1991a, 1991b, 1995a)

Synopsis: A active & relict; AASL 1181-3240m; V yes; SN sorted, nonsorted & stratified; SS chemically weathered, organic & unconsolidated dark, orange-brown & grey modern soil, gravel, grits, peat, silt, clay & a palaeosol; M sand & fines

Solifluctional phenomena characteristics: W <50; L 90cm-2,25km; H 17-93cm; D 6,1-35m

Solifluction apron A fan-like deposit at the base of a slope, produced by solifluction (Brown, 1969; Benedict, 1970; Washburn, 1979).

Solifluction deposit Geomorphological features of varying scale produced by the process of solifluction. Typical solifluction features include solifluction aprons, solifluction lobes (turf-banked lobes and stone-banked lobes), solifluction sheets and solifluction terraces (turf-banked terraces and stone-banked terraces) (Brown, 1969; Benedict, 1970; Washburn, 1979).

Publications: with non-specific reference, Sparrow (1971); Nicol (1973); Lewis & Hanvey (1991)

Synopsis: A relict; AASL 1412-1998m; V yes; SN stratified; SS grits & gravel; M sand; W <50m; D 45m

Solifluction slump:

Publications: Sparrow (1967, 1971)

Synopsis: A relict; AASL 1675-3355m

Solifluction lobe An isolated, tongue-shaped solifluction feature, up to 25m wide and 150m or more long, formed by more rapid solifluction on certain sections of a slope showing variations in gradient. Commonly has a steep (15° to 60°) front and a relatively smooth upper surface. Solifluction lobes consist of *turf-banked lobes* and *stone-banked lobes* (Brown, 1969; Benedict, 1970; Washburn, 1979).

Synonym: mud-debris tongue*

Publications: Marker (1989, 1992)

Synopsis: A relict; AASL 1800-3200m; L 400m

- Solifluction sheet** A broad deposit of nonsorted, water-saturated, locally derived materials that is moving or has moved downslope. Sorted and/or nonsorted stripes are commonly associated with solifluction sheets (Brown, 1969; Benedict, 1970; Washburn, 1979).
- Synonym:* solifluction mantle
- Publications:* Hastenrath (1972)
- Synopsis:* A relict; AASL 2700m
- Solifluction slump** see Solifluction deposit
- Solifluction terrace** A low step, or bench, with a straight or lobate front, the latter reflecting local differences in the rate of solifluction movement. A solifluction terrace may have bare mineral soil on the upslope part and 'folded-under' organic matter in both the seasonally thawed ground and the frozen ground. Those covered with a vegetation mat are called *turf-banked (solifluction) terraces*; those that are stony are called *stone-banked (solifluction) terraces*.
- Synonyms:* solifluction bench, solifluction step, garland terrace*
- Publications:* Harper (1969); Marker (1989); Lewis (1996a)
- Synopsis:* A active & relict; AASL 2600-2744m; V yes; SS unconsolidated grey, orange & red sediments, modern soils & a palaeosol; W 50cm-10m; L 1m; H 1-20cm; D 6,1-12,2m
- Solifluctional smoothing[#]** The smoothing of a surface by solifluction processes.
- Synonyms:* solifluctional forming, solifluctional over-forming, slope smoothing, slope camouflaging:
- Publications:* Hastenrath (1972); Hastenrath & Wilkinson (1973); Marker (1989)
- Synopsis:* A relict; AASL 1181-3240m; SS subsoils
- Sorted circle** A patterned ground form that is equidimensional in several directions, with a dominantly circular outline, and a sorted appearance commonly due to a border of stones surrounding a central area of finer material. Sorted circles occur singly or in groups; their diameter is commonly between 0.5 and 3.0 m. Their central areas have a concentration of fines, with or without stones. The stones of the borders surrounding the central areas tend to increase in size with the size of the circles. Tabular stones tend to stand on edge, with their long axes in the vertical plane parallel to the border (Washburn, 1956).
- Publications:* Dardis & Granger (1986); Boelhouwers (1991a, 1994, 1995a)
- Synopsis:* A active; AASL 3140-3200m; SN sorted; SS modern soils; W 5cm-1.3m

- Sorted net** A type of patterned ground with cells that are equidimensional in several directions, neither dominantly circular nor polygonal, with a sorted appearance commonly due to borders of stones surrounding central areas of finer material. Sorted nets occur most frequently on nearly horizontal surfaces. Diameters of individual cells range from 0.5m to 10m. Central areas have a concentration of fines, with or without stones. The bordering stones tend to increase in size with the size of the net (Washburn, 1979).
- Publications:* Hastenrath & Wilkinson (1973); Boelhouwers (1991a)
- Synopsis:* A active; AASL 1181-3200m; SN sorted; W 5-20cm
- Sorted polygon** A patterned ground form that is equidimensional in several directions, with a dominantly polygonal outline, and a sorted appearance commonly due to a border of stones surrounding a central area of finer material. Sorted polygons commonly occur in extensive patterns, most frequently on nearly horizontal surfaces, and on slopes of less than 20°. They range in size from 10 cm to about 10 m. In places, small sorted polygons occur in the central areas of larger polygons. Central areas have a concentration of fines, with or without stones. The bordering stones tend to increase in size with the size of the polygons, but to decrease with depth, regardless of the size of the polygons (Washburn, 1956).
- Publications:* Harper (1969); Hastenrath & Wilkinson (1973); Lewis (1987); Hanvey & Marker, (1992); Boelhouwers (1991a, 1995a)
- Synopsis:* A active; AASL 2550-3300m; SN sorted; SS gritty modern soils & subsoils; W 5-20cm
- Sorted step** A patterned ground feature with a step-like form and a downslope border of stones embanking an area of relatively fine-grained bare ground upslope. Sorted steps are only found on slopes ranging from 5° to 15°; their downslope border forms a low riser fronting a tread whose slope is less than the general slope. Sorted steps are presumed to be derived either from sorted circles or from sorted polygons, rather than to develop independently. Some sorted steps clearly form an intermediate stage between sorted polygons and sorted stripes (Washburn, 1979).
- Synonym:* stone garland
- Sorted stripe** Sorted stripes form patterned ground with a striped and sorted appearance, due to parallel strips of stones and intervening strips of finer material, oriented down the steepest available slope. Sorted stripes, both large and small, occur on slopes of more than 3°, downslope from sorted polygons or sorted nets; they are derived by downslope extension of sorted polygons or sorted nets and can be several hundred metres long. The stones of the coarse stripes can range from pebbles to boulders, depending on the size of the stripes. The intervening finer material can be stone free or contain stones and be a diamicton (Washburn, 1956).
- Publications:* Lewis (1987); Boelhouwers (1991a, 1994, 1995a); Grab (1996b)
- Synopsis:* A active & relict; AASL 2800-3410m; SN sorted; SS clay, silt, gravels & a modern soil; W 5-20cm; L 1-3m

- Stone-banked terrace** A solifluction terrace with a stony front (Brown, 1969; Benedict, 1970; Washburn, 1979).
Synonyms: stone-banked lobe, garland, stone-banked sheet
Publications: Dardis & Granger (1986); Boelhouwers (1991b, 1994, 1995a)
Synopsis: A active & relict; AASL 1600-3260m; V yes; SN sorted & nonsorted; SS modern soil; W 1cm-15m; L 90cm-60m; H 20cm-3m
- Stripe** A form of patterned ground (see Patterned ground)
Publications: Lewis (1987); Hanvey & Marker (1992); Boelhouwers (1991a, 1994, 1995a); Grab (1996b)
Synopsis: A relict & active; AASL 2800-3410m; V yes; SN sorted & nonsorted; SS modern soil, clay, gravel, sand & silt; W 5cm-2m; L 1cm-10m
- Surface creep** see Needle ice activity
- Surface runoff** The flow of water on hillslopes. Sometimes referred to as storm runoff, direct runoff, or quickflow, it occurs when the infiltration capacity of the soil surface is exceeded, and the subsurface can no longer absorb moisture at the rate at which it is being supplied. Baseflow is the subsurface runoff made up of throughflow and/or groundwater whereas quickflow is a mixture of overland flow and subsurface stormflow. The precipitation collects in surface depressions and is briefly stored but when these depressions are filled, the water begins to flow downslope. As runoff proceeds down a slope, its overall form and process may change. As it begins its journey to the channel, it may move in a wide shallow sheet as sheet flow. When depths increase the water may begin to coalesce into small ephemeral channels called rills. As the water proceeds downslope, the channel flow in rills may coalesce into gullies. The amount of runoff is affected by land use, vegetation, and the porosity of the surface (Goudie *et al.*, 1985; Press & Siever, 1986; Kearey, 1996).
Synonym: runoff
Publications: Backéus (1989); Boelhouwers (1991a)
Synopsis: A active & relict; AASL 3200-3300m; SS humified, amorphous & chemically weathered peat, modern soils & subsoils
- Terminal moraine** A sinuous ridge of unsorted glacial till deposited by a glacier at the terminus of a glacier (Press & Siever, 1986). Terminal moraines form at the toe of a small glacier (Goudie *et al.*, 1985; Lewis, 1996a).
Publications: Lewis (1996b)
Synopsis: A relict; AASL 1900-2000m

Terracette One of a series of narrow horizontal steps from a few centimetres to 60cm in height, making a ribbed pattern on a steep, usually grassland, slope in areas accessible to animals. Their origin is disputed. They may owe their existence to soil creep and, once formed, be used by sheep and other animals; or they may have been formed initially by animals treading the easiest route up the hill (Clark, 1998; Kearey, 1996).

Synonym: cattle step²

Publications: Harper (1969); Hastenrath (1972); Hastenrath & Wilkinson (1973); Dardis & Granger (1986); Verster & Van Rooyen (1988); Watson (1988); Marker (1989); Boelhouwers (1991a); Hanvey & Marker (1992)

Synopsis: A active & relict; AASL all altitudes; SN nonsorted; V yes; SS silt, clay & modern soils, chemically weathered with high acidity; W 10cm-3.38m; L 10cm-34m; H 5cm-1.45m; D 15-35m

Turf-banked terracette

Publications: Boelhouwers (1991a)

Synopsis: A active AASL 3000-3120m; V yes; W 10-30cm; L 5-15m

Thawing (of frozen ground) Melting of the ice in frozen ground, usually as a result of a rise in temperature (Van Everdingen, 1998).

Publications: Sparrow (1971)

Synopsis: A relict; AASL 1600m

Thufur Perennial hummocks formed in either the active layer in permafrost areas, or in the seasonally frozen ground in non-permafrost areas, during freezing of the ground. Thufur (plural *thufa*) can be formed in the warmer part of the zone of discontinuous permafrost and also under conditions of maritime seasonal frost. The hummocks may be as much as 50cm in height and 160cm in diameter and can reform within 20 years following destruction. Growth is favoured by silty sediments, a maritime climate, and reasonably good drainage (Thorarinsson, 1951; Schunke, 1975; Scotter & Zoltai, 1982).

Synonyms: frost mound, hummock

Publications: Harper (1969); Marker & Whittington (1971); Hastenrath (1972); Hastenrath & Wilkinson (1973); Lewis (1987, 1996b); Boelhouwers (1991a); Hanvey & Marker

² Since the inception of the term, terracettes have been described in a number of different ways by various authors. Terminology used includes, amongst others, sheep roads (Warming, 1906, cited in Vincent & Clarke, 1980), cat steps (Bennet, 1938), sheep tracks (Dury, 1959) and cattle steps (Boelhouwers, 1991a). Terms such as these directly imply genesis and are thus far from satisfactory since various modes of formation and sustaining mechanisms have been proposed, most suggesting a geomorphic origin rather than origins related to animal disturbance (Sinclair, 1998). Also see Boelhouwers (1988).

(1992, 1994); Grab (1994)

Synopsis: A active; AASL 2550-3270m; V yes; SS chemically weathered, gritty, organic & homogeneous dark modern soil, subsoil, clay, peat & silt; W 7-50cm; Di 20-98cm

Tor An exposure of prominent, isolated mass of jointed, weathered rock, usually granite *in situ*, upstanding on all sides from the surrounding slopes formed by the differential weathering of a rock bed and the removal of the debris by mass movement (Pullan, 1959:54, as cited by Goudie *et al.*, 1985).

Publications: Sparrow (1964, 1967); Dardis & Granger (1986); Grab (1996a)

Synopsis: A active, relict; AASL 1675-3355m

Trough-like valley see Trough valley

Trough valley A valley with steep sides and truncated spurs and sometimes with steep upvalley termination (or trough's end) that grade into a flat floor usually eroded by a glacier (Press & Siever, 1986; Lewis, 1996a).

Synonym: U-shaped valley, trough

Trough-like valley:

Publications: Lewis (1996b)

Synopsis: A relict; AASL 2000m

Truncated spur A spur which projected into the side of a pre-glacial valley until the valley became glaciated, when it was sharply cut and shortened by the glacier as it moved down the valley (Clark, 1998). Truncated spurs are caused by glacial erosion (Lewis, 1996a).

Publications: Lewis (1996b)

Synopsis: A relict; AASL 2000m

Turf-banked terracette see Terracette

Turf exfoliation Turf exfoliation, the weathering of turf by peeling off of the surface layers, occurs when eolian processes and cold temperatures in periglacial climates preclude vegetation cover or destroy it, and strong winds deflate bare bedrock and debris surfaces. Depending upon the particle sizes transported, the depositional phase of these periglacial eolian processes may range from cover sands to loess (Goudie *et al.*, 1985; Thorn, 1991; Kearey, 1996).

Publications: Hastenrath (1972); Boelhouwers (1991a); exfoliation: Hagedorn (1984)

Synopsis: A active; AASL 3000m

- Turf-banked terrace** A solifluction lobe with its front covered by a vegetation mat (Brown, 1969; Benedict, 1970; Washburn, 1979).
Synonyms: turf-banked lobe, turf-banked step
Publications: Borchert & Sanger (1981); Dardis & Granger (1986); Boelhouwers (1991a, 1995a)
Synopsis: A active; AASL 1800-3120m; V yes; SS dark, heavy modern soil & clay; W 40cm-3m; L 1,82-6m; H 15-35cm
- Valley asymmetry** A river valley or glacial valley of which one side is inclined at a different angle to the other (unequal slopes). Such a valley is a feature of periglacial areas where differences in aspect cause considerable differences in the strength of frost weathering and solifluction, but they can also be caused by structural circumstances (Goudie *et al.*, 1985; Press & Siever, 1986; Kearey, 1996).
Synonym: asymmetric valleys
Publications: Sparrow (1964, 1967); Harper (1969); Marker (1989); Meiklejohn (1992)
Synopsis: A relict; AASL 1675-3355m; SS chemically weathered & gritty modern soil & subsoil
- Valley glacier** see Glacier
- Vertical stacking** The slanting of a plate from the horizontal to the vertical (Clark, 1998).
Synonym: tilting and dislocation of plates
Publications: Hastenrath (1972); Hastenrath & Wilkinson (1973); Borchert & Sanger (1981)
Synopsis: A active; AASL 3073-3100m; SS fine sediments; L 50cm-1m

Not added to the glossary:

- Dislocation (of stones)** *Publications:* Borchert & Sanger (1981)
Synopsis: A active; AASL 1900m
- Gravel sorting** *Publications:* Hastenrath (1972)
Synopsis: A active; AASL 3100m; SN sorted

Planation surface

Paper: Sänger (1988)

Synopsis: A relict

Solution

Publications: Verster & Van Rooyen (1988)

Synopsis: A active; SS clovelly, griffen, hutton, clay & silt

Surface creep

Publications: Sänger (1988)

Synopsis: A active

APPENDIX D
Features and Processes Table

Features and Processes Table

A

FEATURES						
SECTION 1			SECTION 2			
Column 1 Category	Column 2 Terminology used in database	Column 3 Sub-categories	Column 4 Terminology recognised by the IPA	Column 5 Synonyms		Column 6 Other
				Column 5.1 Synonyms recognised by the IPA	Column 5.2 Synonyms not recommended by the IPA	
A. Accumulations of coarse debris	Blockfield	-	Blockfield	Stone field	Blockmeer Felsenmeer	Boulder field Rock-block field Rock river Rockstream
	<i>Blockstream</i>	-	-	-	-	-
	<i>Boulder bed</i>	-	-	-	-	-
	<i>Debris</i>	<i>Debris fan</i> <i>Debris mantle</i> <i>Debris ridge</i> <i>Scattered boulders</i>	-	-	-	-
	Rockglacier	Rockglacier	-	-	-	-
	<i>Scree</i>	<i>Grèzes litées</i> <i>Scree</i>	-	-	-	Stratified scree Openwork block deposit Openwork debris deposit Talus
B. Periglacial ground features	Frozen ground	-	Frozen ground	-	-	-
	Ground ice	-	Ground ice	-	-	-
	Permafrost	-	Permafrost	Perennially frozen ground Perennially cryotic ground	Biennially frozen ground Climafrost Cryic layer Permanently frozen ground	-
C. Snow and ice features	<i>Basalt step</i>	-	-	-	-	-
	Cryoplanation terrace	-	Cryoplanation terrace	-	-	-
	Ice-wedge cast	-	Ice-wedge cast	-	Fossil ice wedge Ice-wedge pseudomorph	-
	Needle ice	-	Needle ice	Pipkrake	-	-
	Segregation ice	-	Segregation ice	Segregated ice	Ice gneiss Sirlion ice Taber ice	-
	Snow patch	-	Snow patch	-	-	-

A

SECTION 1			SECTION 2			
Column 1 Category	Column 2 Terminology used in database	Column 3 Sub-categories	Column 4 Terminology recognised by the IPA	Column 5 Synonyms		Column 6 Other
				Column 5.1 Synonyms recognised by the IPA	Column 5.2 Synonyms not recommended by the IPA	
D. Solifluction features	Solifluction apron	-	Solifluction apron	-	-	-
	Solifluction deposit	-	Solifluction deposit	-	-	Solifluction slump
	Solifluction lobe	-	Solifluction lobe	-	Mud-debris tongue	-
	Solifluction sheet		Solifluction sheet	Solifluction mantle		
	Solifluction terrace		Solifluction terrace	Solifluction bench Solifluction step	Solifluction garland Garland terrace	
	Stone-banked terrace	Stone-banked terrace	-	-	Garland Stone-banked lobe Stone-banked sheet Earth garland Turf-banked lobe Turf-banked step	
	Turf-banked terrace	Turf-banked terrace	-	-		
E. Patterned ground phenomena	Circle		Circle			Stone ring
	Nonsorted circle		Earth hummock	Mud hummock	Tundra hummock Earth mound Tundra hummock	
		Earth hummock	Earth hummock			
		Mud circle Stony earth circle Thufur	Mud circle Stony earth circle Thufur	Mud boil		Frost mound Hummock
		Turf hummock	Turf hummock			
	Sorted circle	-	Sorted circle	-	-	-
	Net	-	Net	-	-	-
	Nonsorted net	-	Nonsorted net	-	-	-
	Sorted net	-	Sorted net	-	-	-
	Polygon	-	Polygon	Frost-crack polygon Frost polygon	Depressed centre polygon Fissure polygon Raised-centre polygon Taimyr polygon Tundra polygon	-
	Nonsorted polygon	-	Nonsorted polygon	-	-	-
	Sorted polygon	-	Sorted polygon	-	-	-
	Step	-	Step	-	-	-
Nonsorted step	-	Nonsorted step	-	-	-	
Sorted step	-	Sorted step	Stone garland	-	-	
Stripe	-	Stripe				
Sorted stripe	-	Sorted stripe	-	-	-	
Nonsorted stripe	-	Nonsorted stripe	-	-	-	
Patterned ground	-	Patterned ground	-	-	-	






A

SECTION 1			SECTION 2			
Column 1 Category	Column 2 Terminology used in database	Column 3 Sub-categories	Column 4 Terminology recognised by the IPA	Column 5 Synonyms		Column 6 Other
				Column 5.1 Synonyms recognised by the IPA	Column 5.2 Synonyms not recommended by the IPA	
F. Gelifluction features	Gelifluction apron	-	-	-	-	-
	Gelifluction deposit	-	-	-	-	-
	Gelifluction head deposit	-	-	-	-	Head
	Gelifluction lobe	-	-	-	-	-
	Gelifluction sheet	-	-	-	-	Gelifluction mantle
	Gelifluction terrace	-	-	-	-	Gelifluction bench Gelifluction step
G. Glacial features	Arete	Arete	-	-	-	-
	Avalanche deposit	-	-	-	-	-
	Cutback	-	-	-	-	-
	Fluvioglacial deposition	-	-	-	-	-
	Glacial pavement	-	-	-	-	-
	Glacial polish	-	-	-	-	-
	Glaciers	Niche glacier Cirque glacier	-	-	-	-
	Glacial striation	-	-	-	-	Stria
	Glacier valleys	Hanging valley Trough valley	-	-	-	U-shaped valley U-shaped valley
	Moraines	Kame terrace Terminal moraine Kame moraine	-	-	-	End moraine Esker
	Roches moutonnées	-	-	-	-	-
Truncated spur	-	-	-	-	-	
H. Erosional hollows and associated features	Erosional hollow		-	-	-	Amphitheatre-shaped hollow Cirque-like hollow Erosional hollow Smooth concave form Spoon-shaped valley end
		Nivation niche	-	-	-	Nivation cirque
	Nivation cirque	-	-	-	-	Debris lobe Nival moraine Nivation moraine Pronival rampart Snowbank accumulation Snowbank deposit Snow slope detritus Winter talus ridge
	Proctalus rampart	-	-	-	-	

A

SECTION 1			SECTION 2			
Column 1 Category	Column 2 Terminology used in database	Column 3 Sub-categories	Column 4 Terminology recognised by the IPA	Column 5 Synonyms		Column 6 Other
				Column 5.1 Synonyms recognised by the IPA	Column 5.2 Synonyms not recommended by the IPA	
	Cirque	-	-	-	-	Corrie Cwm Trough's end
I. Features formed after initial phase of deposition	<i>Channel system</i>	-	-	-	-	-
	<i>Lacustrine deposit</i>	-	-	-	-	-
J. Soil profiles	<i>Compacted soil</i>	-	-	-	-	
	<i>Palaeosol</i>	-	-	-	-	Ancient soil Fossil soil Relict soil
	<i>Permafrost layer</i>	-	-	-	-	
K. Other features	<i>Flark</i>	-	-	-	-	-
	<i>Hogsback</i>	-	-	-	-	
	<i>Lacustrine deposit</i>	-	-	-	-	Lacustral deposit
	<i>Pinnacle</i>	-	-	-	-	Gendarme
	<i>Pothole</i>	-	-	-	-	
	<i>River terrace</i>	-	-	-	-	
	<i>Terracette</i>	-	-	-	-	Cattle step
	<i>Tor</i>	-	-	-	-	
	<i>Valley asymmetry*</i>	-	-	-	-	Asymmetric valley
<i>Vertical stacking</i>	-	-	-	-	Tilting and dislocation of plates	

Table A: Features identified in cold environments of southern Africa. Processes highlighted in italics are those features not necessarily characteristic of periglacial/glacial environments.

-  Periglacial phenomena
-  Glacial phenomena
-  Other phenomena

*Asymmetric valleys (or valley asymmetry) are not recognised by the International Permafrost Association (IPA), but, according to Kearey (1996), valley asymmetry are quite common in periglacial environments where they form as a result of differences in slope aspect and solar radiation received.




B

PROCESSES					
SECTION 1		SECTION 2			
Column 1 Category	Column 2 Term used in the database	Column 3 Terms recognised by the IPA	Column 4 Synonyms		Column 5 Other
			Column 4.1 Synonyms recognised by the IPA	Column 4.2 Synonyms not recognised by the IPA	
A. Freeze-thaw processes	Freezing (of ground)	Freezing (of ground)	-	-	-
	Freeze-thaw	Freeze-thaw	-	-	Gelifraction
	Periglacial process	Periglacial process	-	-	-
Cryoturbation	Cryoturbation	Cryoturbates	Congeliturbation Frost churning Frost stirring	Geliturbation	-
	Cryogenic process	Cryogneic process	-	-	-
	Cryoplanation	Cryoplanation	-	-	-
	Frost action	Frost action	Frost riving Frost wedging Gelifraction	-	-
	Frost creep	Frost creep	-	-	-
	Frost heave	Frost heave	-	Frost thrust	-
	Frost shattering	Frost shattering	(Con-)gelifraction Frost splitting Frost weathering	-	-
	Frost sorting	Frost sorting	-	-	-
	Frost wedging	Frost wedging	Congelifraction Frost bursting Frost prying Frost riving Frost splitting	-	-
	Ice segregation	Ice segregation	-	-	Ice lensing
	Ice	Ice	-	-	-
	Needle ice activity	Needle ice activity	-	-	Needle ice stripe Raked ground Raked pattern Striated soil
		Surface creep	-	-	-
		Nivation*	-	-	-
C. Gelifluction processes	Gelifluction	Gelifluction	-	-	-
	Inversion of the weathering profile	-	-	-	-
	Geliflual action	-	-	-	-
D. Solifluction processes	Solifluction	Solifluction	-	-	Solifluxion
	Solifluctional smoothing	-	-	-	Solifluctional forming Solifluctional over-forming

B

PROCESSES					
SECTION 1		SECTION 2			
Column 1 Category	Column 2 Term used in the database	Column 3 Terms recognised by the IPA	Column 4 Synonyms		Column 5 Other
			Column 4.1 Synonyms recognised by the IPA	Column 4.2 Synonyms not recognised by the IPA	
E. Glacial processes	Avalanching	-	-	-	-
	Fluvio-glacial	-	-	-	-
	Fluvio-glacial deposition	-	-	-	-
	Glacial action	-	-	-	Glacial movement Glacial erosion
	Glacial erosion	-	-	-	-
	Glacial polishing	-	-	-	-
F. Fluvial action	<i>Fluvial</i>	-	-	-	Fluviatile
	<i>Surface runoff</i>	-	-	-	Runoff
G. Soil and mass movement	<i>Debris flow</i>	-	-	-	-
	<i>Emplacement (by slow flow)</i>	-	-	-	Differential mass displacement
	<i>Mass movement</i>	-	-	-	Downslope sludging of individual stones Mass wasting Mass flow Slow mass movement
	<i>Soil creep</i>	-	-	-	Soil flow
	<i>Sheet wash</i>	-	-	-	Sheet-flow
H. Other processes	Contraction	-	-	-	-
	Desiccation	-	-	-	-
	<i>Diurnal oscillation</i>	-	-	-	-
	<i>Erosion</i>	-	-	-	-
	<i>Grazing animals</i>	-	-	-	-
	<i>Turf exfoliation</i>	-	-	-	-

Table B: Processes identified in cold environments of southern Africa. Processes highlighted in Italics are those processes not necessarily characteristic of periglacial/ glacial environments.

-  Periglacial phenomena
-  Glacial phenomena
-  Other phenomena

* The process of nivation is not recognised by the IPA as a periglacial process.



TABLE A	
Contents of column 1	
A. Accumulations of coarse debris	Features consisting of accumulations of coarse debris, such as clasts, and that take on a certain characteristic shape that may be indicative of periglacial activity.
B. Periglacial ground features	Features that are characteristic of frozen ground.
C. Snow and ice features	Features of which formation is closely linked with snow and/or ice.
D. Solifluction features	Features that form through slow downslope flow of saturated unfrozen earth materials (Van Everdingen, 1998), but not necessarily the result of movement over frozen substrate.
E. Patterned ground phenomena	Any ground surface phenomena exhibiting a discernible ordered, more or less symmetrical, morphological pattern of ground, vegetation and rock fragments, defined as circles, stripes, polygons and nets (Van Everdingen, 1998).
F. Gelifluction features	Features forming through slow flowage of unfrozen earth materials on a frozen substrate (e.g. permafrost).
G. Glacial features	Features that were formed by glacial processes and glacier movement.
H. Erosional hollows and associated features	Features that formed through snow and/or ice action, displaying a concave shape, and features that are usually associated with hollow formation (e.g. protalus ramparts).
I. Features formed after initial phase of deposition	Features that were formed after the initial phase of periglacial or glacial deposition. These features may be polygenetic in origin.
J. Soil profiles	The vertical sequence of soil horizons.
H. Other features	Other features associated with, but not exclusively to, periglacial or glacial action.

TABLE B	
Contents of column 1	
A. Freeze-thaw processes	Processes associated with the changing phase from water to ice and vice versa in soil or rock (Van Everdingen, 1998).
B. Cryoturbation	Soil movements due to frost action (Van Everdingen, 1998).
C. Gelifluction processes	Processes of slow downslope flow or unfrozen earth materials on a frozen substrate (e.g. permafrost) (Van Everdingen, 1998).
D. Solifluction processes	Processes of slow downslope flow or saturated earth materials, but not requiring a frozen substrate (Goudie <i>et al.</i> , 1985; Van Everdingen, 1998).
E. Glacial processes	The action and processes that take place where a landscape is occupied by glaciers.
F. Fluvial action	The action of a river, its flow, depositional and erosive activity (Clark, 1998).
G. Soil and mass movement	Processes of downward movement of rock materials and soil.
H. Other processes	Other processes associated with periglacial action, but not necessarily of such origin.

APPENDIX E
General Features and Processes Reference Index

Abbreviations

A	Activity of phenomenon, i.e. whether it is still active or not
AASL	Altitude above sea level
D	Depth range of a phenomenon
Di	Diameter of phenomenon
H	Height range of a phenomenon
L	Length range of a phenomenon
M	The type of matrix present in a matrix supported phenomenon
SN	Sorted, nonsorted or stratified
SS	Soils and sediments present within, under or in the vicinity of the phenomenon in question
V	Vegetated
W	Width range of a phenomenon

General Features and Processes Reference Index

Phenomena	Publications	A	AASL	V	SN	SS	M	W (m)	L (m)	H (m)	D (m)
Arête	Sparrow (1964, 1967b) Sänger (1988)	R	-	-	-	-	-	-	-	-	-
Avalanching	Sparrow (1964) Grab (1996b)	R	3200-3300	-	-	humic	-	-	-	-	-
Avalanche deposit	Lewis & Dardis (1985)	R	-	-	-	-	sand	-	-	-	1,5-1,8
Basalt step	Harper (1969)	R	3230-3325	-	-	chemically weathered modern soil & subsoils	-	-	-	1,8-6,1	-
Blocfield	Linton (1969) Sparrow (1971) Borchert & Sänger (1981) Sänger (1988) Marker (1992) Boelhouwers (1994) Grab (1996a)	R	1500-3260	-	-	-	-	30	25	-	1-7
Blockstream	Hastenrath & Wilkinson (1973) Hagedorn (1984) Lewis (1996a)	R	-	-	-	-	-	10-30	100	4-8	-
Boulder bed	Sparrow (1973) Grab (1996a)	R	1675-3355	-	-	-	-	-	100	1-5	Di: 1
Channel system	Hall (1994)	R	2100	-	-	-	-	100	1000	10	-
Cirque	Sparrow (1967a, 1967b) Harper (1969) Borchert & Sänger (1981) Sänger (1988) Lewis (1996b)	R	1675-3355	-	-	chemically weathered, gritty modern soils & subsoils	-	15,25	-	-	-
Cirque-like hollow	Sparrow (1964) Dyer & Marker (1979)	R	2607-3204	-	-	peat	-	621-1166,7	486-1071,4	93-280	96-230
Cirque glacier	Borchert & Sänger (1981) Sänger (1988)	R	1900	-	-	-	-	-	-	-	-
Clast*	Hanvey & Marker (1992)	A	3275	-	-	-	-	-	-	-	-
Compacted soil	Fitzpatrick (1978)	R	-	-	-	orthic, humic, yellow, brown, grey, black magwa, clovelly, silt-loam	-	-	-	-	-
Contraction	Dyer & Marker (1979)	R	2870-3070	-	-	-	-	-	-	-	-
Corrie sheet	Borchert & Sänger (1981)	R	1900	-	-	-	-	-	-	-	-

Phenomena	Publications	A	AASL	V	SN	SS	M	W (m)	L (m)	H (m)	D (m)
Cryogenic process	Meiklejohn (1992) Boelhouwers (1994) Hanvey & Marker (1994) Marker (1995b)	R A	1850-3250	-	-	humic, massive, organic peat, silt, graveks, modern soils, palaeosols	-	-	-	-	-
Cryoplanation terrace	Hagedorn (1984)	R	1800-2370	-	-	-	-	700-2000	2000	2	-
Cryoturbation	Borchert & Sanger (1981) Lewis & Dardis (1985)	R A	3200-3377	-	-	subsoils	-	-	-	-	-
Cryoturbation features	Borchert & Sanger (1981)	A	1900	-	-	-	-	-	-	-	-
Cutback	Hall (1994) Grab (1996a)	R	2968-3377	-	-	-	-	-	-	-	-
Debris deposit	Lewis (1996a)	R	1930	-	-	-	-	-	400	-	-
Debris fan	Lewis & Hanvey (1991)	R	1407-1648	-	S	fine black sand, palaeosols	sand, gravel	-	-	20-22	-
Debris flow	Hanvey <i>et al.</i> (1986) Lewis & Hanvey (1988) Hall (1994)	R	1900	-	-	-	-	-	-	-	-
Debris mantle	Boelhouwers (1991b)	A	1800	-	N	-	diamicton	-	-	-	-
Debris ridge	Lewis & Hanvey (1993) Grab (1996b)	R	3200-3250	-	-	humic	-	-	18,4-747,35	-	-
Desiccation	Hanvey & Marker (1992)	R	2870-3070	-	-	peat	-	-	-	-	-
Desiccation polygon	Hanvey & Marker (1992)	A	3275	-	-	-	-	-	-	-	Di: 0,15-1
Emplacement	Marker (1992)	A	2300-2800	-	-	-	-	-	-	-	-
Erosion	Harper (1969) Marker & Whittington (1971) Marker (1992) Meiklejohn (1992) Hanvey & Marker (1994)	R	1500-3325	-	-	chemically weathered modern soil, subsoil	-	-	-	-	-
Erosional hollow	Sparrow (1964) Harper (1969) Marker & Whittington (1971) Hastenrath (1972) Hastenrath & Wilkinson (1973) Nicol (1973) Dyer & Marker (1979) Borchert & Sanger (1981) Lewis & Hanvey (1988) Marker (1989, 1990c, 1991b) Hanvey & Marker (1994)	R	1600-3355	-	-	yellow to dark peats, gravels, clays, unconsolidated, oxidised modern soils	gravels, clasts	400-2500	400-2250	21-293	93-1207

Phenomena	Publications	A	AASL	V	SN	SS	M	W (m)	L (m)	H (m)	D (m)
Flark	Backéus (1989)	A	3200-3300	Y	-	humified, amorphous peat	-	-	15	-	0,2-0,6
Fluvial	Lewis & Dardis (1985) Lewis & Hanvey (1991) Meiklejohn (1992)	R A	1675-3355	-	-	-	-	-	-	-	-
Fluvio-glacial deposit(-ion)	Hall (1994) Grab (1996a) Lewis (1996b)	R	2000-3200	-	-	sand, clay, palaeosol	-	100	100-3000	1-20	-
Fluvio-glacial meltwater	Hanvey <i>et al.</i> (1986)	R	2225-2340	-	-	massive, structured sand, clay, silt	massive	-	-	-	-
Freeze-thaw	Harper (1969) Marker & Whittington (1971) Sparrow (1971) Fitzpatrick (1978) Hanvey & Marker (1992)	A	1788-3295	-	-	-	-	-	-	-	-
Freezing	Boelhouwers (1995a)	A	1407-3355	-	-	organic peat, light black fine sand, palaeosols, modern soils	gravels	-	-	-	-
Frost action	Sparrow (1967a) Harper (1969) Hastenrath (1972) Hastenrath & Wilkinson (1973) Fitzpatrick (1978) Borchert & Sanger (1981) Hanvey <i>et al.</i> (1986) Marker (1986) Lewis (1987, 1996a) Lewis & Hanvey (1988) Hanvey & Lewis (1991) Grab (1994)	A R	1582-3355	-	-	humic, massive, homogeneous, organic clovelly, magwa, black, brown, yellow, grey clay, sand, silt, loam	-	-	-	-	-
Frost climate	Borchert & Sanger (1981)	R	1900	-	-	-	-	-	-	-	-
Frost creep	Lewis & Dardis (1985) Hanvey & Marker (1992) Boelhouwers (1991a, 1994, 1995a)	A	1800-3260	-	-	-	mud	-	-	-	-
Frost heave	Hastenrath (1972) Dardis & Granger (1986) Lewis (1987) Hanvey & Marker (1992) Boelhouwers (1995a) Grab (1996b)	A	3200	-	-	-	-	-	-	-	-



Phenomena	Publications	A	AASL	V	SN	SS	M	W (m)	L (m)	H (m)	D (m)
Frost shattering	Harper (1969) Hagedorn (1984) Sänger (1988) Marker (1989) Hanvey & Marker (1992) Lewis & Hanvey (1993)	A	3200	-	-	-	-	-	-	-	-
Frost sorting	Boelhouwers (1994)	R	3140-3260	-	S	-	-	2m	-	-	-
Frost wedging	Sparrow (1967a) Harper (1969) Hastenrath & Wilkinson (1973) Borchert & Sänger (1981)	A R	1900-2530	-	-	modern subsoils	-	-	-	-	-
Frozen ground	Harper (1969) Borchert & Sänger (1981) Lewis & Dardis (1985) Dardis & Granger (1986) Lewis (1987) Boelhouwers (1995a)	A	2744-3200	-	S	clay, palaeosol	mud, diamicton	-	-	-	-
Frozen ground phenomena#	Borchert & Sänger (1981)	R	1900	-	-	-	-	-	-	-	-
Geliflual action	Linton (1969)	R	445-2000	-	-	grey, red, brown modern soil, gravel	brown earth, sand, grits	-	-	-	-
Geliflual apron	Linton (1969)	R	445-2000	Y	-	grey, red, brown modern soil, gravel	brown earth, sand, grits	-	-	-	1-8
Geliflual deposit	Linton (1969)	R	445	Y	-	grey-buff modern soils, gravel	rusty coloured chips	-	-	-	8
Gelifluction	Harper (1969) Linton (1969) Lewis & Dardis (1985) Dardis & Granger (1986) Lewis (1987, 1996a) Hanvey & Marker (1992) Boelhouwers (1994)	A	445-3260	-	-	-	mud, chips	-	-	-	-
Gelifluction deposit	Linton (1969) Lewis & Dardis (1985) Lewis (1987)	R	445-2000	-	S	-	sand, mud	-	-	-	0,3-8
Gelifluction (head) deposit	Nicol (1973)	R	1841-2000	Y	Strat	grits, sand, gravels, palaeosol	-	-	-	-	15
Gelifluction sheet	Boelhouwers (1994)	R	3140-3260	-	S	-	-	10	<20	<0,5	-
Gelisolifluction	Hagedorn (1984)	R	1700-2370	-	-	-	-	-	-	-	-

Phenomena	Publications	A	AASL	V	SN	SS	M	W (m)	L (m)	H (m)	D (m)
Glacial	Sänger (1988) Hanvey & Lewis (1990) Marker (1991b) Lewis & Hanvey (1993)	R	1850-2135	-	-	sand, clay, mud, silt	-	-	-	-	-
Glacial phenomena	Harper (1969) Borchert & Sänger (1981) Sänger (1988) Hanvey & Lewis (1990) Marker (1991b) Lewis & Hanvey (1993) Hall (1994) Grab (1996a) Lewis (1996b)	R	1820-3377	Y	Strat	peat, silt, clay, sand, palaeosol	sand, gravel, mud	-	-	-	-
Glaciation	Grab (1996a)	R	3200-3300	-	-	-	-	-	-	-	-
Glacial erosion	Harper (1969) Borchert & Sänger (1981) Lewis & Hanvey (1993) Lewis (1996b)	R	1820-2350	-	-	chemically weathered, gritty, koalinised, organic modern soil, subsoil, palaeosol	sand, silt, gravel	-	-	-	-
Glacial meltwater	Hanvey <i>et al.</i> (1986)	R	2225-2340	-	-	massive structured sand clay, silt	massive	-	-	-	-
Glacial pavement	Sänger (1988)	R	-	-	-	-	-	-	-	-	-
Glacial pebble	Sänger (1988)	R	-	-	-	-	-	-	-	-	-
Glacial phenomena		R	1820-3377	Y	Strat	peat, silt, clay, sand, palaeosol	sand, gravel, mud	-	-	-	-
Glacial polish	Harper (1969) Borchert & Sänger (1981) Sänger (1988)	R	1900-2350	-	-	chemically weathered gritty modern soil, subsoil	-	-	-	-	-
Glacial striation	Borchert & Sänger (1981) Sänger (1988) Lewis (1996b)	R	1900-2500	-	-	-	-	-	-	-	-
Glaciation	Grab (1996b)	R	3200-3300	-	-	-	-	-	-	-	-
Glacier	Borchert & Sänger (1981)	R	1900	-	-	in situ koalinised granit soil	sand	-	-	-	-
Gravel sorting	Hastenrath (1972)	A R	3100	-	S	-	-	-	-	-	-
Grèzes littées	Lewis & Dardis (1985) Lewis & Hanvey (1988)	R	-	-	S	-	mud, silt, sand	-	-	-	-
Ground freeze	Boelhouwers (1995)	A	1800-1850	Y	S	modern soil	-	-	-	-	-
Ground ice	Hanvey & Marker (1992)	A	3275	-	-	-	-	-	-	-	-
Hanging valley	Lewis (1996b)	R	2000	-	-	-	-	-	-	-	-
Hogsback	Borchert & Sänger (1981)	R	19 00	-	-	-	-	-	-	-	-



Phenomena	Publications	A	AASL	V	SN	SS	M	W (m)	L (m)	H (m)	D (m)
Ice shattered ridge	Sparrow (1967a)	R	1675-3355	-	-	-	-	-	-	-	-
Ice stripped areas	Sparrow (1967a)	R	1675-3355	-	-	-	-	-	-	-	-
Ice wedge	Harper (1969) Lewis (1996a)	A	3050	-	-	gritty modern soil, subsoil	-	0,05-0,1	-	-	0,61
Ice-wedge cast	Lewis & Dardis (1985) Lewis (1996a)	R	1850	-	-	fine sediment, palaeosol	-	0,2-0,4	-	-	1-1,8
Ice-stripped area	Sparrow (1967a)	R	1675-3355	-	-	-	-	-	-	-	-
Inversion of the weathering profile	Linton (1969)	R	1200	-	-	sands, grits	sand, grits	-	-	-	-
Kame moraine	Lewis (1996b)	R	2000	-	-	-	-	100	-	-	-
Kame terrace	Lewis (1996b)	R	2000	-	-	sand, palaeosol, gravel	-	-	3000	20	-
Lacustrine deposit	Hanvey & Lewis (1990)	R	1850	-	Strat	massive, organic, laminated silt, gavel, sandstone	mud, sand	-	60	16	-
Mass movement	Marker (1992) Hanvey & Marker (1994)	-	3000-3250	-	S	subsoil					
Moraine	Sparrow (1967a) Borchert & Sanger (1981) Sanger (1988) Lewis (1996b)	R	1900	-	-	-	-	-	-	-	-
Moraine sheet	Borchert & Sanger (1981)	R	1900	-	-	-	-	-	-	-	-
Needle ice	Hastenrath (1972) Hastenrath & Wilkinson (1973) Lewis (1987) Sanger (1988) Verster & Van Rooyen (1988) Marker (1989) Boelhouters (1991a) Hanvey & Marker (1992) Grab (1996b)	A	1800-3410	-	-	-	-	-	-	0,05	-
Needle ice activity	Hastenrath & Wilkinson (1973) Lewis (1987) Sanger (1988) Marker (1989) Boelhouters (1991a) Hanvey & Marker (1992) Grab (1996b)	A	1800-3410	-	-	-	-	-	-	-	-
Net	Hastenrath & Wilkinson (1973) Boelhouters (1991a)	A	1181-3200	-	S	-	-	0,05-0,2	-	-	-
Niche (hollow)	Marker (1991b) Grab (1996a)	R	3295-3377	-	-	-	-	-	-	-	-
Niche glacier	Hall (1994)	R	-	-	-	-	-	-	-	-	-

Phenomena	Publications	A	AASL	V	SN	SS	M	W (m)	L (m)	H (m)	D (m)
Nivation	Sparrow (1967a) Harper (1969) Nicol (1973) Dyer & Marker (1979) Borchert & Sanger (1981) Lewis & Hanvey (1988) Marker (1986, 1989, 1990b) Hanvey & Lewis (1991) Hall (1994) Lewis (1994, 1996b)	R	1675-3355	-	-	sand, modern soil	silt, clay	-	-	-	-
Nivation niche	Harper (1969) Marker (1989)	R	1800-2837	Y	-	-	-	-	-	-	-
Nonsorted circle	Harper (1969) Hastenrath & Wilkinson (1973) Borchert & Sanger (1981) Boelhouwers (1991a)	A	1181-3354	Y	N	gritty modern soils, subsoils	-	0,4	-	-	Di: 0,2-0,6
Nonsorted polygon	Harper (1969) Hastenrath (1972) Lewis (1987, 1996b) Hanvey & Marker (1992)	A	2900-3354	-	N	gritty modern soil	-	0,06-0,2	-	-	-
Palacosol	Harper (1969) Lewis & Hanvey (1991, 1993) Hanvey & Marker (1994) Marker (1995b) Lewis (1996a)	R	1407-3175	Y	-	brown	-	-	-	-	0,4-2,5
Patterned ground	Harper (1969) Hastenrath (1972) Hastenrath & Wilkinson (1973) Borchert & Sanger (1981) Dardis & Granger (1986) Lewis (1987, 1996a) Boelhouwers (1991a, 1994, 1995a) Hanvey & Marker (1992) Grab (1996b)	A R	1181-3210	-	S N	chemically weathered, gritty modern soils, subsoils, clays, silts, sands & gravels	-	0,06-2	0,01-10	-	Di 0,15-6
Pebble (glacially modified)	Sanger (1988)	R	-	-	-	-	-	-	-	-	-



Phenomena	Publications	A	AASL	V	SN	SS	M	W (m)	L (m)	H (m)	D (m)
Periglacial process	Sparrow (1964) Hastenrath (1972) Borchert & Sanger (1981) Hagedorn (1984) Lewis & Hanvey (1988) Marker (1989) Hanvey & Marker (1992)	A R	1700-3200	-	-	subsoil	-	-	-	-	-
Periglacial slope wash	Lewis & Hanvey (1988)	R	-	-	-	-	sand, silt	-	-	-	-
Permafrost	Boelhouwers (1994)	R	-	-	-	-	-	-	-	-	-
Permafrost layer	Fitzpatrick (1979) Lewis (1996a)	R	2500	-	Strat	orthic, humic, yellow, brown, black magwa, clovelly, silt	-	-	-	-	-
Permafrost process	Lewis (1996a)	R	1930	-	-	-	-	-	-	-	-
Pinnacle	Borchert & Sanger (1981)	R	1900	-	-	-	-	-	-	-	-
Plateau glacier	Sanger (1988)	R	-	-	-	-	-	-	-	-	-
Planation surface	Sanger (1988)	R	-	-	-	-	-	-	-	-	-
Polygon	Harper (1969) Hastenrath (1972) Hastenrath & Wilkinson (1973) Lewis (1987, 1996a) Hanvey & Marker (1992) Boelhouwers (1991a, 1995a)	A R	2550-3355	-	S N	chemically weathered, gritty modern soil, subsoil	-	0,04-0,2	-	-	Di 0,15-6
Pothole	Sanger (1988)	R	-	-	-	-	-	-	-	-	-
Protalus rampart	Nicol (1973) Marker (1989, 1990b, 1990c) Lewis (1994, 1996a)	R	1800-2837	Y	-	-	-	52-83	217-1500	8,5-104	8-16 Di: 27-69
River terrace	Lewis & Hanvey (1991)	R	1407-1607m	-	-	sand, gravel	-	-	-	-	-
Roche moutonee	Grab (1996a)	R	2968-3377	-	-	-	-	-	-	-	-
Rockglacier	Lewis & Hanvey (1993) Lewis (1996a)	R	-	S	-	organic, palaeosols	sand, silts, clays	30-250	200-550	4-30	-
Scree	Sparrow (1967a) Marker (1986, 1992) Lewis (1994) Sumner & De Villiers (<i>in prep</i>)	R	1582-3355	Y	-	-	-	37-75	100-235	1-3	-
Segregation ice	Boelhouwers (1994) Grab (1996b)	A	3140-3410	-	-	-	-	-	-	-	-
Sheet-wash	Lewis & Dardis (1985) Watson (1988)	A R	-	-	-	hutton	-	-	-	-	-

Phenomena	Publications	A	AASL	V	SN	SS	M	W (m)	L (m)	H (m)	D (m)
Sheet-wash (-flow)	Lewis & Dardis (1985) Watson (1988)	A R	-	Y	S	acid leached, weathered hutton, griffen, mispah-glenrosa	mud, sand	-	-	-	-
Slip scar	Harper (1969)	A	2530-3000	Y	-	chemically weathered, gritty modern soil, subsoil	-	-	-	-	-
Snow patch (conditions)	Sparrow (1967a, 1973) Nicol (1973) Dyer & Marker (1979) Marker (1990) Lewis (1994)	R	1675-3355	-	-	-	-	-	-	-	-
Snowpatch meltwater	Marker (1989)	R	1800-2837	-	-	-	-	-	-	-	-
Slope weathering	Hanvey & Marker (1994)		3000-3250	-	-	brown to dark gravels, peat, palaeosol, silt, modern soil	-	-	-	-	-
Soil creep	Borchert & Sanger (1981) Verster & Van Rooyen (1988) Boelhouwers (1991a, 1991b) Lewis & Hanvey (1991)	A R	1407-2249	-		clovelly, silt, griffen, palaeosol, hutton, sand, clay	sand	-	-	-	-
Solifluction	Sparrow (1967a, 1971) Harper (1969) Hastenrath (1972) Hastenrath & Wilkinson (1973) Nicol (1973) Borchert & Sanger (1981) Sanger (1988) Marker (1989) Lewis & Hanvey (1991) Meiklejohn (1992) Boelhouwers (1991b, 1995a)	A R	1181-3240	Y	S N Strat	chemically weathered, organic, unconsolidated dark, orange-brown, grey modern soil, gravels, grits, peat, silt, clay, palaeosol	sand, fines	-	-	-	-
Solifluction deposit	Sparrow (1971) Lewis & Hanvey (1991)	R	1412-1998	Y	Strat	grits, gravel	sand	<50	-	-	45
Solifluction lobe	Marker (1989, 1992)	R	1800-2837	-	-	-	-	-	-	-	-
Solifluction phenomena	Sparrow (1967a, 1971) Harper (1969) Hastenrath (1972) Hastenrath & Wilkinson (1973) Nicol (1973) Borchert & Sanger (1981) Sanger (1988) Meiklejohn (1992) Hanvey & Marker (1994) Boelhouwers (1991a, 1991b, 1995a)	A R	1181-3240	Y	S N Strat	chemically weathered, organic, unconsolidated dark, orange-brown, grey modern soil, gravels, grits, peat, silt, clay, palaeosol	sand, fines	<50	0,9-2250	0,17-9,93	6,1-35

Phenomena	Publications	A	AASL	V	SN	SS	M	W (m)	L (m)	H (m)	D (m)
Solifluction sheet	Hastenrath (1972)	R	2700	-	-	-	-	-	-	-	-
Solifluction slump	Sparrow (1967a, 1971) Harper (1969)	R	1675-3355	-	-	-	-	-	-	-	-
Solifluctional smoothing	Hastenrath & Wilkinson (1973) Marker (1989)	R	1181-3100	-	-	subsoil	-	-	-	-	-
Solifluction terrace	Harper (1969) Marker (1989) Lewis (1996a)	A R	2600-2744	Y	-	chemically weathered, unconsolidated, grey, orange, red sediments, palaeosol, modern soil	-	0,5-10	1	0,01-0,2	6,1-12,2
Solution	Verster & Van Rooyen (1988)	A	-	-	-	clovelly, griffen, hutton, clay, silt	-	-	-	-	-
Sorted circle	Dardis & Granger (1985) Boelhouwers (1991a, 1994, 1995a)	A	3140-3200	-	S	modern soils	-	0,05-1,3	-	-	-
Sorted net	Hastenrath & Wilkinson (1973) Boelhouwers (1991a)	A	1181-3200	-	S	-	-	0,05-0,2	-	-	-
Sorted polygon	Harper (1969) Hastenrath & Wilkinson (1973) Lewis (1987) Hanvey & Marker (1992) Boelhouwers (1991a, 1995a)	A	2250-3300	-	S	gritty modern soils, subsoils	-	0,05-0,2	-	-	-
Sorted stripe	Lewis (1987) Boelhouwers (1991a, 1994, 1995a) Grab (1996b)	A R	2800-3410	-	S	clay, silt, gravels, modern soil	-	0,05-2	-	-	-
Stone-banked terrace	Dardis & Granger (1986) Boelhouwers (1991b, 1994, 1995a)	A R	1600-3260	Y	S N	modern soil	-	0,01-15	0,9-60	0,2-3	-
Stripe	Lewis (1987) Hanvey & Marker (1992) Boelhouwers (1991a, 1994, 1995a) Grab (1996b)	A R	2800-3410	Y	S N	modern soil, clay, gravel, sand, silt	-	0,05-2	0,01-10	-	-
Surface creep	Sanger (1988)	A	-	-	-	-	-	-	-	-	-
Surface runoff	Harper (1969) Backeus (1989) Boelhouwers (1991a)	A R	3200-3300	-	-	humified, amorphous, chemically weathered peat, modern soil, subsoils	-	-	-	-	-

Phenomena	Publications	A	AASL	V	SN	SS	M	W (m)	L (m)	H (m)	D (m)
Terminal moraine	Lewis (1996b)	R	1900-2000	-	-	-	-	-	-	-	-
Terrace	Marker (1989)	R	1800-2837	-	N	-	-	-	-	-	15-35
Terracette	Harper (1969) Hastenrath (1972) Hastenrath & Wilkinson (1973) Dardis & Granger (1986) Verster & Van Rooyen (1988) Watson (1988) Marker (1989) Boelhouwers (1991a) Hanvey & Marker (1992)	A	all altitudes	-	N	silt, clay and modern soils, chemically weathered with high acidity	-	0,1-3,83	0,1-34	0,05-1,45	-
Thawing	Sparrow (1971)	R	1600	-	-	-	-	-	-	-	-
Thufur	Harper (1969) Marker & Whittington (1971) Hastenrath (1972) Hastenrath & Wilkinson (1973) Lewis (1987, 1996a) Boelhouwers (1991a) Hanvey & Marker (1992, 1994) Grab (1994)	A	2550-3270	Y	-	chemically weathered, gritty, organic, homogeneous dark modern soil, subsoil, clay, peat, silt	-	0,07-0,5	-	-	Di 0,2-0,98
Tor	Sparrow (1964, 1967a) Dardis & Granger (1986) Grab (1996a)	A R	1675-3355	-	-	-	-	-	-	-	-
Trough-like valley	Lewis (1996b)	R	2000	-	-	-	-	-	-	-	-
Truncated spur	Lewis (1996b)	R	2000	-	-	-	-	-	-	-	-
Turf exfoliation	Hastenrath (1972) Boelhouwers (1991a)	A	3000	-	-	-	-	-	-	-	-
Turf-banked terrace	Borchert & Sanger (1981) Dardis & Granger (1986) Boelhouwers (1991a, 1995a)	A	1800-3120	Y	-	dark, heavy modern soil, clay	-	0,4-3	1,82-6	0,15-0,35	-
Valley asymmetry	Sparrow (1964, 1967a) Harper (1969) Marker (1989) Meiklejohn (1992)	R	1675-3355	-	-	chemically weathered, gritty modern soil, subsoil	-	-	-	-	-
Valley glacier	Sanger (1988)	R	-	-	-	-	-	-	-	-	-
Vertical stacking	Hastenrath (1972) Hastenrath & wilkinson (1973)	A	3073-3100	-	-	fine sediment	-	-	0,5-1	-	-



APPENDIX F
Geographic Location Reference Index

Geographic Location Reference List

Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Arêtes	East Griqualand	Kwa-Zulu Natal		
	HDALM	HDALM		
	Ingeli (Ngeli)	HDALM	30°37'59"	29°17'39"
	Insizwa (Ntsizwa)	HDALM	30°47'11"	29°12'19"
	Mount Currie	Old Transkei	30°28'22"	29°25'16"
	Western Cape Mts.	Western Cape		
Avalanche deposit	Dynevor Park	Eastern Cape	31°08'44"	27°47'05"
Avalanching	Kwa Ntuba	HDALM	29°31'05"	29°17'58"
	Nhlangeni	HDALM	29°29'15"	29°18'54"
	Ntabamnyama	HDALM	29°10'26"	29°28'07"
	Ship's Prow	HDALM	29°05'45"	29°20'01"
Basalt steps	HDALM	HDALM		
	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Ubutoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"
Blockfields	Amatola(e) Mountains	Eastern Cape		
	East Griqualand	Kwa-Zulu Natal		
	Eastern Cape Drakensberg	Eastern Cape		
	Eastern Lesotho	Lesotho		
	GGHNP	Free State	28°34'05"	28°35'23"
	HDALM	HDALM		
	Mafadi	HDALM	29°12'16"	29°21'39"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Pretoria	Gauteng	25°49'05"	28°18'00"
	Western Cape Mts.	Western Cape		
	Witberge	HDALM		
Blockstreams	Ben MacDhui	Eastern Cape	30°38'44"	27°56'32"
	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Estcourt	Kwa-Zulu Natal	29°00'00"	29°52'44"
	Groot Winterberg	Western Cape		
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mokhotlong	Lesotho	29°17'44"	29°04'38"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
Boulder beds	Bannerman's Pass	HDALM	29°15'25"	29°25'12"
	Nhlangeni	HDALM	29°29'15"	29°18'54"
	Ntabamnyama	HDALM	29°10'26"	29°28'07"
Channel systems	HDALM	HDALM		
Cirque glaciers	Bain's Kloof Pass	Western Cape	33°35'35"	19°07'54"
	Du Toit's Kloof Pass	Western Cape	33°44'30"	19°09'04"
	Hex River Mountains	Western Cape		
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Western Cape Mts..	Western Cape		
Cirques	Bain's Kloof Pass	Western Cape	33°35'35"	19°07'54"
	Ben Nevis	Old Transkei	30°23'11"	29°29'32"
	Danger's Hoek	Eastern Cape	30°35'27"	27°44'23"
	Du Toit's Kloof Pass	Western Cape	33°44'30"	19°09'04"
	Giant's Castle	HDALM	29°21'00"	29°28'55"
	Giant's Cup (Hodgon's Peak)	HDALM	29°37'05"	29°18'08"
	Hex River Mountains	Western Cape		
	HDALM	HDALM		
	Kubutsane	Lesotho	29°52'38"	29°07'10"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mkomazi (Umkomaas)	HDALM	29°28'30"	29°19'47"
	Mount Currie	Old Transkei	30°28'22"	29°25'16"



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Cirques	Mount Fifty	Eastern Cape	30°25'20"	29°23'17"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Thaba Ntsho (Thabana Ntsho or Nts'o)	HDALM	29°50'59"	29°09'06"
	Western Cape Mts.	Western Cape		
	Zwartberg	HDALM	30°07'19"	29°25'47"
Clasts	Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"
Compacted soils	Naude's Pass	Eastern Cape	30°43'35"	28°07'30"
	Sani Pass	HDALM	29°35'35"	29°18'08"
Contraction	Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"
Cryogenic processes	HDALM	HDALM		
	Sani Top	Lesotho	29°35'03'	29°17'02"
	Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"
Cryoplanation terraces	Groot Winterberg	Western Cape		
Cryoturbation	Dynevor Park	Eastern Cape	31°08'44"	27°47'05"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
Cryoturbation features	Dynevor Park	Eastern Cape	31°08'44"	27°47'05"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
Cutbacks	Bannerman's Pass	HDALM	29°15'25"	29°25'12"
	HDALM	HDALM		
	Ka-Langalilabele	HDALM	29°17'03"	29°26'15"
	Kwa Ntuba	HDALM	29°31'05"	29°17'58"
	Mashai	Lesotho	29°44'11"	29°09'07"
	Mbundini	HDALM	28°50'31"	28°56'46"
	Mkomazi (Umkomaas)	HDALM	29°28'30"	29°19'47"
	Mzimude	HDALM	29°47'27"	29°14'49"
	Nhlangeni	HDALM	29°29'15"	29°18'54"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Ship's Prow	HDALM	29°05'45"	29°20'01"
	The Judge	HDALM	29°13'22"	29°24'35"
Debris deposit	Bottelnekspruit	Eastern Cape	31°06'00"	27°36'10"
Debris fans	Glen Orchy	Eastern Cape	31°15'16"	27°51'51"
Debris flow	Carlisle's Hoek	Eastern Cape	30°44'27"	27°58'45"
	HDALM	HDALM		
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
Debris mantles	Western Cape Mts.	Western Cape		
Debris ridges	Bottelnekspruit	Eastern Cape	31°06'00"	27°36'10"
	Chesney Wold	Eastern Cape	31°06'30"	27°49'00"
	Kwa Ntuba	HDALM	29°31'05"	29°17'58"
	Nhlangeni	HDALM	29°29'15"	29°18'54"
	Ship's Prow	HDALM	29°05'45"	29°20'01"
Desiccation polygon	Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"
Dislocation (of stones)	Matroosberg	Western Cape	33°22'46"	19°40'19"
Emplacement	GGHNP	Free State	28°34'05"	28°35'23"
Erosion	Giant's Cup (Hudson's Peak)	HDALM	29°37'05"	29°18'08"
Erosional hollows	Berlin	Free State	28°30'12"	28°30'14"
	Blanca (E)	Free State	28°33'59"	28°18'42"
	Braamhof	Free State	28°33'44"	28°21'11"
	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Dunblane (S)	Free State	28°32'38"	28°24'19"
	East Griqualand	Kwa-Zulu Natal		
	Eastern Cape Drakensberg	Eastern Cape		
	Eastern Lesotho	Lesotho		
	Estcourt	Kwa-Zulu Natal	29°00'00"	29°52'44"
	Giant's Cup (Hudson's Peak)	HDALM	29°37'05"	29°18'08"
	GGHNP	Free State	28°34'05"	28°35'23"
	Groenhoek	Free State	28°26'57"	28°37'15"
		HDALM	HDALM	



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Erosional hollows	Ingeli (Ngeli)	HDALM	30°37'59"	29°37'19"
	Insizwa (Ntsizwa)	HDALM	30°47'11"	29°12'19"
	Koeberg	Free State	28°29'59"	28°32'25"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Melsetter	Free State	28°30'37"	28°41'17"
	Mokhotlong	Lesotho	29°17'44"	29°04'38"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Mount Currie	Old Transkei	30°28'22"	29°25'16"
	Mount Horeb	Free State	28°30'20"	28°27'54"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Spes Bona	Free State	28°32'10"	28°28'59"
	Sunnyside (E)	Free State	28°32'14"	28°31'48"
	Sunnyside (W)	Free State	28°32'14"	28°31'48"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
	Tlaeng Pass	Lesotho	28°54'03"	28°48'28"
	Wilgenhof	Free State	28°29'44"	28°35'08"
Witberge	HDALM			
Wodehouse	Free State	28°32'14"	28°38'39"	
Flarks	Khalong-la-Lithunya (Pass of Guns)	Lesotho	28°49'11"	28°47'14"
Fluvial	Dynevor Park	Eastern Cape	31°08'44"	27°47'05"
	Glen Orchy	Eastern Cape	31°15'16"	27°51'51"
	HDALM	HDALM		
Fluvio-glacial	Bannerman's Pass	HDALM	29°15'25"	29°25'12"
	Bell River valley	Eastern Cape	30°49'38"	27°50'13"
	Carlisle's Hoek	Eastern Cape	30°44'27"	27°58'45"
	HDALM	HDALM		
	Kwa Ntuba	HDALM	29°31'05"	29°17'58"
	Nhlangeni	HDALM	29°29'15"	29°18'54"
	Rifle Spruit	Eastern Cape	30°51'49"	27°57'15"
	Ship's Prow	HDALM	29°05'45"	29°20'01"
	Western Cape	Western Cape Mts.		
Fluvio-glacial deposits	Kwa Ntuba	HDALM	29°31'05"	29°17'58"
	Nhlangeni	HDALM	29°29'15"	29°18'54"
	Rifle Spruit	Eastern Cape	30°51'49"	27°57'15"
	Ship's Prow	HDALM	29°05'45"	29°20'01"
	Western Cape Mts.	Western Cape		
Freeze-thaw	East Griqualand	Kwa-Zulu Natal		
	Eastern Cape Drakensberg	Eastern Cape		
	Eastern Lesotho	Lesotho		
	Giant's Cup (Hudson's Peak)	HDALM	29°37'05"	29°18'08"
	HDALM	HDALM		
	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Mokhotlong	Lesotho	29°17'44"	29°04'38"
	Naude's Pass	Eastern Cape	30°43'35"	28°07'30"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
	Tlaeng Pass	Lesotho	28°54'03"	28°48'28"
	Ubutoane (Ubotoane)	Lesotho	29°12'41"	29°15'46"
Witberge	HDALM			
Freezing	Mount Superior	Western Cape	33°30'49"	19°20'39"
Frost action	Ben MacDhui	Eastern Cape	30°38'44"	27°56'32"
	Bottelnekspruit	Eastern Cape	31°06'00"	27°36'10"
	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Carlisle's Hoek	Eastern Cape	30°44'27"	27°58'45"
	Eastern Cape Drakensberg	Eastern Cape		



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Frost action	Estcourt	Kwa-Zulu Natal	29°00'00"	29°52'44"
	GGHNP	Free State	28°34'05"	28°35'23"
	HDALM	HDALM		
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mohlesi Valley	HDALM	29°28'54"	29°18'08"
	Mokhotlong	Lesotho	29°17'44"	29°04'38"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Naude's Pass	Eastern Cape	30°43'35"	28°07'30"
	Old Transkei	HDALM		
	Ox Bow	Lesotho	28°45'57"	28°39'32"
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"	
Frost climate	Bain's Kloof	Western Cape	33°35'35"	19°07'54"
	Du Toit's Kloof	Western Cape	33°44'30"	19°09'04"
	Hex River Mountains	Western Cape		
	Matroosberg	Western Cape	33°22'46"	19°40'19"
Frost creep	Champagne Castle	Kwa-Zulu Natal	29°05'35"	29°19'55"
	Dynevor Park	Eastern Cape	31°08'44"	27°47'05"
	HDALM	HDALM		
	Little Berg	HDALM		
	Mount Superior	Western Cape	33°30'49"	19°20'39"
	Mount Superior	Western Cape	33°30'49"	19°20'39"
	Nkosazana Cave	HDALM	29°04'19"	29°19'08"
	Nkosazana Valley	HDALM	29°04'14"	29°18'04"
	Tlaeng Pass	Lesotho	28°54'03"	28°48'28"
Frost heave	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Champagne Castle	Kwa-Zulu Natal	29°05'35"	29°19'55"
	Eastern Cape Drakensberg	Eastern Cape		
	Hex River Mountains	Western Cape		
	HDALM	HDALM		
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Mafadi	HDALM	29°12'16"	29°21'39"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Mount Superior	Western Cape	33°30'49"	19°20'39"
	Naude's Pass	Eastern Cape	30°43'35"	28°07'30"
	Nkosazana Cave	HDALM	29°04'19"	29°19'08"
	Nkosazana Valley	HDALM	29°04'14"	29°18'04"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"	
Tlaeng Pass	Lesotho	28°54'03"	28°48'28"	
Frost shattering	Bottelnekspuit	Eastern Cape	31°06'00"	27°36'10"
	Chesney Wold	Eastern Cape	31°06'30"	27°49'00"
	GGHNP	Free State	28°34'05"	28°35'23"
	Groot Winterberg	Western Cape		
	HDALM	HDALM		
	Rose Hill	Eastern Cape	31°06'50"	27°36'00"
	Tlaeng Pass	Lesotho	28°54'03"	28°48'28"
	Western Cape Mts.	Western Cape		
Frost sorting	HDALM	HDALM		
Frost wedging	HDALM	HDALM		
	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Kazani (Kozani)	Lesotho	29°38'47"	29°24'41"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Mafadi	HDALM	29°12'16"	29°21'39"
Makheka	Lesotho	29°13'54"	29°17'17"	



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Frost wedging	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
	Ubutoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"
Frozen ground	Dynevor Park	Eastern Cape	31°08'44"	27°47'05"
	Gray's Pass	HDALM	29°04'14"	29°19'36"
	HDALM	HDALM		
	Mount Superior	Western Cape	33°30'49"	19°20'39"
	Naude's Pass	Eastern Cape	30°43'35"	28°07'30"
	Stellenbosch Mountains	Western Cape	33°57'03"	18°51'31"
Geliflual action	Breede River Mountains	Western Cape		
	Camp's Bay	Western Cape	33°57'00"	18°22'40"
	Drakenstein Mountains	Western Cape		
	Du Toit's Kloof Pass	Western Cape	33°44'30"	19°09'04"
	Giant's Castle	HDALM	29°21'00"	29°28'55"
	Giant's Castle	HDALM	29°21'00"	29°28'55"
	Grahamstown/Port Alfred	Western Cape	33°21'49"	26°31'57"
	Gydo Pass	Western Cape	33°14'11"	19°20'00"
	Gydo Pass	Western Cape	33°14'11"	19°20'00"
	Llandudno	Western Cape	34°00'25"	18°20'31"
	Magaliesburg	Northwest Province	25°59'00"	273216
	Magaliesburg	Northwest Province	25°59'00"	273216
	Pretoria	Gauteng	25°49'05"	28°18'00"
	Stellenbosch Mountains	Western Cape	33°57'03"	18°51'31"
Geliflual apron	Breede River Mountains	Western Cape		
	Camp's Bay	Western Cape	33°57'00"	18°22'40"
	Drakenstein Mountains	Western Cape		
	Du Toit's Kloof Pass	Western Cape	33°44'30"	19°09'04"
	Grahamstown/Port Alfred	Western Cape	33°21'49"	26°31'57"
	Llandudno	Western Cape	34°00'25"	18°20'31"
	Stellenbosch Mountains	Western Cape	33°57'03"	18°51'31"
	Breede River Mountains	Western Cape		
	Camp's Bay	Western Cape	33°57'00"	18°22'40"
	Drakenstein Mountains	Western Cape		
	Du Toit's Kloof Pass	Western Cape	33°44'30"	19°09'04"
	Llandudno	Western Cape	34°00'25"	18°20'31"
	Stellenbosch Mountains	Western Cape	33°57'03"	18°51'31"
	Geliflual deposits	Giant's Castle	HDALM	29°21'00"
Grahamstown/Port Alfred		Western Cape	33°21'49"	26°31'57"
Gydo Pass		Western Cape	33°14'11"	19°20'00"
Gelifluction	Ben MacDhui	Eastern Cape	30°38'44"	27°56'32"
	Breede River Mountains	Western Cape		
	Camp's Bay	Western Cape	33°57'00"	18°22'40"
	Champagne Castle	Kwa-Zulu Natal	29°05'35"	29°19'55"
	Drakenstein Mountains	Western Cape		
	Du Toit's Kloof Pass	Western Cape	33°44'30"	19°09'04"
	Dynevor Park	Eastern Cape	31°08'44"	27°47'05"
	Eastern Cape Drakensberg	Eastern Cape		
	GGHNP	Free State	28°34'05"	28°35'23"
	Grahamstown/Port Alfred	Western Cape	33°21'49"	26°31'57"
	HDALM	HDALM		
	Llandudno	Western Cape	34°00'25"	18°20'31"
	Nkosazana Cave	HDALM	29°04'19"	29°19'08"
	Nkosazana Valley	HDALM	29°04'14"	29°18'04"
	Pretoria	Gauteng	25°49'05"	28°18'00"
	Stellenbosch Mountains	Western Cape	33°57'03"	18°51'31"
	Tiffendell Ski Resort	Eastern Cape	30°40'22"	27°56'53"
Tlaeng Pass	Lesotho	28°54'03"	28°48'28"	
Western Cape Mts.	Western Cape			
Gelifluction (head) deposits	Berlin	Free State	28°30'12"	28°30'14"
	Blanca (E)	Free State	28°33'59"	28°18'42"
	Braamhof	Free State	28°33'44"	28°21'11"



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Gelifluction (head) deposits	Dunblane (S)	Free State	28°32'38"	28°24'19"
	Groenhoek	Free State	28°26'57"	28°37'15"
	Koeberg	Free State	28°29'59"	28°32'25"
	Melsetter	Free State	28°30'37"	28°41'17"
	Mount Horeb	Free State	28°30'20"	28°27'54"
	Spes Bona	Free State	28°32'10"	28°28'59"
	Sunnyside (E)	Free State	28°32'14"	28°31'48"
	Sunnyside (W)	Free State	28°32'14"	28°31'48"
	Wilgenhof	Free State	28°29'44"	28°35'08"
	Wodehouse	Free State	28°32'14"	28°38'39"
Gelifluction deposits	Dynevor Park	Eastern Cape	31°08'44"	27°47'05"
	Eastern Cape Drakensberg	Eastern Cape		
	GGHNP	Free State	28°34'05"	28°35'23"
	HDALM	HDALM		
Gelifluction head deposit	Western Cape Mts.	Western Cape		
	Bell River valley	Eastern Cape	30°49'38"	27°50'13"
	Berlin	Free State	28°30'12"	28°30'14"
	Blanca (E)	Free State	28°33'59"	28°18'42"
	Braamhof	Free State	28°33'44"	28°21'11"
	Dunblane (S)	Free State	28°32'38"	28°24'19"
	Groenhoek	Free State	28°26'57"	28°37'15"
	Koeberg	Free State	28°29'59"	28°32'25"
	Melsetter	Free State	28°30'37"	28°41'17"
	Mount Horeb	Free State	28°30'20"	28°27'54"
	Spes Bona	Free State	28°32'10"	28°28'59"
	Sunnyside (E)	Free State	28°32'14"	28°31'48"
	Sunnyside (W)	Free State	28°32'14"	28°31'48"
	Wilgenhof	Free State	28°29'44"	28°35'08"
Wodehouse	Free State	28°32'14"	28°38'39"	
Gelifluction sheets	HDALM	HDALM		
Gelisolifluction	Groot Winterberg	Western Cape		
	Matroosberg	Western Cape	33°22'46"	19°40'19"
Glacial	Birnam	Eastern Cape	30°54'16"	27°51'15"
	Chesney Wold	Eastern Cape	31°06'30"	27°49'00"
	HDALM	HDALM		
	Rose Hill	Eastern Cape	31°06'50"	27°36'00"
	Western Cape Mts.	Western Cape		
Glacial deposits	Western Cape Mts.	Western Cape		
Glacial erosion	Bain's Kloof Pass	Western Cape	33°35'35"	19°07'54"
	Barkly Pass	Eastern Cape	31°14'11"	27°51'29"
	Bell River valley	Eastern Cape	30°49'38"	27°50'13"
	Bokspruit valley	Eastern Cape	30°52'22"	27°52'06"
	Bottelnekspuit	Eastern Cape	31°06'00"	27°36'10"
	Danger's Hoek	Eastern Cape	30°35'27"	27°44'23"
	Du Toit's Kloof Pass	Western Cape	33°44'30"	19°09'04"
	Franschoek Valley	Western Cape	33°59'05"	19°07'01"
	Hex River Mountains	Western Cape		
	HDALM	HDALM		
	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Jonkershoek Valley	Western Cape	33°58'25"	18°54'53"
	Knockwarren Farm	Eastern Cape	30°55'38"	27°54'45"
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
	Rifle Spruit	Eastern Cape	30°51'49"	27°57'15"
	Stettyn's Kloof	Western Cape		
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
Ubutoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"	
Glacial pavements	Western Cape Mts.	Western Cape		
Glacial polish	HDALM	HDALM		



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Glacial polish	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Jonkershoek Valley	Western Cape	33°58'25"	18°54'53"
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Stettyn's Kloof	Western Cape		
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
	Ubutsoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"
Glacial striations	Western Cape Mts.	Western Cape		
	Barkly Pass	Eastern Cape	31°14'11"	27°51'29"
	Bell River valley	Eastern Cape	30°49'38"	27°50'13"
	Bokspruit valley	Eastern Cape	30°52'22"	27°52'06"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
Glaciation	Western Cape Mts.	Western Cape		
	Kwa Ntuba	HDALM	29°31'05"	29°17'58"
	Nhlangeni	HDALM	29°29'15"	29°18'54"
Gravel sorting	Ship's Prow	HDALM	29°05'45"	29°20'01"
	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
Grèzes litées	Dynevor Park	Eastern Cape	31°08'44"	27°47'05"
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
Ground ice	Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"
Hanging valleys	Danger's Hoek	Eastern Cape	30°35'27"	27°44'23"
Hogsbacks	Matroosberg	Western Cape	33°22'46"	19°40'19"
Ice-shattered ridges	Garden Castle	HDALM	29°45'57"	29°16'24"
	Ntabamnyama	HDALM	29°10'26"	29°28'07"
Ice-stripped areas	Bamboo Mountain	HDALM	29°44'35"	29°21'56"
	Garden Castle	HDALM	29°45'57"	29°16'24"
	Giant's Cup (Hodgon's Peak)	HDALM	29°37'05"	29°18'08"
	Kazani (Kozani)	Lesotho	29°38'47"	29°24'41"
	Mkomazi (Umkomaas)	HDALM	29°28'30"	29°19'47"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Stromness	HDALM	29°42'43"	29°33'43"
	Thaba Ntsho (Thabana Ntsho or Nts'o)	HDALM	29°50'59"	29°09'06"
Ice-wedge casts	Dynevor Park	Eastern Cape	31°08'44"	27°47'05"
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
Ice-wedges	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
	Ubutsoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"
Inversion of weathering profile	Magaliesburg	Northwest Province	25°59'00"	27°32'16"
Kame moraine	Carlisle's Hoek	Eastern Cape	30°44'27"	27°58'45"
Kame-terrace	Bell River valley	Eastern Cape	30°49'38"	27°50'13"
Lacustrine deposits	Birnam	Eastern Cape	30°54'16"	27°51'15"
Mass movement	Amatola(e) Mountains	Eastern Cape		
	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	GGHNP	Free State	28°34'05"	28°35'23"
	HDALM	HDALM		
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Mass movement	Western Cape Mts.	Western Cape		
Moraines	Bain's Kloof Pass	Western Cape	33°35'35"	19°07'54"
	Du Toit's Kloof Pass	Western Cape	33°44'30"	19°09'04"
	Franschoek Valley	Western Cape	33°59'05"	19°07'01"
	Hex River Mountains	Western Cape		
	HDALM	HDALM		
	Knockwarren Farm	Eastern Cape	30°55'38"	27°54'45"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
Needle ice	Western Cape Mts.	Western Cape		
	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Eastern Cape Drakensberg	Eastern Cape		
	Estcourt	Kwa-Zulu Natal	29°00'00"	29°52'44"
	GGHNP	Free State	28°34'05"	28°35'23"
	HDALM	HDALM		
	HDALM	Mike's Pass	28°57'33"	29°13'46"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Little Berg	HDALM		
	Mafadi	HDALM	29°12'16"	29°21'39"
	Mokhotlong	Lesotho	29°17'44"	29°04'38"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Mpumalanga	Long Tom Pass	25°09'00"	30°36'00"
	Old Transkei	HDALM		
	Ox Bow	Lesotho	28°45'57"	28°39'32"
Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"	
Nets	Western Cape Mts.	Western Cape		
	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Estcourt	Kwa-Zulu Natal	29°00'00"	29°52'44"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Little Berg	HDALM		
	Mokhotlong	Lesotho	29°17'44"	29°04'38"
Niche (hollow)	Ox Bow	Lesotho	28°45'57"	28°39'32"
	Bannerman's Pass	HDALM	29°15'25"	29°25'12"
	HDALM	HDALM		
	Kwa Ntuba	HDALM	29°31'05"	29°17'58"
	Nhlangeni	HDALM	29°29'15"	29°18'54"
Niche glacier	Ship's Prow	HDALM	29°05'45"	29°20'01"
	HDALM	HDALM		
Nivation	Bamboo Mountain	HDALM	29°44'35"	29°21'56"
	Ben Nevis	Old Transkei	30°23'11"	29°29'32"
	Berlin	Free State	28°30'12"	28°30'14"
	Blanca (E)	Free State	28°33'59"	28°18'42"
	Bokspruit valley	Eastern Cape	30°52'22"	27°52'06"
	Bottelnekspruit	Eastern Cape	31°06'00"	27°36'10"
	Braamhof	Free State	28°33'44"	28°21'11"
	Bushmansnek	HDALM	29°52'22"	29°08'08"
	Dunblane (S)	Free State	28°32'38"	28°24'19"
	Elandsberg	Eastern Cape	32°30'00"	26°53'14"
	Gaika's Kop	Eastern Cape	32°32'44"	26°57'15"
	Garden Castle	HDALM	29°45'57"	29°16'24"
	Giant's Cup (Hodgon's Peak)	HDALM	29°37'05"	29°18'08"
	GGHNP	Free State	28°34'05"	28°35'23"
	Groenhoek	Free State	28°26'57"	28°37'15"
	Hangklip	HDALM	29°54'46"	29°11'26"
	HDALM	HDALM		
	Ingeli (Ngeli)	HDALM	30°37'59"	29°37'19"
	Ingugu (Nggungqu)	HDALM	30°22'22"	29°32'32"
	Kazani (Kozani)	Lesotho	29°38'47"	29°24'41"
	Koeberg	Free State	28°29'59"	28°32'25"
	Kokstad	Kwa-Zulu Natal	30°32'44"	29°25'16"
Kubutsane	Lesotho	29°52'38"	29°07'10"	
Matroosberg	Western Cape	33°22'46"	19°40'19"	



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Nivation	Melsetter	Free State	28°30'37"	28°41'17"
	Mkomazi (Umkomaas)	HDALM	29°28'30"	29°19'47"
	Mount Currie	Old Transkei	30°28'22"	29°25'16"
	Mount Emma	Old Transkei	30°26'44"	29°35'41"
	Mount Enterprise	Eastern Cape	31°09'04"	27°59'57"
	Mount Fifty	Eastern Cape	30°25'20"	29°23'17"
	Mount Horeb	Free State	28°30'20"	28°27'54"
	Nolangeni	HDALM	30°38'15"	29°26'15"
	Ntabamnyama	HDALM	29°10'26"	29°28'07"
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
	Rockford Ridge	Eastern Cape	32°09'00"	27°16'00"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Spes Bona	Free State	28°32'10"	28°28'59"
	Spitzkop	Old Transkei	30°17'44"	29°31'42"
	Stromness	HDALM	29°42'43"	29°33'43"
	Sunnyside (E)	Free State	28°32'14"	28°31'48"
	Sunnyside (W)	Free State	28°32'14"	28°31'48"
	Tafelberg	Eastern Cape	32°07'46"	26°30'57"
	Thaba Ntsho (Thabana Ntsho or Nts'o)	HDALM	29°50'59"	29°09'06"
	Wilgenhof	Free State	28°29'44"	28°35'08"
Wodehouse	Free State	28°32'14"	28°38'39"	
Zwartberg	HDALM	30°07'19"	29°25'47"	
Nivation niches	GGHNP	Free State	28°34'05"	28°35'23"
	HDALM	HDALM		
Nonsorted circles	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Estcourt	Kwa-Zulu Natal	29°00'00"	29°52'44"
	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Little Berg	HDALM		
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mokhotlong	Lesotho	29°17'44"	29°04'38"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
Ubutsoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"	
Nonsorted polygon	Ben MacDhui	Eastern Cape	30°38'44"	27°56'32"
	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
	Ubutsoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"
Nonsorted stripes	Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"
Palaeosol	Bell River valley	Eastern Cape	30°49'38"	27°50'13"
	Bottelnekspruit	Eastern Cape	31°06'00"	27°36'10"
	Glen Orchy	Eastern Cape	31°15'16"	27°51'51"
	HDALM	HDALM		
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
	Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"
Patterned ground	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
Pebbels	Western Cape Mts.	Western Cape		



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Periglacial processes	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	East Griqualand	Kwa-Zulu Natal		
	GGHNP	Free State	28°34'05"	28°35'23"
	Groot Winterberg	Western Cape		
	HDALM	HDALM		
	Ingeli (Ngeli)	HDALM	30°37'59"	29°37'19"
	Insizwa (Ntsizwa)	HDALM	30°47'11"	29°12'19"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Maluti Range	HDALM		
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Mount Currie	Old Transkei	30°28'22"	29°25'16"
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"	
Tlaeng Pass	Lesotho	28°54'03"	28°48'28"	
Periglacial slope-wash	Rhodes	Eastern Cape	30°47'27"	27°58'06"
Permafrost layers	Mokhotlong	Lesotho	29°17'44"	29°04'38"
	Naude's Pass	Eastern Cape	30°43'35"	28°07'30"
	Sani Pass	HDALM	29°35'35"	29°18'08"
Permafrost processes	Bottelnekspuit	Eastern Cape	31°06'00"	27°36'10"
	Naude's Pass	Eastern Cape	30°43'35"	28°07'30"
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
Pinnacles	Matroosberg	Western Cape	33°22'46"	19°40'19"
Planation surfaces	Western Cape Mts.	Western Cape		
Plateau glaciers	Western Cape Mts.	Western Cape		
Polygons	Ben MacDhui	Eastern Cape	30°38'44"	27°56'32"
	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Eastern Cape Drakensberg	Eastern Cape		
	Hex River Mountains	Western Cape		
	HDALM	HDALM		
	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Little Berg	HDALM		
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Mount Superior	Western Cape	33°30'49"	19°20'39"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Sehlabathebe National Park	HDALM	28°54'11"	29°03'54"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
Tlaeng Pass	Lesotho	28°54'03"	28°48'28"	
Ubutsoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"	
Potholes	Western Cape Mts.	Western Cape		
Protalus ramparts	Berlin	Free State	28°30'12"	28°30'14"
	Blanca (E)	Free State	28°33'59"	28°18'42"
	Bokspruit valley	Eastern Cape	30°52'22"	27°52'06"
	Braamhof	Free State	28°33'44"	28°21'11"
	Dunblane (S)	Free State	28°32'38"	28°24'19"
	GGHNP	Free State	28°34'05"	28°35'23"
	Groenhoek	Free State	28°26'57"	28°37'15"
	Koeberg	Free State	28°29'59"	28°32'25"
	Melsetter	Free State	28°30'37"	28°41'17"
	Mount Enterprise	Eastern Cape	31°09'04"	27°59'57"
	Mount Horeb	Free State	28°30'20"	28°27'54"
	Spes Bona	Free State	28°32'10"	28°28'59"
	Sunnyside (E)	Free State	28°32'14"	28°31'48"



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Protalus ramparts	Sunnyside (W)	Free State	28°32'14"	28°31'48"
	Wilgenhof	Free State	28°29'44"	28°35'08"
	Wodehouse	Free State	28°32'14"	28°38'39"
River terraces	Cathedral Cave valley	Kwa-Zulu Natal	29°01'30"	29°15'00"
	Glen Orchy	Eastern Cape	31°15'16"	27°51'51"
	Ribbok Valley	Free State	28°32'22"	28°36'19"
Rockglaciers	Bokspruit valley	Eastern Cape	30°52'22"	27°52'06"
	Bottelnekspruit	Eastern Cape	31°06'00"	27°36'10"
	Chesney Wold	Eastern Cape	31°06'30"	27°49'00"
	Rose Hill	Eastern Cape	31°06'50"	27°36'00"
Screes	Amatola(e) Mountains	Eastern Cape		
	Bokspruit valley	Eastern Cape	30°52'22"	27°52'06"
	Elandsberg	Eastern Cape	32°30'00"	26°53'14"
	Gaika's Kop	Eastern Cape	32°32'44"	26°57'15"
	GGHNP	Free State	28°34'05"	28°35'23"
	Hogsback	Eastern Cape	32°37'05"	27°00'00"
	Kazani (Kozani)	Lesotho	29°38'47"	29°24'41"
	Rockford Ridge	Eastern Cape	32°09'00"	27°16'00"
Sedimentary sequences	Tafelberg	Eastern Cape	32°07'46"	26°30'57"
	Bottelnekspruit	Eastern Cape	31°06'00"	27°36'10"
	Carlisle's Hoek	Eastern Cape	30°44'27"	27°58'45"
	Rhodes	Eastern Cape	30°47'27"	27°58'06"
	Sani Top	Lesotho	29°35'03"	29°17'02"
Segregation ice	Tlaeng Pass	Lesotho	28°54'03"	28°48'28"
	HDALM	HDALM		
Sheet-wash	Mafadi	HDALM	29°12'16"	29°21'39"
	Cathedral Peak Forestry Research St.	Kwa-Zulu Natal	28°55'05"	29°06'48"
Slip scars	Dynevor Park	Eastern Cape	31°08'44"	27°47'05"
	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
Snow patch conditions	Ubutsoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"
	Bamboo Mountain	HDALM	29°44'35"	29°21'56"
	Ben Nevis	Old Transkei	30°23'11"	29°29'32"
	Berlin	Free State	28°30'12"	28°30'14"
	Blanca (E)	Free State	28°33'59"	28°18'42"
	Bokspruit valley	Eastern Cape	30°52'22"	27°52'06"
	Braamhof	Free State	28°33'44"	28°21'11"
	Bushmansnek	HDALM	29°52'22"	29°08'08"
	Dunblane (S)	Free State	28°32'38"	28°24'19"
	Garden Castle	HDALM	29°45'57"	29°16'24"
	Giant's Castle	HDALM	29°21'00"	29°28'55"
	Giant's Cup (Hodgon's Peak)	HDALM	29°37'05"	29°18'08"
	GGHNP	Free State	28°34'05"	28°35'23"
	Groenhoek	Free State	28°26'57"	28°37'15"
	Hangklip	HDALM	29°54'46"	29°11'26"
	HDALM	HDALM		
	Ingeli (Ngeli)	HDALM	30°37'59"	29°37'19"
	Ingugu (Ngqungqu)	HDALM	30°22'22"	29°32'32"
	Kazani (Kozani)	Lesotho	29°38'47"	29°24'41"
	Koeberg	Free State	28°29'59"	28°32'25"
	Kokstad	Kwa-Zulu Natal	30°32'44"	29°25'16"
	Kubutsane	Lesotho	29°52'38"	29°07'10"
	Melsetter	Free State	28°30'37"	28°41'17"
	Mkomazi (Umkomaas)	HDALM	29°28'30"	29°19'47"
	Mount Currie	Old Transkei	30°28'22"	29°25'16"
	Mount Emma	Old Transkei	30°26'44"	29°35'41"
	Mount Fifty	Eastern Cape	30°25'20"	29°23'17"
	Mount Horeb	Free State	28°30'20"	28°27'54"



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)	
Snow patch conditions	Nolangeni	HDALM	30°38'15"	29°26'15"	
	Ntabamnyama	HDALM	29°10'26"	29°28'07"	
	Sani Pass	HDALM	29°35'35"	29°18'08"	
	Spes Bona	Free State	28°32'10"	28°28'59"	
	Spitzkop	Old Transkei	30°17'44"	29°31'42"	
	Stromness	HDALM	29°42'43"	29°33'43"	
	Sunnyside (E)	Free State	28°32'14"	28°31'48"	
	Sunnyside (W)	Free State	28°32'14"	28°31'48"	
	Thaba Ntsho (Thabana Ntsho or Nts'o)	HDALM	29°50'59"	29°09'06"	
	Wilgenhof	Free State	28°29'44"	28°35'08"	
	Wodehouse	Free State	28°32'14"	28°38'39"	
	Zwartberg	HDALM	30°07'19"	29°25'47"	
Snow patch meltwater	GGHNP	Free State	28°34'05"	28°35'23"	
	GGHNP	Free State	28°34'05"	28°35'23"	
Soil creep	Glen Orchy	Eastern Cape	31°15'16"	27°51'51"	
	Little Berg	HDALM			
	Long Tom Pass	Mpumalanga	25°09'00"	30°36'00"	
	Matroosberg	Western Cape	33°22'46"	19°40'19"	
	Mike's Pass	HDALM	28°57'33"	29°13'46"	
	Western Cape Mts.	Western Cape			
Solifluction	Amatola(e) Mountains	Eastern Cape			
	Berlin	Free State	28°30'12"	28°30'14"	
	Blanca (E)	Free State	28°33'59"	28°18'42"	
	Braamhof	Free State	28°33'44"	28°21'11"	
	Brandwag	Free State	28°34'05"	28°34'36"	
	Butha-Buthe	Lesotho	28°46'01"	28°14'59"	
	Cathedral Cave valley	Kwa-Zulu Natal	29°01'30"	29°15'00"	
	Dunblane (S)	Free State	28°32'38"	28°24'19"	
	East Griqualand	Kwa-Zulu Natal			
	Eastern Cape Drakensberg	Eastern Cape			
	Eastern Lesotho	Lesotho			
	Estcourt	Kwa-Zulu Natal	29°00'00"	29°52'44"	
	Giant's Castle	HDALM	29°21'00"	29°28'55"	
	Glen Orchy	Eastern Cape	31°15'16"	27°51'51"	
	GGHNP	Free State	28°34'05"	28°35'23"	
	Groenhoeck	Free State	28°26'57"	28°37'15"	
	HDALM	HDALM			
	Koeberg	Free State	28°29'59"	28°32'25"	
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"	
	Little Berg	HDALM			
	Matroosberg	Western Cape	33°22'46"	19°40'19"	
	Melsetter	Free State	28°30'37"	28°41'17"	
	Mokhotlong	Lesotho	29°17'44"	29°04'38"	
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"	
	Mount Horeb	Free State	28°30'20"	28°27'54"	
	Mount Superior	Western Cape	33°30'49"	19°20'39"	
	Ntabamnyama	HDALM	29°10'26"	29°28'07"	
	Ox Bow	Lesotho	28°45'57"	28°39'32"	
	Ribbok Valley	Free State	28°32'22"	28°36'19"	
	Sani Pass	HDALM	29°35'35"	29°18'08"	
	Seqouqou	Lesotho	29°31'46"	29°09'07"	
	Spes Bona	Free State	28°32'10"	28°28'59"	
	Sunnyside (E)	Free State	28°32'14"	28°31'48"	
	Sunnyside (W)	Free State	28°32'14"	28°31'48"	
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"	
	Western Cape Mts.	Western Cape			
	Wilgenhof	Free State	28°29'44"	28°35'08"	
	Witberge	HDALM			
	Wodehouse	Free State	28°32'14"	28°38'39"	
	Solifluction deposits	Bushmansnek	HDALM	29°52'22"	29°08'08"



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Solifluction deposits	East Griqualand	Kwa-Zulu Natal		
	Eastern Cape Drakensberg	Eastern Cape		
	Eastern Lesotho	Lesotho		
	Garden Castle	HDALM	29°45'57"	29°16'24"
	Giant's Cup (Hodgon's Peak)	HDALM	29°37'05"	29°18'08"
	Glen Orchy	Eastern Cape	31°15'16"	27°51'51"
	Hangklip	HDALM	29°54'46"	29°11'26"
	Kazani (Kozani)	Lesotho	29°38'47"	29°24'41"
	Mkomazi (Umkomaas)	HDALM	29°28'30"	29°19'47"
	Mount Currie	Old Transkei	30°28'22"	29°25'16"
	Mount Fifty	Eastern Cape	30°25'20"	29°23'17"
	Ntabamnyama	HDALM	29°10'26"	29°28'07"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Stromness	HDALM	29°42'43"	29°33'43"
Witberge	HDALM			
Solifluction lobes	Amatola(e) Mountains	Eastern Cape		
	GGHNP	Free State	28°34'05"	28°35'23"
Solifluction sheet	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
Solifluction slump	Bushmansnek	HDALM	29°52'22"	29°08'08"
	East Griqualand	Kwa-Zulu Natal		
	Eastern Cape Drakensberg	Eastern Cape		
	Eastern Lesotho	Lesotho		
	Garden Castle	HDALM	29°45'57"	29°16'24"
	Giant's Cup (Hodgon's Peak)	HDALM	29°37'05"	29°18'08"
	Hangklip	HDALM	29°54'46"	29°11'26"
	Kazani (Kozani)	Lesotho	29°38'47"	29°24'41"
	Mkomazi (Umkomaas)	HDALM	29°28'30"	29°19'47"
	Mount Currie	Old Transkei	30°28'22"	29°25'16"
	Mount Fifty	Eastern Cape	30°25'20"	29°23'17"
	Ntabamnyama	HDALM	29°10'26"	29°28'07"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Stromness	HDALM	29°42'43"	29°33'43"
Witberge	HDALM			
Solifluction terraces	Ben MacDhui	Eastern Cape	30°38'44"	27°56'32"
	Brandwag	Free State	28°34'05"	28°34'36"
	Cathedral Cave valley	Kwa-Zulu Natal	29°01'30"	29°15'00"
	HDALM	HDALM		
	Ribbok Valley	Free State	28°32'22"	28°36'19"
	Tiffendell Ski Resort	Eastern Cape	30°40'22"	27°56'53"
Solifluction smoothing	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Estcourt	Kwa-Zulu Natal	29°00'00"	29°52'44"
	GGHNP	Free State	28°34'05"	28°35'23"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Mokhotlong	Lesotho	29°17'44"	29°04'38"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
Solution	Long Tom Pass	Mpumalanga	25°09'00"	30°38'00"
	Mike's Pass	HDALM	28°57'33"	29°13'46"
Sorted circles	Gray's Pass	HDALM	29°04'14"	29°19'36"
	HDALM	HDALM		
	Little Berg	HDALM		
	Mount Superior	Western Cape	33°30'49"	19°20'39"
Sorted nets	Butha-Buthe	Lesotho	28°46'01"	28°14'59"



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Sorted nets	Estcourt	Kwa-Zulu Natal	29°00'00"	29°52'44"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Little Berg	HDALM		
	Mokhotlong	Lesotho	29°17'44"	29°04'38"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
Sorted polygons	Eastern Cape Drakensberg	Eastern Cape		
	Hex River Mountains	Western Cape		
	HDALM	HDALM		
	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Little Berg	HDALM		
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mount Superior	Western Cape	33°30'49"	19°20'39"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
	Sehlabathebe National Park	HDALM	28°54'11"	29°03'54"
	Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"
	Ubutoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"
Sorted stripes	Eastern Cape Drakensberg	Eastern Cape		
	Hex River Mountains	Western Cape		
	HDALM	HDALM		
	Little Berg	HDALM		
	Mafadi	HDALM	29°12'16"	29°21'39"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mount Superior	Western Cape	33°30'49"	19°20'39"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
Stone-banked terraces	Giant's Castle	HDALM	29°21'00"	29°28'55"
	HDALM	HDALM		
	Mount Superior	Western Cape	33°30'49"	19°20'39"
	Nkosazana Valley	HDALM	29°04'14"	29°18'04"
	Western Cape Mts.	Western Cape		
Stripes	Eastern Cape Drakensberg	Eastern Cape		
	Hex River Mountains	Western Cape		
	HDALM	HDALM		
	Little Berg	HDALM		
	Mafadi	HDALM	29°12'16"	29°21'39"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mount Superior	Western Cape	33°30'49"	19°20'39"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"	
Surface creep	Western Cape Mts.	Western Cape		
Surface runoff	Khalong-la-Lithunya (Pass of Guns)	Lesotho	28°49'11"	28°47'14"
	Little Berg	HDALM		
Terminal moraine	Carlisle's Hoek	Eastern Cape	30°44'27"	27°58'45"
Terracettes	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Cathedral Peak Forestry Research St.	Kwa-Zulu Natal	28°55'05"	29°06'48"
	Estcourt	Kwa-Zulu Natal	29°00'00"	29°52'44"
	GGHNP	Free State	28°34'05"	28°35'23"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Little Berg	HDALM		
	Long Tom Pass	Mpumalanga	25°09'00"	30°38'00"
	Mike's Pass	HDALM	28°57'33"	29°13'46"
	Mokhotlong	Lesotho	29°17'44"	29°04'38"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Nkosazana Cave	HDALM	29°04'19"	29°19'08"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"	



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Terracettes (turf-banked)	Little Berg	HDALM		
Thawing	HDALM	HDALM		
	Sekakes Mission	Lesotho	30°00'00"	28°21'00"
Thufur	Bell River valley	Eastern Cape	30°49'38"	27°50'13"
	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Estcourt	Kwa-Zulu Natal	29°00'00"	29°52'44"
	Giant's Cup (Hudson's Peak)	HDALM	29°37'05"	29°18'08"
	HDALM	HDALM		
	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Little Berg	HDALM		
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Mohlesi Valley	HDALM	29°28'54"	29°18'08"
	Mokhotlong	Lesotho	29°17'44"	29°04'38"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Naude's Pass	Eastern Cape	30°43'35"	28°07'30"
	Ox Bow	Lesotho	28°45'57"	28°39'32"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
	Tina Head Farm	Eastern Cape	30°39'33"	28°12'49"
	Tlaeeng Pass	Lesotho	28°54'03"	28°48'28"
	Ubutsoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"
Tors	Bannerman's Pass	HDALM	29°15'25"	29°25'12"
	Champagne Castle	Kwa-Zulu Natal	29°05'35"	29°19'55"
	East Griqualand	Kwa-Zulu Natal		
	HDALM	HDALM		
	Ingeli (Ngeli)	HDALM	30°37'59"	29°17'39"
	Insizwa (Ntsizwa)	HDALM	30°47'11"	29°12'19"
	Ka-Langalilabele	HDALM	29°17'03"	29°26'15"
	Kwa Ntuba	HDALM	29°31'05"	29°17'58"
	Mashai	Lesotho	29°44'11"	29°09'07"
	Mbundini	HDALM	28°50'31"	28°56'46"
	Mkomazi (Umkomaas)	HDALM	29°28'30"	29°19'47"
	Mount Currie	Old Transkei	30°28'22"	29°25'16"
	Mzimude	HDALM	29°47'27"	29°14'49"
	Nhlangeni	HDALM	29°29'15"	29°18'54"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Ship's Prow	HDALM	29°05'45"	29°20'01"
	The Judge	HDALM	29°13'22"	29°24'35"
	Danger's Hoek	Eastern Cape	30°35'27"	27°44'23"
Trough-like valleys	Rifle Spruit	Eastern Cape	30°51'49"	27°57'15"
Truncated spurs	Rifle Spruit	Eastern Cape	30°51'49"	27°57'15"
Turf exfoliation	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Little Berg	HDALM		
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
Turf-banked terraces	Champagne Castle	Kwa-Zulu Natal	29°05'35"	29°19'55"
	Little Berg	HDALM		
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mount Superior	Western Cape	33°30'49"	19°20'39"
Valley asymmetry	East Griqualand	Kwa-Zulu Natal		
	Garden Castle	HDALM	29°45'57"	29°16'24"
	GGHNP	Free State	28°34'05"	28°35'23"
	Hangklip	HDALM	29°54'46"	29°11'26"
	HDALM	HDALM		
	Ingeli (Ngeli)	HDALM	30°37'59"	29°37'19"



Phenomenon	Location	Province/District/ Region	Latitude (S)	Longitude (E)
Valley asymmetry	Ingugu (Ngqungqu)	HDALM	30°22'22"	29°32'32"
	Injasuthi (Njesuthi)	HDALM	29°12'00"	29°20'43"
	Insizwa (Ntsizwa)	HDALM	30°47'11"	29°12'19"
	Kokstad	Kwa-Zulu Natal	30°32'44"	29°25'16"
	Mafadi	HDALM	29°12'16"	29°21'39"
	Makheka	Lesotho	29°13'54"	29°17'17"
	Maluti Range	HDALM		
	Mount Currie	Old Transkei	30°28'22"	29°25'16"
	Mount Emma	Old Transkei	30°26'44"	29°35'41"
	Nolangeni	HDALM	30°38'15"	29°26'15"
	Spitzkop	Old Transkei	30°17'44"	29°31'42"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"
	Ubutsoane (Ubotsoane)	Lesotho	29°12'41"	29°15'46"
Valley glaciers	Western Cape Mts.	Western Cape		
Vertical stacking	Butha-Buthe	Lesotho	28°46'01"	28°14'59"
	Letseng-la-Draai (Letseng-la-Terae)	Lesotho	28°53'15"	28°49'32"
	Matroosberg	Western Cape	33°22'46"	19°40'19"
	Mont-aux-Sources	Lesotho	28°46'22"	28°52'16"
	Sani Pass	HDALM	29°35'35"	29°18'08"
	Seqouqou	Lesotho	29°31'46"	29°09'07"
	Thabana Ntleyana	Lesotho	29°28'11"	29°16'06"

Abbreviations

GGHNP	Golden Gate National Park
HDALM	High Drakensberg and Lesotho Mountains
St.	Station
Mts.	Mountains

APPENDIX G
English/Afrikaans Terminology Index

English/Afrikaans Terminology Index

For more geomorphological terminology in Afrikaans, refer to Van der Merwe & De Villiers (1978). *Vir meer Afrikaanse geomorfologiese terme, raadpleeg Van der Merwe & De Villiers (1978).*

Terminology	Preferred usage	Afrikaans
Amphitheatre-shaped hollow	Hollow	Holte
Ancient soil	Palaeosol	Fossilgrond
Arête	Arête	Arête
Avalanche ¹	Avalanche	Lawine
Avalanche deposit	Avalanche deposit	Lawine afsetting
Avalanche front	Avalanche front	Lawine uitloper*
Basalt step	Basalt step	Basaltiese teras*
Biennially frozen ground	Permafrost	Permafrost
Block masses	Boulder bed	Rostbloklaag*
Blockfield	Blockfield	Blokveld
Blockmeer	Blockfield	Blokveld
Blockstream	Blockstream	Blokstroom*
Boulder	Boulder	Rotsblok
Boulder bed	Boulder bed	Rotsbloklaag*
Boulder field	Blockfield	Blokveld
Cattle step	Terracette	Terraset
Channel system	Channel system	Kanaalsisteem
Cirque	Cirque	Trogeinde
Cirque glacier	Cirque glacier	Trogeindeglester
Cirque-like hollow	Erosional hollow	Erosieholte
Clast	Clast	-
Climafrost	Permafrost	Permafrost
Compacted soil	Compacted soil	Gekompakteerde grond
Congelisolifluction	Solifluction	Bodemvloei
Congelifraction	Frost shattering	Ysverwering
Congeliturcation	Cryoturcation	Krioturbasie
Contraction	Contraction	Inkrimping
Corrie	Cirque	Trogeinde
Corrie sheet	Cirque glacier	Trogeindegletser
Crylic layer	Permafrost	Permafrost
Cryogenic process (action)	Cryogenic process (action)	Ys- en sneeuwerking

¹ It is recommended that the term "avalanche" should be specified, e.g. "snow avalanche", "mud avalanche", "stone avalanche" etc., depending on the researcher's findings. *Dit is wenslik om die term "lawine" te kwalifiseer, byv. "sneulawine", "modderlawine", "rotslawine" ens., afhangende van navorsingsbevindinge. In die meeste gevalle kan die woord "-storting", wat 'n beter Afrikaanse beskrywing is, ook gebruik word, byv. "sneeu-storting", "rotsstorting", "modderstorting" ens.*

Terminology	Preferred usage	Afrikaans
Cryoplanation	Cryoplanation	Krioplanasie, vlaktevorming deur ys
Cryoplanation terraces	Cryoplanation terraces	Krioplanasie terrasse
Cryoturbates	Cryoturbation	Krioturbasie
Cryoturbation	Cryoturbation	Krioturbasie
Cryoturbation feature(s)	Cryoturbation feature(s)	Krioturbasie verskynsels
Cutback	Cutback	Terugsnydingsvallei
Cwm	Cirque	Trogeinde
Debris	Debris	Puin
Debris fan	Debris fan	Puinwaaier
Debris flow	Debris flow	Puinvloei*
Debris lobe	Protalus rampart	Protalusstruktuur*
Debris mantle	Debris mantle	Puinoppervlaklaag*
Debris ridge	Debris ridge	Puinrug
Debris tongue	Debris deposit	Puinafsetting
Depressed-centre polygon	Polygon	Poligoon
Desiccation	Desiccation	Uitdroging
Desiccation polygon	Desiccation polygon	Uitdrogingspoligoon*
Diamicton	Diamicton	-
Dislocation (of stones)	Dislocation (of stones)	Verplasing (van klippe)
Downslope sludging (of stones)	Mass movement	Massaverplasing
Earth garland	Turf-banked terrace	Veenterras*
Earth hummock	Earth hummock	Veenbultjie
Earth mound	Earth hummock	Veenbultjie
Embossed rock	Roches moutonnées	Roches moutonnées
Emplacement	Emplacement	Inplasing
Erosion	Erosion	Erosie
Erosional hollow	Erosional hollow	Erosieholte
Esker	Kame moraine	Kamemoreen
Felsenmeer	Blockfield	Blokveld
Fissure polygon	Polygon	Poligoon
Flark	Flark	Moerasagtige gebied
Fluvial	Fluvial	Fluviaal
Fluviatile	Fluvial	Fluviaal
Fluvio-glacial	Fluvio-glacial	Glasio-fluviaal
Fossil ice wedge	Ice-wedge cast	Yswigvorm
Fossil soil	Palaeosol	Fossielgrond
Freeze-thaw weathering	Freeze-thaw weathering	Vries-en-dooiing
Freezing	Freezing	Bevriesing*
Frost action	Frost action	Yswerking
Frost bursting	Frost wedging	Yssplitsing

Terminology	Preferred usage	Afrikaans
Frost churning	Cryoturbation	Krioturbasie
Frost climate	Frost climate	-
Frost cracking	Frost wedging	Yssplitsing
Frost creep	Frost creep	-
Frost heave	Frost heave	Ysopdrukking
Frost mound	Thufur	Veenbultjie, thufur
Frost polygon	Polygon	Poligoon
Frost prying	Frost wedging	Yssplitsing
Frost riving	Frost action, frost wedging	Yswerking, yssplitsing
Frost shattering	Frost shattering	Ysverwering
Frost sorting	Frost sorting	-
Frost splitting	Frost shattering, frost wedging	Ysverwering, yssplitsing
Frost stirring	Cryoturbation	Krioturbasie
Frost thrust	Frost heave	Ysopdrukking
Frost weathering	Frost shattering	Ysverwering
Frost wedging	Frost wedging	Yssplitsing
Frost-crack polygon	Polygon	Poligoon
Frozen ground	Frozen ground	Bevrore grond
Frozen ground phenomenon	Frozen ground phenomenon	Bevrore grond verskynsel
Garland	Stone-banked terrace	Rotsterras*
Garland terrace	Solifluction terrace	Bodemvloeiterras
Geliflual action ²	Geliflual action	Yssmering
Geliflual apron	Geliflual apron	Yssmeringskort*
Gelifluction	Gelifluction	(Kon)gelifluksie
Gelifluction apron	Gelifluction apron	(Kon)gelifluksieskort
Gelifluction bench	Gelifluction terrace	(Kon)gelifluksieterras
Gelifluction deposit	Gelifluction deposit	(Kon)gelifluksieafsetting
Gelifluction head deposit	Gelifluction head deposit	-
Gelifluction lobe	Gelifluction lobe	(Kon)gelifluksielob
Gelifluction mantle	Gelifluction sheet	(Kon)gelifluksieplaat
Gelifluction sheet	Gelifluction sheet	(Kon)gelifluksieplaat
Gelifluction step	Gelifluction terrace	(Kon)gelifluksieterras
Gelifluction terrace	Gelifluction terrace	(Kon)gelifluksieterras
Gelifraction	Frost action, freeze-thaw weathering	Yswerking, vries-en-ontdooi
Gelisolifluction	Gelisolifluction	-
Geliturban	Cryoturbation	Krioturbasie
Gendarme	Pinnacle	Toring
Glacial	Glacial	Glasiaal
Glacial erosion	Glacial erosion	Gletser erosie

² The term "geliflual" is not recognised by the International Permafrost Association (IPA). Die term "yssmering" (geliflual) word nie deur die Internasionale Permafrost Vereeniging (IPV) erken nie.

Terminology	Preferred usage	Afrikaans
Glacial pavement	Glacial pavement	Gletservloer
Glacial phenomenon	Glacial phenomenon	Gletserverskynsel
Glacial polish	Glacial polish	Gletserskuring*
Glacial scratch	Glacial striation	Gletserskraap
Glacial striation	Glacial striation	Gletserskraap
Glaciation	Glaciation	Vergletsring
Glacier	Glacier	Gletser
Glaciofluvial	Fluvio-glacial	Glasio-fluviaal
Grèzes litées	Grèzes litées	Grèzes litées
Ground freeze	Freezing (of the ground)	Bevriësing (van die grond)
Ground ice	Ground ice	Grondys
Hanging valley	Hanging valley	Swewende vallei
Head	Gelifluction head deposit	-
Head deposit	Gelifluction head deposit	-
Hogsback	Hogsback	Isoklinale rug
Hollow	Hollow	Holte
Hummock	Thufur	Veenbultjie, thufur
Ice	Ice	Ys
Ice gneiss	Segregation ice	Gesegregerde ys
Ice lensing	Ice segregation	Gesegregerde ys
Ice segregation	Ice segregation	Gesegregerde ys
Ice shattering	Ice shattering	Ysversplintering
Ice shattered ridge	Ice shattered ridge	Ysversplinteringsrif*
Ice stripping	Ice stripping	Afskuring deur ys*
Ice stripped area	Ice stripped area	Afskuring deur ys*
Ice-wedge	Ice wedge	Yswig
Ice-wedge cast	Ice-wedge cast	Yswigvorm*
Inversion of weathering profile	Inversion of weathering profile	Verweringsinversie*
Kame	Kame	Kame
Kame terrace deposit	Kame terrace deposit	Kameterras (-afsetting)
Kame moraine	Kame moraine	Kamemoreen
Kame terrace	Kame terrace	Kameterras
Lacustral deposit	Lacustrine deposit	Meerafsetting
Lacustrine deposit	Lacustrine deposit	Meerafsetting
Mass flow	Mass movement	Massaverplasing
Mass displacement	Mass movement	Massaverplasing
Mass movement	Mass movement	Massaverplasing
Mass wasting	Mass movement	Massaverplasing
Moraine	Moraine	Moreen
Moraine sheet	Moraine sheet	Moreenplaat
Mud hummock	Earth hummock	Veenbultjie
Mud-debris tongue	Solifluction lobe	Bodemvloeilob

Terminology	Preferred usage	Afrikaans
Needle ice	Needle ice	Naaldys
Needle ice activity	Needle ice activity	Naaldys aktiwiteit, werking
Needle ice stripes	Needle ice activity	Naaldys aktiwiteit, werking
Net	Net	Web*
Niche	Niche hollow	Nisholte*
Niche glacier	Niche glacier	Nisgletser
Nivation cirque	Erosional hollow	Erosieholte
Nivation hollow	Erosional hollow	Erosieholte
Nivation niche	Nivation niche	Sneeuwerkingsnis
Nivation	Nivation	Nivasie, sneeuwerking
Nonsorted circle	Nonsorted circle	Ongesorteerde sirkel
Nonsorted net	Nonsorted net	Ongesorteerde web
Nonsorted polygon	Nonsorted polygon	Ongesorteerde poligoon
Nonsorted step	Nonsorted step	Ongesorteerde trap
Nonsorted stripe	Nonsorted stripe	Ongesorteerde streep
Oversteepened slope	Valley asymmetry	Asimetriese valley
Palaeosol	Palaeosol	Fossielgrond
Patterned ground	Patterned ground	Struktuurbodem, gemodelleerde grond
Pebble	Pebble	Rolsteen
Perennially cryotic ground	Permafrost	Permafrost
Perennially frozen ground	Permafrost	Permafrost
Periglacial process	Periglacial process	Periglasiale proses
Periglacial slope-wash	Periglacial slope-wash	Periglasiale hangafspoeling
Permafrost	Permafrost	Permafrost
Permafrost layer	Permafrost layer	Permafrostgrondlaag
Permafrost process	Permafrost process	Permafrostproses, permafrostwerking
Permanently frozen ground	Permafrost	Permafrost
Pinnacle	Pinnacle	Toring
Pipkrake	Needle ice	Naaldys
Planation surface	Planation surface	Vlaktevormingsoppervlak
Plateau glacier	Plateau glacier	Plato-gletser
Polygon	Polygon	Poligoon
Pothole	Pothole	Maalgat, slagat
Protalus rampart	Protalus rampart	Protalusstruktuur*
Pseudomorph	Ice-wedge cast	Yswigvorm*
Raised centre polygon	Polygon	Poligoon
Raked ground	Needle ice activity	Naaldys aktiwiteit
Raked pattern	Needle ice activity	Naaldys aktiwiteit

Terminology	Preferred usage	Afrikaans
Relict soil	Palaeosol	Fossielgrond
River terrace	River terrace	Rivierterras
Roches moutonnées	Roches moutonnées	Roches moutonnées
Rockglacier	Rockglacier	Rotsgletser
Rock river	Blockfield	Blokveld
Rockblock field	Blockfield	Blokveld
Rockstream	Blockfield	Blokveld
Runoff	Surface runoff	Oppervlakafloop
Scree (deposit)	Scree (deposit)	Talusafsetting
Sedimentary sequences	Sedimentary sequences	Sedimentêre opeenvolgings
Segregated ice	Segregation ice	Gesegregerde ys
Segregation ice	Segregation ice	Gesegregerde ys
Sheet-flow	Sheet-wash	Oppervlakovloei, laminêre vloei
Sheet-wash	Sheet-wash	Oppervlakovloei, laminêre vloei
Sirloin ice	Segregation ice	Gesegregerde ys
Slip scar	Slip scar	Hangverskuiwing*
Slope wash	Periglacial slope-wash	Periglaciale hangafspoeling
Slope weathering	Slope weathering	Hangverwering
Slow mass movement	Mass movement	Massaverplasing
Snow patch	Snow patch	Sneeuholte*
Snow patch conditions	Snow patch conditions	Sneeuholte toestand*
Snow patch meltwater	Snow patch meltwater	Sneeusmeltwater
Soil creep	Soil creep	Grondvloeiing, grondkruip
Soil flow	Soil creep	Grondvloeiing, grondkruip
Solifluction	Solifluction	Bodemvloei
Solifluction apron	Solifluction apron	Bodemvloeiskort*
Solifluction bench	Solifluction terrace	Bodemvloeiterras
Solifluction deposit	Solifluction deposit	Bodemvloeiafsetting
Solifluction lobe	Solifluction lobe	Bodemvloeilob*
Solifluction mantle	Solifluction sheet	Bodemvloeiplate
Solifluction process	Solifluction process	Bodemvloeiproses
Solifluction sheet	Solifluction sheet	Bodemvloeiplate
Solifluction slump	Solifluction slump	Bodemvloeiversakking*
Solifluction step	Solifluction terrace	Bodemvloeiterras
Solifluction terrace	Solifluction terrace	Bodemvloeiterras
Solifluctional forming	Solifluctional smoothing	-
Solifluctional overforming	Solifluctional smoothing	-
Solifluctional smoothing	Solifluctional smoothing	-
Solifluxion	Solifluction	Bodemvloei
Sorted circle	Sorted circle	Gesorteerde sirkel
Sorted net	Sorted net	Gesorteerde web*

Terminology	Preferred usage	Afrikaans
Sorted polygon	Sorted polygon	Gesorteerde poligoon
Sorted step	Sorted step	Gesorteerde trap
Sorted stripe	Sorted stripe	Gesorteerde streep
Spew-frost (formations)	Cryoturbation feature(s)	Krioturbasie verskynsel(s)
Stone field	Blockfield	Blokveld
Stone garland	Sorted step	Gesorteerde trap
Stone-banked lobe	Stone-banked terrace	Rotsterras*
Stone-banked sheet	Stone-banked terrace	Rotsterras*
Stone-banked step	Stone-banked terrace	Rotsterras*
Stone-banked terrace	Stone-banked terrace	Rotsterras*
Stratified scree	Grèzes litées	Grèzes litées
Stria	Glacial striation	Gletserskraap
Striated soil	Needle ice activity	Naaldys aktiwiteit
Striated solifluction deposit	Grèzes litées	Grèzes litées
Striation	Glacial striation	Gletserskraap
Surface creep	Surface creep	Oppervlakkruip, (oppervlak-) reptasie
Surface runoff	Surface runoff	Oppervlakafloop
Taber ice	Segregation ice	Gesegregeerde ys
Taimyr polygon	Polygon	Poligoon
Talus	Scree (deposit)	Talus
Terminal moraine	Terminal moraine	Trogeindemoreen
Terracette	Terracette	Terraset
Thawing	Thawing	Dooi, ontdooiing
Thufur	Thufur	Veenbultjie, thufur
Tilted and dislocated plates	Vertical stacking	-
Tor	Tor	Tor
Trough's end	Cirque	Trogeinde
Trough valley	Trough valley	Trogvallei
Trough-like valley	Trough-like valley	Trogagtige vallei
Truncated spur	Truncated spur	Afgeknotte bergspoor, afgeknotte uitloper
Tundra hummock	Earth hummock	Veenbultjie
Tundra hummock	Earth hummock, unsorted circle	Veenbultjie, ongesorteerde sirkel
Tundra polygon	Polygon	Poligoon
Turf exfoliation	Turf exfoliation	Veenafskilfering*
Turf hummock	Turf hummock	Turfbultjie
Turf-banked lobe	Turf-banked terrace	Veenterras*
Turf-banked step	Turf-banked terrace	Veenterras*
Turf-banked terrace	Turf-banked terrace	Veenterras*
Turf-banked terracette	Turf-banked terracette	Veenterraset*



Terminology	Preferred usage	Afrikaans
U-shaped valley	Trough valley	Trogvallei
Valley asymmetry	Valley asymmetry	Asimetriese vallei
Valley glacier	Valley glacier	Valleigletsjer
Vertical stacking	Vertical stacking	-

***Own translation.**

****Eie vertaling.***