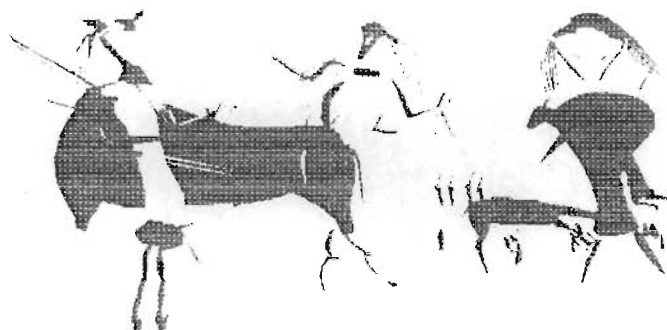
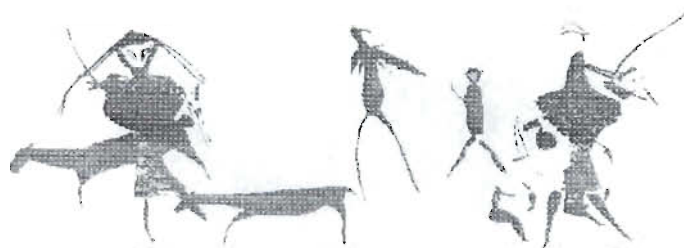


**ASPECTS OF THE WEATHERING OF THE CLARENS FORMATION
IN THE KWAZULU/NATAL DRakensBERG:
IMPLICATIONS FOR THE PRESERVATION OF INDIGENOUS ROCK ART**



by

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ABSTRACT

The Clarens Formation in the KwaZulu/Natal Drakensberg, South Africa, contains some of the World's finest examples of rock art. This heritage is fast disappearing primarily as a result of natural weathering processes. A lack of knowledge of rock weathering mechanisms has resulted in the limited success of attempts to preserve these paintings. In an attempt to elucidate the operative weathering processes, a range of microclimatic, rock temperature, rock moisture, rock chemistry and rock property data were monitored.

Results indicate that rock thermal and moisture regimes are crucial to the weathering of the Clarens Formation. In shelters, where most Bushman paintings are found, the rock moisture regime is the most important control on weathering processes. At exposed sites there is also the potential for thermal stress fatigue as the rapid rates of temperature change may exceed $2^{\circ}\text{C}.\text{min}^{-1}$. The major active weathering processes in the study area are: solution, chemical alteration of minerals, hydrolysis, crystallisation pressures from precipitating salts, together with hydration and dehydration of rock minerals, precipitates and clays. Weathering enlarges the existing pores of the sandstone, so that moisture intake and movement is increased. A more dynamic moisture regime allows for increased rock weathering, and the acceleration of the rate of breakdown. Given the high microporosity of the Clarens Formation (>80%) it will be difficult for rapid moisture changes to occur deep below the rock surface. The rock weathering processes that cause the deterioration of rock art, therefore, take place at, or close to, the rock surface.

As no methods for the preservation of rock art in southern Africa have been developed, there is a need for more research in the future. It is recommended that contemporary management of rock art, in the absence of suitable methods for its preservation, needs to neutralise the effect of environmental changes, such that rock weathering processes are minimised. While considerable international research towards preserving stone buildings has been undertaken, little has been achieved with respect to establishing preservation techniques for indigenous rock art. The most suitable agents for preventing building deterioration are silanes. These minimise the influence of moisture and may also be used for rock art preservation. The future existence of indigenous rock art in the KwaZulu/Natal Drakensberg depends on the development of techniques for its preservation.

PREFACE

**"This fragile, fading heritage, so often misunderstood,
so often trivialised, has something to say to all of us,
irrespective of our social status or background"
(Lewis-Williams, 1990).**

The experimental work described in this thesis was carried out in the department of Geography, University of Natal, Pietermaritzburg from May 1990 to December 1994, under the supervision of Professor Kevin Hall.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others it is duly acknowledged in the text.



K.I. Meiklejohn

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THE TERM BUSHMAN

There is some debate in southern Africa regarding the naming of the hunter-gatherers who left us the rich heritage of rock art. The names "Bushman" (or the collective "Bushmen") and "San" have frequently been used, but both have negative connotations (Lewis-Williams, 1992; Deacon, 1994). The word "Bushman" (or Boesman in the Afrikaans language) has frequently been used to describe a bandit or a robber, while "San" is a Nama (an indigenous southern African people) word for a "vagabond" (Lewis-Williams, 1992; Deacon, 1994). Hunter-gatherer people living in Namibia and Botswana today, do themselves, prefer to be called "Bushmen" (Deacon, 1994). In this thesis the word "Bushmen" is used as a collective name for the hunter-gatherer people who painted their art onto the walls of the Clarens Formation and, in so doing, all negative connotations attached to this word (including sexism) are rejected in the strongest possible way.

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CHAPTER 1

INTRODUCTION

1.1. A BACKGROUND TO THE DETERIORATION OF ROCK ART IN THE KWAZULU/NATAL DRAKENSBERG

A large part of the interior of southern Africa was occupied by the Bushman people for at least 25 000 years until approximately 1870 (Rudner, 1989). These hunter-gatherers, although now extinct in much of southern Africa, have left behind a valuable heritage through their paintings and engravings. Clarens Formation sandstones contain the highest concentration of rock paintings in the world, amounting to approximately 80% of all southern African rock art (Ward, 1979; Rudner, 1989; Batchelor, 1990). Bushman paintings on the Clarens Formation in the KwaZulu/Natal Drakensberg (Fig. 1.1) are located on the walls of shallow shelters or, occasionally, on the lee sides of isolated boulders (Avery, 1974; Ward, 1979; Mazel 1983; Batchelor, 1990; Lewis-Williams and Dowson, 1992).

The discovery of cave paintings in France and Spain, early in this century, precipitated considerable interest in rock art throughout the world (Loubser, 1991). Petroglyphs and paintings are seen in many places; the best known sites are in Australia, France, Spain, and southern Africa (Brunet, pers. comm., 1993). Currently rock art is seen as an important ethnographic record of earlier groups of people, and consequently has been used in cultural research (Rudner, 1989; Lewis-Williams, 1990; Lewis-Williams and Dowson, 1992). An increased awareness of the value of rock art has led to investigations into methods to preserve this cultural heritage in Japan, Australia and a number of countries in Europe, amongst others (Breisch, 1987; Loubser, 1991; Brunet, pers. comm., 1993).

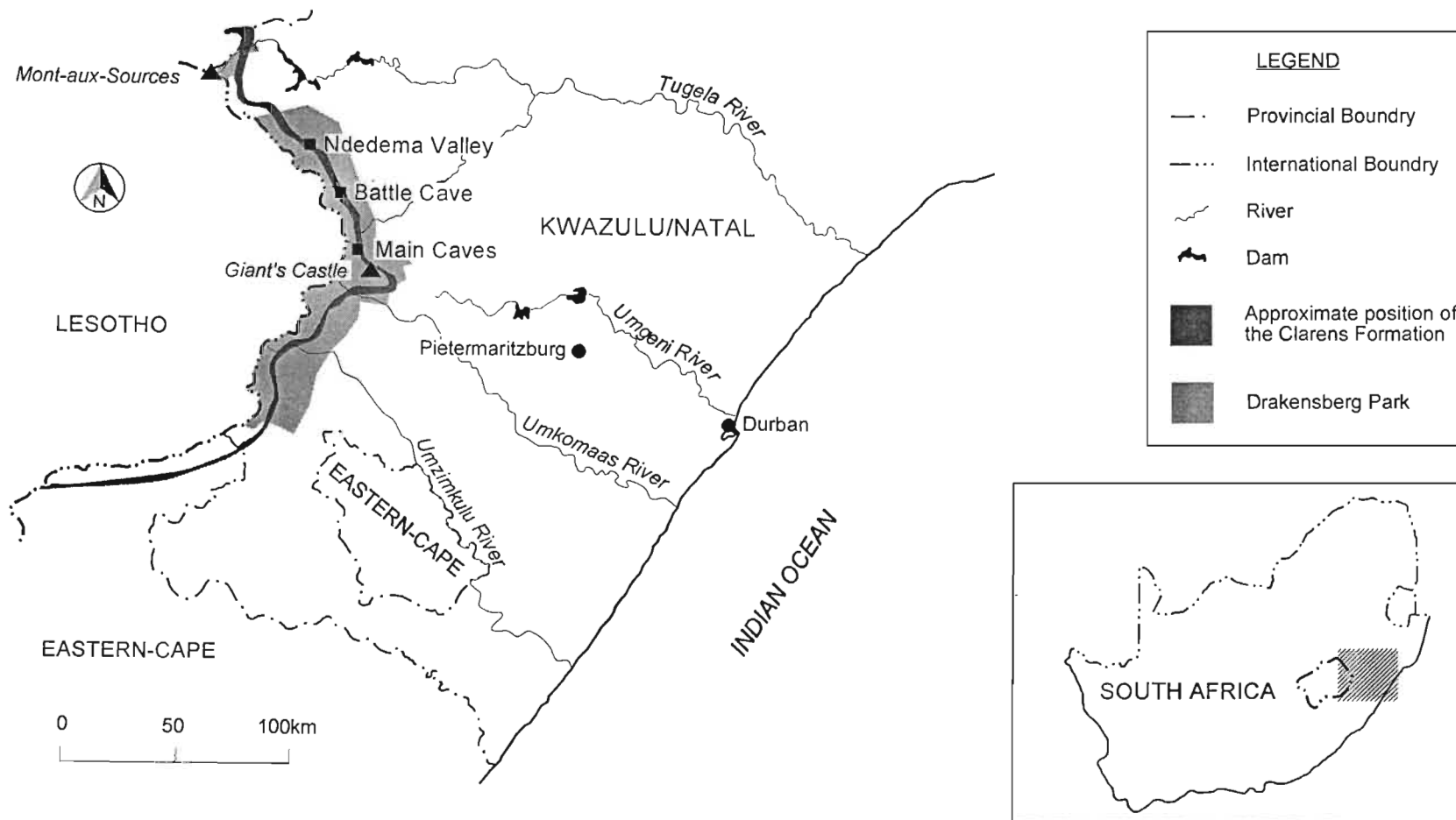


Figure 1.1: Location map for the Clarens Formation in the KwaZulu/Natal province of South Africa.

It has been recognised that rock art is rapidly being lost; earliest records for the deterioration of Bushman paintings in southern Africa are from the western Cape and date to the late Eighteenth Century. The decay of rock art in the KwaZulu/Natal Drakensberg was first noticed in the late Nineteenth Century (Hoffman, 1971; Avery, 1974; van Rijssen, 1987; Rudner, 1989; Batchelor, 1990). Geomorphologists have themselves acknowledged that rock art is decaying; King (1942, p25), uses the deterioration of paintings to provide an "evaluation" of the relative weathering rates of the sandstones onto which they are painted.

Significantly, the Clarens Formation is particularly prone to weathering, thereby resulting in deterioration of the rock art painted on it (Rudner, 1989; Batchelor, 1990; Lewis-Williams and Dowson, 1992). The nature and rate of decay of rock art in southern Africa have previously been, and still are, a source of great concern to many researchers (e.g. Pager, 1971; Avery, 1974; Ward, 1979; Mazel, 1982; National Building Research Institute, 1983; van Rijssen, 1987; Rudner, 1989; Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991; Lewis-Williams and Dowson, 1992). However, although there has been a great deal written concerning the location, interpretation, restoration and archaeological importance of rock art in southern Africa (e.g. van Riet Lowe, 1946; Willcox, 1960, 1980; Hoffman, 1971; Pager, 1971, 1973; Avery, 1974, 1978; Vinnicombe, 1976; Loubser and van Aardt, 1979; Ward, 1979; Lewis-Williams, 1981, 1983, 1990; Mazel, 1981, 1982, 1983; Rudner, 1982, 1989; National Building Research Institute, 1983; Gamble, 1986; van Rijssen, 1987; Lewis-Williams and Dowson, 1989, 1992; Batchelor, 1990; Yates *et al.*, 1990; Loubser, 1991; Pager *et al.*, 1991), little has been achieved in determining the processes of deterioration or techniques for its preservation.

The general lack of understanding concerning specific mechanisms of rock weathering has been cited as a major reason for inadequate research into rock art preservation in southern Africa (Loubser, 1991). Much of the literature concerned with the deterioration of rock art as a result of rock weathering processes has been speculative (e.g. van Riet Lowe, 1946; Hoffman, 1971; Pager, 1973; Avery, 1974; National Building Research Institute, 1983; van Rijssen, 1987; Batchelor,

1990; Lewis-Williams and Dowson, 1992), and few investigations into specific weathering processes have been undertaken. Even within the field of geomorphology, in which weathering processes are a major focus, there is little literature relating to rock weathering in southern Africa. While some research has been conducted into biological weathering and other selected weathering topics relating to the Clarens Formation (Eriksson, 1979; Cooks and Pretorius, 1987; Wessels and Schoeman, 1988; Cooks, 1989), this is not adequate for an understanding of rock weathering processes that cause the deterioration of rock art. Therefore, a need arises for extensive research to evaluate the mechanisms causing the decay of rock art, not only on the Clarens Formation, but throughout southern Africa.

1.2. LITERATURE REVIEW

1.2.1. INTRODUCTION

Given the paucity of data regarding the deterioration of Bushman paintings in the KwaZulu/Natal Drakensberg, considerable research is required to preserve this heritage. Literature from other countries and from allied fields, such as the earth sciences, can be used to help determine the processes responsible for the deterioration of rock art and, potentially, indicate methods for its preservation. Following is a review of literature relevant to the study of rock art deterioration with special emphasis on rock weathering processes.

1.2.2. FACTORS AFFECTING ROCK ART DETERIORATION

It is possible to group rock art deterioration into four broad categories, namely: (1) processes weathering the actual rock base, (2) the deterioration of pigments, (3) damage due to anthropogenic origins, and (4) damage caused by plants and animals.

1. Rock weathering.

Weathering of the rock, on which Bushman paintings are found, is responsible for much of their decay in southern Africa (Avery, 1974; Rudner, 1989; Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991; Woodhouse, 1991; Lewis-Williams and Dowson, 1992) (Fig. 1.2). Weathering, which can occur as a result of physical, chemical and biological activity, is the most difficult agent of rock art deterioration to evaluate and control (Avery, 1974; Rudner, 1989; Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991; Woodhouse, 1991; Lewis-Williams and Dowson, 1992). The effect of rock weathering is the major focus of this thesis, and will therefore be discussed in detail later.

2. The decay of pigments.

The degree of adhesion of a painting to the rock surface and its resistance to decay will depend on the nature of the rock, the nature of the pigment and its binder, and the mode of application of the pigments (Batchelor, 1990; Loubser, 1991). The paints used by Bushmen for their rock art were derived from a variety of sources and will, therefore, vary considerably with respect to their durability (Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991; Lewis-Williams and Dowson, 1992).

Dry pigments and those applied as a paste can easily be removed by rubbing and so may deteriorate rapidly, whereas those that are more fluid can penetrate deeper into the rock making them more durable (Loubser, 1991). Paints that comprise large particles, for example black and white pigments, are unable to penetrate deeply into rock pores and are consequently more prone to deterioration (Batchelor, 1990; Loubser, 1991; Lewis-Williams and Dowson, 1992) (Fig. 1.3). Conversely, small particles, such as those comprising the ochre colours, can penetrate deeply into the pores of the rock and are less prone to deterioration (Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991). However, even



Figure 1.2: Deterioration of rock art due to rock weathering processes in the north shelter of the Main Caves.



Figure 1.3: White pigments from a painting of an armadillo in Battle Cave deteriorating more rapidly than the underlying red paintings.

fine-grained pigments, such as ochre, sometimes fade over time, due to coating by minerals and dust, the direct action of water, and/or exposure to bright light (National Building Research Institute, 1975; Hughes and Watchman, 1983; van Rijssen 1987; Rudner, 1989; Batchelor, 1990; Loubser, 1991). The nature and composition of pigments influences the durability of paintings and therefore plays a role in the determination of the effects of active weathering processes.

3. Damage to rock art by anthropogenic sources.

Damage to rock art sites and to the rock art can be unintentional or deliberate (Gamble, 1986; Rudner, 1989; Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991; Lewis-Williams and Dowson, 1992).

i. Intentional damage by humans.

Southern African rock art is easily accessible to the public and consequently prone to damage by vandals and "trophy hunters" (Avery, 1974; Batchelor, 1990; Lewis-Williams, 1990) (Fig. 1.4). Further vandalism results from graffiti that, apart from defacing the art itself, is exceptionally difficult to remove (Avery, 1974; Gamble, 1986; Rudner, 1989; Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991; Lewis-Williams and Dowson, 1992) (Fig. 1.5). Conscious attempts to enhance the appearance of rock paintings by applying water have been known to cause considerable damage (Batchelor, 1990; Lewis-Williams, 1990; Lewis-Williams and Dowson, 1992). It has been suggested, qualitatively, that vandalism results in more damage to rock art than all other agents combined (Avery, 1974). However, adequate protection of individual sites, legislation and increased public awareness, can facilitate prevention of vandalism (Gamble, 1986; Batchelor, 1990). It is particularly evident that rock art conservation and preservation in France have gained a great deal from increased public awareness, although, there is some debate as to the extent to which increased publicity and accessibility is beneficial (Dragovich, 1986; Breisch, 1987; Aujoulat, pers. comm.,



Figure 1.4: Vandalism of rock art in the north shelter of the Main Caves.

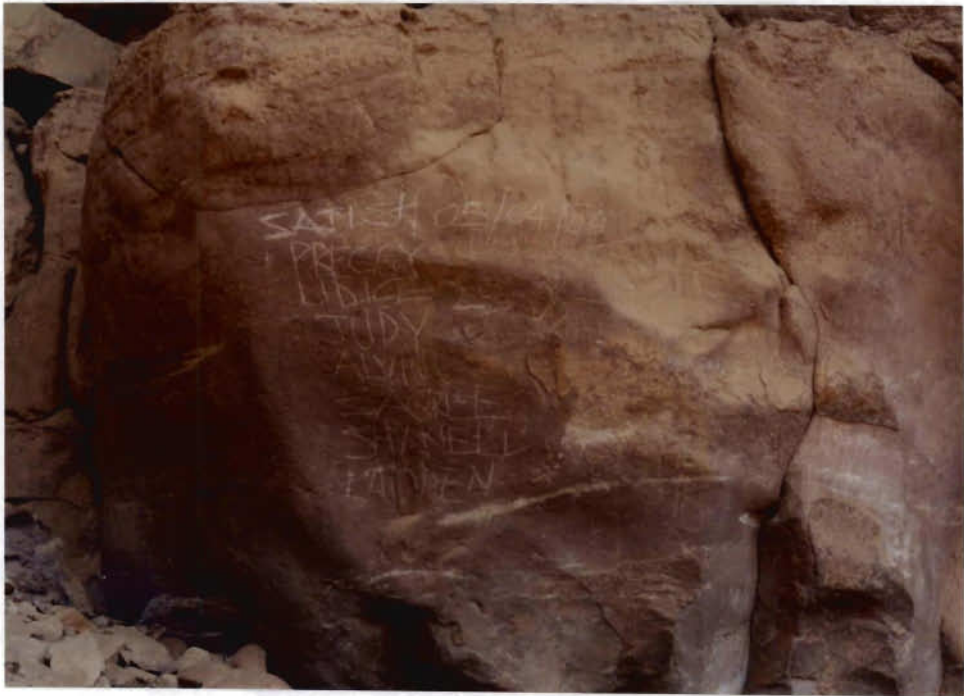


Figure 1.5: Grafitti on walls in the east shelter of the Main Caves.

1993; Brunet, pers. comm., 1993). It is argued that increased visitor numbers may increase the number of vandals and also detrimentally affect the microclimate of caves containing rock art (Dragovich, 1986; Breisch, 1987; Aujoulat, pers. comm., 1993; Brunet, pers. comm., 1993). In some cases, like Lascaux, human visitation resulted in the shelter microclimate being changed to the extent that rock art was being damaged and the cave was closed to the public (Breisch, 1987).

ii. Unintentional damage by humans.

The use of overhangs in the Clarens Formation for shelter by humans has resulted in discernible damage to rock art (Avery, 1974; Batchelor, 1990; Lewis-Williams, 1990; Woodhouse, 1991). Fires lit within shelters for warmth and cooking have two possible effects: first, soot may adhere to the rock surface, thereby obliterating paintings (Avery, 1974; Batchelor, 1990; Woodhouse, 1991) (Fig. 1.6). Second, the rapid temperature changes associated with fires lit within shelters are said to cause rock failure and damage to rock art (Avery, 1974; Clarke, 1978; Batchelor, 1990).

Interested persons visiting rock art sites can, unintentionally, cause considerable damage (Avery, 1974). For example, the action of simply walking over the floor of a shelter can lift dust particles that will adhere to paintings (Avery 1974; Batchelor 1990). Bodies rubbing against shelter walls will remove paintings, especially those pigments comprised of large particles (Batchelor, 1990).

4. Damage caused by biological agents.

Just as humans have used shelters so too have wild and domestic animals (Avery, 1974; Woodhouse, 1991). The major cause of damage from animals results from the removal of pigments by rubbing as well as the coating of paintings by dust lifted from the floor (Avery, 1974; Batchelor, 1990; Woodhouse, 1991). Wasps and birds nests are known



Figure 1.6: Part of the north shelter of the Main Caves used for shelter by humans; note the soot coated ceiling.

to be constructed over paintings (Batchelor, 1990). Further hazards are urine and excreta from wild animals, such as hyrax, and birds that may affect paintings (Batchelor, 1990; Woodhouse, 1991) (Fig 1.7). Fortunately, damage to rock art by urine and excreta is limited to very few sites (Woodhouse, 1991).

Animals are not the only biological agents of rock art deterioration; some plant species have been identified as damaging. Cryptogamic growth is especially detrimental under conditions of low temperature and high humidity (Batchelor, 1990). Lichens, fungi and bacteria cause the breakdown of rock physically, by producing acids from their hyphae which aid weathering by solution and by chemical alteration of minerals (Ollier, 1984; Ciarallo *et al.*, 1985; Jones and Wilson, 1985; Callot *et al.*, 1987; Wessels and Schoeman, 1988; Batchelor, 1990; Cooks and Otto, 1990; Danin and Caneva, 1990; Hall and Otte, 1990; Ortega-Calvo *et al.*, 1991; Woodhouse, 1991; Jatón, 1993) (Fig. 1.8). Larger biological species such as trees widen cracks in rocks thereby potentially damaging the rock on which the paintings are found (Batchelor, 1990).

1.2.2.1. Rock Weathering Processes and their role in the Deterioration of Rock Art

Despite there being a poor perception of weathering mechanisms, many authors (e.g. Avery, 1974; Batchelor, 1990; Lewis-Williams, 1990; Lewis-Williams and Dowson, 1992; Loubser, 1991 and Rudner, 1989) have speculated that certain specific processes are involved in causing rock art deterioration in southern Africa. Further, although climatic variables are said to be important controls on the deterioration of rock art in southern Africa, there is, nevertheless, a poor perception of the role of climate (e.g. Avery, 1974; Rosenfeld, 1985; Hough, 1986; Rudner, 1989; Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991; Woodhouse, 1991; Lewis-Williams and Dowson, 1992). The lack of understanding of the role of weathering in the deterioration of southern African



Figure 1.7: Excretia from bald ibis covering painted rock surfaces in the east shelter of the Main Caves.



Figure 1.8: Damage to rock art, caused by lichen at a site (White elephant Shelter) in the Giant's Castle region of the KwaZulu/Natal Drakensberg.

rock art, is exemplified by a quote from Woodhouse (1991, p7): "The extreme of weathering or shifting of strata is an actual fall of rock".

Despite the absence of adequate research into rock weathering processes in southern Africa, some authors have, qualitatively, identified what they consider to be mechanisms responsible for the deterioration of rock art. A synopsis of these hypotheses and the controls on weathering processes from available literature follows.

1. Temperature.

The role of temperature in rock weathering processes is well documented in geomorphological texts (e.g. Blackwelder, 1933; Griggs, 1936; Peel, 1974; Rice, 1976; Aires-Barros, 1977; Ollier, 1984; Jenkins and Smith, 1990; Galan, 1991; Hall and Hall, 1991). In the KwaZulu/Natal Drakensberg many rock surfaces are exposed to direct sunlight for some part of the day which, apart from affecting the paint pigments, may also cause thermal stresses within the rock (Batchelor, 1990; Loubser, 1991; Rudner, 1989; van Rijssen 1987). Temperature fluctuations around dew point may be especially damaging when moisture is present as they will influence several deterioration processes (e.g. hydration/dehydration and salt crystallisation), through condensation/evaporation cycles (Hough, 1986; Batchelor, 1990).

The determination of the role of temperature is difficult considering the complex relationship between air and rock temperatures (McGreevy, 1985; Hough, 1986). The rock temperature depends on the air temperature, direct solar radiation, air and rock moisture conditions, thermal conductivity, albedo and mineral composition, amongst other factors (Freeman *et al.*, 1963; Clark, 1966; Aires-Barros, 1975; Ollier, 1984; McGreevy, 1985; Hough, 1986; Jenkins and Smith, 1990; Galan, 1991). The impact of surface temperature changes below the rock surface diminishes exponentially and depends on the size and rate of change of temperature (Hough, 1986). This impact extends from

centimetres for diurnal changes to tens of meters for long term changes (Roth, 1965; Peel, 1974; McGreevy, 1985; Hough, 1986; Matsuoka, 1994).

2. Moisture.

An agent of rock art deterioration which is said to be potentially the most damaging is moisture (Avery, 1974; Rudner, 1989; Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991; Lewis-Williams and Dowson, 1992). Moisture responsible for damage to Bushman paintings can be from external or internal sources (e.g. precipitation and mist or seepage and drips respectively: Avery, 1974). Some authors have shown that even humidity changes affect the moisture content of rocks (Dube and Singh, 1972; Venter, 1981a, 1981b), whilst Venter (1981a, 1981b) has shown that humidity changes have more impact on the weathering of mudrock than do temperature changes.

i. Precipitation.

Although most rock art in the Clarens Formation is located under overhangs, some is, nevertheless, exposed directly to rain and running water (Avery, 1974; Lewis-Williams, 1990; Lewis-Williams and Dowson 1992). Much of the precipitation in the KwaZulu/Natal Drakensberg is derived from mist coming into contact with the rock surface, from which even the most sheltered sites are not protected (Avery, 1974). Running water dissolves soluble pigments, causing paintings to fade, and can also deposit minerals on the surface that may cover the art (Avery, 1974; Batchelor, 1990). The former is especially true for paintings on granite and quartzite, where absorption and adhesion of pigments are limited (Batchelor, 1990).

ii. Interstitial rock moisture.

A potentially damaging influence to rock art is ground and interstitial rock water, especially in porous sandstones (Avery, 1974; Lewis-Williams, 1990). This water can both dissolve minerals and

precipitate salts on or near the surface (Avery, 1974; Batchelor, 1990). The solubility of many minerals is largely determined by the pH and Eh values, such that even silica, which is a cement in the many weathering resistant sandstones, becomes soluble in water under acidic conditions (Curtis, 1975; Bennet *et al.*, 1988; Batchelor, 1990; Loubser, 1991).

The evaporation of water at the rock surface results in moisture migration to the rock surface by capillary action (Batchelor, 1990). Some authors claim that more rock breakdown occurs during the drying phase rather than during the moisture absorption phase (Batchelor, 1990; Rosenfeld, 1985). On the other hand, it is also argued that wetting of rocks results in the expansion of minerals which do not return to their original size (Nepper-Christensen, 1965; Venter, 1981a; Hall, 1991), thereby making moisture absorption the primary cause of failure. Yatsu (1988) argues that rock breakdown, when water is adsorbed onto the surface and walls of pore spaces in rocks, is primarily due to the swelling pressures. Swelling pressures are a function of the rock's mineralogy and the period of exposure of the rock to moisture (Yatsu, 1988).

3. Salt Weathering.

Hydration and dehydration of salts associated with changes in moisture and temperature are particularly destructive near the surface of sandstone (Batchelor, 1990). This is particularly so as most of the salts are frequently found mixed with the paint or deposited between paints and the rock surface (Batchelor, 1990; Loubser, 1991). The pressures exerted by crystallisation will depend on the type of salt and the speed and temperature at which crystallisation occurs; the faster the rate of crystallisation, the smaller are the crystals formed and, as a consequence, the pressure is relatively low (Goudie, 1970, 1977, 1984; Winkler and Wilhelm, 1970; Arnold, 1975, 1976; Arnold and Kueng, 1985; Fahey, 1985, 1986; Puehringer *et al.*, 1985; Davison, 1986;

Matsuoka and Kanai, 1988; Batchelor, 1990; Doornkamp and Ibrahim, 1990). Conversely, with slow crystallisation larger crystals result and, consequently, greater pressures are exerted (Goudie, 1970, 1977, 1984; Winkler and Wilhelm, 1970; Arnold, 1975, 1976; Arnold and Kueng, 1985; Fahey, 1985, 1986; Puehringer et al, 1985; Davison, 1986; Matsuoka and Kanai, 1988; Batchelor, 1990; Doornkamp and Ibrahim, 1990). If a constant humidity were maintained, growth and shrinkage of salt crystals would be at a minimum and, therefore, the effects of salt weathering would be minimal (Batchelor, 1990).

4. Surface crusts.

Another aspect influencing Clarens Formation weathering, in which moisture may, or may not, play a role, is the formation of crusts, or patinas, on the rock surface (Walston and Dolanski, 1976; Dorn and Oberlander, 1982; Watchman, 1989; Batchelor, 1990; Loubser, 1991, Woodhouse, 1991). It has been suggested (Batchelor, 1990; Loubser, 1991), that silicate patinas less than 1mm thick result from the precipitation of silica moved, in solution, by capillary action from inside the rock, to the surface (Fig. 1.9). Silica can also form a cement between particles near the surface to form a case-hardened layer which can vary in thickness from 0.3mm to 200mm (Fig. 1.9) (Walston and Dolanski, 1976; Loubser, 1991).

Geomorphological research has shown that patinas are largely derived from extraneous sources and not from inside the rock (Dorn and Oberlander, 1982). Further, there is increasing evidence that patination may frequently be the result of microbiological activity (Dorn and Oberlander, 1982; Watchman, 1989; Loubser, 1991). The durability of these crusts is determined by moisture pH, and the crust constituents (Batchelor, 1990). Here, the crusts are commonly composed of clay minerals, oxides and hydroxides of manganese and/or iron, silica, calcium carbonate and trace elements, the most common being magnesium, calcium, potassium, sodium, titanium and copper (Dorn and

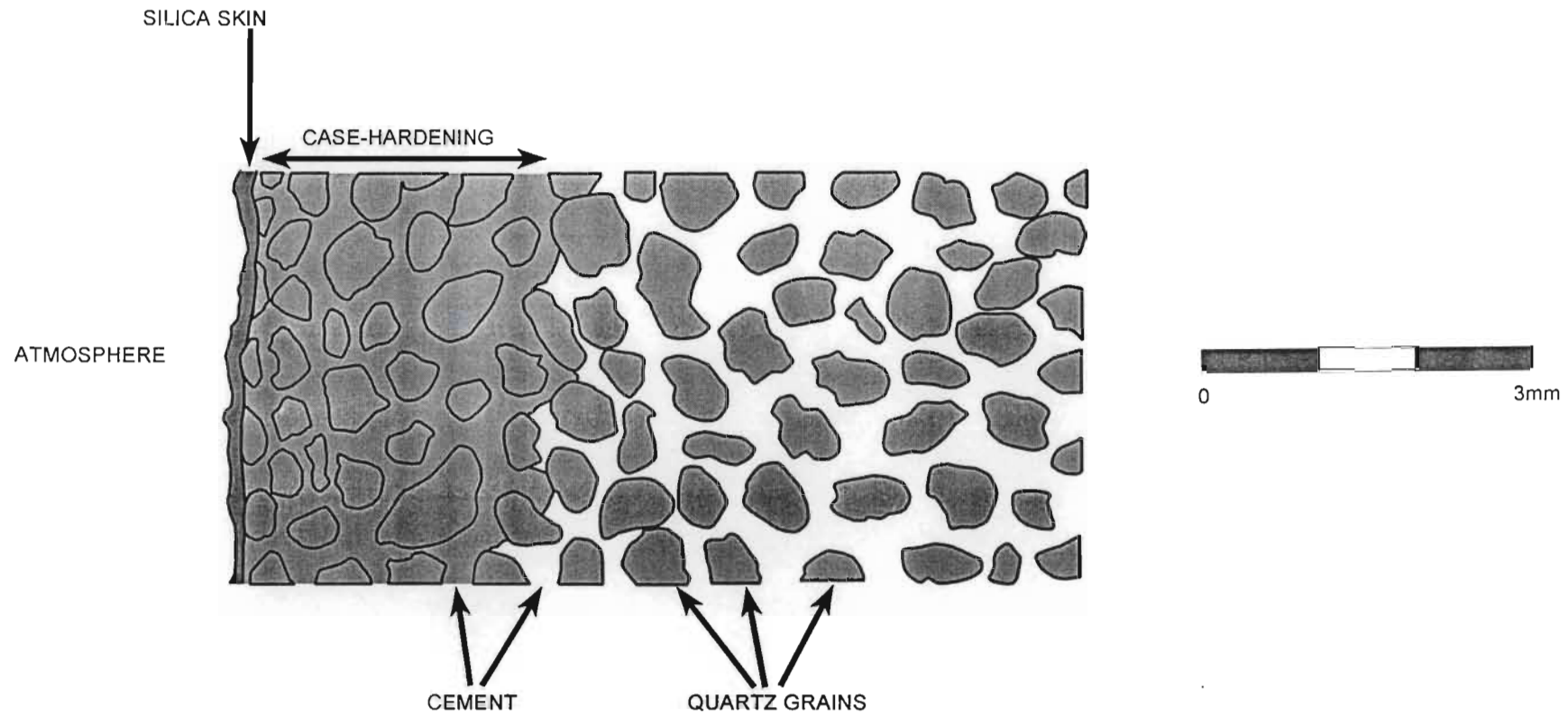


Figure 1.9: Silica skins on, and case-hardening of, sandstones (after Loubser, 1991).

Oberlander, 1982). Patinas vary in thickness between 10 and 30µm but can be as thick as 500µm (Dorn and Oberlander, 1982). Surface crusts can, however, facilitate accelerated sub-surface weathering, thereby causing large fragments to be released which fall away under the influence of gravity (Fig. 1.10) (National Building Research Institute, 1975; Rudner, 1989; Loubser, 1991; Rautureau, 1991).

4. Wind.

Wind has the effect of speeding up evaporation at the surfaces of rocks, potentially causing the precipitation of salts and therefore weathering due to crystallisation pressures (Batchelor, 1990). Wind blown particles have themselves been identified as agents of weathering (Ollier, 1984; Campbell and Claridge, 1987; Hall, 1989). Particles carried by wind act as abrasives that can cause considerable damage to paintings (Batchelor, 1990).

Archaeological studies have hypothesised the possible agents of weathering that cause the deterioration of rock art in the Clarens Formation (e.g. Avery, 1974; Batchelor, 1990; Lewis-Williams, 1990; Lewis-Williams and Dowson, 1992; Loubser, 1991 and Rudner, 1989). However, none provide, or claim to provide, conclusive evidence on specific weathering mechanisms. On the other hand, the geomorphological research cited above provides substantial discussion regarding weathering processes. Geomorphological research can, therefore, provide an insight into the processes leading to the deterioration of rock art and, thereby, facilitate research into its preservation.

1.2.3. MONITORING THE DETERIORATION OF ROCK ART

Weathering of Bushman paintings on the walls of shallow sandstone overhangs in the KwaZulu/Natal Drakensberg is significantly influenced by the local weather conditions (Avery, 1974). The factors that influence the weathering of sandstone and, therefore, the deterioration of rock art, are difficult to isolate as they do not

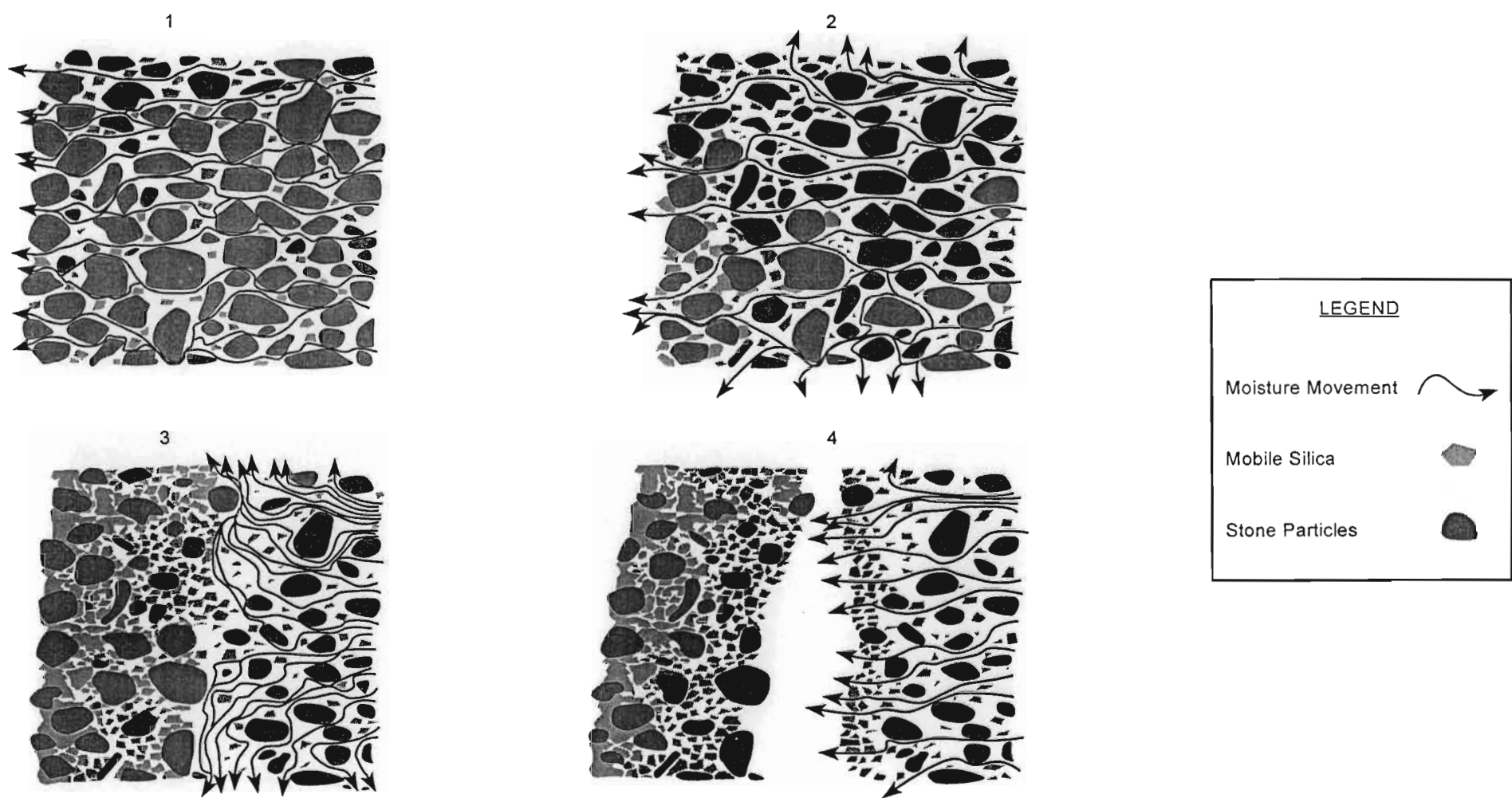


Figure 1.10: The formation of surface crusts and subsequent sub-surface weathering encountered in building stone (after Ratreau, 1991).

operate independently (Batchelor, 1990). Thus, investigations to accurately determine the weathering processes that lead to the deterioration of rock art must precede any preservation attempts (Hough, 1986; Batchelor, 1990). A strategy is required to identify priorities for the preservation of rock art and to identify sites most suitable for research (Hough, 1976; Loubser, 1991). Of particular importance in determining the processes of weathering is the monitoring of the microclimate and, therefore, the monitoring of temperature and humidity (Hough, 1986).

Previous research into the deterioration of rock art (National Building Research Institute, 1976, 1983; Loubser and van Aardt, 1979; Loubser, 1991), has provided little evidence of process determination, although weathering processes, operating individually or synergistically, contribute towards the art's deterioration (Avery, 1974; Rudner, 1989; Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991; Woodhouse, 1991; Lewis-Williams and Dowson, 1992). Determination of active weathering mechanisms requires the monitoring of the environment in which these processes are active (McGreevy and Whalley, 1982; Thorn, 1988; Hall, 1989; Hall and Lautridou, 1991).

Research into the mechanisms causing the decay of rock art extends beyond South Africa. Australian research relating to the environment and mechanisms causing the decay of rock art (Pearson, 1978; Lambert, 1979, 1980, 1989; Dragovich, 1981; Gillespie, 1983; Bell, 1984; Gunn, 1984; Rosenfeld, 1985; Watchman, 1985, 1987, 1989; Clarke and North, 1986, 1987; Hough, 1986; Cook *et al.*, 1989) is considerable and more comprehensive than that from South Africa. However, much of these data are not published and, therefore, of little value to the international community (Brunet, pers. comm., 1993). Similarly, French studies (Andrieux, 1973, 1974; Calède, 1976; Brunet and Vidal, 1979, 1981, 1984, 1988; Brunet *et al.*, 1980, 1983, 1988, 1993, 1990; Soleilhac, 1985, 1986; Vouvre *et al.*, 1985, 1987, 1989; Breisch, 1987; Vidal *et al.*, 1988; Aujoulat, pers. comm., 1993; Brunet, pers. comm., 1993; Dangas, *et al.*, 1993) have shown considerable progress in establishing the microclimate at rock art sites and the processes of rock art deterioration, but these data are published in

French and only readily available in France. Although conditions in the subterranean caves of France are different to north African, southern African and Australian rock art sites, the methodologies used, the emphasis on monitoring microclimatic conditions, and some of the terminology are similar (Flood, 1985; Soleilhavoup, 1985). To standardise research and assist in overcoming the lack of data with respect to the state of rock art in open sites, Soleilhavoup (1985) suggests that basic data and terminology are required for the following themes (Flood, 1985; Rosenfeld, 1985; Soleilhavoup, 1985):

1. The physical, geographical and human environment: past and present.
2. The geomorphological environment: general and particular.
3. Basic research on the causes and effects of weathering and changes in condition of rock art.
4. Recording of rock art for conservation, interpretation and archiving.
5. Conservation of rock art sites.

Preliminary work into the state of rock art should include map, aerial photographic, satellite image and bibliographic analysis with selected criteria and logistical analysis for specific sites (Flood, 1985; Soleilhavoup, 1985). Research into rock art deterioration should be conducted using a multi-disciplinary team comprising geomorphologists, geologists, climatologists, archaeologists and anthropologists, among others (Davis, 1985; Flood, 1985; Rosenfeld, 1985; Soleilhavoup, 1985, 1986; Virili, 1985; Brunet, pers. comm., 1993). It is important to note that the role of the geomorphology is regarded as crucial to studies of rock art deterioration and preservation (Davis, 1985; Flood, 1985; Rosenfeld, 1985; Soleilhavoup, 1985, 1986; Virili, 1985; Brunet, pers. comm., 1993), a view that is apparently not held by most rock art specialists within South Africa.

Hough (1986) suggests that the initial phase of research should be the determination of the link between the ambient microclimate and the processes of deterioration. However, there is sufficient literature regarding the dependence of weathering processes on the ambient microclimate, (Reiche, 1950; Keller, 1978; Lal Gauri, 1978; Ashton and Sereda, 1982; Ollier, 1984; Bernadi and Camuffo, 1985). Therefore, the emphasis of research should be on quantifying this

relationship, a step which Hough (1986) suggested as being subsequent to initial research. Hough (1986) suggests the following approach for monitoring:

1. Concurrent recording of shelter microclimate and art deterioration.
2. Recording of the microclimate within and outside shelters is needed to establish the effect of shelters.
3. The monitoring of sufficient shelters for the research to represent the weathering environment.
4. The measuring of surface and subsurface rock temperatures.
5. Identified methods of data analysis must be used.

Hough (1986) emphasises the need to monitor rock temperature and this is particularly important since, it is widely accepted that rock temperature and not air temperature controls rock weathering processes (Rejmánek, 1971; Smith, 1977; Peel, 1974; Kerr *et al.*, 1984; Ollier, 1984; McGreevy, 1985; Jenkins and Smith, 1990). No known published work from South Africa includes the monitoring of rock temperature for investigating weathering processes. In a single shelter in the Ndedema Valley only air and ground temperature have been monitored (Pager, 1971; National Building Research Institute, 1979).

Research in France, Spain and Australia has taken note of the importance of monitoring rock temperatures so that conditions favouring the deterioration of rock art may be established (Andrieux, 1973,1974; Breisch, 1987; Brunet and Vidal, 1979, 1981; Dragovich, 1981; Brunet *et al.*, 1983, 1990, 1993; Soleilhavoup, 1985,1986; Hough, 1986; Vouvre *et al.*, 1985, 1987, 1988; Vidal *et al.*, 1988; Aujoulat, pers. comm., 1993; Brunet, pers. comm., 1993; Malaurent, *et al.*, date unknown). Indeed, at the Lascaux cave in the Dordogne region of France rock temperatures have been monitored since 1965 (Malaurent, *et al.*, date unknown). Studies by Dragovich (1981), in Australia, show that rock art in shelters still deteriorates where rock and temperatures show little variability. However, the fact that temperature within shelters is relatively stable, does not preclude slight temperature variations from influencing weathering processes (Dragovich, 1981). Thus, the need for accuracy in monitoring temperature variations is great, even in the subterranean environments where temperatures may vary by less than a

degree Celsius over a year (Aujoulat, pers. comm., 1993; Brunet, pers. comm., 1993; Malaurent, *et al.*, date unknown).

Hough (1986), in the methodology cited earlier, fails to acknowledge the importance of monitoring rock moisture content, especially when considering the role that moisture plays in rock weathering processes (Nepper-Christensen, 1965; Roth, 1965; Dube and Singh, 1972; Broch, 1974, 1979; Venter 1981a, 1981b; Ollier, 1984; Hall, 1986, 1988a, 1988b, 1991, 1993a). The porosity and mineralogy of the Clarens Formation are such that moisture is, potentially, a major influence on weathering processes (Batchelor, 1990). Although the importance of moisture in the deterioration of rock art has been acknowledged by many authors, specific deterioration processes have not been elucidated (Avery, 1974; Loubser and van Aardt, 1979; National Building Research Institute, 1979, 1983; Rudner, 1989; Batchelor, 1990; Loubser, 1991; Lewis-Williams, 1992). Evidence for the role of moisture is readily observed within the Clarens Formation; for instance gypsum precipitates, which are derived from solution of calcite in acidic media, are seen around joints at locations of water seepage (Lewis-Williams, 1990; Lewis-Williams and Dowson, 1992). The dependence of rock moisture changes on atmospheric moisture has however, not been considered by any authors concerned with the deterioration of southern African rock art. One study, by the National Building Research Institute (NBRI), determined rock moisture contents for samples at a single site in the Ndedema Valley at one point in time (National Building Research Institute, 1979), but failed to establish how this moisture changed through time. It is the change in moisture conditions and not simply the presence of moisture that will control weathering processes (Hall 1988a, 1991).

From the above discussion, it is evident that future research into the deterioration of rock art must address the paucity of knowledge pertaining to weathering processes. If specific processes of weathering are recognised and understood, it will be possible to investigate methods of preserving rock art.

1.2.4. PRESERVATION OF ROCK ART

Any attempt at preserving rock art must create a stable environment within the rock and at the rock-atmosphere interface (Batchelor, 1990). The building of structures to modify the microclimate and maintain a stable environment can be used to control weathering. Examples of such structures are those used in the French subterranean caves of Lascaux and Font de Gaume, which have been successful in aiding the preservation of rock art (Brunet *et al.*, 1990). Some rock shelters in France, such as the one observed at Abri le Cap Blanc near Les Eyzies, in the Dordogne Region, have even been walled in to protect rock art. However, both subterranean caves and rock shelters in France show little similarity to the shelters containing Bushman paintings in the KwaZulu/Natal Drakensberg, where the large extent of rock art sites would make climatic modification prohibitively expensive. Further, climatic modification, although creating a stable external environment, does little to prevent weathering caused by interstitial moisture (Hough, 1986). Preservation methods will, of necessity, have to vary considerably from site to site and consider local factors such as lithology, microclimate and biological activity (Batchelor, 1990). Preservation should ideally be of such a nature that it that it can be tested, repeated, and reversed if it is found to damage rock art (Loubser, 1991).

The basis for most rock art preservation is the research undertaken in France (e.g. Andrieux, 1973, 1974; Breisch, 1987; Brunet and Vidal, 1979, 1981; Dragovich, 1981; Brunet *et al.*, 1983, 1990, 1993; Soleilhavoup, 1985, 1986; Hough, 1986; Vouvre *et al.*, 1985, 1987, 1988; Vidal *et al.*, 1988; Aujoulat, pers. comm., 1993; Brunet, pers. comm., 1993; Malaurent, *et al.*, date unknown). In the French limestone caves rock deterioration is relatively 'easy' to investigate as limestone contains a single mineral (calcium carbonate), the alteration of which (by carbonation) facilitates its being taken into solution (Hough, 1986). Sandstone has a complex mineralogy and consequently the range of potential rock weathering processes is vast (Hough, 1986). A further difference when comparing caves in Europe to shelters in South Africa and Australia, is that the climate in the caves is relatively stable, whereas in the shelters it is continually

changing (Hough, 1986). Consequently, with respect to southern Africa, much can be gained from consideration of work undertaken in Australia and north Africa where climatic and lithological controls are similar (e.g. Pearson, 1978; Lambert, 1979, 1980, 1989; Dragovich, 1981; Gillespie, 1983; Bell, 1984; Gunn, 1984; Rosenfeld, 1985; Soleilhavoup, 1985, 1986; Watchman, 1985, 1987, 1989; Clarke and North, 1986, 1987; Hough, 1986; Cook *et al.*, 1989; Loubser, 1991; Brunet, pers. comm., 1993).

Several authors have proposed general methods that might help in the preservation of rock art (Avery, 1974; Batchelor, 1990; Loubser, 1991); some of those suggested are:

- i. The erection of barriers and shelters for protection against humans, animals and the direct effects of the weather.
- ii. Improvement of drainage on slopes near shelters by construction of water channels.
- iii. The application of preservatives on the rock surface.
- iv. Impregnation of rocks with protecting substances.
- v. The appointment of resident caretakers.
- vi. The establishment of more effective legislation for the protection of rock art and the education of the public.
- vii. The removal of paintings to protected environments.

More specific methods of preserving the state of the rock surface and, therefore, rock art have been proposed, these are discussed below.

1. Moisture control.

- i. Measures that prevent moisture from reaching a rock surface.

The immediate surroundings of caves and shelters are significant for the preservation of rock art (Brunet *et al.*, 1988). It is particularly important to control vegetation surrounding rock art sites as this regulates moisture infiltration by evaporation and transpiration

(Brunet *et al.*, 1988; Batchelor, 1990). Management of vegetation at the entrances to rock shelters can help control humidity so that a balance is maintained (Batchelor, 1990). Although it is possible to improve drainage around shelters to a limited extent, it is not possible to control interstitial rock moisture (Batchelor, 1990). Totally isolating a rock surface from its environment is almost impossible and would be prohibitively expensive (Batchelor, 1990). Further, removing all sources of moisture from the rock surface may be counter productive in that it might encourage salt crystallisation (Batchelor, 1990).

Silicone drip lines are effective in keeping water from running down the surface of rocks. The drip line is installed on a clean surface along the junction of the vertical and horizontal planes at the upper edge of a rock shelter (Gillespie, 1983; Batchelor, 1990; Loubser, 1991). A problem with the installation of drip lines is that they eventually discolour and peel off (Loubser, 1991). Further, driplines that are effective may impede the formation of silica skins and aid the precipitation of salts thereby accelerating weathering (Watchman, 1989; Loubser, 1991). Drip lines have been used in the KwaZulu/Natal Drakensberg at Beersheba Shelter (Loubser and van Aardt, 1978; National Building Research Institute, 1979, 1983), but no evaluation of the success, or otherwise, of this approach has been forthcoming. Besides drip lines, it is possible to construct gutters, shelters and walls around sites to protect them from running water: methods often used in southern France (Batchelor, 1990; van Riet Lowe, 1946). Any protective screen constructed would need to ensure sufficient ventilation (Batchelor, 1990). Constructions such as screens are suitable in controlling human access (Batchelor, 1990). They are, however, expensive to build, generally not aesthetically pleasing, and divorce the art from its contextual surroundings by creating a 'museum' type of atmosphere (Hough, 1986).

ii. The application of chemical compounds to rock surfaces.

A possible method of controlling interstitial moisture is the application of water repellents to the surface of rocks (Batchelor, 1990). Few attempts have been made to protect rock art with chemical applications, while surface treatment of stone has been conducted on a large scale within the building industry (e.g. Arnold and Price, 1976; Rossi-Manaresi, 1976; Torraca, 1976; Webber, 1976; Felix *et al.*, 1978; British Standards Institution, 1984; Fukuda *et al.*, 1984; Lewin and Wheeler, 1985; Dupas *et al.*, 1989; Hammecker *et al.*, 1992; Henriques, 1992; Kozlowski *et al.*, 1992; Moropoulou *et al.*, 1992; Pien, 1991; Roselli and Rosati, 1992; Saleh *et al.*, 1992; Valdeón *et al.*, 1992; Valle *et al.*, 1985; Villegas and Vale, 1992; Wendler *et al.*, 1992; Wheeler *et al.*, 1992). This valuable research can be applied to preserving rock art by using silicon esters, silanes and acrylics or related polymers at selected sites (Spry, 1975; Batchelor, 1990). Unfortunately, diagnostic and control methods for the treatment of stone materials are poorly developed (Pien, 1991), this applies particularly to rock art preservation (Batchelor, 1990). Further, there is little standardisation in research methodologies used to test preservatives, making comparisons difficult (Henriques, 1992).

A problem with certain sealants is that they often block pores, thereby prohibiting the diffusion of gases, including water vapour, through the rock which can cause subsurface weathering (Batchelor, 1990; Rossi-Manaresi, 1976; Villegas and Vale, 1992; Wendler *et al.*, 1992). Ideally the surface treatment should not change the permeability and porosity of a rock, and although strengthening rock it should still allow both gaseous and fluid diffusion (Rossi-Manaresi, 1976; Torraca, 1976; Valle *et al.*, 1985; Batchelor, 1990; Villegas and Vale, 1992; Wendler *et al.*, 1992; Brunet, pers. comm., 1993; Ozouf,

pers. comm., 1993). Silanes (particularly alkyloxysilanes) fulfil most of the requirements for a suitable sealant, in that they consist of short chained molecules, allowing suitable penetration, with excellent water repelling properties (National Building Research Institute, 1979, 1983; Fukuda *et al.*, 1984; Lewin and Wheeler, 1985; Rudner, 1989; Batchelor, 1990; Loubser, 1991). Adequate absorption of these compounds may be prevented by rapid drying and application should, therefore, be done under cool, dry conditions (Loubser, 1991). Another product that can be used to treat rock surfaces is ethyl silicate which can be used repeatedly as a cementing agent for quartz grains (Loubser, 1991).

Although chemical applications have been used, in an attempt to preserve rock art in the KwaZulu/Natal Drakensberg, their use has been limited (National Building Research Institute, 1979, 1983; Rudner, 1989; Batchelor, 1990). A silicone sealant was applied to paintings at Botha's Shelter in the Ndedema Valley in 1958 (National Building Research Institute, 1979, 1983) (Fig. 1.11). In 1979 some rock surfaces within Botha's Shelter, and Beersheba Shelter, in East Griqualand, were protected with 'Wacker Agent H' (National Building Research Institute, 1979, 1983) (Fig. 1.12). Monitoring of the above sites has not been conducted regularly by the NBRI and now appears to have ceased entirely; as a result, a comparison between treated and untreated rock is not available.

The choice of 'Wacker Agent H' as a preservative by the NBRI followed the testing of several products which showed it to be the most durable. Unfortunately, the most successful stone preservatives used in international tests, silanes (Batchelor, 1990; Fukuda *et al.*, 1984; Loubser, 1991; National Building Research Institute, 1979, 1983; Rudner, 1989), were not investigated by the NBRI, due to the high costs involved (National Building Research Institute, 1979, 1983). Testing of preservation techniques by the



Figure 1.11: A painting of an eland at Botha's shelter, which was covered by a silicone sealant in 1958.



Figure 1.12: A rock surface in Botha's shelter coated with "Wacker Agent H" in 1979.

NBRI was not conclusive on three accounts; first, there was no conclusive evidence for the microenvironment in which rock art deteriorates (National Building Research Institute, 1979, 1983). Second, the processes responsible for the deterioration of rock art are not known. Third, there is no record of the testing of preservation techniques by the NBRI being based on field data. Research in Italy has shown that products used for preservation are, despite their durability in the laboratory, not necessarily the most long-lasting in the field (Roselli and Rosati, 1992). For simulations to be representative, they need to be based on field conditions (McGreevy and Whalley, 1982; Thorn, 1988; Hall, 1989; Hall and Lautridou, 1991).

2. Consolidation of rock surfaces.

To maintain the integrity of a flaking surface some form of consolidation may be required. Methyl methacrylate and polyvinyl butyryl can be used in places, but care should be taken as these compounds can act as sealants, and insufficient evidence has been obtained to test their effectiveness (Loubser, 1991). A product, 'Paraloïd B72', enabled apparent successful consolidation of a rock surface at Niaux, France (Dangas *et al.*, 1993), but it is worth noting that even in France, where rock art preservation is more advanced than anywhere else, this type of research is still in its infancy (Dangas *et al.*, 1993). Silicone resin was used in Sebaaini Shelter in the Ndedema Valley during 1979 in an attempt to consolidate the rock surface (National Building Research Institute, 1979, 1983), but, no literature is available regarding the effectiveness of this measure.

3. Cleaning.

Cleaning of rock art includes the removal of foreign particulate matter, for example soot and dust, graffiti, biological matter, and salt precipitates

from rock surfaces. The objective of cleaning a rock surface is to prevent the potential damage that may occur if it were not cleaned (Dias, 1992). Dias (1992) recommends the following basic methodology for cleaning of stone surfaces:

- i. The cleaning process should be slow enough that it can be controlled.
- ii. Cleaning should not produce products that might be damaging at a later stage.
- iii. The cleaning process should not provide any new discontinuities in the surface of the stone.
- iv. Specialist workers should be used.

Efflorescences of soluble salts are easily removed by applying a poultice of distilled water while less soluble salts can be removed using ammonium carbamate or carbonates instead of water (Loubser, 1991). The method of removal of graffiti depends on its type and nature; the Cave Research Organisation of South Africa (from Gamble, 1986) provides guidelines on graffiti removal and a summary of methods of its removal which were appropriate to the Golden Gate Highlands National Park (Appendix 1).

4. Temperature and insolation control.

Apart from the construction of walls and shelters, little can be done to control temperature and insolation (Batchelor, 1990).

5. Removal of rock art for safe keeping.

Many works of art that have been removed to museums and other controlled environments are in a far better condition than paintings at the sites from which they were removed (Avery, 1974; Batchelor, 1990; Loubser, 1994). A problem with removal of rock art to museums is that it is removed from its natural surroundings, which would be of great

detriment to the place from which it was removed and detract from its contextual significance. Further, in many cases the rock panels on which rock art is painted break during transport (Loubser, 1994). The spiritual significance of the art to the painter needs consideration; removal of some art could amount to desecration (Loubser, 1991; Loubser, 1994).

6. Human and animal access.

Control of sites can be achieved by effective 'site management' (Batchelor, 1990). Mazel (1981, 1982) recommends the following criteria that can be applied to the preservation of rock art located in shelters:

- i. No camping be allowed in shelters of archaeological importance;
- ii. No locational information is made available for any site other than those controlled sites with interpretative displays;
- iii. Fires are prohibited within or near any important sites;
- iv. All archaeological sites are to be assessed and graded, for a conservation and management strategy, as:
 - a. interpretative sites that may receive visitors, which should include interpretative displays,
 - b. sites with high management ratings,
 - c. sites with low management ratings but of scientific importance.

Limiting of access to sites can be achieved by opening up and encouraging the public to visit certain designated sites that are set aside for high intensity utilisation, while not publicising and discouraging visits to other sites (Mazel, 1981, 1982). Possibly the most extreme example of public control has occurred in France where the famous Lascaux Cave has been closed to the public and a copy, Lascaux II, has been made of the original that attracts more than 400 000 visitors a year (Vovré *et al.*, 1989; Delluc *et al.*, 1990, 1992). The construction of wooden boardwalks and balustrades can serve the dual purpose of controlling dust and keeping visitors beyond reach of paintings (Batchelor, 1990). Dust can also be controlled by covering the floor with sand (Batchelor, 1990).

7. Education.

The most effective means of controlling damage caused by humans is education: by using interpretative displays and guided visitation at open sites, brochures and lectures (Batchelor, 1990). French researchers have made considerable efforts to publicise their research (Aujoulat, pers. comm., 1993; Brunet, pers. comm., 1993) and have even gone to the extent of publishing a booklet (Brunet *et al.*, 1990), available in curio shops, in which conservation and preservation of rock art is discussed.

8. Fire Protection.

The negative effects of bush fires can be overcome by the burning of firebreaks around rock art sites (Batchelor, 1990).

9. Legislation.

The National Monuments Council Act (No. 28 of 1969 as amended by No. 13 of 1981) provides for fines of up to R5 000 (c. \$1 500) that can be implemented for any person removing or interfering with rock art in any way (Batchelor, 1990). This act includes the requirement that permits be required for any work that will remove or damage paintings (Loubser, 1991).

Initial legislation to protect rock art was passed in 1911 as the "Bushman Relics Protection Act No. 22", and was extended by Act No. 6 of 1923 to include natural and historical objects (Rudner, 1989; Batchelor, 1990). A supporting administrative body "The Commission for the Preservation of Natural and Historical Monuments", was created as a consequence of the extension of this act (Batchelor, 1990). In 1934 this act was replaced by Act No. 4 that also included control over archaeological excavations. (Rudner, 1989; Batchelor, 1990). After several amendments (Act No. 9

of 1937 and Act No. 13 of 1967) this act was replaced by Act No. 28 of 1969 (National Monuments Act). As a result the National Monuments Council was established to replace The Commission for the Preservation of Natural and Historical Monuments (Rudner, 1989; Batchelor, 1990). The current Act, amended in 1986, is included as an appendix to the Environmental Conservation Act (Batchelor, 1990).

1.3. THE PROBLEM

Given that the valuable heritage of South African rock art is deteriorating and, without intervention, will disappear, it is surprising that the attempts at preserving Bushman paintings have not been more comprehensive (National Building Research Institute, 1983; Rudner, 1989; Batchelor, 1990). Only one detailed study, by the National Building Research Institute (1983), has been undertaken to investigate the processes that are causing the deterioration of rock art in South Africa. There has never been any attempt to monitor microclimatic conditions, which influence rock weathering processes, in the field. Without measuring field conditions it is impossible to accurately determine the weathering mechanisms that are causing the deterioration of rock art.

Although research in France has successfully identified many processes that cause the deterioration of rock art, the weathering environment there is different to that in the KwaZulu/Natal Drakensberg (Loubser, 1991; Aujoulat, pers. comm., 1993; Brunet, pers. comm., 1993). Therefore, research in the KwaZulu/Natal Drakensberg cannot rely on studies from elsewhere in the world. The poor development of materials, diagnostic and control methods for treating stone materials (Pien, 1991), which could be used in rock art preservation, further emphasises the need for additional research.

From evidence presented in this chapter, there is a need for considerable research into rock art deterioration and preservation in the KwaZulu/Natal Drakensberg: this applies particularly to rock weathering processes. The research focus should be on establishing the environment and processes

associated with the deterioration of rock art. Knowledge of weathering mechanisms will facilitate investigation of potential methods of art preservation.

1.4. AIMS AND OBJECTIVES

The dependence of weathering on the ambient conditions requires that several microclimatic and other variables are monitored, including: solar radiation, air temperature, rock temperature, rock moisture content, relative humidity, wind speed and wind direction. Knowledge of this environment will allow the development of a database that can form the foundation for weathering simulations. Simulations, using instrumentation that cannot be used in the field and offering time compression, facilitate determination of weathering mechanisms and rates. An awareness of the mechanisms of deterioration will provide a suitable platform upon which the preservation of rock art can be investigated. Testing preservation techniques is also possible under simulated conditions.

Given the background of a lack of knowledge of weathering processes and expertise within the Earth Sciences there is a need to re-evaluate research into the mechanisms that are responsible for the deterioration of rock art in South Africa. The relevance of geomorphological investigations into weathering mechanisms extends beyond that of being of academic interest to the geomorphologist as they can influence research into rock art preservation. Thus, the insights gained into weathering by Earth Science research will provide a significant contribution to the fields of geomorphology and archaeology, and potentially lead to the preservation of the international heritage that is rock art.

CHAPTER 2

SETTING

The effects of geology, situation and the ambient microclimate on weathering processes are well documented (Ollier, 1984). Thus, it is necessary, in any investigation into the processes causing the deterioration of rock art, to consider these factors.

2.1. GENERAL GEOLOGY OF THE CLARENS FORMATION

Literature regarding the geology of the Clarens Formation is sparse, the only detailed investigation being those by Eriksson (1979a, 1979b, 1983). The most recent study of Eriksson (1983) is the most comprehensive and provides the basis for a discussion of the general geology. However, due to the vast area covered by the Clarens Formation, specific sites in this thesis (e.g. Battle Cave) are not adequately covered by the work of Eriksson (1983). The Clarens Formation, which is the product of an initial alluvial fan deposition followed by aeolian dune deposition (Fig. 2.1), is located between the Elliot Formation sandstones and the basaltic lavas of the high Drakensberg (Fig. 2.2) (Eriksson, 1983). A variety of sedimentary rock types, ranging from mudstones to coarse conglomeratic sandstones, characterises the Clarens Formation (Eriksson, 1983). Generally, the Clarens Formation is composed mainly of fine to very-fine grained sands, which are dominantly sub-rounded to sub-angular with subordinate rounded and angular forms (Eriksson, 1983). Quartz-rich feldspathic wackes make up the major constituents of this series, with plagioclase (Na and Ca aluminosilicates) accounting for 5% to 25% of individual sections; accessory minerals present are zircon (zircon silicate), hornblende (aluminosilicate containing one or more of the following: Mg, Fe(II), Fe (III), Ca, and Na), sphene (titanite), and garnet (silicate) (Eriksson, 1983). Other interstitial constituents include clay minerals and related phyllosilicates, such as kaolinite, illite, mica, chlorite, and smectite (Eriksson, 1983). Certain of the clay

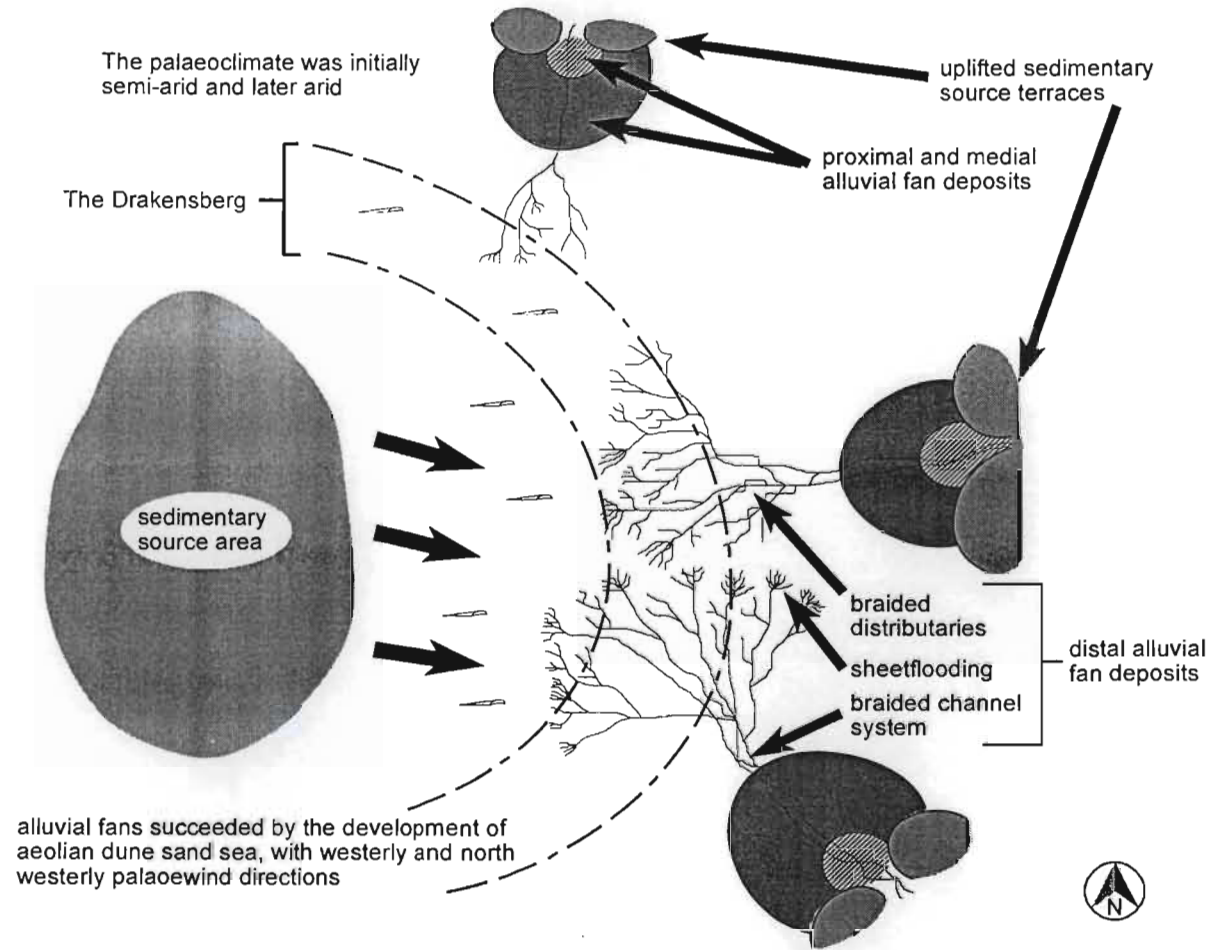


Figure 2.1: Proposed palaeoenvironment of deposition for the Clarens Formation in the KwaZulu/Natal Drakensberg and north eastern Orange Free State, South Africa (after Eriksson, 1983) (*The diagram is not drawn to scale*).

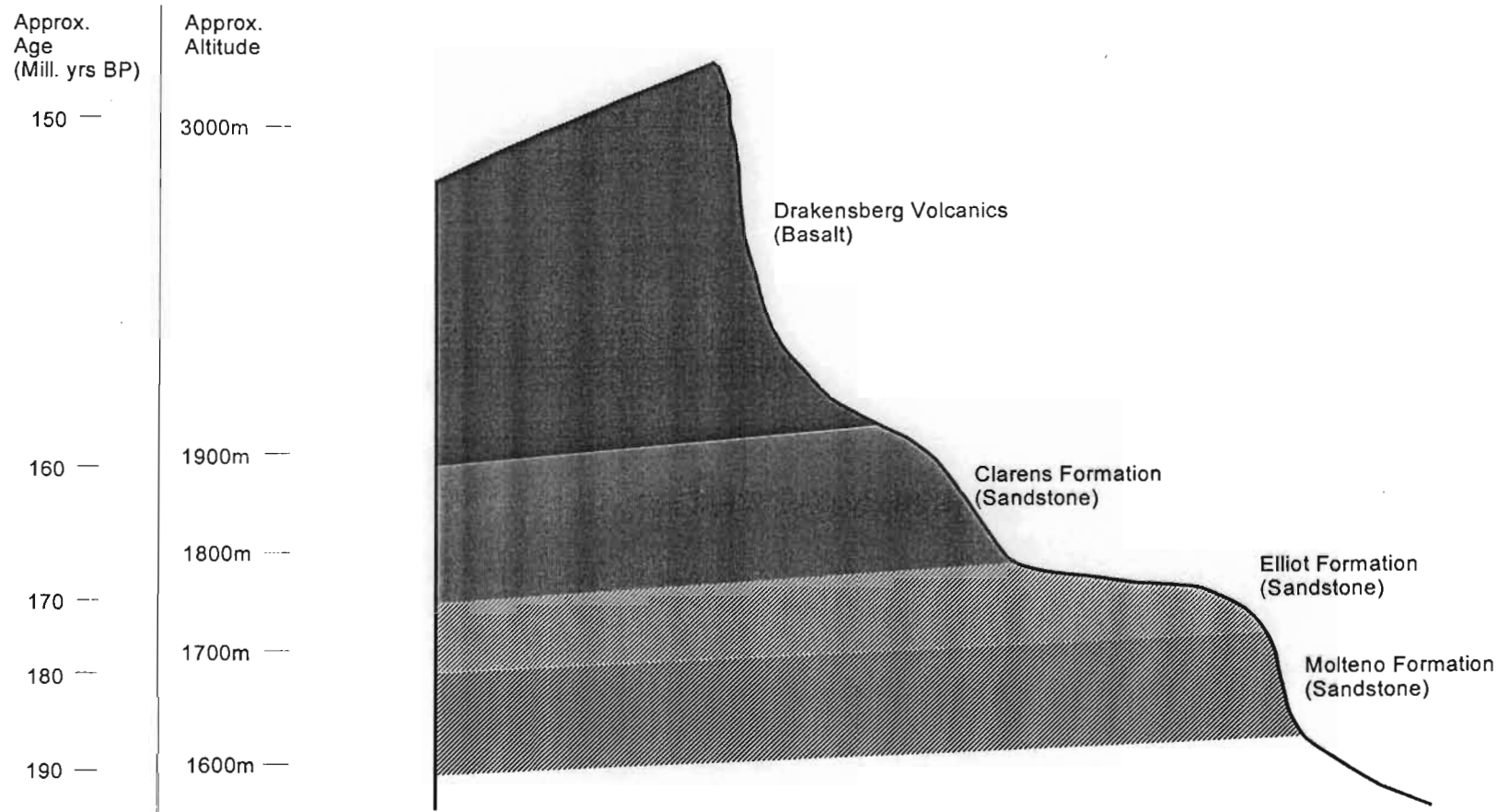


Figure 2.2: Geological setting of the Clarens Formation in the KwaZulu/Natal Drakensberg, South Africa (after Eriksson, 1983) (the diagram is not drawn to scale).

minerals present, notably ^{smectite}kaolinite and illite, can shrink and swell with changes in temperature and moisture (Ollier, 1984).

Where cementing agents are present in the Clarens Formation they are either calcareous or siliceous (Eriksson, 1983). Eighteen per cent of the Clarens Formation has been found to have a calcite cement, while silica is found as a cement in 43% of the Formation (Eriksson, 1983). The above cements rarely occur together; when they do, the calcite post-dates the silica (Eriksson, 1983). Calcite, being soluble under acidic conditions, facilitates the weathering of sandstone by solution processes, given the availability of adequate moisture. Recognising that the recorded pH of rain water in Giant's Castle is frequently around five, then the presence of calcite is important in understanding the nature of the chemical weathering of the Clarens Formation.

Within the Clarens Formation, Eriksson (1983) identifies four lithofacies (Fig. 2.3):

1. A poorly sorted massive sediment facies, characterised by poorly sorted, massive sedimentary rocks, that show local evidence of reworking. This facies is restricted to the Highmoor area of the Drakensberg.
2. Very fine-grained to fine-grained sandstones predominate a planar stratified fine sediment facies that is inter-layered with subordinate siltstones and mudstones. This lithofacies, which predominates in the Giant's Castle, Highmoor and Kamberg regions, represents the initial alluvial fan deposition discussed previously. This planar stratified fine sediment facies is also found at the bottom of the Clarens Formation in the southern KwaZulu/Natal Drakensberg and in the Champagne Castle area.
3. The third lithofacies, is a cross-bedded sandstone facies, characterised by planar and trough cross-bedded sandstones with subordinate beds of massive argillite, inter-stratified with arenaceous deposits. This lithofacies can be split into two groups: the first being characterised by planar cross-stratified sandstones with inter-layered argillite, and the second, composed of trough, cross-bedded sandstones and inter-stratified fine material.

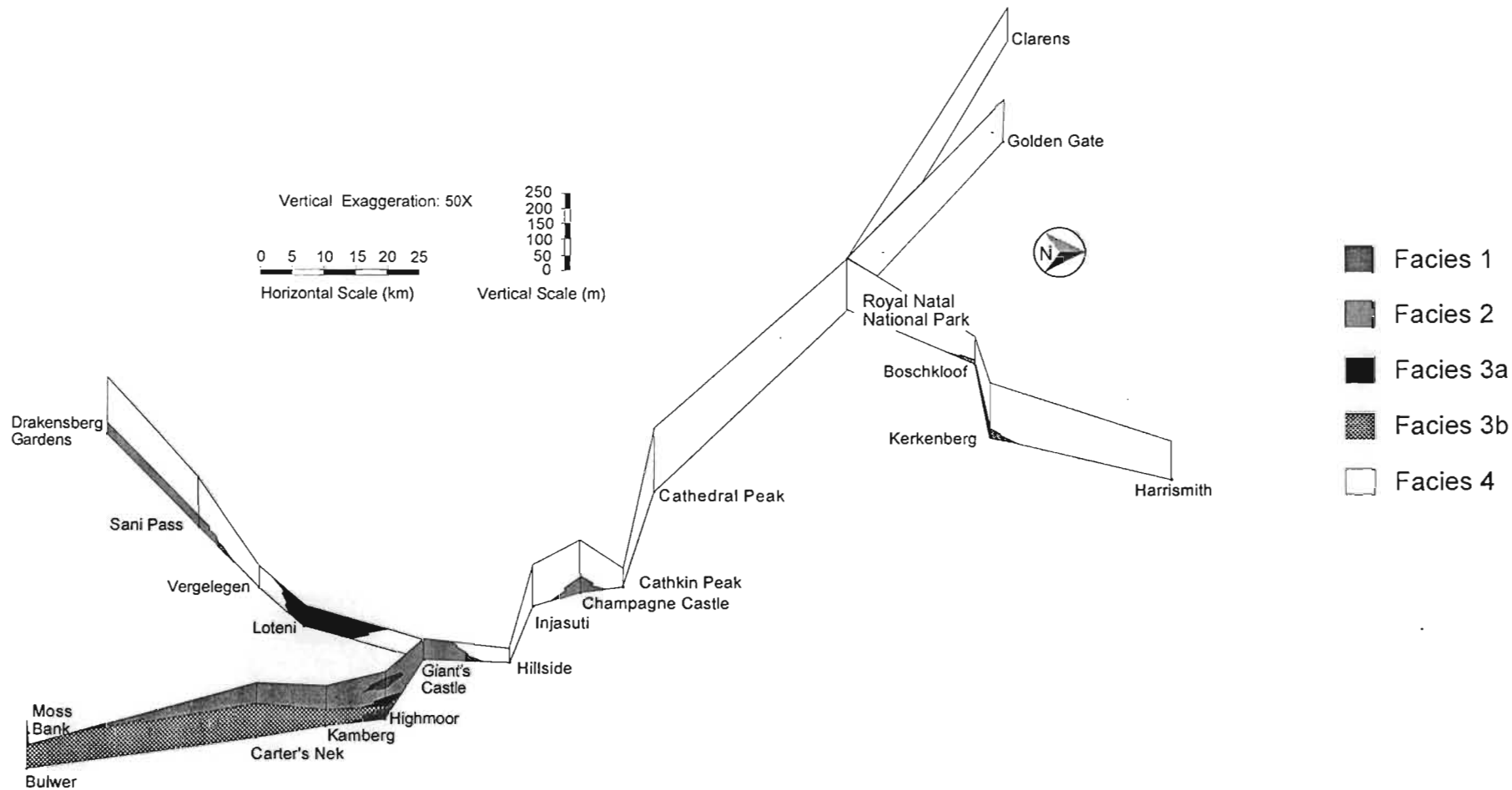


Figure 2.3: Fence diagram of the four lithofacies of the Clarens Formation in KwaZulu/Natal and north-eastern Orange Free State, South Africa (after Eriksson, 1983).

4. The forth and dominant lithofacies in the Clarens Formation in the KwaZulu/Natal Drakensberg comprises large scale planar cross-bedded and massive sandstone predominately of aeolian origin. This facies includes a range of other sedimentary rocks from siltstones to medium-grained arenites dominated by very fine-grained to fine-grained sandstone.

Given both the cementing by calcite and the presence of interstitial clay minerals, both of which are affected by changes in moisture, it is probable that moisture will affect the weathering of the Clarens Formation. This is especially so when considering that much of the sequence at the Main Caves study site is made up by fluvially deposited sediments and consequently contains many salts that precipitated out during lithogenesis.

2.2. STUDY SITES

Two sites were chosen which serve as the focus of this thesis: namely the Main Caves near the main rest camp and Battle Cave near the Injasuti rest camp, in the Giant's Castle Region of the Drakensberg Park in the KwaZulu/Natal province of South Africa (Fig. 2.4). The above sites were chosen because of their protected locations, both being open air fenced museums administered by the Natal Parks Board. Further, the different lithologies found at the two sites means that the study is more representative of the lithogenic variety occurring in the Clarens Formation of the KwaZulu/Natal Drakensberg.

2.2.1 MAIN CAVES MUSEUM, GIANT'S CASTLE

The Main Caves Museum is located within Giant's Castle Game Reserve at an altitude of approximately 1800m (Fig. 2.4). This was the initial location of the study and was chosen primarily for reasons of accessibility and security. The museum is fenced and is visited daily by a guide, employed by the Natal Parks Board, who assisted with data collection.

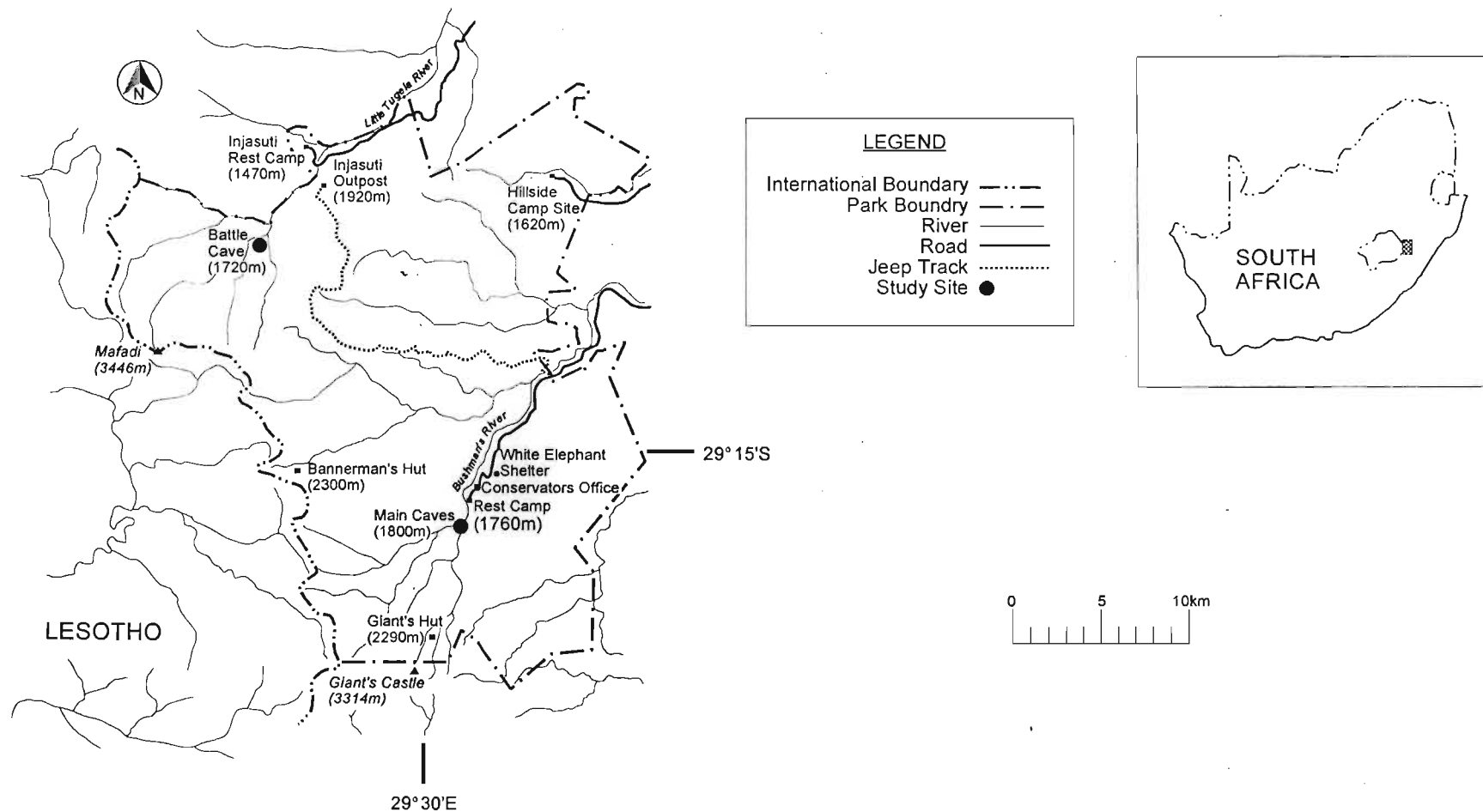


Figure 2.4: Location map for the study sites in the Giant's Castle region of the Drakensberg Park, KwaZulu/Natal, South Africa.

The Main Caves study site is situated entirely within the Clarens Formation sandstone (Eriksson, 1983; Eriksson, pers. comm., 1991). While the Clarens Formation is of aeolian origin over most of the KwaZulu/Natal Drakensberg, this location is within what Eriksson (1983) identifies as a planar stratified fine sediment facies, which is part of an initial alluvial fan deposit (facies 2 of the preceding description). Evidence for fluvial deposition of the sediments found at the Main Caves is indicated by tabular planar and trough cross-bed sets, small channels, convolutions, mud volcanoes, fold structures and fossils (Fig. 2.5) (Eriksson, 1983).

Of major significance is the fluvial origin of the sequence at the Main Caves, as it accounts for the occurrence of components that are particularly prone to weathering by solution processes. The presence of soluble minerals and cementing agents as well as clay minerals suggest that moisture is potentially a major influence on weathering and consequently upon the decay of the rock art found at this location.

The Main Caves study site consists of two shelters, one east-facing and the other north-facing, which will be referred to as the east shelter and the north shelter respectively in this study (Fig. 2.6, 2.7). Automated logging equipment was located only in the north-facing shelter. However, temperature sensors for the manual recording of rock temperature were positioned so as to provide adequate coverage of the study site. Samples used for the monitoring of rock moisture changes were located at three different positions within the Main Caves study site (specific details concerning monitoring equipment will be discussed in Chapter 3)

2.2.2. BATTLE CAVE, INJASUTI VALLEY

Battle Cave is located in the Injasuti Valley, at an approximate altitude of 1700m, to the north of the Giant's Castle region of the Drakensberg Park (Fig. 2.4, Fig. 2.8). A major motivation for the inclusion of Battle Cave as a study site is that its geology and situation differ from that of the Main Caves Museum. Hence, the range of lithologies and situations covered in this study can be applied to most rock art sites in the KwaZulu/Natal Drakensberg. Although no geological sequence for Battle

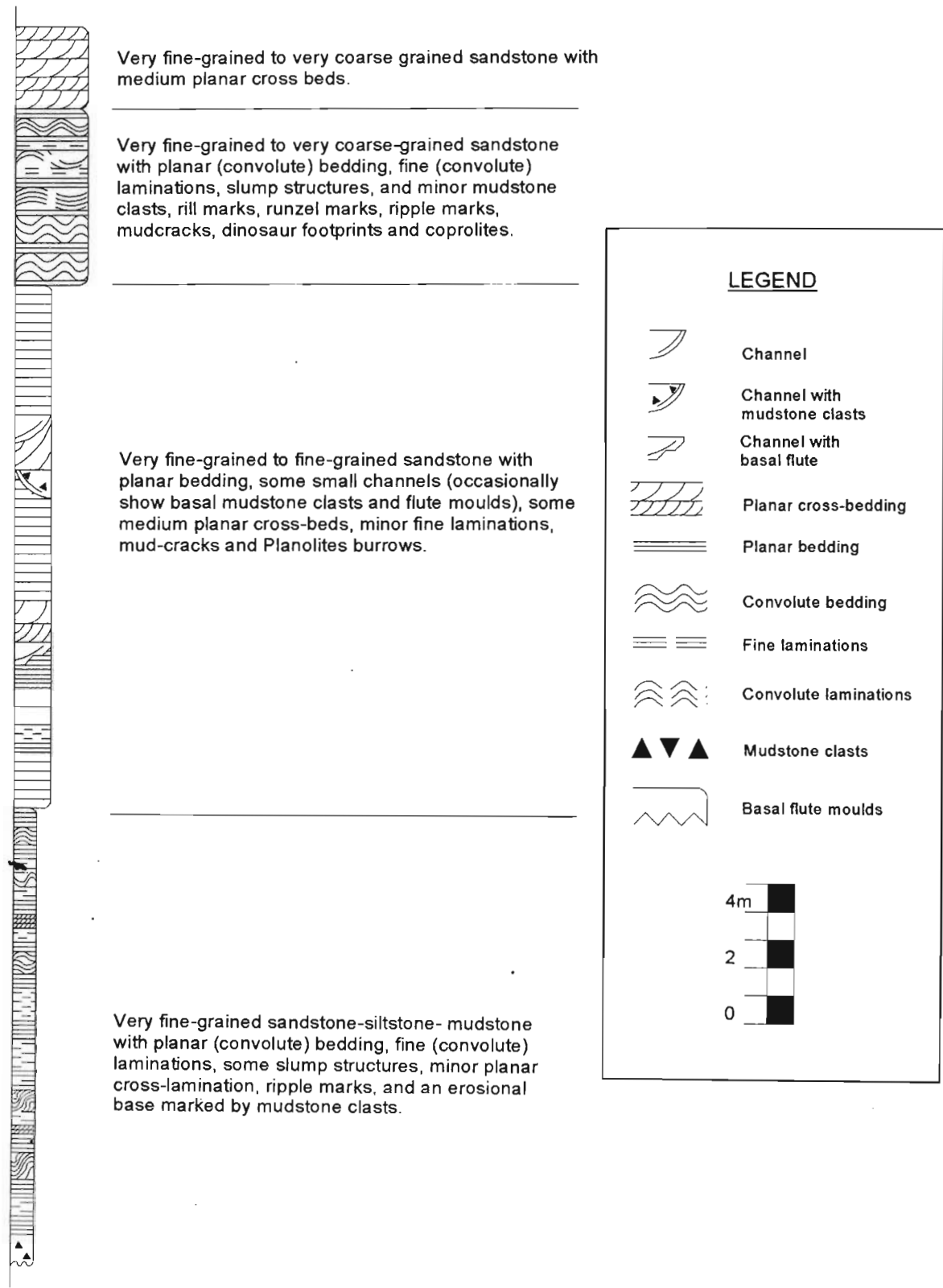
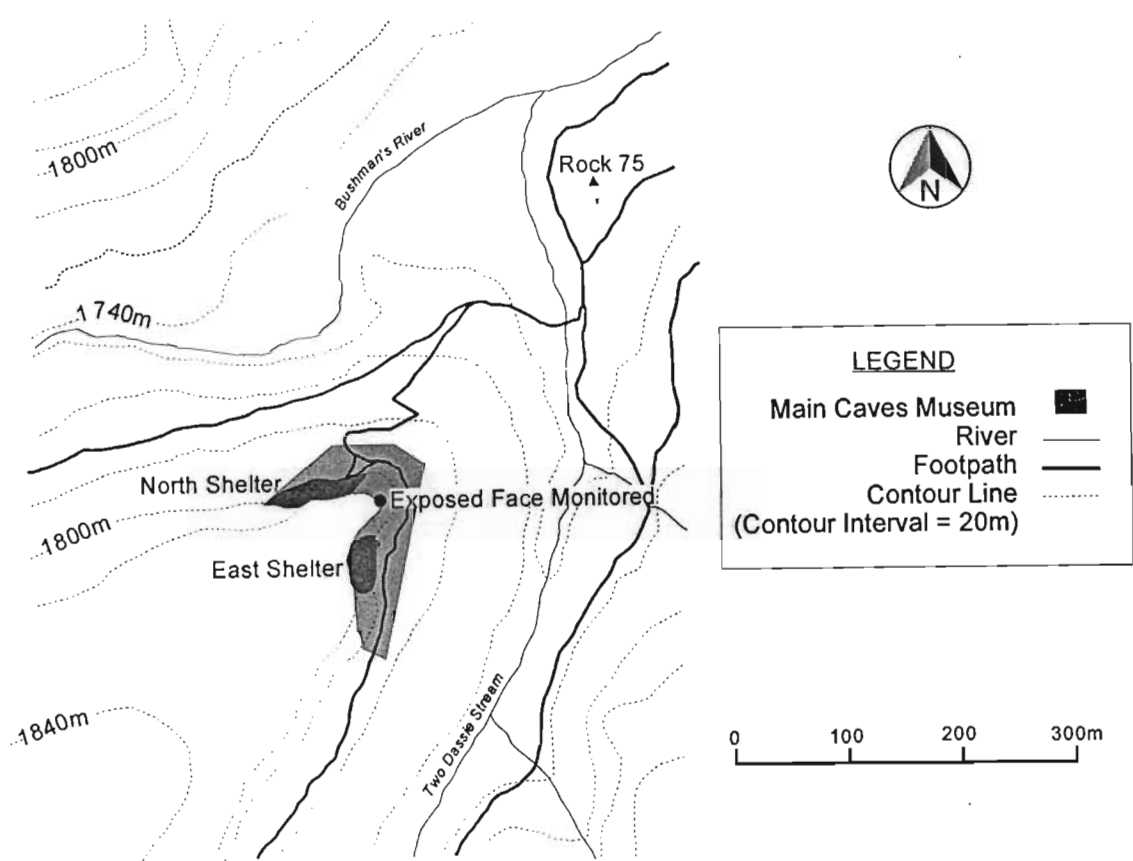


Figure 2.5: Representative Clarens Formation measured section at Giant's Castle (after Eriksson, 1983).



a. Locational Map.



b. View of the Main Caves from the Bushmans River Valley.

Figure 2.6: The Main Caves study site, Giant's Castle, Drakensberg Park.

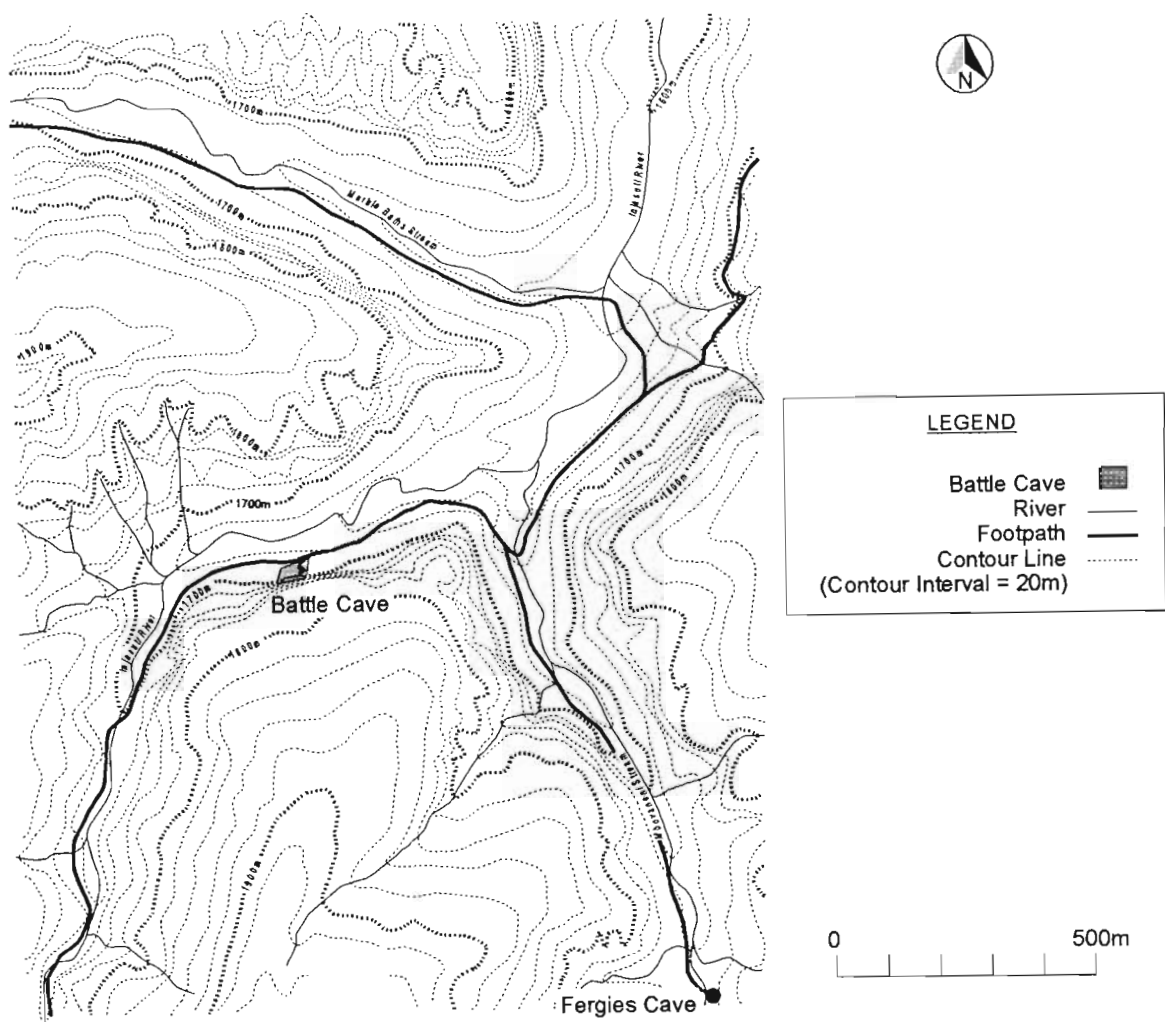


a. North Shelter



b. East Shelter.

Figure 2.7: The two shelters of the Main Caves study site, Giants Castle, Drakensberg Park.



a. Location Map.



b. View of Battle Cave from the north-west.

Figure 2.8: The Battle Cave study site, Injasuti Valley, Drakensberg Park.

Cave has been established by Eriksson (1983), most of the study site is part of a large scale planar cross-bedded and massive sandstone facies of aeolian origin. Near the base of the Battle Cave shelter there are, however, structures that are part of a planar fine sediment facies from a braided channel system (Fig. 2.9), which are not found at the nearby Solitude section investigated by Eriksson (1983) (Fig. 2.10). Besides the lithology being different from that of the Main Caves site, Battle Cave is unusual in that its shelter is shallow and, due its north-facing aspect, it receives considerably more radiation than other known sites within the Clarens Formation.

2.3. CLIMATE

Rock weathering processes are directly influenced by the surrounding environment (Ashton and Sereda, 1982; Ollier, 1984), this necessitates that the microclimate at the study sites is monitored. Few climatic data are available for the KwaZulu/Natal Drakensberg owing to the scarcity of weather stations. As no climatic data exist for the specific sites in this study, literature presented by Tyson *et al.* (1976) from an overview of the whole of the KwaZulu/Natal Drakensberg will be considered. In 1990 an automated weather station was installed, at an altitude of 1737m, near the Conservator's Office at Giant's Castle (Fig. 2.4), approximately 1800m (NNE) away from the Main Caves Site. As the data from the automated weather station at Giant's Castle do not cover a sufficient period of time for climate extrapolation, and because the equipment was damaged for much of this study, it has not been possible to use this data.

2.3.1. SUNSHINE AND SOLAR RADIATION

The influence of solar radiation on rock temperatures requires that both incoming radiation and rock temperatures are monitored (Jenkins and Smith, 1990; Kerr *et al.*, 1984; McGreevy, 1985; Peel, 1974; Rejmánek, 1971; Smith, 1977). Radiation data are available from a site at Cathedral Peak, and as Giant's Castle is only approximately 45 kilometres to the south-east, it is not envisaged that these values will vary greatly between the two sites. Although net summer radiation is higher than winter, only 53% to 58% of potential radiation is received in summer while the



Figure 2.9: Part of the planar fine sediment facies, as identified by Eriksson (1983), of the Clarens Formation at the Battle Cave study site.

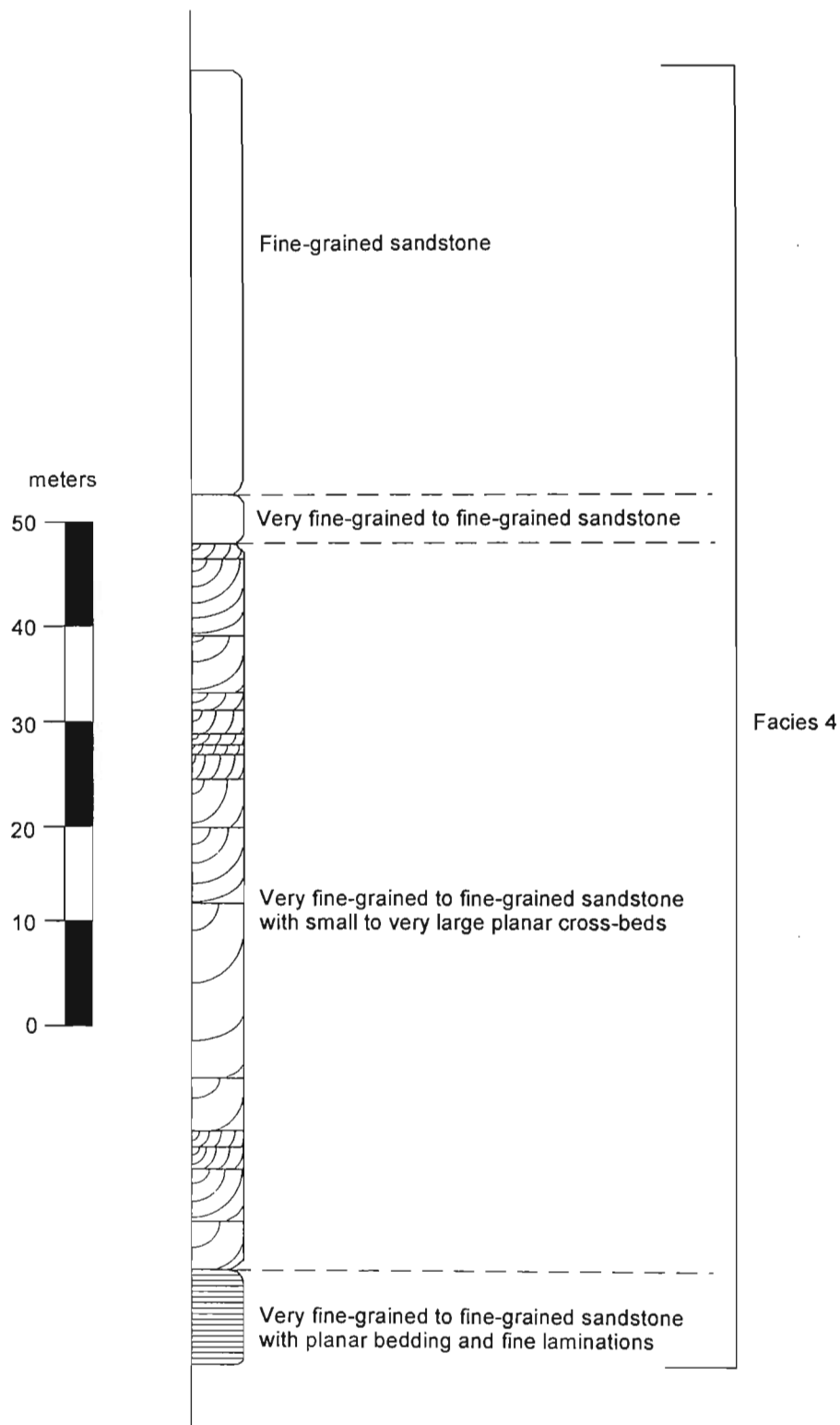


Figure 2.10: Representative Clarens Formation measured section at Solitude (now known as Injasuti) (after Eriksson, 1983).

winter receipt is 65% to 75% of the potential (Fig. 2.11) (Schulze, 1975; Tyson *et al.*, 1976). On a level surface, typical summer daily maximum radiation receipts are in the region of 1200W.m^{-2} , while those in winter are in the region of 650W.m^{-2} (Schulze, 1975; Tyson *et al.*, 1976). Significantly, daily maximum solar radiation receipts for steep ($>30^\circ$) north facing slopes are greatest during the March and September equinoxes (Fig. 2.12) (Tyson *et al.*, 1976). Most north-facing rock faces within the Clarens Formation, where much of the known rock art is found, have slope angles more than 30° , and hence receive maximum direct incoming radiation during autumn. Diurnal changes in radiation receipts are consequently also greatest on steep north-facing slopes during equinoxes and, therefore, weathering mechanisms that are temperature dependant are potentially most active during this period.

2.3.2. AIR TEMPERATURE

Rock temperature, rather than air temperature, is the major control on weathering processes (Jenkins and Smith, 1990; Kerr *et al.*, 1984; McGreevy, 1985; Peel, 1974; Rejmánek, 1971; Smith, 1977). However, underneath rock shelters where little, if any, direct solar radiation is received, the ambient air temperature will influence rock temperatures and, thus, needs to be measured. Nowhere in available literature is there any indication of rock temperatures being monitored in the study area. Further, the paucity of recording stations in the KwaZulu/Natal Drakensberg prevents accurate representation of the area's air temperature profile (Tyson *et al.*, 1976). Available literature offers little other than to show the Drakensberg region as having a uniform temperature profile when, in reality, the highly dissected nature of the study area exerts a significant influence on temperature (Tyson *et al.*, 1976). This study shows that the temperature regime in shelters in the KwaZulu/Natal Drakensberg are highly site specific (see Chapter 4). Therefore, air temperatures used for this study are based solely on that actually collected at the study sites (see Chapter 4).

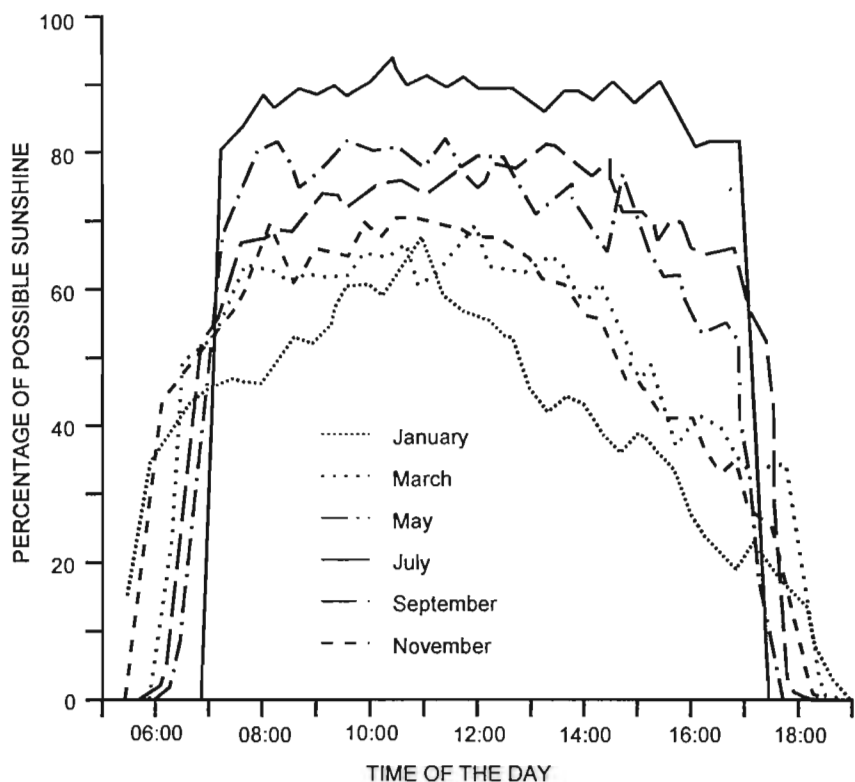


Figure 2.11: Diurnal variation in sunshine receipts, expressed as a percentage of possible sunshine at Cathedral Peak (after Tyson, et al., 1976).

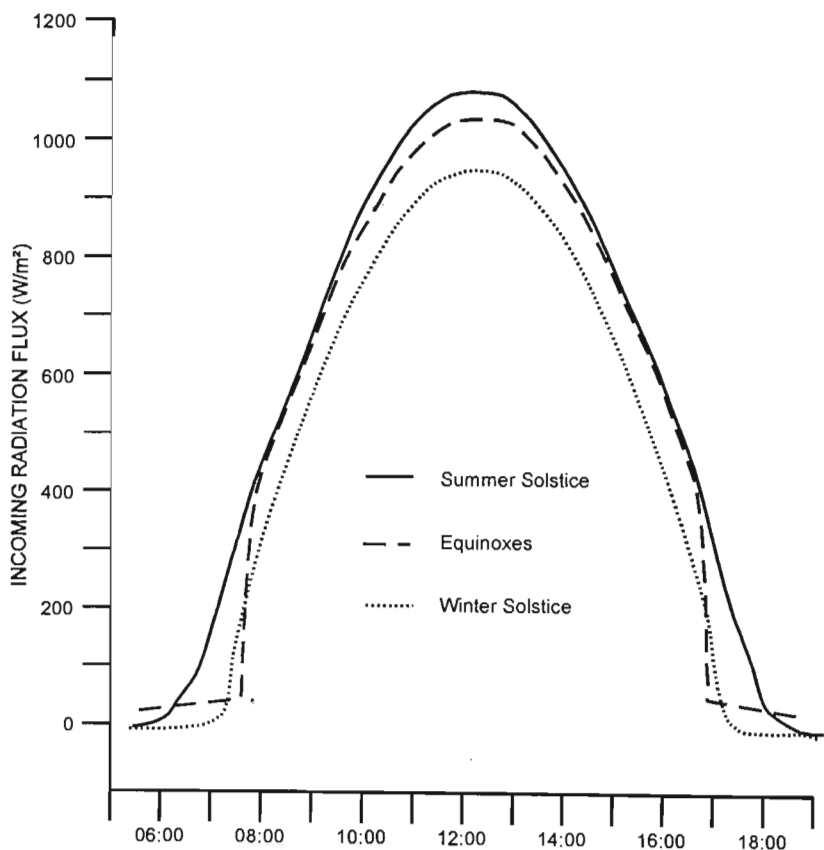


Figure 2.12: Diurnal variation of incoming radiation on a 30° north-facing slope at different times of the year at latitude 29°S under clear skies (after Tyson, et al., 1976).

2.3.3. PRECIPITATION AND ATMOSPHERIC MOISTURE

The role of moisture in most weathering processes is acknowledged to be critical (Broch, 1974, 1979; Hall, 1986, 1988a, 1988b, 1988c, 1991a, 1991b; McGreevy and Whalley, 1985; Nepper-Christensen, 1965; Ollier, 1984; Roth, 1965; Venter, 1981a, 1981b). Moisture in the areas surrounding the study sites is derived primarily from precipitation in the form of rain and/or mist, with snow and hail contributing lesser components. Average rainfall at Giant's Castle is 1038mm per annum and shows distinct seasonality (Fig. 2.13), with 70% falling in the summer months (November to March), and less than 10% falling in the winter months (May to August) (Tyson *et al.*, 1976). Humidity data reflects the seasonality of the rainfall with summers being more humid than winters. The protected rock surfaces within the study site are wetted by condensation of atmospheric moisture and mist as well as seepage along joints within the sandstone. Seasonal variations in the quantity of moisture available to rock surfaces will influence possible active weathering mechanisms. Recognising that the seasonal and the diurnal variability of atmospheric moisture together with other rock weathering controls, are not mutually exclusive, their interrelationships need to be investigated. In this regard, the most active period for rock weathering by thermally controlled processes is, potentially, during autumn, but it is then that atmospheric moisture conditions are relatively dry thus limiting moisture-related mechanisms. Field monitoring of rock mass, as used in this study, provides a more accurate indication of rock moisture conditions than meteorological data and is more reliable for evaluating rock weathering processes.

2.4. SUMMARY

Given the geology of the Clarens Formation, as described by Eriksson (1983), and the seasonal nature of the atmospheric moisture regime, moisture-related weathering processes must be considered in any study investigating the deterioration of rock art in this region. However, due to the highly dissected nature of the environment, the lack of site-specific data, and the limitations of the climatic data presented by Tyson *et al.* (1976), there is a need to monitor conditions at

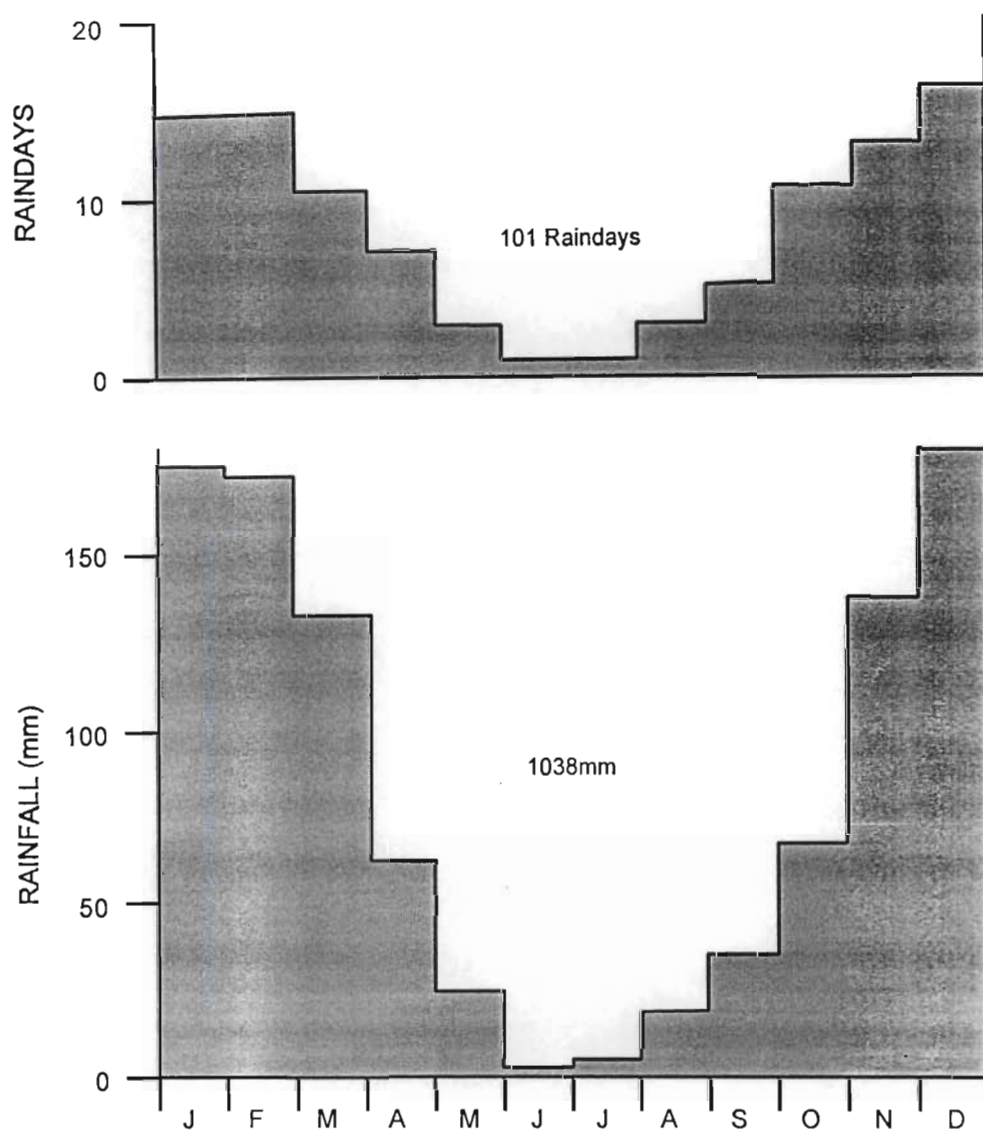


Figure 2.13: Average rainfall data from the Conservator's Office at Giants Castle (after Tyson, *et al.*, 1976).

particular locations to determine the environment in which rock weathering takes place.

CHAPTER 3

METHODOLOGY

3.1. AIMS

The aim of this thesis is to provide an assessment of rock weathering mechanisms in the Clarens Formation of the KwaZulu/Natal Drakensberg and to consider the implications of this deterioration for the preservation of indigenous rock art. Therefore, the primary aim regarding the field and laboratory work was the development of a data base that could be used for the identification and evaluation of active weathering processes at two sites in the study area. Given the dependency of weathering mechanisms on the ambient environment (Reiche, 1950; Keller, 1978; Lal Gauri, 1978; Ashton and Sereda, 1982; Ollier, 1984; Bernadi and Camuffo, 1985), a focus of the data collection was to develop a data base of microclimatic data for the two study sites. Apart from being a record of the microclimate in some Clarens Formation shelters, the data base would also provide a foundation for laboratory simulations, thereby facilitating an evaluation of potential rock weathering mechanisms. Further research was aimed at investigating factors that would influence weathering such as the physical properties and chemical composition of the Clarens Formation at the study sites.

While the primary aim of the project was determining and evaluating the weathering of the Clarens Formation and its effect on indigenous rock art, the results obtained would facilitate further research into investigating methods of conserving and preserving this valuable heritage.

3.2. FIELDWORK

The purpose of fieldwork was to evaluate the weathering environment under shelters in the Clarens Formation of the KwaZulu/Natal Drakensberg. This involved both manual and automated data collection at the Main Caves and Battle

Cave study sites. Manual data collection included the recording of rock temperatures, rock moisture content, pH and electrical conductivity of rain- and drip-water, and rock hardness. Automated data collection involved the use of automated logging equipment to determine the shelter microclimates together with rock temperature and rock moisture conditions.

3.2.1. MANUAL DATA COLLECTION

3.2.1.1. Rock Temperatures

At the Main Caves rock temperature was measured, between May 1990 and May 1994, at fourteen points using LM 35DZ thermistors linked to a digital display (Fig. 3.1). The points chosen were in the north (Fig. 3.2) and east shelters (Fig. 3.3) as well as on the external rock faces, including the back walls of shelters and fallen rocks. The variety of locations covered by the points used to monitor rock temperatures is such that comparisons between these different positions could be made. Apart from sensors at the rock surface, some were located in drill holes at a depth of 4cm in order to evaluate the difference between rock surface temperature and that below the surface. Readings of rock temperatures were taken twice daily, by a Natal Parks Board guide, usually at 10:00 hours and at 15:00 hours (the actual time of measurement depended on the work-load of the guide). On occasions, during personal site visits, temperatures were measured at different intervals, usually every fifteen minutes, but sometimes as frequently as every minute, to obtain data for short-term changes in rock temperature.

3.2.1.2. Rock Moisture Content

Given the prominent role of moisture in rock weathering processes (Nepper-Christensen, 1965; Roth, 1965; Dube and Singh, 1972; Broch, 1974, 1979; Venter 1981a, 1981b; Ollier, 1984; Hall, 1986, 1988a, 1988b, 1991, 1993a), it was clearly necessary to measure rock moisture content in the field. To determine field rock moisture contents, the masses of five rock samples were measured using a



Figure 3.1: Digital display linked to a LM 35DZ thermistor reading rock temperature.

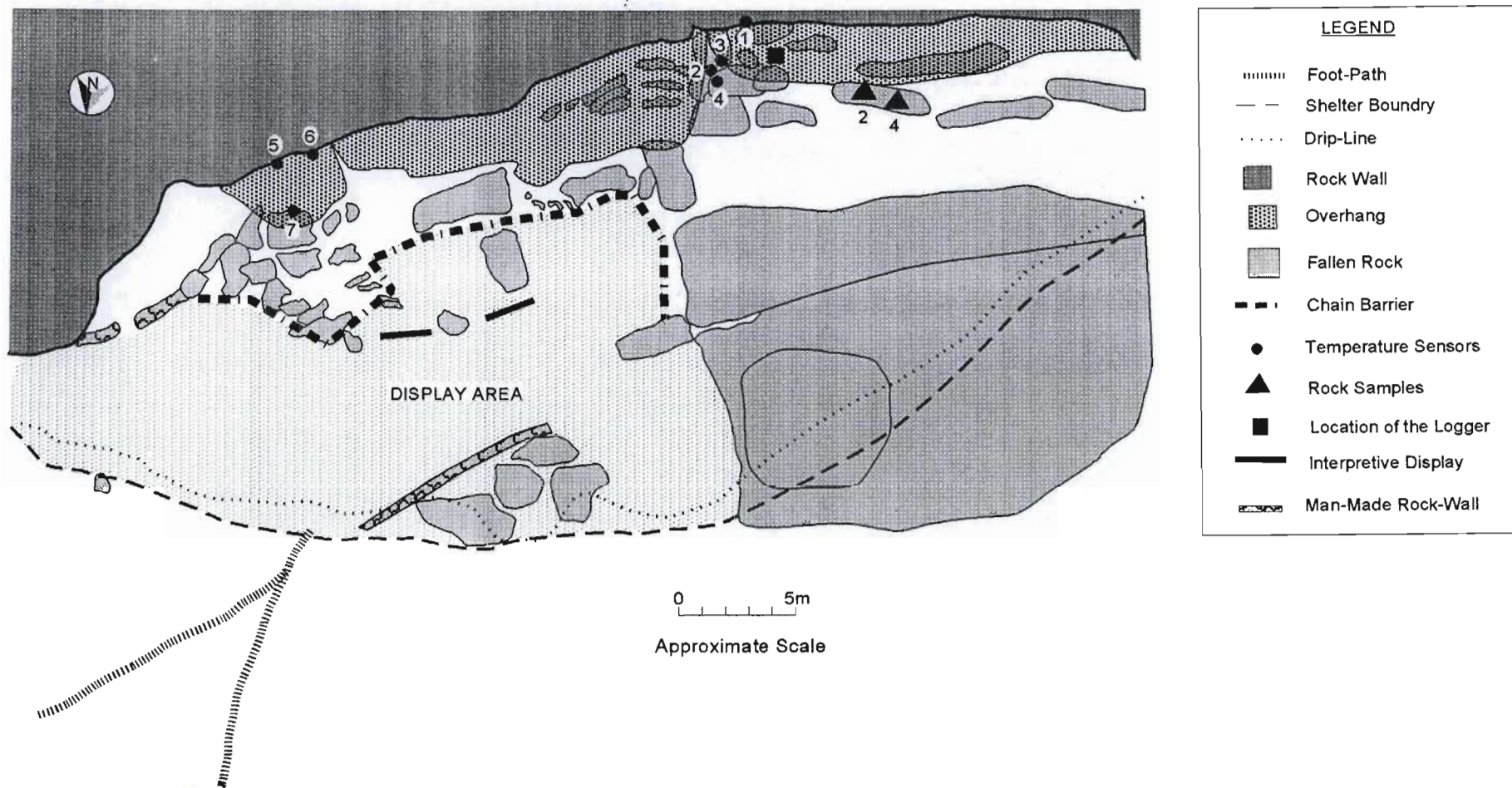


Figure 3.2: The north shelter of the Main Caves study site showing the location of rock temperature sensors, rock samples used for rock moisture measurements and the data logger.

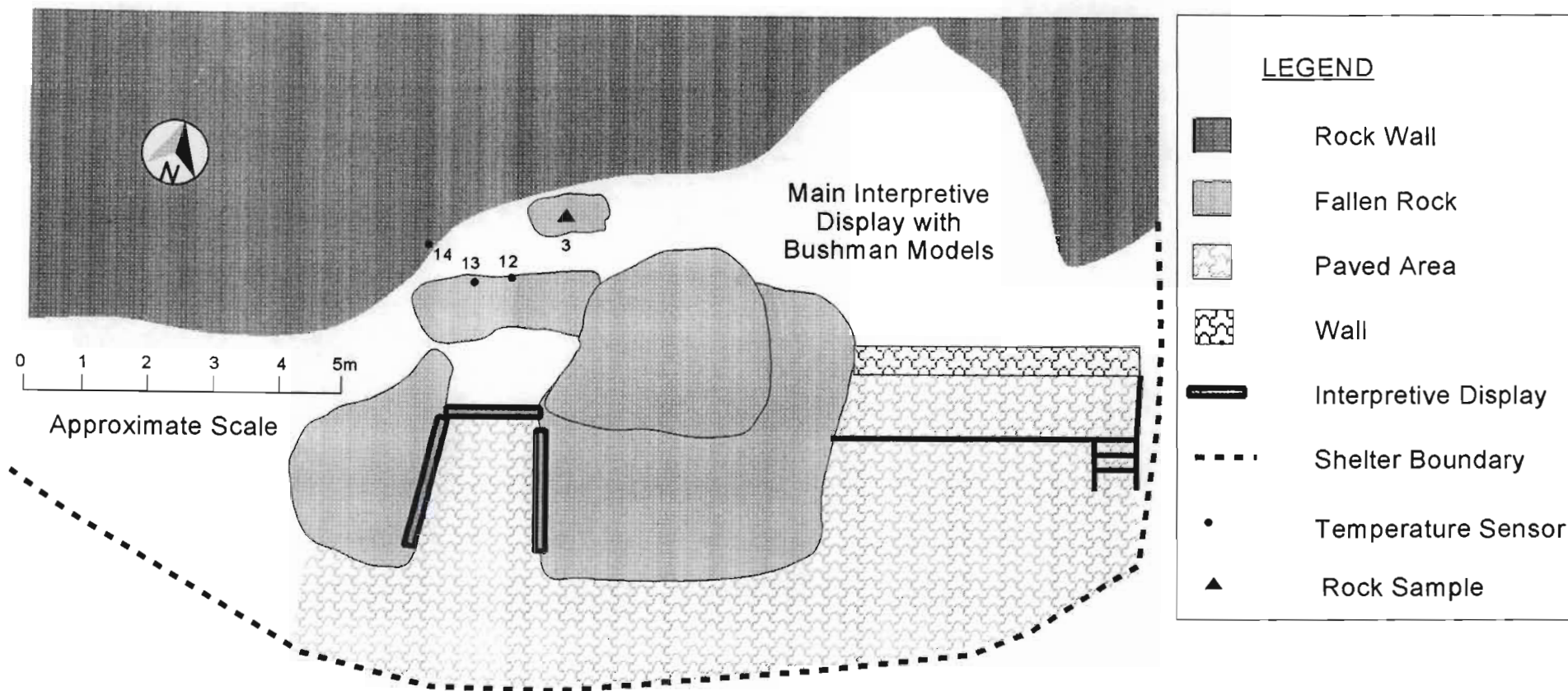


Figure 3.3: The east shelter of the Main Caves study site showing the location of rock temperature sensors and rock samples used for rock moisture measurements.

Sartorius 1002 MP9 balance (Fig. 3.4), between May 1990 and September 1994 at the same times as the rock temperatures were taken. The percentage saturation of each sample was determined, as per the method employed by Hall (1988a, 1991, 1993a), by using the rocks dry, saturated and field masses in the following equation:

$$\% \text{ Saturation} = \frac{\text{field mass} - \text{dry mass}}{\text{saturated mass} - \text{dry mass}} \times 100.$$

Two of the samples used were located in the north shelter (see Fig. 3.2), two at an external rock face and one sample in the east shelter (see Fig. 3.3). The masses of the rock samples were measured at 10:00 hours and 15:00 hours, at the same time as the rock temperature measurements, discussed above (section 3.2.1.1), were taken, and then at shorter time intervals, during personal site visits in order to evaluate more rapid changes in rock moisture content.

3.2.1.3. pH and Electrical Conductivity

At the Main Caves, pH measurements of drip-water, at the back wall of the north shelter, were made using a "Hana, Piccolo 2 ATC" portable pH meter on a fortnightly basis. Electrical conductivity of the same drip-water was measured, at the same time as pH readings were taken, using a "Hana, Conmet 1" portable electrical conductivity meter. Electrical conductivity and pH readings were only taken during the summer months, as the drip at the back wall of the north shelter was seasonal and dried up during the winter months (May-September). The absence of any drip occurrences at Battle Cave prevented similar measurements from being taken there.

3.2.1.4. Rock Hardness

The Schmidt Hammer has been used frequently to determine rock hardness, thereby providing a relative measure of the degree of weathering of a rock (Day and Goudie, 1977; Day, 1980; Williams and Robinson, 1983; Mathews and Shakesby, 1984; Robinson and Williams, 1987; Ballantyne, *et al.*, 1989;



Figure 3.4: Sartorius 1002 MP9 balance used to determine mass of a rock sample.

Augustinus, 1991, 1992; Campbell, 1991; Sjöberg and Broadbent, 1991; Hall, 1993b). While it is accepted that reservations have been expressed concerning the use of the Schmidt Hammer, especially when used on sandstone, it does, nevertheless, provide a relative indication of the weathering of a rock (Williams and Robinson, 1983; Campbell, 1991; Day and Goudie, 1977; McCarroll, 1990, 1991; Hall, 1993b). At both study sites a Schmidt type N Hammer was used to determine rock hardness. Readings were taken on shelter back walls and on fallen rocks in both study sites. At the Main Caves, measurements were taken in the north shelter, the east shelter and external rock faces, to allow comparison between these sites. Measurements were taken giving due attention to the potential hazards Schmidt Hammers can be subjected to as outlined by Day and Goudie (1977).

3.2.2. AUTOMATED DATA COLLECTION

Two MCS 120-02EX data loggers were used for the purposes of monitoring shelter microclimates and rock surface conditions (Fig. 3.5). The first logger was set up in the north shelter of the Main Caves in October 1991. A second logger was installed outside the shelter at the Main Caves between August 1992 and September 1992 to provide a comparison between the environment inside the shelter and that outside. The second logger was then installed in Battle Cave in October 1992. The logging systems initially recorded 20 minute averages on a 16 000 data point EPROM chip that was changed fortnightly. Later, the high cost of travelling to and from the study sites and logistical constraints prevented 20 minute measurements from being taken and, so the time interval for recording was extended to hourly averages.

At Main Caves, air temperature, relative humidity, total incoming radiation, rock temperature, rock surface moisture, soil moisture, wind speed and wind direction measurements were made. At Battle Cave the aforementioned were monitored with the exception of soil moisture, wind speed and wind direction. Financial considerations prevented the logging equipment at both sites being totally



a. The logging system in the north shelter of the Main Caves study site.



b. A close up view of the MCS 120-02 EX data logger.

Figure 3.5: MCS 120-02 EX data logger set up at the Main Caves.

complementary. Details of the specifications for the sensors used for monitoring the various microclimatic variables are provided in Appendix 2.

Values for soil moisture and rock surface moisture are purely relative and do not indicate specific quantities. Further, as relative humidity is only a relative indication of atmospheric moisture content, specific atmospheric moisture content, as indicated by vapour pressure, was determined using the Goff-Gratch formulation (List, 1971).

3.3. LABORATORY ANALYSES

3.3.1. ROCK PROPERTIES

Certain properties were identified by Cooke (1979) as possibly being related to rock disintegration, these included porosity, microporosity, water absorption capacity and saturation coefficient and are defined below:

- i. porosity is the volume of pore space expressed as a percentage of the bulk volume of the sample.
- ii. microporosity is the amount of moisture retained under a negative pore water pressure of 640 cm of water.
- iii. saturation coefficient is the amount of water absorbed in 24 hours expressed as the percentage of available pore space.
- iv. water absorption capacity is a measure of the amount of water absorbed in a specified time (24 hours).

Samples, for use in determining the above rock properties from both study sites were collected, from the same lithologies as that on which rock art was painted. In total 35 samples were used for the determination of rock properties. At the Main Caves four samples with differing degrees of visual weathering were collected for the purposes of comparison. In addition, rock properties were

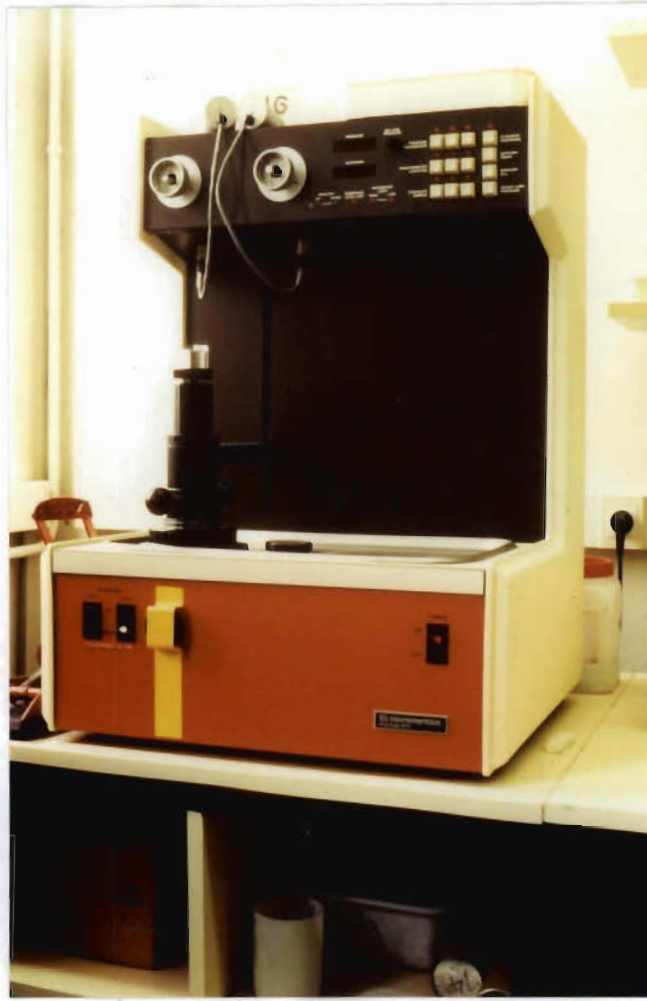
determined for those samples used in simulation experiments, prior to, and then again at specific stages during, the simulations.

To provide a more accurate measure of pore sizes and to give a real measure of microporosity, four samples from the Main Caves with differing degrees of weathering and one from Battle Cave, were analysed using a “Micrometrics PoreSizer 9310” mercury intrusion porosimeter (Fig. 3.6), at the Centre de Geomorphologie du CNRS at Caen University, France. This apparatus is able to determine pore sizes in the range 360 - 0.006 μm using the capillary law governing liquid penetration into small pores (Micrometrics, 1988). Measurements obtained from the “PoreSizer 9310” include the following:

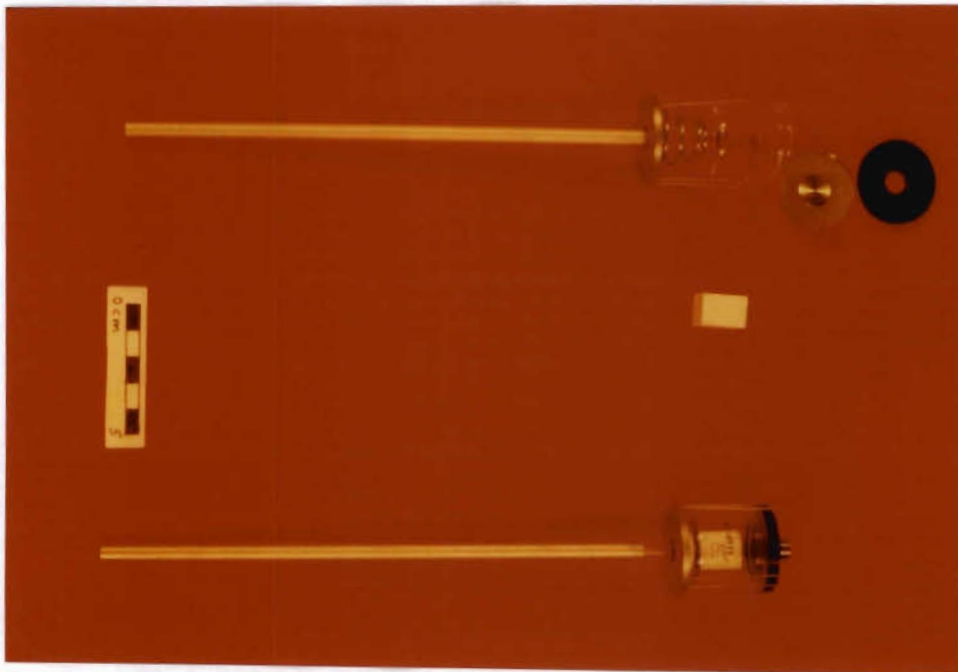
1. cumulative pore volume,
2. cumulative pore area,
3. incremental pore volume,
4. incremental pore area, and
5. differential pore volume (dV/dR).

3.3.2. ROCK CHEMISTRY

Rock samples for chemical analysis were collected from both study sites. At the Main Caves an attempt was made to collect samples of the same lithology, but with differing degrees of visual weathering. Five samples, four from the Main Caves and one from Battle Cave (the same rock samples used in rock property tests discussed above), were prepared by first crushing them in a jaw crusher, to fragments less than 2cm in size, and then milling them in a steel swing-mill for 2 minutes to produce a fine powder. The powder was then used for XRF (X-ray fluorescence spectroscopy) determination of the major element compositions, XRD (X-ray diffraction) spectroscopy for major mineral compositions, AA (atomic absorption) spectroscopy for the determination of soluble cations and IC (ion chromatography) for the determination of soluble anions.



a. The Micrometrics PoreSizer 9310.



b. A close-up view of the sample assembly.

Figure 3.6: Micrometrics PoreSizer 9310 mercury intrusion porosimeter.

3.3.2.1. Major Element Compositions

Powdered samples from the study sites were analysed for the determination of major element compositions, namely silicon, aluminium, iron, manganese, magnesium, calcium, sodium, potassium, titanium and phosphorus, using a Phillips PW1404 XRF (X-ray fluorescence) spectrometer at the Department of Geology, University of Natal, Pietermaritzburg. Only major element compositions were determined as financial constraints prevented identification of trace elements.

3.3.2.2. Major Mineral Compositions

Powdered samples from the study sites were analysed for the determination of major mineral compositions at the Department of Agronomy and Soil Science, University of Natal, Pietermaritzburg, using XRD (X-ray diffraction). Only major mineral compositions were determined as financial constraints prevented a more complete analysis.

3.3.2.3. Cation Analysis

Cation analysis of interstitial soluble material from samples at the Main Caves and Battle Cave followed the method used by Hall, *et al.* (1986). Fifty grams of each powdered rock sample was crushed and mixed with 50ml of deionised water. The mixture was stirred for 15 minutes, to dissolve soluble material, and then filtered. Further filtration through a 0.4µm micropore filter was undertaken before 20ml of the product was ionised with 0.2ml concentrated nitric acid. Analysis was undertaken in a Plasma 100 atomic absorption spectrophotometer at the Department of Chemistry, University of Natal, Pietermaritzburg.

3.3.2.4. Anion Analysis

For the analysis of soluble anions from rock samples, 50g of powder as obtained above was mixed with 50 ml of water, stirred for 15 minutes, and then filtered. Following final filtration through a 0.4µm micropore filter the samples were analysed in a Waters ion liquid chromatography at the Department of Agronomy and Soil Science at the University of Natal, Pietermaritzburg.

3.3.3. DRIP-WATER CHEMISTRY

The analysis of drip-water followed collection of samples from a seasonally active drip at the back wall of the north shelter of the Main Caves (there were no drips suitable for sample collection at Battle Cave). Samples were collected from the above drip, after it became active in October 1993, at approximately fortnightly intervals until it stopped in April 1994. Drip-water samples from the Main Caves were analysed for soluble cations and anions using atomic absorption and ion chromatography respectively. The equipment outlined above in the chemical analyses for rock samples was used. Each sample was prepared by filtering through a 0.4µm micropore filter. The samples used for cation analysis in the Plasma atomic absorption spectrophotometer were first ionised with concentrated nitric acid (20ml of the sample with 0.2ml conc. nitric acid).

3.4. SIMULATIONS

A computer-controlled climatic cabinet, developed by Hall *et al.* (1989) was used for the purposes of simulating the temperature regime at the study sites. The design and operation of the cabinet are outlined in Appendix 3. Cabinet, and hence air, temperatures were controlled for the purposes of establishing the internal rock temperature regime. Given that simulations need to represent field conditions (McGreevy and Whalley, 1982; Thorn, 1988; Hall, 1988c, 1989; Hall and Lautridou, 1991), the programmed thermal regimes used for the cabinet were extracted from data collected at the study sites. Daily temperature cycles, which

closely resembled the regime in the natural environment at each of the study sites (Fig. 3.7), were established from the field data in order to conduct the simulations. A rock sample, with temperature sensors at specific depths (rock surface, 5cm, 10cm and 15cm depths), was encased in insulating foam such that one face was exposed in order to simulate conditions on the rock face (Fig. 3.8). Further simulations were conducted using the greatest rates of change of temperature at the two study sites to investigate the thermal regime within the rock under extreme conditions; The temperature cycle for this simulation in the cabinet is outlined in Fig. 3.9.

Samples, of approximate size 5cm x 5cm x 5cm, were used to determine the possible effect of moisture on the weathering and rock properties of the Clarens Formation under laboratory conditions. The temperature cycles from the Main Caves (Fig. 3.7) were used for this investigation. Samples were divided into five categories:

1. Dry samples were used as a control in the cabinet.
2. Samples were partially immersed in deionised water.
3. Free draining samples were sprayed daily with deionised water.
4. Samples were partially immersed in rain water collected at the Main Caves.
5. Free draining samples were sprayed daily with water collected at the Main Caves.

The rock properties, as described by Cooke (1979), and outlined in the procedure above (section 3.3.1), of the above samples were calculated prior to the commencement of investigations and then again after 25, 50, 75 and 100 cycles.

The objectives of the simulations were to provide an indication of the rock temperature regime with increasing depth and to determine the changes in rock properties under different micro-climatic conditions. While accepting that the simulations conducted cannot replicate all microclimatic variables exactly, they do, nevertheless, allow an investigation into processes at a scale which is not possible in the field.

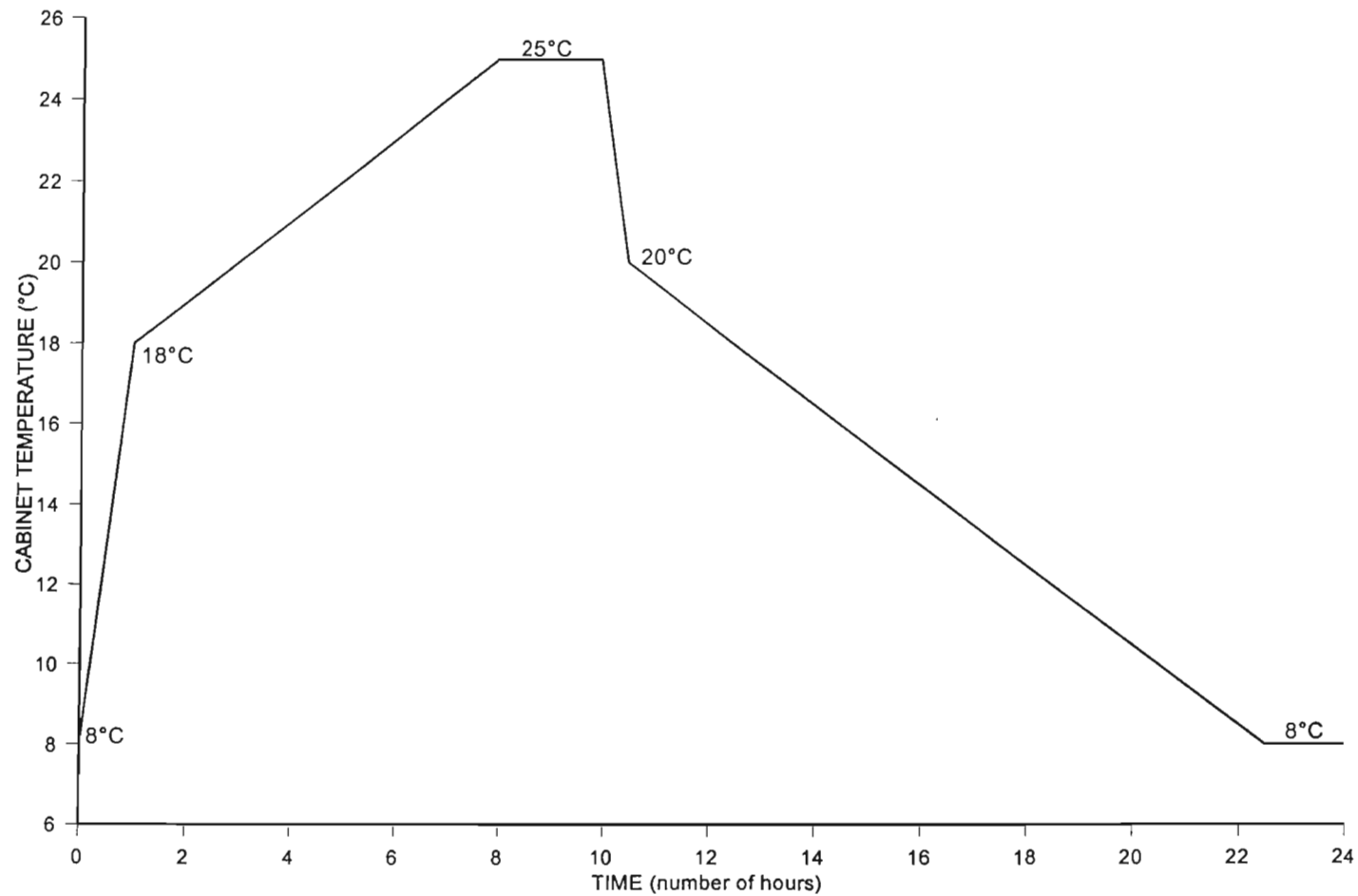


Figure 3.7: Field based temperature regime used for weathering simulations.

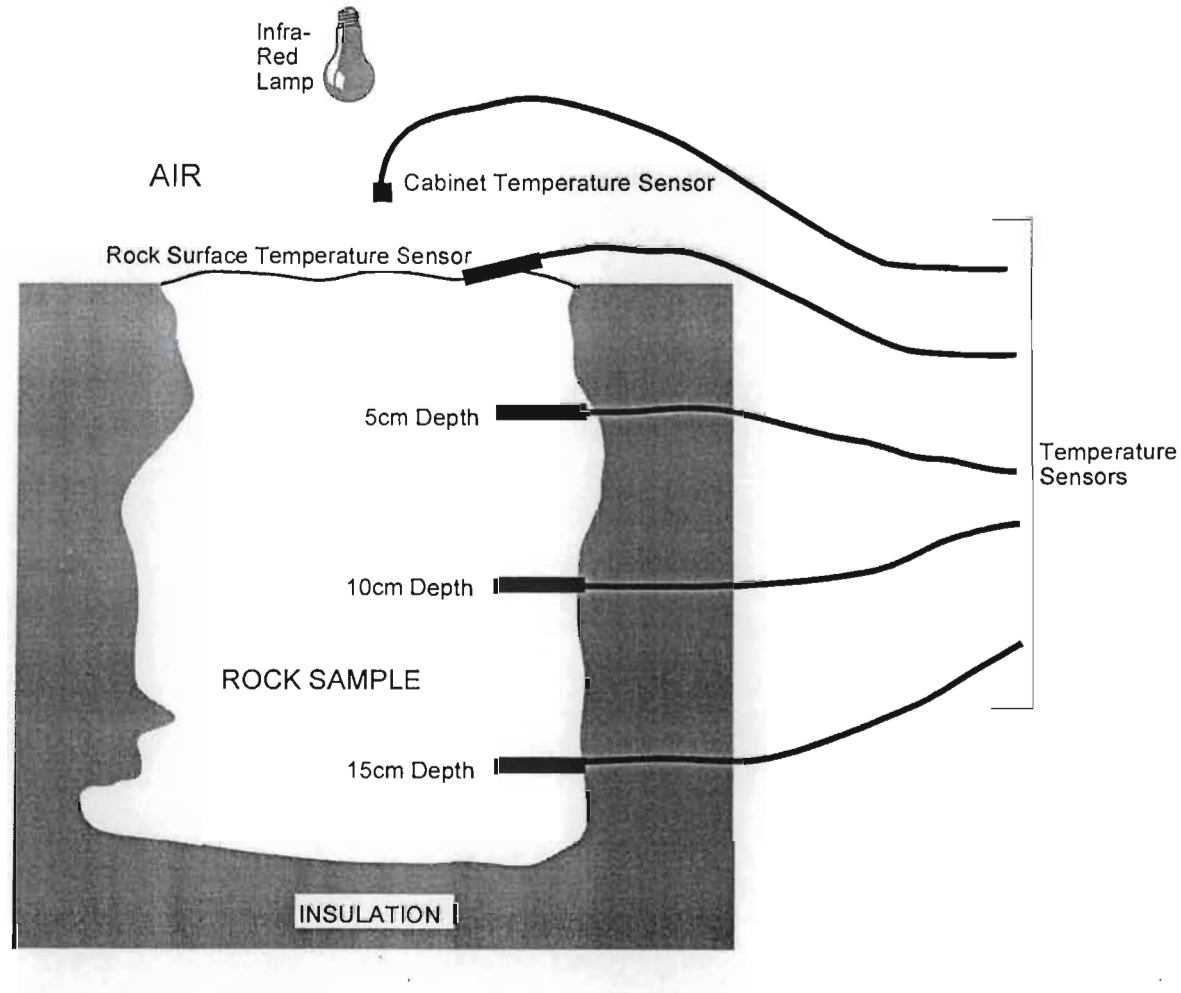


Figure 3.8: Insulated rock sample, as used in weathering simulations, for investigating thermal regimes.

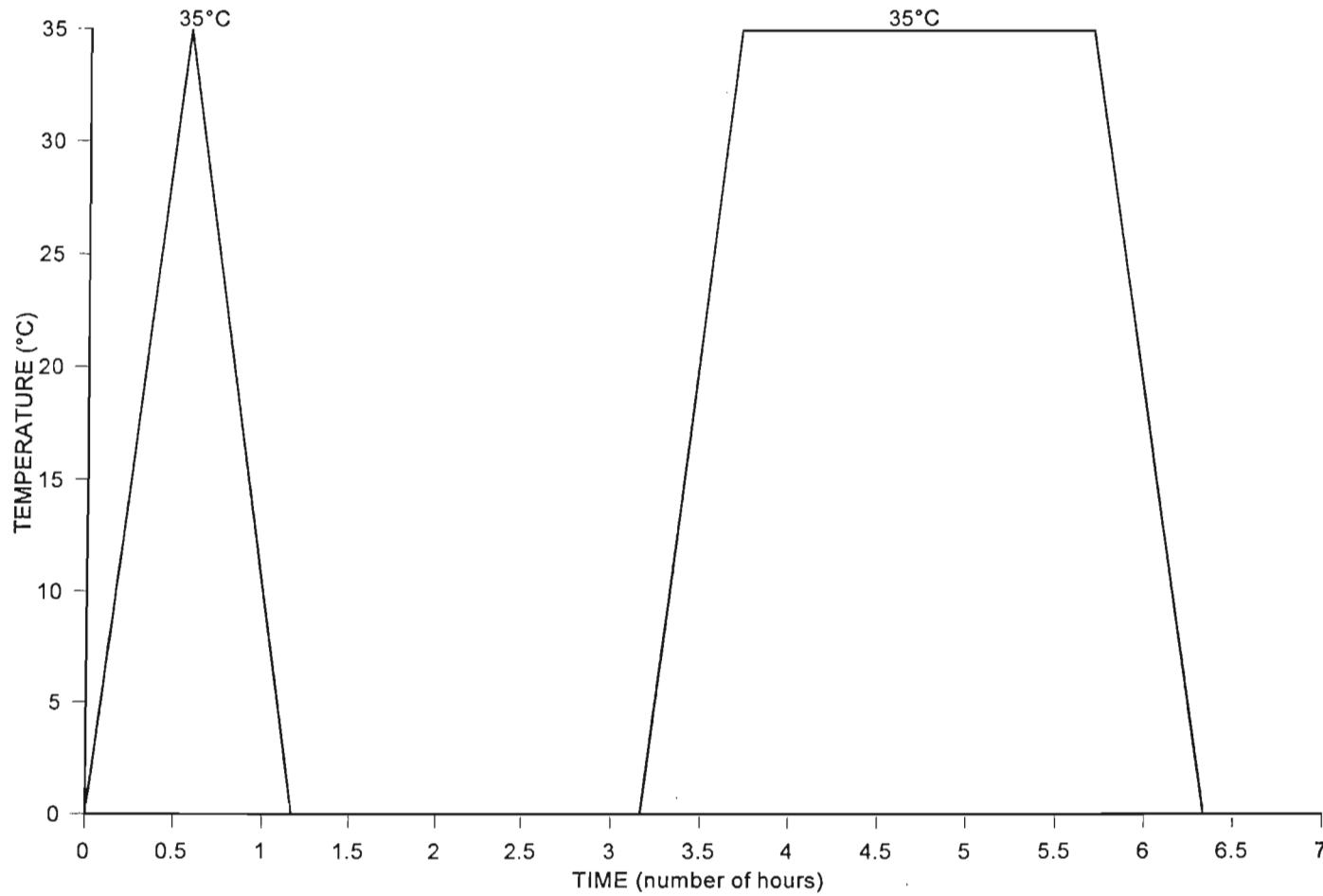


Figure 3.9: Temperature regime used in simulations, which was based on extreme rates of temperature change recorded in the field.

3.5. SUMMARY

The methodology outlined in this chapter was designed to provide an evaluation of the rock weathering mechanisms that are causing the deterioration of indigenous rock art in the Clarens Formation of the KwaZulu/Natal Drakensberg. Both manual and automated data collection was conducted in the field in an attempt to establish the environment under which rock weathering processes took place in the study area. Laboratory analyses were aimed at determining the chemical composition and physical properties of rock and water samples from the Clarens Formation, as well as samples of drip-water at the Main Caves study. Further research included simulations conducted in the laboratory which were aimed at elucidating weathering processes.

A knowledge of active weathering processes in the study area will provide an insight into processes causing the deterioration of Bushman paintings. Sufficient understanding of active rock weathering mechanisms will facilitate future research aimed at methods that may be used to conserve and preserve this indigenous rock art.

CHAPTER 4

RESULTS

4.1. INTRODUCTION

The data recorded for the purposes of this thesis are presented in this chapter. These include manually and electronically recorded data, as well as laboratory analyses of samples from the study area. Much of the data presented are as monthly averages, but these data hide significant variations within them which are a function of the record period used. Therefore, to show the variability in the data collected, readings from different temporal regimes are presented, namely, monthly, weekly and hourly averages, together with values read manually at even smaller intervals.

Much of the data in this study is interactive, and for the sake of clarity this chapter is only a presentation of the results. Further, it is not possible to present all the data recorded for this study within the constraints of this chapter due to the large volume collected (in excess of 1 million data points). Therefore, only a representative portion of the data are presented and these being those which are considered of importance to the weathering of the Clarens Formation and the deterioration of rock art. While the process has been selective, every effort has been made to make the data representative; there are no known instances where the presented material differs significantly from the points raised in the discussions.

Manually recorded data are presented as weekly and monthly averages, together with some records at shorter time intervals. Automated data collection includes monthly and weekly averages as well as data for one representative day for each season to show daily variations. For the purpose of showing the aforementioned

daily variations, 1 April 1993, 1 July 1993, 10 October 1993 and 1 January 1994 were chosen as they represent a typical day for each of the four seasons. It was intended to use the equinoxes and solstices for the purposes of comparison, but malfunctions of the recording equipment at the Battle Cave site prevented this. The first days of each quarter were then selected; again a problem arose in that an unusual series of cold fronts passed over the study area at the beginning of October 1993 disrupting the regular weather pattern, and so 1 October could not be used as a representative sample for that time of the year. The alternative date of 10 October was chosen because it was the first day after the 1 October with data that was representative for that time of the year. The daily synoptic charts from the published daily weather bulletin of the South African Weather Bureau (1993a, 1993b, 1993c, 1994) were used to confirm that on the four days chosen no abnormal synoptic conditions prevailed.

Data from each of the study sites are presented separately apart from the analyses of precipitates for both study sites which are shown together in section 4.2.2.3 (i.e. with the data for the Main Caves study site). The significance of the data and comparisons between the study sites will be discussed in Chapter 5.

4.2. MAIN CAVES STUDY SITE

4.2.1. FIELDWORK

4.2.1.1. Manual Data Collection

4.2.1.1.1. ROCK TEMPERATURE

Rock temperatures were recorded at the Main Caves study site between May 1990 and May 1994. The sample period from December 1991 to May 1994 is presented in Figures 4.1 and 4.2, which represents the longest unbroken period of monitoring. Please note that in Figures 4.1 and 4.2 the temperature for the external face is plotted on the right-hand axis so that scale of the graph would

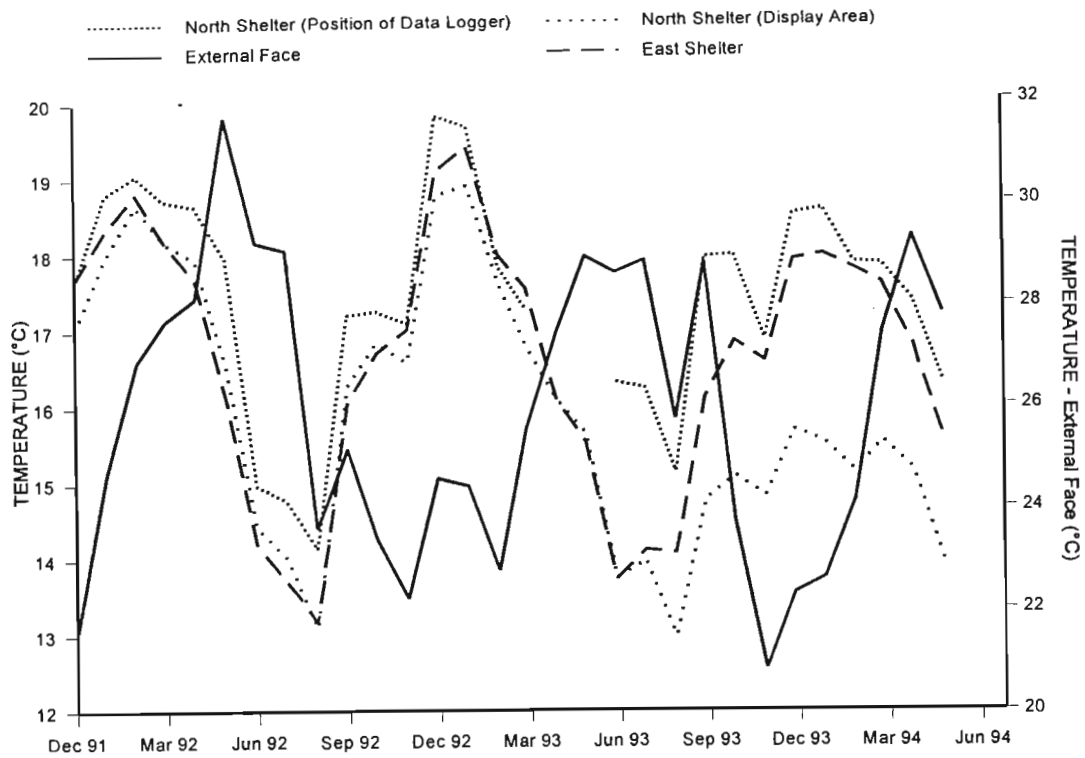


Figure 4.1: Monthly average rock temperatures for the Main Caves study site from December 1991 to May 1994.

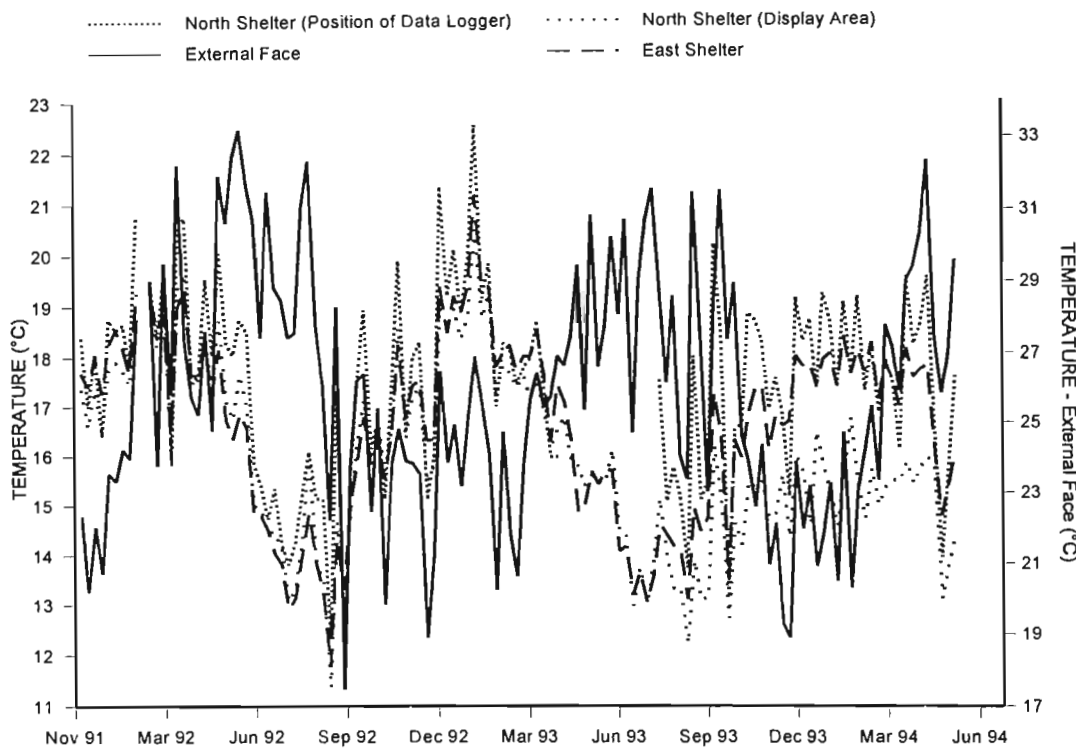


Figure 4.2: Weekly average rock temperatures for the Main Caves study site from December 1991 to May 1994.

allow adequate representation of the other temperatures. Underneath the overhangs of both the north and east shelters, summer temperatures were higher than those in winter (Fig. 4.1, 4.2). This trend was most evident when monthly averages were plotted (Fig. 4.1); weekly averages showed the same trend, but with greater variability (Fig. 4.2). Rock temperatures were higher in summer than in winter, in both the north and east shelters of the Main Caves. However, at more exposed sites (e.g. outside the shelter) the highest rock temperatures were recorded during the autumn and spring months (Fig. 4.1, 4.2). There was no apparent difference between the temperature regime at the rock surface and that beneath the surface up to depths of 5cm. However, the fact that temperatures were only recorded twice a day means that probable differences between at the surface and sub-surface temperatures were not recorded.

Rock temperature changes measured at time intervals shorter than the twice-daily readings discussed above revealed a more complex temperature regime characterised by rapid changes in temperature. At exposed sites, rates of rock temperature increase of $1^{\circ}\text{C}.\text{min}^{-1}$ for a period of 15 minutes were recorded when the first rays of the early morning sun reached the relatively cool rock face on three occasions (14 July 1990, 6 February 1991 and 26 March 1991). Rock temperature decreases were also monitored on the above three occasions and the greatest recorded rate of change was $0.25^{\circ}\text{C}.\text{min}^{-1}$.

The effect on rock temperatures of passing clouds obscuring the sun was only monitored once (2 October 1994), when an extremely complex regime was recorded on an external rock face at the Main Caves study site (Fig. 4.3). Over a 20 minute period rock surface temperatures, as well as those 2.5cm below the surface, were measured when a number of small clouds obscured the sun. Recorded rates of rock temperature increase and decrease reached a maximum of $2^{\circ}\text{C}.\text{min}^{-1}$ (Fig. 4.3).

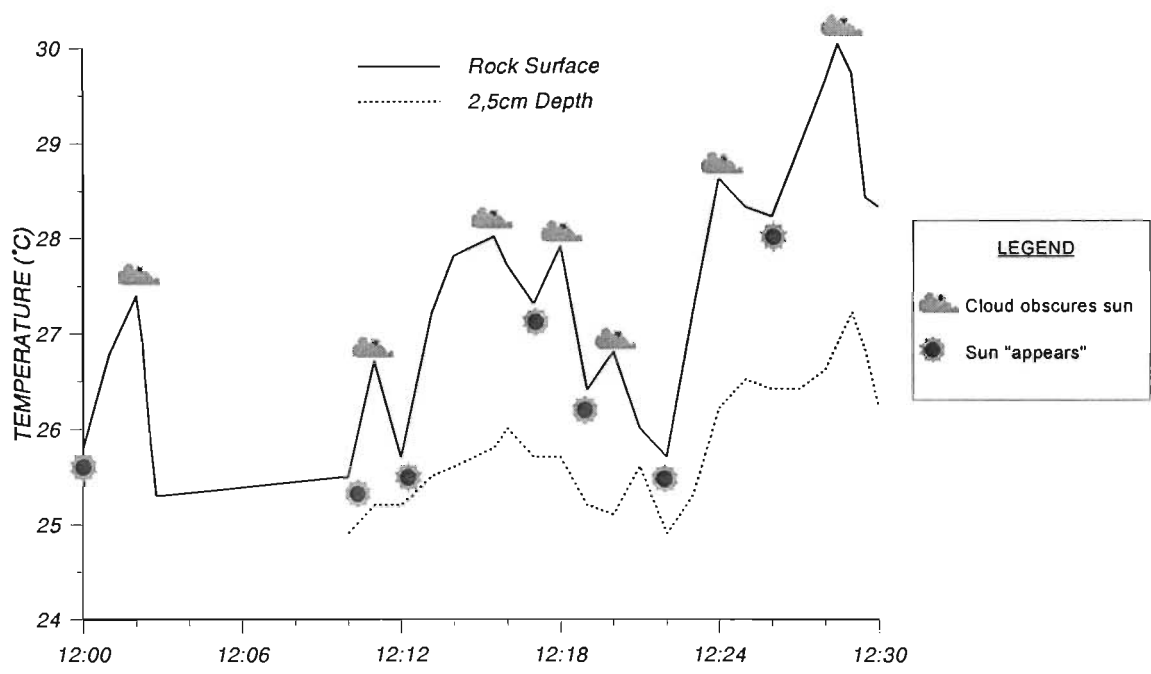


Figure 4.3: Rock temperature measured on an external rock face at the Main Caves study site on 2 October 1994.

4.2.1.1.2. ROCK MOISTURE

Rock saturation values obtained for this study are considered to be relative as problems were experienced with correcting rock saturation values with mass lost by natural weathering processes. However, results obtained do provide an indication of the changes in rock moisture through time. In cases where results over a short period of time are considered, the relative changes in rock moisture can be regarded as being an accurate representation of the changes in rock moisture content, as the mass lost by the sample due to natural weathering was minimal.

The results displayed (Fig. 4.4, 4.5) are from three locations within the Main Caves study site, namely the north shelter, the east shelter and at an external rock face; they reflect the monthly (Fig. 4.4), as well as the weekly (Fig. 4.5), rock moisture regimes for three of the five samples monitored. The remaining two samples, which were located in the north shelter and at the external rock face respectively, are not discussed as their results replicate those discussed above.

Results indicate seasonal variations in rock moisture conditions with summer moisture contents greater than those in winter (Fig. 4.4, 4.5). As might be expected, at exposed positions rock moisture content was more variable than underneath rock shelters (Fig. 4.5). Field work aimed at determining short term changes in rock moisture content was undertaken on 5 different occasions. The results from two such occasions are presented (Fig. 4.6, 4.7, 4.8, 4.9). At both exposed sites and in the relatively protected environment underneath rock shelters, rock moisture content changed rapidly, and showed a strong correlation to rock temperature (Fig. 4.6, 4.7). However, the above observation did not always hold true; rock moisture often showed a positive correlation with atmospheric moisture (Fig. 4.8, 4.9). The response of the rock moisture content to humidity changes appears to be delayed (Fig. 4.8). This was often observed to be the case for samples underneath rock shelters (Fig. 4.8) and also for rocks in shadow (Fig. 4.9). When rock samples were in direct sunlight, their rock moisture content was found to exhibit an inverse relationship to atmospheric moisture (Fig.

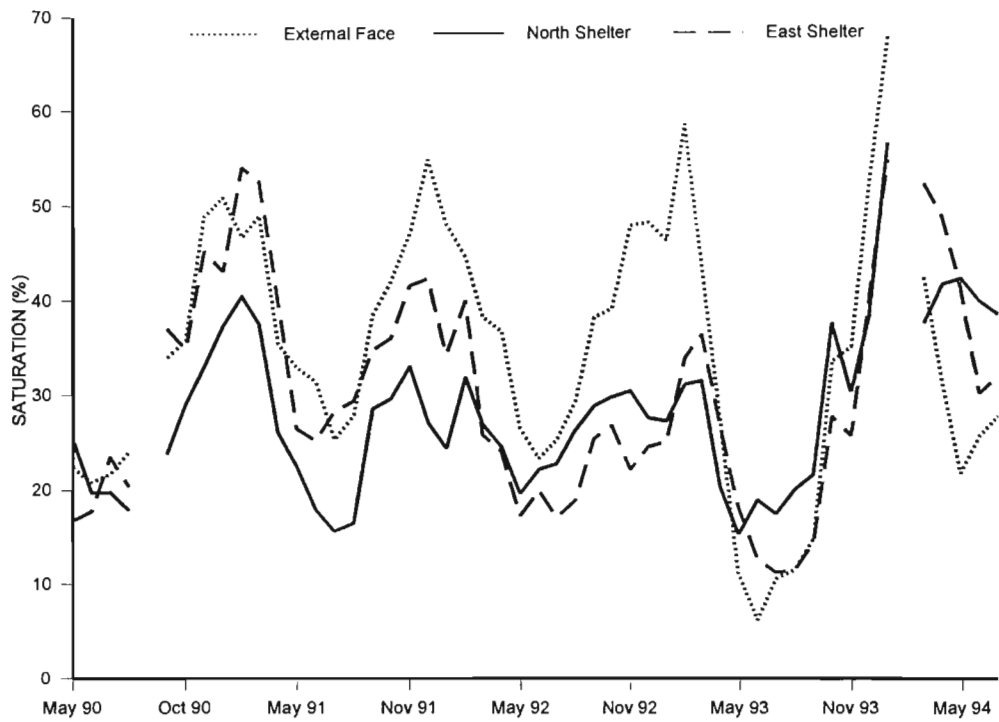


Figure 4.4: Monthly average rock moisture content for the Main Caves study site from May 1990 to July 1994.

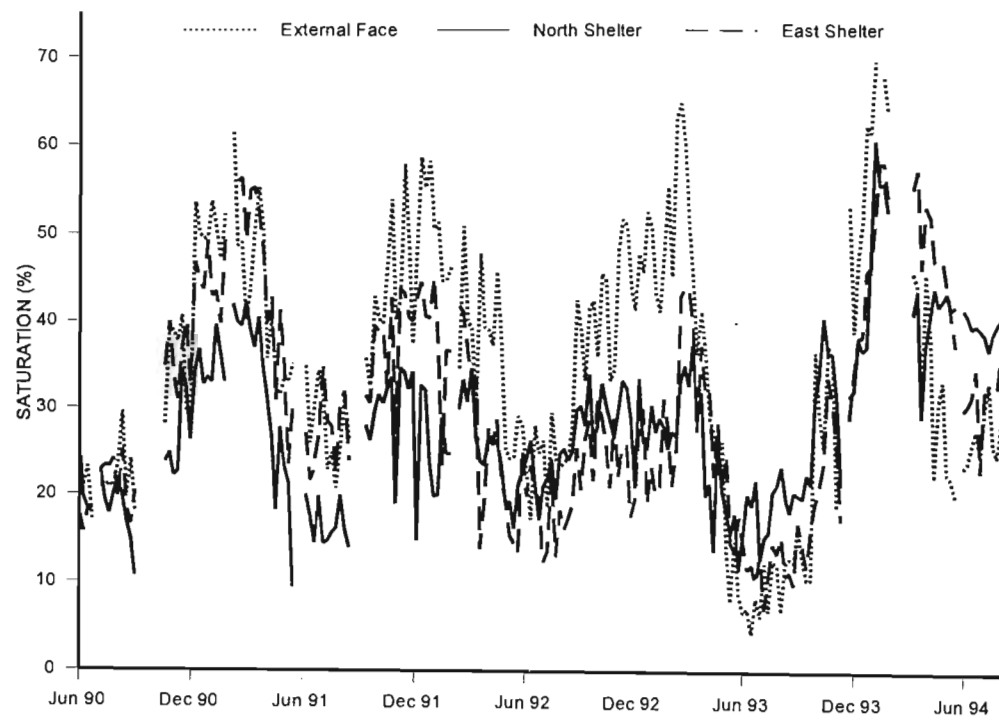


Figure 4.5: Weekly average rock moisture content for the Main Caves study site from May 1990 to July 1994.

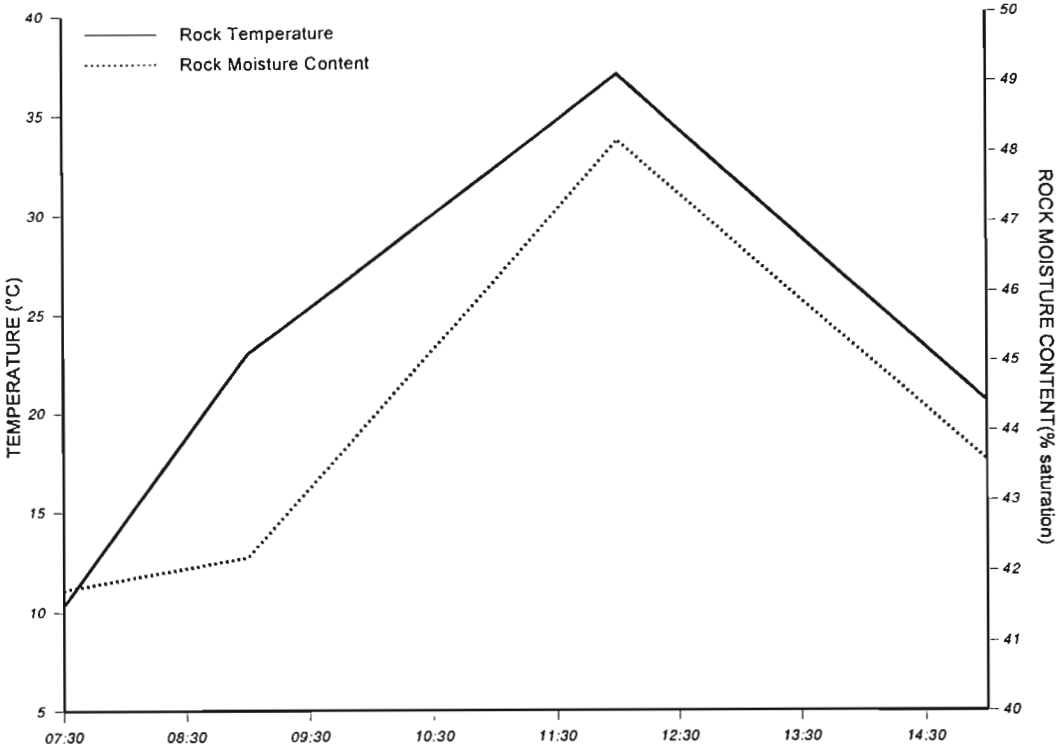


Figure 4.6: Short term data showing rock temperature and rock moisture content at an external face of the Main Caves study site on 14 July 1990.

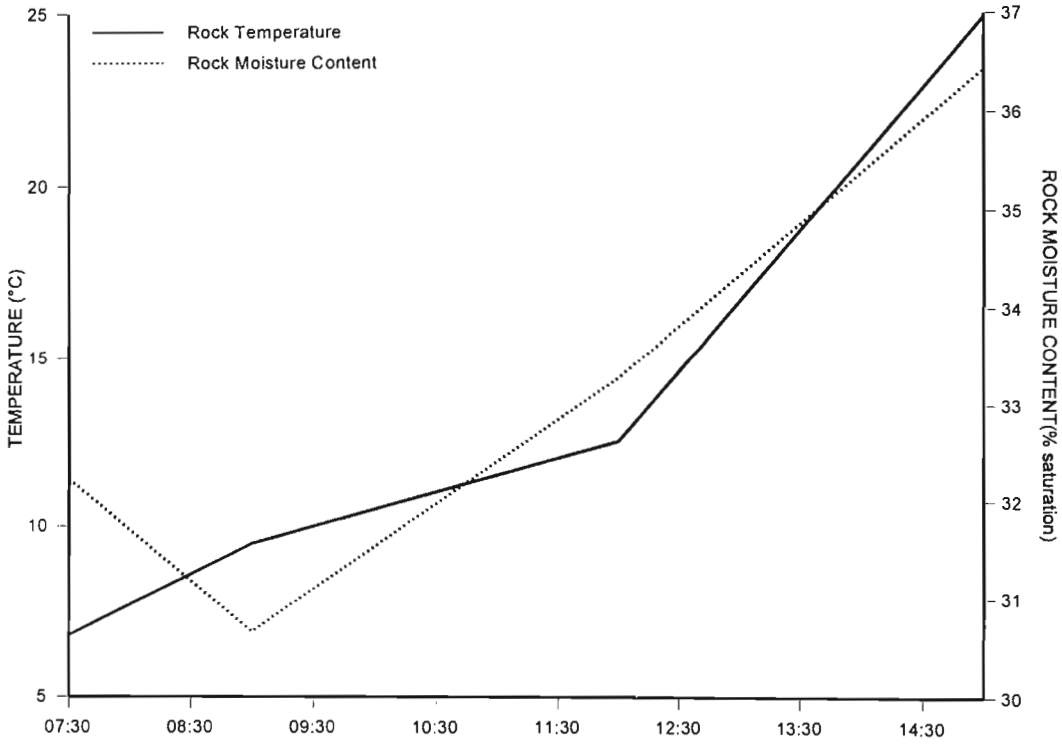


Figure 4.7: Short term data showing rock temperature and rock moisture content in the north shelter of the Main Caves study site on 14 July 1990.

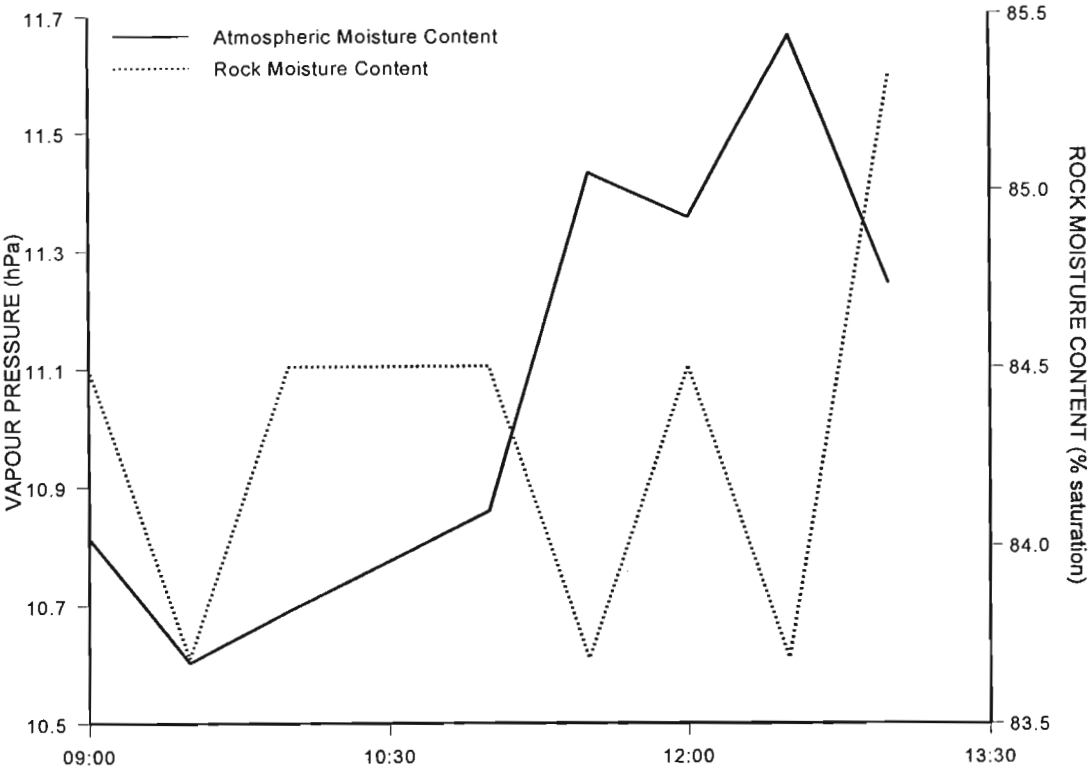


Figure 4.8: The relationship between atmospheric moisture (indicated by vapour pressure) and rock moisture content in the north shelter at the Main Caves study site on 2 October 1994.

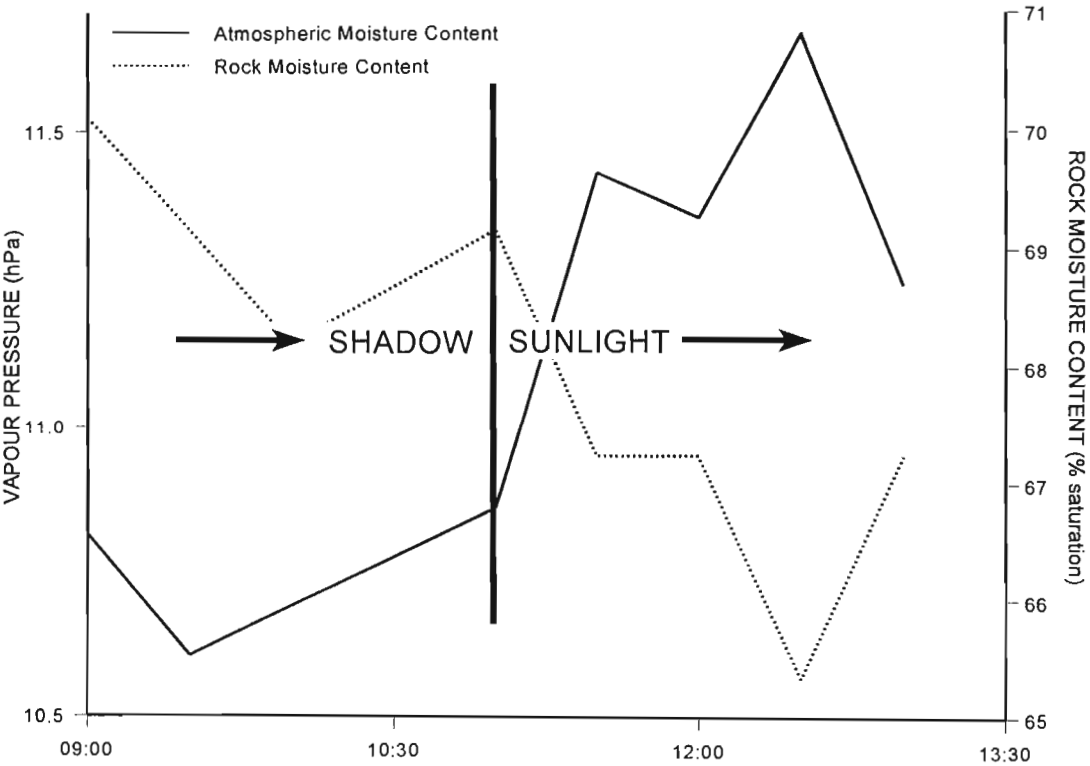


Figure 4.9: The relationship between atmospheric moisture (indicated by vapour pressure) in the north shelter and rock moisture content at an external face at the Main Caves study site on 2 October 1994.

4.9). However, in the latter case the humidity and temperature sensors, used to calculate atmospheric moisture conditions, were located in the shadow approximately 10m from the rock samples which were in the sun and so perhaps do not exactly reflect the microclimatic conditions to which the samples are exposed.

4.2.1.1.3. ROCK HARDNESS

A Schmidt type N Hammer was used to provide an indication of rock hardness at the Main Caves study site. Tests were conducted in both shelters and in exposed areas outside the shelters. Readings were taken on rock faces (back walls) and on rocks that had fallen away from the back walls. Due to the debate over the use of the Schmidt Hammer as a tool in weathering studies (Williams and Robinson, 1983; Campbell, 1991; Day and Goudie, 1977; McCarroll, 1990, 1991; Hall, 1993), discussed earlier (3.2.1.4), the data collected for this study will be used for comparisons only. Further, as the Schmidt Hammer data are only being used as a relative measure of weathering, the actual rebound values are presented and have not been converted to shear strength values.

Rebound values were highest on exposed rock faces outside the shelters (Table 4.1). The back walls of the two shelters had rebound values which were from the same statistical population (Table 4.2). Further, the rebound values on the back walls of shelters were lower than those from the external rock faces. In all areas monitored (east shelter, north shelter and exposed sites) rebound values were greater on the rock wall than those on fallen rocks (Tables 4.1, 4.2). Rebound values on fallen rocks in the east and north shelters were found to be from the same statistical population (Table 4.2). The lowest rebound values were obtained from fallen rocks at exposed positions outside the shelters. A possible reason for the lower Schmidt Hammer rebound values on exposed fallen rock, outside the shelters, is that they are covered with lichen, and as a result, obtaining an accurate reading on bare rock was difficult, if not impossible.

STATISTIC	EAST SHELTER		NORTH SHELTER		EXTERNAL ROCK FACE	
	BACK WALL	FALLEN ROCKS	BACK WALL	FALLEN ROCKS	BACK WALL	FALLEN ROCKS
Observations	51	58	104	104	53	53
Mean	49.67	45.64	51.46	43.91	53.55	41.68
Variance	56.02	62.73	33.84	88.93	52.48	51.72
Std Deviation	7.49	7.92	5.82	9.43	7.24	7.19
Median	49	47	52.5	45	53	42

Table 4.1: Summary statistics for Schmidt Hammer rebound values at the Main Caves Study site.

SAMPLES COMPARED	CRITICAL t VALUE	CALCULATED t VALUE	RESULT
BACK WALLS: NORTH- vs EAST- FACING SHELTERS	1.98	1.64	Same Population
FALLEN ROCKS: NORTH- vs EAST- FACING SHELTERS	1.97	1.18	Same Population
BACK WALL: INSIDE SHELTER vs EXTERNAL FACE	1.97	2.53	Different Populations
FALLEN ROCKS: INSIDE SHELTER vs OUTSIDE SHELTERS	1.97	2.11	Different Populations
BACK WALLS vs FALLEN ROCKS: INSIDE SHELTERS	1.97	7.22	Different Populations
BACK WALLS vs FALLEN ROCKS: OUTSIDE SHELTERS	1.98	8.46	Different Populations

Note: Confidence level = 95%

Table 4.2: Comparisons of Schmidt Hammer rebound values for different areas of the Main Caves study site using the “t-Test”.

4.2.1.2. Automated Data Collection

Only the north shelter of the Main Caves study site was used for automated data collection. For a short period a second logger was installed at an exposed site outside the shelters and used to compare the microclimate underneath the shelter with that outside. The length of time for which the latter logger was used was not

sufficient to notice any trends; consequently the data for this are not presented in this chapter, but will be used for comparisons in Chapter 5.

4.2.1.2.1. AIR TEMPERATURE

Predictably, air temperatures were greatest in summer and lowest in the winter months (Fig. 4.10). Weekly average temperatures were more variable than the monthly averages but they both, nevertheless, show the same seasonal trends (Fig. 4.11). The 1993/4 summer season was much cooler than that of the preceding two summers (Fig. 4.10, 4.11), whilst the temperatures in winter of 1994 were cooler and less variable than the previous two winters. It is notable that the air temperature in the north shelter of the Main Caves study was never below freezing, while early morning temperatures recorded outside the shelter were frequently below zero. An interesting feature of Figure 4.10 is that during the winters of 1992 and 1993 air temperatures displayed similar patterns in that they were at a low during June, they rose during July, dropped during August, rose again in September and then dropped in October. However, in July 1993 air temperatures were lower than those of June 1993, thus not following the pattern of the previous two years.

The daily temperature regime in the north shelter was predictable with minima ($\pm 14^{\circ}\text{C}$ in summer and $\pm 5^{\circ}\text{C}$ in winter) being recorded shortly before sunrise ($\pm 07:00\text{hrs}$ in winter and $\pm 04:00\text{hrs}$ in summer) and maxima ($\pm 25^{\circ}\text{C}$ in summer and $\pm 23^{\circ}\text{C}$ in winter) after midday ($\pm 14:00\text{hrs}$ in summer and $\pm 15:00\text{hrs}$ in winter) (Fig. 4.12). The maxima were generally recorded after midday as the location of the logger was less protected from the afternoon sun than the morning sun. Summer air temperatures, as discussed above, were the warmest (e.g. January $\bar{x} = 17^{\circ}\text{C}$), followed by autumn and spring (e.g., April $\bar{x} = 15.2^{\circ}\text{C}$ and October $\bar{x} = 14.9^{\circ}\text{C}$), whilst winter temperatures were the lowest (e.g. July $\bar{x} = 11.6^{\circ}\text{C}$). However, at the logging site the maximum daily air temperature on 1 July 1993 (22°C) was greater than that on the two days that were monitored close to the equinoxes (e.g. 1 April 1993 = 20.2°C and 10 October 1993 = 20.8°C) (Fig 4.12);

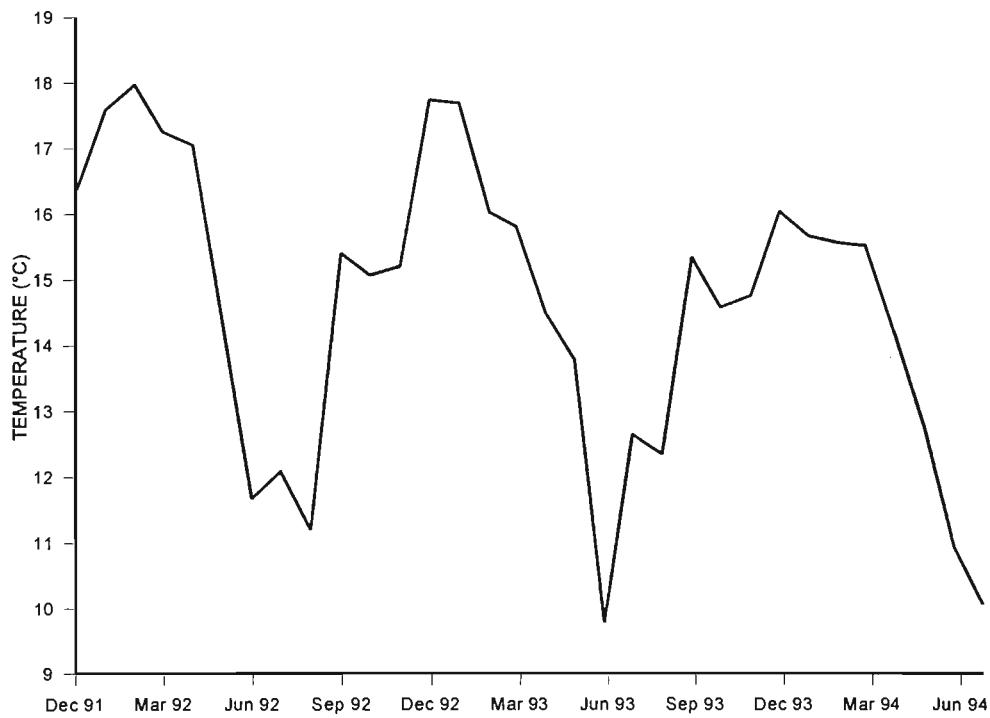


Figure 4.10: Monthly average air temperatures for the north shelter of the Main Caves study site.

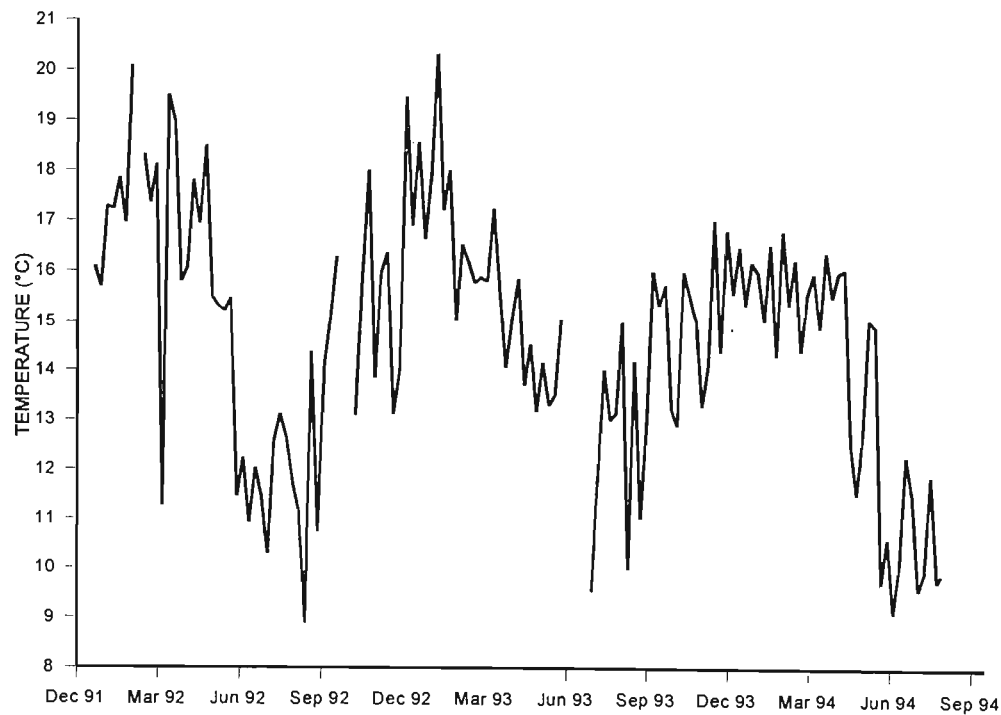


Figure 4.11: Weekly average air temperatures for the north shelter of the Main Caves study site.

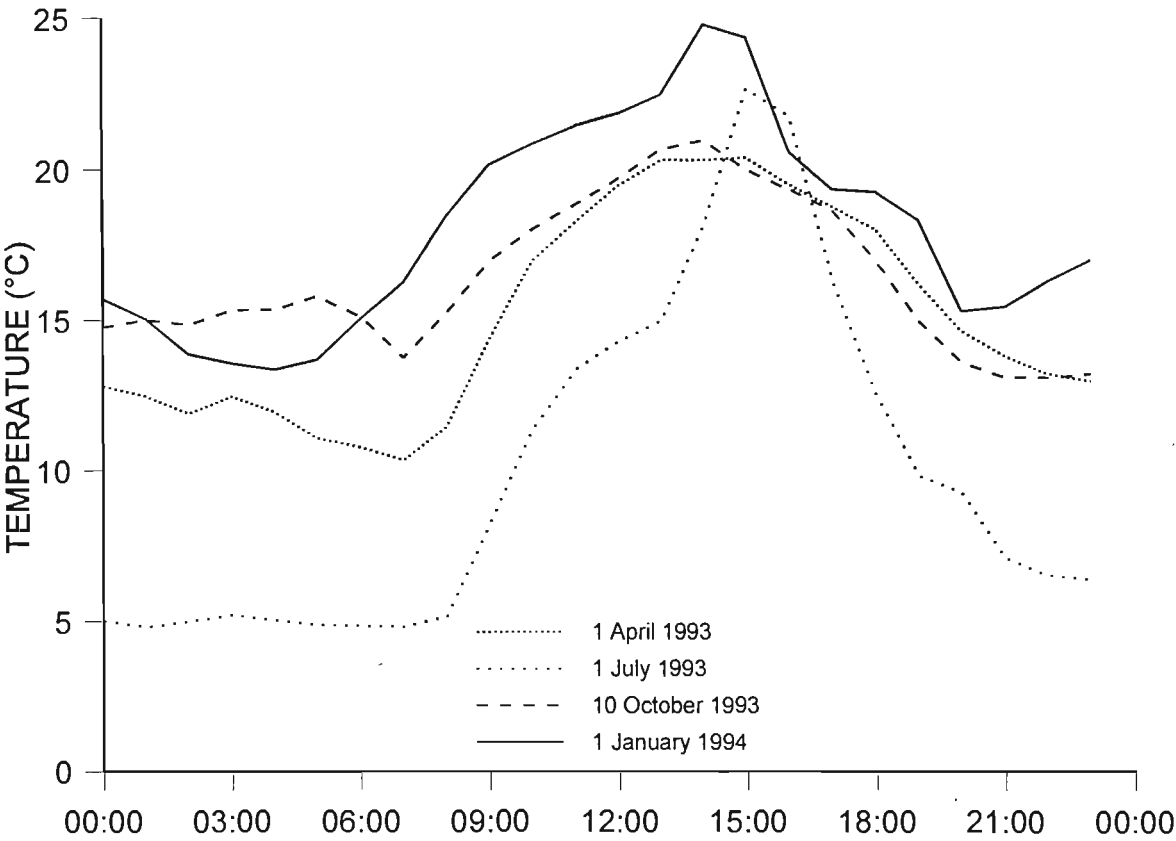


Figure 4.12: Hourly average air temperatures in the north shelter of the Main Caves study site on four selected days between 1 April 1993 and 31 March 1994.

this being due to the direct rays of the sun which were only able to reach the logging station in winter when the sun's altitude was sufficiently low. The rock overhang of the north shelter of the Main Caves was such that it was able to shield the logging site from the direct rays of the sun throughout most of the year.

4.2.1.2.2. ROCK TEMPERATURE

The recording of rock temperature was a particularly important aspect of data collection given that it is a major control on rock weathering processes as discussed earlier (see 1.2.1.1). Rock temperatures under shelters in the study area which receive no direct radiation followed a seasonal trend with summer temperatures being warmer than those in winter (Fig. 4.13, 4.14). On each side of a fallen boulder (i.e. on the side of the display area, or inward facing, and, on the side where the logger is located, or outward facing; see Fig. 3.2) rock temperature regimes were similar, apart from summer maximum averages, when the rock was warmer on the inward-facing side (Fig. 4.13, 4.14). Temperatures of the back wall of the north shelter of the main Caves were always cooler than those of the fallen rocks (Fig. 4.13, 4.14), and did not appear to be as variable (Fig. 4.14).

Comparisons were made between rock surface temperatures and those 4cm below the surface for different situations in the north shelter of the Main Caves. On the outward-facing side of the fallen rock where the logger was located, monthly and weekly average rock temperatures were normally greater below the surface than they were on the surface (Fig. 4.15, 4.16). However, the differences between the surface and sub-surface temperatures were seldom greater than 0.2°C. If the daily temperature regimes are considered then the picture is more complex (Fig. 4.17). At night and in the early morning, rock temperatures were cooler at the surface, whilst in the mid-morning through to the late afternoon the reverse was true. Differences between summer and winter were particularly evident in Figure 4.17, where the effect of direct radiation from a low sun was shown by increased rock temperatures during the mid-afternoon. Apart from the mid-afternoon peak, the difference between winter temperatures and those for the rest of the year was marked. The rapid drop in monthly and weekly average rock

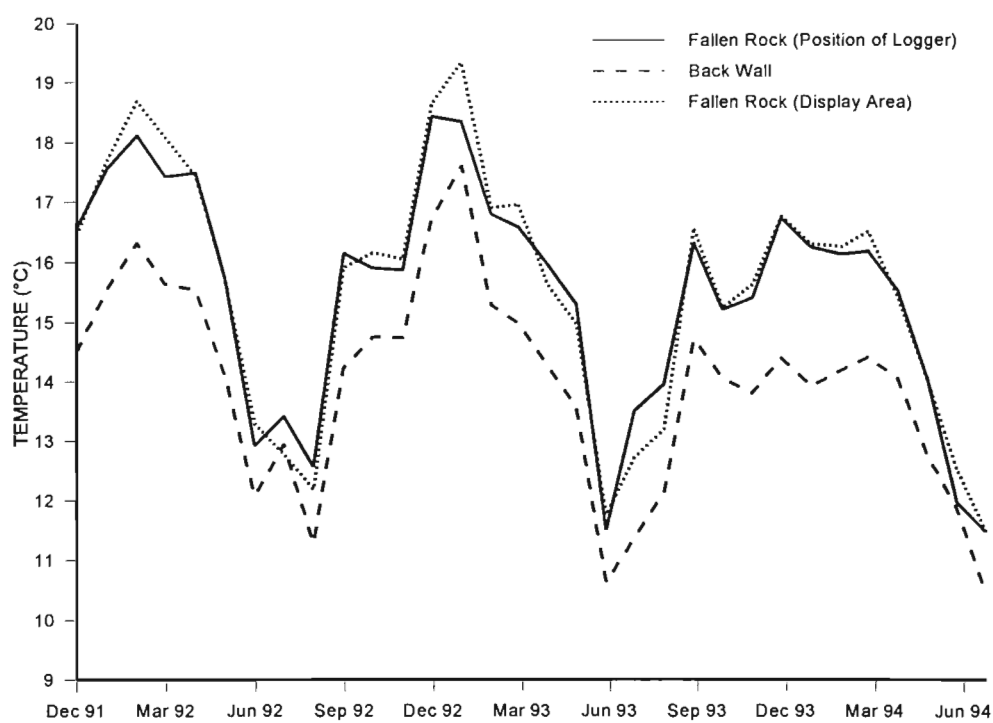


Figure 4.13: Monthly average rock temperatures for the north shelter of the Main Caves study site.

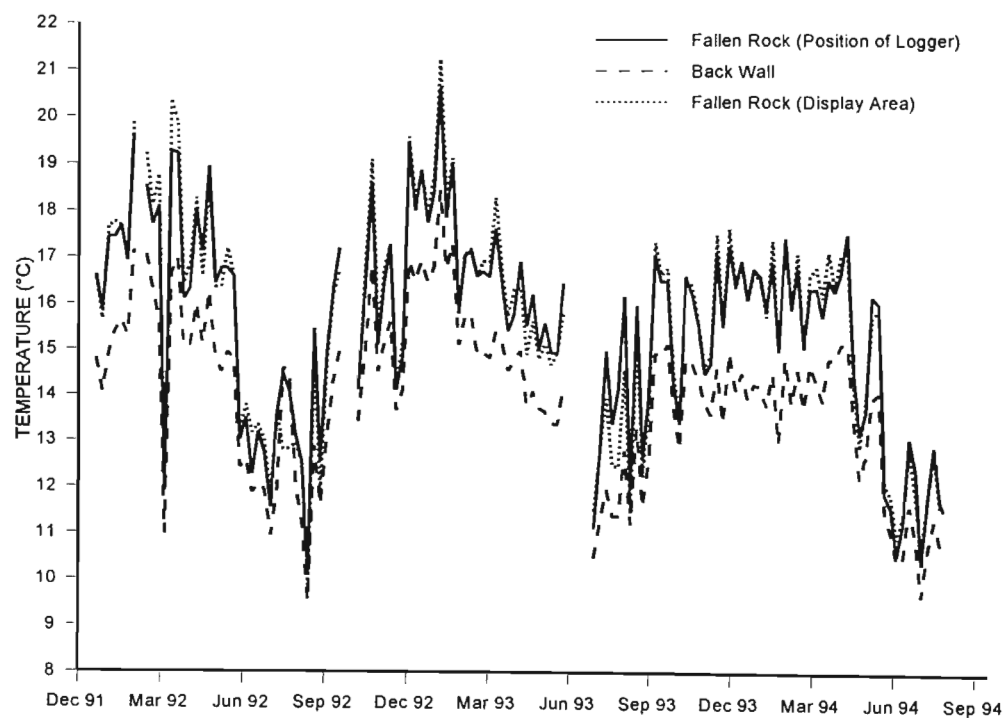


Figure 4.14: Weekly average rock temperatures for the north shelter of the Main Caves study site.

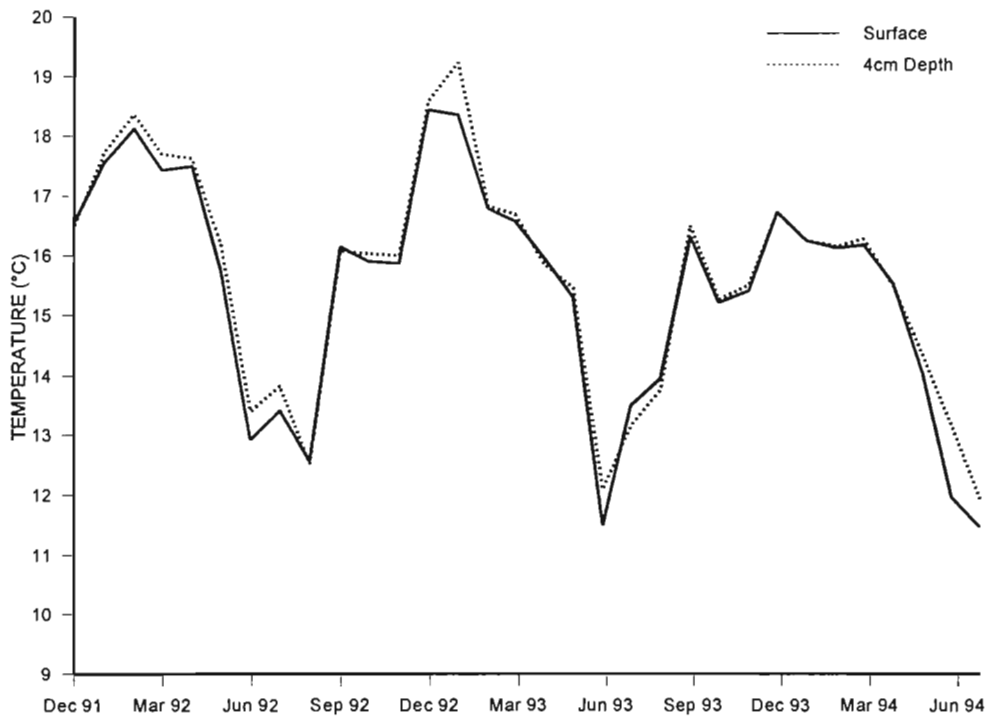


Figure 4.15: Monthly average rock temperatures of a fallen rock at the position of the logger in the north shelter of the Main Caves study site.

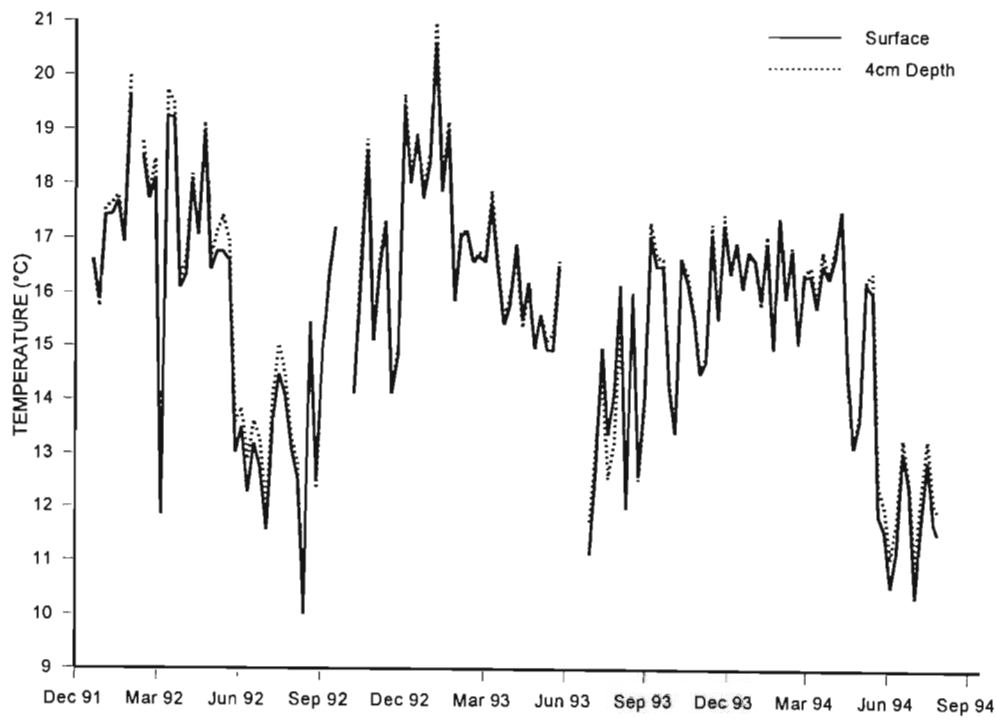


Figure 4.16: Weekly average rock temperatures of a fallen rock at the position of the logger in the north shelter of the Main Caves study site.

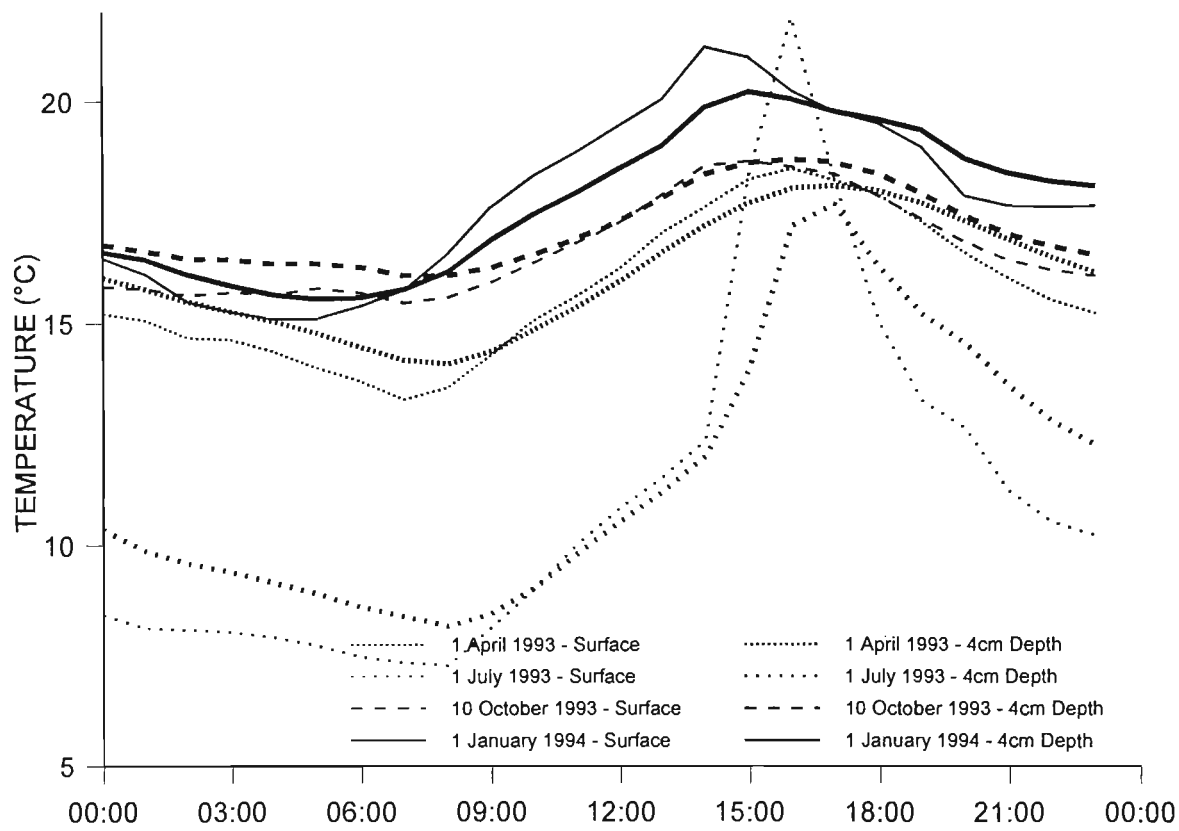


Figure 4.17: Hourly average rock temperatures of a fallen rock at the position of the data logger in the north shelter of the Main Caves study site on four selected days between 1 April 1993 and 31 March 1994.

temperatures, which resulted in the mid-winter temperatures being much lower than the rest of the year, appeared to happen around May and was then followed by a rapid increase in September (Fig. 4.15, 4.16).

The rock temperatures monitored for the inward-facing side of the fallen rock, had a regime similar to that on the other side of the same rock near the logger. However, the sub-surface temperatures mirrored those at the surface more closely (Fig. 4.18, 4.19). The daily temperature regimes analysed for this site (Fig. 4.20) showed the same pattern as those in Figure 4.17, but for the lack of a mid-afternoon peak in July. The differences between surface temperatures and those 4cm below the surface were not as marked as those on the opposite side of the same boulder. Further, at night and during the early morning rock surface temperatures were, generally the same as temperatures at 4cm depth.

The back wall of the north shelter of the Main Caves study site had a slightly different temperature regime to that of the fallen boulder. As with the other sites monitored and discussed above, summer temperatures were greater than those in winter (Fig. 4.21, 4.22). Rock temperatures 4cm below the surface were always warmer than those on the surface of the back wall (Fig. 4.21, 4.22, 4.23). Daily rock temperatures in January showed the least variation (Fig. 4.23), and were, surprisingly, lower than those in April and October.

4.2.1.2.3. RADIATION

Values recorded for total incoming radiation reflect the average values recorded on the logger and not the total radiation received during a logging period. Radiation receipts underneath the north shelter of the Main Caves study site were at a maximum during winter (June) (Fig. 4.24, 4.25, 4.26). The increased solar radiation received in the shelter was due to the low angle of the sun during winter. During the summer months the angle of the incoming sun's rays was too acute for direct radiation to be received at the back of the shelter. The apparent change in the amount of incoming solar radiation after August 1992 (Fig. 4.24; 4.25) was a result of the radiation sensor being moved to a position closer to the air

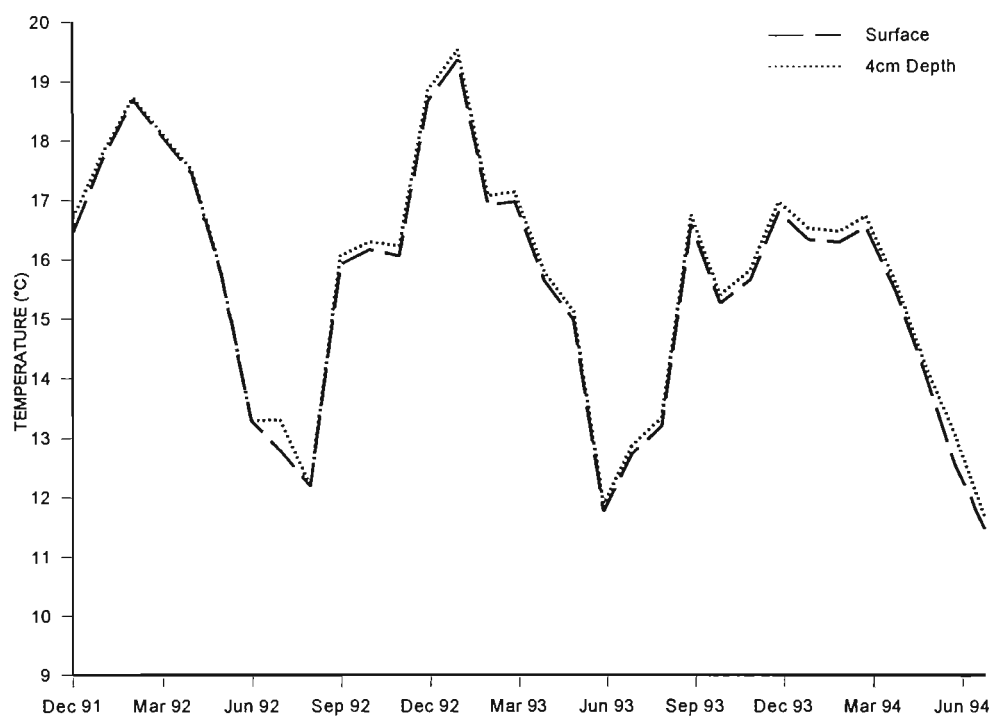


Figure 4.18: Monthly average rock temperatures of a fallen rock in the display area of the north shelter of the Main Caves study site.

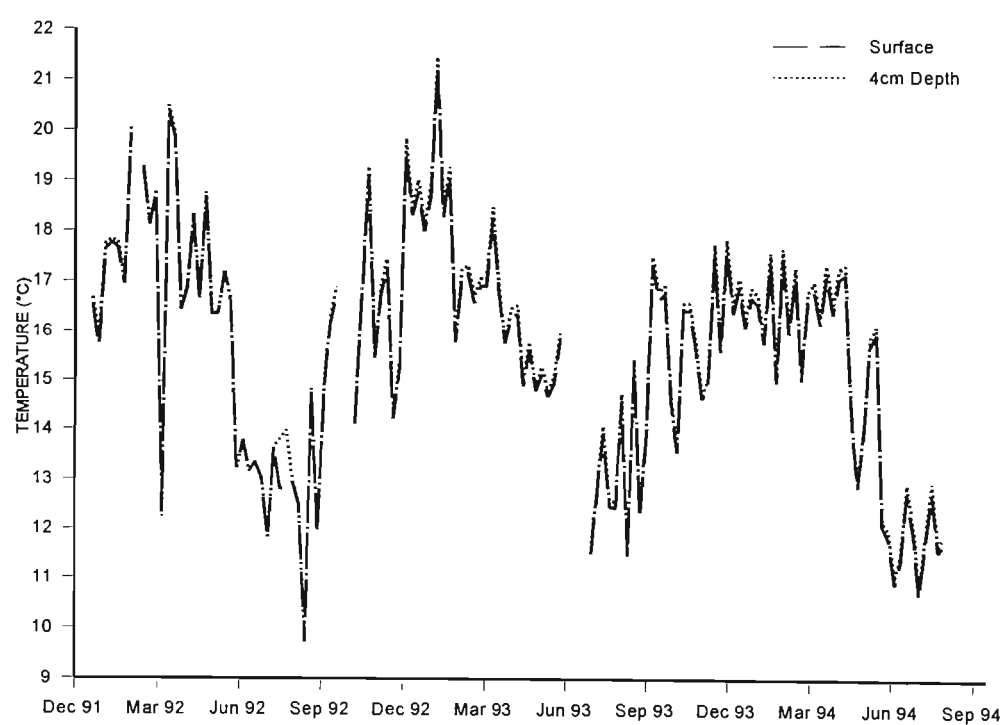


Figure 4.19: Weekly average rock temperatures of a fallen rock in the display area of the north shelter of the Main Caves study site.

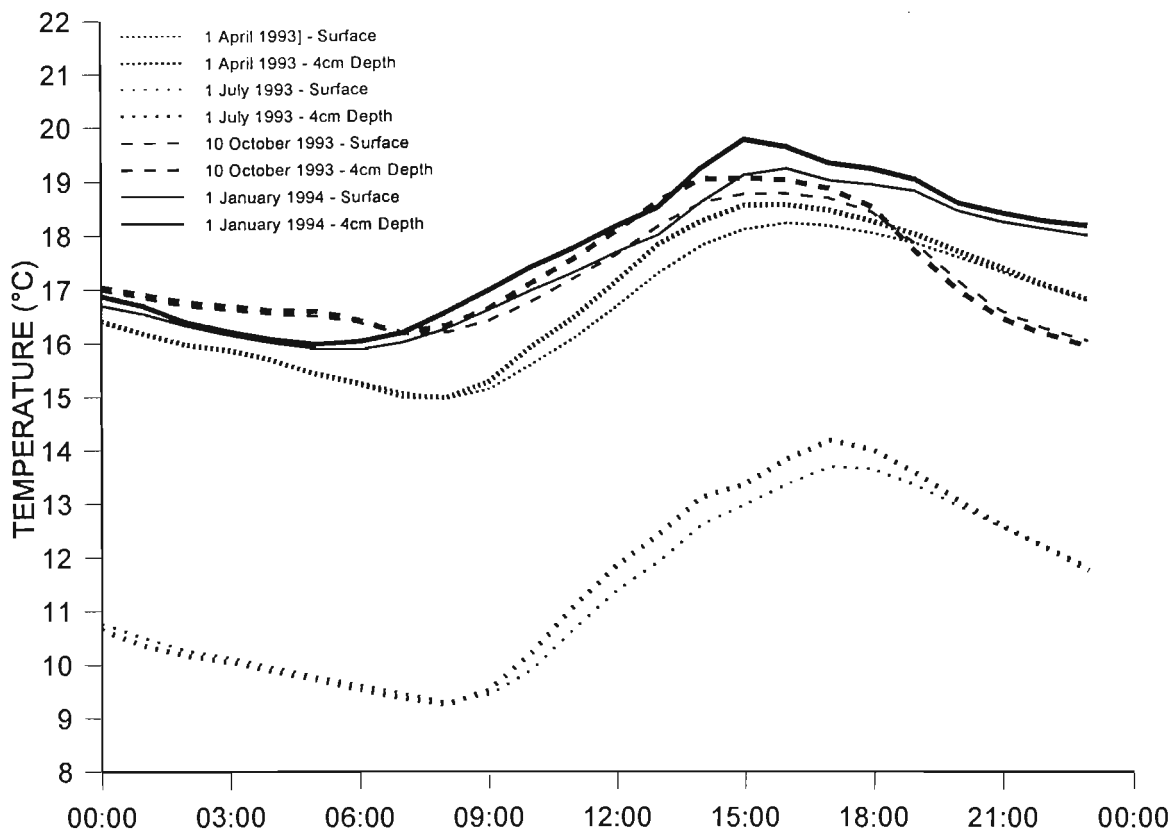


Figure 4.20: Hourly average rock temperatures of a fallen rock in the display area of the north shelter of the Main Caves study site on four selected days between 1 April 1993 and 31 March 1994.

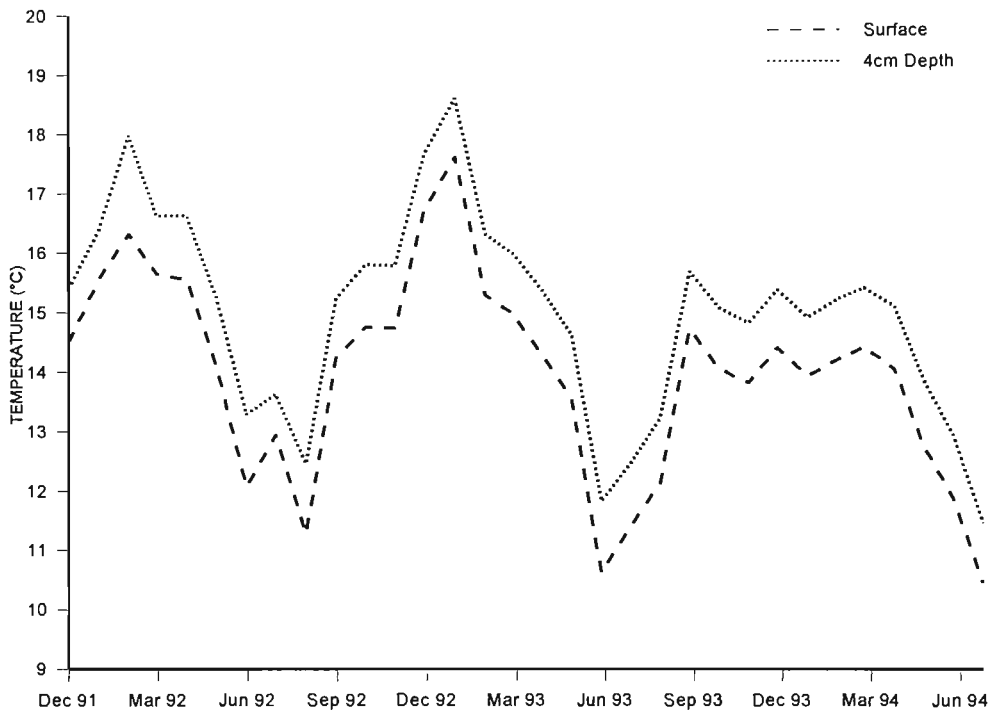


Figure 4.21: Monthly average rock temperatures of the back wall in the north shelter of the Main Caves study site.

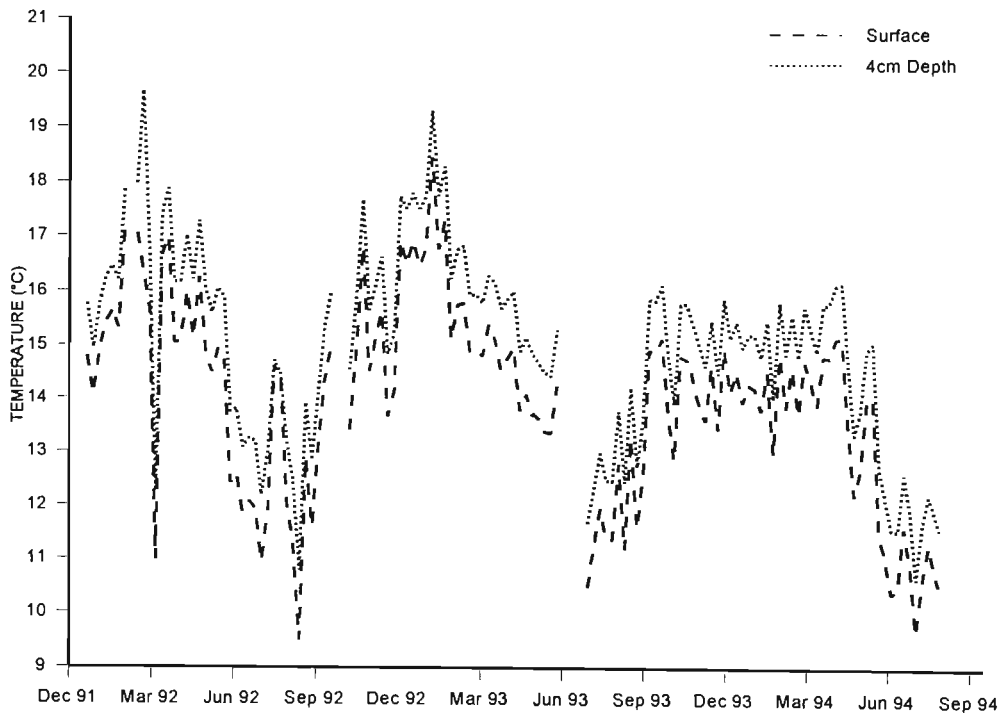


Figure 4.22: Weekly average rock temperatures of the back wall in the north shelter of the Main Caves study site.

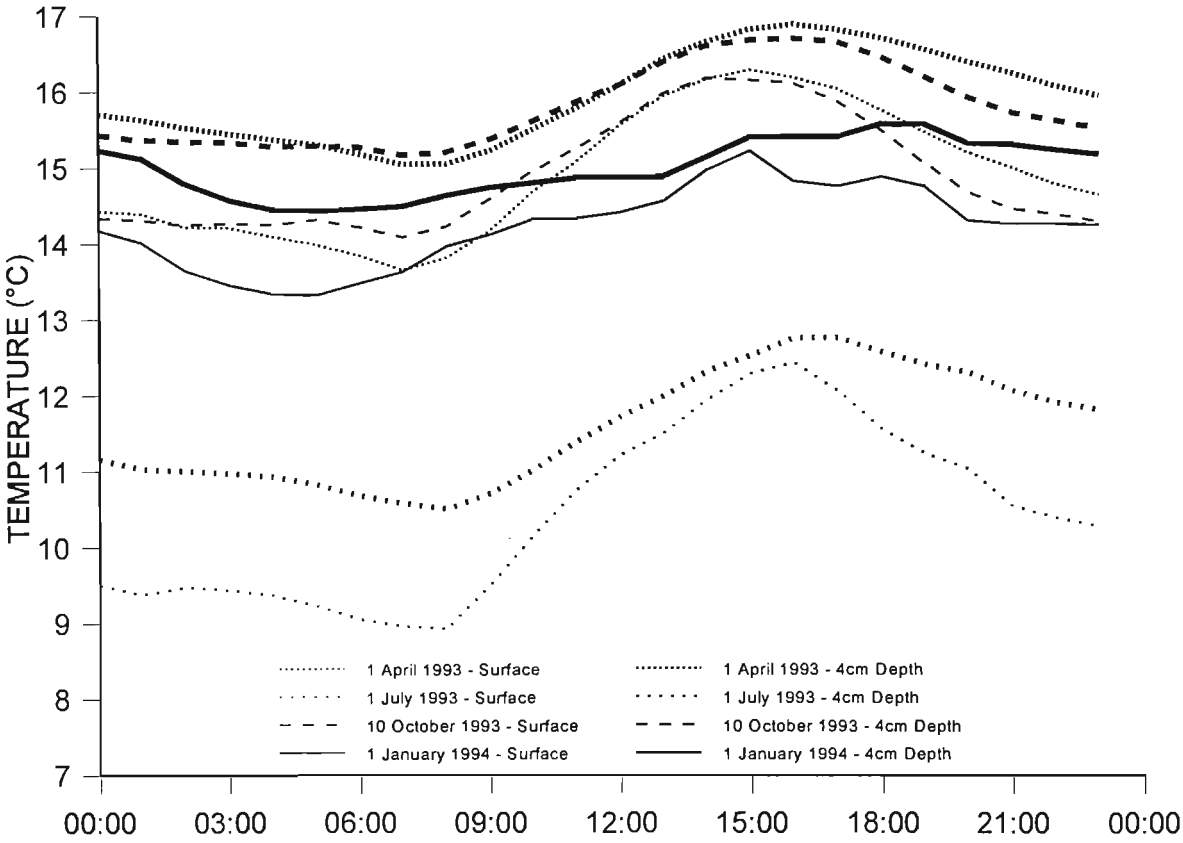


Figure 4.23: Hourly average rock temperatures of the back wall of the north shelter of the Main Caves study site on four selected days between 1 April 1993 and 31 March 1994.

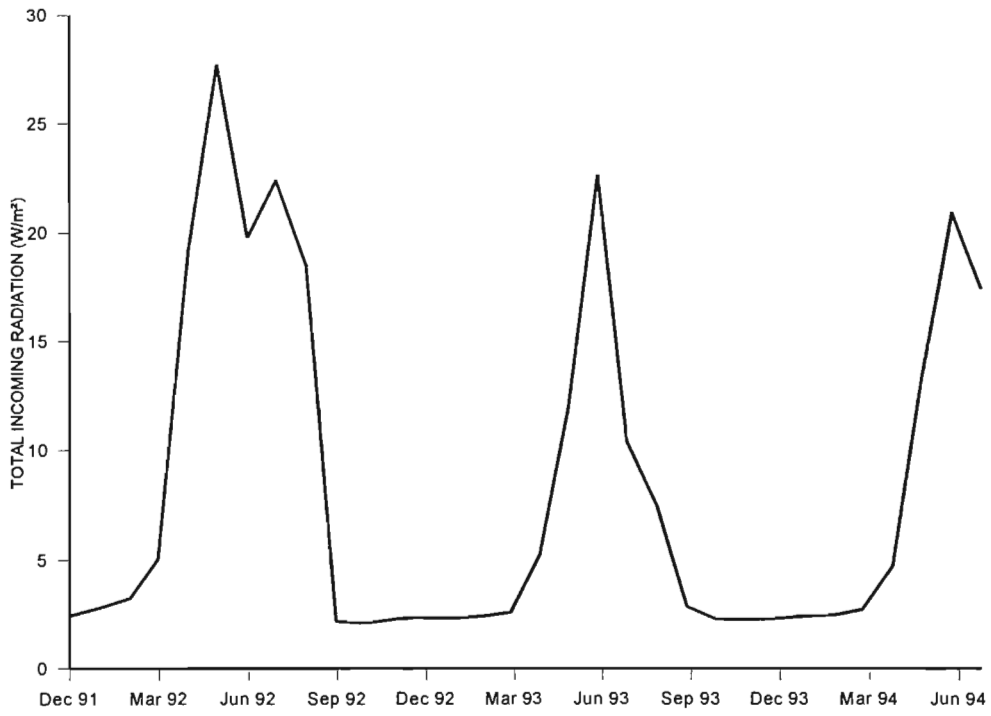


Figure 4.24: Monthly average total incoming radiation in the north shelter of the Main Caves study site.

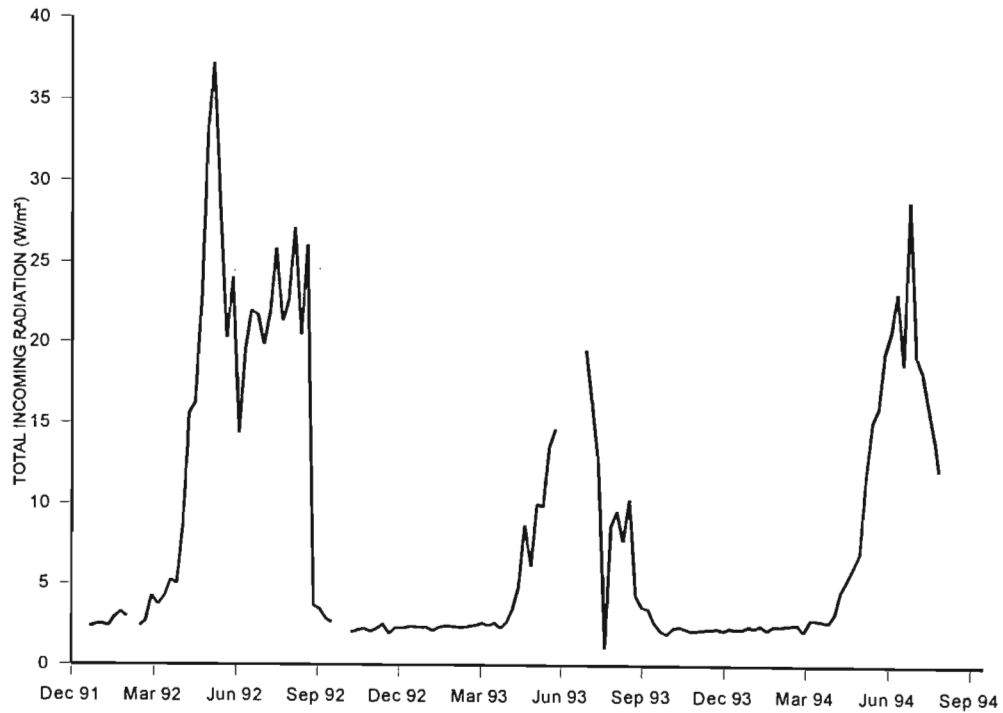


Figure 4.25: Weekly average total incoming radiation in the north shelter of the Main Caves study site.

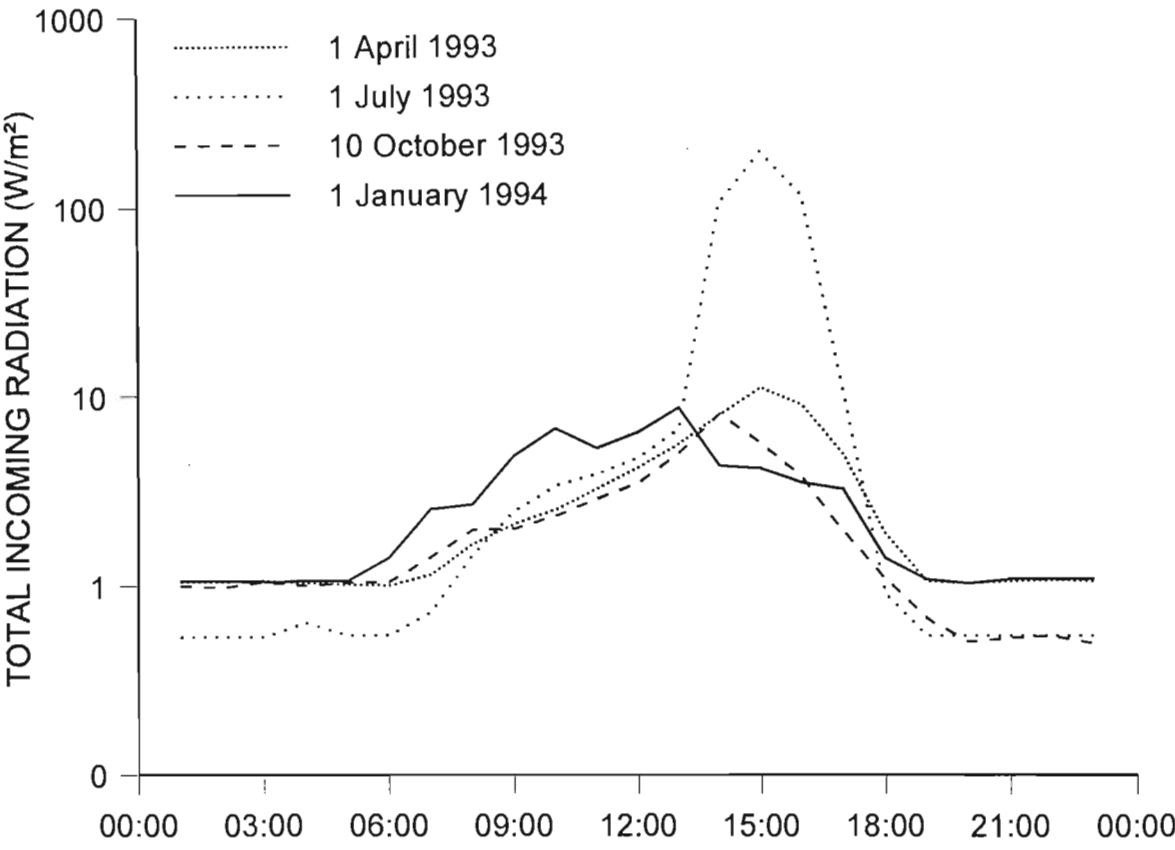


Figure 4.26: Hourly average total radiation receipts in the north shelter of the Main Caves study site on four selected days between 1 April 1993 and 31 March 1994.

temperature, rock temperature and humidity sensors, so that it more accurately reflected the actual radiation receipts where rock art is found. Outside of the winter months (April to September), total incoming radiation averages were consistent (Fig. 4.24; 4.25). The latter observation is particularly evident from the daily records (Fig. 4.26), where the curves for April and October are almost identical and not dissimilar to that of January, while the curve for July shows radiation receipts to be orders of magnitude greater. The direct solar radiation which reached the radiation sensor from oblique sun's rays was responsible for the increased readings in the mid-afternoon during winter in the north shelter of the Main Caves study site.

4.2.1.2.4. ATMOSPHERIC MOISTURE

Together with temperature, it is moisture that constitutes a major influence on the weathering processes and therefore this formed a critical variable in microclimatic monitoring. Atmospheric moisture, determined from actual vapour pressures, showed seasonal trends with high summer values and low winter values (Fig. 4.27, 4.28). January and February were the most humid months of the year, while June and July were the driest months of the year. These trends correspond to the seasonal rainfall pattern, in which 70% of the annual rainfall is between October and March (Tyson *et al.*, 1976). Atmospheric humidity fell rapidly at the end of summer, in March. The winter of 1992 appears to have been a particularly dry one, with July of that year recording the lowest humidity; this period was recognised as the driest in living memory (Yunie, personal communication, 1992). Daily regimes show the low winter humidity and the atmospheric moisture contents during the rest of the year (Fig. 4.29). On the days shown in Figure 4.29 the atmospheric moisture content on 1 July 1993 was the most stable, followed by that on 1 April 1993, whilst humidities were the most variable on the displayed days in October and January.

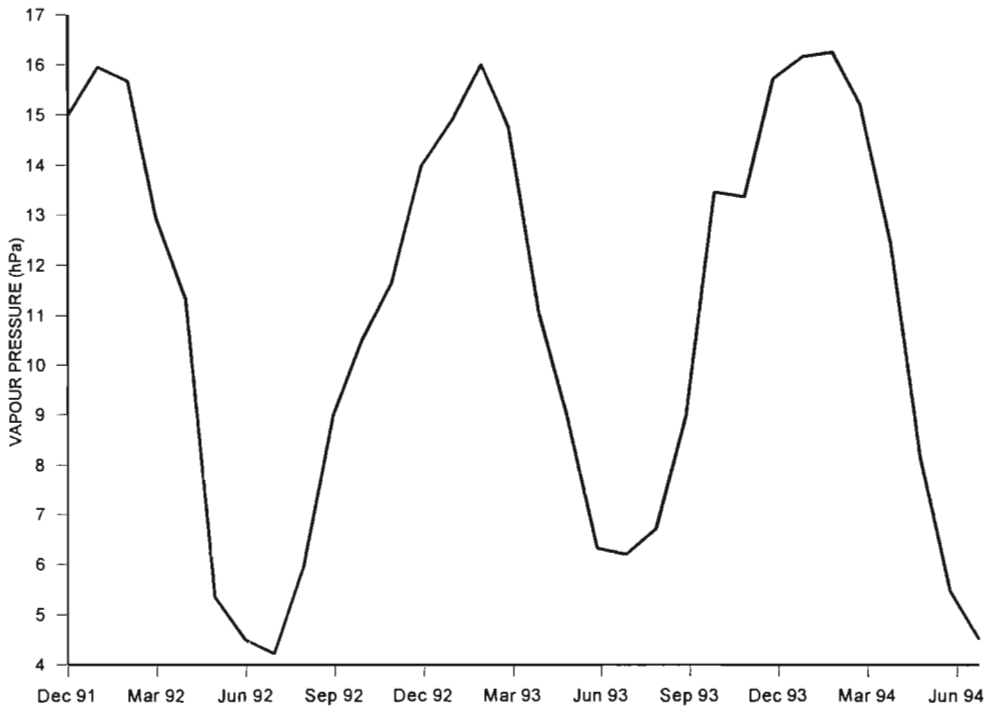


Figure 4.27: Monthly average atmospheric moisture content (as represented by vapour pressure) in the north shelter of the Main Caves study site.

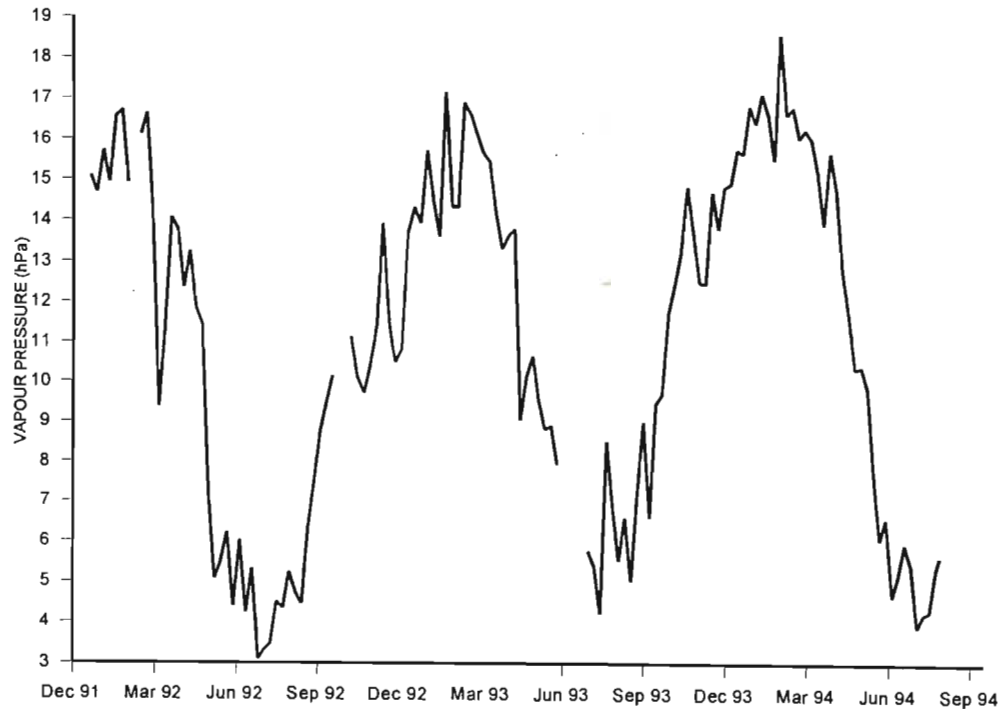


Figure 4.28: Weekly average atmospheric moisture content (as represented by vapour pressure) in the north shelter of the Main Caves study site.

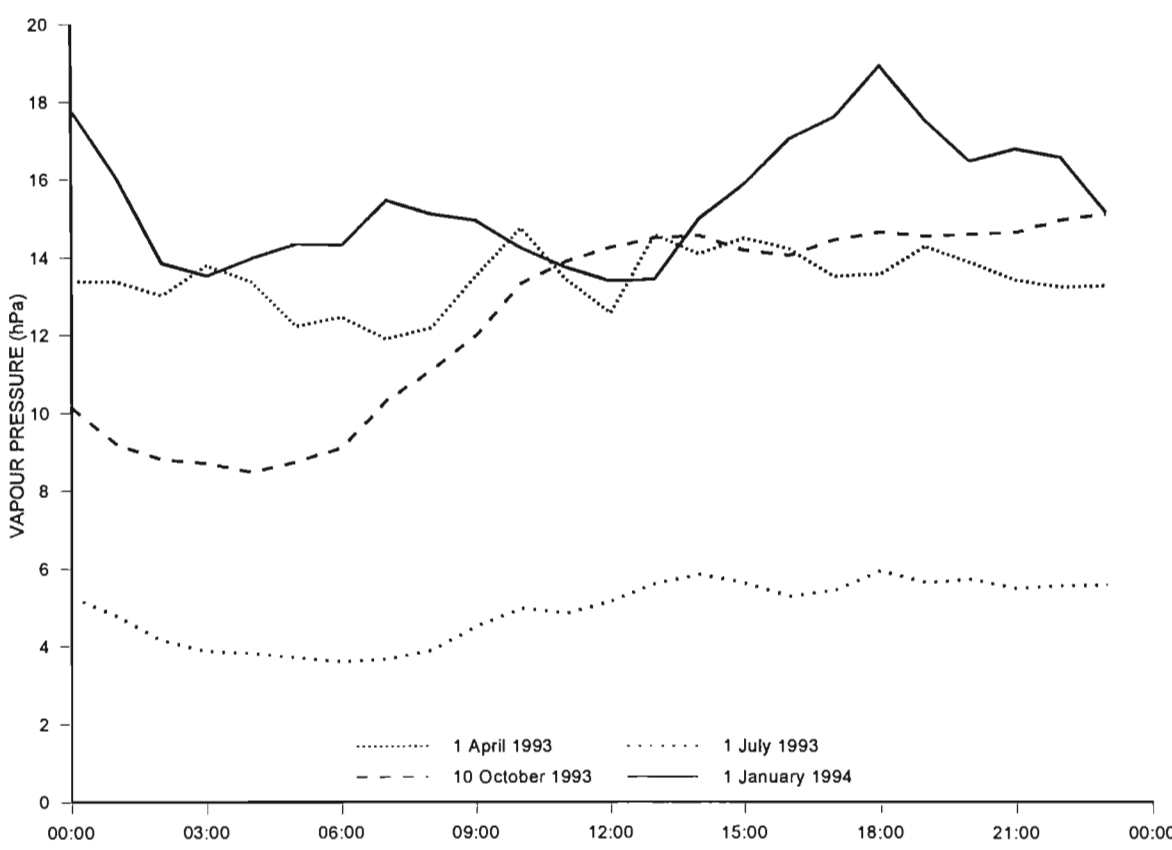


Figure 4.29: Hourly average atmospheric moisture content (represented by vapour pressure) in the north shelter of the Main Caves study site on four selected days between 1 April 1993 and 31 March 1994.

4.2.1.2.5. ROCK SURFACE MOISTURE

A “leaf wetness” sensor was used to provide a relative measure of rock surface moisture for this study. Relative rock surface moisture was highest during summer (December - February) and lowest during winter (June - August), showing the same seasonal trends as atmospheric moisture (Fig. 4.30, 4.31). However, it is apparent, from weekly (Fig. 4.31) and hourly averages (Fig. 4.32), that rock surface moisture was variable, especially during the more humid periods of the year. During the drier part of the year rock moisture showed little variation (Fig. 4.32). The variability of relative rock surface moisture is particularly evident if it is considered that a logarithmic scale (which reduces the visual impact of the graphical representation) is used on the Y axis in Figure 4.32 to show hourly changes in relative rock surface moisture content.

4.2.1.2.6. SOIL MOISTURE

As the soil moisture sensor was located in the soil below a drip-line at the back wall of the north shelter of the Main Caves, it provided an indication of when the drip was active. The data obtained from the soil moisture changed directly from the minimum and the maximum values, with very few readings recorded between these two extremes (Fig. 4.33, 4.34). Only between October 1993 and March 1994 was any variation evident, when the relative soil moisture varied between approximately 50% and 95% of saturation. Hourly average moisture values showed no significant movement (Fig. 4.35). Despite the lack of any significant trends shown, other than seasonal variations, the data can, nevertheless, be used to determine periods when water flows down the drip at the back wall of the shelter. The data do not, however, reflect the precise time when water ceased to drip at the back wall, because the soil, where the moisture sensor was located, was observed to remain saturated for up to six weeks after water stops dripping. The late increase in soil moisture content in the spring/summer of 1993 (Fig. 4.33, 4.34) reflects the very dry winter experienced that year.

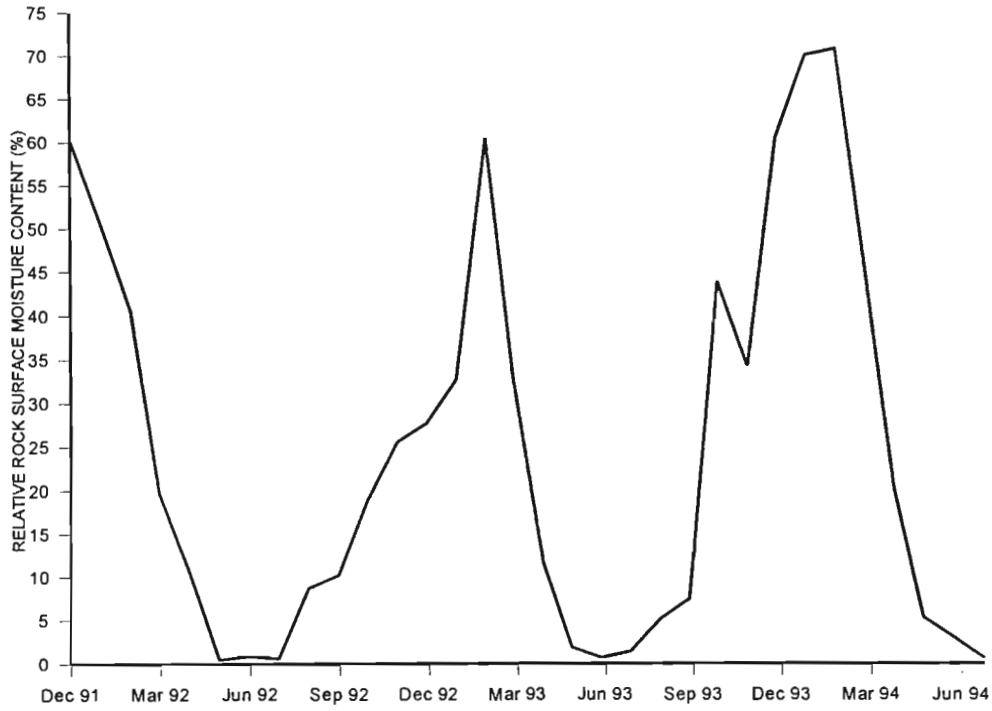


Figure 4.30: Monthly average relative rock surface moisture content in the north shelter of the Main Caves study site.

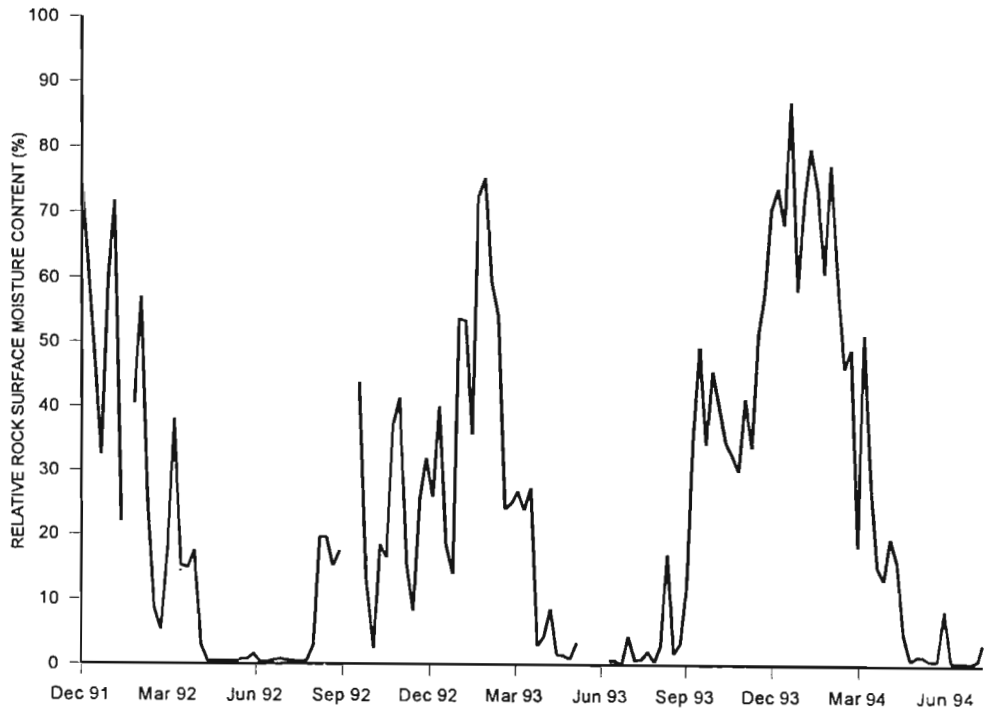


Figure 4.31: Weekly average relative rock surface moisture content in the north shelter of the Main Caves study site.

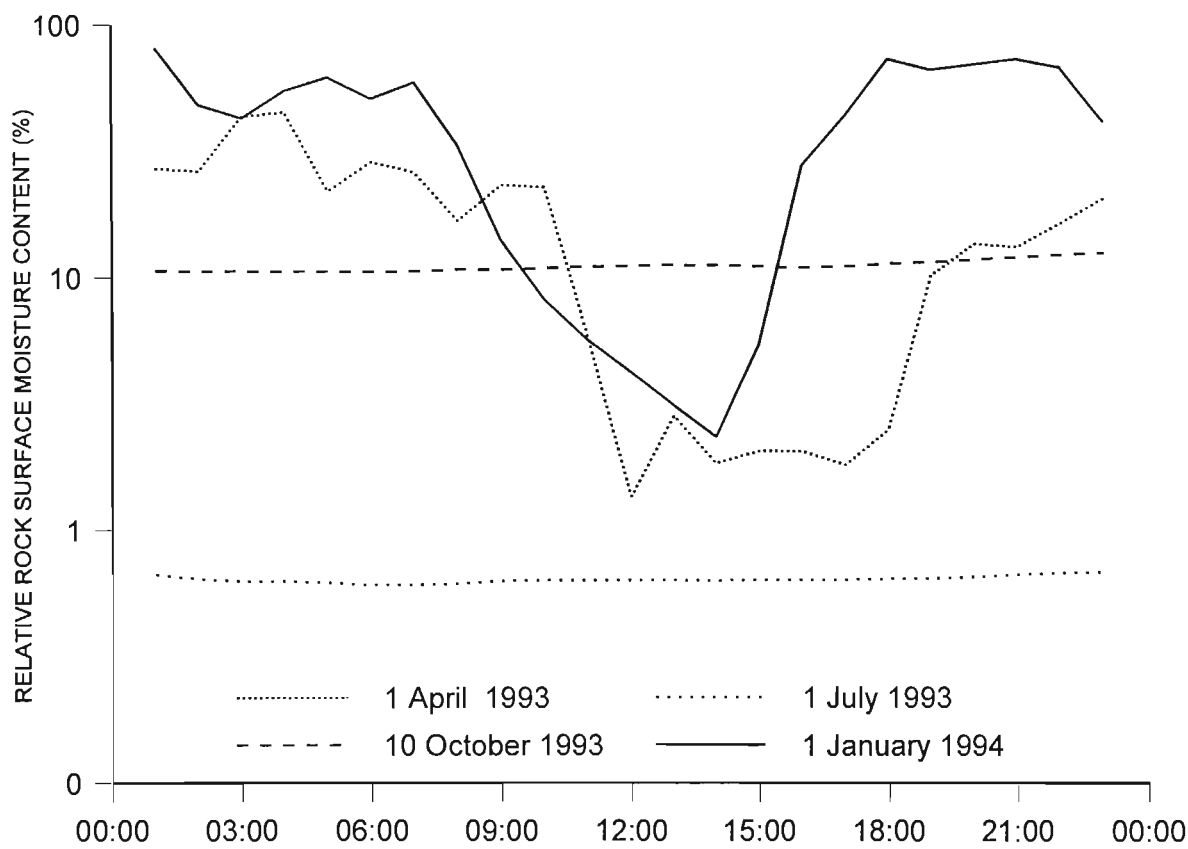


Figure 4.32: Hourly average relative rock surface moisture content in the north shelter of the Main Caves study site on four selected days between 1 April 1993 and 31 March 1994.

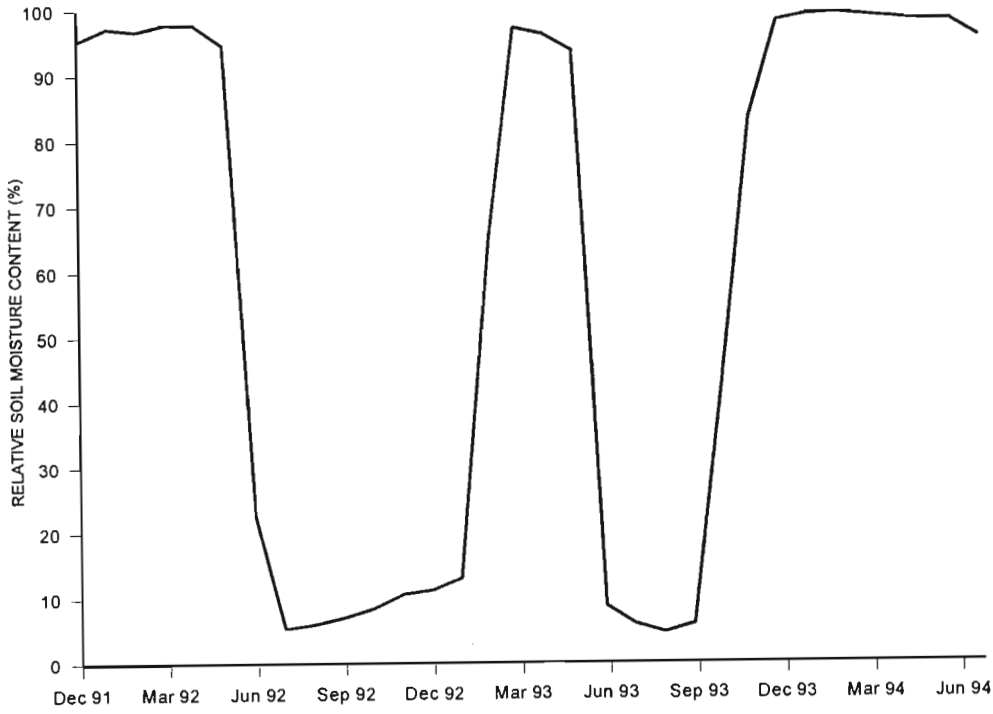


Figure 4.33: Monthly average relative soil moisture content in the north shelter of the Main Caves study site.

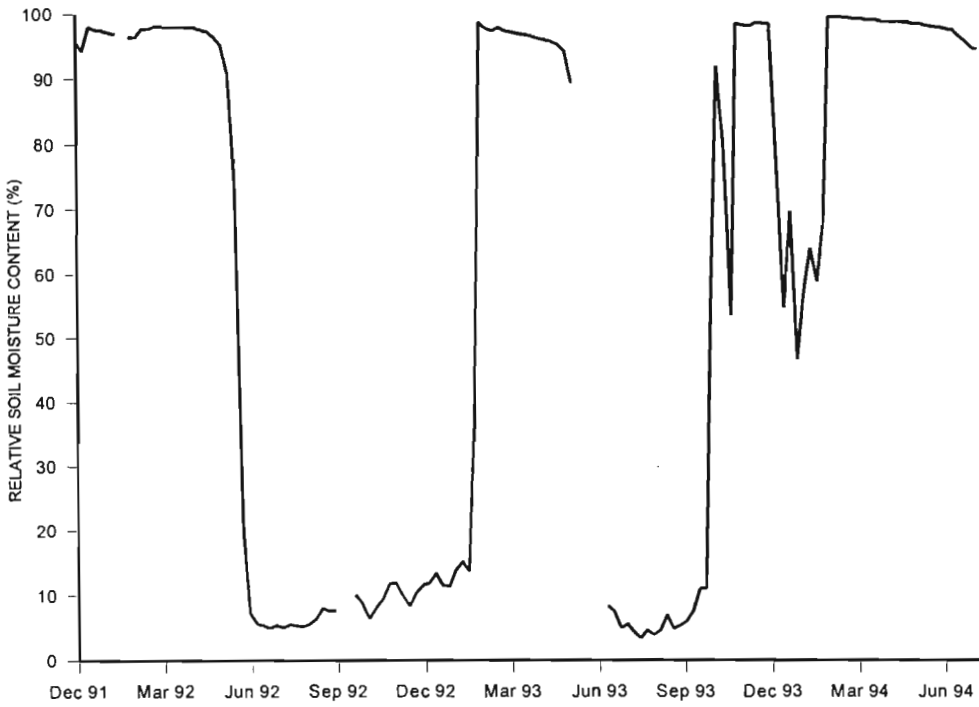


Figure 4.34: Weekly average relative soil moisture content in the north shelter of the Main Caves study site.

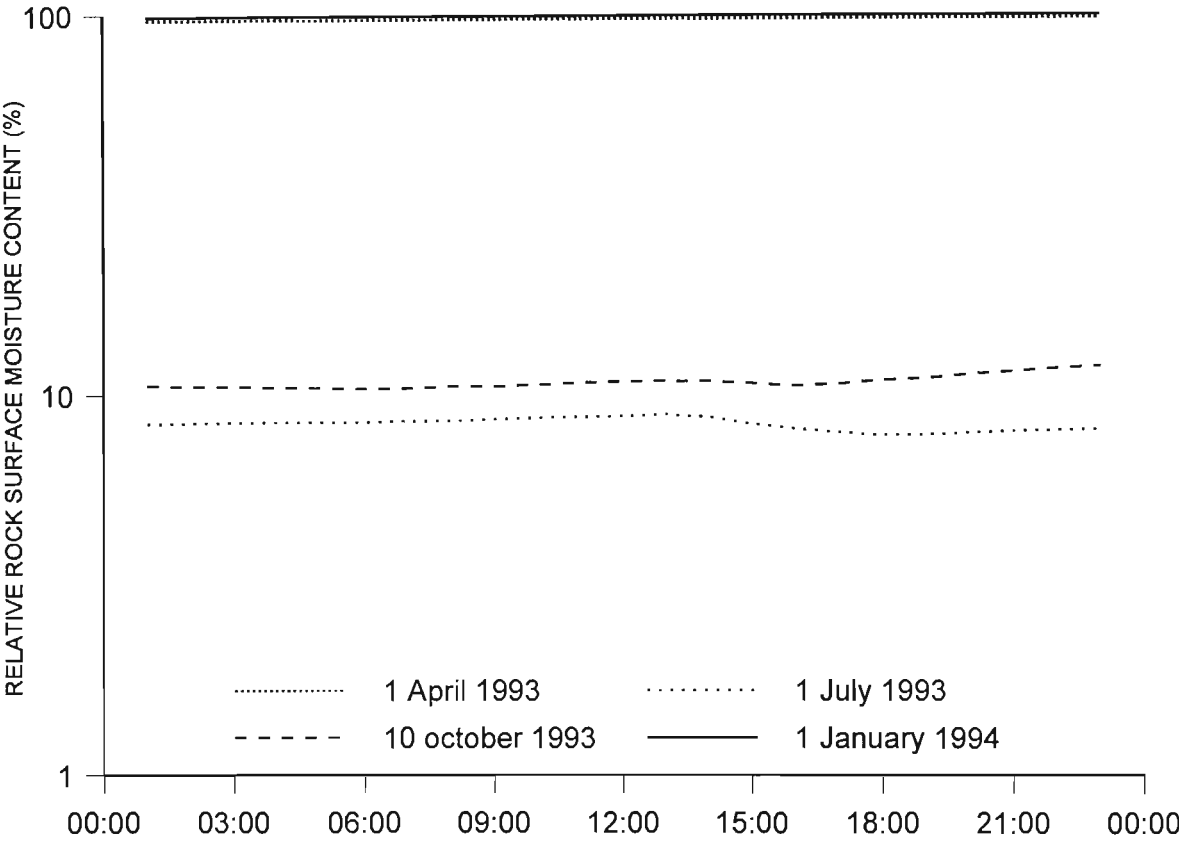


Figure 4.35: Hourly average relative soil moisture content in the north shelter of the Main Caves study site on four selected days between 1 April 1993 and 31 March 1994.

4.2.1.2.7. WIND SPEED AND DIRECTION

In the north shelter of the Main Caves study site the mean wind directions, as determined using the von Mises distribution (Till, 1980), and modes were calculated, together with mean wind speed. From observations at the study site, and recorded measurements (Fig. 4.36), the wind direction data is largely bi-modal with winds from the north-west and the south-east being the most common. The mode for the whole period of data collection was 286° (Fig. 4.38). Due to the bi-modal wind distribution, and the fact that it was not possible for wind to come from all 360° , it was decided not to use the mean vector for wind direction as determined using von Mises distribution (Till, 1980). For example the mean wind vector is 10.99° , which bears no relationship to the most common wind direction of 286° . When the mode wind vector is plotted on a map it is evident that the most common wind is down-valley and parallel to the back wall of the north shelter (Fig. 4.38).

Monthly and weekly average wind speeds show little variation other than the fact that they were lower at the end of summer (February - March) than at any other time of the year (Fig. 4.36, 4.37). The greatest average wind speeds were recorded in October 1992 (Fig. 4.36), however little can be derived from this observation.

Hourly wind data on the four days chosen for graphic display (Fig. 4.39) were predominately from the north-west during all seasons of the year. Directions were generally consistent at night and in the very early morning, whilst directions were more variable during the day (Fig. 4.39). The lack of wind activity at night and in the early morning was shown in wind speed data, as speeds were very low at these times during all seasons (Fig. 4.40).

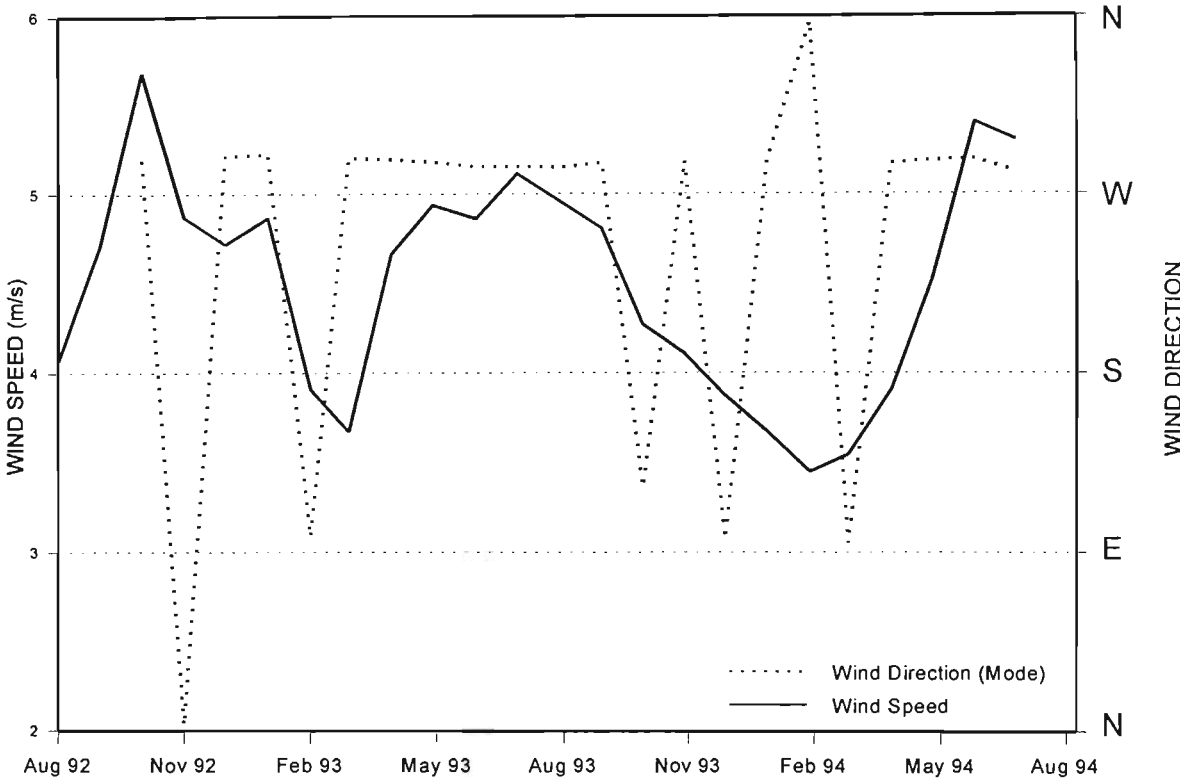


Figure 4.36: Monthly wind statistics for the north shelter of the Main Caves study site (Note: directions represent the mode for that particular month).

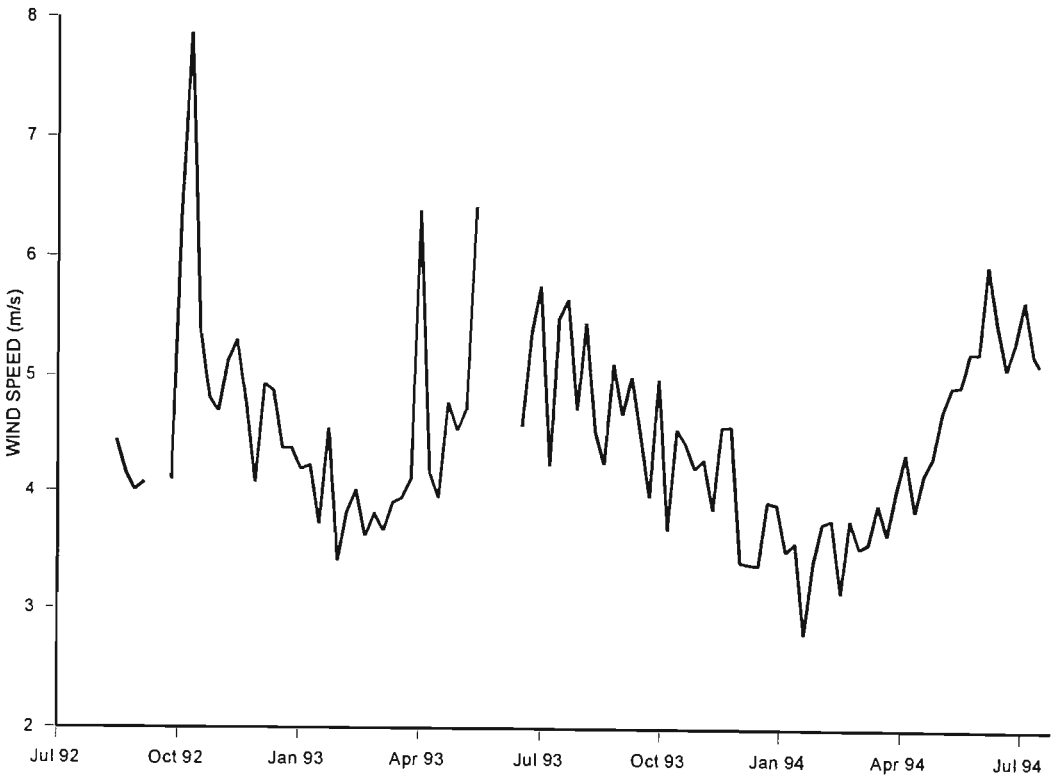


Figure 4.37: Weekly average wind speeds in the north shelter of the Main Caves study site.

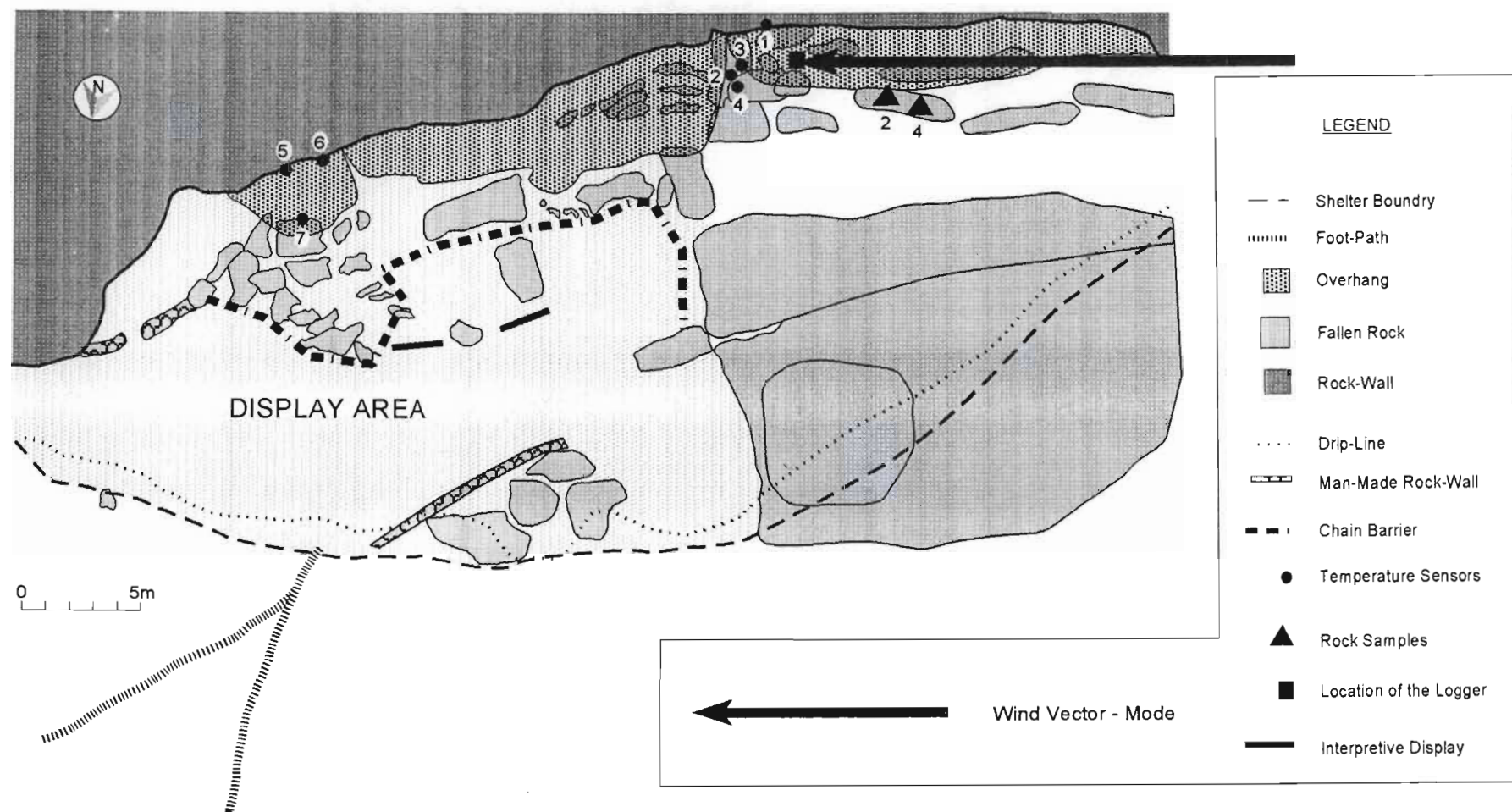


Fig. 4.38: Map of the north shelter of the Main Caves study site with the mode wind vector shown.

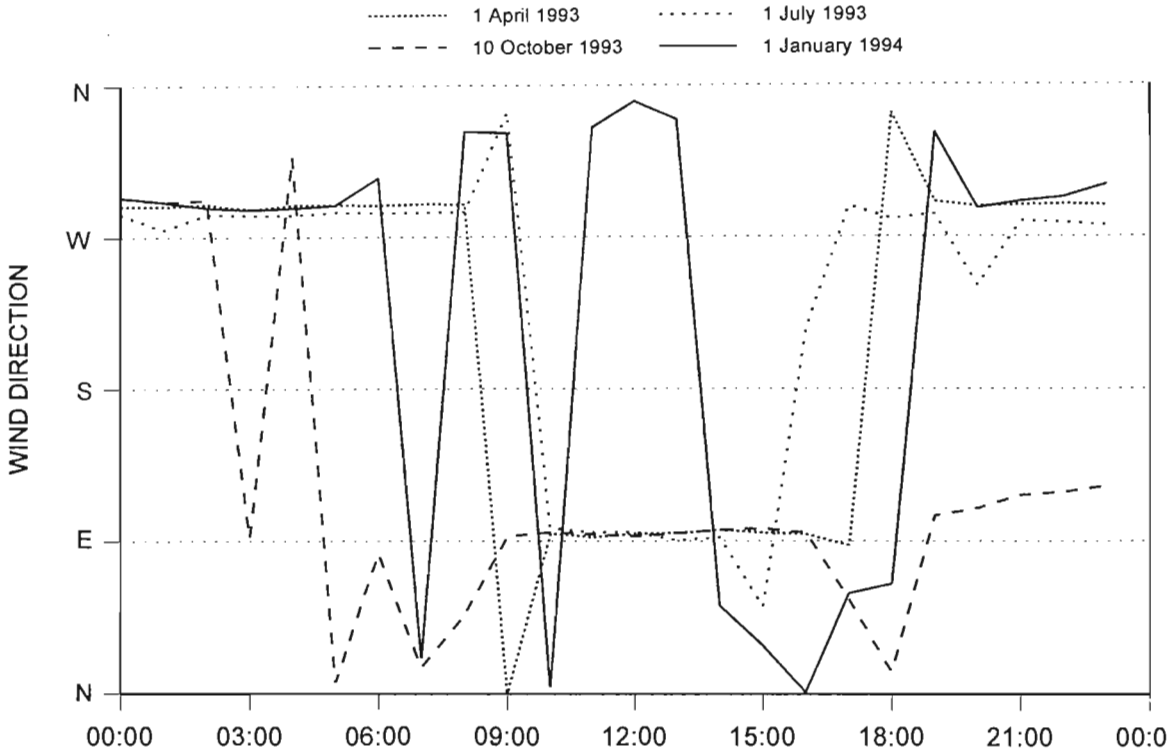


Figure 4.39: Hourly wind directions in the north shelter of the Main Caves study site on four selected days between 1 April 1993 and 31 March 1994.

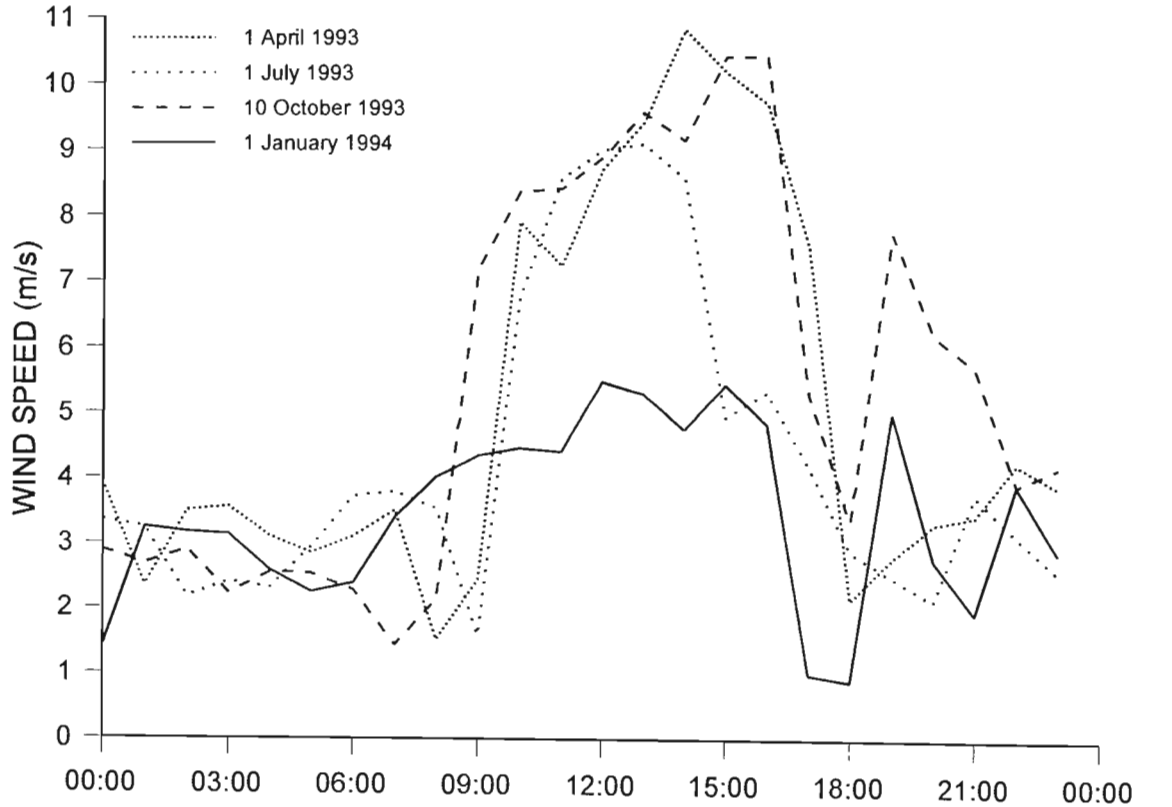


Figure 4.40: Hourly average wind speed in the north shelter of the Main Caves study site on four selected days between 1 April 1993 and 31 March 1994.

4.2.2. LABORATORY ANALYSES

4.2.2.1. Rock Properties

The methodology outlined by Cooke (1979) was used to determine the main rock properties for this project. Porosity was calculated using two additional methods: mercury porosimetry and the volume of water taken up under vacuum (undertaken at the Centre de Geomorphologie, University of Caen). The results obtained for porosity values indicate that the Cooke (1979) methodology used for rock property determinations in this study may overestimate the values for rock porosity (Table 4.3). Discussions concerning the significance of the rock property values in the following chapter (Chapter 5) will consider the fact that actual rock porosity values may be lower than calculated.

METHOD	Cooke (1979)	Volume of water taken up under Vacuum	Mercury Porosimetry
Sample 1	12.26	7.05	8.66
Sample 2	9.07	4.00	5.56
Sample 3	7.80	3.68	4.42
Sample 4	5.70	2.94	3.00

Note: 1. Measurements are in %.
2. The samples used were broken down into smaller pieces and the values shown for Cooke's (1979) method represent averages for those samples.

Table 4.3: Porosity of samples from the Main Caves study site using three different methods.

Rock properties calculated for this study are displayed in Table 4.4 below. The samples used in simulations were all cut from the same rock sample, hence the similarity in the values obtained. However, of the samples used in simulations, samples 14 and 15 were small pieces that appeared to be more weathered than the others. Rock porosity values of samples from the Main Caves study have porosities ranging from 3.5% to 15.65%, with an average of 8.84 % (Table 4.4). The samples used for mercury porosimetry were ranked according to the degree of weathering that each had undergone, with sample 1 being the most weathered and sample 4 being the least weathered. If the above observation is accepted as being correct then, as the amount of weathering increases, so does the porosity of

the samples (Table 4.4). The lowest porosity values, samples 9a - 9d from the Main Caves, are from an apparently impermeable layer at the base of the north shelter of the study site, along which water has been observed to flow. The highest porosity values, on the other hand, are from highly weathered samples (sample 11 of the general samples, and sample 1 of those used for mercury porosimetry) in the north shelter of the Main Caves.

Microporosity of samples from the Main Caves site is between 59% and 99.19%, with an average of 83.49%, but is generally in excess of 80% (Table 4.4). The samples used for mercury porosimetry had a microporosity of approximately 80% for the most weathered sample and just under 90% for the least weathered sample using Cooke's (1979) method (samples 1a - 4d, Table 4.4). If Bousquie's (1979) definition for microporosity, of pore radii being less than $1\mu\text{m}$, is used (note that Cooke's method does not specify a pore size for microporosity), then mercury porosimetry gives values of 85% microporosity for the most weathered sample and approximately 95% for the least weathered sample from the Main Caves site (Fig. 4.41, 4.42). The least weathered sample had an infraporosity (pores of radius less than $0.01\mu\text{m}$ as defined by Bousquie (1979)) of approximately 67% (Fig. 4.42). The average size of micro-pores increases as the degree of weathering of a sample increased (Fig. 4.43). The least weathered sample, of those tested, had the largest range of pore sizes (Fig. 4.43), while the more weathered samples had a smaller ranges. It is evident from the tests undergone that the more weathered samples do not have any significant numbers of very small pores (e.g. infra-pores) (Fig. 4.42, 4.43).

The water absorption capacities of the samples tested were consistently between 5 and 10%. However, an impermeable sample from the north shelter of the Main Caves and another, (sample 3) used for monitoring rock moisture content, were both below 3.3 %, while the three highly weathered samples had absorption capacities greater than 10 % (Table 4.4). It was found that, for those samples used for mercury porosimetry, the water absorption capacity was positively linked to the degree of weathering of a sample (Table 4.4).

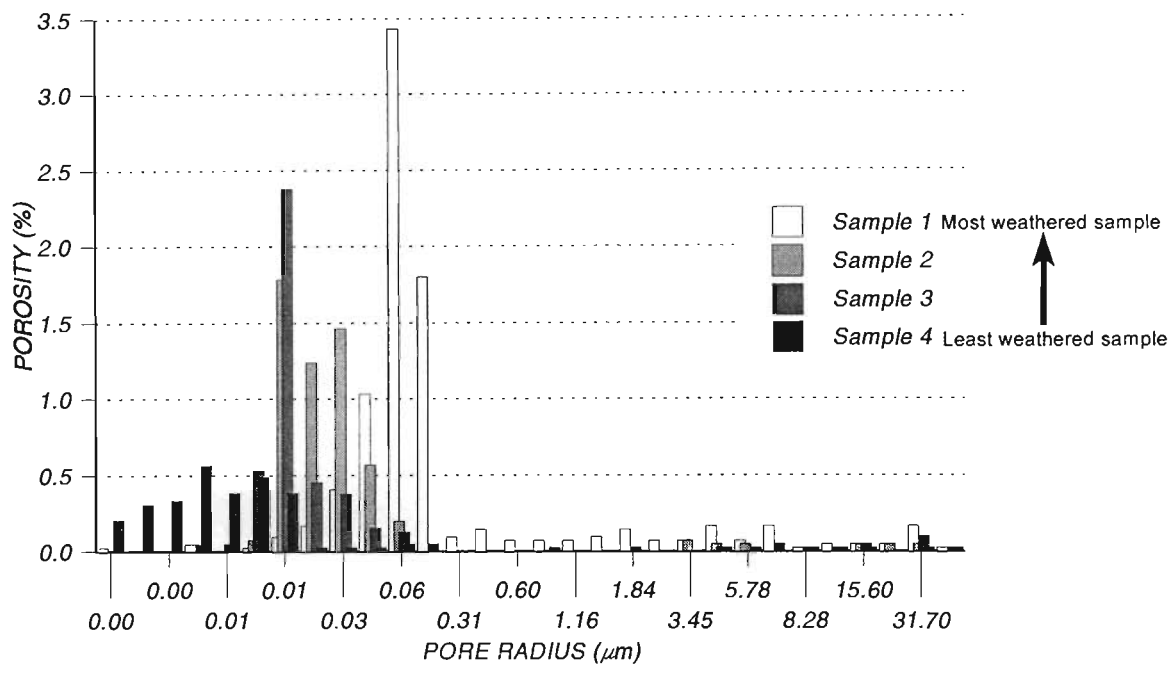


Figure 4.41: Porosity of certain pore sizes for samples from the Main Caves study site, determined using mercury porosimetry.

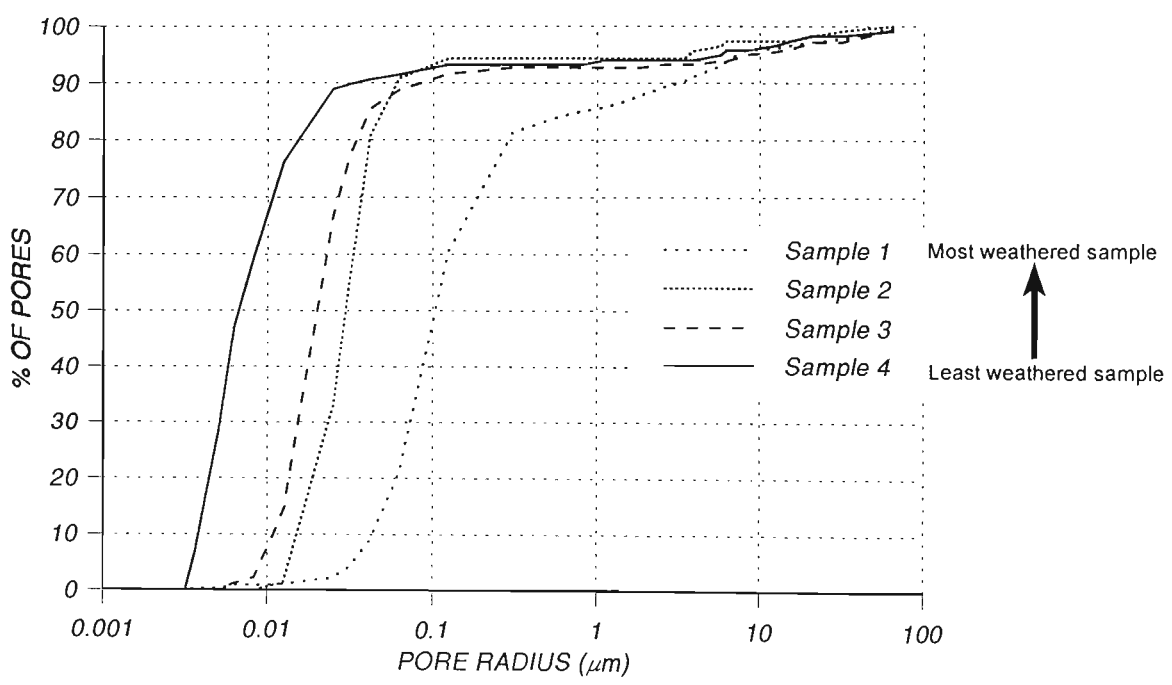


Figure 4.42: Graph of pore radius against the % of pores in each of the pore sizes monitored for four samples of varying degrees of weathering from the Main Caves study site, determined using mercury porosimetry.

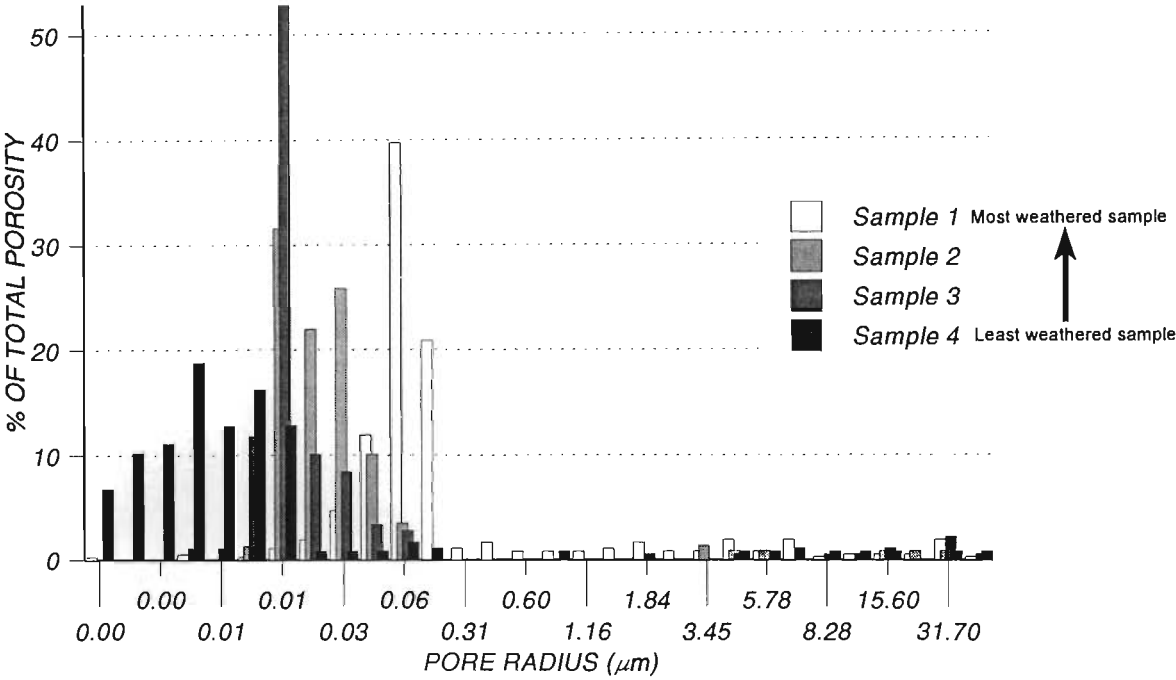


Figure 4.43: Percentage of the total porosity of each sample for certain pore sizes for four samples of varying degrees of weathering, from the Main Caves Study site, determined using mercury porosimetry.

SAMPLE	POROSITY	WATER ABSORPTION CAPACITY	SATURATION COEFFICIENT	MICROPOROSITY
Field samples used for rock moisture monitoring at the Main Caves				
1	7.18	7.13	0.99	99.19
2	8.35	8.19	0.98	96.19
3	3.59	3.13	0.87	87.23
4	7.65	7.38	0.96	93.75
5	9.21	8.93	0.97	95.96
Samples from the Main Caves				
1	8.70	7.41	0.85	90.80
2	9.09	7.84	0.86	88.62
3	7.26	6.25	0.86	73.50
4	7.70	7.19	0.93	81.22
5	7.56	6.60	0.87	77.00
6	8.20	8.14	0.99	76.52
7	7.35	6.56	0.89	81.88
8	7.62	6.72	0.88	78.43
9a	3.56	2.60	0.73	96.27
9b	3.57	2.59	0.72	96.19
9c	3.59	2.65	0.74	97.89
9d	3.50	2.61	0.74	97.96
10a	9.55	8.60	0.90	60.67
10b	10.06	8.44	0.84	59.00
11a	15.65	13.39	0.86	93.81
11b	12.05	10.04	0.83	84.97
Samples used in simulations				
1	6.92	6.24	0.90	94.30
2	7.23	6.58	0.91	90.98
3	7.32	6.20	0.85	92.44
4	6.75	5.52	0.82	90.44
5	7.89	7.07	0.90	87.79
6	7.46	6.69	0.90	89.16
7	7.92	6.77	0.85	93.02
8	8.11	7.14	0.88	86.25
9	*6.86	5.94	0.87	94.52
10	7.31	6.51	0.89	91.97
11	8.17	7.44	0.91	81.06
12	6.34	5.35	0.84	89.41
13	9.01	8.10	0.90	89.57
14	8.20	7.56	0.92	82.57
Samples for mercury porosimetry				
1a	11.91	9.70	0.81	79.07
1b	11.63	9.87	0.85	79.80
1c	13.24	10.66	0.81	78.81
1d	12.27	10.29	0.84	79.41
2a	8.56	7.00	0.82	80.30
2b	9.76	8.23	0.84	81.25
2c	8.46	7.53	0.89	82.93
2d	9.50	8.31	0.88	82.81
3a	7.53	6.61	0.88	85.02
3b	8.06	6.80	0.84	82.86
4a	5.54	5.20	0.94	89.69
4b	5.60	5.32	0.95	90.00
4c	5.68	5.23	0.92	88.89
4d	5.97	5.73	0.96	88.00
Avg.	8.84	7.61	0.87	83.49

Note:

When letters are used in the sample numbering system, they represent pieces of the same sample (e.g. 1a, 1b, 1c and 1d were all cut from the same block of rock).

Table 4.4: Properties of rock samples from the Main Caves study site, determined by using Cooke's (1979) method.

Saturation coefficients of samples from the Main Caves study site were generally greater than 0.8, except for the apparently impermeable rock (sample 9) from the north shelter of the Main Caves site (Table 4.4). There tended to decrease in saturation coefficient with increased weathering (seen from the values for the samples used for mercury porosimetry) (Table 4.4). The significance of this data will be discussed in the following chapter (Chapter 5).

4.2.2.2. Rock Chemistry

Four samples which visually appeared to be of identical lithologies, and which were representative of the rock on which Bushman paintings were found in the north shelter of the Main Caves study site, were used to investigate their chemical composition. The samples were selected as they appeared to be weathered to different degrees, with sample 1 being the most weathered and sample 4 being the least weathered.

4.2.2.2.1. MAJOR ELEMENT COMPOSITION

All four samples analysed using XRF (X-ray fluorescence) for major element concentrations had silica as the dominant element, with aluminium and iron as subsidiary elements, while manganese, magnesium, calcium, sodium, potassium, titanium and phosphorous were also present (Table 4.5). The percentage of silica and calcium increased with an increase in sample weathering, while concentrations of aluminium, iron, magnesium, sodium, potassium and titanium decreased with increased weathering (Table 4.5). However, either sample 2 or sample 3 does not fit with the trends, possibly because of mineralogy differences.

SAMPLE	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	TOTAL	L.O.I.
1	78.93	10.64	2.19	0.03	1.12	0.54	3.36	2.48	0.52	0.07	99.88	2.70
2	74.96	12.46	3.03	0.04	1.33	0.47	3.43	3.37	0.60	0.07	99.76	3.13
3	76.75	11.72	2.89	0.03	1.25	0.51	3.19	2.86	0.51	0.07	99.78	2.80
4	73.3	13.53	3.58	0.04	1.53	0.34	3.62	3.25	0.64	0.06	99.89	2.30

Note: 1. Values represent mass percentages of the oxides of major elements
 2. L.O.I. = mass percentage of material lost on ignition.
 3. Sample 1 is the most weathered and sample 4 is the least weathered.

Table 4.5: Major element concentrations for rock samples from the Main Caves study site, determined by XRF (X-ray fluorescence) spectroscopy.

4.2.2.2.2. MINERAL COMPOSITION

Mineral composition, determined using XRD (X-ray diffraction), of the samples analysed appears to vary according to the degree of weathering that the sample has undergone, with the least weathered sample (sample 4) having the lowest concentration of quartz and the highest concentration of feldspar (Table 4.6). On the other hand, the most weathered sample (sample 1) had the highest concentration of quartz and the lowest concentration (together with samples 2 and 3) of feldspar (Table 4.6). As with XRF analyses above, the observed trends are disrupted by either sample 2 or sample 3. Other minerals identified using XRD were kaolin, mica and possibly hematite in all samples (Table 4.6). A clay mineral, which is most likely chlorite is identified in samples 1,3 and 4, while smectite was identified in sample 2 and anatase in sample 3 (Table 4.6).

MINERAL	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4
Quartz	50%	35%	45%	30%
Feldspar	35%	35%	35%	50%
Kaolin	✓	✓	✓	✓
Mica	✓	✓	✓	✓
Clay Mineral (possibly chlorite)	✓	-	✓	✓
Haematite	?	?	?	?
Smectite	-	✓	-	-
Anatase	-	-	✓	-

Note: 1. Major mineral concentrations are indicated in %.
 2. ✓ indicates that the mineral is definitely present.
 3. ? indicates that the mineral is possibly present.
 4. Sample 1 is the most weathered and sample 4 is the least weathered.

Table 4.6: Minerals identified in samples from the Main Caves Study Site, using X-ray diffraction (XRD) spectroscopy.

4.2.2.2.3. SOLUBLE CATION ANALYSIS

Cation analysis of soluble material from the four Main Caves samples with differing degrees of weathering (sample 4 being the least weathered sample and, sample 1 the most weathered), showed that magnesium, calcium, sodium and potassium were the most common soluble cations while silica and iron were also found to be present in solution (Table 4.7). Calcium was the cation found in the highest concentrations, which were as high as 2010 mg.l⁻¹ on the most weathered sample (sample 1). There was a general increase in calcium, magnesium and sodium concentrations with increases in the amount of weathering (Table 4.7). Potassium ion concentrations were lowest in the least weathered sample, followed by the most weathered sample, while samples 2 and 3 had very high concentrations (between 1000mg.l⁻¹ and 1500mg.l⁻¹) (Table 4.7). The concentration of soluble iron, when present, appears to decrease with an increase in the amount of weathering, while there were no apparent trends with the concentration of soluble silicon (Table 4.7). As with all the chemical analyses discussed above, samples 2 and 3 appear to present anomalies to any trends that were present, which are likely to be because of slight differences in mineralogy, even though visually they appeared to be identical.

SAMPLE	Mg ²⁺	Ca ²⁺	Na ⁺	K ⁺	Fe ^{2+,3+}	Si ⁴⁺
1	485	2010	370	607	0.5	1
2	422	1480	260	1470	-	1
3	355	1652	370	1190	2	2
4	163	482	140	380	3	1

Note: 1. Concentrations are in mg/l.
2. -, indicates that the signal was not significantly higher than the blank.
3. Sample 1 is the most weathered and sample 4 is the least weathered.

Table 4.7: Selected cation concentrations of soluble material from rock samples collected at the Main Caves study site, determined by AA (atomic absorption) spectroscopy.

4.2.2.2.4. SOLUBLE ANION ANALYSIS

Chlorides were the most common anions identified in the four samples analysed, followed by nitrates and sulphates, with no other significant concentrations of any

anions identified (Table 4.8). Only nitrate concentrations showed a general increase from the least weathered sample (sample 4) to the most weathered sample (sample 1), apart from sample 2 (Table 4.8). There were no clear trends evident other than the fact that chloride and nitrate concentrations were lowest in the least weathered sample (Table 4.8). Samples 2 and 3 had the highest concentrations of chlorides, while the sulphate concentrations were relatively high in sample 2 and relatively low in sample 3 (Table 4.8).

SAMPLE	Cl ⁻	NO ₂ ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
1	1153.5	0	525.84	0	61.3
2	1352.6	0	566.32	0	46.78
3	1693.3	0	163.27	0	19.48
4	261.95	0	88.19	0	48.83

Note: 1. Concentrations are in mg/l.
2. Sample 1 is the most weathered and sample 4 is the least weathered.

Table 4.8: Selected anion concentrations of soluble material from rock samples collected at the Main Caves study site, determined by ion chromatography.

4.2.2.3. Precipitate Chemistry

Precipitates found at the Main Caves and Battle Cave study sites (2 from each site) were identified by X-ray diffraction analyses as gypsum (CaSO₄ · 2H₂O).

4.2.2.4. Water Chemistry

4.2.2.4.1. pH AND ELECTRICAL CONDUCTIVITY

Some drip-water and rain water samples were used to determine pH and electrical conductivities. Rain occurred during very few occasions when the Main Caves site was visited and so collection was rare. Water samples from these visits were tested and found to be slightly acidic (Table 4.9). Samples regularly tested at the Conservator's Office at Giant's Castle had pH values which average between pH 5 and pH 6. Thus, the pH value of 6.48 obtained on 7 February 1991 (Table 4.9), appears to be an outlier. Drip water samples over the 1990/1 summer season

were slightly alkaline. Drip-water samples analysed during the 1993/4 summer were almost neutral (Table 4.9).

Electrical conductivity readings for both rain- and drip-water are low (Table 4.9), indicating that little ionic material was in solution. There are no noticeable trends for pH and electrical conductivity for the drip monitored in the north shelter of the Main Caves study site; a possible reason is that the concentration of solutes present, which affects pH and conductivity, could be related to the drip’s flow regime. No data relating to the flow volumes and rates of drips were collected.

SAMPLE	TYPE	pH	ELECTRICAL CONDUCTIVITY (µs)
1990/1 Summer (Avg.)	Rain	5.12	-
07/02/91	Rain	6.48	22
1990/1 Summer (Avg.)	Drip	7.13	-
22/10/93	Drip	6.80	35
26/11/94	Drip	7.05	27
01/12/94	Drip	7.03	22
18/01/94	Drip	7.02	23
16/02/94	Drip	6.90	31
23/02/94	Drip	7.00	61
08/03/94	Drip	7.02	38

Table 4.9: Some of the pH and electrical conductivity values for rain- and drip-water samples from the Main Caves study site.

4.2.2.4.2. CATION ANALYSIS

Only three cations, magnesium, calcium and silicon, could be identified in samples taken from the drip at the back wall of the north shelter of the Main Caves site. The highest concentrations are for silica (Si⁴⁺), which varied between 3mg.l and 1mg.l for the drip-water (Table 4.10). There does not appear to be any apparent trend to the data in Table 4.10 below, other than higher solute concentrations at the beginning and at the end of the period of monitoring, when flow levels were lowest (i.e. just after the drip started and shortly before it ceased). Solute concentrations in rain water samples collected were not high enough for any measurements to be made.

SAMPLE	DATE	Mg ²⁺	Ca ²⁺	Na ⁺	K ⁺	Fe ^{2+,3+}	Si ⁴⁺
1	22/10/93	0.30	1.1	*	*	-	2
2	13/11/93	0.38	1.7	*	*	-	3
3	26/11/93	0.19	0.7	*	*	-	3
4	01/12/93	0.17	0.7	*	*	-	2
6	18/01/94	0.19	0.6	*	*	-	2
7	28/01/94	0.20	0.9	*	*	-	3
8	16/02/94	0.24	0.9	*	*	-	1
9	21/03/94	0.21	0.9	*	*	-	3
10	10/05/94	0.24	1.2	*	*	-	2
Rain Water	Various	*	*	*	*	*	*

Note: 1. Concentrations are in mg/l.
 2. -, indicates that the signal was not significantly higher than the blank.
 3. *, indicates that the signal was too weak for determination of concentration.

Table 4.10: Selected cation concentrations of drip samples from the north shelter, Main Caves, determined by AA (atomic absorption) spectroscopy.

4.2.2.4.3. ANION ANALYSIS

The most common anions found in drip-water samples are chlorides, followed by nitrates and sulphates (Table 4.11). Only chloride concentrations were sufficiently high to observe any noticeable changes in concentration with time (Table 4.11), and even then the results are very erratic and so little can be deduced. As with the cation analyses, anion concentrations were too low in the rain water for any conclusions to be drawn.

SAMPLE	DATE	Cl ⁻	NO ₂ ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
1	22/10/93	10.98	0	0.00	0	0.11
2	13/11/93	1.01	0	0.63	0	0.07
3	26/11/93	7.04	0	0.00	0	0.00
4	01/12/93	6.78	0	0.05	0	0.00
6	28/12/93	0.43	0	0.05	0	0.00
7	18/01/94	0.38	0	0.24	0	0.07
8	16/02/94	6.7	0	0.13	0	0.07
9	21/03/94	8.1	0	0.02	0	0.00
10	10/05/94	1.03	0	0.06	0	0.12
Rain Water	Various	*	*	*	*	*

Note: 1. Concentrations are in mg/l
 2. *, indicates that the signal was too weak for the determination of concentration.

Table 4.11: Selected anion concentrations of drip samples from the north shelter of the Main Caves study site, determined by ion chromatography.

4.3. BATTLE CAVE

4.3.1. FIELDWORK

4.3.1.1. Manual Data Collection

4.3.1.1.1. ROCK HARDNESS

Schmidt Hammer rebound values were greatest for the lower aeolian deposit at the Battle Cave study site and lowest, for what is most likely the fluvial deposit at the base of the shelter (Table 4.12). It was not possible to collect any data from the fluvially deposited layers between the aeolian deposits as the rock was too fragmented for readings to be taken. It must be considered that the fallen rocks were originally part of the main face of the shelter and that unless weathering has taken place they are likely to be similar to the material from the back wall. The rebound values from fallen rocks in Battle Cave and from the upper level of aeolian deposit were from the same statistical population; no other two sets of data were found to be from the same populations (Table 4.13).

STATISTIC	UPPER AEOLIAN DEPOSIT	LOWER AEOLIAN DEPOSIT	FALLEN ROCKS	FLUVIAL DEPOSIT (Base of shelter)
Observations	60	97	126	81
Mean	41.78	45.85	41.41	30.38
Variance	12.92	32.92	35.09	40.86
Standard Deviation	3.59	5.74	5.92	6.39
Median	42	46	42	30

Table 4.12: Summary statistics for Schmidt Hammer rebound values at the Battle Cave Study site.

SAMPLES COMPARED	CRITICAL t VALUE	CALCULATED t VALUE	RESULT
UPPER AEOLIAN & LOWER AEOLIAN	1.98	4.92	Different Populations
UPPER AEOLIAN & FALLEN ROCKS	1.97	0.45	Same Population
UPPER AEOLIAN & FLUVIAL	1.98	12.43	Different Populations
LOWER AEOLIAN & FALLEN ROCKS	1.97	5.62	Different Populations
LOWER AEOLIAN & FLUVIAL	1.97	17.00	Different Populations
FALLEN ROCKS & FLUVIAL	1.97	12.67	Different Populations

Note: Confidence level = 95%.

Table 4.13: Comparisons of Schmidt Hammer rebound values for different areas of the Battle Cave study site using the "t-Test".

4.3.1.2. Automated Data Collection

4.3.1.2.1. AIR TEMPERATURE

There were general seasonal trends for air temperature at the Battle Cave study site with summer temperatures being warmer than winter (Fig. 4.44, 4.45). However, the data reveal a more complex regime than the expected "warm summer and cool winter". The summer of 1994 was relatively cool when compared with that of the previous year (Fig. 4.44, 4.45); January 1994 mean monthly air temperature was 16.3°C, while January 1993 mean monthly air temperature was 18°C. The coldest periods were in June 1993 ($\bar{x} = 12.9^{\circ}\text{C}$) and July 1994 ($\bar{x} = 12.7^{\circ}\text{C}$) (Fig. 4.44, 4.45). The graph of weekly air temperatures (Fig. 4.45) provides a good indication of the complex nature of the air temperature regime at Battle Cave.

The four days chosen for the monitoring of hourly average air temperature show that air temperatures were highest just after midday ($\pm 13:00\text{hrs}$ on 1 April 1993 and $\pm 14:00\text{hrs}$ on the three other days) and at a minimum at sunrise (Fig. 4.46), with a maximum daily range, for the data displayed, of approximately 22°C on 1 April 1993. The air temperatures on 1 January 1994 showed the least variation (the daily range was 9°C), when despite the exposure of the site there was enough of an overhang to afford some protection to the rock face from the acute angled incident rays of the sun (Fig. 4.46). On the graph it was expected that the daily temperatures in April and October would be the same, as they were both close to equinoxes, however, the maximum hourly average temperature recorded

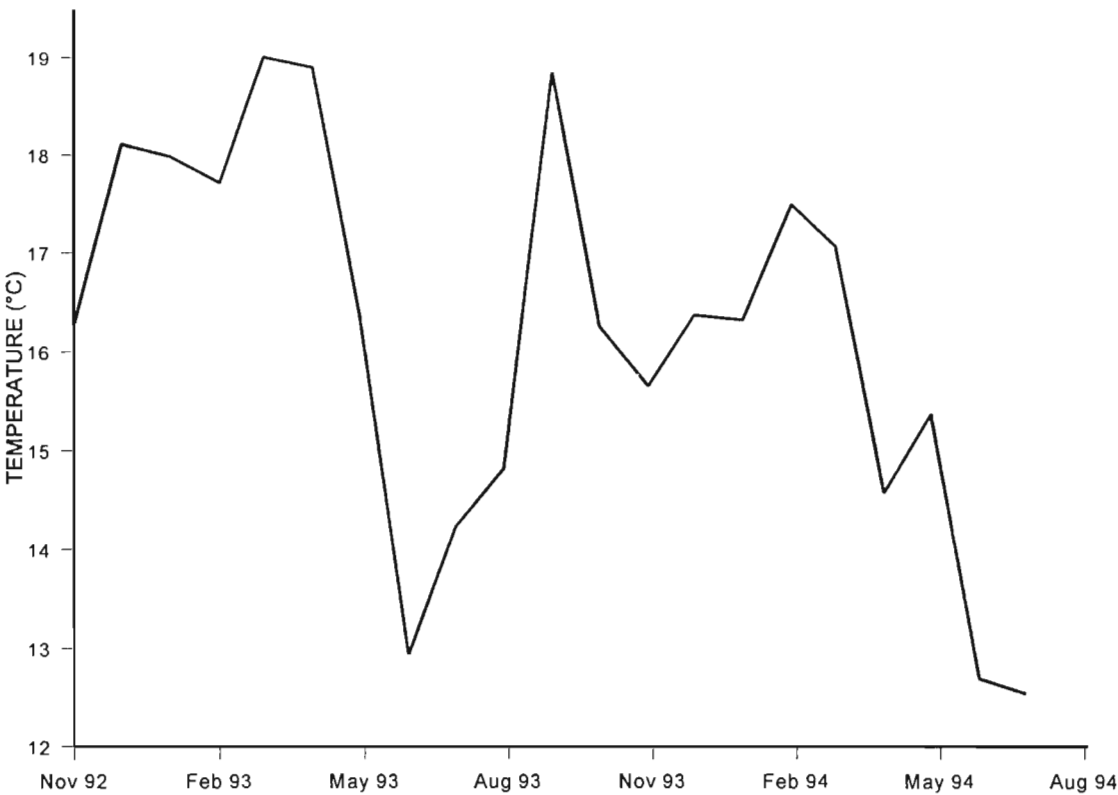


Figure 4.44: Monthly average air temperatures at the Battle Cave study site.

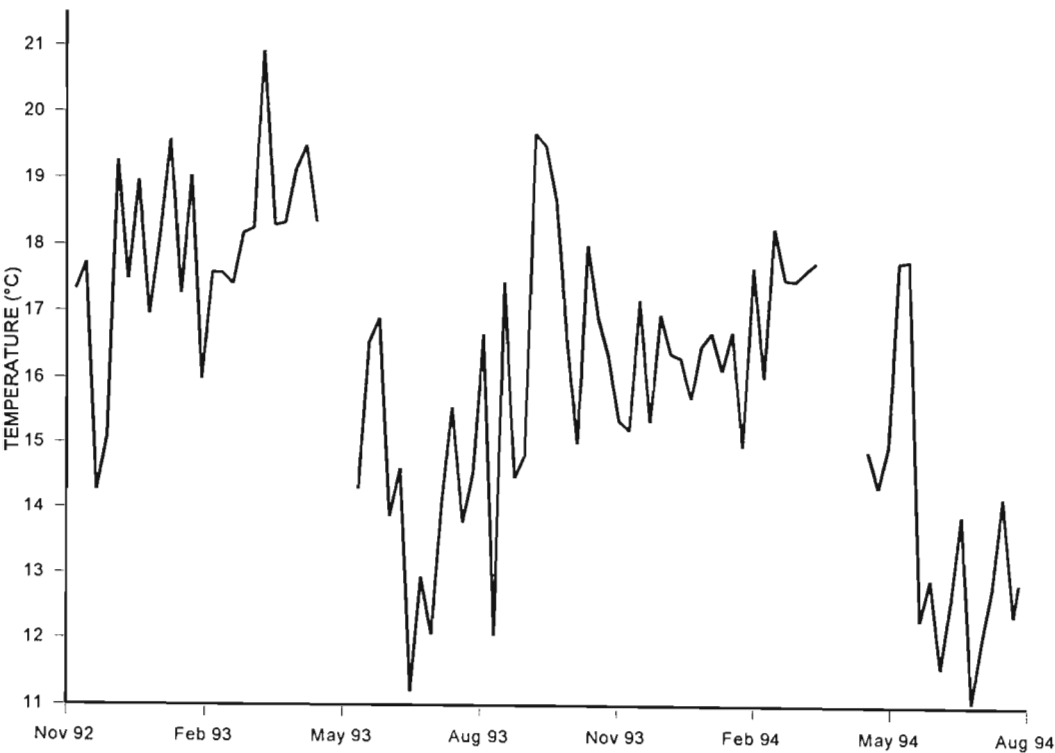


Figure 4.45: Weekly average air temperatures at the Battle Cave study site.

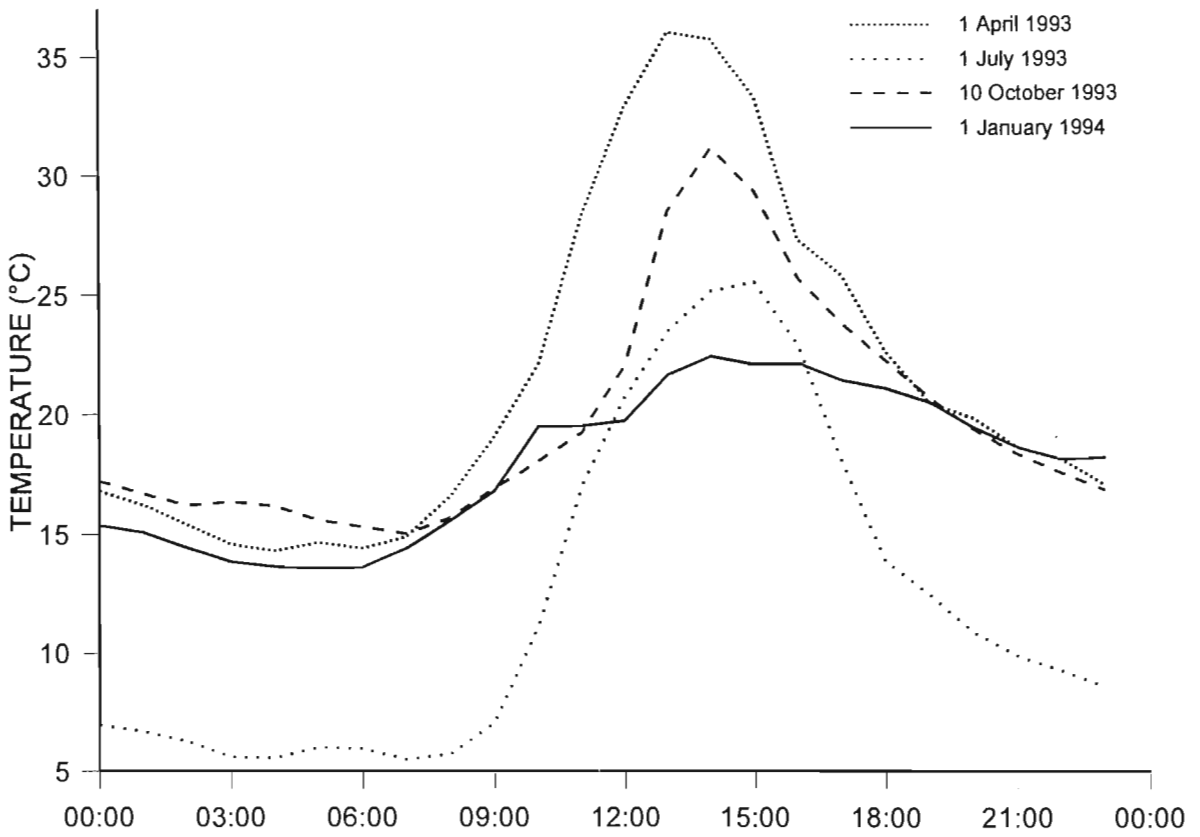


Figure 4.46: Hourly average air temperatures for the Battle Cave study site on four selected days between 1 April 1993 and 31 March 1994.

on 1 April 1993 (35.9°C) was greater than that for 10 October 1994 (25.4°C) (Fig. 4.46).

4.3.1.2.2. ROCK TEMPERATURE

In the period that rock temperatures were monitored at Battle Cave the highest average monthly and weekly rock temperatures were recorded in September 1993 (\bar{x} overall = 20.7°C) with relatively high temperatures being recorded in March (\bar{x} = 20.1°C), April (\bar{x} = 20°C) and May (\bar{x} = 19.2°C) of the same year (Fig. 4.47, 4.48). The lowest rock temperatures during the same period were recorded in June 1993 (\bar{x} = 16.2°C), June 1994 (\bar{x} = 15.9°C) and July 1994 (\bar{x} = 15.8°C) (Fig. 4.48). The northern aspect of the fallen rock on which temperature was monitored had the greatest average monthly and weekly temperature ranges of 6.5°C and 19.5°C respectively (Fig. 4.47, 4.48). The site in Battle Cave which had the most consistent temperature was the base of the back wall in fluvially-deposited sediments (Fig. 4.47, 4.48).

Daily ranges were not calculated but from the graphs it can be seen that they were sometimes in excess of 20°C during the winter months for both the northern aspect of the fallen rock (Fig. 4.49) and at the base of the shelter back wall (Fig. 4.50). The smallest daily ranges in temperature were during summer, as can be seen on the daily charts plotted for both fallen rocks and the shelter back wall (Fig. 4.49, 4.50). It would be expected that the equinox regimes would be similar, however, at this particular site, 1 April appears to have been abnormally hot (Fig. 4.49).

The thermal regime of the back wall of the Battle Cave shelter was not consistent with the base of the shelter. The base showed relatively little variation of monthly and weekly averages (range in weekly averages was 4.9°C), whilst at 2m above the ground, the range was greater (8.1°C) (Fig. 4.47, 4.48). However, if the daily graphs are considered (Fig. 4.49, 4.50) then it is apparent that the ranges were greater at the ground level and that there was less variation at 2m above the

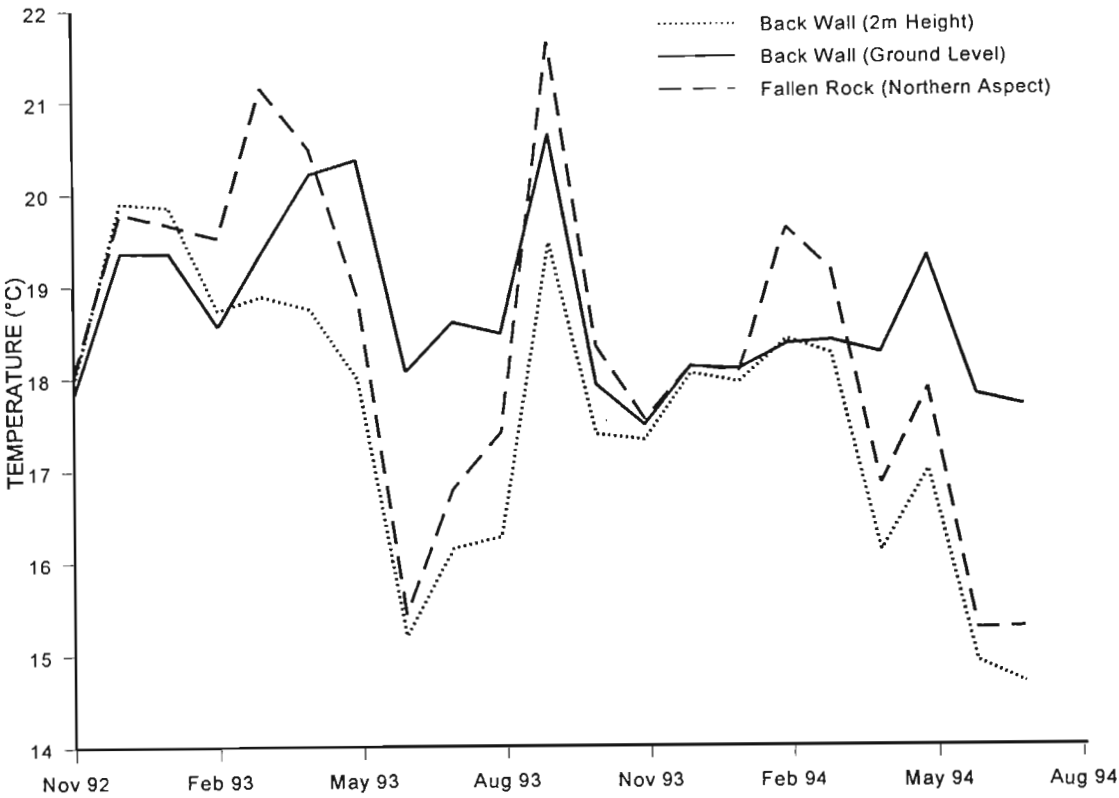


Figure 4.47: Monthly average rock temperatures at the Battle Cave study site.

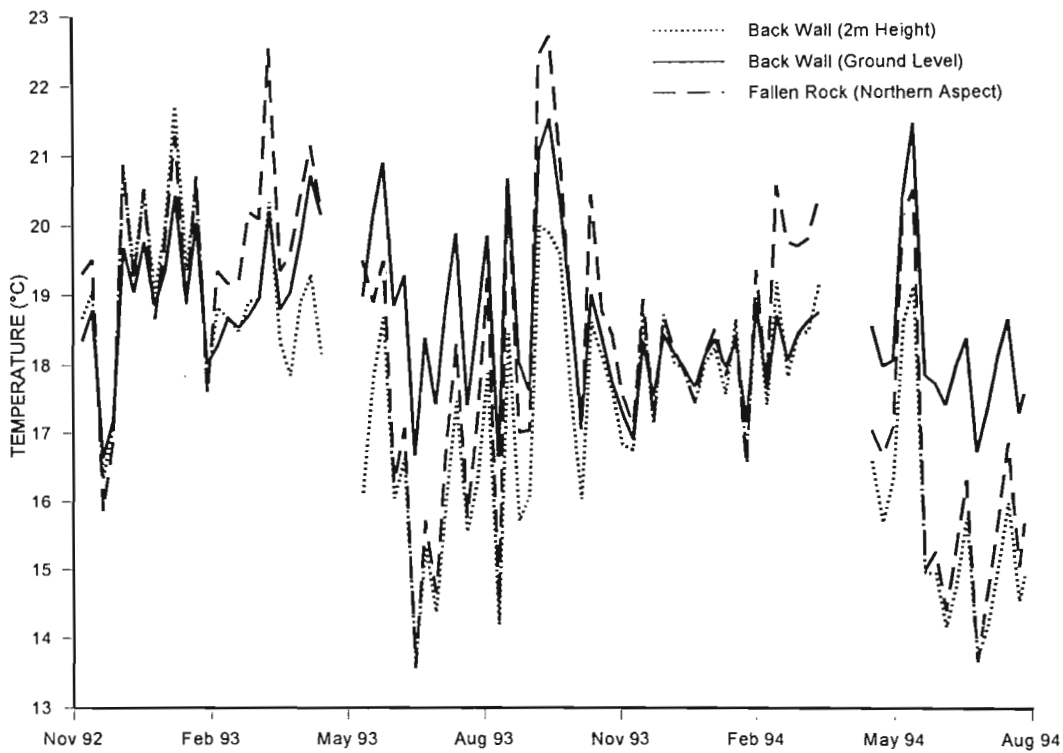


Figure 4.48: Weekly average rock temperatures at the Battle Cave study site.

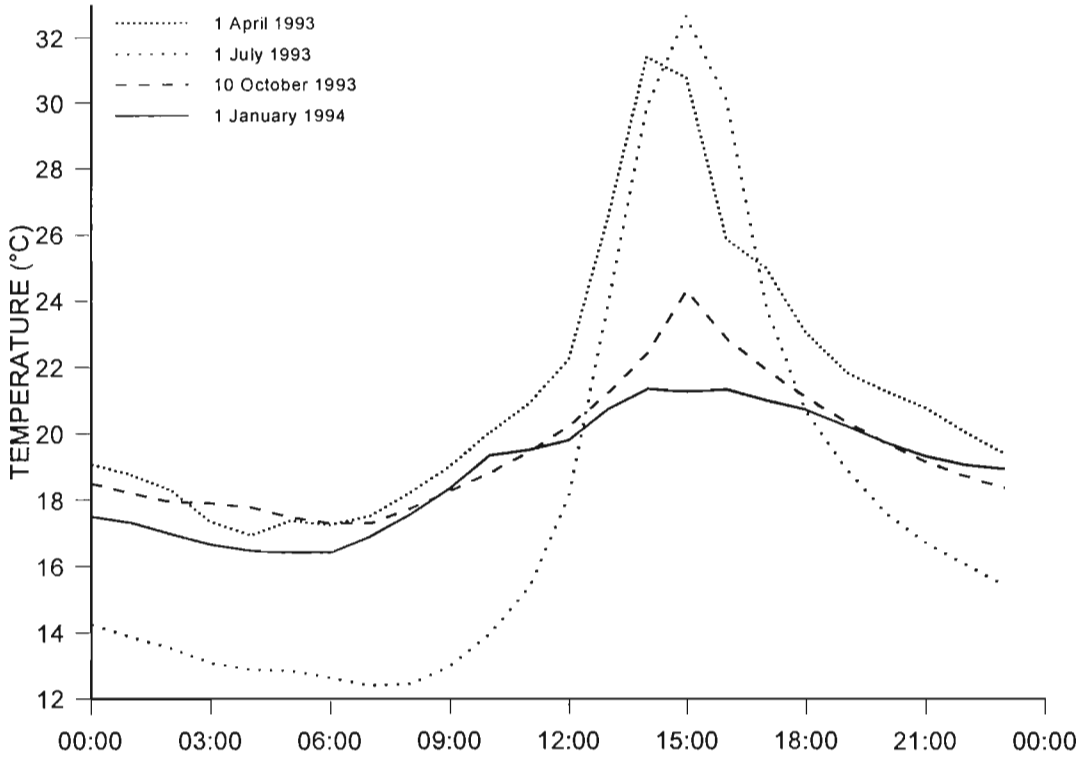


Figure 4.49: Hourly average rock temperatures for the northern aspect of a fallen rock in the Battle Cave study site on four selected days between 1 April 1993 and 31 March 1994.

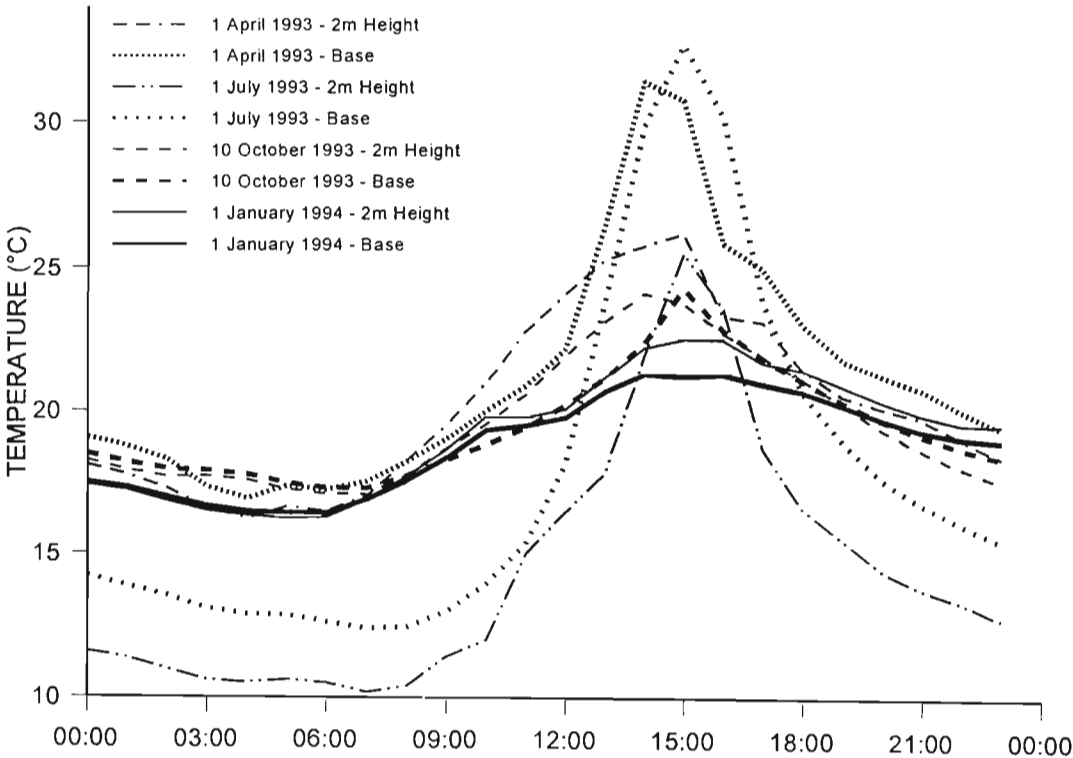


Figure 4.50: Hourly average rock temperatures at different heights of the back wall of the Battle Cave study site on four selected days between 1 April 1993 and 31 March 1994.

ground. The low monthly temperature range for rock temperatures near the ground was as a result of high day-time values during the winter months generating a relatively high weekly and monthly average. On the other hand, at a height of 2m above the ground winter daytime rock temperatures were low thus resulting in lower overall averages and differences between summer and winter values. The most constant rock temperature distribution on the back wall of the Battle Cave study site was during summer, the graph for 1 January 1994 (Fig. 4.50) shows almost isothermal conditions between the base and a height of 2m, with a maximum difference of less than a degree Celsius at 15:00hrs.

A fallen block from the roof in the Battle Cave site was used to investigate the temperature differences between various aspects of the rock. The monthly and weekly averages of the east-facing side of the rock were consistently higher than those for the other faces (Fig. 4.51, 4.52). The east-face of the rock was always the first to receive the rays of the early morning sun and the north- and west-faces had the last rays of the sun. However, if the temperature profiles are viewed on specific days the thermal regime is more complex.

In winter (Fig. 4.53), the east-face received the first rays of the sun and, as a result, heated up fastest. The temperature of the south-face of the rock was next to increase (Fig. 4.53), since, although this face was usually protected from the direct rays of the sun, reflected radiation from the back wall of the shelter was able to heat this face rapidly. The north- and west-faces of the rock had similar temperature profiles for winter (Fig. 4.53). In spring and autumn the temperature profiles had identical trends, so the graph for 10 October 1993 (Fig. 4.54) is used in the following discussion. The west-face of the fallen rock in the Battle Cave site experienced the highest (37.8°C) and lowest daily temperatures (15.3°C) and as a result had the greatest daily range during the equinox periods (Fig. 4.54). During this period the north- and east- faces had similar profiles (Fig. 4.54).

During summer the difference between the four aspects of the fallen rock is at a minimum (Fig. 4.55). The west-face experienced the lowest (16.7°C) and the east-face the highest (24.3°C) temperatures on the 1 January 1994 (Fig. 4.55). In

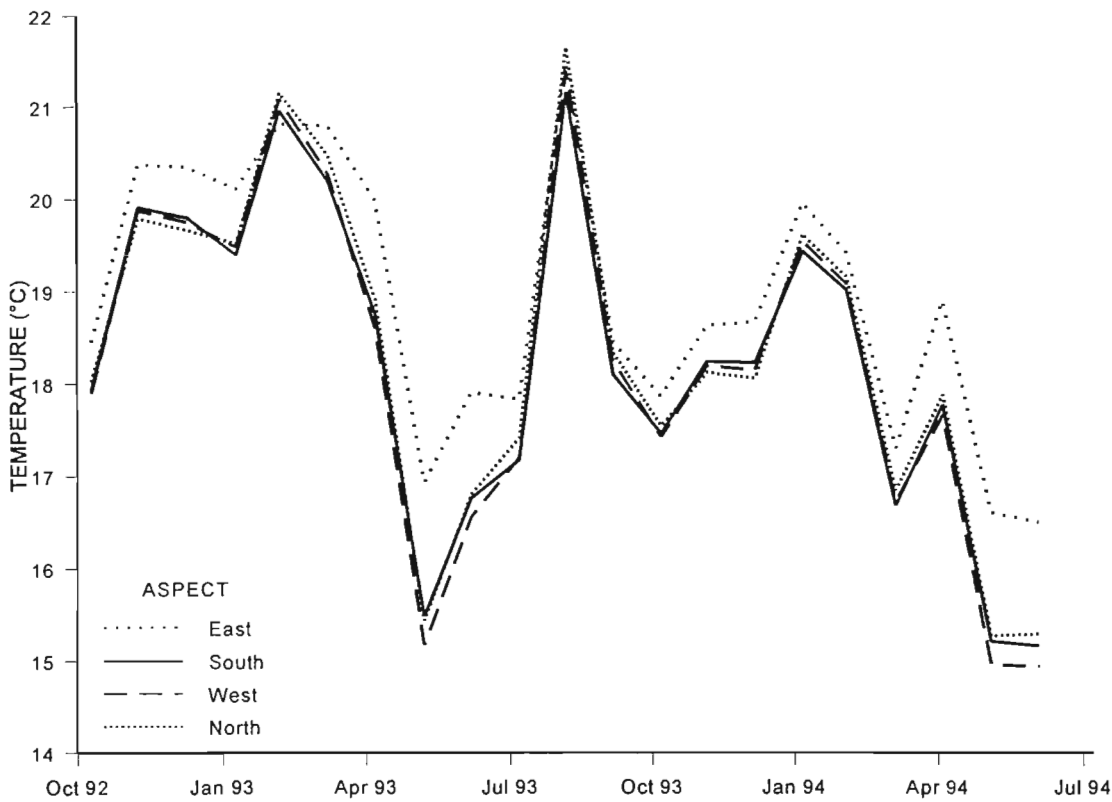


Figure 4.51: Monthly average rock temperatures of different aspects of a fallen rock at the Battle Cave study site.

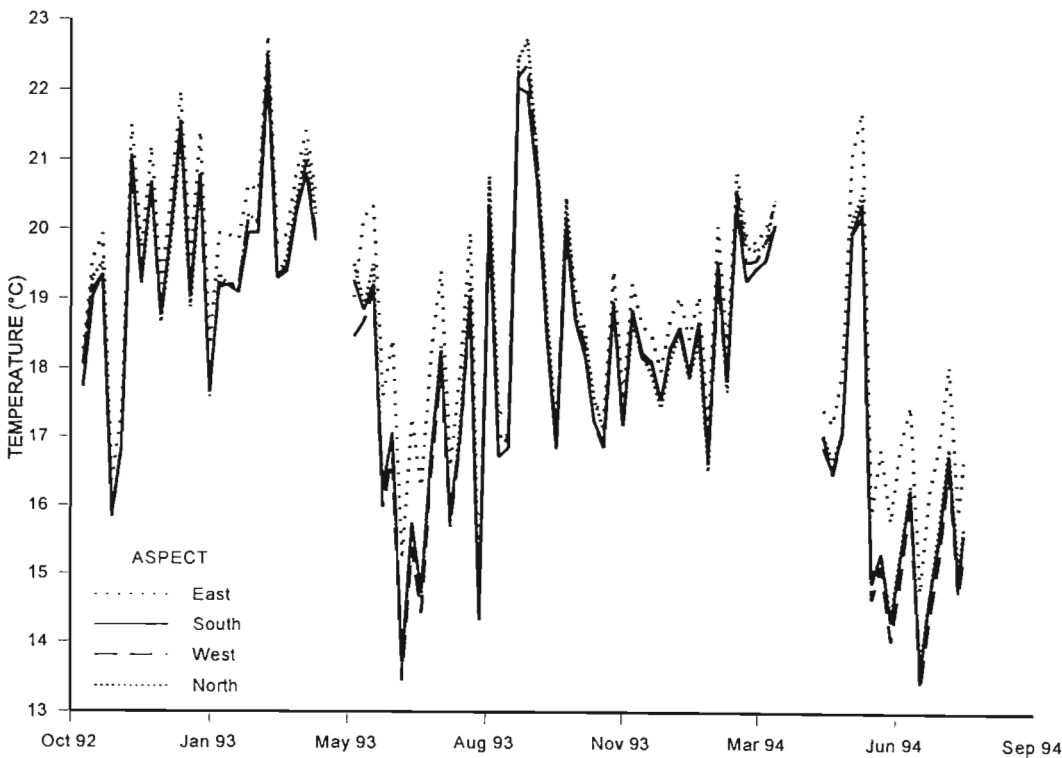


Figure 4.52: Weekly average rock temperatures of different aspects of a fallen rock at the Battle Cave study site.

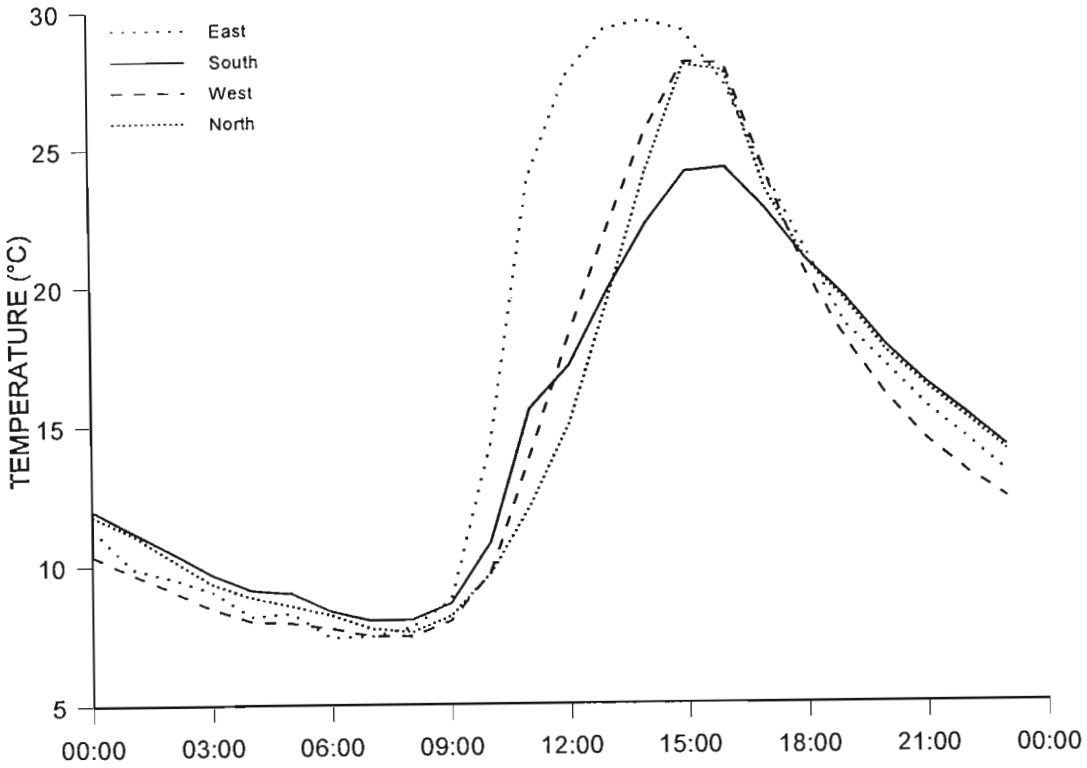


Figure 4.53: Hourly average rock temperatures of different aspects of a fallen rock at the Battle Cave study site on 1 July 1993.

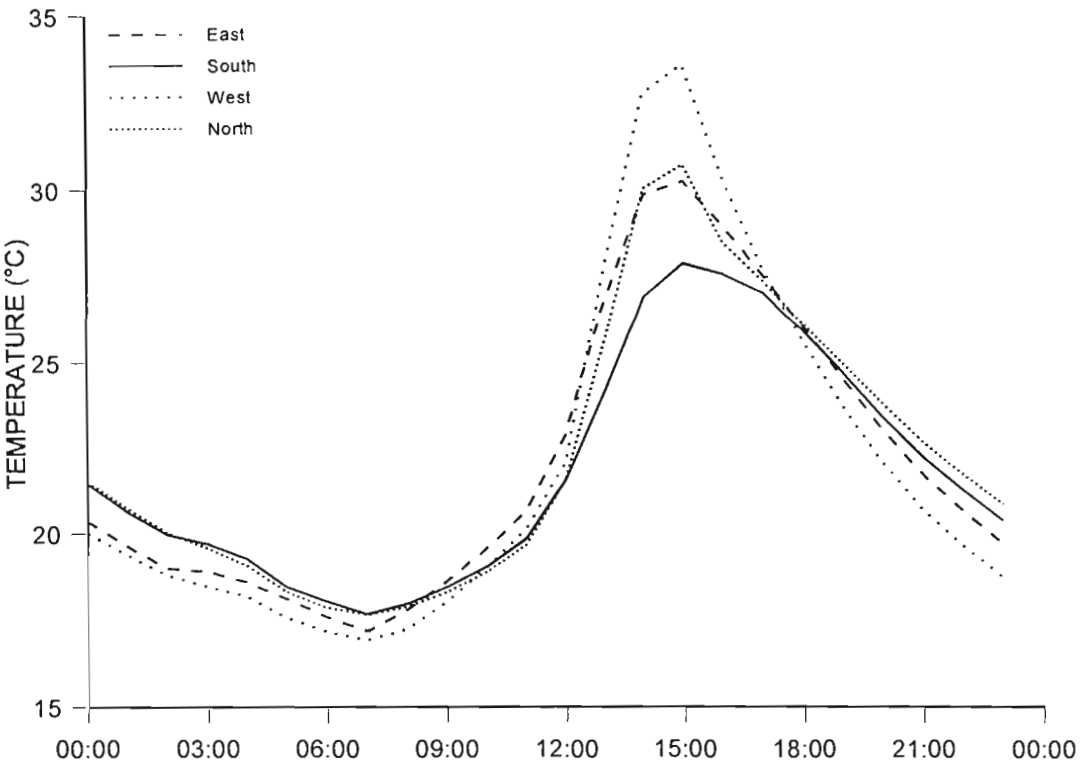


Figure 4.54: Hourly average rock temperatures of different aspects of a fallen rock at the Battle Cave study site on 10 October 1993.

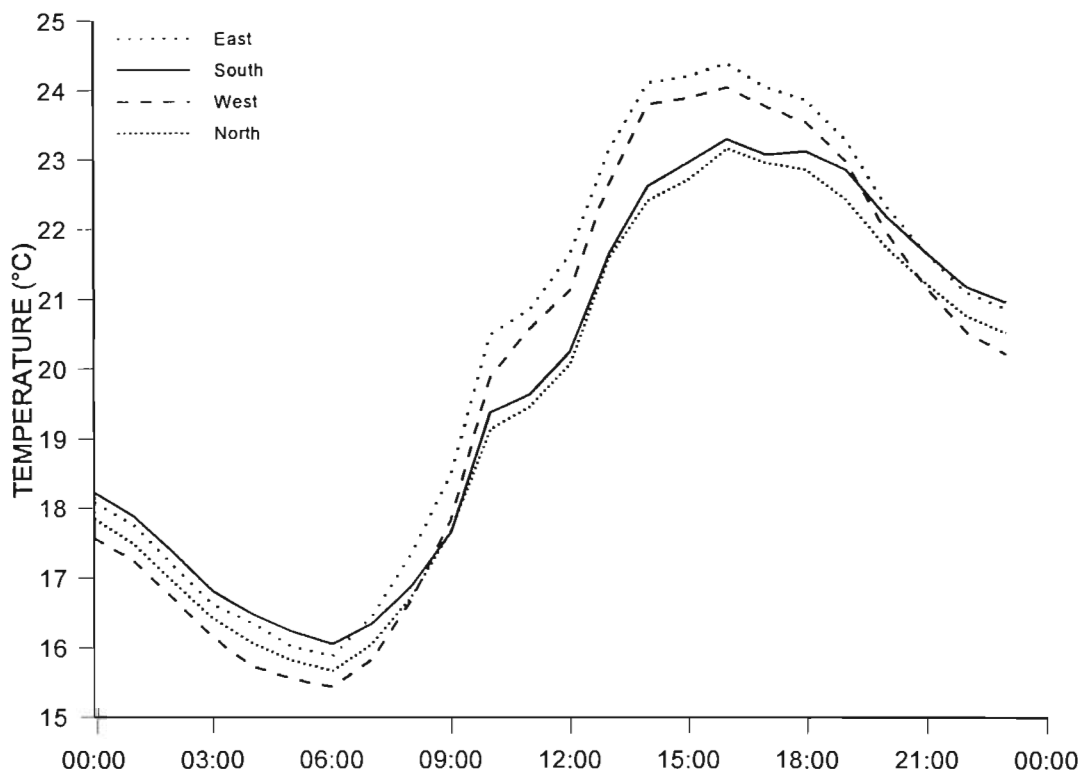


Figure 4.55: Hourly average rock temperatures of different aspects of a fallen rock at the Battle Cave study site on 1 January 1994.

summer the acute angle of the sun's incident rays prevented the north-face from receiving direct radiation and resulted in this face having the lowest daily maximum temperature (Fig. 4.55). As discussed above, the south-face, although sheltered from the direct rays of the sun, received considerable reflected radiation from the back wall of the shelter resulting in its temperature being higher than that of the north-face (Fig. 4.55).

Further temperature data from the Battle Cave study site included measurements at two minute intervals on 15 May 1993 (Fig. 4.56, 4.57). The site with the greatest rock temperature variability was at the base of the back wall of the shelter (Fig. 4.56). The maximum rate of rock temperature increase recorded at the base of the back wall was $0.55^{\circ}\text{C}.\text{min}^{-1}$, while the maximum rate of rock temperature decrease was $0.45^{\circ}\text{C}.\text{min}^{-1}$. The effect of the early morning sun on the east-face of the fallen rock is clearly seen in its high morning temperatures (Fig. 4.57). The sheltered position on the south-face of the fallen rock exhibited the lowest temperature range and the slowest response time (Fig. 4.57), however, it still experienced relatively high temperatures due to it receiving reflected radiation from the back wall of the shelter.

On 8 and 9 May 1992 an isolated rock in the Injasuti valley was also used for monitoring the differences in rock temperature with aspect. This study was deliberately taken away from any shelters such that there was no influence from reflected radiation. As the study was conducted away from any protective shelter, the rock temperatures would not be identical to those at the Battle Cave or Main Caves study sites. However, these data do have relevance for rock art studies as rock art is frequently found on isolated boulders in the study area; the particular site was only 400m from paintings on "Copulation Rock". The resulting temperature and radiation data are presented in a graph (Fig. 4.58). The greatest rock temperature range during the study period was 28°C on the north-face of the rock, whilst the lowest range was on the south-face, which received no direct incident radiation. The effect of the early morning and late afternoon sun on the east- and west-faces respectively are clearly seen (Fig. 4.58).

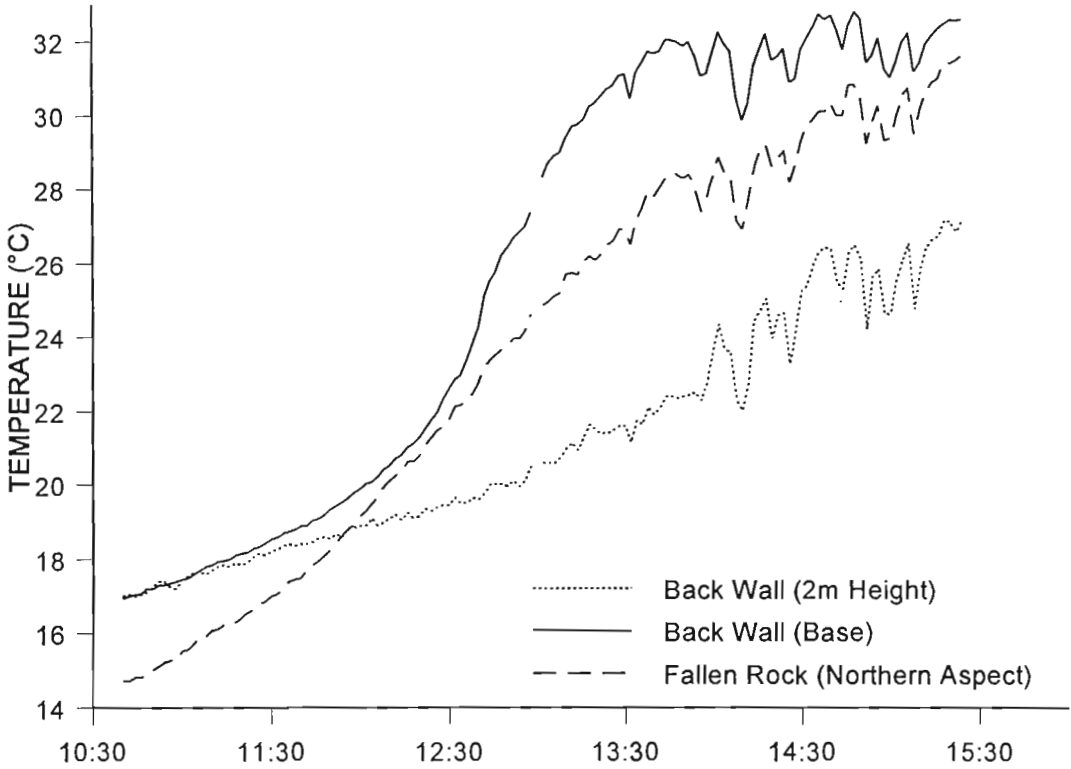


Figure 4.56: Short term rock temperature readings from the Battle Cave study site on 15 May 1993.

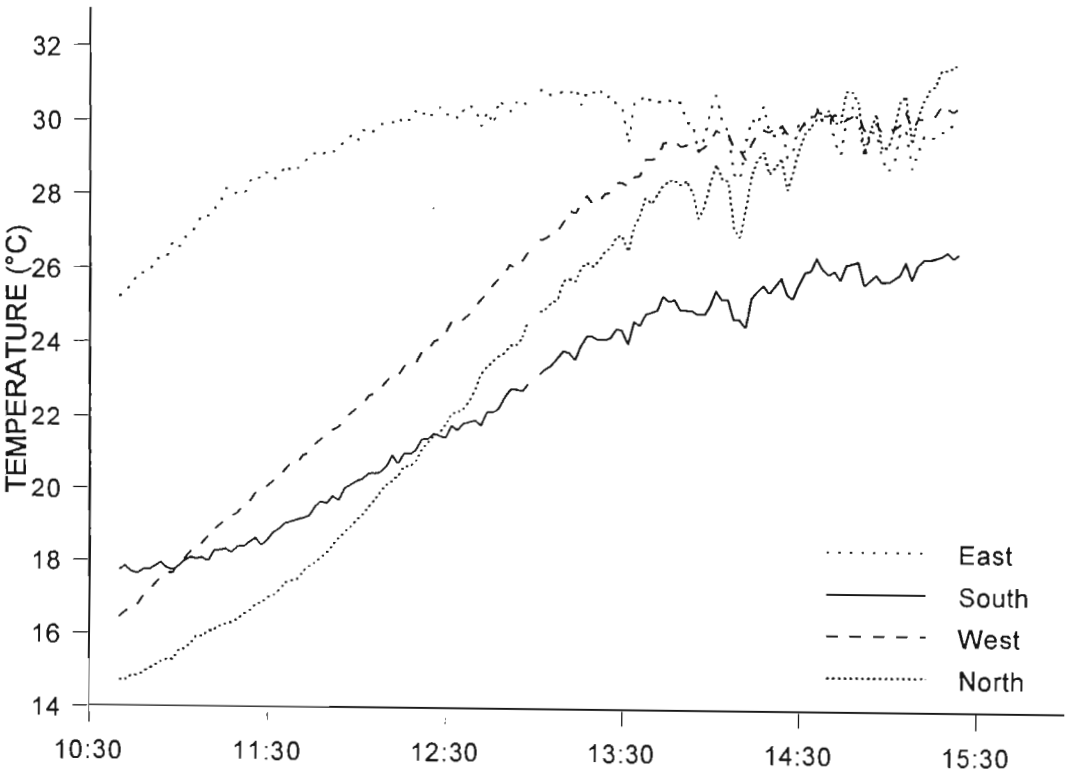


Figure 4.57: Short term rock temperature readings from different aspects of a fallen rock at the Battle Cave study site on 15 May 1993.

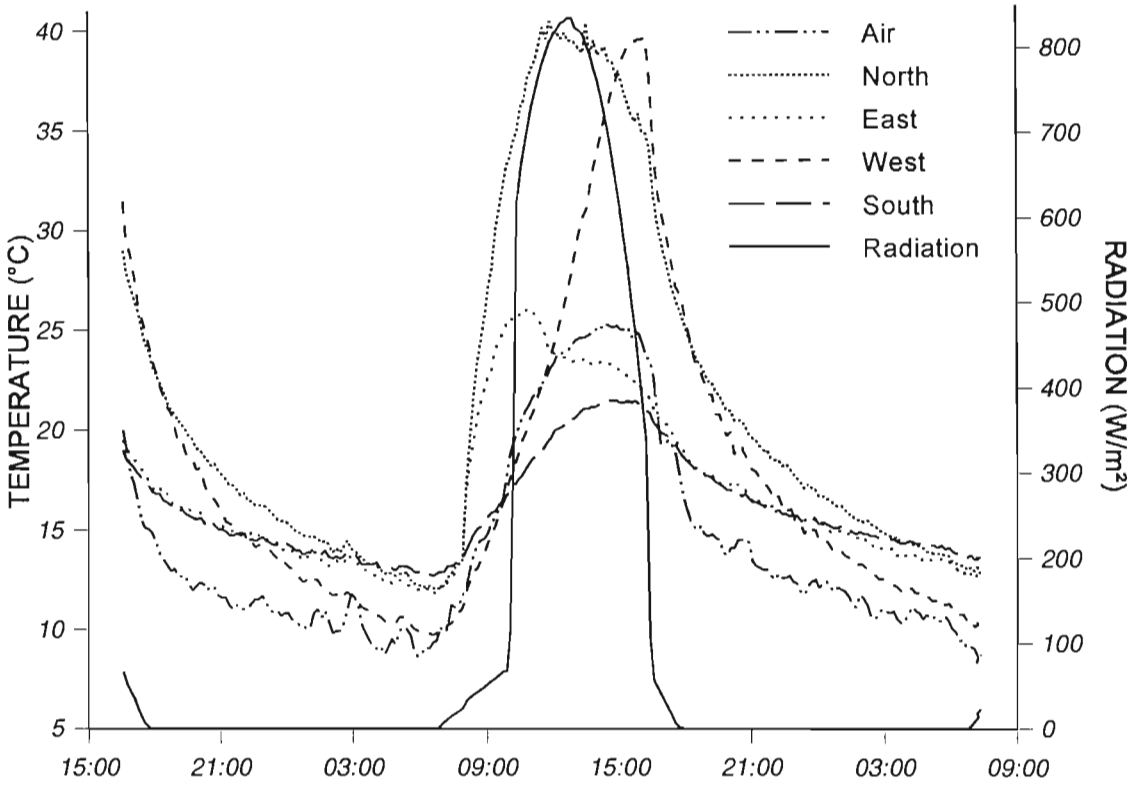


Figure 4.58: Rock temperatures on different aspects of an isolated rock in the Injasuti valley, together with total incident radiation on 8 and 9 May 1992.

4.3.1.2.3. RADIATION

Data of average monthly (Fig. 4.59) and weekly (Fig. 4.60) radiation receipts at the Battle Cave study site exhibited maxima between March and August during each year of monitoring, whilst minima were experienced in the November months (Fig. 4.59, 4.60). The reason for the low summer radiation receipts was that during much of the summer season the shelter, despite being exposed, has an overhang which is sufficient to block the acute incident rays of the sun (as noted above with respect to rock temperatures). It is apparent that the radiation receipts during the 1994 winter were marginally greater than those during the same period in the previous year (Fig. 4.59, 4.60). Hourly average radiation receipts measured on the four selected days chosen were similar, apart from 1 January when less radiation was received than on the other days chosen (Fig. 4.61) due to the effect of the shelter overhang. Although visually (Fig. 4.61) the differences between the January radiation receipts appear not to be great, it should be noted that the radiation axis has a logarithmic scale which under emphasises this variance. The total incoming radiation readings for 1 April 1993 and the 10 October 1993 do not reflect any major differences in their regimes (Fig. 4.61).

4.3.1.2.4. ATMOSPHERIC MOISTURE

Average monthly atmospheric moisture content, represented by vapour pressures, showed the expected trends at the Battle Cave study site, with summers being moist and winters dry (Fig. 4.62). The weekly average humidities showed little variation from the above trend (Fig. 4.63). The winter of 1994 was drier than that of 1993 whilst the summer of 1994 was more moist than that of the preceding year (Fig. 4.62, 4.63).

From hourly average values on certain monitored days it can be seen that atmospheric moisture is greatest during the summer and lowest during the winter months (Fig. 4.64). Of the days chosen, moisture contents were greatest on 1 January 1994, followed by 1 April 1993, 10 October 1993, whilst the driest day

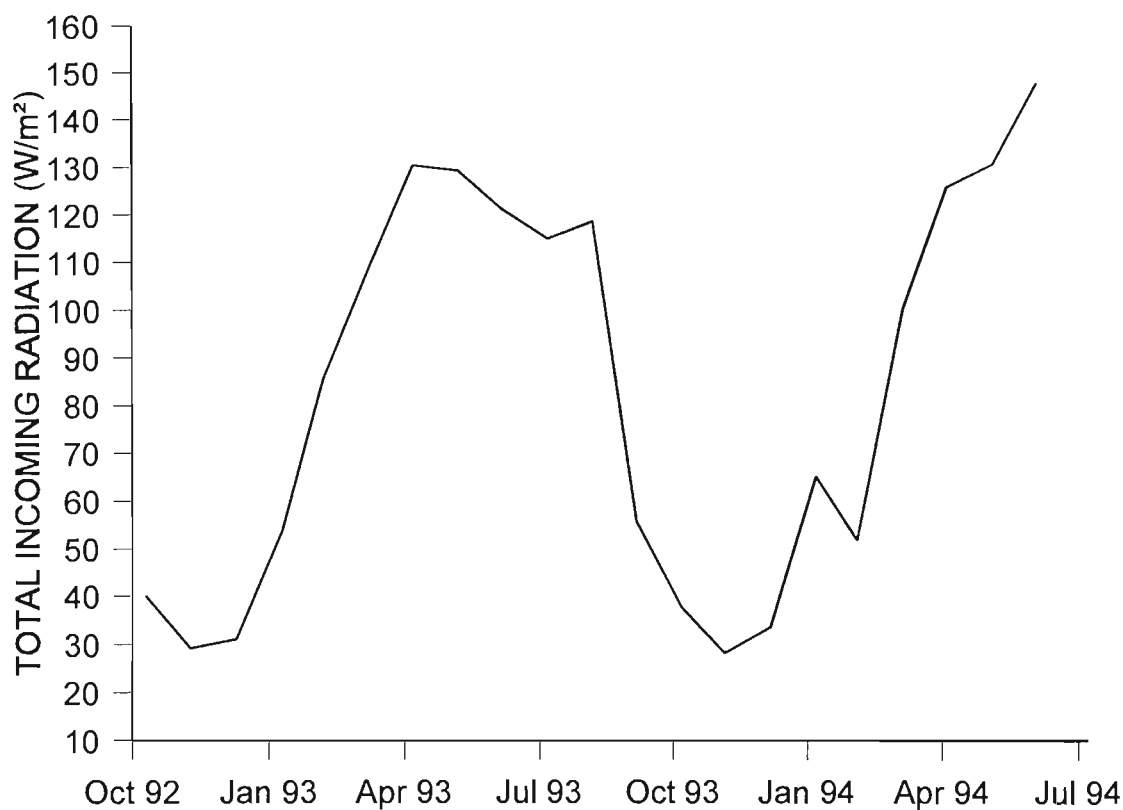


Figure 4.59: Average monthly total incoming radiation for the Battle Cave study site.

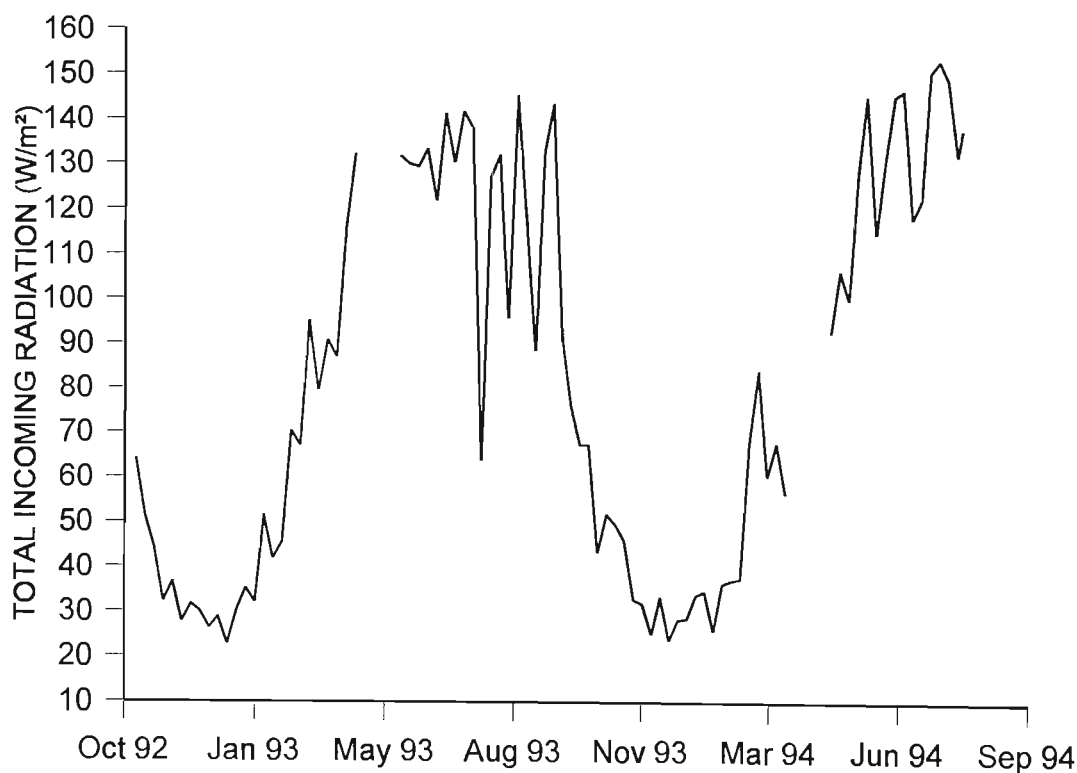


Figure 4.60: Average weekly total incoming radiation for the Battle Cave study site.

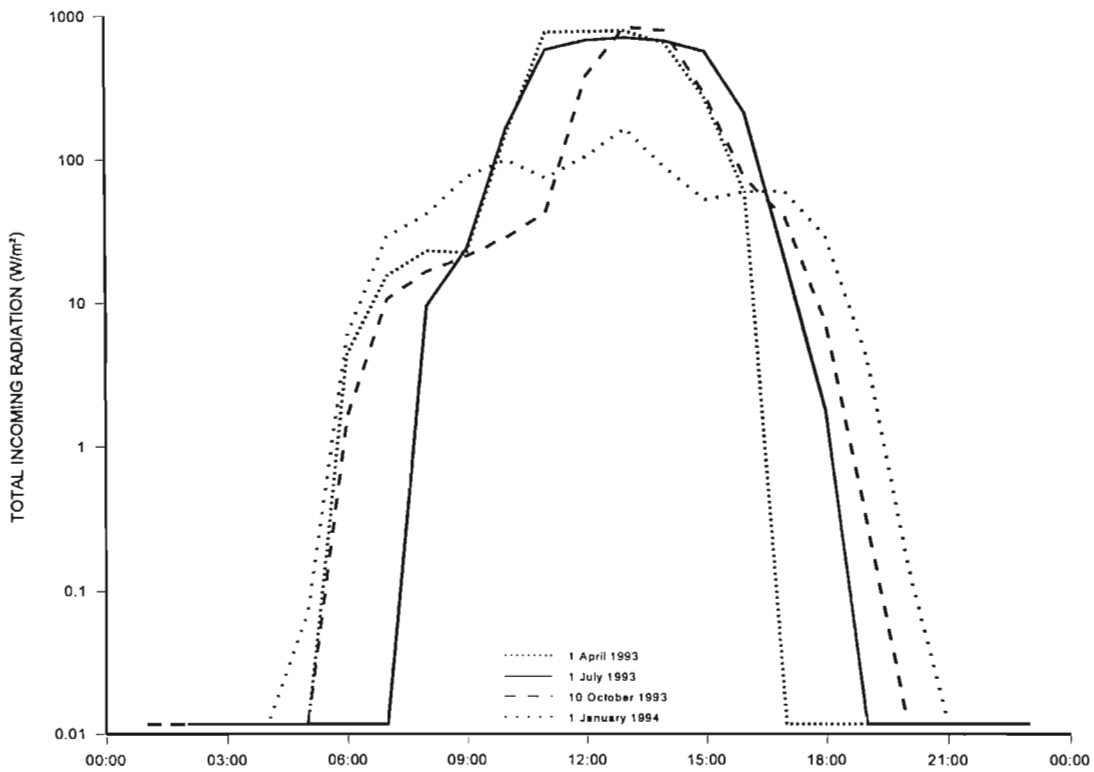


Figure 4.61: Hourly average total incoming radiation for the Battle Cave study site on four selected days between 1 April 1993 and 31 March 1994.

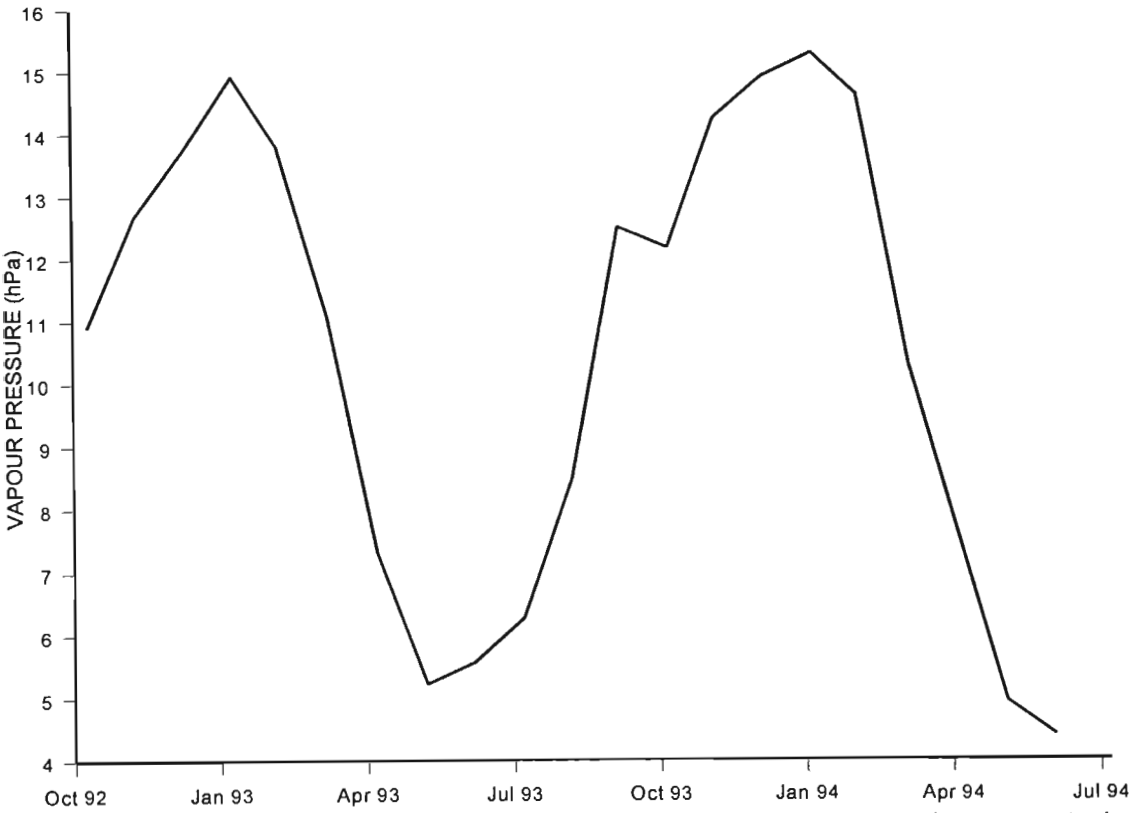


Figure 4.62: Average monthly atmospheric moisture content (represented by vapour pressure) for the Battle Cave study site.

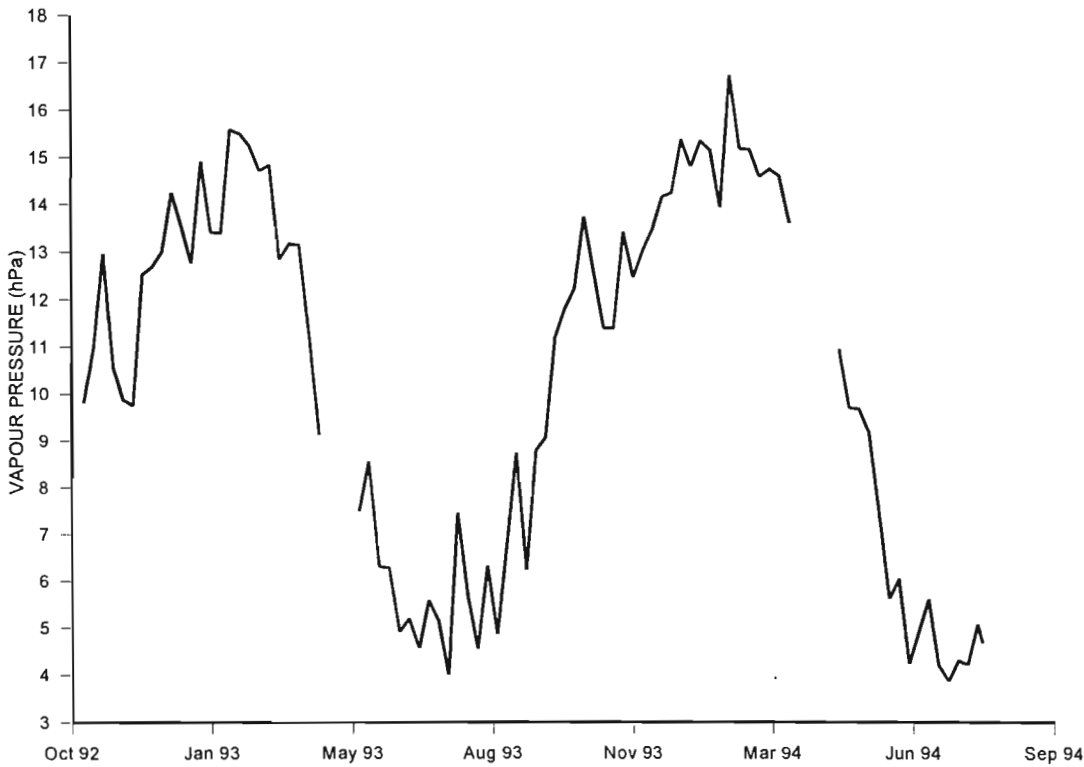


Figure 4.63: Average weekly atmospheric moisture content (represented by vapour pressure) for the Battle Cave study site.

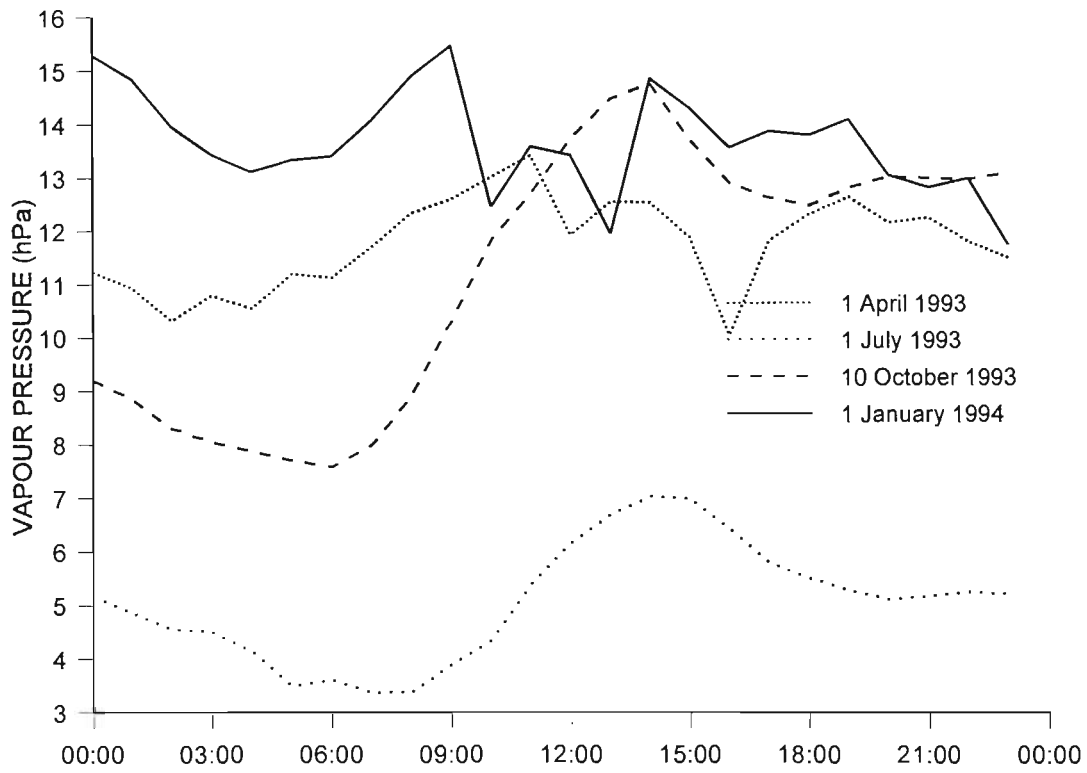


Figure 4.64: Hourly average atmospheric moisture content (represented by vapour pressure) for the Battle Cave study site on four selected days between 1 April 1993 and 31 March 1994.

monitored was 1 July 1993 (Fig. 4.64). The two driest days were the only ones where definite trends were noticeable, and then atmospheric moisture was at a minimum just after sunrise and at a maximum just after mid-day (Fig. 4.64). The greatest daily humidity range for the days shown was 7hPa encountered on 10 October 1993.

4.3.1.2.5. ROCK MOISTURE

Relative rock moisture contents at the Battle Cave study site were low with the highest monthly average being less than 30% in January 1994 (Fig. 4.65) and the highest weekly average being 42.5% during the same month (Fig. 4.66). Apart from the months of January and February 1994, the highest monthly average rock moisture content was less than 5% (Fig. 4.65), while the highest weekly average was only marginally greater than 5% (Fig. 4.66). Hourly averages of relative rock surface moisture content showed little variation except for the wettest month, of January 1994, when on the day monitored, relative rock surface moisture content was approximately ten times greater than on the other days shown (Fig. 4.67). On 1 January 1994 relative rock surface moisture was at a maximum at midnight, following which it decreased until it was less than 1% after 09:00hrs, the value at which it stayed for the rest of the day (Fig. 4.67). It is notable that the rock moisture content did not rise late at night so it could not have started off the next day at the same level as it did on the 1 January 1994. From the above data it is obvious that rock surfaces in the Battle Cave study site are relatively dry and that there is not much daily change in rock surface moisture apart from during the wettest months.

4.3.2. LABORATORY ANALYSIS

4.3.2.1. Rock Properties

Three different methods were used to determine the porosity of samples from the Battle Cave study site (Table 4.14). The volume of water taken up under vacuum produced similar results to mercury porosimetry, while Cooke's (1979) method

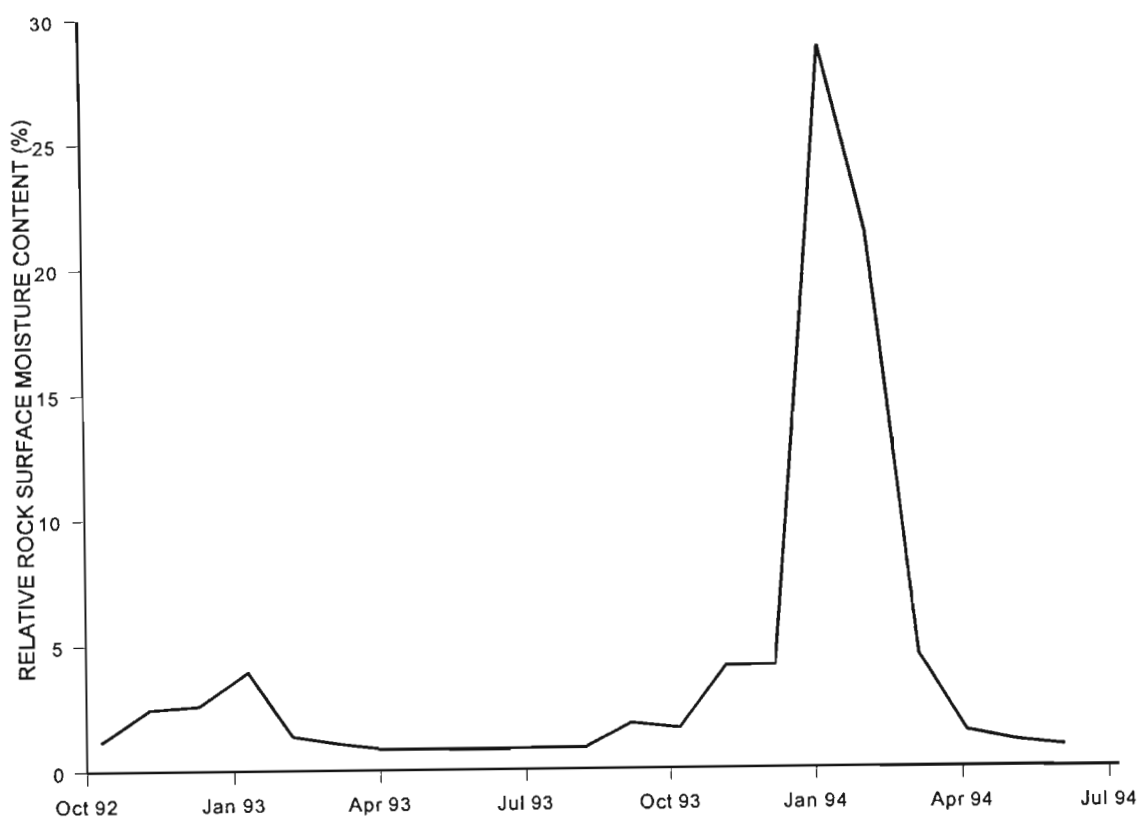


Figure 4.65: Average monthly relative rock surface moisture content for the Battle Cave study site.

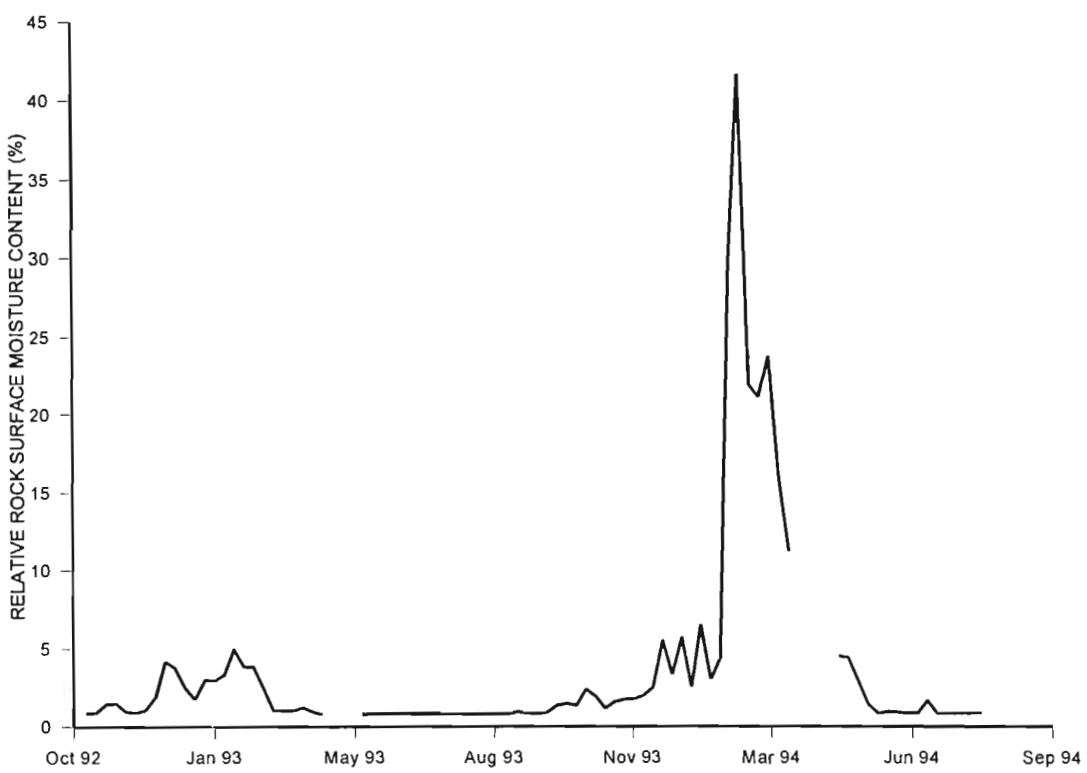


Figure 4.66: Average weekly relative rock surface moisture content for the Battle Cave study site.

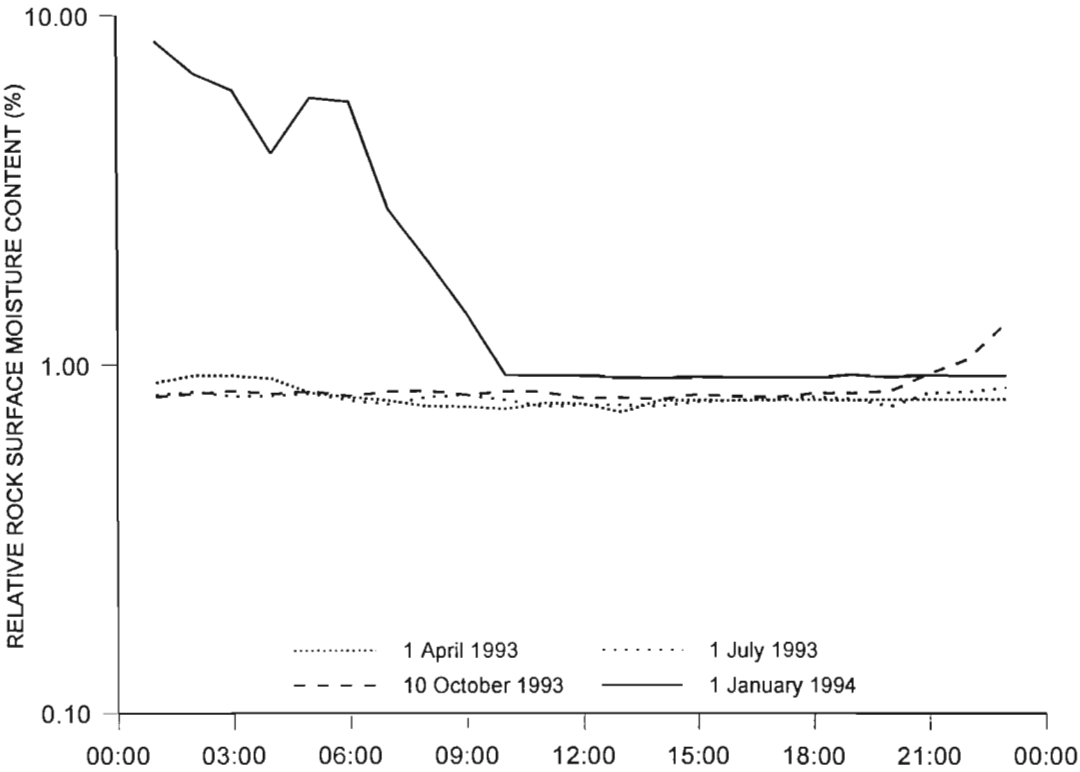


Figure 4.67: Hourly average relative rock surface moisture content for the Battle Cave study site on four selected days between 1 April 1993 and 31 March 1994.

gave readings that were just over 2% greater. The samples used in Cooke's (1979) method were very small and consequently had a high surface area to volume ratio which could explain the higher results.

The porosity of rock samples from aeolian deposited sandstones at the Battle Caves site was relatively low, averaging 5.73% (Table 4.15). Two samples from the fluvially deposited sandstones at the same site had an average porosity of 10.12% (Table 4.15). However no further rock properties were able to be determined as the samples used crumbled upon further contact with water.

METHOD	Cooke (1979)	Volume of water taken up under Vacuum	Mercury Porosimetry
Aeolian Deposit	5.73	2.65	2.51
Fluvial Deposit	10.12	-	-

Note: Measurements are in %.

Table 4.14: Average porosity of samples from the Battle Cave study site using three different methods.

The microporosity of samples from Battle Cave was relatively high, averaging 90.11% using Cooke's (1979) method (Table 4.15). According to mercury porosimetry tests, approximately 94% of the pores had a radius smaller than 1µm (Fig. 4.68), and are considered to be micropores (Bousquie 1979). From a bar chart (Fig. 4.69) it can be seen that there are relatively few pores larger than 0.06µm. Further data includes water absorption capacity and the saturation coefficient for samples from the Battle Cave site which were 4.66% and 0.82 respectively.

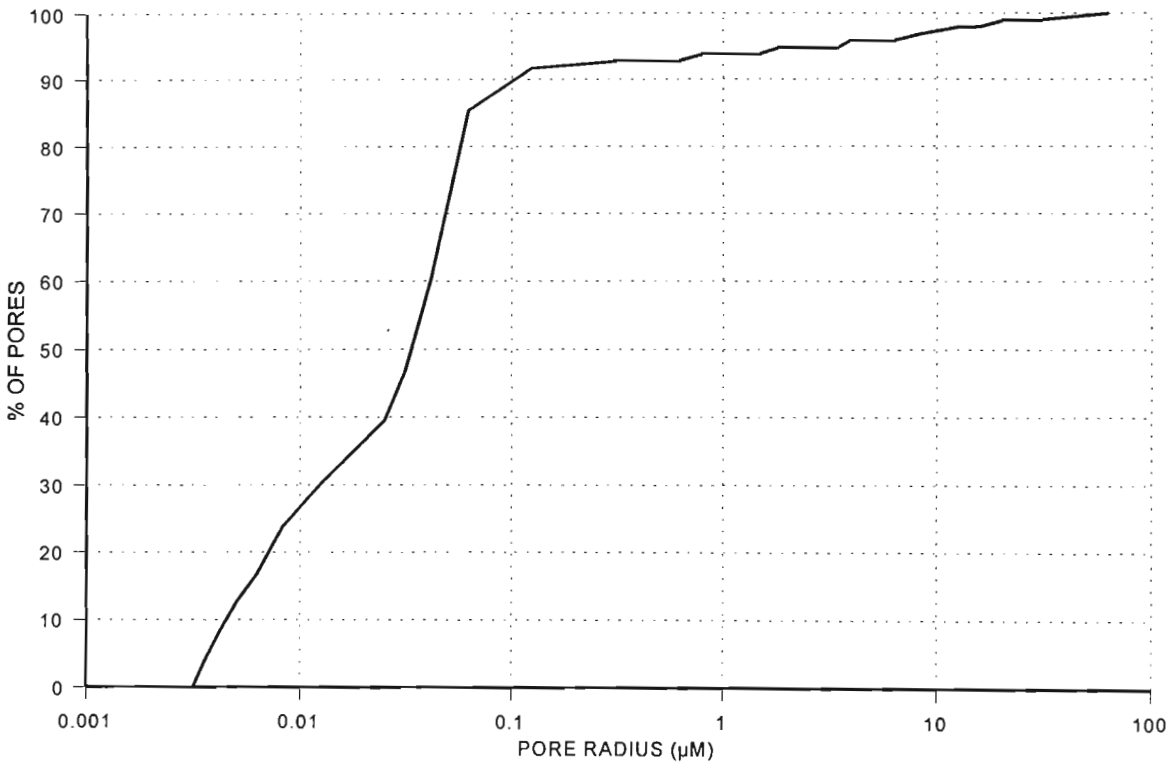


Figure 4.68: Pore radii and % of pores for a sample from the Battle Cave study site, determined using mercury porosimetry.

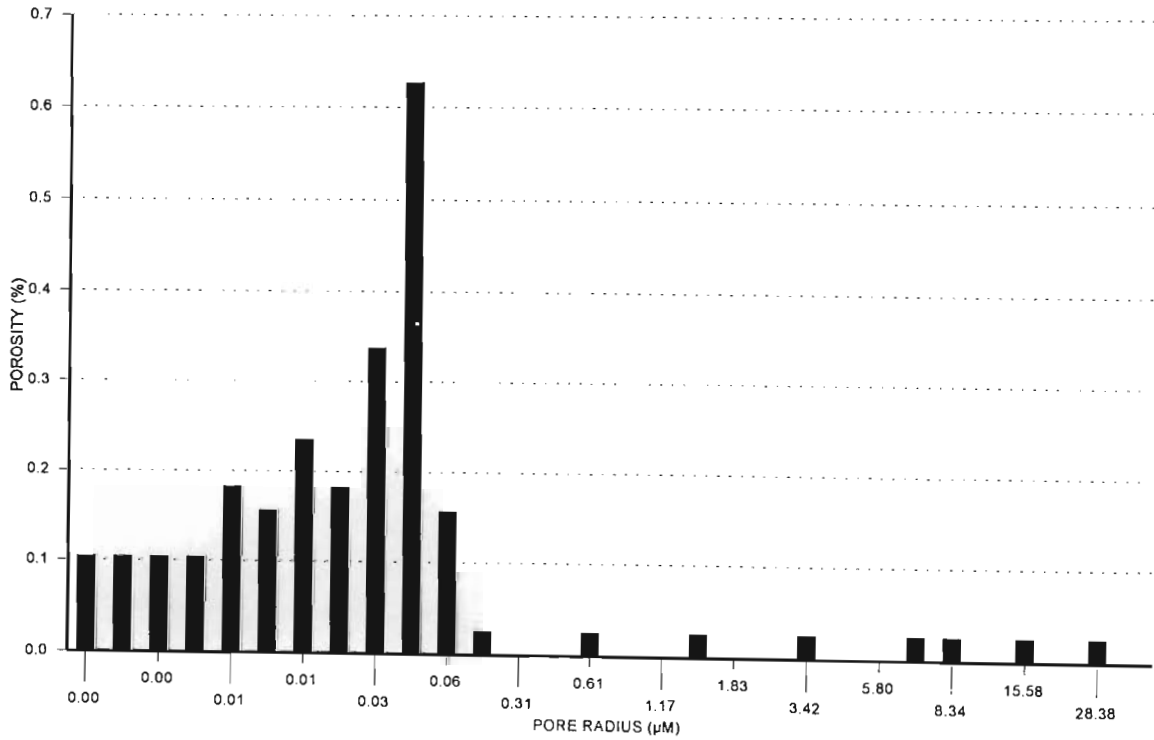


Figure 4.69: Porosity of certain pore sizes for a sample from the Battle Cave study site, determined using mercury porosimetry.

SAMPLE	POROSITY	WATER ABSORPTION CAPACITY	SATURATION COEFFICIENT	MICROPOROSITY
(Aeolian Deposit)				
1	3.80	3.61	0.95	91.77
2	5.23	4.25	0.81	87.50
3	5.22	4.04	0.77	90.32
4	6.20	4.39	0.71	91.67
5	8.19	7.02	0.86	89.29
Average	5.73	4.66	0.82	90.11
(Fluvial Deposit)				
6	9.70	-	-	-
7	10.54	-	-	-
Average	10.12	-	-	-

Table 4.15: Properties of rock samples from the Battle Cave study site, determined using Cooke's (1979) method.

4.3.2.2. Rock Chemistry

4.3.2.2.1. MAJOR ELEMENT COMPOSITION

The most common element found by XRF (X-ray fluorescence) was silicon, which constituted 76.2% of the sample, while aluminium was the next most common element (Table 4.16). Other elements present, in decreasing order of concentration, were calcium, iron, sodium, potassium, magnesium, titanium, manganese and phosphorous (Table 4.16).

Oxide	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	TOTAL	L.O.I.
Conc.	76.20	9.38	3.3	0.08	1.42	4.31	2.47	2.39	0.37	0.05	99.97	4.84

Note: 1. Values represent mass percentages of the oxides of major elements.
 2. L.O.I. = mass percentage of material lost on ignition.
 3. Conc. = concentration.

Table 4.16: Major element concentrations of rock samples from the Battle Cave study site, determined by X-ray fluorescence (XRF) spectroscopy.

4.3.2.2.2. MINERAL COMPOSITION

Quartz and feldspar were the most common minerals found in the aeolian deposited sandstones at Battle Cave, with calcite contributing a further 10% (Table 4.17). Other minerals found were kaolin, mica and a clay mineral, which

was most probably chlorite, while it is likely that haematite was also present (Table 4.17).

MINERAL	CONCENTRATION
Quartz	45%
Feldspar	20%
Calcite	10%
Kaolin	✓
Mica	✓
Clay Mineral (possibly chlorite)	✓
Hematite	?

Note: 1. Major mineral concentrations are indicated in %.
2. ✓ indicates that the mineral is definitely present.
3. ? indicates that the mineral is possibly present.

Table 4.17: Minerals identified in samples from the Battle Cave Study Site, using X-ray diffraction (XRD) spectroscopy.

4.3.2.2.3. ANALYSIS OF SOLUBLE MATERIAL

Soluble cations identified from samples at the Battle Cave site included, in order of decreasing concentration, potassium, calcium, sodium, magnesium and silica (Table 4.18). There was insufficient soluble iron present for accurate measurement. Soluble anions identified were limited to chloride and sulphate at relatively low concentrations (Table 4.19)

ION	Mg ²⁺	Ca ²⁺	Na ⁺	K ⁺	Fe ^{2+,3+}	Si ⁴⁺
Concentration	19	174	135	183	-	2

Note: 1. Concentrations are in mg/l.
2. -, indicates that the signal was not significantly higher than the blank.

Table 4.18: Selected cation concentrations, determined by AA (atomic absorption) spectroscopy, of rock samples from the Battle Cave study site.

ION	Cl ⁻	NO ₂ ⁻	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
Concentration	12.66	0	0	0	6.1443

Note: Concentrations are in mg/l.

Table 4.19: Selected anion concentrations of soluble material from rock samples, determined by ion chromatography, collected at the Battle Cave study site.

4.4. SIMULATIONS

4.4.1 TEMPERATURE REGIMES

The simulations conducted to investigate the thermal regime showed that only near the rock surface are rapid changes in temperature evident. This observation was true for tests based on field data (Fig. 4.70), tests where the rock sample was subjected to extreme temperature conditions (Fig. 4.71, 4.72) and tests where the rock sample was subjected to the most extreme rates of temperature change measured in the field (Fig. 4.71, 4.72). In all the above cases the response of rock temperature to external changes, diminished with depth below the rock surface, the relationship between depth and the temperature gradient being an inverse linear one, such that the correlation coefficient for this relationship is -0.99998 using simulated normal field conditions and -0.99213 when extreme conditions were simulated (Fig. 4.73). Maximum temperature gradients measured in simulations were: $2.12^{\circ}\text{C.cm}^{-1}$, for the first 5cm below the rock surface, $1.1^{\circ}\text{C.cm}^{-1}$, between 5cm and 10cm depth and $0.3^{\circ}\text{C.cm}^{-1}$, between 10cm and 15cm depth. The greatest difference in temperature regimes occurred between the rock surface and that 5cm below the surface, while as the depth below the surface increased so the differences between temperature regimes at increasing depths diminished (Fig. 4.70, 4.71 and 4.72, 4.73).

Simulations also provided evidence for transmission times of heating and cooling pulses through the Clarens Formation samples. In the simulations based on field data (Fig. 4.70) and extreme temperatures (Fig. 4.71), heating and cooling pulses took approximately 30 minutes to be transmitted 5cm, one hour to be transmitted 10cm and two hours to be transmitted 15cm into the rock. Due to the nature of the output and the rapid changes in surface temperature the precise times for pulse transmission could not be established. However the data recorded does provide evidence for an exponential relationship between temperature changes and depth below a rock surface.

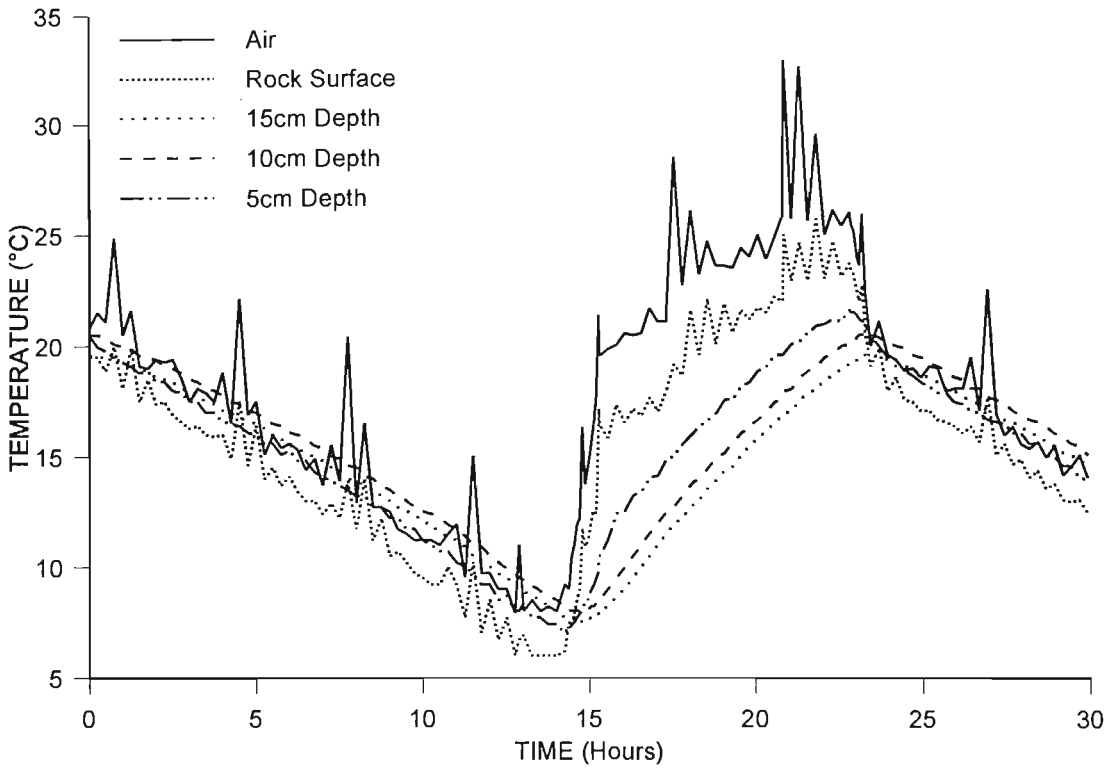


Figure 4.70: Temperature profiles at different depths of a Clarens Formation sample, from a simulation based on field data.

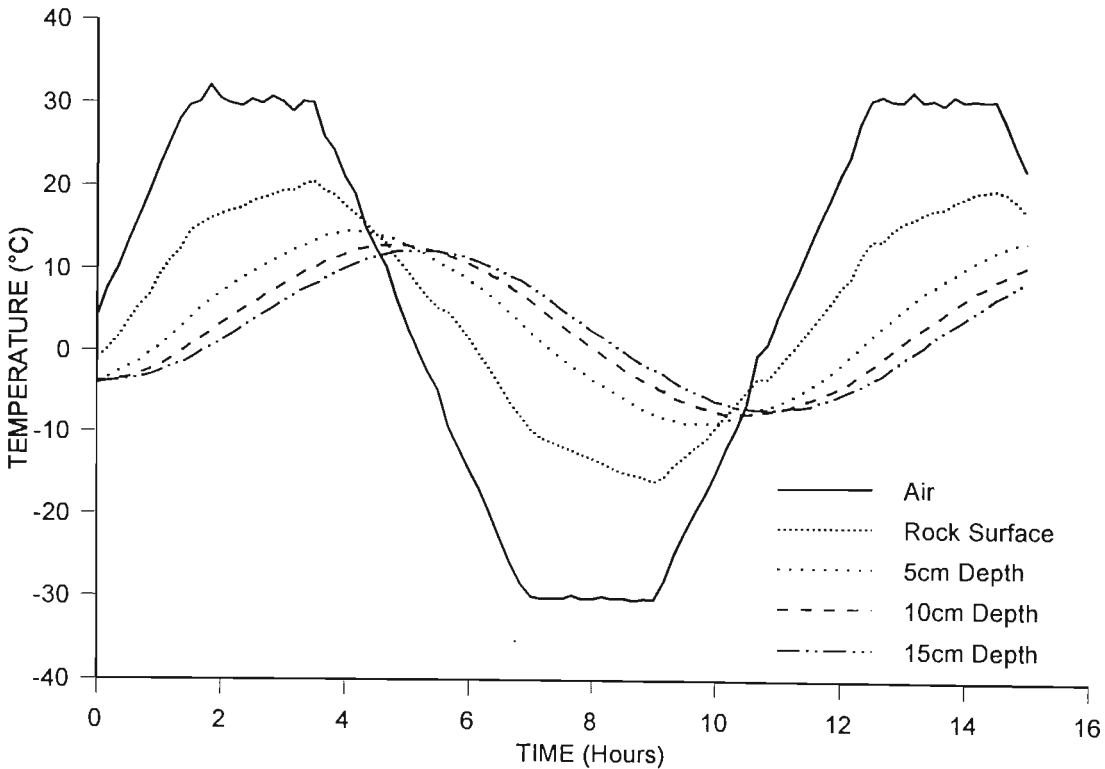


Figure 4.71: Temperature profiles at different depths of a Clarens Formation sample, from a simulation conducted under extreme conditions.

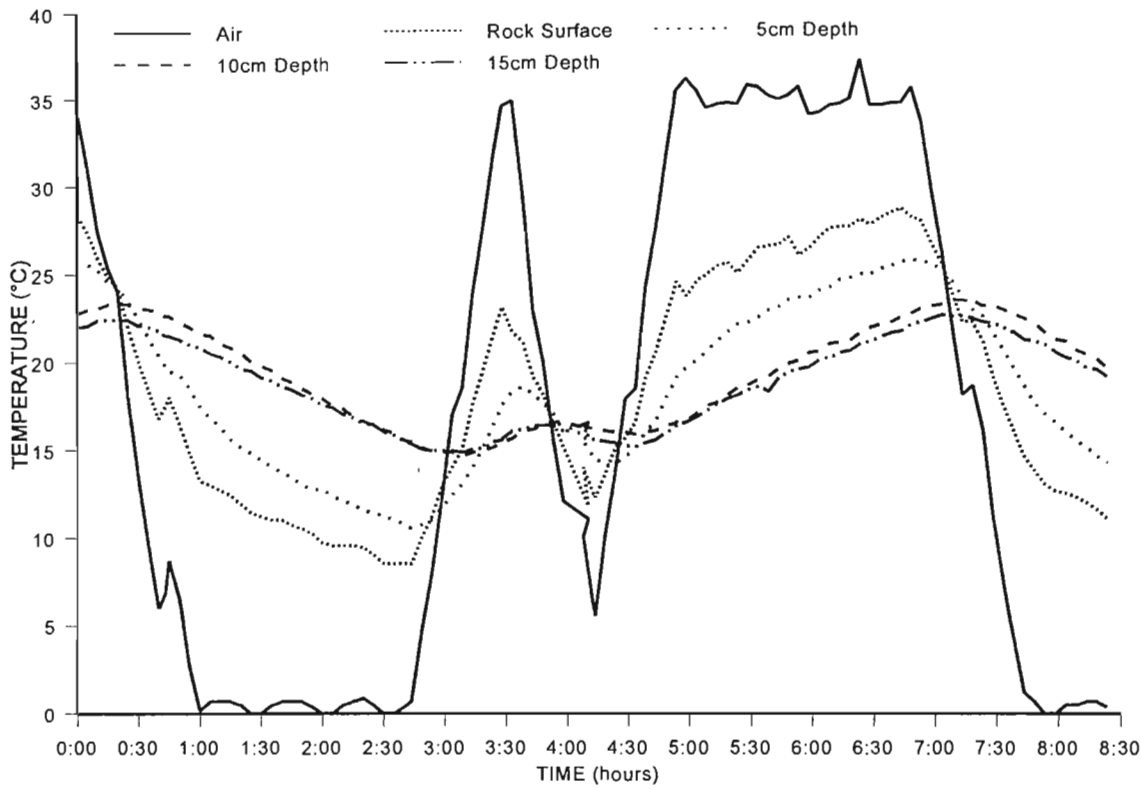


Figure 4.72: Temperature profile at different depths of a Clarens Formation sample, from a simulation carried out using extreme rates of temperature change measured in the field.

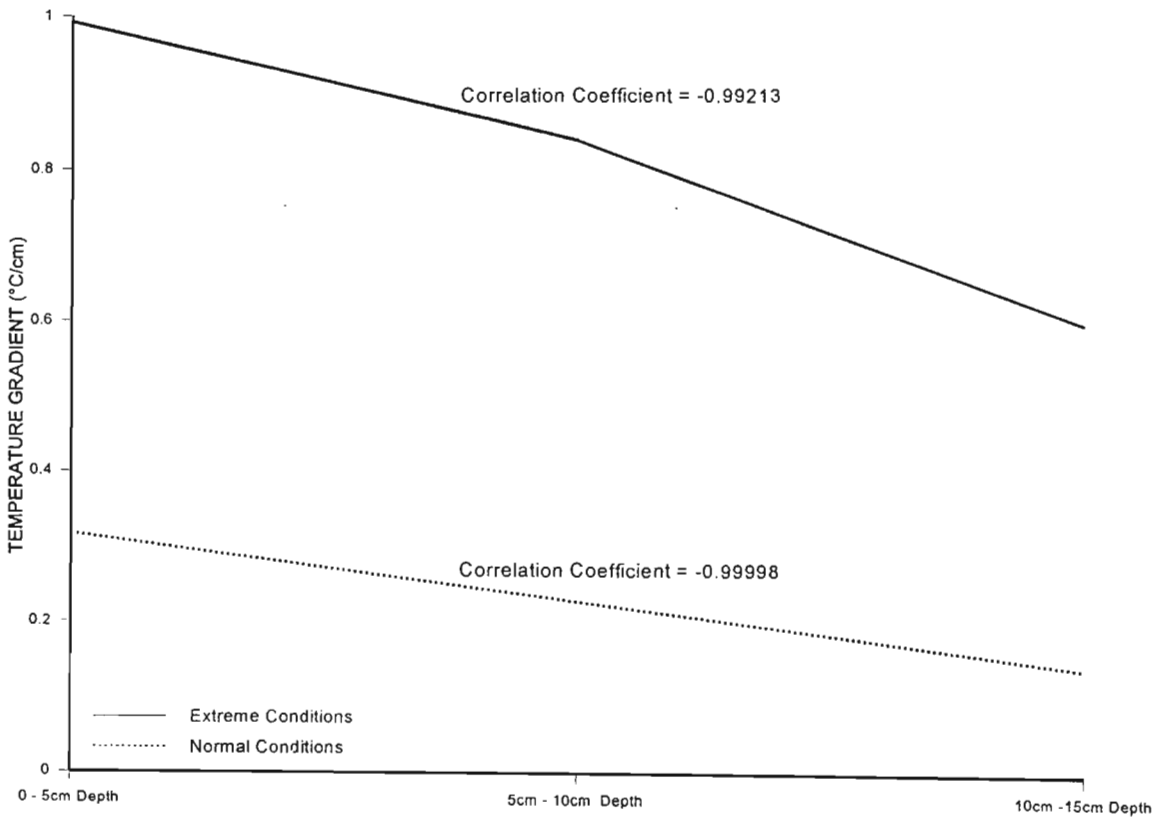


Figure 4.73: Graph showing the average temperature gradients over 5cm intervals under different simulation conditions.

4.4.2. RESPONSE OF SMALL SAMPLES TO DIFFERING MOISTURE CONDITIONS.

A total of fifteen samples were placed in a simulation cabinet to test the response of the rock properties of small samples to different moisture regimes. One of the samples (sample 15), which was actually a piece that had broken off sample 14 before testing commenced, was entirely made up of apparently weathered material. The data relating to this sample was, therefore, not considered in this discussion.

A general trend of an increase of mass lost from samples kept dry to those partially immersed in water was found (Table 4.20). During one of the test periods, after 25 cycles, it was noticeable that many samples lost some mass (Table 4.20). It is not possible to determine whether this loss of mass was due to the simulations the samples were subjected to, or due to weathering during the testing phase. However, the fact that the samples partially immersed in water experienced the greatest losses in mass does support the argument that their weathering environment was at least partially responsible for their more rapid deterioration. Some of the control samples lost relatively large amounts of mass, it is not possible to estimate the significance of the observations discussed above.

The greatest changes in rock properties occurred in the samples that were partially immersed in water during the simulation experiments. Rock porosities (Fig. 4.21) generally increased with time as the simulations progressed, while there appeared to be no real trend to changes in microporosity (Fig. 4.22). Water absorption capacities (Fig. 4.23) and saturation coefficients (Fig. 4.24) followed the same general trend as porosities and increased with increasing weathering. It may be argued that the testing procedure (to determine rock properties) was responsible for the changes in rock properties. However, the fact that there is some evidence that the samples partially submerged in water lost the most mass (Fig. 4.20) and had the greatest changes to their rock properties (Fig. 4.21, 4.22, 4.23, 4.24), show that the reaction conditions did influence weathering. It was

difficult to deduce any trends for the data relating to rock properties and analyses of the actual changes will be presented in the following chapter (see 5.6).

DESCRIPTION	SAMPLE	25 Cycles	Tests	50 Cycles	75 Cycles	100 Cycles	OVERALL
Partially Immersed - Drakensberg water	1	0.09	0.4	0.09	0	0.04	0.62
Partially Immersed - Drakensberg water	3	0.1	0.14	0.07	0	0.04	0.34
Partially Immersed - Distilled water	4	0.12	0.16	0.08	0.01	0.04	0.41
Partially Immersed - Distilled water	5	0.08	0.06	0.12	0	0.09	0.34
Sprayed - Drakensberg water	9	0.09	0.1	0.05	0.01	0.04	0.29
Sprayed - Drakensberg water	13	0.07	0.04	0.06	0	0.02	0.19
Sprayed - Distilled water	6	0.1	0.04	0.04	0	0.04	0.22
Sprayed - Distilled water	8	0.06	0.05	0.04	0	0.03	0.18
Draining - Control	7	0.14	0.06	0.04	0.02	0.04	0.3
Draining - Control	12	0.08	0.05	0.03	0	0.04	0.2
Control	2	0.07	0.06	0.04	0	0.07	0.24
Control	10	0.1	0.13	0.04	0	0.04	0.31
Control	11	0.03	0.04	0.05	0	0.04	0.17
Control	14	0.05	0.08	0.06	0	0.04	0.22

Table 4.20: Mass lost by each sample for each 25 cycles (expressed as % of its mass before the specific 25 cycles) plus the overall mass lost (expressed as % of the original mass of the sample).

CONDITIONS	SAMPLE	BEGINNING	25 Cycles	50 Cycles	75 Cycles	100 Cycles
Partially Immersed - Drakensberg water	1	6.92	7.41	7.25	7.38	8.93
Partially Immersed - Drakensberg water	3	7.32	7.82	7.7	7.79	7.51
Partially Immersed - Distilled water	4	6.75	7.31	7.19	7.35	7.18
Partially Immersed - Distilled water	5	7.89	8.15	8.12	8.20	7.94
Sprayed - Drakensberg water	9	6.86	7.27	7.1	7.25	7.05
Sprayed - Drakensberg water	13	9.01	9.07	8.89	9.27	8.59
Sprayed - Distilled water	6	7.46	7.62	7.48	7.58	6.26
Sprayed - Distilled water	8	8.11	8.08	7.84	7.98	7.75
Draining - Control	7	7.92	8.35	8.19	8.39	7.87
Draining - Control	12	6.34	6.49	6.44	6.61	6.30
Control	2	7.23	7.51	7.42	7.50	7.14
Control	10	7.31	7.74	7.57	7.51	7.42
Control	11	8.17	8.24	8.19	8.07	8.01
Control	14	8.2	8.41	8.16	8.29	7.98

Table 4.21: Porosity data for 14 samples used in simulation experiments based on field conditions.

CONDITIONS	SAMPLE	BEGINNING	25 Cycles	50 Cycles	75 Cycles	100 Cycles
Partially Immersed - Drakensberg water	1	94.3	96.96	91.74	93.59	93.89
Partially Immersed - Drakensberg water	3	92.44	98.38	92.16	89.14	95.26
Partially Immersed - Distilled water	4	90.44	96.36	92.37	93.92	93.78
Partially Immersed - Distilled water	5	87.79	92.76	89.83	90.58	93.69
Sprayed - Drakensberg water	9	94.52	92.59	96.61	96.57	99.18
Sprayed - Drakensberg water	13	89.57	92.43	92.01	88.89	93.95
Sprayed - Distilled water	6	89.16	94.82	95.98	95.74	97.96
Sprayed - Distilled water	8	86.25	88.65	91.52	89.63	93.44
Draining - Control	7	93.02	92.41	89.98	95.19	92.11
Draining - Control	12	89.41	93.84	92.11	91.27	94.44
Control	2	90.98	94.36	89.13	90.16	92.36
Control	10	91.97	94.38	91.76	92.34	94.75
Control	11	81.06	88.95	91.04	90.94	94.43
Control	14	82.57	88.91	90.19	88.79	92.84

Table 4.22: Microporosity data for 14 samples used in simulation experiments based on field conditions.

CONDITIONS	SAMPLE	BEGINNING	25 Cycles	50 Cycles	75 Cycles	100 Cycles
Partially Immersed - Drakensberg water	1	6.24	6.57	6.66	5.93	8.41
Partially Immersed - Drakensberg water	3	6.2	6.58	6.77	6.77	6.81
Partially Immersed - Distilled water	4	5.52	5.98	6.43	6.67	6.73
Partially Immersed - Distilled water	5	7.07	7.35	7.36	7.00	7.32
Sprayed - Drakensberg water	9	5.94	5.86	6.13	6.19	6.43
Sprayed - Drakensberg water	13	8.1	8.27	8.25	8.03	8.16
Sprayed - Distilled water	6	6.69	6.89	6.89	6.78	5.83
Sprayed - Distilled water	8	7.14	7.23	7.32	7.26	7.40
Draining - Control	7	6.77	7.04	7.15	7.19	7.15
Draining - Control	12	5.35	5.54	5.62	5.66	5.72
Control	2	6.58	6.8	6.78	6.64	6.84
Control	10	6.51	6.86	6.87	6.62	6.98
Control	11	7.44	7.44	7.49	7.38	7.57
Control	14	7.56	7.57	7.65	7.38	7.64

Table 4.23: Water absorption capacity data for 14 samples used in simulation experiments based on field conditions.

CONDITIONS	SAMPLE	BEGINNING	25 Cycles	50 Cycles	75 Cycles	100 Cycles
Partially Immersed - Drakensberg water	1	0.9	0.89	0.92	0.80	0.94
Partially Immersed - Drakensberg water	3	0.85	0.84	0.88	0.87	0.91
Partially Immersed - Distilled water	4	0.82	0.82	0.89	0.91	0.94
Partially Immersed - Distilled water	5	0.9	0.9	0.91	0.85	0.92
Sprayed - Drakensberg water	9	0.87	0.81	0.86	0.85	0.91
Sprayed - Drakensberg water	13	0.9	0.91	0.93	0.87	0.95
Sprayed - Distilled water	6	0.9	0.9	0.92	0.89	0.93
Sprayed - Distilled water	8	0.88	0.89	0.93	0.91	0.95
Draining - Control	7	0.85	0.84	0.87	0.86	0.91
Draining - Control	12	0.84	0.85	0.87	0.86	0.91
Control	2	0.91	0.91	0.91	0.89	0.96
Control	10	0.89	0.89	0.91	0.88	0.94
Control	11	0.91	0.9	0.92	0.91	0.94
Control	14	0.92	0.9	0.94	0.89	0.96

Table 4.24: Saturation coefficient data for 14 samples used in simulation experiments based on field conditions.

4.5. SUMMARY

This study involved the collection of data for the purposes of investigating the weathering of the Clarens Formation and its implications for the preservation of rock art. The data also provided a foundation from which weathering simulations could be undertaken under controlled laboratory conditions. Due to the large volume of data collected, it was possible to present only part in this chapter. For the sake of clarity interactions were not considered. The following chapter (Chapter 5) is an interpretation of the data, together with a discussion of the relevance of the data collected and the inter-relationships between variables.

CHAPTER 5

DISCUSSION OF THE RESULTS

5.1. INTRODUCTION

Six aspects which affect the weathering of the Clarens Formation, were investigated in this study, namely:

1. the thermal regime of the rocks.
2. the moisture regime of the rocks.
3. rock properties and their relationship to moisture movement.
4. rock strength.
5. rock chemistry.
6. simulation experiments.

While it is accepted that the weathering processes acting at the study site are interdependent, this chapter is broken down into the above headings to facilitate discussion, particularly in view of the large volume of data that has been collected.

5.2. ROCK THERMAL REGIMES

The rock temperature regimes can be broken down into three categories: first, seasonal cycles where summer temperatures are compared with those in winter. Second, diurnal variations were exhibited with daytime temperatures being warmer than those at night. A third category of temperature changes included short-term changes, measured at intervals as short as one minute. The differences in rock temperature regimes between the east shelter and north shelter of the Main Caves site, shown earlier (see 4.2.1.1.1), are insignificant and discussion of conditions at the Main Caves study site will, therefore, focus on the north shelter, where a greater range of variables was monitored.

The seasonal temperature regimes at the two study sites depended on the situation of the recording sensors. Underneath shelters, where no direct incoming radiation was received, summer temperatures were warmer than winter (Fig. 5.1). However, at exposed sites (e.g. Battle Cave), and on cliff faces (e.g. the external rock face at the Main Caves), the situation was different, as rock temperatures were highest close to the equinoxes and during winter (Fig. 5.1). This observation highlights the link between total incoming radiation and rock temperature. As discussed earlier (see 2.3.1.), daily maximum radiation for steep slopes ($> 30^\circ$) is greater during the equinoxes (Schulze, 1975, Tyson *et al.*, 1976). Radiation data presented for this study represent readings on a flat surface and are, therefore, not entirely representative of the incident sun's rays on the back walls of rock shelters where the rock art is located.

The role of solar radiation in influencing air temperatures is clearly evident in Battle Cave; rock temperature at the base of the back wall diminishes minimally during the winter months, when air temperatures were relatively low but when radiation receipts were relatively high (Fig. 5.2). It is also apparent that rock temperatures in Battle Cave are influenced by the temperature of the surrounding air (Fig. 5.2). The rock thermal regime at the Battle Cave site is determined not only by the rock mineralogy, its structure and properties, but also by complex interactions between air temperatures and incoming radiation.

In contrast to the situation at the Battle Cave site, the temperature of the back wall at the north shelter of the Main Caves study site shows little evidence of being influenced by incoming solar radiation. Data indicates an inverse relationship between average monthly incoming solar radiation and average monthly rock temperature ($\bar{r} = -0.64$) (Fig. 5.3). Only between the months of June and August of 1992 did rock, and air temperatures show any relationship with radiation (Fig. 5.3). In the north shelter of the Main Caves there is a closer relationship between air and rock temperature ($\bar{r} = 0.98$) than that between radiation and rock temperature ($\bar{r} = -0.64$) (Fig. 5.3). At the Battle Cave site the relationships are similar to those at the Main Caves (Fig. 5.3). Air temperatures have a correlation coefficient of 0.96 with rock

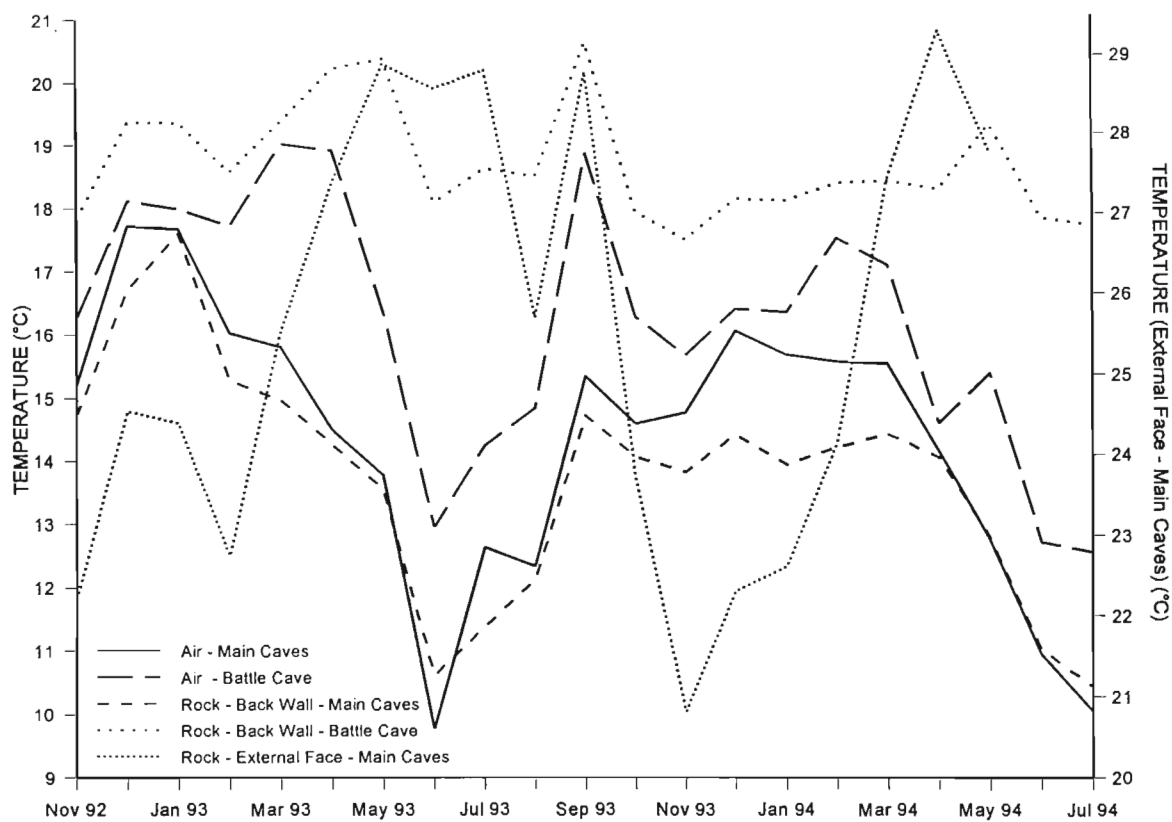


Figure 5.1: Rock and air temperatures for the Main Caves and Battle Cave study sites.

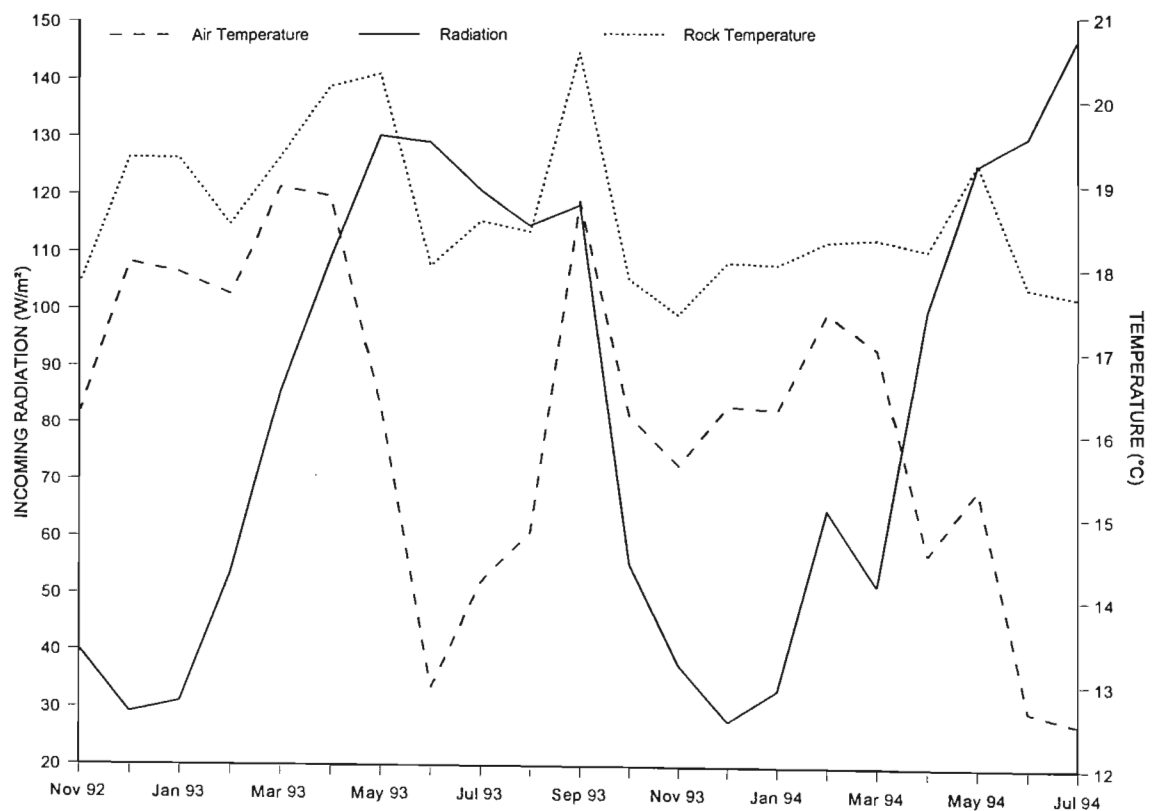


Figure 5.2: Average incoming radiation, with air and rock temperatures for the Battle Cave study site.

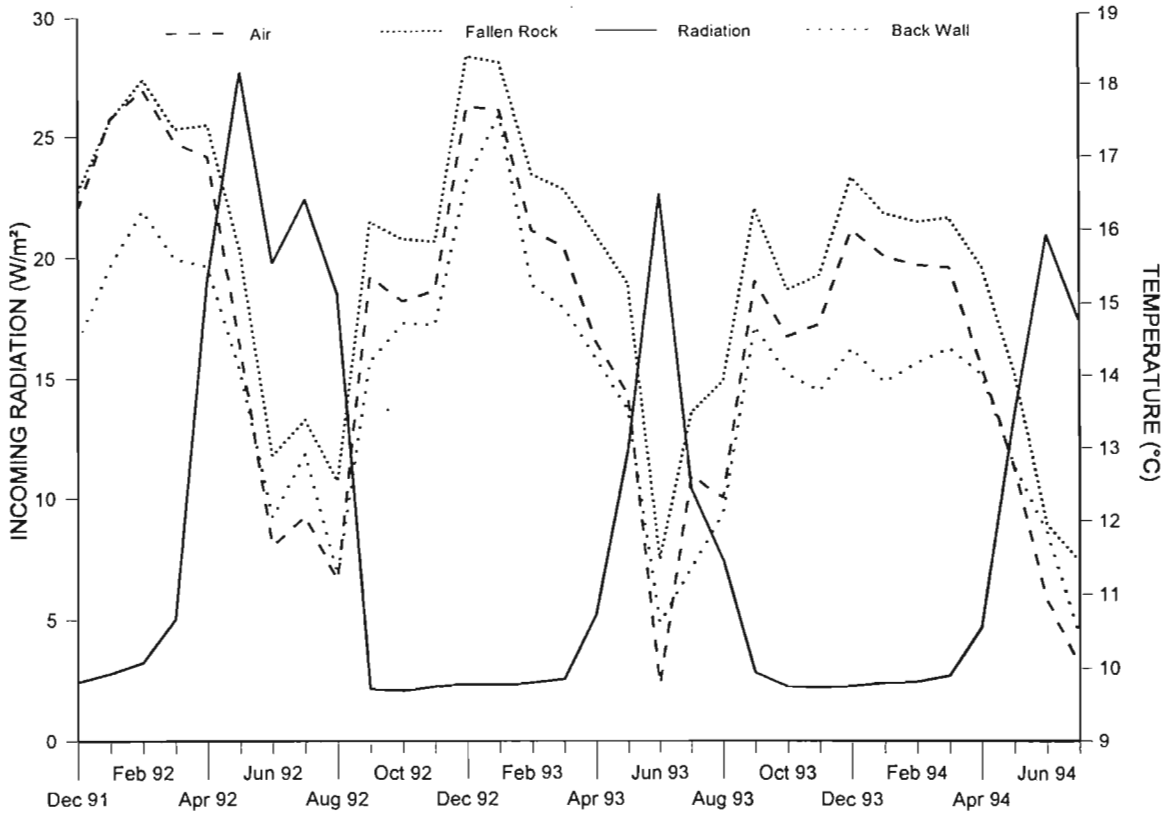


Figure 5.3: Average monthly incoming radiation, with air temperatures and rock temperatures on a fallen rock, and at the back wall, in the north shelter of the Main Caves study site.

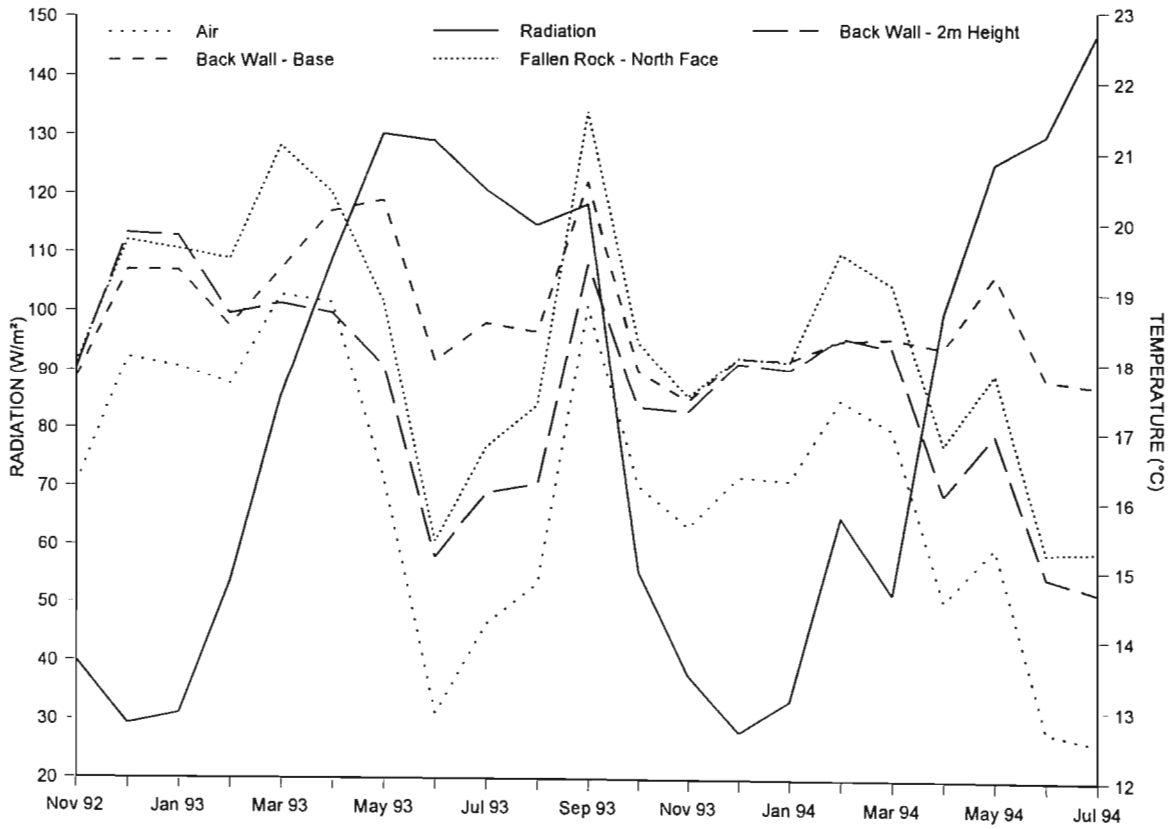


Figure 5.4: Average incoming radiation receipts with rock and air temperatures for the Battle Cave site.

temperatures 2m up the back wall of Battle Cave, and an average coefficient of 0.98 with all aspects of a fallen rock (Fig. 5.4). It is obvious that for the fallen rocks at both sites and for places where less incoming radiation is received (e.g. the high up the back wall of Battle Cave), that radiation inputs have less of an impact on rock temperature than they do at more exposed positions (e.g. at the base of the back wall at Battle Cave and at an external face of the Main Caves site). Even then, at the exposed base of the back wall at Battle Cave, there is a greater relationship between air temperature and rock temperature ($r = 0.63$) than between radiation and rock temperature ($r = 0.24$).

At the Battle Cave site there was an increasing correlation between radiation and rock temperature as the exposure of the rock increased; at 2m height above the ground (the most protected position) the correlation (r) value was -0.62, at 1m above the ground it was -0.41 and at the base of the back wall (in the most exposed position) it was +0.24. It can thus be said that the dependence of rock temperature on total incoming radiation increases with increasing exposure of the particular site. Similarly, the dependence of rock temperatures on the air temperature increases with a decrease in exposure of a site.

The effect of radiation on both air and rock temperatures is seen when comparing the two study sites; both air and rock temperatures at the Battle Cave site are higher than those of the Main Caves which is as a result of greater incoming radiation received at Battle Cave (Fig. 5.5). However, there does not appear to have been a linear relationship between rock temperature and incoming radiation. If this were to be the case then the difference in temperatures between the two study sites would have been greater than the one displayed in Figure 5.5.

A comparison between the rock temperature and radiation regimes from the north shelter and an external face of the Main Caves site elucidates the difference between an exposed and a sheltered site even more than the results discussed above. A logarithmic scale is used on the Y axis depicting radiation in Figure 5.6, which shows that rock temperatures were strongly affected by the radiation differences between the two sites. Further, rock temperatures on different aspects of the exposed face at the

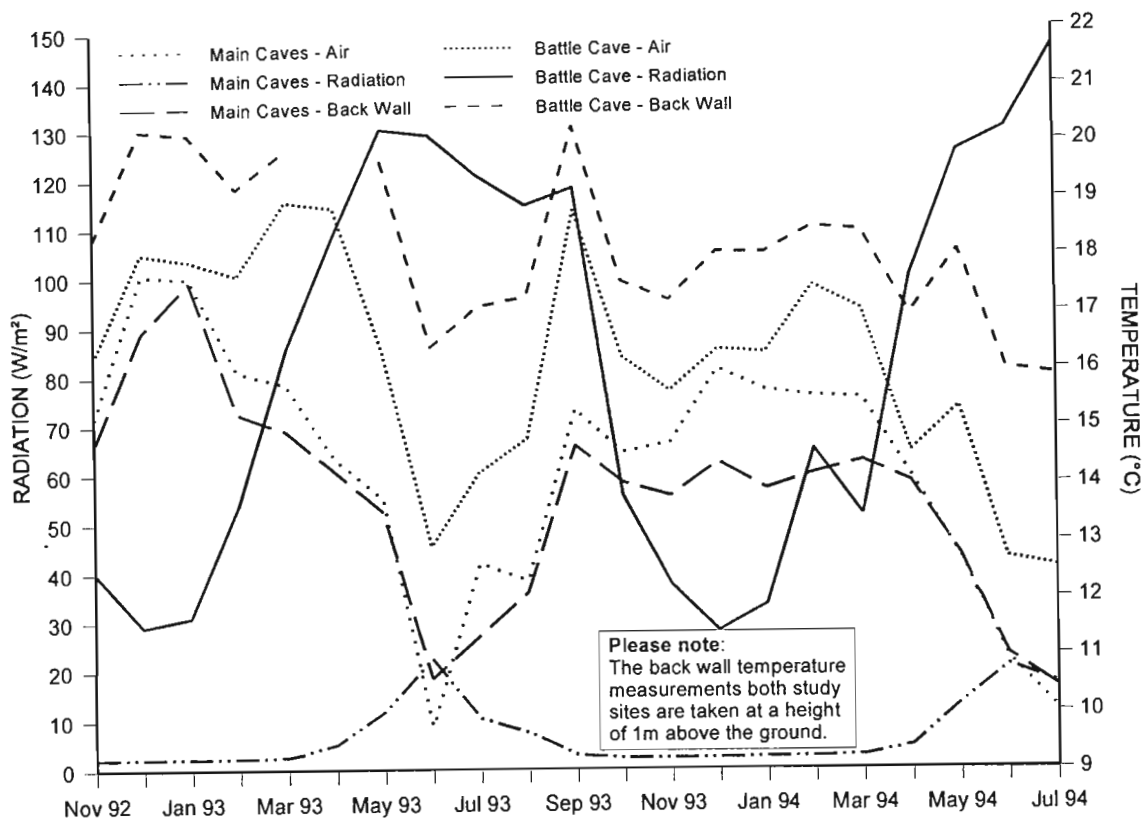


Figure 5.5: Average incoming radiation receipts with rock and air temperatures for both study sites.

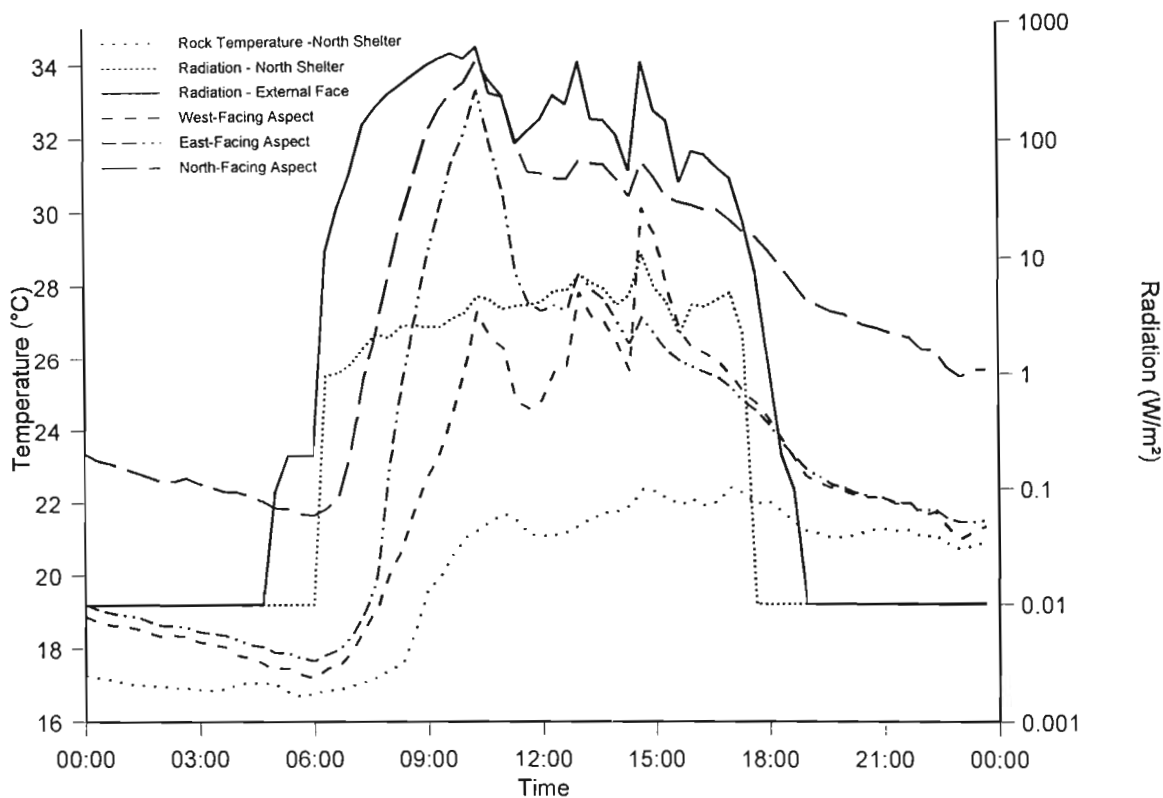


Figure 5.6: Rock temperatures and radiation receipts of the north shelter and an external face of the Main Caves study site on 19 September 1992.

Main Caves site, show evidence of the influence of radiation (Fig. 5.6). The temperature of the east- and north-facing aspects of the external face increased early in the morning due to the rays of the early morning sun; both these aspects received the first rays of the early morning sun together. After the incoming solar radiation had reached a peak, shortly before midday, the east-facing aspect was in shadow and its temperature dropped rapidly, followed soon after by dropping temperatures for the north-facing aspect (Fig. 5.6). However, the west-facing aspect only received its maximum radiation later in the day ($\pm 15:00$) and this is reflected by its temperature profile (Fig. 5.6). The influence of radiation and aspect on rock temperatures for an isolated boulder in the Injasuti valley was illustrated earlier (see 4.3.1.2.2 and Fig. 4.56).

The effect of aspect at the Battle Cave site was not as evident as that at the Main Caves site, largely because of the close proximity of the fallen rock to the back wall of the shelter (see Fig. 4.53, 4.54, 4.55). Reflected and long-wave radiation from the back wall of the shelter increased the temperature of the south, east and west faces of the boulder, such that there was a minimal difference between the temperature on the different aspects. Thus, this study reveals that aspect is not a major influence on the thermal regime of fallen rocks within shelters. Hence, aspect is not likely to influence the weathering regime of fallen rock in shelters of the Clarens Formation.

Comparisons of the daily temperature and radiation profiles for the two study sites for dates near an equinox (10 October 1993) (Fig. 5.7), midwinter (1 July 1993) (Fig. 5.8) and midsummer (1 January 1994) (Fig. 5.9), respectively, show the higher rock temperature and radiation at the exposed Battle Cave site. Only in summer, as seen in Figure 5.9, are rock temperatures at the Main Caves close to those recorded at Battle Cave. Although the summer rock temperatures at Battle Cave are greater than those at the Main Caves, the data presented show that the daily temperature range and rates of change of rock temperature are greater at the Main Caves than at Battle Cave (Fig. 5.9). It is during summer that both sites are most protected from the direct rays of the sun.

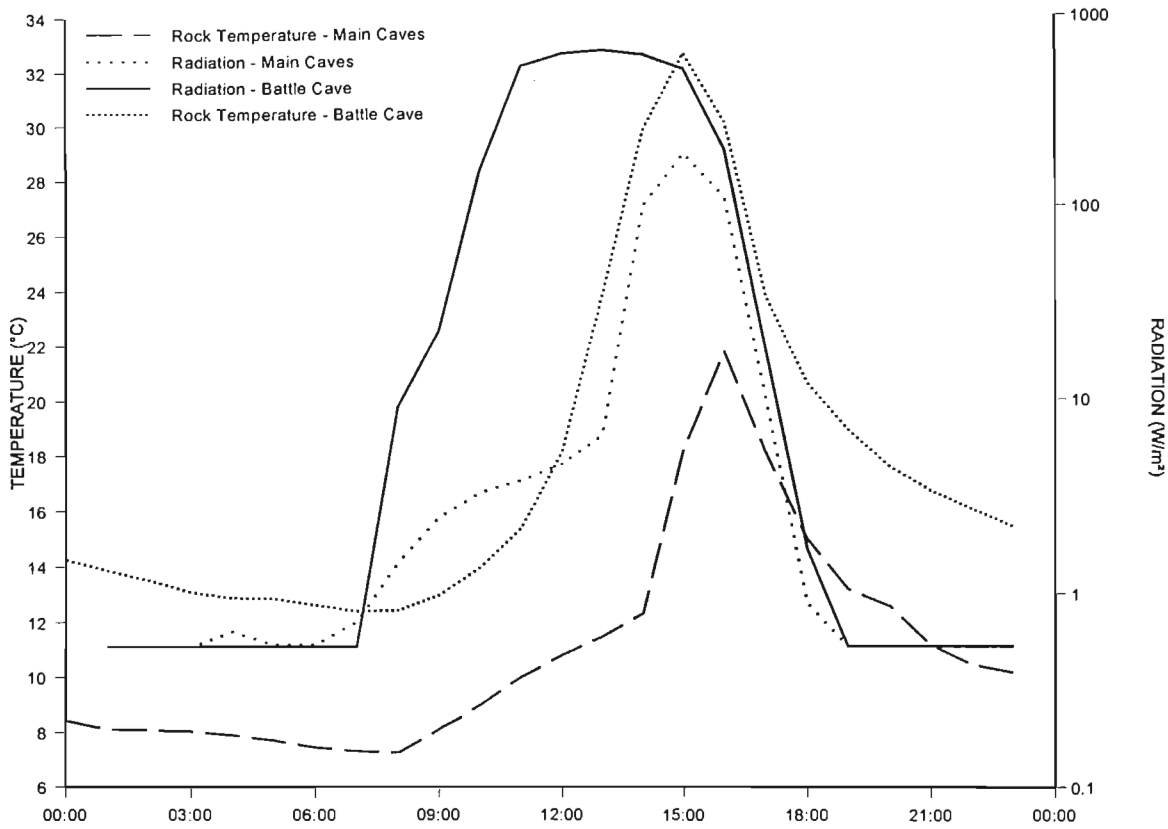


Figure 5.7: Comparative rock temperatures and radiation receipts for the north shelter of the Main Caves and the Battle Cave study sites for 1 July 1993.

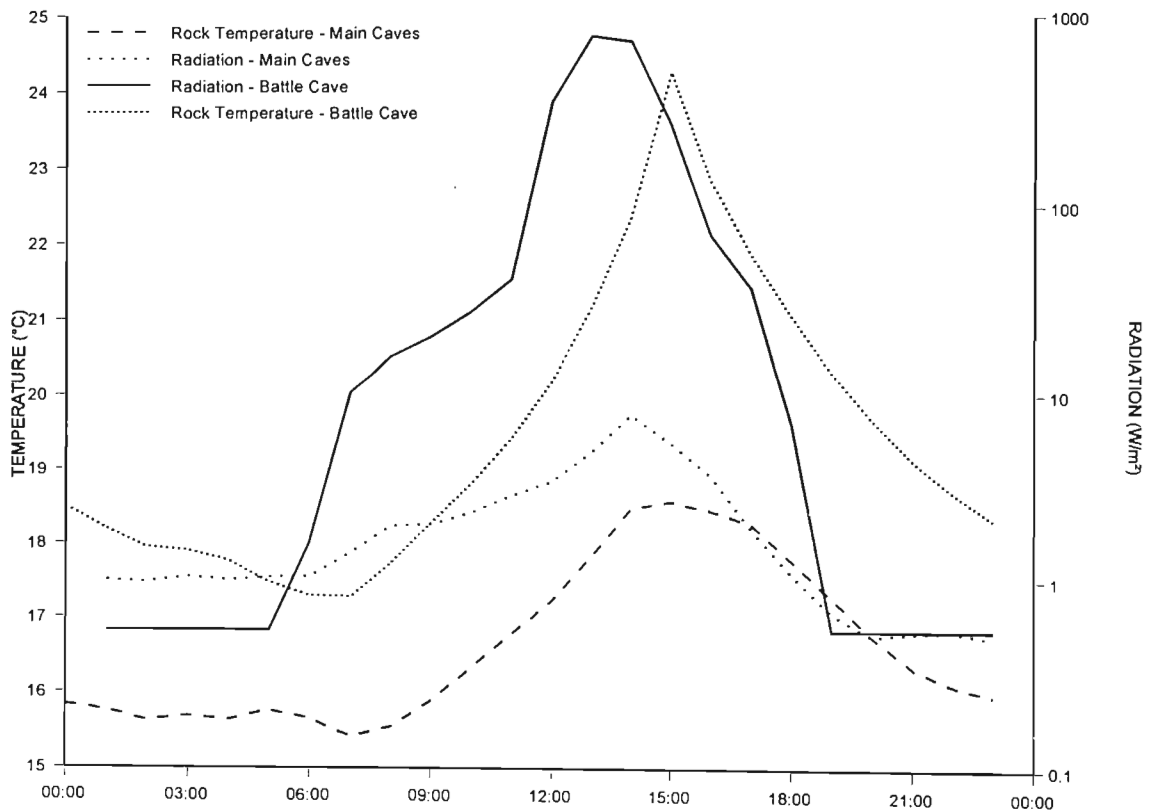


Figure 5.8: Comparative rock temperatures and radiation receipts for the north shelter of the Main Caves and the Battle Cave study sites for 10 October 1993.

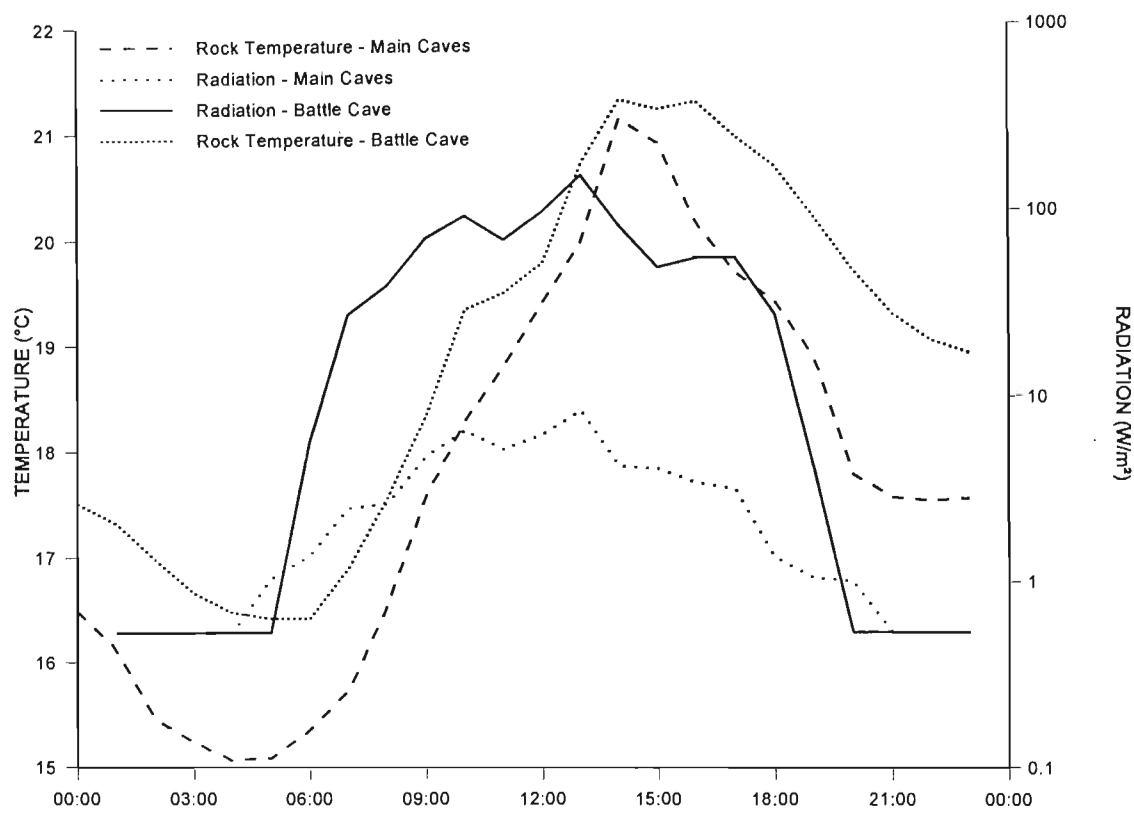


Figure 5.9: Comparative rock temperatures and radiation receipts for the north shelter of the Main Caves and the Battle Cave study sites for 1 January 1994.

As discussed earlier, the primary methods of data collection at the Main Caves site included twice daily manual readings and logging of hourly averages, while at Battle Cave only hourly averages were logged. However, these time intervals do not present an adequate coverage of short term changes in rock temperature. In order to supplement the collected data, shorter interval readings, rather than hourly averages, were taken at both study sites and these showed a more complex picture than that indicated by monthly, weekly and hourly profiles. The temperature data recorded and shown earlier (Fig. 4.3) indicated that rock temperatures can increase and decrease at rates of $2^{\circ}\text{C}.\text{min}^{-1}$. The greatest rate of rock temperature change that was found in the literature consulted was $3.3^{\circ}\text{C}.\text{min}^{-1}$, recorded on Tenerife by Jenkins and Smith (1990), which is $1.3^{\circ}\text{C}.\text{min}^{-1}$ more than that recorded in this study. However, the greatest rates of temperature increase and decrease recorded at the Main Caves (Fig. 4.3) were all similar, at approximately $2^{\circ}\text{C}.\text{min}^{-1}$; there is thus a possibility that this rate of temperature change represents the maximum sensitivity of the sensor. It is, therefore, probable that the actual changes of rock temperature occurred at greater rates than those recorded. If the rates of change of temperature are indeed greater than $2^{\circ}\text{C}.\text{min}^{-1}$, they may be sufficient to induce cracks along grain boundaries (Richter and Simmons, 1974; Yatsu, 1988; Hall and Hall, 1991). There is thus a great potential for thermal stress fatigue to be active at exposed sites in the Clarens Formation.

In a period of 20 minutes on 2 October 1994 at the Main Caves study site, when the aforementioned rates of change of $2^{\circ}\text{C}.\text{min}^{-1}$ were recorded, and as a group of clouds passed overhead intermittently blocking the direct rays of the incoming sun, there were 12 reversals in the temperature trend of the exposed rock face. Similar, and lesser, changes in rock temperature were said by Jenkins and Smith (1990) to be significant in inducing stress at the rock surface and thereby enhancing fatigue failure and the operation of other mechanical weathering mechanisms. Not only are the rates of change of temperature recorded at exposed sites sufficient to result in rock breakdown (as proposed by Richter and Simmons (1974) and Yatsu (1988)), but the rapid reversal in temperature trends may be sufficient to cause considerable stresses.

Rock temperatures 2.5cm below the surface did not experience the same dramatic changes as those on the surface (Fig. 5.10). Thermal gradients over the first 2.5cm below the rock surface averaged at $0.6^{\circ}\text{C.cm}^{-1}$ and had a maximum of $1.2^{\circ}\text{C.cm}^{-1}$. Given that it was not possible for the sensor at 2.5cm depth to be entirely sealed from the external environment in the field, it is likely that recorded thermal gradients underestimated the actual situation. When gradients measured in the field were compared to those extrapolated from simulation experiments this was found to be so; while the average gradient in the field was $0.6^{\circ}\text{C.cm}^{-1}$, that measured under controlled conditions was found to be $0.95^{\circ}\text{C.cm}^{-1}$ (Fig. 4.73). It has already been shown (see 4.4.1) that the thermal gradients are greatest close to the rock surface. The evidence presented above, thus, shows that temperature changes are greatest close to the rock surface and that it is thus likely that these temperature changes will induce stresses close to the rock surface (Jenkins and Smith, 1990).

Temperature measurements at 2 minute intervals at the Battle Cave study site showed complex regimes, with the influence of radiation clearly evident (Fig. 5.11). The rates of change of rock temperature were, however, not as great as those discussed above from an external exposed face at the Main Caves site on 2 October 1994. The variation of rock temperature regimes at different positions at the Battle Cave study site can be seen in Figure 5.11, with the most protected position, at 2m height on the back wall, having the lowest temperatures and the most exposed position, at the base of the back wall having the highest temperatures.

Simulation experiments have shown that the thermal regime beneath the rock surface is complex. As heating and cooling "pulses" pass through the rock it can be seen, especially when rapid changes in temperature occur, that different weathering processes from those at the surface might be taking place at depth in the rock. While the rock surface may be warming, it may be cooling beneath the surface (Fig. 5.12). Thus, processes affected by heating could be taking place on the surface while those associated with cooling could be taking place internally within the rock. Similarly the reverse of the above could also take place (Fig. 5.12).

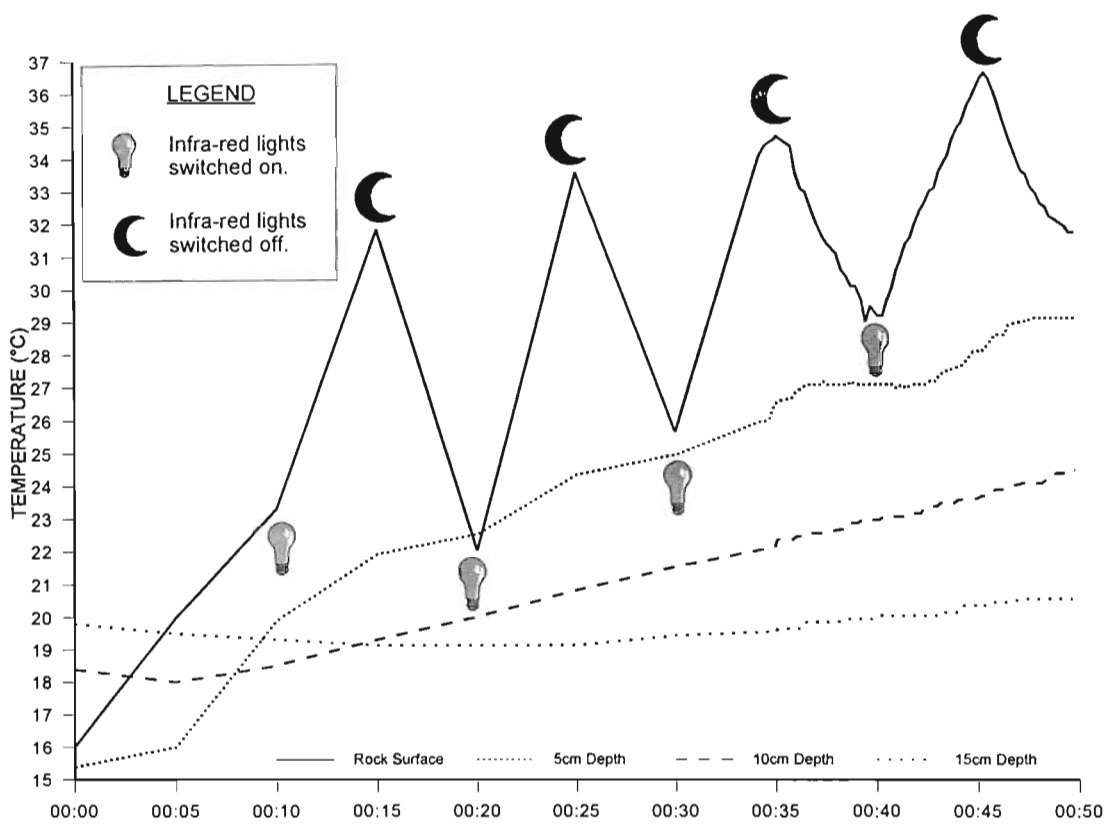


Figure 5.10: Rock temperatures at different depths of a sample used in a simulation experiment.

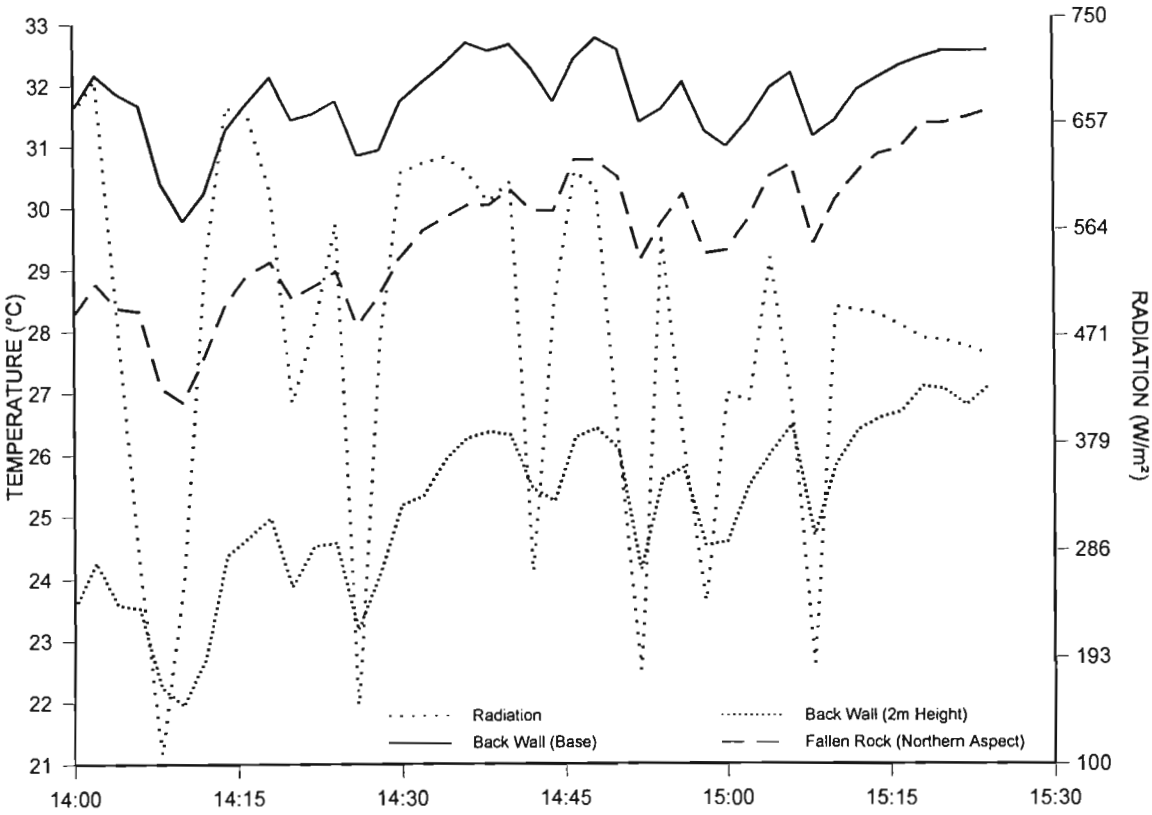


Figure 5.11: Rock temperatures and total incoming radiation from the Battle Cave study site measured at 2 minute intervals on 15 May 1993.

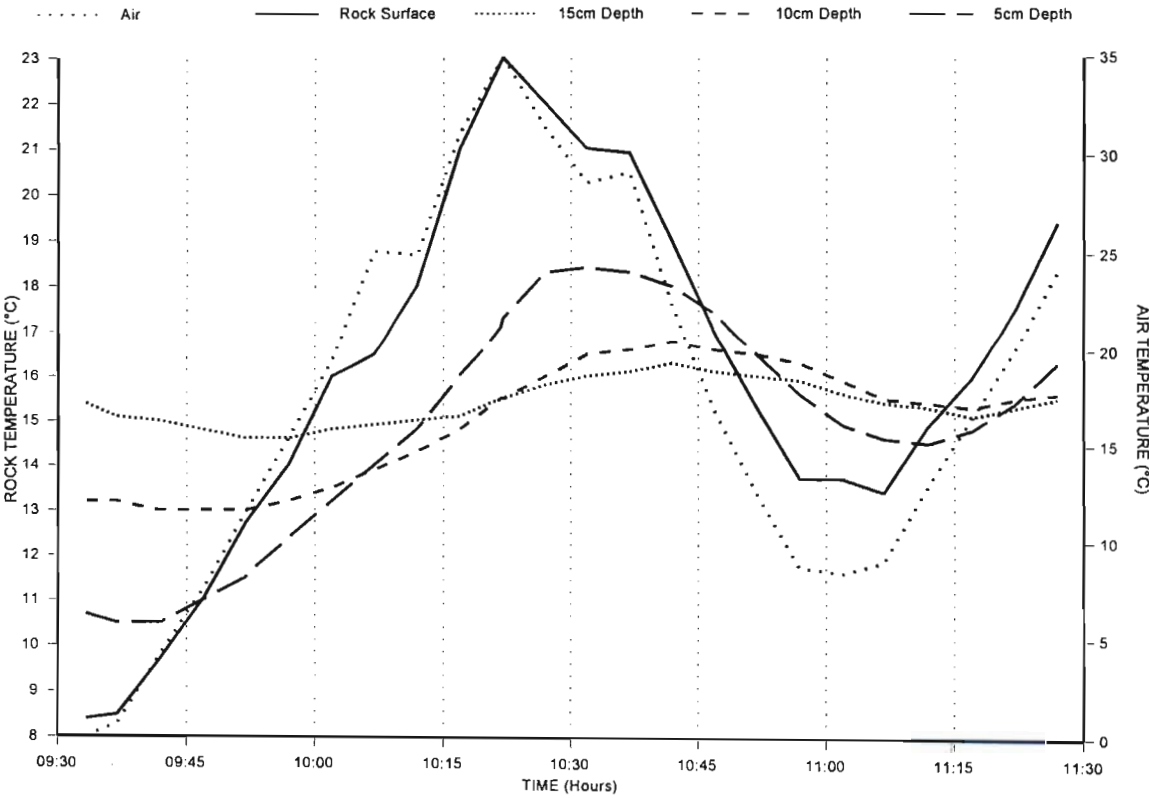


Figure 5.12: Temperature profiles from a rock sample used in simulation experiments.

Rock temperatures measured in simulation experiments showed that the greatest thermal gradients occurred near the rock surface and as the depth from the rock surface increased, so the temperature tended towards an isothermal state. It was shown (see Fig. 4.73) and it can be seen (Fig. 5.11 and 5.12) that the greatest rock temperature gradients occur within the first 5cm below the rock surface. Extrapolating the data from simulations (especially Fig. 4.73), it is likely that the greatest thermal gradients actually occur within the first few μm below the surface. True thermal gradients in the first few μm may actually be greater than those suggested by data for this study (e.g. Fig. 4.73), and the gradient may actually increase exponentially near the surface, as has been suggested by other studies (e.g. Hall and Hall, 1991). However, limitations with recording equipment prevented this difference from being monitored.

An important observation borne out by this study, especially the short-term records, is that air temperatures cannot be used as a surrogate for rock temperatures. In order to evaluate weathering mechanisms it is, thus, critical that rock temperatures, rather than air temperatures, be monitored. It is apparent that temperature regimes are not only site specific, but also dependant on the situation within the site. Therefore, any weathering investigation needs to be site specific as well as covering the site in such a way that an accurate temperature profile can be deduced. Unfortunately, the recording of such a profile, requires a great deal of expense in terms of monitoring equipment.

A process that can be discounted entirely in this study as a contemporary mechanism of rock art decay is that of cryogenic weathering. While it is accepted that freeze-thaw weathering is controlled by several factors considered important here (e.g.: rock albedo, rock temperature regime, rock moisture content, rock moisture chemistry, rock properties, and rock strength) (Hall, 1991b, 1992), this process can be excluded as a present day process at any of the study sites, on the basis of the rock temperature regime recorded for this study. Rock temperatures below 0°C were never recorded during the study period at either of the study sites. Due to the exposure of Battle Cave, it experiences not only the warmest, but also the coldest, rock temperatures of any known rock art sites in the study area. Therefore, if Battle Cave does not

experience temperatures cold enough for freeze-thaw weathering, it is unlikely that many, if any, other sites will experience this process. Further, during winter months, when rock temperatures are at their coldest at many rock art sites, rock moisture contents are at their lowest, especially at the exposed Battle Cave site, and are insufficient for cryogenic weathering to be active. The fact that freeze-thaw weathering is not a contemporary process at the study sites in the KwaZulu/Natal Drakensberg, does not preclude the process from having been active in the past. However, the available evidence for Holocene palaeoclimates (Partridge *et al.*, 1990), does not suggest an environment suitable for cryogenic activity at the study sites.

Given that rock temperatures influence a range of weathering processes, including, thermal fatigue, freeze-thaw, hydration/dehydration, crystallisation of precipitates, chemical reactivity and chemical equilibria, amongst others, the thermal regime of rocks is particularly significant in determining the weathering that will take place. The data presented in Chapter 4 and the present chapter show that rock temperatures are influenced by incoming radiation and air temperatures. It is well documented that other factors such as the rock properties, rock mineralogy, albedo, and rock structure also affect thermal weathering processes (Ollier, 1984; McGreevy, 1985; Yatsu, 1988). However, data collected indicated that there is no significant difference between the study sites as far as the latter four variables are concerned. The fact that there was no significant difference in rock temperatures between the east shelter and the north shelters of the Main Caves, both of which were sheltered, shows that the amount of exposure is an important control in determining rock temperature regimes. Therefore, while it has been found that aspect is not important for fallen rock in shelters, the aspect of an exposed rock face is of significance.

Results obtained show that the highest temperatures, the largest temperature ranges and the greatest rates of temperature change occur on exposed surfaces and are largely a function of radiation receipts, and aspect. Underneath rock shelters the rock temperature regime is less complex and more stable. Further, the data from the shortest time interval recording, show that the temperature regimes at exposed rock surfaces are extremely complex, and will result in a complex of rock weathering mechanisms being active. It is likely, therefore, that thermally controlled weathering

processes are most active on exposed rock surfaces. However, in the study area, the exposed sites are generally places of reduced weathering activity and rock shelters places of enhanced weathering. It is, thus, unlikely that thermal fatigue itself is a major process responsible for the deterioration of rock art in the Clarens Formation of KwaZulu/Natal. However, the role of rock temperatures, especially in affecting other weathering processes, even in the relatively protected environments under rock shelters, should not be underestimated.

5.3. ROCK MOISTURE REGIMES

It has already been argued that moisture is the primary agent of rock art deterioration in the study area (Avery, 1974; Rudner, 1989; Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991; Lewis-Williams and Dowson, 1992), but few specific weathering processes have been identified. It has also been argued above (see 5.2) that temperature changes on their own may not be sufficient to cause the weathering of Clarens Formation sandstone in the protected shelters. It is thus possible that moisture changes rather than temperature changes, or even a combination of the two may be the major cause of rock weathering and rock art deterioration in the KwaZulu/Natal Drakensberg. In other rock, for example, mudrock, it has been found that humidity changes may cause more breakdown than temperature changes (Venter, 1981a, 1981b). In order to ascertain the active weathering processes at the study sites it is thus imperative that the rock moisture regime is determined, together with the rock properties, mineralogy and other influences on rock moisture.

As was the case with rock temperatures (see 5.2), there is more than one temporal rock moisture regime in the study area. There was a seasonal trend of summer rock moisture contents being higher than those in winter. This trend at the Main Caves study site is paralleled by relative rock surface moisture contents (and atmospheric humidity) (Fig. 5.13). As all the rock samples monitored at the Main Caves study site showed the same rock moisture (represented by percentage saturation) trends (e.g. see Figures 4.4 and 4.5), only one sample from the external rock face is shown (Fig. 5.13). At the Main Caves site rock surface moisture, atmospheric humidity and rock moisture content followed the same trends (Fig. 5.13); the average correlation

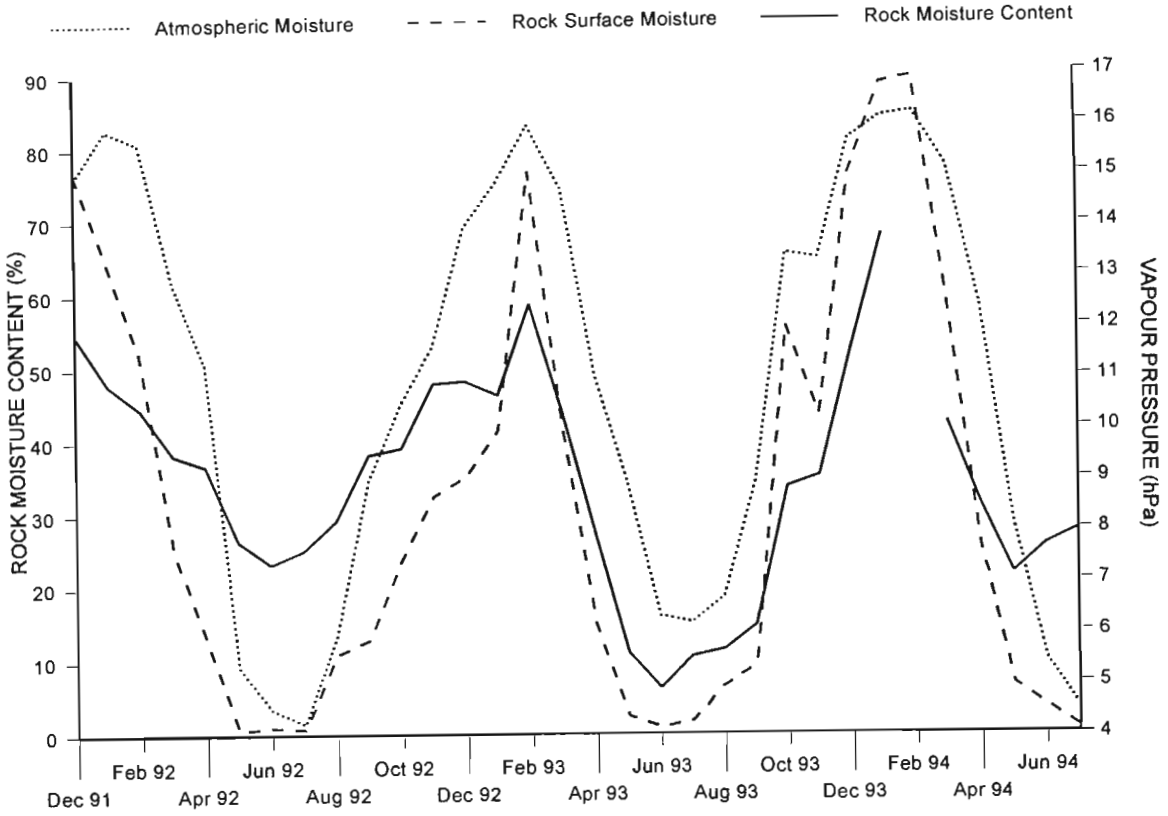


Figure 5.13: Rock moisture (% saturation), relative rock surface moisture and atmospheric moisture contents for the Main Caves study site.

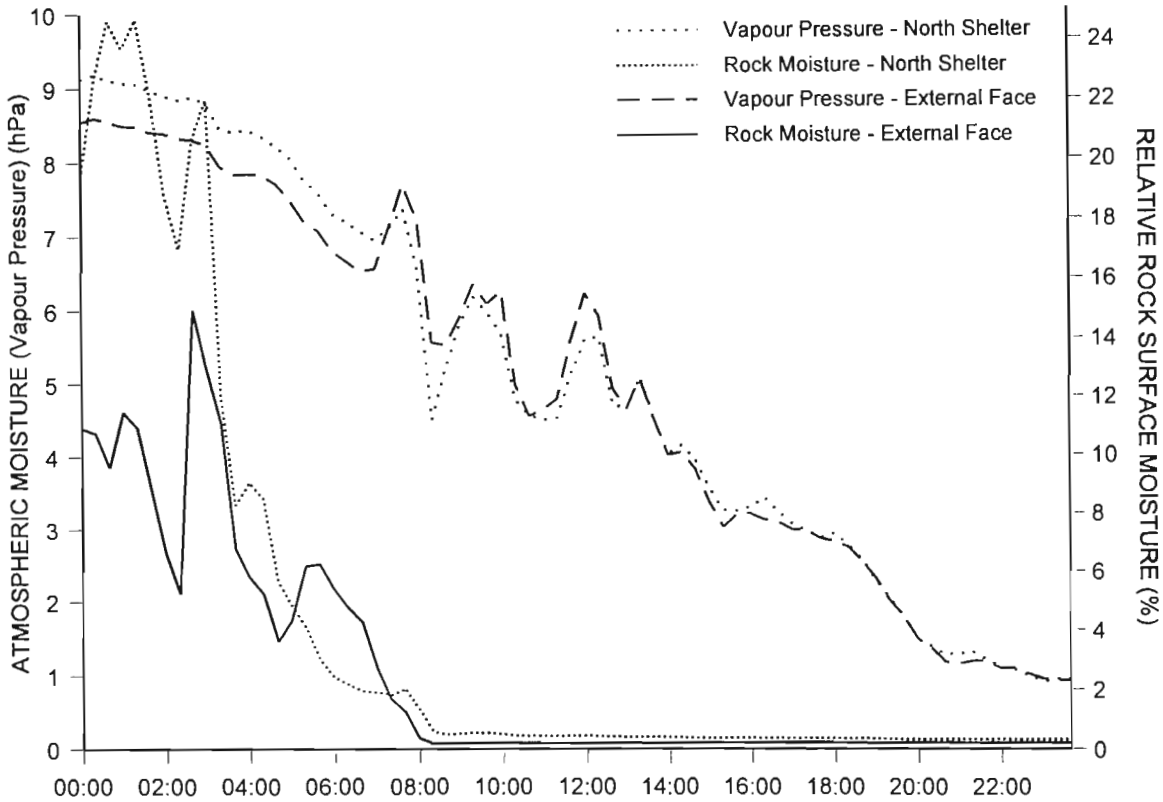


Figure 5.14: Graph comparing atmospheric moisture content and relative rock surface moisture content between the north shelter and an external face of the Main Caves on 24 August 1992.

coefficient of monthly averages of rock moisture contents, for the five rock samples monitored, with atmospheric moisture was +0.64 (the highest being +0.83), while that for rock moisture and rock surface moisture was +0.71 (the highest being +0.92). Samples in both shelters showed exactly the same trends as the sample displayed, which was located outside the north shelter. It thus appears that rocks are able to take up and release moisture with changes in atmospheric humidity. Data show that for a selected day at the Main Caves study site relative rock surface moisture content is related to atmospheric moisture (Fig. 5.14). These data also show that atmospheric humidity and rock moisture may be more variable in the north shelter of the Main Caves than at an external rock face during the winter months (Fig. 5.14). The above relationship was only tested using automated data during winter and not at any other time of the year due to the unavailability of equipment and so the trends observed cannot always be taken as the norm.

A positive relationship between atmospheric humidity and actual rock moisture content exists both in the north shelter (Fig. 5.15) and at an external face (Fig. 5.16) of the Main Caves study site. This relationship is evidence that the rock moisture regime is closely linked to the atmospheric moisture regime. As a number of weathering processes (e.g. hydration/ dehydration, solution, crystallisation of salts, hydrolysis and solute transport) are affected by changes in moisture, it then follows that changes in atmospheric moisture will result in certain weathering processes being active. Further, moisture may weaken rock such that saturation may reduce the dry compressive strength of sandstone by up to 60% (Bell, 1983).

Despite the positive relationship between rock moisture and atmospheric humidity being the norm, there were occasions when this was not the case. For example, data on the 2 October 1994 showed that at an external face, while there was a general positive relationship between actual rock moisture and atmospheric moisture under the shelter and when the rock samples were in the shade (see Fig. 4.8, 4.9), the relationship was reversed when the sun began to shine (see Fig. 4.9). On another occasion (see Fig. 4.6, 4.7) rock moisture contents showed a positive connection to rock temperature; a similar relationship was observed by Hall (1991a) on the Juneau Icefield. It was originally thought that as rock temperatures increase, so atmospheric

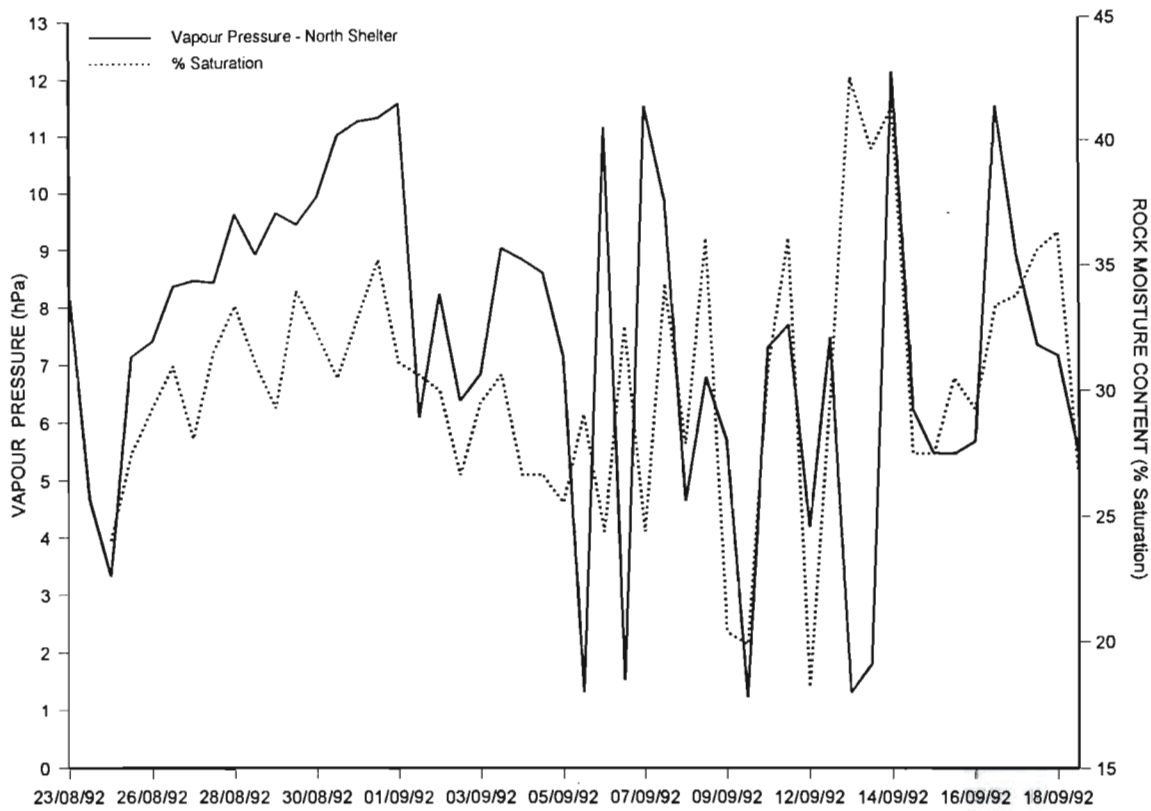


Figure 5.15: Graph of atmospheric moisture (vapour pressure) content and rock moisture content (% saturation) in the north shelter of the Main Caves study site.

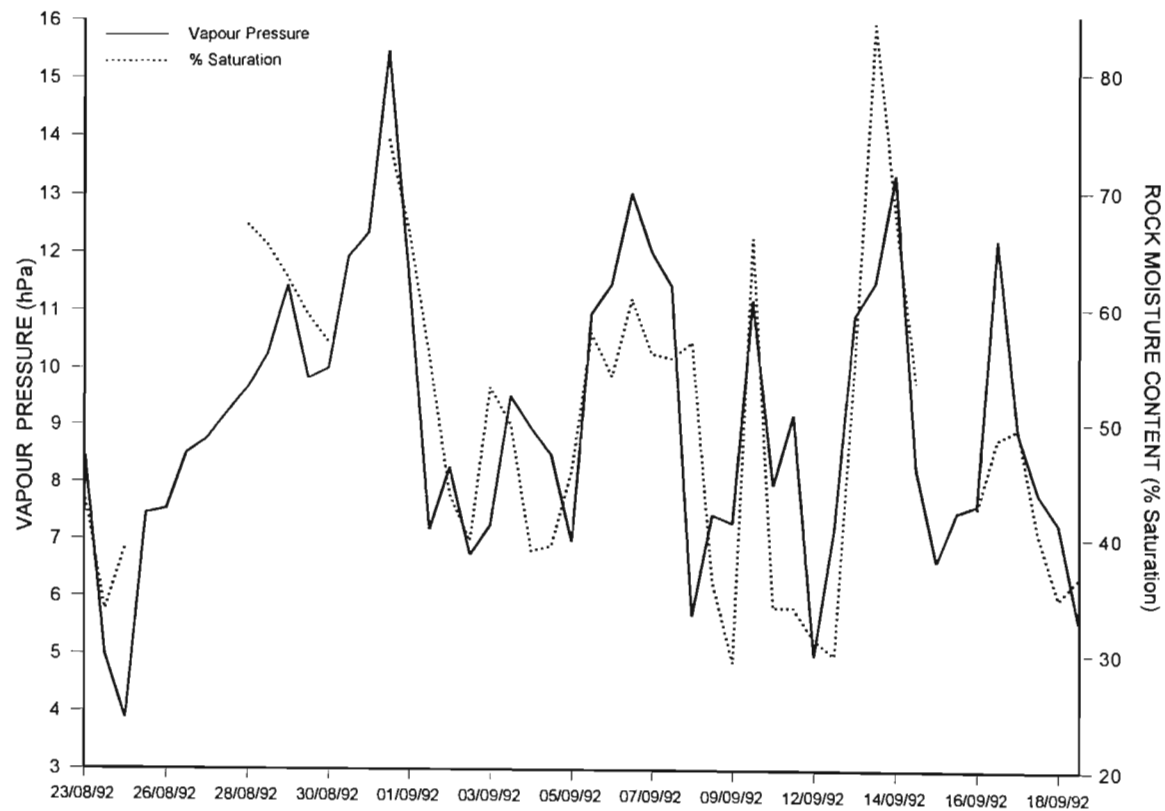


Figure 5.16: Graph of atmospheric moisture (vapour pressure) content and rock moisture content (% saturation) at an external face of the Main Caves study site.

moisture decreased and no explanation could be found for the observed link. However, atmospheric moisture did sometimes increase with increasing temperature (e.g. Fig. 5.17), and so the observed increase in rock mass may be due to increasing humidity.

The rock surface moisture regime at Battle Cave differs from that at the Main Caves in that the relationship between atmospheric humidity and relative rock surface moisture at the former site is positively exponential. When plotted on a mathematically normal axis there is only a weak relationship between the above two variables at Battle Cave (Fig. 5.18). However, the relationship between humidity and rock surface moisture content is strongest when relative rock surface moisture is plotted on a logarithmic axis (Fig. 5.18). The relationship between rock surface moisture contents and atmospheric humidity at the Main Caves is mathematically normal suggesting that moisture contents there are greater than those at Battle Cave. This observation is confirmed when comparing the atmospheric and rock moisture regimes of the Main Caves to those of Battle Cave (Fig. 5.19). While average monthly atmospheric moisture contents at the two sites are similar, the relative rock surface moisture contents, and the variability of rock surface moisture, is greatest at the Main Caves study site (Fig. 5.19). This trend is also visible if daily regimes are considered; in summer (e.g. 1 January 1994) (Fig. 5.20) and near the equinoxes (e.g. 10 October 1993) (Fig. 5.21) rock moisture content and variability are greatest at the Main Cave study site. During winter this may not be the case, as Figure 5.22 shows: on 1 July 1993, rock moisture contents and variability are greatest at Battle Cave. However, the differences between the two sites are less evident during winter; this can also be seen in the monthly averages (Fig. 5.19). The increase in atmospheric and rock moisture during the evening of 10 October 1993 (Fig. 5.21), may be due to the arrival of a cold front which is observed on the daily weather bulletin (South African Weather Bureau, 1993c). The aforementioned increase further illustrates the affect of atmospheric moisture on the rock moisture content.

The relationship between incoming radiation and relative rock moisture contents is apparently inverse ($r = -0.69$) (Fig. 5.23). It has already been shown that atmospheric moisture has a greater role in affecting the rock moisture contents than radiation in

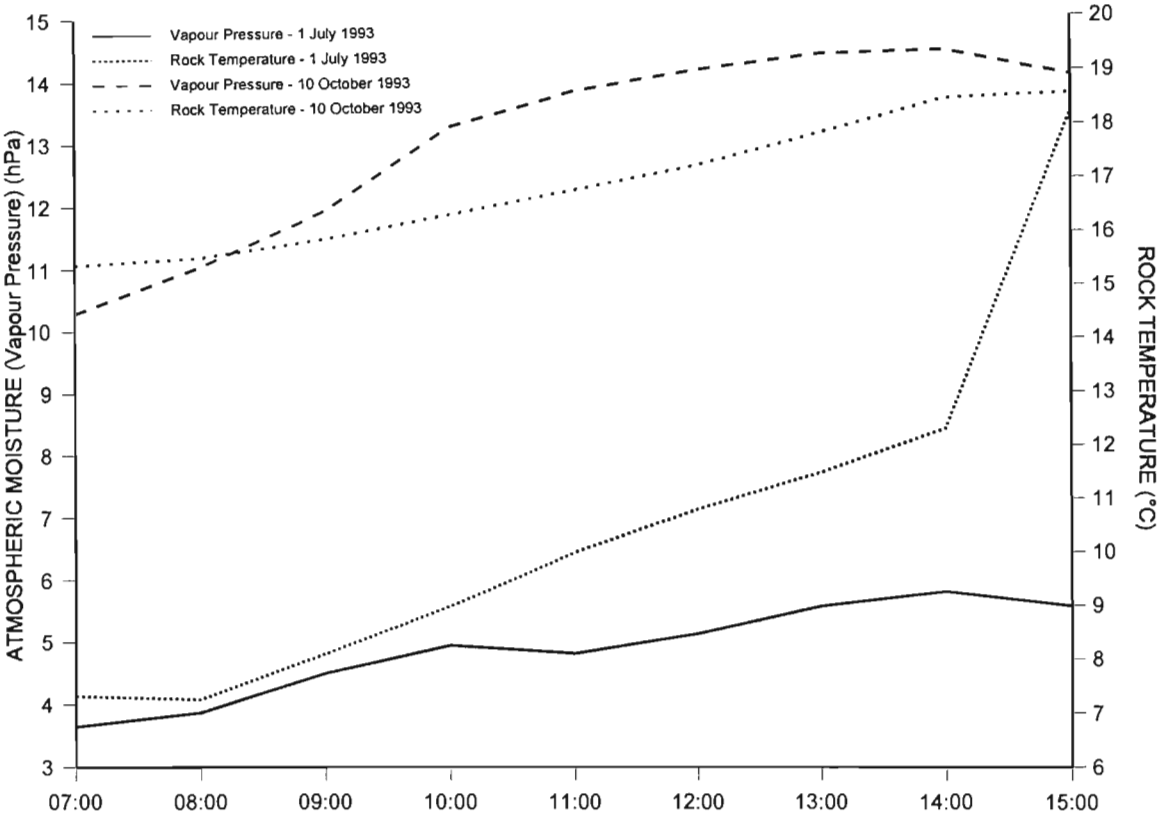
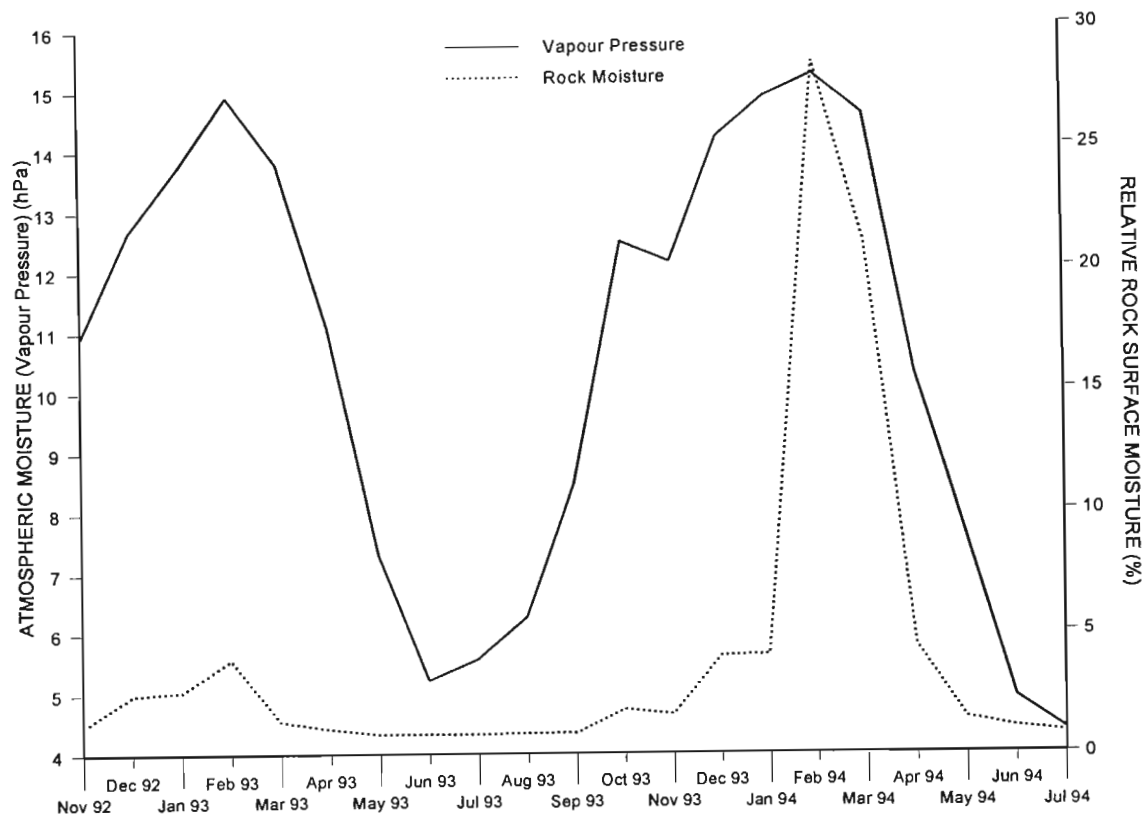
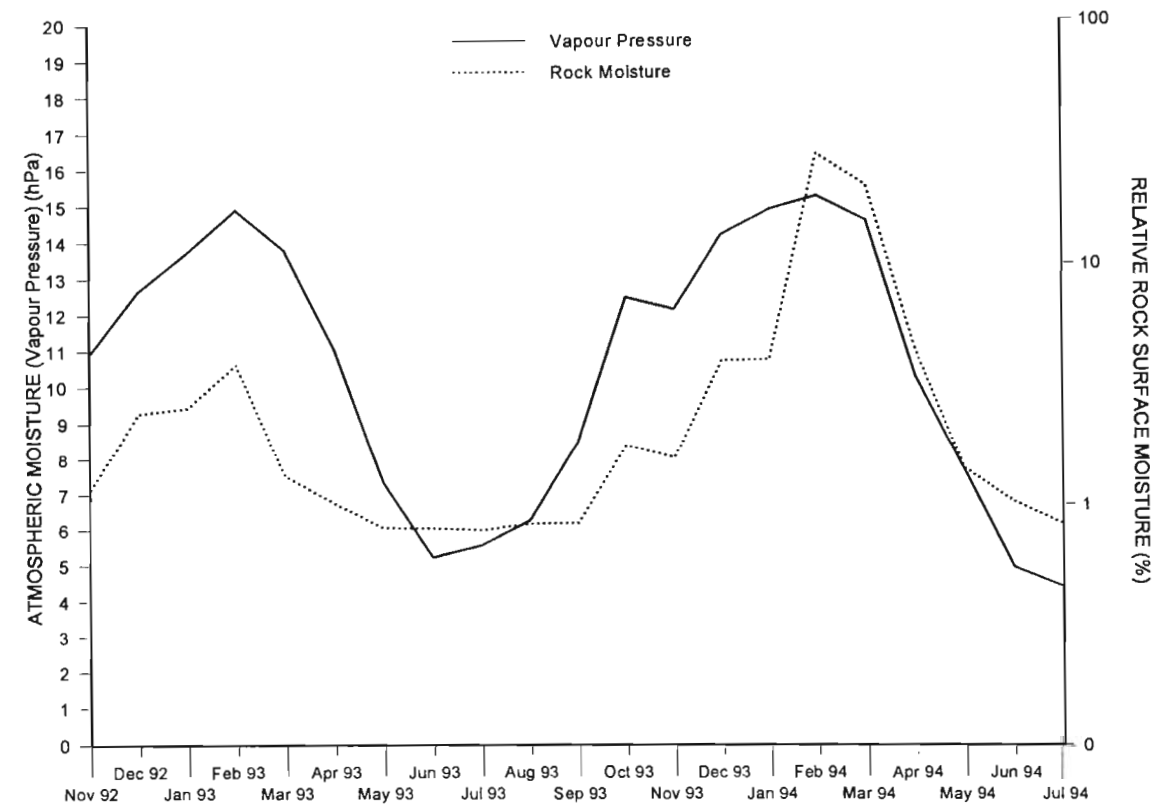


Figure 5.17: Atmospheric moisture and rock surface moisture contents for the north shelter of the Main Caves on 1 July 1993 and 10 October 1993.



a: Using a normal scale for the rock surface moisture axis.



b: Using a logarithmic scale for the rock surface moisture axis.

Figure 5.18: Average monthly atmospheric humidity and relative rock surface moisture contents for the Battle Cave study site.

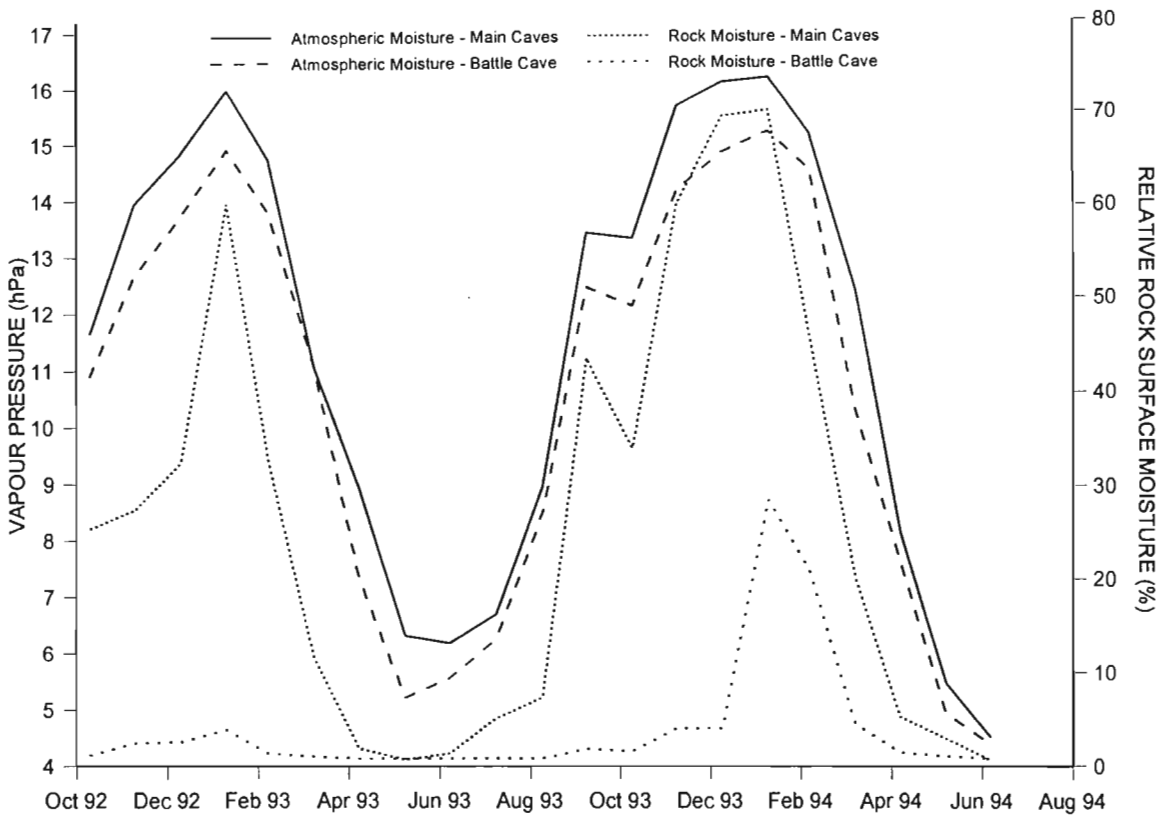


Figure 5.19: Average monthly atmospheric moisture and relative rock surface moisture contents at the Main Caves and Battle Cave study sites.

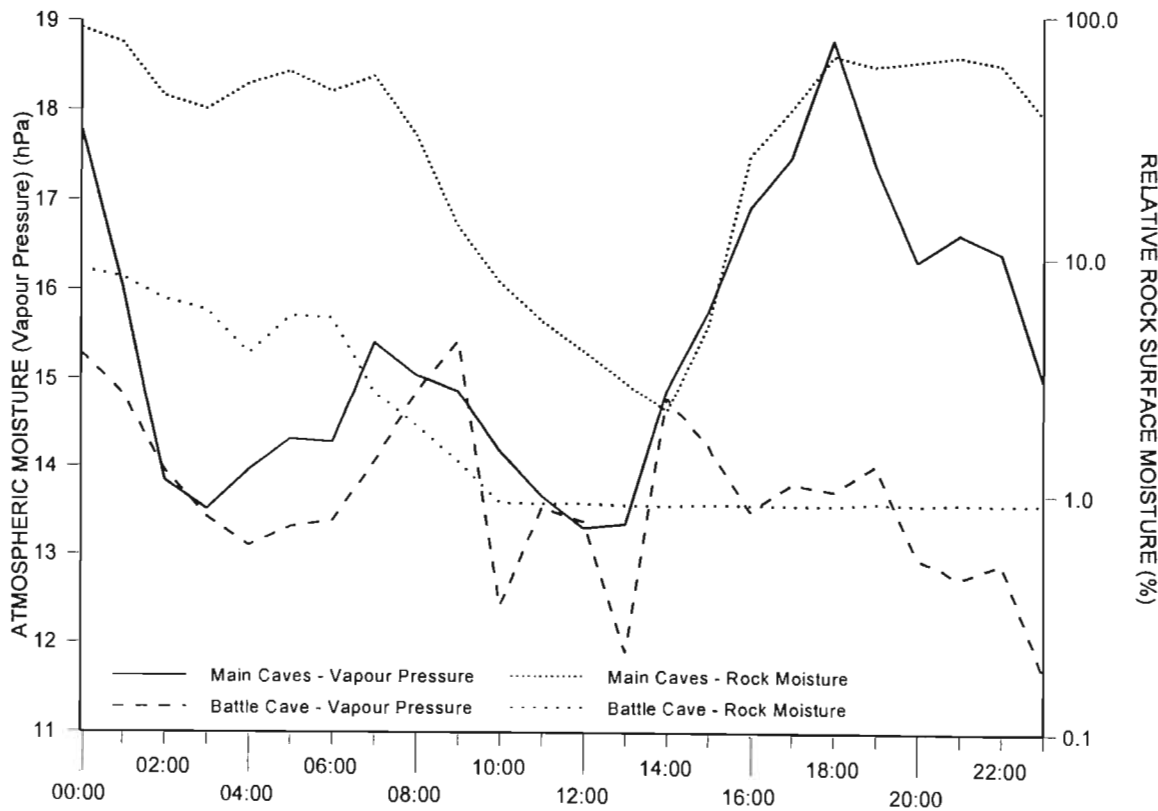


Figure 5.20: Atmospheric moisture and rock surface moisture contents for the north shelter of the Main Caves and for the Battle Cave study site on 1 January 1994.

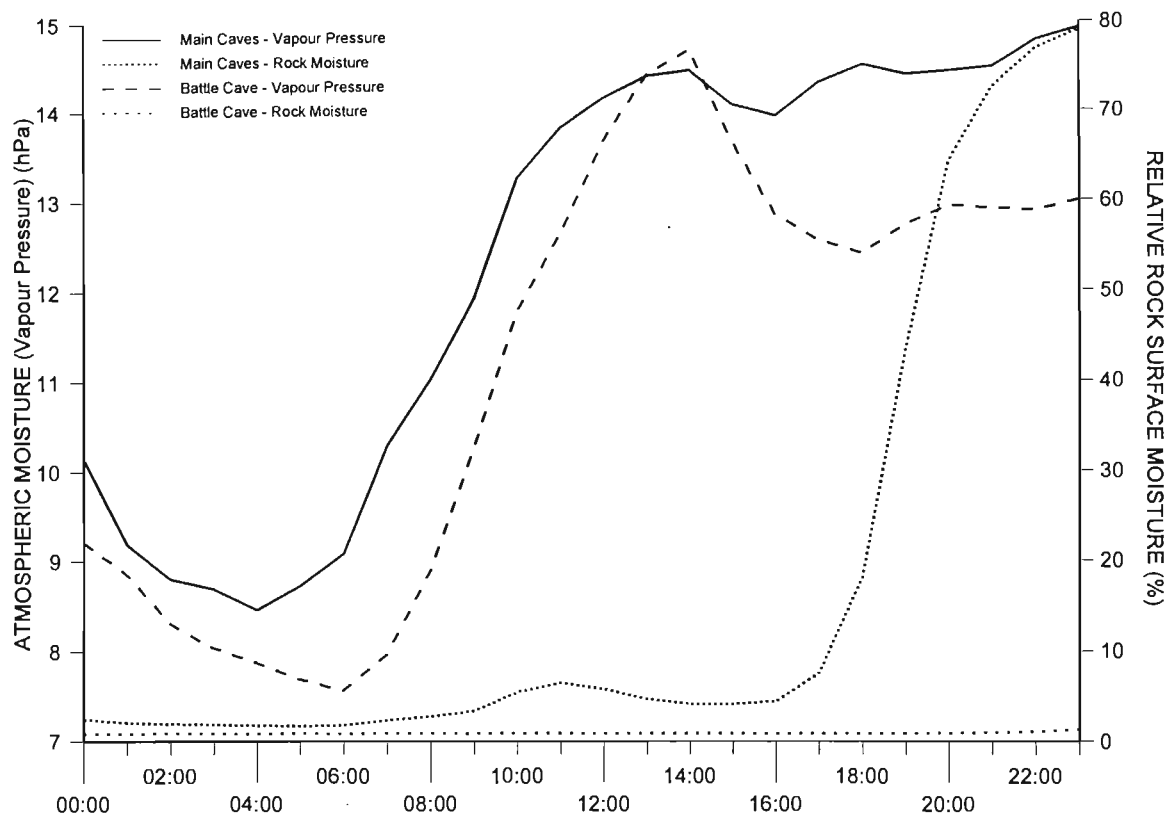


Figure 5.21: Atmospheric moisture and rock surface moisture contents for the north shelter of the Main Caves and for the Battle Cave study site on 10 October 1993.

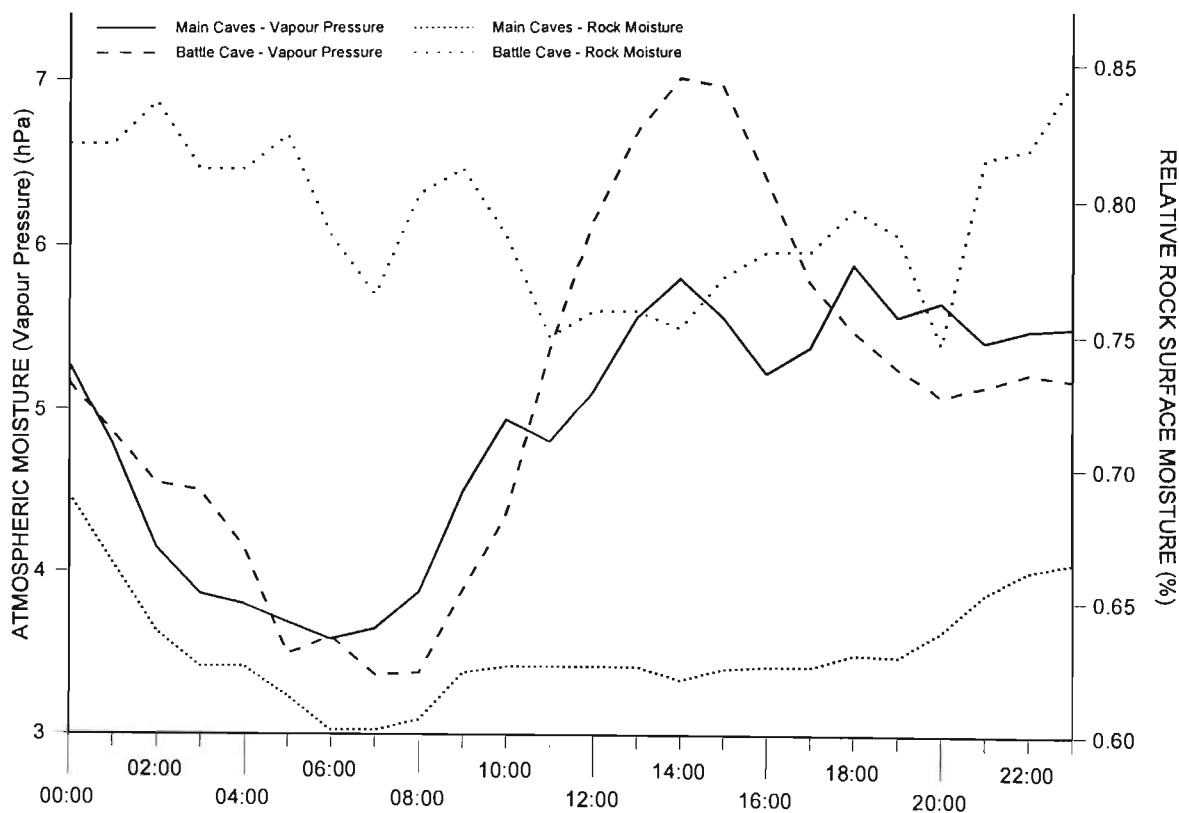


Figure 5.22: Atmospheric moisture and rock surface moisture contents for the north shelter of the Main Caves and for the Battle Cave study site on 1 July 1993.

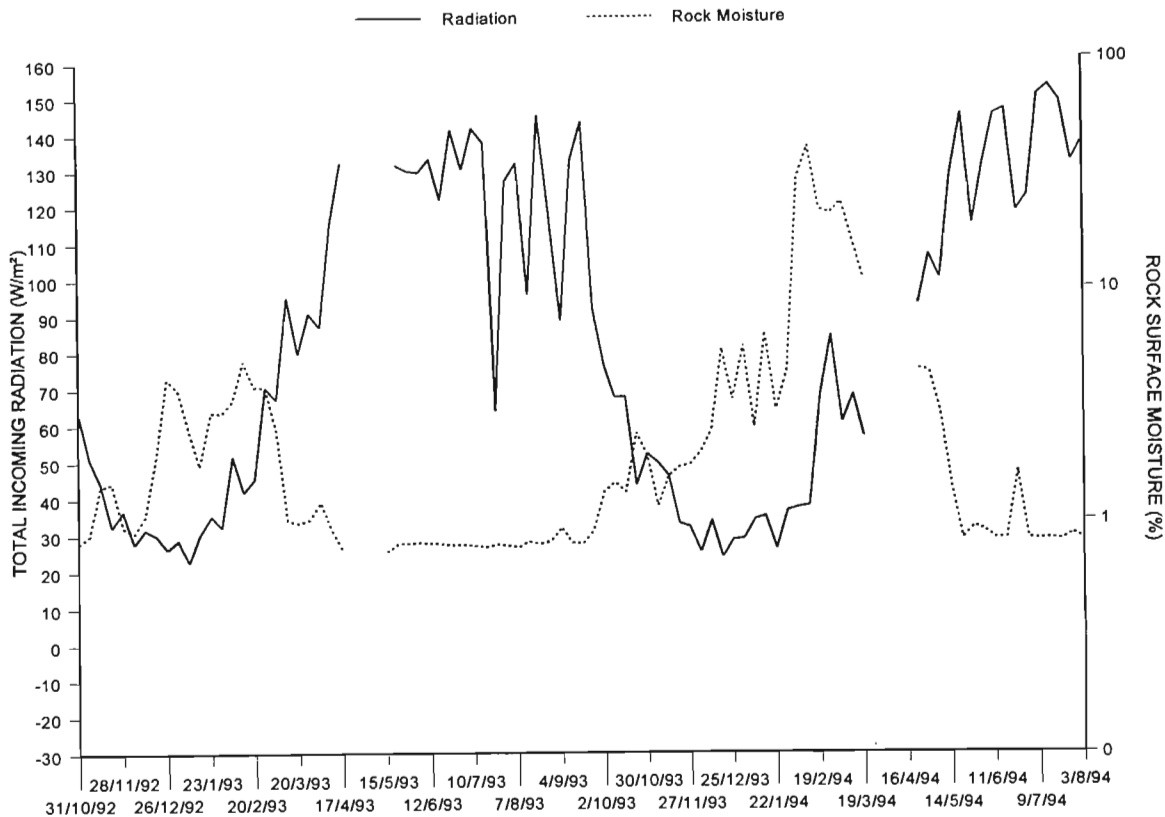


Figure 5.23: Weekly average incoming radiation and relative rock surface moisture for the Battle Cave Study site.

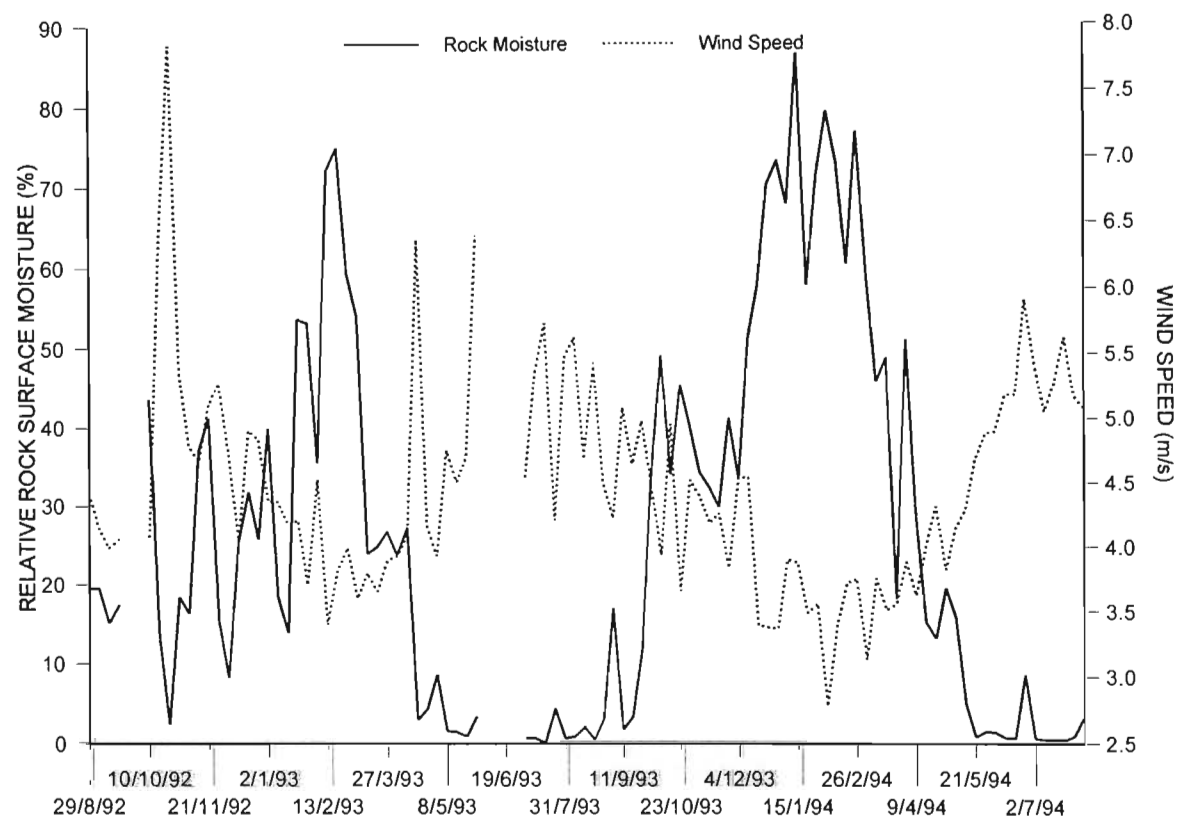


Figure 5.24: Average weekly rock surface moisture contents and wind speeds for the north shelter of the Main Caves study site.

the more moist environment of the Main Caves (see Fig. 5.18). The relatively small influence of radiation on rock moisture contents at the Main Caves may be due to the fact that only in winter is there any direct radiation on the rock surface. However, the high radiation receipts at the exposed and dry environment of Battle Cave, would cause evaporation of any rock moisture, thus explaining the difference in rock moisture content between the two sites.

While wind data from the Main Caves study site, in itself, provides little information which directly relates to the weathering of the Clarens Formation, it does show that the predominant wind direction was parallel to the rock face and down-valley. Thus, the wind could have indirectly affected rock weathering in that it would have aided evaporation at the rock surface thereby enhancing weathering processes associated with drying of rocks. Further, as the prominent wind direction is down valley, it is likely to be relatively dry, thereby increasing evaporation at the rock surface. There was an apparent inverse relationship between the weekly average wind speeds and rock surface moisture ($r = -0.75$) (Fig. 5.24), implying that winds do affect rock surface moisture and hence influence rock weathering processes. The same relationship was seen from hourly averages on 1 January 1994 (Fig. 5.25) and 1 April 1993 (Fig. 5.26), while the connection was not present on 1 July 1993 (Fig. 5.27), probably because the rock surface was relatively dry (relative rock surface moisture varied between 0.6% and 0.69%). Thus, it is apparent that wind does potentially affect weathering processes at the Main Caves study site by evaporating moisture from the rock surface. Similar data were not collected from Battle Cave and so the above relationships cannot be tested for that site. Given that Battle Cave is more exposed, it is likely to experience greater wind speeds than the Main Caves. Therefore, it is possible that wind may be responsible for more evaporation at the rock surface and, thereby contribute (together with radiation receipts, as discussed earlier) towards the lower rock surface moisture contents observed at Battle Cave.

It could be argued that the differences in mineralogy, rock properties and rock structure may explain the differences in weathering regimes between the two sites. However, at the Main Caves site there were large differences in relative rock surface moisture between a protected site and an exposed site which were of the same

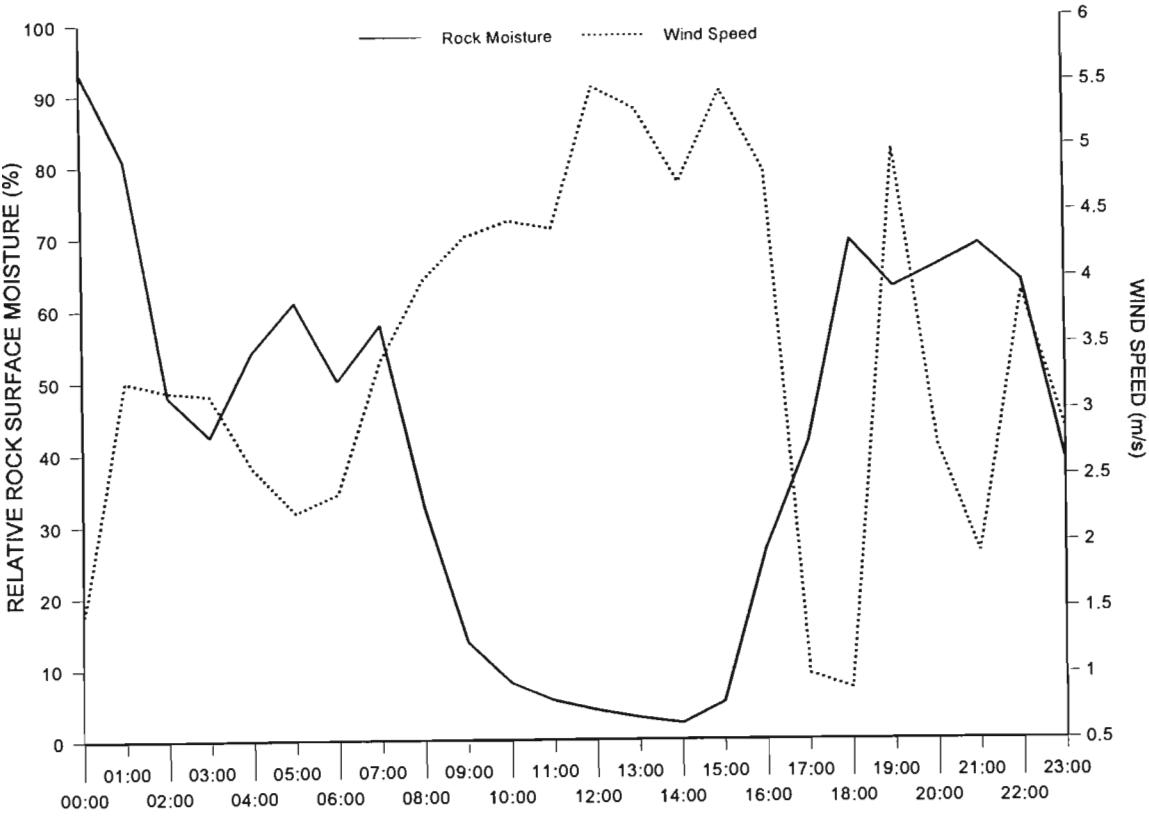


Figure 5.25: Average hourly rock surface moisture contents and wind speeds for the north shelter of the Main Caves study site on 1 January 1994.

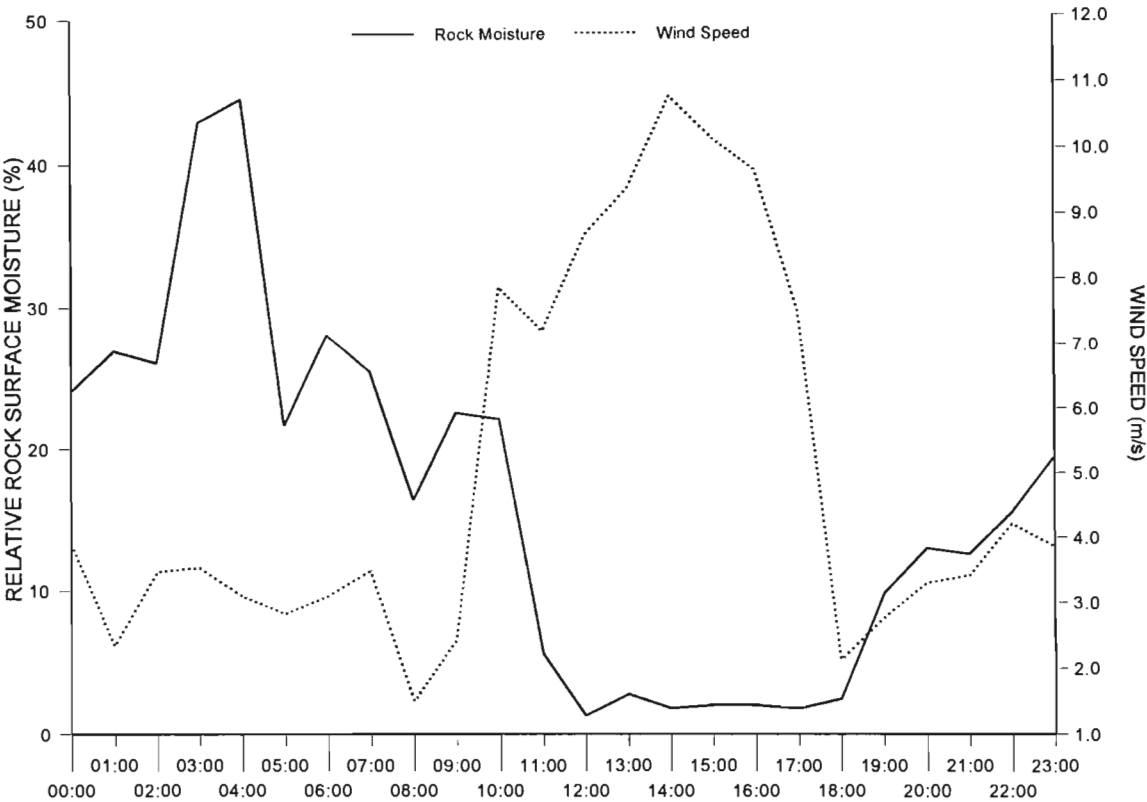


Figure 5.26: Average hourly rock surface moisture contents and wind speeds for the north shelter of the Main Caves study site on 1 April 1993.

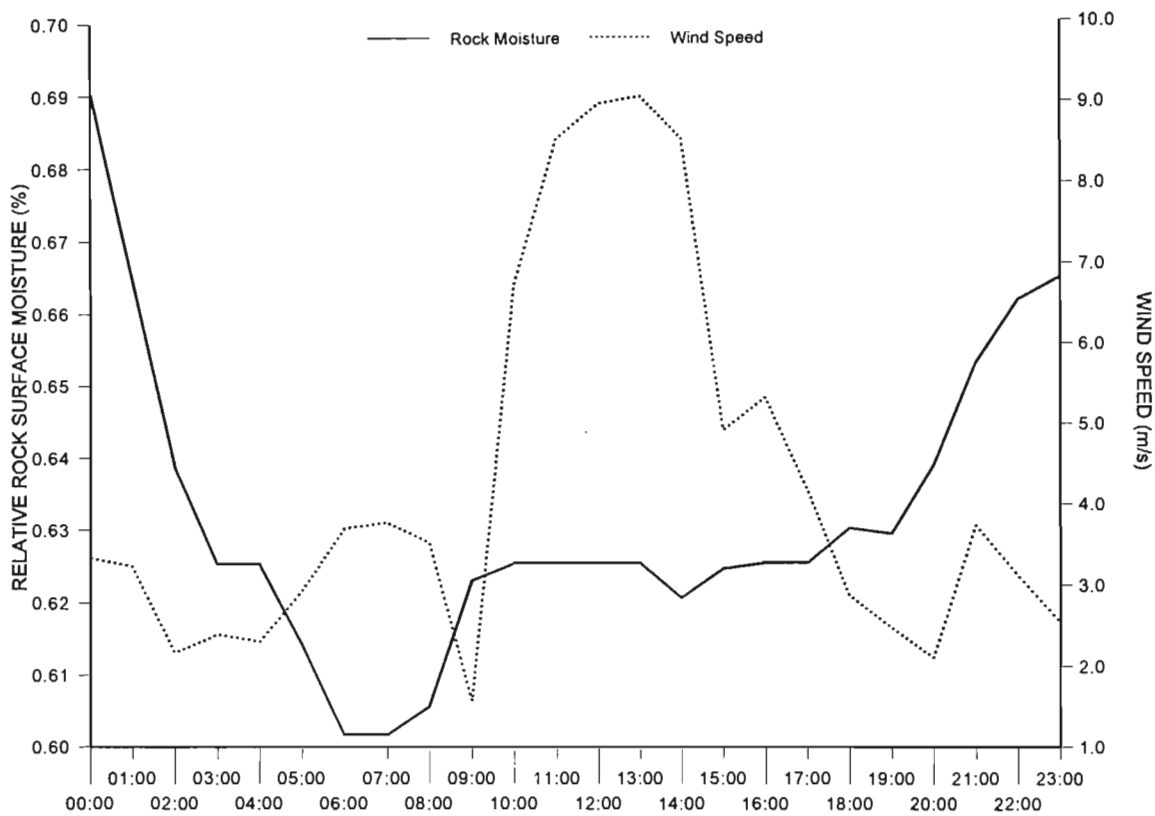


Figure 5.27: Average hourly rock surface moisture contents and wind speeds for the north shelter of the Main Caves study site on 1 July 1993.

lithology (Fig. 5.28). Both the amount of rock surface moisture, and its variability are greater beneath the rock shelter than at the exposed face, and this is when the atmospheric moisture contents for the two sites are almost identical (Fig. 5.28). A possible explanation for this above observed difference is that the increased radiation receipts, and a possible higher wind velocity, at the external face would cause moisture at the rock surface to evaporate. The problems encountered in changing rock masses to percentage saturation (see 4.2.1.1) and a lack of short term data, prevented the testing of differences in actual rock moisture content between the shelter and external face at the Main Caves.

When visually comparing the two study sites it appears that weathering processes are more active at the Main Caves than at Battle Cave. Similarly, rock weathering at both sites is more active underneath rock shelters than on the exposed rock faces. The deterioration of rock art at the Main Caves site appears to be largely due to rock weathering processes, while at Battle Cave, especially on the most exposed surfaces, much of the deterioration of Bushman paintings is due to the decay of the paint pigments themselves (Fig. 5.29). It is thus apparent that more rock weathering is taking place at the Main Caves site than at the Battle Cave site, which in itself may be a possible reason why the former site has a deeper overhang than the latter. In the discussion above (5.2), it was noted that the thermal regime in the shelters was less suitable for active weathering processes than those at exposed places. However, it can be seen that while the atmospheric moisture regimes are similar at the two study sites, the rock moisture contents and the changes in rock moisture content are greatest at the sheltered site, where rock weathering is apparently the most active. It can, thus, be argued that the differences in the weathering regime between the two study sites are a function of the differences in their rock moisture regimes. While Battle Cave is dry with little variation in rock moisture content, the Main Caves site is relatively moist and data show that the rock moisture content there is highly variable. It is, thus, probable that moisture related weathering processes are responsible for much of the deterioration of rock art in the KwaZulu/Natal Drakensberg.

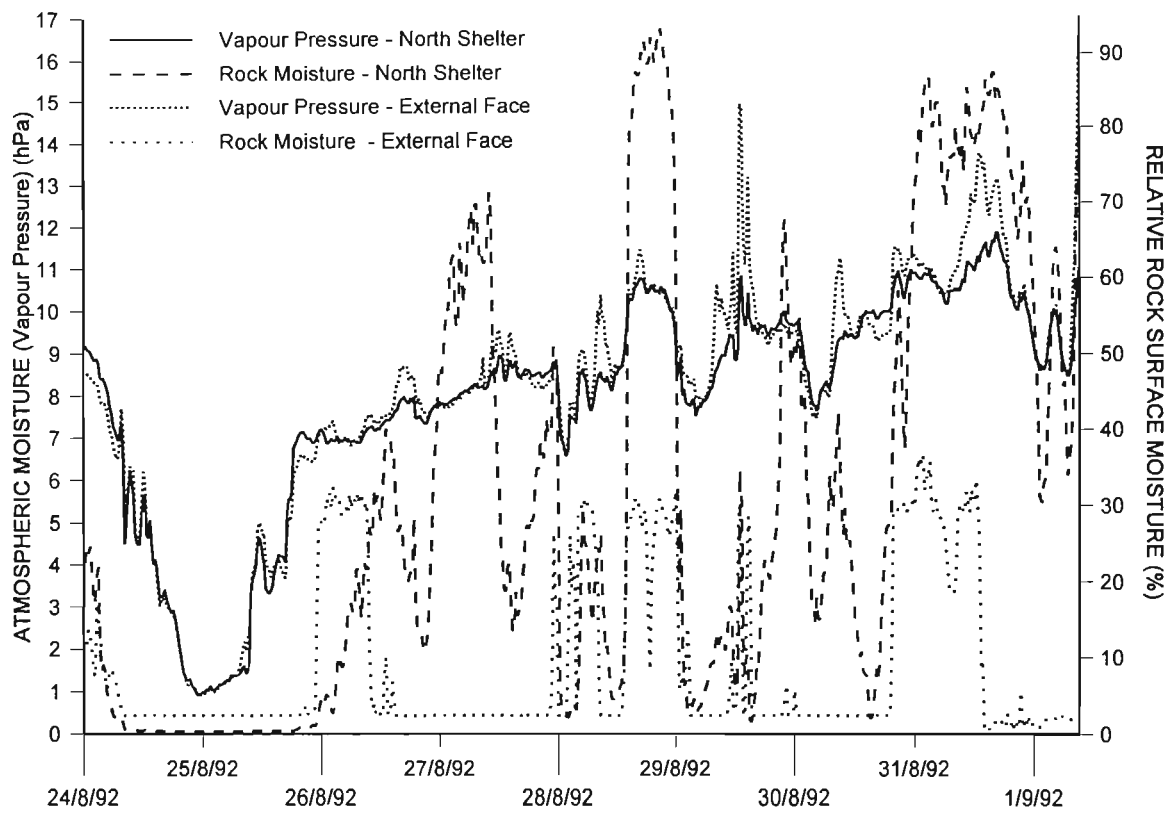


Figure 5.28: Hourly average atmospheric moisture and rock surface moisture contents for the Main Caves study site.



Figure 5.29: The deterioration of a Bushman painting of lion in the Battle Cave site as a result of pigment decay.

5.4. ROCK PROPERTIES AND MOISTURE MOVEMENT IN THE CLARENS FORMATION.

The observation of gypsum at the rock surface has lead writers to assume that moisture moves through the rock and precipitates salts at the rock surface (Avery, 1974; Batchelor, 1990; Lewis-Williams, 1990). It has even been suggested that the seepage of moisture may contribute to the formation of the sandstone shelters in which rock art is found (Pager, 1971) (Fig. 5.30), and that this moisture is responsible for the deterioration of much of the rock art (Avery, 1974; Batchelor, 1990; Lewis-Williams, 1990). A major reason for the movement of moisture through the rock is said to be the high porosity of the sandstone (Avery, 1974; Batchelor, 1990; Lewis-Williams, 1990). However, at the study sites the gypsum precipitates, which were identified using X-ray diffraction (see 4.2.2.3), are only located at joints and discontinuities in the rock walls, rather than at the surface of rocks (Fig. 5.31). In many cases rock art has been painted over gypsum precipitates (Fig. 5.31) and so the precipitation may not be contemporary. This may provide evidence for a wetter climate in the past when the drips were active.

It has been found that there is a relationship between the log values of permeability and porosity in sandstones (Pettijohn, et al., 1972; Pettijohn, 1975; Doyen, 1988). Therefore, some authors (e.g. Pager, 1971; Avery, 1974; Batchelor, 1990; Lewis-Williams, 1990) by proposing considerable moisture movement through the sandstone, imply that the rock is very porous. However, data regarding the porosity of Clarens Formation sandstone indicates that it may be less porous than is envisaged by the above authors (i.e. Pager, 1971; Avery, 1974; Batchelor, 1990; Lewis-Williams, 1990). The average porosity for samples from this study was 8.84% at the Main Caves while at Battle Cave the values were 5.73% for aeolian deposits and 10.12% for fluvial deposits. The porosities measured, ranged from 3.5% to 15.65% (see Tables 4.4 and 4.15). It must be considered that the porosity results obtained may be over-estimated (see Tables 4.3 and 4.14 and the discussion in section 4.2.2.1), and that the porosity of rock in the study site may actually be lower than the values obtained using Cooke's (1974) methodology. Studies elsewhere have shown the porosities of sandstones to be extremely variable and in many cases

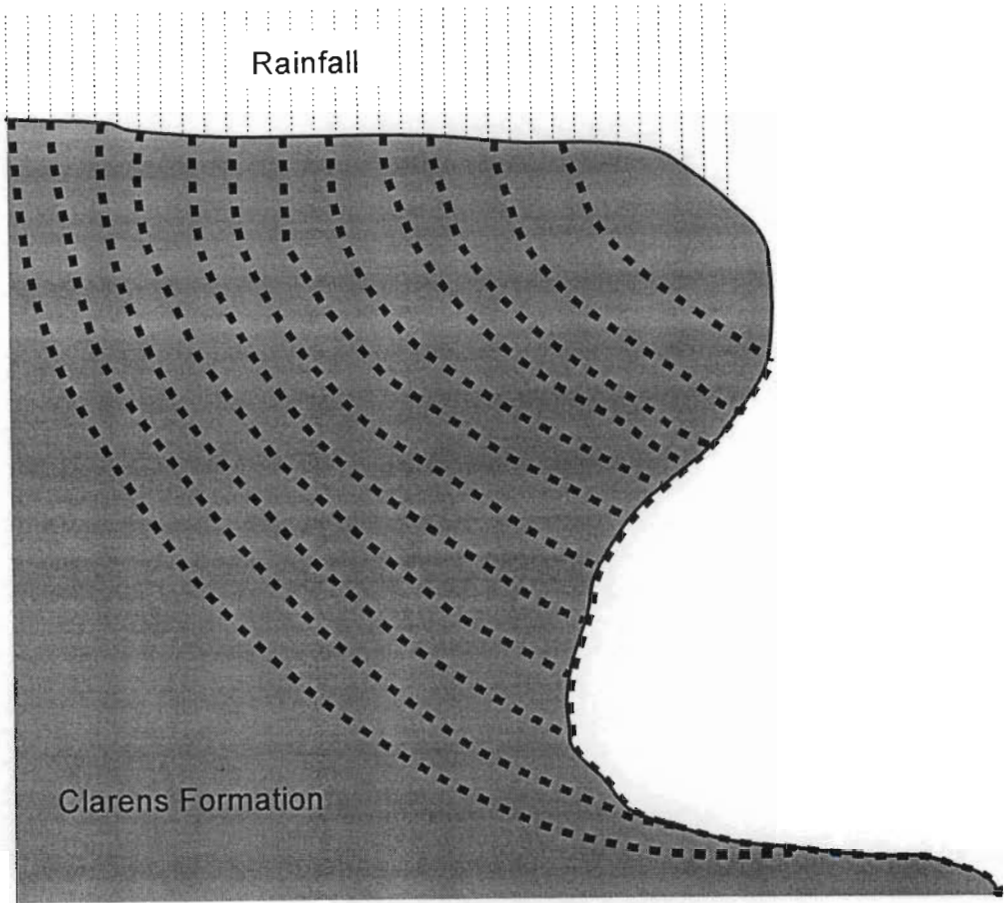


Figure 5.30: Payer's (1971) hypothesis for the movement of moisture through Clarens Formation sandstone (After Payer, 1971)



Figure 5.31: Gypsum precipitation at a joint in the rock wall in Battle Cave. Please note that this drip is no longer active and that some of the "Battle Scene" has been painted over the precipitate.

to be higher than those in the Clarens Formation (Table 5.1). It thus appears that the sandstone in the study area has relatively low porosities. Unweathered rock from the Clarens Formation will have even lower porosity values since nearly all the samples tested were already weathered. In order to get unweathered rock, it would have required the removal of considerable material, for which permission was not granted as the study was conducted in protected archaeological sites. In any case, the rock tested was chosen as it was thought to be representative of sandstone on which rock art was painted, and there are unlikely to be Bushman paintings on unweathered surfaces.

AUTHORS	SANDSTONE POROSITIES
Pettijohn (1975)	0% - 35%, average of 15%
Cooke (1979)	9.77% - 24.9%
Bell (1983)	1.8% - 25.7%
Lee <i>et al.</i> (1983)	10% - 20%
Ordaz and Esbert (1985)	11% - 29% (plus, 1 sample with porosity of 2%)
Meng (1992)	11.5% - 25.8%
Brandes and Stadlbauer (1992)	7% - 27%
This Study	3.5% - 15.65%, average of 8.6%

Table 5.1: Some porosity values for sandstones from available literature.

Data indicate that as the degree of weathering of a rock increases, so too does its porosity (see Table 4.4 and Fig. 4.43). Given that permeability and porosity are related, it can therefore be assumed that as a rock mass becomes weathered the movement of moisture through the sample is easier and greater. If weathering causes an increase in water movement through the sample, this could result in further weathering, thus causing an increase in the rate of rock breakdown. At Battle Cave the aeolian deposits are less porous than the sediments at the Main Cave and it is consequently more difficult for moisture to move through the rock at the former site.

Microporosity values provide further evidence for the argument against moisture movement through the back walls of rock shelters. The average microporosity for samples from the study sites, measured using Cooke's (1979) methodology, is in excess of 80%, (see Tables 4.4 and 4.15). Rock samples tested using mercury porosimetry, had microporosities in excess of 90% (see Figs 4.42 and 4.68), apart from one highly weathered sample from the Main Caves study site (please note that

for these samples, Bousquie's (1979) definition of microporosity was used; that is those pores with a radius smaller than $1\mu\text{m}$. In fact, apart from the aforementioned single highly weathered sample, over 80% of pores in samples from both study sites were smaller than $0.1\mu\text{m}$. Given the transport regime proposed by Meng (1992) (Fig. 5.32), it is likely that there is little, or no, capillary movement of moisture in the Clarens Formation. Further, little moisture is likely to move through the pores of the rock as the pore size range of the samples analysed for this study are at the limits for this mode of movement (Meng, 1992) (Fig. 5.32). The movement of moisture in Clarens Formation sandstone is, thus, likely to be a complex of adsorption and absorption processes as well as gaseous and surface diffusion. However, the precise modes of moisture movement will depend on the pore architecture (Meng, 1992). Pores can be divided into coarse, medium and fine fractions (Fig. 5.33), and their interconnectivity will determine the mode of moisture movement (Meng, 1992). Although no precise modes of moisture movement are deduced, the indications are that in the Clarens Formation moisture does not move at the same rate and in the same manner as has previously been proposed (e.g. Pager, 1971; Avery, 1974; Batchelor, 1990; Lewis-Williams, 1990). However, while it can be said that moisture does not move through the Clarens formation as much as previously thought, moisture movement does still take place. It is possible that the seasonal changes in rock moisture content are due to the movement of moisture along discontinuities which will, given sufficient time, be able to move into the rock, through sorption processes and diffusion.

Data show that the microporosity of the Clarens Formation may be related to the amount of weathering a sample has undergone. Sample 1, which was the most weathered sample tested using mercury porosimetry, had the lowest microporosity, while the least weathered sample, sample 4, had the highest microporosity. Trends in pore size distribution of samples indicate that the average pore radius increases with the amount of weathering (see Fig. 4.43). Further, it can be seen in Figure 4.43, that as the amount of weathering increases, no new pores with small radii are formed. It thus appears that, in the process of a rock weathering in the Clarens Formation, existing pores are enlarged rather than new ones being formed. As the pores get enlarged, so moisture movement is enhanced.

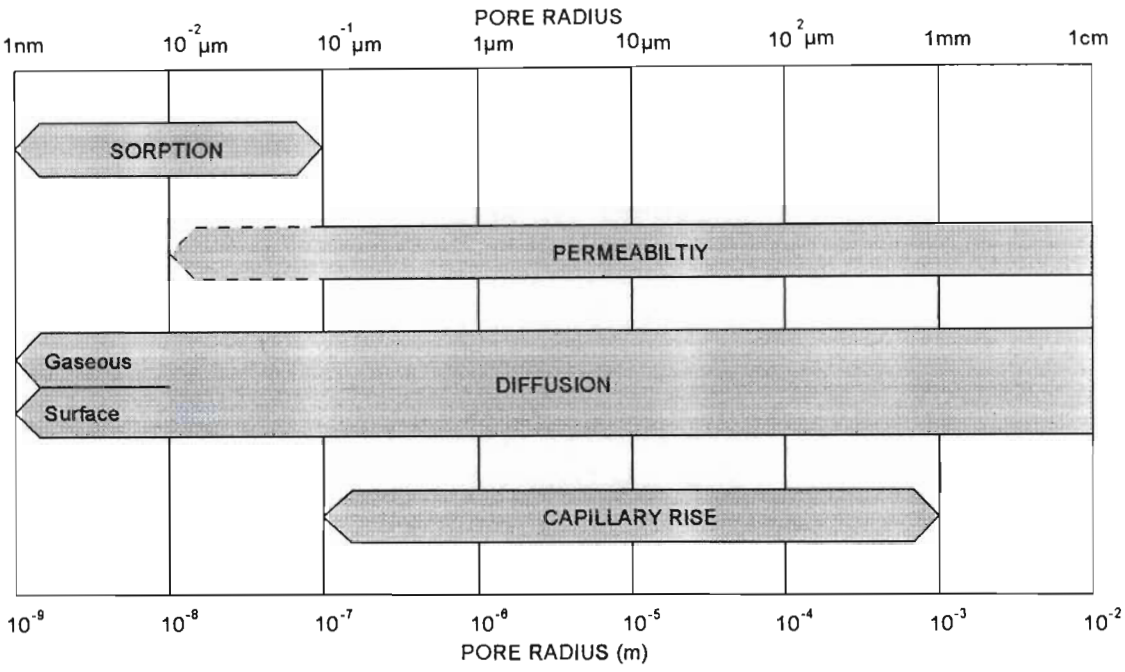


Figure 5.32: Diagram showing the relationship between the mode of moisture movement in a rock and pore size (after Meng, 1992).

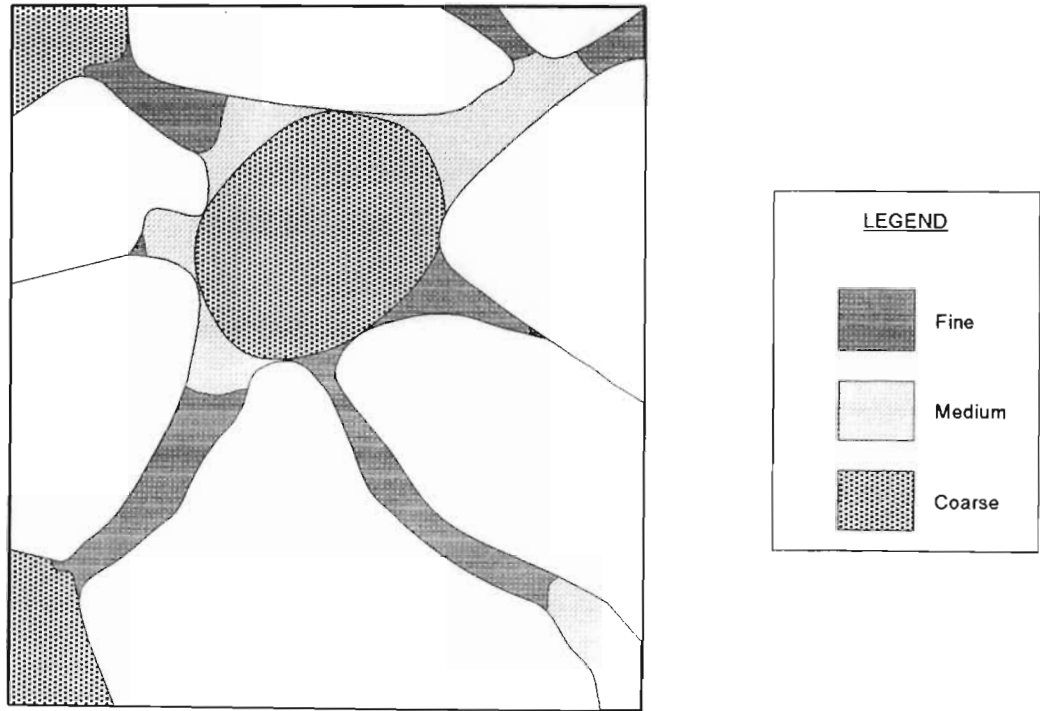


Figure 5.33: Definition of pore fractions (after Meng, 1992).

A further trend observed in this study is that microporosity has an inverse relationship to porosity; the correlation coefficient for this relationship is -0.42 (Fig. 5.34). This observation supports the above argument that existing pores are enlarged by weathering. In other words, the porosity of the Clarens Formation in the KwaZulu/Natal Drakensberg is increased by an enlargement of the existing pores during the process of weathering. Further, mercury porosimetry showed that the sample with the lowest porosity, from Battle Cave, has the greatest microporosity, and that of the samples from the Main Caves the one with the lowest porosity had the greatest microporosity (see Figures 4.42 and 4.68).

While the data collected for this study show that moisture movement has been overestimated in the past, the values for saturation coefficients and water absorption capacities do, nevertheless, imply that the Clarens Formation sandstone has the ability to absorb moisture. There is a strong relationship between the water absorption capacity and porosity ($r = +0.98$) (Fig. 5.35), while a correlation coefficient of $+0.11$ implies that there is a minimal relationship between porosity and saturation coefficient for rocks from the study area. Further, it has also been shown that rock moisture content has a strong relationship with atmospheric humidity (see Figures 5.15 and 5.16) such that changes in atmospheric humidity are accompanied by rapid changes in rock moisture content. It is unlikely that the rapid changes in rock moisture content recorded in this study result from moisture moving through the rock. Therefore, the moisture changes observed (Fig. 5.15, 5.16), must take place at or near the rock surface. It is highly probable that the most weathered rock, and the largest pores are found near the rock surface. In its turn this would facilitate moisture sorption, diffusion and transport taking place in the outer shell of the rock. Weathering processes that depend on moisture and changes in moisture are, thus, likely to take place at, or very close to the rock surface.

It has been argued above, that moisture regimes at the study sites are potentially the most important controls of rock weathering. Apart from at and near the rock surface, the most suitable sites for rock weathering are likely to be along discontinuities in the rock, such as joints and bedding planes, where moisture movement (in gaseous or

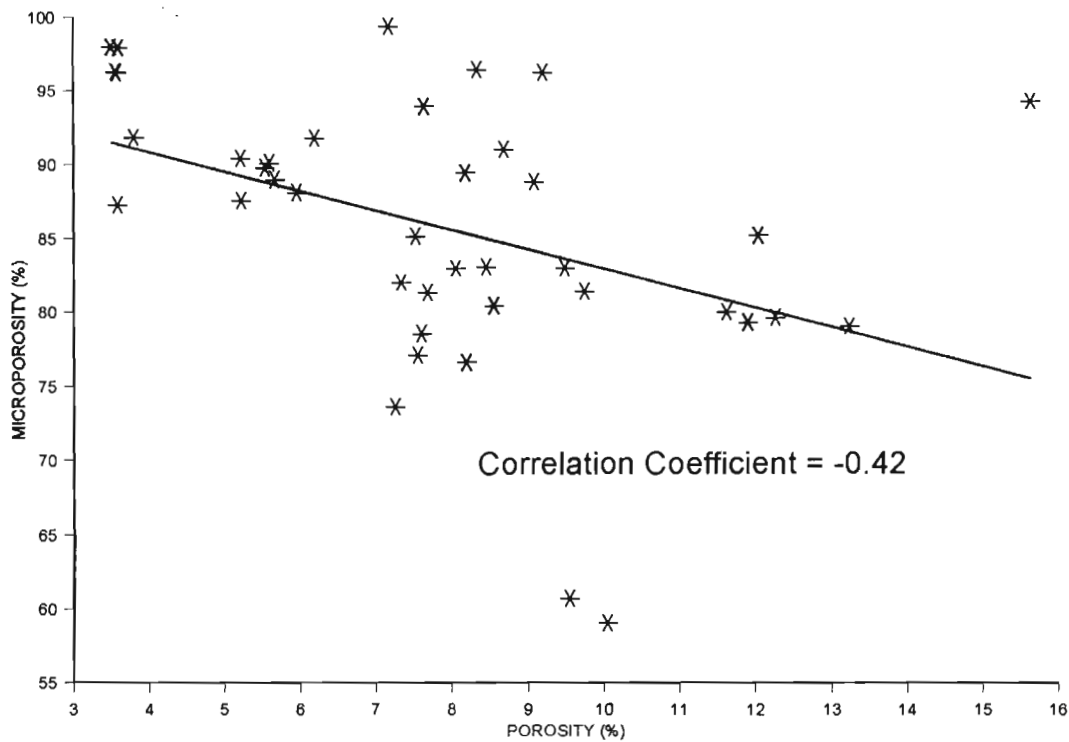


Figure 5.34: The relationship between porosity and microporosity for samples from the Main Caves and Battle Cave.

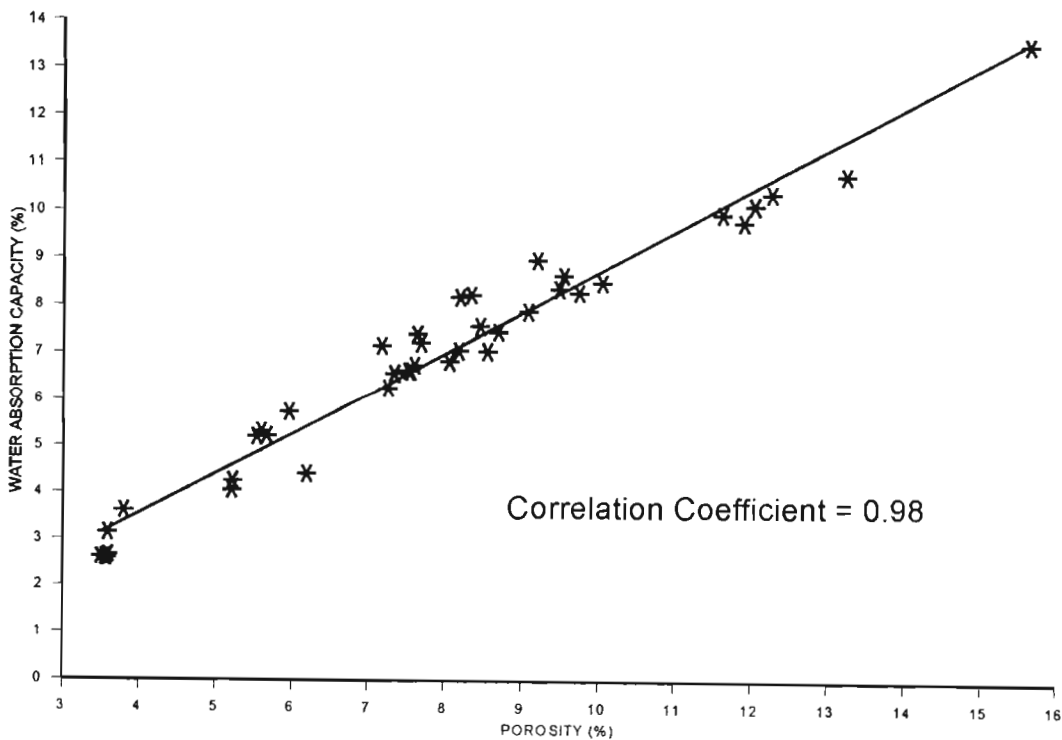


Figure 5.35: The relationship between porosity and water absorption capacity for samples from the Main Caves and Battle Cave.

liquid form) is facilitated. At the Main Caves study site, it can be seen that bedding planes have been exploited by weathering processes and that these discontinuities are sites of enhanced deterioration of Bushman Paintings (Fig. 5.36). Further support for the aforementioned argument is that many of the bedding planes (Fig. 5.37) and joints have gypsum deposits which are likely to result from weathering processes. As argued above, there are few places where gypsum deposition is contemporary; these precipitates thus provide support for a more moist climate in the past. There is, a substantial literature available which suggests that the climate might have been wetter earlier in the Holocene (e.g. Partridge, *et al.* 1990; February, 1994; Hanvey and Marker, 1994).

The effect of discontinuities on weathering is seen in the data relating to the mass lost by the samples which were monitored for rock moisture contents at the Main Caves. The total length of edges was recorded and there was an apparent relationship between the total edge length and the mass lost (Fig. 5.38). In other studies (e.g. Robinson and Williams, 1982) it has been found that the total edge length was a more significant control on rock weathering than the total surface area or the orientation of bedding planes. Edges provide contact with the environment on more than one aspect, and can therefore facilitate multiple rock weathering processes.

The data relating to rock moisture and rock moisture movement at the study sites, provide evidence for two temporal regimes. First a seasonal regime, where summers are more moist than winters and where changes are relatively slow. In this regime changes to the rock moisture which extend below the rock surface are likely to occur. The second temporal scale involves the rapid changes of rock moisture which can occur over a period of a minute or less. However, it is the short-term changes which occur at or near the rock surface, which are likely to be most damaging to rock art, as they affect the paintings themselves as well as the contact between the paint pigments and the rock.



Figure 5.36: Bushman paintings in the north shelter of the Main Caves site, showing enhanced weathering along planar bedding planes.



Figure 5.37: Gypsum deposits along joints in the east shelter of the Main Caves site. A rock has fallen away from this position leaving a thick gypsum precipitate. The precipitation occurred prior to the rock falling away.

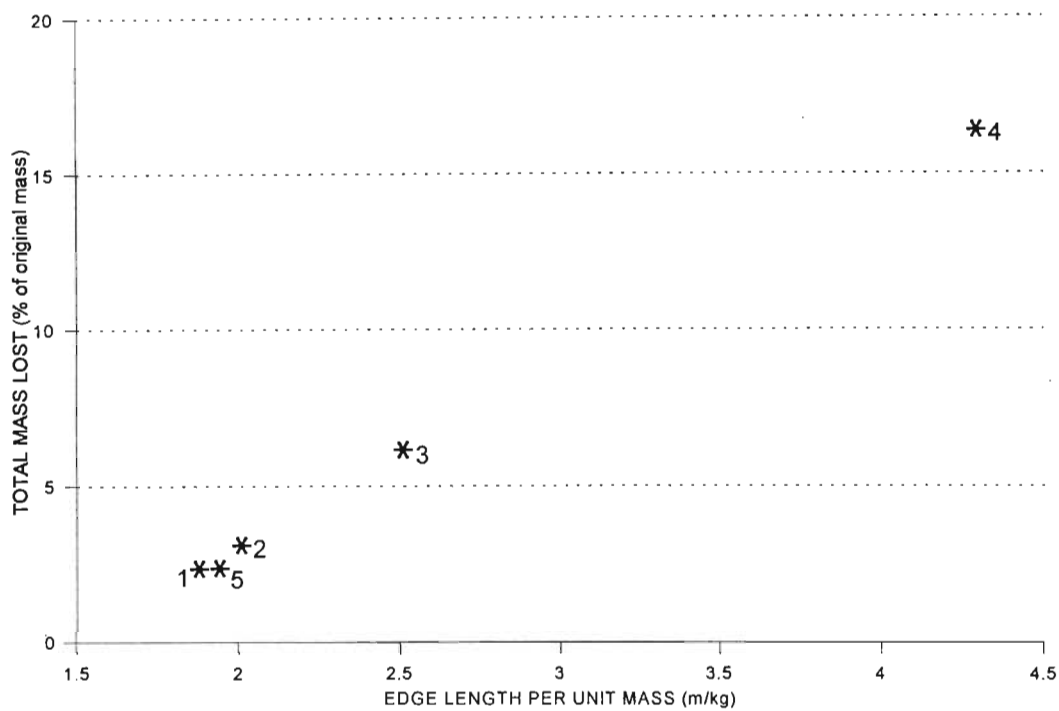


Figure 5.38: Graph showing a ratio of total edge length to unit mass against the percentage of total mass lost for the five samples used in rock moisture conten monitoring at the Main Caves study site.

5.5. ROCK STRENGTH

Rebound tests using a Schmidt Hammer provide a relative measure of the hardness and, therefore, given that the tests are conducted on the same lithology, the amount of weathering a rock has undergone (Day and Goudie, 1977; Day, 1980; Williams and Robinson, 1983; Mathews and Shakesby, 1984; Robinson and Williams, 1987; Ballantyne, *et al.*, 1989; Augustinus, 1991, 1992; Campbell, 1991; Sjöberg and Broadbent, 1991; Hall, 1993b). The Schmidt Hammer readings from both study sites show that fallen rock has lower rebound values than that from the back walls (Fig. 5.39). This implies that fallen material is more weathered than that from the back wall, which is logical on two accounts: first, the fallen material originated from the back wall, and has hence been exposed to the external weathering environment for longer than the back walls. Second, the fallen material has a greater surface area per unit volume exposed to the external environment than the back wall and it will, thus, break down more rapidly. Back walls and fallen material from the two shelters at the Main Caves have Schmidt Hammer rebound values which were from the same statistical population. Given that both shelters are well protected, they are likely to experience similar weathering environments even though they have different aspects. Further, the fact that the two shelters at the Main Caves are lithologically identical and have comparable microclimates, it is unlikely that the weathering patterns in the two shelters will differ to any great extent.

The outside back wall at the Main Caves study site had the highest rebound values (Fig. 5.39), which supports the visual perception that the rock faces outside the shelters are less weathered than those in the shelters. No rebound measurements were taken for the external faces at Battle Cave, but it is assumed that the rebound tests there would be higher than those in the shelter at this site for the same reasons as noted above. The fact that the shelters are places where undercutting of the cliff faces has occurred, means that they are likely to be situations where weathering is favoured and it is thus logical that the rock there would be softer than on the cliffs themselves. It must be noted that there is no literature available on the formation of caves/shelters in the Clarens Formation of the KwaZulu/Natal Drakensberg, and that the above observation does not provide a solution to this problem.

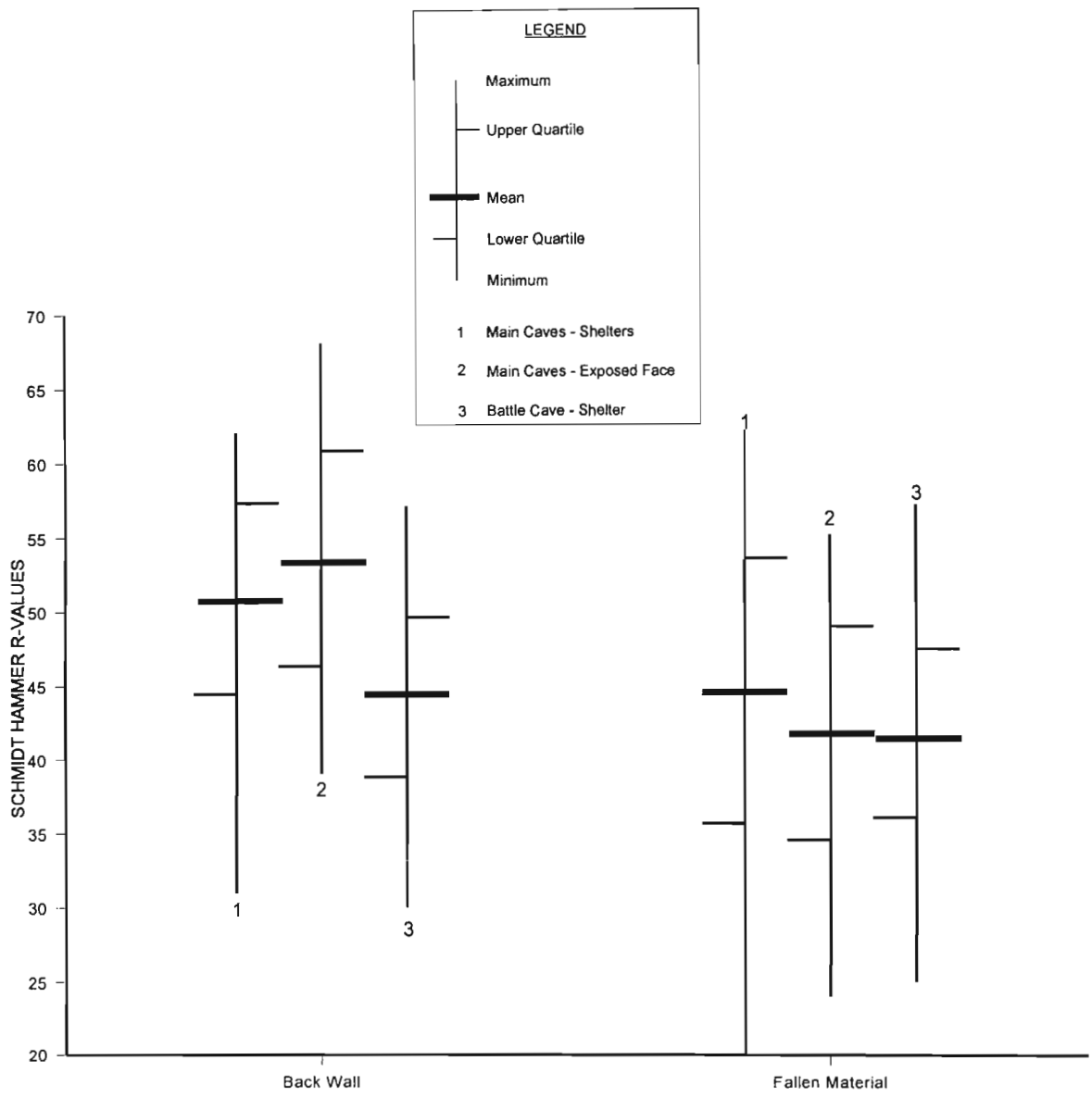


Figure 5.39: Summary of Schmidt Hammer rebound data for the Main Caves and Battle Cave study sites.

An apparent contradiction to earlier statements to the effect that weathering causing the deterioration of rock art is less prevalent at Battle Cave than at the Main Caves, is the fact that rebound values are lower at the former site (Fig. 5.39). It must be noted that there are slight differences in mineralogy and structure between the Battle Cave and Main Cave study sites, as they are from different lithofacies, and that these variations might be the cause of the difference in rebound values, rather than the rock being less weathered at Battle Cave. It should be noted that the rebound values will only be useful as a comparative technique for rock of the same lithofacies, and comparisons between the two study sites are therefore limited in their use.

A further observation, which was discussed earlier (see section 4.2.1.1.3), is that the rebound values are lowest on fallen material outside the shelters at the Main Caves study site. The rocks at this location are covered by biological growth, in the form of lichen, and no clean surfaces were available for testing. It is not clear whether the rock here was actually more weathered than elsewhere or whether the lichen influenced the readings. Further, the testing was not random, as it was necessary to find places where lichen growth was at a minimum, and some sort of selection was thus used.

The strength of sandstones is influenced by a number of factors, including, porosity, the composition of individual grains and the amount and type of cement and matrix material (Bell, 1983). Of the above factors, porosity has been found to exhibit a roughly linear relationship with dry compressive strength for sandstones which have porosities in excess of 6%, such that, for every 1% increase in porosity there is a 4% decrease in compressive strength (Price, 1960, 1963;). For sandstones with a porosity of less than 3.5%, strength is controlled by quartz content and degree of compaction (Price, 1960, 1963; Bell, 1983). Between 3.5% and 6%, a complex of factors influences rock strength (Price, 1960, 1963; Bell, 1983). The total pore volume and pore sizes also affect the tensile strength of rocks; in general, the greater the total pore volume and/or the pore size, the lower is the tensile strength of the rock (Tamura and Suzuki, 1984; Yatsu, 1988).

In the Clarens Formation, as the rock becomes more weathered so porosity increases and, especially in the case of the more weathered samples, where porosity exceeds 6%, a decrease in compressive strength results. A further effect of porosity on rock strength is the fact, discussed above, that saturation of a rock's pores may cause up to a 60% decrease in dry compressive strength (Bell 1983). The more porous a sample in this study, the more it was able to absorb moisture and thus the greater its potential for weakening.

The existence of crusts was another influence on the ability of rock art to withstand weathering processes. Patinas were found at both study sites, those at the Main Caves being predominantly silica, while those at Battle Cave were iron oxide and silica. Only at the Main Caves was it possible to test the comparative hardness of patinated and non-patinated rock. It was found that the rock surfaces with silica coatings had greater rebound values than those without (Table 5.2).

	PATINATED ROCK	NON-PATINATED ROCK
SAMPLE SIZE	75	162
AVERAGE	57.6	44.5
STANDARD DEVIATION	5.1	8.9
MAXIMUM	67	62
MINIMUM	42	42

Table 5.2: Schmidt Hammer rebound values for patinated and non-patinated rock at the Main Caves study site.

While it can be seen that patinated rock is harder than non-patinated rock, it was observed that many rocks with silica coatings in both shelters of the Main Caves showed signs of enhanced sub-surface weathering and that thin pieces of rock would often detach from the rest of the rock and fall to the ground. The same subsurface weathering was not observed under the iron oxide crusts at Battle Cave, but the surfaces of the rocks were discoloured. Although surface crusts may protect the rock surface and strengthen the surface of a rock, it is possible that they may not ultimately protect rock art.

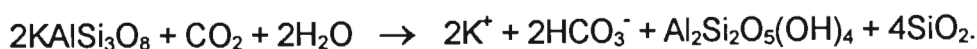
5.6. CHEMICAL ANALYSES

The chemical composition of a rock constitutes a major influence not only on chemical weathering, but also on mechanical weathering (Ollier, 1984; Yatsu, 1988). Samples of rock from both study sites were analysed to determine their chemical and mineral compositions. Further, water samples from the Main Caves were analysed to determine their chemical composition. The following discussion regarding the identification and source of elements and minerals, refers to results presented in sections 4.2.2 and 4.3.2 and, draws on several references, namely: Curtis (1976a, 1976b), Ollier (1984), Blythe and de Freitas (1984), Whitten and Brooks (1985), Yatsu (1988) and Young and Young (1992). In samples from both study sites silicon was the most common element, in concentrations varying from 73.3% to 78.93%. The silica was derived from quartz and feldspar which were the most common minerals identified. Aluminium concentrations were second highest, presumably also derived from the aluminosilicates that constitute the feldspars. Sodium is found in feldspars, while potassium is derived from both the feldspars and the micas. Calcium's presence is probably due to plagioclase feldspars and calcite.

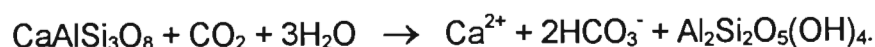
At the Main Caves no calcite was detected using X-ray diffraction as it is probably only found in very small concentrations as a cement. A certain amount of the calcium will be a constituent of gypsum, which, although it was not identified in the X-ray diffraction analysis with other samples, it was identified as a precipitate in bedding planes at both sites. At Battle Cave, however, calcite constituted 10% of the mass of the samples collected, and this explains the relatively high concentration (4.31%) recorded at that site. Magnesium is likely to be a constituent of the mica, while most of the iron will be from haematite and the titanium from anatase.

The kaolin, which is made up primarily of kaolinite, is likely to be derived from the weathering of feldspar by the action of water and carbon (IV) oxide (Curtis, 1976a; Blythe and de Freitas, 1984). The presence of kaolinite is in itself important in that it will shrink and swell with changes in moisture (Ollier, 1984). The following examples of the formation of kaolinite are the breakdown of feldspars that are likely to be present in the Clarens Formation:

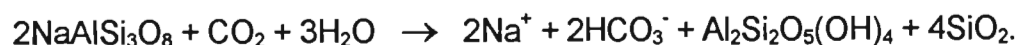
1) the breakdown of orthoclase (Blythe and de Freitas, 1984):



2) the breakdown of a calcium plagioclase (Curtis, 1976):



3) the breakdown of a sodium plagioclase (Curtis, 1976):



The general decrease in feldspar concentrations, and corresponding increase in quartz concentrations, from the least weathered sample to the most weathered sample at the Main Caves study site is likely to be due to the breakdown of feldspars into simpler aluminosilicates and quartz. As these chemical reactions require water, and produce soluble cations such as calcium, sodium and potassium, there will be a removal of solutes away from the reaction site if the moisture is mobile. If so, this would explain the decrease in concentration of many elements, such as iron, magnesium, sodium and potassium amongst others, that was found to occur with an increase in weathering. If evaporation of moisture follows, then the solutes will precipitate out as salts. This precipitation will result in crystallisation pressures and potential breakdown of the rock if it occurs beneath the rock surface. Calcium compounds are less soluble than compounds formed by other ions released in the above reactions (e.g. Na^+ , K^+ and Mg^{2+}) (Curtis, 1976b, Aylward and Findlay, 1978), and hence precipitate out more readily. If the above chemical processes are ongoing there would be an accumulation of calcium, as shown by the observed increase in concentration. The higher concentration of calcium at Battle Cave is primarily due to the relatively high concentration of available calcite (10%).

Analysis of soluble cations shows a general increase in the concentrations of most ions from the least weathered to the most weathered sample. This must not be confused with the observations discussed above where concentrations of elements, apart from calcium, decreased with increased weathering. The cation analysis only considers soluble material, whereas the analysis of elements considers insoluble

material as well. The increase in concentration of ions is probably due to the fact that not all the products of weathering have been removed and so some are still interstitial. As the amount of weathering increases there is likely to be an accumulation of chemical products, and hence the recorded higher concentrations.

The most noticeable increase in anion concentration with increased weathering was calcium, and that was most probably because some calcium compounds are less soluble than those of the other cations analysed (Curtis, 1976b, Aylward and Findlay, 1978) and, therefore, less likely to be removed in solution. A further source of soluble calcium is calcite, which is a cement in the Clarens Formation at the Main Caves and Battle Cave (Eriksson, 1983), and which is present as a mineral in samples from Battle Cave. This calcite is readily weathered under acidic conditions and this helps to explain the abundance of calcium ions, especially at the Main Caves. The weathering of calcite is described by Curtis,(1976) in the equation: $\text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^-$.

The lower concentrations of all soluble cations in rock from Battle Cave support the argument that weathering, in this case chemical weathering, rates are lower at the Battle Cave site. Despite the higher concentrations of calcite in the samples examined there is less soluble calcium. A possible reason is that the chemical weathering of the Clarens Formation requires moisture and because Battle Cave is a relatively dry site there is not sufficient moisture available for the reactions to take place. Where moisture is present at Battle Cave, along joints and bedding planes, precipitates of gypsum are observed (Fig. 5.31), probably originating from the dissolution of calcite which is a major constituent of the rock there. However, as argued previously, much of this deposition is not contemporary, which supports the argument for a wetter climate in the past. On the other hand, the more moist microclimate at the Main Caves site is more suited to moisture related weathering processes, and chemical weathering processes are likely to be more active there than at Battle Cave.

There is no clear indication of the source of many of the soluble anions identified at any of the study sites. Chlorides were found in relatively high concentrations, while nitrates were also in high concentrations at the Main Caves, but were absent from Battle Cave. Sulphates were identified in relatively low concentrations at both study sites. It must be assumed that some of these anions are derived from the minerals present in the rock. It is possible that some anions are extraneous in their origin, and are derived from atmospheric sources, by dry deposition on the rock surface and gaseous diffusion, especially in the case of the sulphates. In addition moisture movement through the rock would also affect this and it is possible that the chlorides and nitrates are derived from that moisture. The data regarding the analysis drip-water cations shows that the same cations as found in the rock prevail. This could either be the source of the anions, as proposed above, or it could be part of the transport mechanism involved in removing solutes from the rock. Porosity data do, however, imply that moisture movement through the rock is limited, but as stated above it cannot be excluded on a seasonal basis. As with cation concentrations, anion concentrations at Battle Cave are relatively low, again an indication of less weathering than at the Main Caves site.

Data regarding the concentration of cations in drip-water samples show that the most prevalent species are silicon, calcium and magnesium ions. The relatively high concentrations of silicon ions is probably facilitated by the relatively high pH of the drip-water when compared to the rain water. Given the high concentrations of soluble sodium and potassium ions in the rock it is surprising that neither of these cations is found in the drip-water samples. It is possible that most of these ions have already been removed from the rock which is in close proximity to the drips. Alternatively it is possible that little interstitial material from the rocks is contained in the drip-water and that the solutes contained therein are from extraneous origins. Further support for the argument that the solutes in the soils are from external origins is the fact that silica ion concentrations are higher in the drip-water than they are in soluble material from the rock.

The trends that are evident in concentrations of solutes (cations and anions) are probably a function of the flow regime of the drips as was discussed earlier (4.2.2). At

the beginning and end of the wet season and at other times when the flow level of the drip is low, the concentration of solutes in the drip is likely to be high. High solute concentrations are reflected by high electrical conductivity values, although the trend is not very clear. Alternatively, during periods of high flow, the solutes will be diluted and therefore the concentrations lower. It was not possible to determine the flow regime of the drips and neither are there any evident relationships between the solute concentrations and other climatic variables monitored. Solute concentrations in the rain water were too low for either cation or anion determination. It is, however, clear that some form of chemical change does take place in that increased pH values and solute concentrations indicate that the rain water takes up solutes either from the soil or from the rock as it passes through it.

It is evident that chemical weathering is an important cause of the breakdown of Clarens Formation sandstones in the KwaZulu/Natal Drakensberg. The increased moisture supply at the Main Caves study site provides an environment which is more suited to chemical weathering than the relatively dry Battle Cave. However, there is evidence that chemical weathering was more active in the past, under a more moist climate. The major chemical processes at the study site involve the breakdown of feldspars into simpler aluminosilicates and quartz together with soluble alkali and alkali earth ions. Further chemical alterations, which would have been more active in the past, involve the reaction of calcite with acidic moisture to produce gypsum. The breakdown of calcite would mainly be active at Battle Cave but may also be operative at the Main Caves site in breaking down the calcite cement.

5.7. SIMULATIONS

Much of the discussion regarding the significance of the thermal regime investigated in simulations has already been considered (see 5.1.). The most important observation was that the effect of radiation and air temperature changes diminishes with depth below the surface of the rock and that the greatest thermal gradients are near the rock surface. Considering that temperature has an effect on a whole range of weathering processes it is likely that a whole range of mechanisms will be active near the rock surface. Further, as was discussed earlier, thermal pulses are

transmitted through the rock, and it is conceivable that certain parts of the rock might be warming, while others may be cooling, thus invoking different weathering processes which may be active in close proximity to each other and also causing thermal stress fatigue. The resulting stresses may contribute to the breakdown of the rock.

Although the tests conducted to determine the effect of differing moisture regimes on the weathering of sandstone samples were not conclusive in showing the effect of moisture, it was nevertheless apparent that the samples which were permanently in water lost more mass than the other samples (Fig. 5.40). There were no trends evident with mass lost in the other samples. As the simulation cabinets were dry the moisture sprayed onto the rock surfaces quickly evaporated, thus effectively diminishing the value of this part of the experiment. If the simulations had carried on for longer it may have been possible to notice trends.

It was extremely difficult to identify trends in changes of rock properties as simulations progressed. Therefore, the only data which are to be considered for this discussion are with respect to comparisons of the initial and final values for the various rock properties. Line graphs are used for the following comparisons rather than bar charts as they show relationships better. There was an apparent general increase in rock porosity following the simulations, and rock porosity changes closely followed those of mass changes (Fig. 5.41). It is thus obvious that the more mass that was lost, in other words the more weathering that had taken place, the greater was the increase in porosity (Fig. 5.41). The greatest increase in porosity took place in the samples which were permanently in water; given that there were calcium, sodium and iron ions present (no concentrations were determined) in the water after completion of the simulation, it is likely that the increase in porosity of these samples was due to ongoing chemical weathering. There was no apparent difference in changes in porosities for samples which were sprayed with water and the control samples.

Microporosities were found to decrease when porosities increased and vice versa (Fig. 5.42). If the argument used earlier that the Clarens formation weathered by increasing the size of existing pores then the above observation supports this theory

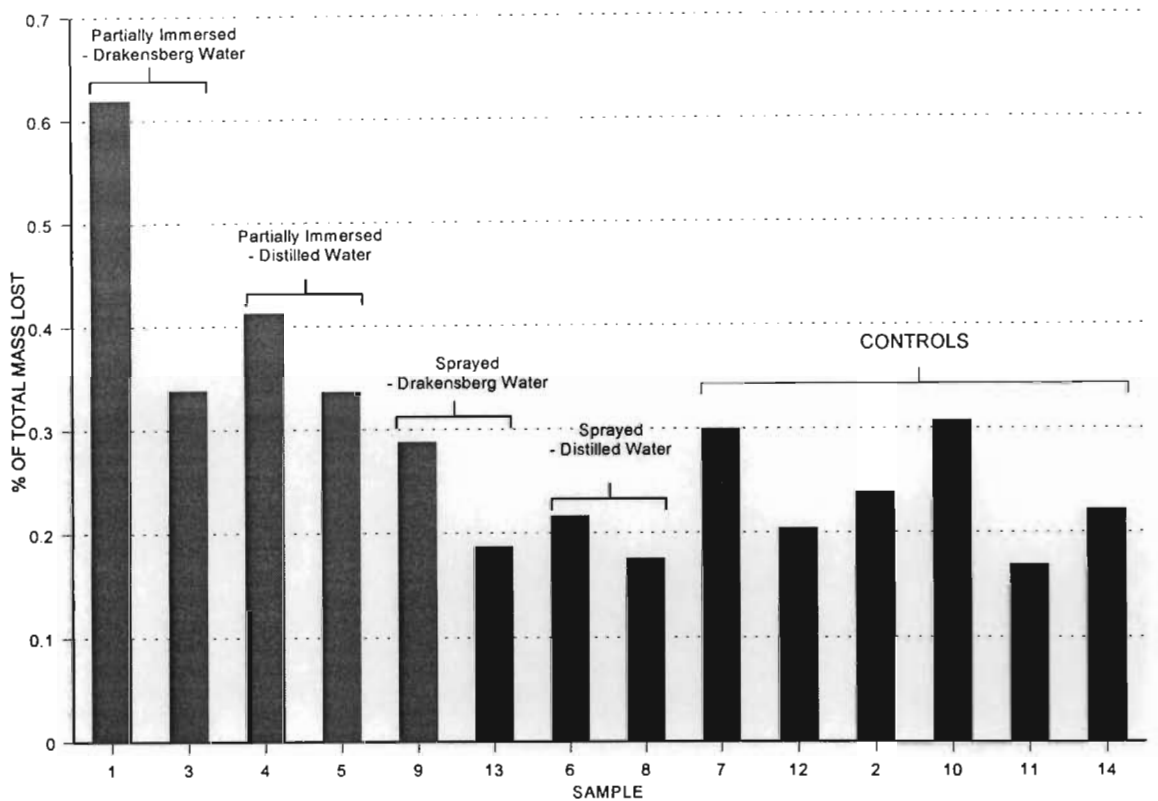


Figure 5.40: Graph showing total mass lost in simulations conducted under differing moisture conditions after 100 cycles.

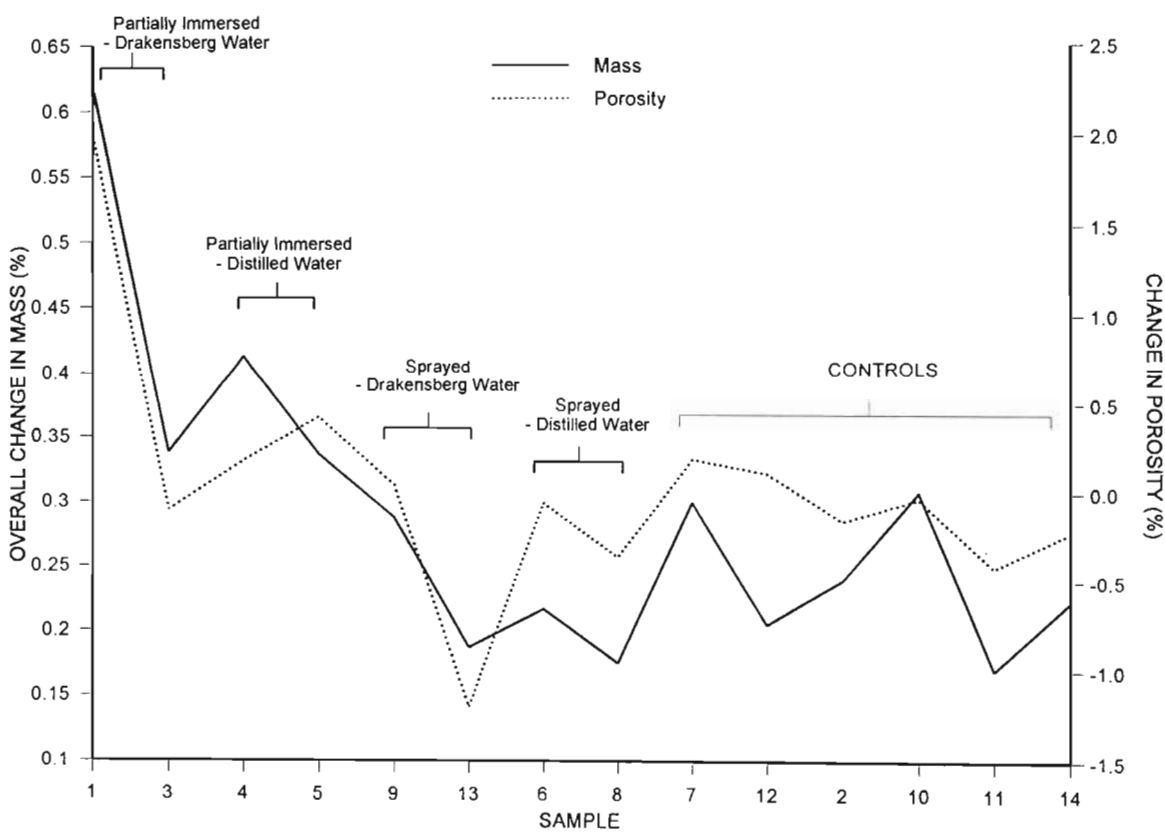


Figure 5.41: Graph showing the loss of mass and change in porosity after 100 cycles in a simulation cabinet.

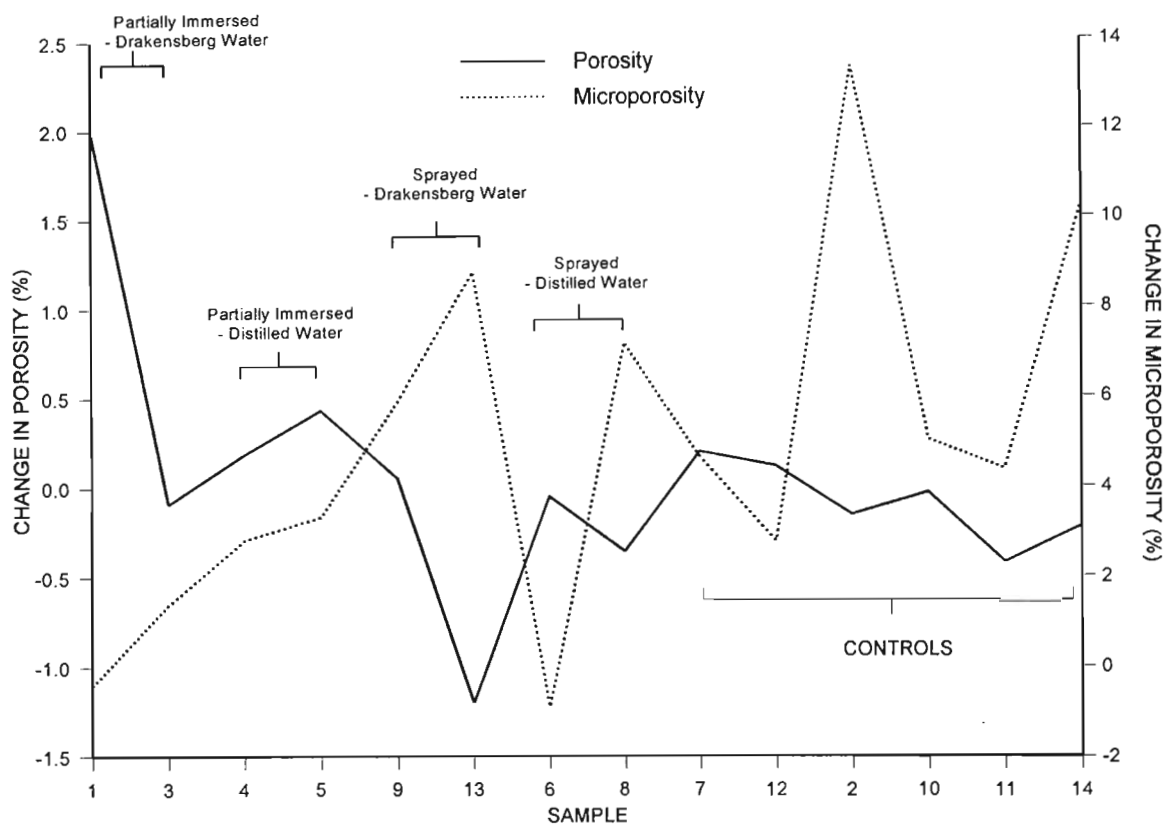


Figure 5.42: Graph showing the change in porosity and microporosity after 100 cycles in a simulation cabinet.

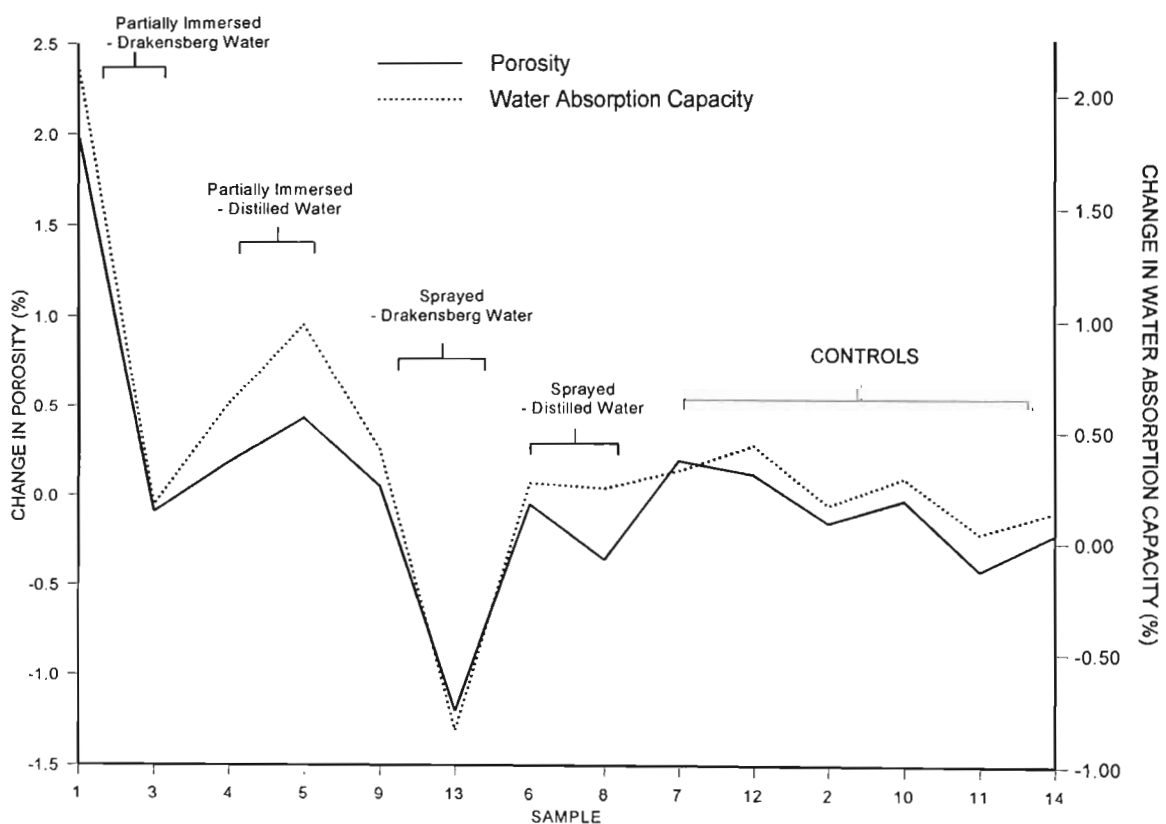


Figure 5.43: Graph showing the change in porosity and water absorption capacity after 100 cycles in a simulation cabinet.

in that while pores were enlarged, the overall porosity increased and, fewer smaller pores remained; the microporosity would thus have decreased. The expected positive relationship between porosity and water absorption capacity was observed (Fig. 5.43). As the porosity of samples increased so too does their ability to absorb moisture; put simply, as the porosity increases, with a corresponding decrease in microporosity, there is more space for moisture and, moisture movement into the rock becomes easier. The positive relationship between saturation coefficient and porosity is not as clear as the above connection between porosity and water absorption coefficient (Fig. 5.44).

While it is possible that the simulations did not continue for long enough to observe any real trends in changes to rock properties, they did nevertheless show that moisture played a positive role in the weathering of samples. Further, the changes in rock properties that were observed provided support for the hypothesis that weathering enlarges existing pores thereby increasing the rock's porosity, water absorption capacity and saturation coefficient, while the microporosity decreases. If the rock weathers in the above way, it becomes easier for moisture to penetrate the rock. An increase in moisture content will provide an environment which is more conducive to weathering and thus increase the rate of rock breakdown. It must be emphasised that the moisture conditions used in the simulations were extreme and not representative of the true weathering environment. However, the simulations do show that moisture is an important control in the weathering processes that are likely to affect Clarens Formation sandstones in the KwaZulu/Natal Drakensberg.

5.8. SUMMARY

In developing a hypothesis for weathering of the Clarens Formation in the study area it is necessary to consider that no single process can be isolated, and that rock breakdown is due to an interdependent complex of mechanisms, which are mechanical, chemical and biological. This study has focused on aspects of physical and chemical weathering, as logistics and a lack of expertise prevented adequate investigations into biological weathering processes. Despite the interdependence of the weathering mechanisms, it was necessary to investigate the controlling factors

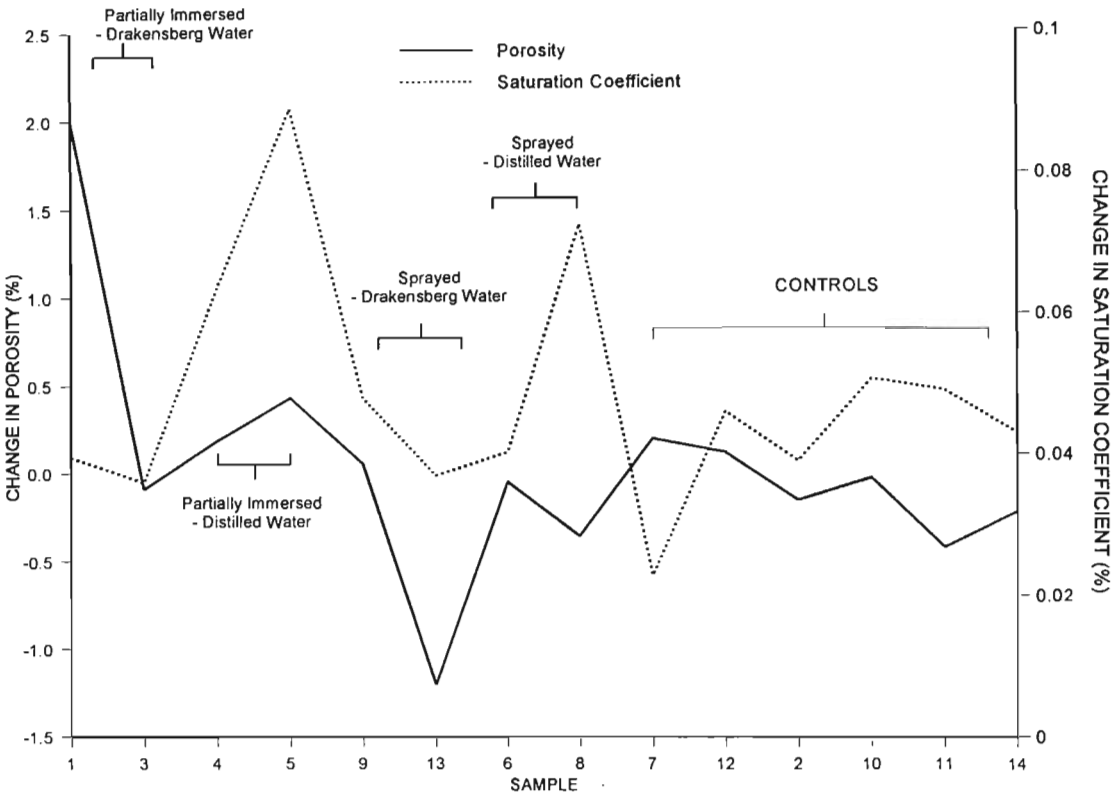


Figure 5.44: Graph showing the change in porosity and saturation coefficient after 100 cycles in a simulation cabinet.

separately. For this reason two of the major controls on rock weathering, temperature and moisture, were identified as topics for discussion, together with chemical analyses, rock strength determination and some aspects from simulation experiments.

At exposed sites it is possible that thermal fatigue is active, given that the rate of temperature change could be greater than 2°C (Richter and Simmons, 1974; Yatsu, 1988). However, it is apparent that thermal fatigue and other thermally controlled weathering processes on their own were not responsible for the breakdown of rock in the rock shelters. Rock weathering was most active in protected sites underneath rock overhangs, where the moisture regime was most suitable. It can therefore be said that, in this study, moisture is more important than rock temperature in controlling the rock weathering causing deterioration of rock art. Nevertheless, rock temperature is still an important influence on all weathering mechanisms at the two study sites in that it will affect amongst others: the rate of chemical reactions, chemical equilibria, as well as evaporation and condensation cycles (Ollier, 1984; Yatsu, 1988).

The rock moisture regime is influenced by two temporal scales of variation, namely seasonal variations, and more rapid variations that occur within periods of a few minutes. However, it was found that moisture did not move through the rock to the degree proposed by some authors (e.g. Pager, 1971; Avery, 1974; Batchelor, 1990; Lewis-Williams, 1990). Most of the samples examined had high microporosity values which would have made moisture movement difficult. A major influence on the moisture regime is atmospheric humidity, and it is proposed that humidity changes control weathering processes near the rock surface. Weathering that takes place close to or at the rock surface is the most damaging to rock art as it takes place at the interface between the paintings and the rock, or within the pigments themselves. Weathering processes that are likely to be active at this interface include salt crystallisation, hydration/dehydration of both minerals and precipitates, hydration/dehydration of clay minerals, solution processes, and hydrolysis.

Chemical analyses provide evidence for two main processes, namely the alteration of feldspars and the breakdown of calcite as both a mineral and a cementing agent. Chemical breakdown is most active at sites with sufficient moisture, for example the

Main Caves. The chemical weathering aided other processes of deterioration by providing a source of ionic precipitates that are themselves able to cause rock breakdown by mechanical processes such as crystallisation pressures and hydration/dehydration. Further, the products of solution together with certain extraneous chemicals are able to form surface crusts which may retard rock art deterioration. However, much of the chemical weathering does not appear to be contemporary, but is likely to have taken place under more moist conditions during the Quaternary.

In this study an attempt has been made to categorise various weathering processes and the controls on weathering. However, the weathering at the study site is a complex set of interactions rather than unrelated individual processes. While the rock moisture regime has been identified as the major influence on weathering, other controls (e.g. thermal regime, differences in mineralogy and depositional environment) should not be ignored. The rock moisture regime itself is influenced by rock temperature, atmospheric moisture and ground water that is able to move along rock discontinuities (Fig. 5.45, 5.46). In order to recognise the processes that may be active it is necessary to consider increasing and decreasing rock moisture contents separately. An increase in rock moisture content will involve: hydration of rock minerals, clay minerals and precipitated salts, solution of rock minerals and precipitates, hydrolysis and chemical alteration (Fig. 5.45). On the other hand, a decrease in rock moisture content, which may be due to increasing rock temperatures, decreasing atmospheric moisture or a decrease in the amount of moisture moving along rock discontinuities, will cause: dehydration of clay minerals, rock minerals and precipitated salts, and precipitation (crystallisation) of solutes (Fig. 5.46). The above moisture controlled weathering processes, plus others (e.g. thermal fatigue) will enlarge existing pores and cause granular disintegration thereby increasing the rock porosity and widening bedding planes. Enlargement of pores will cause the rock's microporosity to decrease (Fig. 5.45, 5.46). An increased porosity, lower microporosity and wider bedding planes results in moisture infiltration being easier, which in turn causes increased weathering. It can, thus, be seen that weathering of the Clarens Formation is an "accelerating" process. The processes discussed above, some of which are highlighted in Figures 5.45 and 5.46, apart from

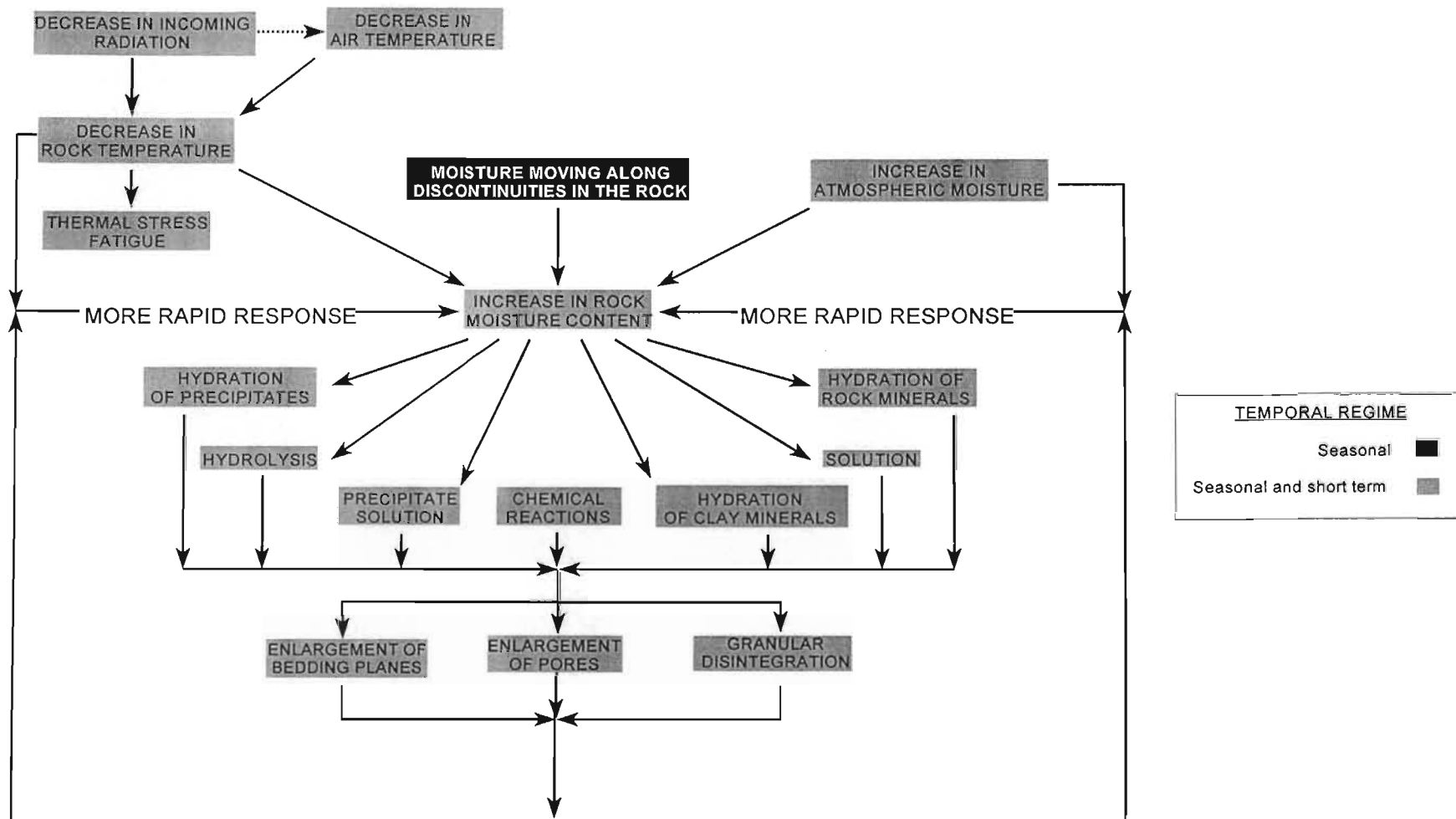


Figure 5.45: Weathering processes related to an increase in rock moisture content in the Clarens Formation in the KwaZulu/Natal Drakensberg.

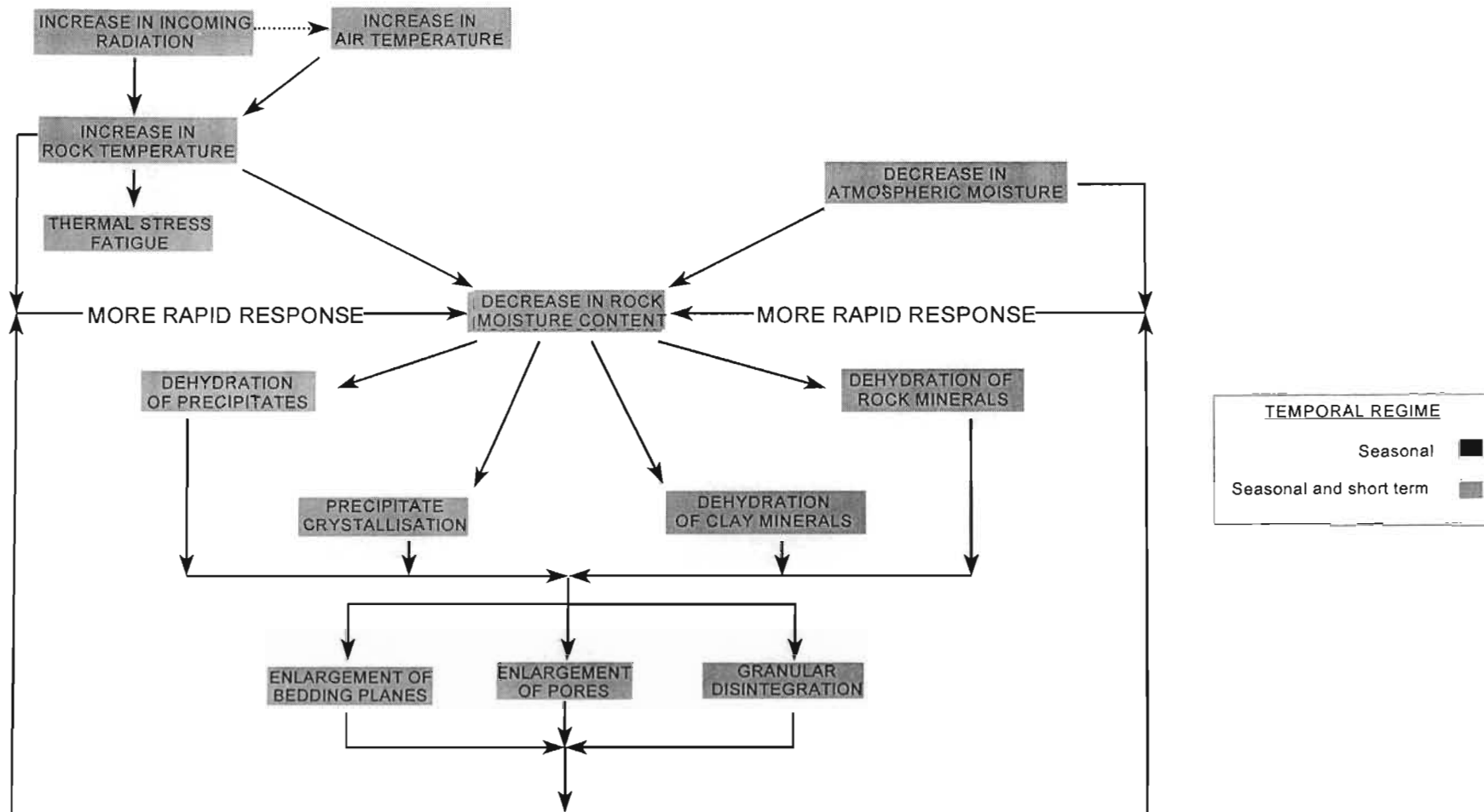


Figure 5.46: Weathering processes related to a decrease in rock moisture content in the Clarens Formation in the KwaZulu/Natal Drakensberg.

those that take place along bedding planes, will be most active at, and in the first few μm below, the rock surface. This is the very environment in which Bushman paintings are located and as a result weathering processes are going to cause the deterioration of rock art.

While this study has generalised with respect to weathering processes in the Drakensberg, it was found that microclimatic and other environmental variables, such as rock moisture, rock structure and rock chemistry, not only differ from site to site, but also from one part to another within a single shelter. The weathering processes in the study area are, therefore, not only site specific, but also depend on the precise situation of a rock surface within a site. However, it is logistically impossible for a single study of this nature to cover all aspects of weathering in such a large area. The ideas presented above thus provide a suitable foundation for discussion of the weathering processes and research into preservation of rock art in the study area.

CHAPTER 6

IMPLICATIONS OF ROCK WEATHERING FOR THE PRESERVATION AND MANAGEMENT OF ROCK ART

The primary aim of this project has been to evaluate rock weathering within the Clarens Formation of the KwaZulu/Natal Drakensberg. It is highly likely that weathering processes will have an affect upon the Clarens Formation sandstone and as this region contains some fine examples of indigenous rock art, it is imperative that some understanding of the nature of the weathering be achieved. However, as stated earlier (Chapter 1), little has been achieved with respect to determining the actual processes causing the deterioration of rock art or towards its preservation. This chapter will consider the effect of rock weathering processes on rock art in the study area, and includes a discussion on the management of this valuable heritage.

6.1. THE DETERIORATION OF ROCK ART IN THE CLARENS FORMATION: IMPLICATIONS FOR ITS MANAGEMENT AND PRESERVATION

South Africa is one of many countries in the world with rock art in open air sites. Considering that there is a lack of research into the processes causing the deterioration of Bushman paintings, it is necessary to place this study in the context of international and local research.

6.1.1. THE INTERNATIONAL RESEARCH CONTEXT

It has been said that, while research on the processes causing the deterioration of rock art and its preservation is well developed in subterranean caves, this is not the case for rock art in the open air (Soleilhavoup, 1985; Flood, 1985) (Please

note that the South African Bushman paintings are considered to be “open air rock art” (Flood, 1985)). In southern Africa there are no known published studies regarding rock weathering process studies and their influence on rock art. In Australia (e.g. Dragovich, 1976, 1981) and north Africa (e.g. Soleilhavoup, 1979, 1980, 1983, 1985) there are some published studies, but according to Soleilhavoup (1985), they are not sufficient. It is likely that most process studies are published in specific journals that are not frequently read by rock art interest groups. It has been suggested that Geomorphological journals such as “Earth Surface Processes and Landforms” and “Zeitschrift für Geomorphologie” should be used for extracting information relevant to the deterioration of rock art (Soleilhavoup, 1985, Rosenfeld, 1985). Recent literature (e.g. Loubser, 1991) indicates no evidence that the need for detailed scientific investigations into the weathering of rock art has been met in Australia. Accepting that Australian research into rock art conservation is more advanced than that in southern Africa (Loubser, 1991), the future of South African rock art is tenuous, to say the least.

Considering the lack of research into deterioration of rock art internationally, it has been suggested there be co-ordination amongst interested groups to seek common ground for future research (Soleilhavoup, 1985). It is proposed that a handbook be developed with terminology and basic policy on the following themes (Soleilhavoup, 1985 translated by Flood, 1985, p132):

- “The physiographic setting and natural and human environment, past and present, of open air rock art.”
- “The general and particular geomorphological setting and environment.”
- “Basic research on the causes and effects of weathering and changes in the condition of open air rock art.”
- “The recording for conservation or interpretation of open air rock art. This section contains a warning about the dangers of damaging rock art in the

course of recording, and particularly of the immense danger of making casts.”

- “Conservation: methods of intervention and site protection.”

It should be noted that considerable emphasis is placed on geomorphological aspects of research into rock art conservation in the above themes. Although the above are merely ideas for inclusion in sections of a handbook, they do also identify the topics that are necessary for research. In South Africa the focus of research has been the recording and interpretation of rock art (e.g. Willcox, 1960, 1980; Hoffman, 1971; Pager, 1971, 1973; Vinnicombe, 1976; Ward, 1979; Lewis-Williams, 1981, 1983, 1990; Rudner, 1982; van Rijssen, 1987; Lewis-Williams and Dowson, 1989, 1992; Yates *et al.*, 1990; Pager *et al.*, 1991; Deacon, 1994), while there is no known published study that investigates geomorphic processes causing the deterioration of rock art.

Soleilhavoup's (1985) ideas provoked considerable comment (e.g. Flood, 1985; Davis, 1985; Virili, 1985; Rosenfeld, 1985). At least one commentator (Davis, 1985) while accepting that weathering processes are important, was unwilling to acknowledge fully the importance of scientific process in research towards the conservation of rock art. Discussions at meetings in South Africa (e.g. The Rock Art Colloquium at Modderport on 14-16 September 1992 and the Rock Art Workshop at Golden Valley Resort on 14-16 October 1994) showed that some interested parties in southern Africa do acknowledge the importance of geomorphological research, however for many there is a reluctance, similar to that shown by Davis (1985), to accept scientific process studies as being crucial to rock art's future. The impression given is that the rock art enthusiasts view geomorphological research as an “invasion into their territory”. However, it should be noted that the most publicised and most successful rock art conservation and preservation occurs in France (e.g. Andrieux, 1973, 1974; Breisch, 1987; Brunet and Vidal, 1979, 1981; Brunet *et al.*, 1983, 1990, 1993; Vouvre *et al.*, 1985, 1987, 1988; Vidal *et al.*, 1988; Malaurent, *et al.*, date unknown) where the multi-disciplinary approach is followed.

While Davis's (1985) contention that recording and interpretation of rock art is the major concern of the archaeological community is accepted, there is nevertheless a need to preserve this heritage for future generations and to ensure that future academics have material to interpret. It is thus evident that there exists an urgent need for process geomorphologists not only in South Africa, but throughout the world to conduct research into rock art deterioration, if rock art is to have any chance of surviving into the future. This is, however, no easy task; Soleilhavoup (1985) and Brunet (pers. comm., 1993) suggest that a multi-disciplinary team consisting of amongst others, a process orientated earth scientist, a microbiologist, an archaeologist and a draftsman, is needed for research into rock art deterioration. The number of people that need to be involved would make the entire process extremely expensive, and this is without even considering the equipment that would be required.

6.1.2. SOUTH AFRICAN RESEARCH CONTEXT

Given the need for research and the difficulties associated with conducting research into rock art deterioration and preservation, this study should be seen as the first step in attempting to identify the processes causing the deterioration of rock art. It was shown that rock weathering processes are the major cause of rock art deterioration in the KwaZulu/Natal Drakensberg. The most damaging mechanisms are those that take place at, or close to the rock surface which is the very interface between the Bushman paintings and the rock. While previous work, has identified weathering as being important (Avery, 1974; National Building Research Institute, 1975, 1983; Rudner, 1989; Batchelor, 1990; Lewis-Williams, 1990; Loubser, 1991; Woodhouse, 1991; Lewis-Williams and Dowson, 1992), little field data have been collected which relate to rock art deterioration processes. This is the only project in the Drakensberg mountains aimed at identifying particular mechanisms of rock weathering that are causing the deterioration of rock art. While no specific methods of rock art preservation were tested, the results obtained from data collected for this study, nevertheless provide an indication of active processes that need to be controlled.

In order to consider the implications of weathering for the preservation of rock art in the Drakensberg study area it is necessary to consider the arguments advanced in the previous chapter. Below, (see Figure 6.1) is a summary of some of the processes relating to the weathering of the Clarens Formation and thus the deterioration of rock art in the study area:

- The mineralogy, rock structure, rock properties and especially the rock moisture and thermal regimes influence rock weathering processes.
- Thermal stress fatigue, salt crystallisation, hydration and dehydration of rock minerals, clay minerals and precipitated salts, solution, hydrolysis and chemical alteration, are the principal rock weathering mechanisms.
- The most important environmental control on the weathering processes is the rock moisture regime.
- The rock weathering processes result in granular disintegration and the enlargement of pores and bedding planes.
- While there is more than one temporal weathering regime, it is the short-term changes that especially affect the rock surface and the area immediately beneath the rock surface and it is these that are most damaging to the deterioration of rock art.
- The existing weathering processes produce a more dynamic environment with respect to both the thermal and rock moisture regime results, thereby accelerating rock weathering processes.

Two temporal scales were found to be in operation with respect to the moisture regimes at the study sites, namely a seasonal regime and a short-term regime in which moisture changes are in immediate response to climatic variables. Both regimes are affected by atmospheric moisture. In addition, seasonal variations of

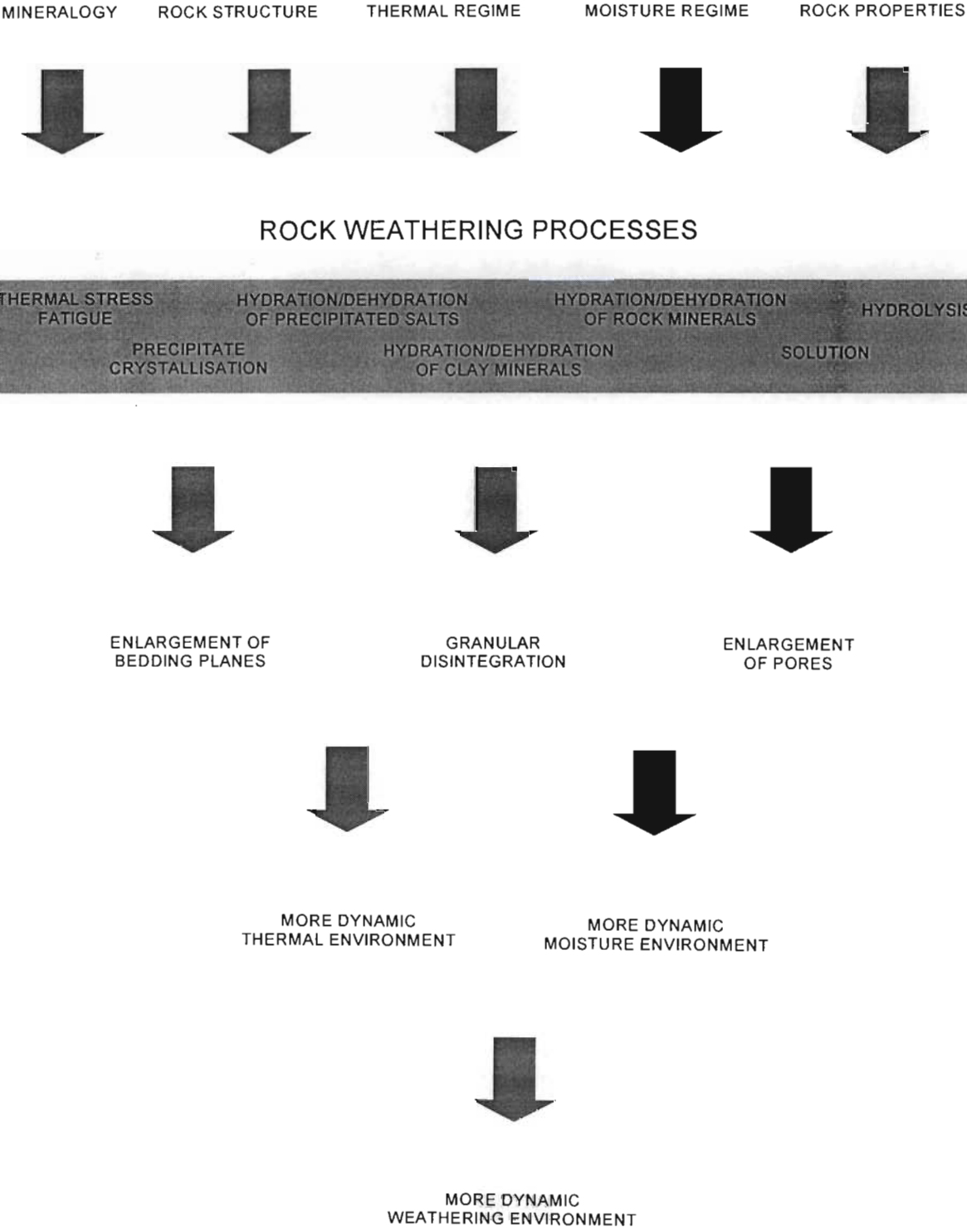


Figure 6.1: Flow diagram of the weathering processes causing the deterioration of indigenous rock art in the Clarens Formation of the KwaZulu/ Natal Drakensberg.

rock moisture may be affected by moisture moving along joints and bedding planes during summer. Given that the rock art is painted on the rock surface and that the pigments are only likely to penetrate a short distance into the rock, it is processes acting at or close to the surface that are likely to be the most destructive. The rock moisture changes effected by atmospheric humidity have the greatest impact at the rock surface and the area immediately below the rock surface, and are therefore the most damaging. As discussed previously (Chapter 5), the role of rock temperature should not be ignored as an important influence. If rock art is to be preserved, then it is imperative that the rock is protected against moisture related processes, either by protecting the rock itself or by changing the environment so that moisture and temperature changes are kept to a minimum.

In addition to rock weathering processes, the pigments of the paintings most exposed to solar radiation have faded at Battle Cave study site (see Fig. 5.29), while those paintings in more sheltered locations are in a better state of preservation. On the other hand, at the Main Caves study site there is little evidence of pigment fading due to ultra-violet radiation, and most of the deterioration of the rock art is due to rock weathering processes. As discussed earlier, rock weathering processes occur at a greater rate in the Main Caves, and this is primarily due to the moisture regime which is more suitable for rock weathering than that at Battle Cave.

In order to preserve rock art it is necessary to stop or at the very least minimise rock weathering processes. It must be remembered that while conservation of rock art may involve a few measures that slow weathering processes, they will not ultimately ensure the preservation of this valuable heritage. Unfortunately the controls on the deterioration are environmental and so, in the absence of any chemical applications that may preserve rock art, there is little that can be done to stop rock weathering processes. It may be possible to insulate rock art sites from the natural environment by building walls and barricades. However, such approaches remove the rock art from its contextual surroundings. Further, most of the rock art sites in the study area are isolated and very extensive with respect

to their size; it would, thus, be logistically nearly impossible for such an undertaking.

Although, this study has provided some answers as regards specific weathering processes in the Clarens Formation, there are still several aspects of weathering that require investigation. Therefore, for an effective policy to be implemented for the preservation of rock art more research is required. Considering that the microclimate recorded in this study, and hence the weathering regime was not only site specific but varied according to the situation within the sites, so further equally detailed research is needed. In order to cover all possibilities, a multi-disciplinary study such as that suggested by Soleilhac (1985) and Brunet (pers. comm., 1993) is required. Unfortunately, a detailed study such as the aforementioned, would be possible at few of the approximately 600 sites (Natal Parks Board, 1994) and some sort of selection process is required to identify ideal sites for research (A future research agenda will be presented in the summary at the end of this chapter). The discussion that follows investigates the present and future management of rock art in the KwaZulu/Natal Drakensberg and the potential for both conservation and preservation of this heritage.

6.2. MANAGEMENT OF ROCK ART IN THE DRAKENSBERG

Given that rock art is a valuable international as well as national heritage, it needs to be managed as a cultural resource. An effective management policy can provide the potential for future research, while at the same time also providing the foundation for rock art preservation. The first step in the processes must be for the National and Provincial Governments and for land owners to recognise the importance of rock art, not only for its importance as a cultural heritage, but also as a potential tourist attraction and revenue earner (as it is in France (Malaurent, *et al.*, date unknown)). While legislation is in force to protect rock art (it is an appendix to the Environmental Conservation Act (Batchelor, 1990)), it does not provide for the future preservation of rock paintings or engravings for that matter.

There are several management options open to the respective authorities (in the case of the Drakensberg Park, it is the Natal Parks Board and the KwaZulu Department of Nature Conservation, who are due to amalgamate under the new South African dispensation), which will be discussed below, namely:

- 1) to conserve rock art.
- 2) to remove rock art to places of safe keeping.
- 3) to educate and inform the public.
- 4) to preserve rock art in *situ*.

6.2.1. CONSERVATION OF ROCK ART

Fortunately the status of rock art is such that there are sufficient interest groups to implement management policies for its protection. Recently an initiative of an archaeologist at the Natal Museum, Dr. Aron Mazel, has been carried forward and a policy is being instituted by the Natal Parks Board, for the management of rock art in the Drakensberg Park (Natal Parks Board, 1994). A similar initiative is already underway in areas of the Drakensberg controlled by the KwaZulu Department of Nature Conservation. The first priority is to identify rock art sites and to monitor them for changes in the condition of the paintings (Natal Parks Board, 1994). All sites are ranked according to criteria agreed upon by the Natal Parks Board Rock Art Advisory Committee, which take the degree of deterioration, the importance of the particular art and its accessibility into account. If a location has paintings which are deteriorating rapidly then it is hoped to take action to prevent further deterioration. Unfortunately, this only involves controlling access by humans and animals as no methods of preventing the deterioration of Bushman paintings, caused by rock weathering processes, are presently financially viable. A summary of the proposals for management and the management procedures that are to be adopted in areas under the control of the Natal Parks Board is attached in Appendix 4.

Apart from recognised bodies, such as the National Monuments Council and provincial conservation bodies, several interest groups have been established in

South Africa (e.g. ROCUSTOS, the Soutpansberg Rock Art Conservation Group and the Waterberg Nature Conservancy, amongst others), with the conservation of rock art being a priority (Eastwood, *et al.*, 1994; Steyn, pers. comm., 1994). The National Monuments Council has produced a draft pamphlet with minimum standards for rock art sites, which is intended for use by interested parties intending to open up sites to the public (Appendix 5).

Most of the management policies adopted by the Natal Parks board involve limiting public access and the monitoring of rock art sites for signs of enhanced deterioration (Natal Parks Board, 1994). The existing facilities at sites where public visitation is encouraged are going to be upgraded, while a conscious effort will be made not to make information about other sites available to the general public. It is hoped that by concentrating public impact at only a few sites, and in that way making them "sacrificial sites", other rock art in the Drakensberg will be less affected and in this manner "conserved" (Natal Parks Board, 1994).

6.2.2. REMOVAL OF ROCK ART TO PLACES OF SAFE KEEPING

Removing rock art for safe keeping is a policy that has been successfully adopted in the past (Loubser, 1994). However, in doing so, much needless destruction of art work has taken place. There are several problems which have been encountered. The rock art is not necessarily painted on surfaces where bedding planes are at places that allow for easy removal (Loubser, 1994). For example, many of the Bushman paintings in the Main Caves and Battle Cave are painted on surfaces which have horizontal bedding planes (i.e. normal to the surface). It is likely that, even if it was possible to detach some blocks, they would break along the bedding planes. Further, the rock would then have to be displayed on an inert substance, as gypsum from concrete mortars has been recorded to have passed through the rock and crystallise out on the surface and damage rock art (Loubser, 1994). If the art were to be stored in a cabinet with a dry, inert atmosphere, kept at a constant temperature, weathering would be kept to a minimum. A major consideration is that most of the rock art sites in the KwaZulu/Natal Drakensberg are not accessible by road which would prevent excavation equipment from being

brought to the rock face, without even considering the mass of the blocks that would then need to be moved. Except for very small pieces, logistics would prevent fallen rocks with paintings, from being removed from the field.

Ethical issues also need to be considered before rock art is removed. Rock art sites may have been places of worship for the Bushman people, and removing paintings would amount to desecration of these places. Further, removing rock art involves it being taken away from its contextual surroundings. A more appropriate solution for the deterioration of rock art would be *in situ* preservation (see 6.2.4 below).

6.2.3. EDUCATION AND INFORMATION

While it has been recognised that rock art is an important heritage in South Africa and that it should be managed in such a way that it is protected (Mazel, 1982, 1983; Loubser, 1991, 1994), much of this motivation is, sadly, from a purely academic perspective. At present there are only three sites in the KwaZulu/Natal Drakensberg that have been set aside for tourism, namely the Main Caves, Battle Cave and Game Pass Shelter. While personnel are employed to show visitors these three sites, none of the guides are trained and only at the Main Caves is there an interpretive display (Fig. 6.2). There are tape recorded commentaries (and even then only in English) for the Battle Cave and the Main Caves which are played while the visitor is shown around. Similar sites in France, for example Abri du Cap Blanc, Grotte les Combarelles, Grotte de Font de Gaume and Lascaux II, have qualified guides to take visitors through caves and in peak "tourist season" tours are conducted in languages other than French.

Through education and awareness programmes, it may be possible to generate interest in rock art, such that the need for its conservation and preservation is realised. Through an interested public, it may be possible to generate the necessary finance, in the form of sponsorship, advertising, etc. for further research into techniques for preserving Bushman paintings. While there are some cheap booklets available to the public for information about local rock art in



Figure 6.2: Interpretive display with models of Bushman People in the east shelter of the Main Caves study site.

a few regions of South Africa (e.g. Lewis-Williams and Dowson, 1992 and Deacon, 1994), these are limited and only available at a few outlets. Only recently have popular magazines begun to publish articles related to rock art, rock art conservation and rock art preservation (e.g. Deacon and Bassett, 1994; Howard, 1994; Rogers, 1994). Even in South African school syllabi there is little relating to the Bushman People and their rock art (Nuttal, pers. comm., 1994). Recent attempts to publicise rock art include the incorporation of rock art into the 1994 South African, Environmental Awareness Week campaign which had the theme "The arts and the environment" (Department of Environmental Affairs, 1994), for which an information brochure was published (National Monuments Council, 1994) (see Appendix 6). Another brochure from the National Monuments Council is planned (It has not been published yet) to advise rock art enthusiasts on procedures of recording rock art (see Appendix 7 for a draft copy). However, these attempts to create public awareness do not fulfil the need to develop a population which is educated with respect to rock art. In the United Kingdom museums have been particularly active in promoting awareness of older civilisations and their art, an example of this is an educational pamphlet issued for teaching purposes by the Natural History Museum in London (see Appendix 8).

It is only through adequate publicity and education that the importance of this heritage will be realised by the public at large. In other countries, for example France, and Australia the importance of rock art as a cultural heritage is recognised and publications concerning the preservation of rock art are more numerous and more widely distributed (e.g. Parish, 1992; Brunet, *et al.*, 1990).

6.2.4. PRESERVATION OF ROCK ART

There are two major methods that can be used to preserve rock art *in situ*, first by altering the environment in which the rock art is found and second, by applying preservatives to the rock surface. The lack of adequate research towards preserving stone in southern Africa means that studies from elsewhere have to be consulted. However despite there being considerable literature on building and monument restoration in Europe (e.g. Arnold and Price, 1976; Rossi-Manaresi,

1976; Torracca, 1976; Webber, 1976; Felix *et al.*, 1978; British Standards Institution, 1984; Fukuda *et al.*, 1984; Lewin and Wheeler, 1985; Donganis, *et al.*, 1992; Dupas *et al.*, 1989; Hammecker *et al.*, 1992; Henriques, 1992; Kozlowski *et al.*, 1992; Moropoulou *et al.*, 1992; Pien, 1991; Roselli and Rosati, 1992; Saleh *et al.*, 1992; Valdeón *et al.*, 1992; Valle *et al.*, 1985; Villegas and Vale, 1992; Wendler *et al.*, 1992; Wheeler *et al.*, 1992), Egypt (e.g. Kérisel, 1989; Bongrani, 1992; Saleh, *et al.*, 1992), and Japan (e.g. Fukuda, *et al.*, 1984), little is applicable to rock art in southern Africa. This is especially the case with some of the restoration of the Sphinx (Bongrani, 1992) and the Parthenon (Donganis, *et al.*, 1992), which is concerned more with using compounds to reconstruct the particular monuments, rather than preserving existing surfaces. However, as a great deal of research has been conducted in Europe, all the lessons learnt there with respect to the success or failure of particular techniques can be applied to the situation in South Africa.

As has been discussed above (see 6.1), altering the ambient environment is, in most cases not a feasible solution to the problem of deteriorating rock art. One occasion where environmental alteration is effective is when drip-lines are used to prevent precipitates from washing over and obliterating rock art. In cases where water washes over Bushman paintings, it may be possible to install the aforementioned drip-lines to divert water away from being in direct contact with rock art (Fig. 6.3). Paintings such as those in Figure 6.4, which have gypsum and possibly magnesium precipitates covering them, will benefit from drip-lines. On two occasions drip-lines have been used in the study area to protect paintings (see 1.2.3) (Loubser and van Aardt, 1978; National Building Research Institute, 1979, 1983), but no information has been published with regard to their success. However, drip-lines are insignificant when art in the Drakensberg is considered as a whole. The only method which may be successful in preserving rock art is the application of a chemical protective to the rock art surface

Chemical treatments have been applied to many stone surfaces, primarily in the preservation of historical buildings in Europe (for example: Arnold and Price, 1976; Rossi-Manaresi, 1976; Torracca, 1976; Webber, 1976; Felix *et al.*, 1978;

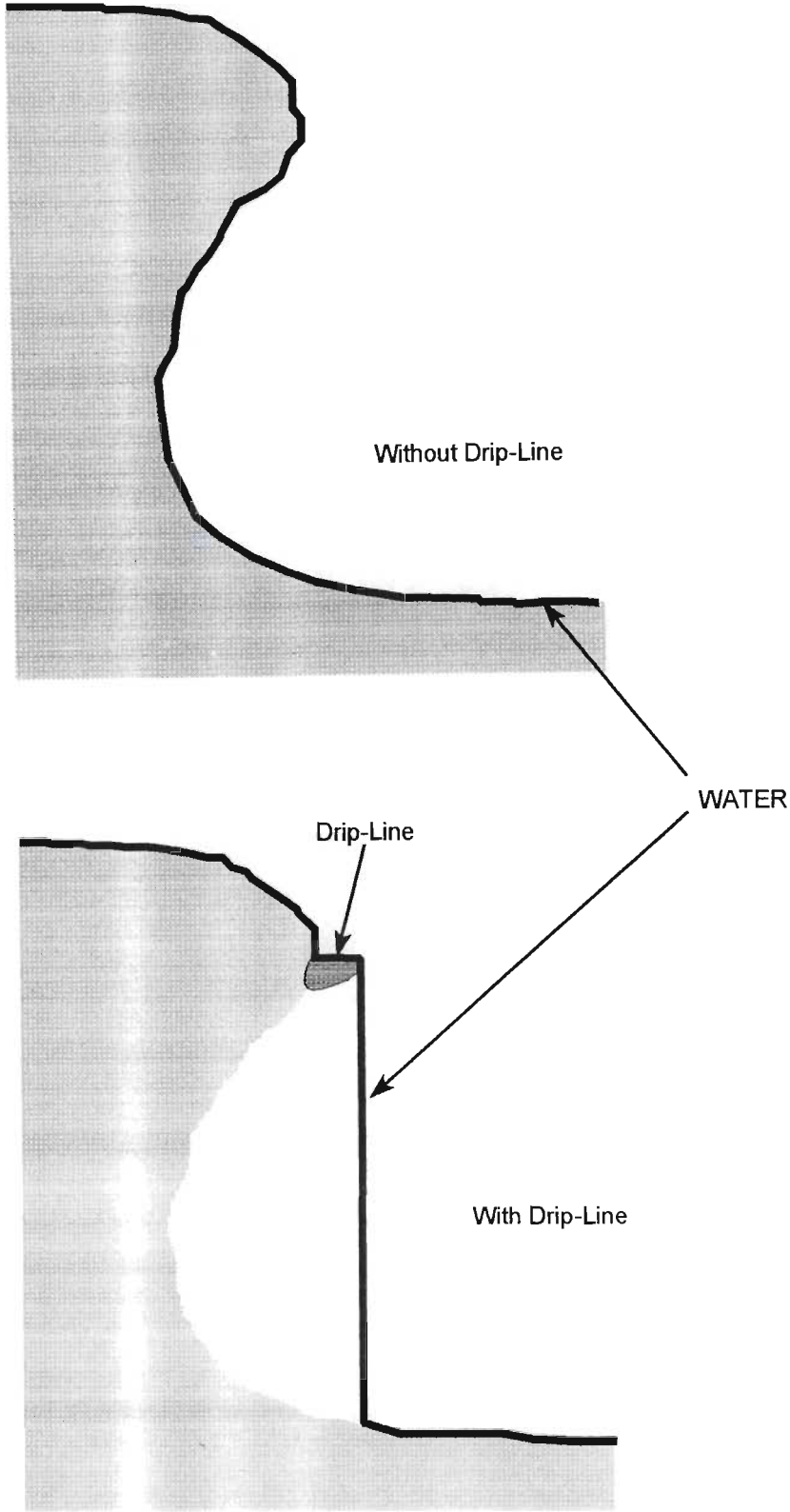


Figure 6.3: The effect of drip-lines, which prevent water from running over Bushman paintings.

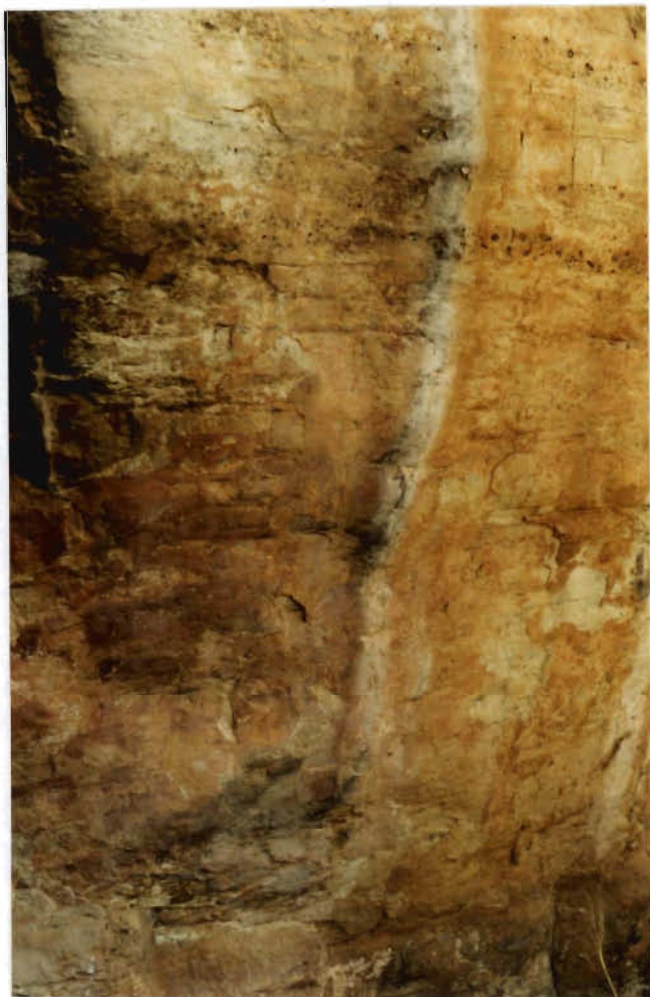
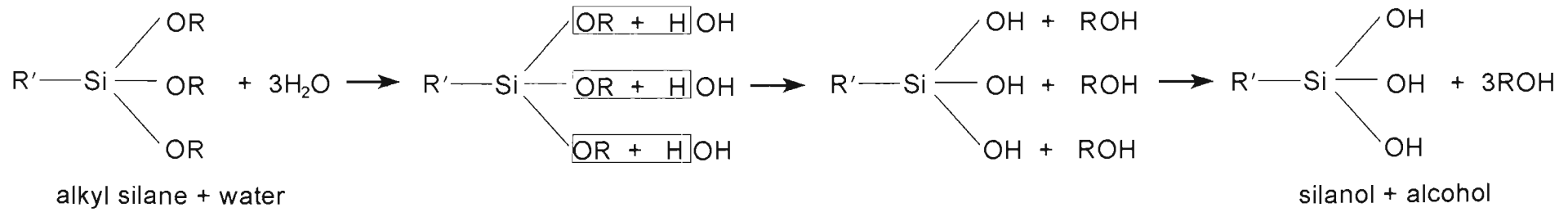


Figure 6.4: Bushman paintings on a free-standing rock below the Main Caves study site which will benefit from the installation of a drip-line.

British Standards Institution, 1984; Fukuda *et al.*, 1984; Lewin and Wheeler, 1985; Dupas *et al.*, 1989; Hammecker *et al.*, 1992; Henriques, 1992; Kozlowski *et al.*, 1992; Moropoulou *et al.*, 1992; Pien, 1991; Roselli and Rosati, 1992; Saleh *et al.*, 1992; Valdeón *et al.*, 1992; Valle *et al.*, 1985; Villegas and Vale, 1992; Wendler *et al.*, 1992; Wheeler *et al.*, 1992). The most effective chemical preservatives are those which are hydrophobic, but have a minimal effect on the porosity and permeability (gaseous and liquid) of the parent material (Rossi-Manaresi, 1976; Torraca, 1976; Valle *et al.*, 1985; Batchelor, 1990; Villegas and Vale, 1992; Wendler *et al.*, 1992; Brunet, pers. comm., 1993; Ozouf, pers. comm., 1993). The most effective chemicals that are used for the preserving of natural stone are the silanes, (National Building Research Institute, 1979, 1983; Fukuda *et al.*, 1984; Lewin and Wheeler, 1985; Rudner, 1989; Batchelor, 1990; Loubser, 1991), but that the most effective compounds differed according to the type of building material and the weathering environment. Even in the harsh environment of the Sahara desert, a silane (methyl trimethoxy silane) was found to be the most effective preservative of the exposed limestone surfaces of the Sphinx (Saleh, *et al.*, 1992). Silanes exhibit both hydrophobic and hydrophilic properties; the non polar organic alkyl group repels moisture, while the alkoxy group reacts with water to form a silanol and an alcohol (Hüls, 1991) (Fig. 6.5). The silanol is highly reactive and is able to react with the inorganic building material or rock, so that it protects the building material, and repels external moisture (Hüls, 1991). The permeability of the rock to water and gas is not altered significantly, so that both are able to escape from the rock, thereby preventing enhanced sub-surface weathering (Ozouf, pers. comm., 1993).

Despite the fact that silanes may be effective on new building material their usefulness is limited when applied to already weathered material (Midgley, pers. comm., 1994; Swanepoel, pers. comm., 1994). Further, without catalysts the polymerisation of silanes is too slow to be of any practical use in the field (Lewin and Wheeler, 1985). Additional problems arise in that moisture is required for the reaction with silanes when it is applied; atmospheric and rock moisture contents are insufficient for this reaction (Lewin and Wheeler, 1985). The ideal is for the silane to be added to a water-alcohol mixture (Lewin and Wheeler, 1985). It is



LEGEND

- R' = water-repellent alkyl residue
- OR = alkoxy group

Figure 6.5: The reaction of a alkyl silane with water to form a silanol and an alcohol (after Hüls, 1991).

possible that the water in the mixture may damage rock art, and until detailed research is carried out, the effectiveness of the products for the preservation of rock art will not be known.

Despite the effectiveness of silanes in the treatment of stone materials, diagnostic and control methods of stone preservation are poorly developed (Pien, 1991). This situation influences the selection and the adjustment of interventions and the control of applications such that the incorrect treatment is often adopted (Pien, 1991). After observations of stone treatments that are thirty years old in Florence, Italy, Roselli and Rosati (1992) argue that there is a need for future research. Some applications of chemical preservatives, rather than slowing weathering processes down, often result in enhanced sub-surface weathering; this applies particularly to acrylic treatments (Batchelor, 1990; Rossi-Manaresi, 1976; Villegas and Vale, 1992; Wendler *et al.*, 1992). There is thus a fear amongst rock art enthusiasts that chemical applications may damage rock paintings rather than preserve them (Mazel, pers. comm., 1994).

The use of silanes for protecting rock art may thus be limited as all the Bushman paintings in the study area are on weathered surfaces. However, even though they may not be able to provide a permanent solution, silanes may be able to preserve rock art for a longer period than would be the case under natural conditions. It is, therefore, proposed that future research should investigate the possibility of testing the effectiveness of silanes, and for that matter any other chemical application which may be suitable for the preservation of rock art. Financial and time limitations prevented this aspect from being investigated in this study.

In order to conduct "nature-adapted" simulation tests, meteorological data as well as information on microclimatic variations within a shelter are essential (Fitzner and Kalde 1991; Snethlage and Simon, 1992; Brunet, pers. comm., 1993). As data are now available on the microclimatic conditions that rock art is subjected to in the KwaZulu/Natal Drakensberg, laboratory testing of preservatives can be conducted based on field conditions. However, given that the rate of deterioration

of rock samples in simulations was slow, it is imperative that such research is commenced as soon as possible so that solutions may be obtained before more of the rock art has disappeared. It may be possible to use time compressed simulations, which are still based on field data, for a quicker evaluation of preservatives.

6.3. SUMMARY

While it is recognised that rock art is fast disappearing as a result of rock weathering processes, little has been achieved with respect to its preservation. Considerable research is required to investigate specific methods of ensuring the survival of Bushman Paintings in the KwaZulu/Natal Drakensberg. Several topics in this study have been highlighted for further research and an agenda for future investigations would need to include the following:

- the identification of sites suitable for preservation.
- an extension of this study with detailed analysis at specific sites including: microclimate, mineralogy, rock moisture and thermal regimes, rock and rock moisture chemistry and determination of rock properties (the use of scanning electron microscopy should be considered).
- more detailed simulation experiments than were done in this study, to determine weathering processes.
- investigations into the effect of case hardening.
- the role of micro-organisms in rock weathering processes.
- specific preservation techniques, which are tested under field conditions.

It can be seen that considerable research is required before it will be possible to preserve rock art in situ in the KwaZulu/Natal Drakensberg. Until such time as an

CHAPTER 7

CONCLUSION

Weathering of the Clarens Formation at the two study sites is affected by the rock moisture and thermal regimes. Rock weathering is more evident at the Main Cave study site where the rock moisture regime is more conducive for weathering processes. It is thus proposed that rock moisture constitutes the largest influence on rock weathering processes in the Clarens Formation of the KwaZulu/Natal Drakensberg. However, rock temperatures cannot be excluded as an important control on weathering, especially considering the rapid temperature changes that were recorded in this study.

The rock moisture regime at the two study sites is influenced by moisture from seepage along joints and discontinuities and from atmospheric moisture. There is a clear relationship between atmospheric moisture and rock moisture contents. Weathering processes influenced by the moisture regime include solution, chemical alteration of minerals, crystallisation pressures from precipitating solutes, hydration and dehydration of both precipitated salts and of minerals, shrinkage and swelling of clay minerals. An enlargement of existing pores and a corresponding increase in porosity and decrease in microporosity result from the weathering in the study area. Greater porosities, and lower microporosities, allow increased moisture access, which results in a more dynamic environment with respect to weathering processes. The weathering of the Clarens Formation is thus likely to accelerate through time.

Two temporal scales were identified from monitoring variables affecting weathering mechanisms, a regime dependant on seasonal variations and another in response to immediate changes in microclimatic variables. Short term variations affect the rock surface and area immediately adjacent to the rock surface as well as along joints and other discontinuities in the rock. However, it is unlikely that, even along joints, short term changes will have an influence at any great depth beneath the rock surface. With seasonal regimes, there is sufficient

time for moisture to penetrate into the rock so weathering will influence the rock at depths below the surface. It is likely that much of the weathering along joints and bedding planes occurred during a wetter palaeoclimate, while most of the contemporary weathering is at or near the rock surface.

Rock weathering processes are the major cause of the deterioration of Bushman paintings on the surface of Clarens Formation sandstone in the two study sites. This has also been observed to be the case at other known rock art sites in the KwaZulu/Natal Drakensberg. As weathering in the study area accelerates through time, much of the rock art that is present will deteriorate at a greater rate than has already been observed. As no method of preserving the rock art has been forthcoming, it is imperative that research is continued to develop techniques that will ensure the survival of this valuable heritage. Until such time as a method for preservation is found, rock art should be managed in such a way that the effects of rock weathering processes are minimised. The proposal that rock art sites are monitored should be implemented as soon as possible, so that the most important sites for preservation may be identified. Certain measures, such as the construction of drip lines, where running moisture is destroying paintings, can be implemented immediately. It may be necessary, if no preservation method is forthcoming, to build structures at the most important sites to create a stable environment, whereby rock weathering is kept to a minimum.

A major thrust should be that of public information which could, through advertising, provide the motivation for the private sector to contribute financially towards research into preservation of Bushman Paintings. With public support it may be possible to pressure for legislation towards protection of rock art sites. Public awareness and legislation on their own could lead to the minimising of damage to rock art by all agencies other than rock weathering. Further, an awareness of the importance of rock art, has the potential to engender pride in a heritage that is truly South African.

effective technique for the preservation of rock art has been developed, a management policy needs to be implemented, so that the deterioration of this valuable heritage can be minimised.

EPILOGUE

A major motivation for the writing of this thesis was a truly wonderful heritage of art which is deteriorating and will continue to do so unless something is done soon. In my discussion and even in the acknowledgements I have failed to mention anything about the people who painted this treasure on the sandstones of the Clarens Formation, when it should be to them that this study is dedicated. Unfortunately, the Bushman People were systematically killed or driven out from the Drakensberg mountains of the then Natal province (Pearse, 1989), so that we now know nothing of their culture, the meaning of their art, or even the reasons for it being painted in the first place. If the Bushman People of the Drakensberg were anything like the Bushman People who today live in the desert regions of southern Africa, then judging by the accounts of van der Post and Taylor (1985), we are poorer for their absence. In closing, a quote from Laurence van der Post may describe the hunter-gatherer people best. It would be the fulfilment of a dream if this study could contribute towards the preservation of their heritage.

“The essence of his being, I believe, was his sense of belonging: belonging to nature, the universe, life and his own humanity. He had committed himself utterly to nature as a fish to the sea. He had no sense whatever of property, owned no animals and cultivated no land. Life and nature owned all and he accepted without question that, provided he was obedient to the urge of the world within him, the world without him, which was not separate in his spirit, would provide”.

(van der Post and Taylor, 1984, pp150; this quote is also cited by Eastwood, *et al.* 1994).

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APPENDIX 1

GUIDELINES FOR GRAFFITI REMOVAL PROJECTS AND A SUMMARY OF GRAFFITI REMOVAL METHODS APPROPRIATE TO GOLDEN GATE HIGHLANDS NATIONAL PARK (Cave Research Organisation of Southern Africa, from Gamble, 1986).

GUIDELINES FOR GRAFFITI REMOVAL PROJECTS

The removal of graffiti from any surface has very positive results, in terms of both the aesthetic improvement of the environment and the positive regard to the cleaning party.

A number of points are provided as brief guidelines to parties intending to undertake graffiti removal projects:

1. THE AIM OF GRAFFITI REMOVAL

The aim of any graffiti removal project must be:

*TO RESTORE THE SITE AS NEARLY AS POSSIBLE TO ITS ORIGINAL
UNDAMAGED STATE
(without causing additional damage to the site)*

2. THE NATURE OF THE PROBLEM:

The surface on which the graffiti appears must be respected.

The problem of what is graffiti and what is history must be carefully assessed.

The removal of graffiti is a slow, painstaking process, requiring hours of patience, often under wet and or dirty conditions.

Depending on the location of the graffiti, it may present hazardous situations to cleaners, requiring for example the use of ropes to reach inaccessible sites

3. THE NATURE OF THE PARTY:

A small group of reasonably mature people under supervision of a person who has some knowledge of the problem and techniques is most suitable.

Such projects are not usually suitable for young children.

The group must be concerned about the problem and sensitive to its solution.

4. THE CLEANING METHODS:

The methods used for removal of graffiti depend on FOUR vital factors:

- the NATURE OF THE SURFACE on which the graffiti occurs
- the MATERIALS which have been used
- the METHODS available for graffiti removal
- the AMOUNT OF WEATHERING to which the surface is exposed

Graffiti occurs on two types of SURFACE: NATURAL and MAN-MADE.

NATURAL SURFACES:

Always use the GENTLEST possible method of removal; start with sponges and progress to brushes and chisels only in extreme circumstances. Use lots of water. Use chemicals sparingly if at all. NEVER paint over graffiti.

MAN-MADE SURFACES:

e.g. a concrete bridge.
Scrub initially, even with wire brushes.
If necessary paint over the graffiti with wet cement or a suitable PVA.
Sandblast the surface if necessary.

Materials for cleaning are cheap and easily obtainable. They range from sponges and brushes of varying hardness to water and chemical paint removers.

5. ESSENTIAL ADDITIONAL AIDS:

Always keep a photographic record of your project, especially the Befores and Afters. Keep a written record of methods that worked and others that were

unsuccessful. Follow-up your project with monitoring and repeat-exercises as appropriate. Try to ensure that there are some controls to reduce further graffiti occurrence e.g. notices, fines, etc.

Write articles about your projects and talk to people about the problem and its solution as both help to educate people.

TABLE 1: Summary of graffiti removal methods appropriate to Golden Gate Highlands National Park

SURFACES GRAFFITI	CAVES			EXTERNAL SURFACES Hard Weathered
	Soft Grey/White	Hard White/beige/pink	Crusts	
Scratchings/ engraving using sandstone	1. Brush dry - softest brush - sponge scourer	1. Brush wet - sponge scourer - medium brush 2. Rinse	1. Brush dry - softest brush 2. Brush wet - sponge scourer 3. Rinse	1. Brush wet - hard brush 2. Rinse
Charcoal	1. Brush dry - softest brush - sponge scourer	1. Brush wet - sponge scourer - medium brush 2. Rinse	1. Brush wet - sponge scourer - softest brush 2. Rinse	1. Brush wet - hard brush 2. Rinse
Ball-point and other pens	1. Brush dry - softest brush - sponge scourer	1. Brush wet * - sponge scourer - medium brush 2. Rinse * Methylated spirits may be necessary on ball-point ink	1. Brush dry - sponge scourer - softest brush 2. Brush wet - sponge scourer 3. Rinse	1. Brush wet * - hard brush 2. Rinse * Methylated spirits may be necessary on ball-point ink
Paint	1. Brush dry - soft brush 2. Flake off surface: - sharp-pointed knife 3. Nova paint stripper: * - fine, natural-bristle brush 4. Rinse	1. Nova paint stripper: * - fine, natural-bristle brush 2. Lift with sharp blade 3. Wipe 4. Rinse 5. Brush wet 6. Rinse	1. Flake off surface: - sharp-pointed knife 2. Nova paint stripper: * - fine, natural-bristle brush 3. Lift with sharp blade 4. Wipe gently 5. Rinse	1. Nova paint stripper: * - fine, natural-bristle brush 2. Lift with sharp blade 3. Wipe gently 4. Rinse
Engravings	1. Brush dry: - softest brush - sponge scourer - sandstone if shallow engraving	1. Brush dry: - sandstone if shallow engraving - hard brush - wire brush 2. Flake surface * - hammer and chisel	1. Brush dry 2. Flake surface * if deep engraving: - hammer and chisel	1. Brush dry 2. Flake surface * if deep engraving: - hammer and chisel

NOTE:

1. All cleaning must commence with the gentlest methods and progress to more stringent.
2. Use extreme methods (+) only when more gentle methods fail.
3. Avoid the use of chemicals (especially in caves) unless absolutely essential.

4. Rinsing is very important in all wet methods - large quantities of water are necessary.
5. Every effort must be made to blend all cleaned surfaces into the surrounding rock by for example spreading cave floor dust on walls of the same colour and texture.

These methods were adapted and developed considerably for application in dolomite caves where the situation is far more fragile; eternally dark and frequently crystal coated.

APPENDIX 2

DETAILS OF SENSORS USED WITH MCS 120-02 EX DATA LOGGERS AT THE
MAIN CAVES AND BATTLE CAVE STUDY SITES (after MC Systems, 1992)

RELATIVE HUMIDITY AND AIR TEMPERATURE (with sintered filter)

Sensor:	MCS 174
Power Requirements:	4.8 to 6.5V, at 300μA

RELATIVE HUMIDITY SENSOR

Measuring Range:	0 to 98% RH
Operating Temperature:	-10 to +50°C
Maximum Air Velocity:	20m.s ⁻¹
Accuracy:	±2% RH at 20°C
Temperature Coefficient:	<2% RH deviation between -10 and +50°C
Response Time:	10 seconds
Output Signal:	Analog output voltage, proportional to relative humidity

TEMPERATURE SENSOR

Measuring Range:	-20 to +50°C
Accuracy:	±0.1°C
Resolution:	±0.1°C
Response Time:	20 seconds
Output Signal:	Analog output voltage, proportional to temperature

ROCK TEMPERATURE

Sensor:	MCS 153
Measuring Range:	-20 to +70°C
Accuracy:	±0.2°C at 25°C
Resolution:	±0.1°C
Output Signal:	Analog output voltage proportional to temperature
Power Requirements:	4.8 to 6.5V, at 300μA
Size:	4mm diameter x 25mm

Mass: 50mg

TOTAL INCOMING RADIATION

Sensor: MCS 155-1

Accuracy: Analog output voltage, proportional to radiation

Size: 25mm diameter x 35mm

Mass: 50mg

ROCK SURFACE MOISTURE

Sensor: MCS 158-1 (Leaf Wetness Sensor)

Measuring Range: 0 to 100% moisture

Operating Temperature: -10 to +50°C

Accuracy: Relative only

Response Time: 2 to 20 minutes depending on coating

Size: 35 x 25 x 10mm

Active Area: 6cm²

SOIL MOISTURE

Sensor: MCS 159 (Leaf Wetness Sensor)

Measuring Range: 0 to 100% moisture

Operating Temperature: -10 to +50°C

Accuracy: Soil dependant, relative only

Response Time: 5 to 20 minutes depending on coating

Size: 70 x 18 x 4mm

Active Area: 25cm²

WIND DIRECTION

Sensor: MCS 176-2

Measuring Range: 0 to 45 m.s⁻¹

Operating Temperature: -20 to +50°C, non-freezing

Threshold: 0.5m.s⁻¹

Accuracy:	$\pm 1.5\%$ from 0-360°, $\pm 1\%$ at 180°
Turning Radius:	300mm
Vane Size:	250mm x 70mm
Output Signal:	Analog output voltage, proportional to angular rotation
Power Requirements:	2 to 2.5V, 200 μ A
Vertical Height:	120mm
Mounting Requirements:	25.4mm ID
Weight:	1.0kg

WIND SPEED

Sensor:	MCS 177-3
Measuring Range:	0 to 45 m.s ⁻¹
Operating Temperature:	-20 to +50°C, non-freezing
Threshold:	0.5m.s ⁻¹ , sealed bearings
Accuracy:	$\pm 2\%$, full scale
Turning Radius:	150mm
Cup Size:	70mm diameter
Output Signal:	CMOS logic pulses; internal digital divider which can be set from 1 to 32
Power Requirements:	4.8 to 6.5V, 5 μ A
Vertical Height:	160mm
Mounting Requirements:	25.4mm ID
Weight:	0.5kg

APPENDIX 3

THE DESIGN AND OPERATION OF A CABINET FOR SIMULATING A
WEATHERING ENVIRONMENT (extracted from Hall, *et al.*, 1989)

The basic design specifications for the cabinet used are:

- a. it could work in the temperature range $+70^{\circ}\text{C}$ to -50°C ,
- b. it would allow sequences of temperature cycles of a wide range of duration, magnitude, frequency and rate of change,
- c. data output would be displayed on both VDU and printer and stored on disk
- d. data could be read at varying pre-specified intervals (range 5s to 99 min) throughout the cycle sequences,
- e. facilities would be available for a range of sensor types,
- f. a feedback system continuously checked the programmed sequence and instituted corrective action where necessary,
- g. programming (in Basic) was very simple,
- h. the machine needed minimal attention,
- i. mechanical and electronic equipment protection be built-in,
- j. data output contained experiment time, programmed status and actual status together with other sensor data outputs.

The cabinet based upon the above broad specifications, was built utilising a Commodore 64 PC which, via additional hardware, acted as the central control unit (Fig. A3.1). The PC also provided the facility for the writing, storing and input of the main control programmes. The programmed temperature was updated every 10s, compared with the actual cabinet temperature and then a power controller adjusted the heating or cooling.

Output from the six thin film platinum resistance temperature sensors was sequentially selected and converted into digital values which were stored in the PC. Information from the humidity sensor was converted to a linear analogue output and switched into the analogue to digital converter at the appropriate time. A variable infra-red lamp controller to supply surface heating could be activated via software control. If an 'out of range' condition occurred for any reason for a period greater than 3 min then the whole system is automatically shut down.

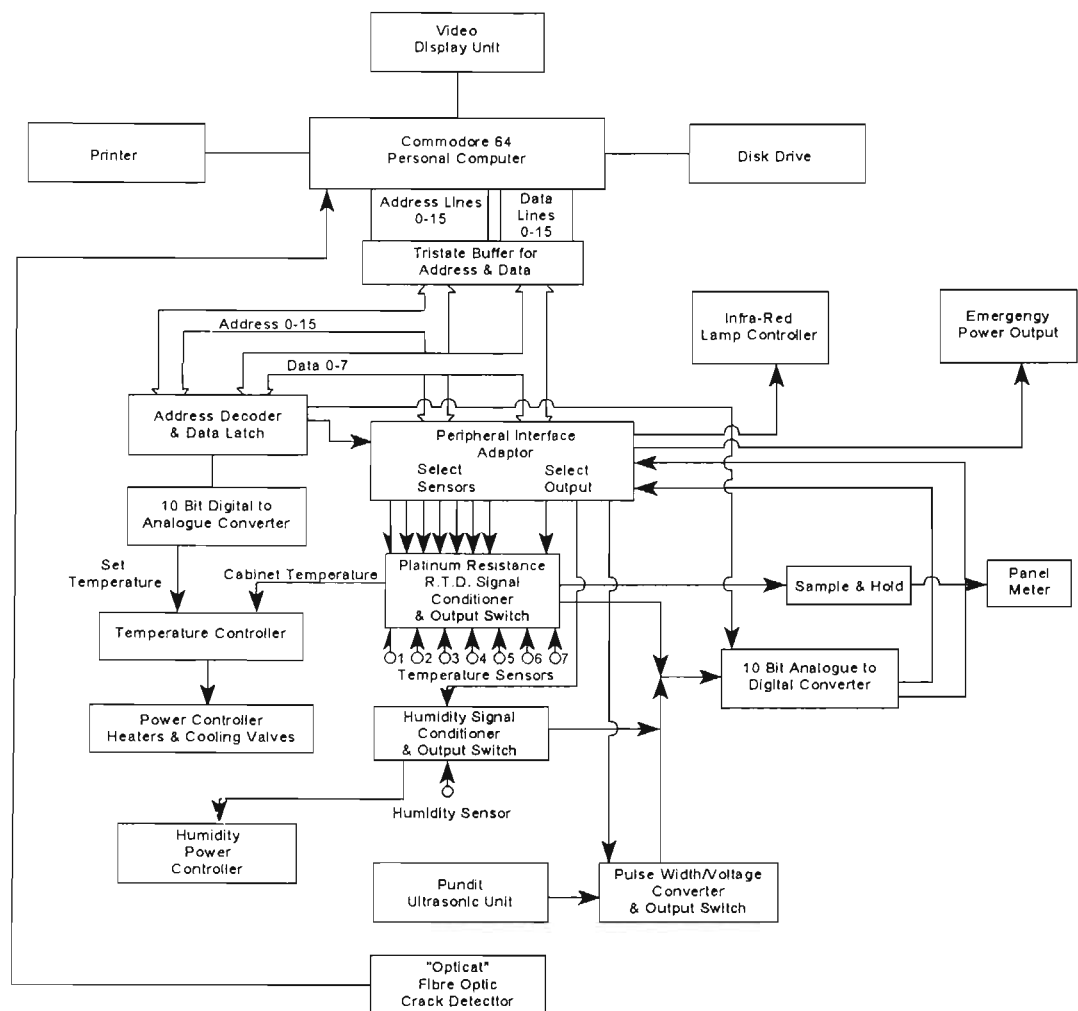


Figure A3.1: Circuit diagram of the simulation cabinet control system (after Hall, *et al.*, 1989).

The cabinet itself was constructed with an outer body of 'Zintex' and an inner shell of Type 316 stainless steel (with argon welded seams to make it watertight), with 100 mm of expanded polystyrene foam between the two as an insulator. Refrigeration was provided by a 1-HP compressor utilising 1 kg of Freon 502 as refrigerant. The liquid 502 was divided into two streams (Fig. A3.2), one passed through an expansion valve into 6 m of 10-mm diameter copper tube, supported in wooden slats, that rested upon the base of the box, providing the ground cooling. This was supplemented by the second stream that gave, aided by a fan, air cooling. Defrosting of the air chiller was achieved by hot gas injection, a process initiated by the PC every 6 h for a period of 7 min. Heating was provided by a commercially available heating element whose power output was regulated by the PC and which can be balanced against the cooling system.

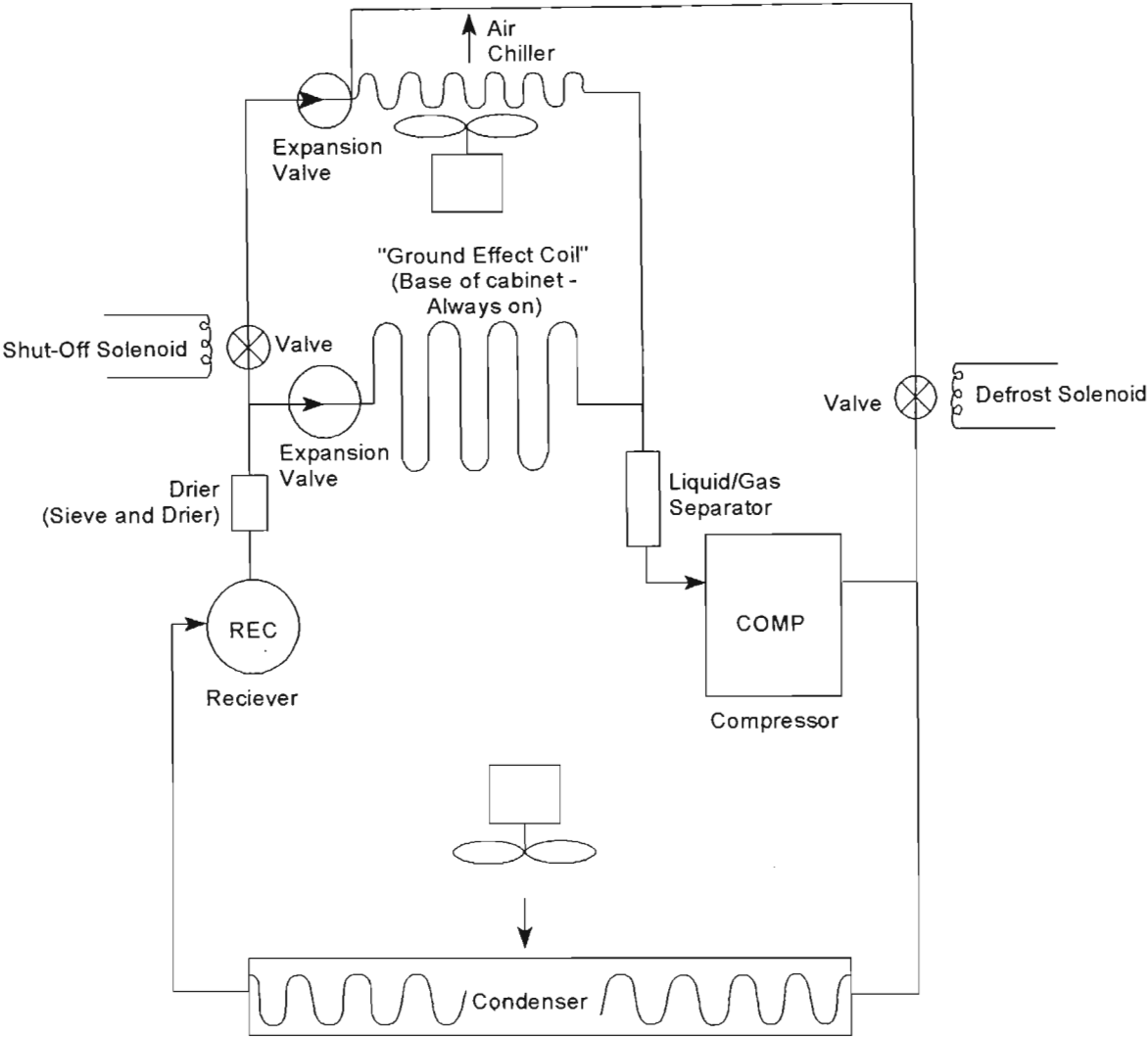


Figure A3.2: Refrigeration system of the simulation cabinet (after Hall, *et al.*, 1989).

APPENDIX 4

MANAGEMENT POLICIES OF THE NATAL PARKS BOARD
ROCK ART ADVISORY COMMITTEE
FOR ROCK ART IN THE KWAZULU/NATAL DRAKENSBERG
(Mazel, 1982; Natal Parks Board, 1994).

The following is a summary of management policies which were decided upon at the first meeting of the Natal Parks Board Rock Art Advisory Committee on 15 June 1994:

Recording of rock art sites:

The following policies are to be implemented with regard to the recording of the positions of each site. This system has already been used over most of the KwaZulu/Natal Drakensberg, but still needs to be completed in the Giant's Castle region and in the region controlled by the KwaZulu Department of Nature Conservation. Each site is to be numbered and recorded in a digital data base. At places where rock art is found a number on steel strip is to be placed at the left hand side of the site at knee height.

Monitoring of rock art sites:

Each site is to be visited at least once a year by personnel of the Natal Parks Board and the KwaZulu Department of Nature Conservation. Important sites will be visited more frequently with the most valuable and vulnerable sites being visited once or twice a month. During site visits, records are to be made of new signs of vandalism, the use of the site and fire damage. The criteria for evaluating the importance of rock art sites are from a study by Mazel (1982) and include the scientific significance of the site, its accessibility, the local path network, its visibility, its location with respect to tourists, and human usage. A points system is used which is weighted in favour of the scientific importance of the site and this category considers: the number of paintings at a site, the importance of the particular paintings (i.e. if they are unique, rare or complex), surface artefacts and archaeological deposits.

Reporting procedure:

The following procedure is to be followed with respect to monitoring rock art sites:

1. An annual plan is to be developed by the Officer in Charge of each area.
2. Personnel are to visit the sites and record the relevant information.
3. Personnel are debriefed.
4. Information is to be sent to the department headquarters for processing.
5. Action will be taken if it is required and possible.

APPENDIX 5

DRAFT DOCUMENT FROM THE NATIONAL
MONUMENTS COUNCIL OF SOUTH AFRICA.

MINIMUM STANDARDS FOR ARCHAEOLOGICAL SITE MUSEUMS
AND ROCK ART SITES OPEN TO THE PUBLIC (Deacon, 1992a).

(Note: The document was copied using HP ScanJet IIC scanner, and in the reproduction the pagination has changed and so is not identical to the original.)

NATIONAL MONUMENTS COUNCIL

MINIMUM STANDARDS FOR ARCHAEOLOGICAL SITE MUSEUMS AND ROCK ART SITES OPEN TO THE PUBLIC

Archaeological sites, including those with rock paintings or rock engravings, are especially vulnerable to damage caused unwittingly by visitors. Anyone making a site available to the public, either as a formal site museum or simply as a place of interest, should therefore take basic precautions to ensure the safety of the site and its contents. Expert advice should be sought from the National Monuments Council and/or from one of the museums or university departments listed below. No site should be opened to the public without a professional investigation that includes complete documentation in case of damage. Liaison with the local publicity office and regional services council is recommended. The following minimum standards are suggested.

1. Approach to the site

Arrangements for visiting -

- if the site is open at all times, there should be adequate signposting;
- if the site is kept locked, there should be clear arrangements for the collection and return of a key;
- if it is open only by appointment, there should be someone to guide people to the site and that this person has had clear instructions on what to do and say.

Provision for vehicles -

- there should be an adequate and well-maintained road with off-road parking;
- the parking should not encroach on the site - vehicles should not park closer than about 100 m from the edge of the site;
- the parking area should be marked by a barrier between it and the start of the path.

Facilities -

- there should be a litter bin at the parking lot and it should be emptied regularly;
- consider the need for toilets and the supply of refreshments and other facilities such as a shop, public telephone, rest room, etc., depending on the number of visitors expected;
- consider the need to establish an interpretive centre separate from the site, where people can see the excavated artefacts in a museum-type situation and where you may be able to store material, provide accommodation, etc.

Design of the path -

- make sure that the path to the site is distinct;
- the path should follow the contours to avoid unnecessary erosion of the hill slope;
- make sure there are discreet signs to indicate direction where the path crosses a rocky area;
- the path should not enter the site at a position where the deposits or the rock art can be damaged;
- the introductory notice board should be displayed at the end of the path and the beginning of the site, where it will not interfere with good photographic views.

2. Protection of the site

The principles for protecting archaeological deposits and sites are that the methods used should be effective, reversible and recognisable yet harmonious. It is important that visitors get the impression that the site is being well looked after, so it should be clean and as 'natural' as possible.

If you take, or expect to take, more than 50 people a year to the site, there should be:

Provision of information -

- at least an introductory notice board explaining that the site is protected by law;
- where appropriate, a display with more detailed information on what can be seen at the site and what it means;
- a visitors' book in a container to protect it from the weather, or at the farmhouse or other convenient place;
- an explanatory leaflet or pamphlet that is specific to the site.

Protection of the art -

- a psychological or a physical barrier could be set up between the visitor and the rock art or display area in the form of anything from a low wooden railing to a fence that encloses the entire site, depending on the vulnerability of the site or precautions necessary for the safety of the visitor;
- every effort should be made to remove graffiti from the site as it attracts more graffiti. A permit from the National Monuments Council is required to remove graffiti at a rock art site.

Protection of the surface and deposits -

- an effective cover should be put on the floor of the site to prevent dust being kicked up and damaging rock art and to stop people picking up material on the surface. Cover can be provided by a boardwalk, geotextile, commercially crushed stone (the layer should be at least 30 mm thick) or medium to large slabs of natural rock from the surrounds of the site. Plastic sheeting can be used to seal off the natural surface from the covering stone or rock but must be completely covered or it will degrade. Do not cover the original surface with soil from the surrounding area as it will not be possible to distinguish this from the natural deposit at a later date;
- there should be effective shoring up of excavated sections to prevent collapsing and to prevent people from entering the excavated area. This should be done in consultation with the National Monuments Council.

Regular maintenance

- provision should be made for regular visits to the site by the manager or property owner to check on litter, damage, graffiti, etc.
- there should be regular monitoring of vegetation around the site so that, if necessary, - measures can be taken to protect it against trampling, - potentially dangerous plants such as those with thorns can be controlled, dead wood can be removed so that damage by veld fires can be avoided.

Avoid having:

- a litter bin on site unless very large groups are catered for;
- braai or picnic places on the site or right next to it;
- camping places within 500 m (or preferably 1 km) of an archaeological site;
- plastic sheeting or plastic bags exposed to view unless there is no other option;
- concrete barriers or surfaces;
- metal poles or wire in contact with rock shelter or cave walls as they rust and stain the rock;
- a sandy surface on the outer side of a fence as this will be eroded by people walking there and the fence will be under-cut.

APPENDIX 6

PAMPHLET FROM THE NATIONAL MONUMENTS COUNCIL OF SOUTH AFRICA FOR THE 1994 ENVIRONMENTAL AWARENESS WEEK.

DISCOVER THE WORLD OF ROCK ART AND HELP PRESERVE SOUTH AFRICA'S OLDEST ARTISTIC TRADITION (National Monuments Council, 1994).

Discover the World of Rock Art



*and help preserve
South Africa's
oldest artistic tradition*

This pamphlet has been published by the National
Monuments Council in the interests of
heritage conservation

P037

WHAT IS ROCK ART?

The San or Bushman rock paintings and rock engravings of southern Africa were part of a remarkable religious tradition. The art was not simply decorative or a record of daily life. Its purpose was a deeper one.

The trance dance was the central religious ritual of the San. Shamans, or medicine people, used supernatural power obtained during trance states to make rain, heal the sick and maintain social harmony.

Many of the rock paintings and engravings are depictions of the visions experienced while in trance. Others depict ritual occasions or the animals whose power the shamans hoped to use.

The art is also a monument to the Bushmen who struggled to retain their rights and their land. It is therefore part of the history of South Africa. Please don't let it be destroyed!

WHY CONSERVE ROCK ART?

- * It is artistically and intellectually sophisticated.
- * The tradition is at least 27 500 years old.
- * It is fragile and has already been damaged through ignorance and vandalism.
- * It can never be repaired or replaced.

WHAT CAN YOU DO?

BE A WATCHDOG!

- * Make the law work. The National Monuments Act (Act No 28 of 1969) protects all rock art sites. Anyone found guilty of removing or damaging rock paintings or engravings can be fined up to R10 000, or be imprisoned for two years, or both. If you see anyone damaging rock art, report them to the police immediately.

- * Remember that water and other substances will destroy the paintings and engravings. Salts are drawn to the rock surface by water. The salts then expand and weathering is accelerated.
- * Make people aware that touching the painted surfaces or rubbing or chipping at paintings or engravings will destroy them.
- * Remember that rock paintings and engravings are works of art. Don't put your name or any other writing on or near to them.
- * Rock art must not be removed from its original setting as this destroys much of its meaning.
- * Dust and soot from fires obscure rock paintings, so avoid using rock art sites as camping places.
- * Rock shelters with paintings should not be used as kraals as animals rub against the painted surfaces.
- * Join an organization that promotes rock art conservation.

FOR FURTHER INFORMATION approach any of the following institutions:

Albany Museum, Somerset St, Grahamstown, 6140
Department of Archaeology and the Archaeology Workshop,
University of Cape Town, Private Bag, Rondebosch, 7700
Department of Archaeology, University of Stellenbosch,
Stellenbosch, 7600
McGregor Museum, P O Box 316, Kimberley, 8300
Natal Museum, Loop St, Pietermaritzburg, 3200
National Museum, P O Box 266, Bloemfontein, 9300
National Monuments Council, P O Box 4637, Cape Town, 8000
Rock Art Research Unit, Department of Archaeology, University of
the Witwatersrand, P O Wits, 2050.
Rocustos (an organization for Rock Art Custodians), National Cultural
History Museum, P O Box 28088, Sunnyside, 0132
S A Archaeological Society, P O Box 15700, Vrolijkheid, 8018
South African Museum, P O Box 61, Cape Town, 8000
S A Rock Art Research Association, P O Box 81292, Parkhurst, 2120
Soutpansberg Rock Art Conservation Group, P O Box 168,
Louis Richardt, 0920

Copy of rock painting from the north-eastern Cape reproduced by
courtesy of the Rock Art Research Unit, University of the
Witwatersrand.



APPENDIX 7

DRAFT DOCUMENT FROM THE NATIONAL
MONUMENTS COUNCIL OF SOUTH AFRICA.

GUIDELINES FOR RECORDING ROCK PAINTINGS
AND ENGRAVINGS (Deacon, 1992b).

(Note: The document was copied using HP ScanJet IIC scanner, and in the reproduction the pagination has changed and so is not identical to the original.)

National Monuments Council

GUIDELINES FOR RECORDING ROCK PAINTINGS AND ENGRAVINGS

The Science Committee of the National Monuments Council (NMC) is responsible for the implementation and monitoring of Section 12 (2A) and (2B) of the National Monuments Act (Act No. 28 of 1969, as amended) which deals with the protection of rock art and archaeological, palaeontological and historical sites and objects and shipwrecks.

The Section relevant to rock art states that:

no person shall destroy, damage, excavate, alter, remove from its original site or export from the Republic . . . any drawing or painting on stone or a petroglyph known or commonly believed to have been executed by Bushmen; or any drawing or painting on stone or a petroglyph known or commonly believed to have been executed by any other people who inhabited or visited the Republic before the settlement of the Europeans at the Cape ... without a permit from the National Monuments Council.

In the past the main role of the NMC in rock art conservation has been to encourage research into preservation methods, to attempt to protect rock art by not publicising it, and to erect noticeboards at selected sites. Permits have been required for the export of original examples of rock paintings and for the removal of samples of paint for dating and other analyses, but not for recording.

However, as damage can be done to paintings by tracing them and to engravings by making casts, permits from the NMC may be required. The following guidelines are designed to show how a contribution towards rock art recording and conservation can be made without using these potentially harmful methods. The paintings and engravings are not put at risk and the site records can be updated in museums where the information is kept in perpetuity.

The last time a list of South African rock art sites was drawn up was in the 1950s (Van Riet Lowe 1956). It included 1938 farm names in South Africa, Lesotho, Swaziland, Botswana and Namibia. This is undoubtedly a small fraction of the actual number of sites, for each farm probably includes more than one and wherever detailed surveys have been undertaken the number has multiplied several fold.

The National Monuments Council encourages everyone who is interested in enriching our knowledge of rock art in South Africa to participate in a national recording programme.

AIMS

The main aim of the recording project is to compile an accurate list of rock art sites in South Africa.

Members of the public can play an important role by systematically searching areas of their choice and by recording the location of sites and the number and nature of the rock paintings or engravings found there.

This kind of research does not require expensive equipment or unusual skill, but if it is to be useful it must be done accurately and systematically in collaboration with a museum where the records will be kept for the future.

BEFORE YOU START

1. As the data will be kept in a museum, you should make contact with the archaeologist there as soon as possible.
2. Make your intentions known and ask which area needs to be surveyed In your region.
3. Ask for one or more copies of the museum's site recording form and familiarise yourself with the information required.
4. Find out about their site numbering system so that you do not cause confusion by developing a system of your own that is incompatible.
5. Obtain copies of the 1:50 000 map sheets of the area you intend working in. They cost R5,00 each at the Trig Survey office or Government Printer.
6. It is useful to have a compass, a soft pencil and an eraser when you are ready to plot the position of a site on the map, and to have two measuring tapes and graph paper for making a sketch plan of the site.
7. Plan where you want to survey and divide the area into sections so that you can do your search systematically.
8. Make sure you have permission from the landowner/s before you begin looking for sites on a property.

SITE RECORDING

1. As the terrain varies greatly from one part of South Africa to another, it is difficult to prescribe the way in which a search path should be planned as it depends on accessibility. Whatever route you take, mark it on your 1:50 000 map so that you know where you have searched even if there are not sites there.

2. Use a numbering and filing system for your records so that the same site number can be used in your notebooks, on your maps and site record sheets and on your photographs.
3. In the field, mark the position of sites as accurately as possible on the 1:50 000 map. Give the site a number. It is useful to write the site number on the right-hand margin of the map sheet at the same latitude. This makes it easy to check the last number on the list, and to re-locate sites. It is best to do this in pencil so that additions and corrections can be made more easily.
4. Back home, file the site record sheets according to the map reference number. It is useful to have a card index for quick reference as well, or to record the information on a computer database. Send copies of your site record sheets to the museum.
5. Where appropriate, draw a scale plan of the shelter or rock face. This can be done by running a measuring tape across the mouth of the rock shelter and then measuring the distance from the tape to the back wall at right angles at regular intervals and sketching the shape of the back wall onto graph paper. Number the painted panels and give a brief description of each. Note the panel numbers on your plan and photos or slides so they can be keyed together.

Rock engraving sites sometimes stretch over several square kilometres and decisions have to be made about where one site begins and other ends. It is useful to give each engraved rock a number and to do a sketch map of their distribution on the site.

6. Do not camp in painted caves and never light fires there. Take care not to stir up dust as you walk around.
7. Never touch painted surfaces or put water or any other substance on them. Do not put water or any other substance on engravings either.
8. Do not attempt to remove graffiti without professional guidance.

ROCK ART RECORDING

1. The purpose of rock art recording is to make a copy of the image for study and future records without damaging the original. The accuracy of the copy will vary with the method used and the experience of the copier and the degree of accuracy attained will depend on the purpose for which it is required.
2. All recording programmes should therefore start with methods that are the least damaging. Those that could affect the physical state of the paintings or engravings should not be attempted.
3. The recorder should have a clear idea of the purpose of his or her recording programme and plan for both what is required and what will be done with the recordings after they are completed. If you are interested only in a general record of what kinds of paintings or engravings are at the site, a checklist is useful. Do you

wish to record graffiti as well? Is the rock art in danger of being destroyed or damaged by development or encroachment?

Rock paintings

Recording methods are listed below in the order in which they should be used, from those involving least contact with the painted surface (photography) to those involving more complex methods.

1. In the majority of cases, photography will be the most suitable method. Remember:
 - as colour prints do not retain their true colour beyond 10-20 years, it is advisable to use this film only for short-term purposes;
 - colour slides have a longer life than colour prints, as long as they are kept in a dust-free environment and at a cool and equable temperature; they can be digitised for image enhancement;
 - black and white photographs last the longest, but as they do not record colours, they should be taken in conjunction with colour slides;
 - video cameras are becoming more widely available. Although the quality of the images is generally not as good as with still photography, as video film quality improves it will be possible to digitise the images and store them electronically;
 - for general recording purposes, it is useful to have a photograph or slide of the site as well as a series taken systematically from left to right. Details can then be filled in with close-up shots;
 - if photography is the only recording method you are using, always use a scale on at least one photograph of the panel. It can be taken out for publication purposes, but it can never be inserted accurately afterwards;
 - use a simple numbering and filing system for your slides and prints, make sure the negatives are labelled as well as the prints, and keep an on-going list of photographs you have taken; remember to remove all photographic litter from the site before you leave.
2. Other recording techniques that do not involve contact with the rock face include photogrammetry, camera lucida and scale drawings. All involve skill which improves with practise, and photogrammetry and the camera lucida require specialist equipment.
3. A combination of photography and painting has been used successfully by some recorders. A black and white photograph is printed at a scale of 1:1 and is then treated to reduce contrast and to allow the paper to take paint. It is then painted either on-site to ensure accurate colours or at home where colours are matched to a chart or to slides/photographs. It is a useful method in that it does not involve contact with the rock surface, but may have a limited lifespan.

4. Tracing rock paintings is not as easy as it looks. It requires a great deal of patience as well as skill, not only in tracing in the field, but also in re-drawing. Do not attempt to trace unless you have had professional guidance. A bad tracing is of no use to anyone.

Rock engravings

1. Black and white photography gives excellent results and can be used in conjunction with colour slides. Do not use chalk or any other material to highlight the engravings for photographic purposes as it introduces foreign material and is sometimes difficult to remove.
2. Tracing can be done most efficiently with clear plastic (the kind used for covering school books) and permanent pens (the kind used for overhead projectors). Tracings should be transferred to tracing film using indian ink as soon as possible because the ink of the overhead pens wipes off the plastic when it gets dry and brittle. Tracing should not be done if the rock surface is friable.
3. Rubbings, using carbon paper on airmail or rice paper, have been made successfully on well defined engravings where the rock surface is dense. As rubbings can damage the engravings, however, it is recommended that they be done only under supervision.
4. Rubber latex and plaster of paris casts both damage the engraved surfaces and leave residues on the surrounding rock and should not be used. Less destructive products are available and have been used successfully elsewhere, but all will remove particles of rock and organic material trapped in the engraved surface. As this may be used for dating, do not take casts unless this can be done with professional supervision.

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Draft
Janette Deacon
December 1992
9/4/6

APPENDIX 8

PAMPHLET FROM THE NATURAL HISTORY MUSEUM.

PREHISTORIC PEOPLE (Natural History Museum, 1985).

Centre information sheet

Natural History Museum

Classroom activities

PREHISTORIC PEOPLE



Cave paintings

Prehistoric humans painted pictures in caves and rock shelters throughout Europe. The artists often used a variety of colours - reds, blacks, yellows and browns. Such works can be reproduced quite simply in the classroom for your project on prehistoric people.

Plaster of Paris to make a block to paint on
Things you will need -

- Plaster of Paris
- Water
- Spoon
- Powder paint
- Jam board

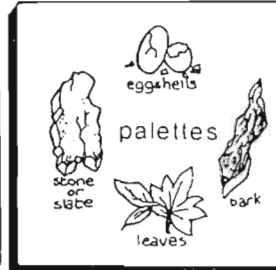
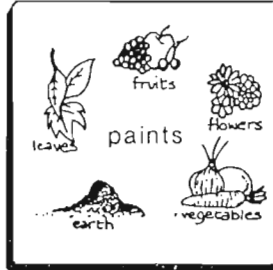
1. Mix plaster with water to make a thick paste and spread it on the walls of plasticine around the board.

2. Add powder paint to the plaster as recommended on the packet to give a stone-like effect.

3. Press the plaster onto the board and leave to set.

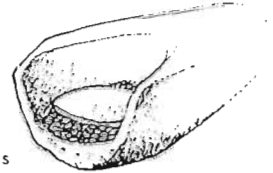


- 3 Early people used natural materials as paints and tools. Here are some ideas that you can try - maybe you can invent some more.

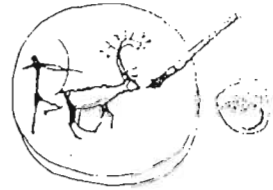


- 4 To make the paints crush the materials you have selected between stones to obtain the pigments.

Pigments were often mixed with animal fats to thicken them. This is necessary if you want to paint on a non-porous surface. Early artists painted pictures of the animals they hunted - horse, bison, ox, deer, mammoth, antelope, rhinoceros, lion and wolf. Occasionally crude drawings of the hunters themselves were made.



Now use the paints and tools to create a prehistoric picture on the plaster block.

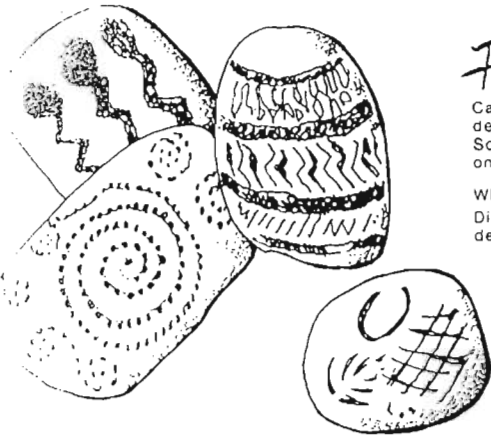


Painted stones

Caves were also decorated with abstract designs - combinations of dots, lines and grids. Sometimes these striking symbols were painted on stones.

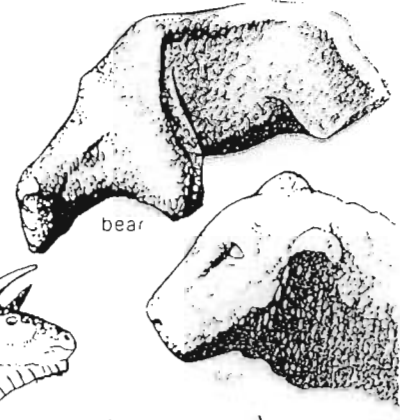
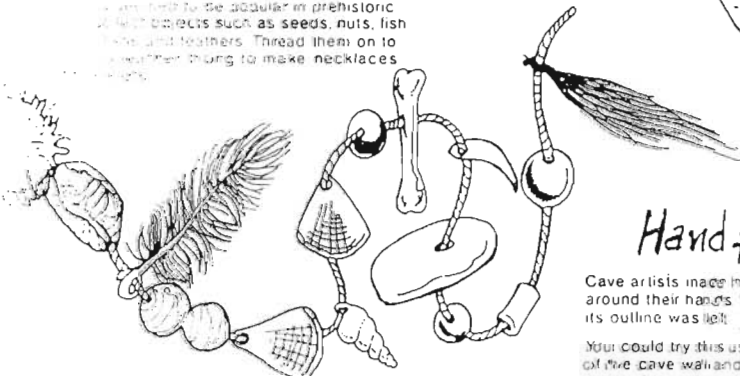
What could these symbols mean?

Discuss this with your class and ask them to design and paint their own symbols on stones.



Jewellery

Simple objects such as seeds, nuts, fish bones and feathers. Thread them on to make necklaces and bracelets.



Clay animals

Beautiful model animals fashioned in clay were probably made in prehistoric times. You could easily make these in the classroom.

Handprints

Cave artists made handprints by spraying paints around their hands. When the hand was removed, its outline was left.

You could try this using paper or plaster instead of the cave wall and by drawing the paint from the surface of a leaf through a straw or blowing it from a feather.



ADDENDUM

After this thesis had been completed and bound, a publication was received from Australia (Rosenfeld, 1988), which is of significance to this study (please note that this publication was requested in September 1993). According to Walsh (pers. comm., 1994) this is the most comprehensive document yet produced relating to the conservation of rock art.

While the document by Rosenfeld (1988) is comprehensive, the problem of a lack of field recorded data can again be highlighted. Rosenfeld (1988) acknowledges the importance of process studies in research into rock art deterioration, especially in that the work of Soleilhavoup (1979a, 1979b, 1981) in north Africa is highlighted. There are, however, few data relating to any such research or any information relating to detailed process studies. The role of moisture is considered by Rosenfeld (1988) to be particularly significant in the deterioration of rock art and several processes relating to the moisture regime are mentioned (e.g. salt crystallisation, hydration, biological weathering, chemical alteration, solution and the formation of patinas). Moisture movement is discussed in some detail, but no reference is made to the way in which it is affected by rock properties. This book again highlights the contention in this study that there is a need for further research relating to the processes of rock weathering.

There has been considerable success in overcoming the problem of moisture flowing over rock art by the installation of silicone drip-lines in Australia (Rosenfeld, 1988). While other methods of rock art preservation are discussed in some detail by Rosenfeld (1988), there is no reference to a permanent solution to the problem of decaying rock art. Silanes are considered to be a potential solution for preserving rock art but much research is required to test their effectiveness (Rosenfeld, 1988).

The discussion above is critical, so as to highlight the need for further research, particularly with regard to rock weathering processes and preservation of rock art. It is believed that the target audience for the publication by Rosenfeld (1988)

includes the general public (in a similar way to that by Brunet, *et al.* 1990); it cannot, therefore, include too much detail and, hence, may not represent the full extent of research in Australia. The above publication, nevertheless, represents more than has been done in South Africa, with respect to rock art conservation and preservation, and should be held up as an example.

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