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Marker, M. E.

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Bernard Price Institute for Palaeontological Research
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SOME PROBLEMS IN USING LANDFORMS AS EVIDENCE FOR CLIMATIC CHANGE

by

M.E. Marker

Fort Hare University, Private Bag X1314, Alice 5700

ABSTRACT

Landforms are used as evidence for past climatic conditions on the basis of morphoclimatic explanation. Problems arise because the relationships from climatic parameters through process to landforms are not direct. The problems inherent in employing landform evidence are discussed under the headings: Recognition, Interpretation, Application, Correlation and Chronology.

It is concluded that certain landforms provide unequivocal evidence for climatic change even though landform evidence must always be circumstantial. An individual landform alone does not prove climatic change although an entire assemblage exhibiting similar tendencies might. Where, however, evidence from other areas and other lines of evidence also point to the same conditions, then the conclusions may be accepted more securely. Landform evidence has a place in Quaternary studies, but it must be used with caution.

INTRODUCTION

Landform explanation on a morphoclimatic basis has a long history. Morphoclimatic explanation is founded on the premise that form results from process which is itself directly dependent on climate. Belief that changes in climate will cause changes in landforms follows logically. It is a small step further to argue in reverse that landforms store information about past climates. Agassiz' mapping of the northern extent of Quaternary Alpine glaciation in Europe was based on this assumption.

Acceptance of climatic control of process is fundamental; the most significant parameters are precipitation and temperature. Precipitation includes amount, type, intensity and seasonality, and temperature is important for its control of evaporation rates, chemical weathering and soil reaction rates. Climate also affects process indirectly through vegetation, in particular type, height and density. I intend to expand on these interrelationships and to indicate some of the difficulties and dangers that are associated with an uncritical acceptance of the basic assumptions of morphoclimatic explanation.

SOME CLIMATIC FACTORS

Climatic parameters are highly variable from hour to hour, from day to day, from season to season and over longer time periods. That much of southern Africa is affected by 20 year cycles from wet to dry is now accepted, but within these cycles individual years depart from the trend (Tyson and Dyer 1975). There is furthermore no reason to believe that South Africa escaped the longer wave length and bigger amplitude cycles known from the rest of the world. In fact considerable evidence is accruing that long return fluctuations are an inherent part of the southern African system. The climatic fluctuations considered in this paper are restricted to long periodicity and large amplitude fluctuations similar to those that caused glacial-interglacial events in northern latitudes.

The first aspect to be considered, having accepted the existence of climatic fluctuations according to this definition, is the climatic impact of such fluctuations on southern Africa. Southern Africa is a low latitude and relatively low altitude subcontinent. Only the Lesotho plateau remnants above 3 000 m can be classed as high altitude environments. From world glacial temperature gradients it can be seen that southern Africa lies in latitudes where the degree of temperature reduction was small (fig. 1). In addition, the direct effects of temperature changes on landform development are relatively slight except on either side of 0° Centigrade. The climatic parameter of greatest significance today is precipitation, and this was probably also the case in the past. Evidence already to hand suggests that climate has been both wetter and drier than today.

The present climate is seasonal. It is controlled by the latitudinal shift of the pressure belts. The actual climate experienced at a site is a function of

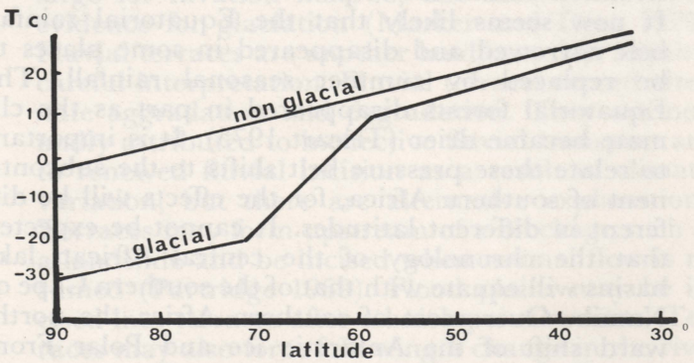


Figure 1. Present-day latitudinal mean temperature gradient compared to a glacial temperature gradient.

the precise position in relation to those pressure belts (fig. 2). The critical factor is the position of the Intertropical Convergence Zone (ITCZ) and the Polar Front relative to the Tropical high pressure cell. When the latter is weak, the ITCZ and the Polar Front can converge, and rainfall in all areas is above average. Storm tracks related to the location of the Polar Front govern the route followed by the Atlantic frontal systems. When the high pressure cell is weak, these are routed farther north.

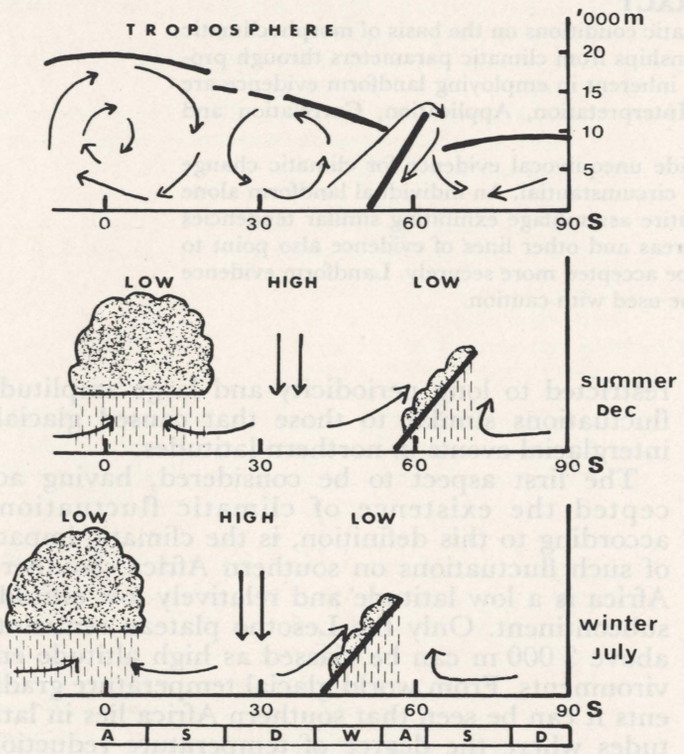


Figure 2. Latitudinal pressure and rainfall patterns showing variation by season. (A = all year rainfall, S = summer rainfall, D = desert, W = winter rainfall)

At its maximum extent the Antarctic ice margin reached Marion and Bouvet Islands, a northward shift of 15° (Van Zinderen Bakker 1976). The Polar Front would have shifted northwards proportionally to lie close to South Africa (fig. 3). There is also evidence that the extension of the polar ice was synchronous in both hemispheres. The situation within the tropics is less well established. It now seems likely that the Equatorial rainfall belt narrowed and disappeared in some places to be replaced by summer seasonal rainfall. The Equatorial forests disappeared in part as the climate became drier (Tricart 1975). It is important to relate these pressure belt shifts to the subcontinent of southern Africa, for the effects will be different in different latitudes. It cannot be expected that the chronology of the central African lake basins will equate with that of the southern Cape or Namib. Over most of southern Africa the northward shift of the Antarctic ice and Polar Front would have resulted in a lowering of mean annual temperature. Temperature depression of 5–9 degrees has been postulated (Talma *et al.*, 1974). In southern areas actual precipitation would have increased because the more northerly storm track would result in more frequent precipitation and in an extended wet season. The high pressure cell would also probably have weakened and summer rainfall have been more prolonged. Everywhere lower temperatures would have resulted in less evaporation and more effective precipitation. However, even with more total precipitation and lower temperatures it was probably still too dry for glaciation in Lesotho.

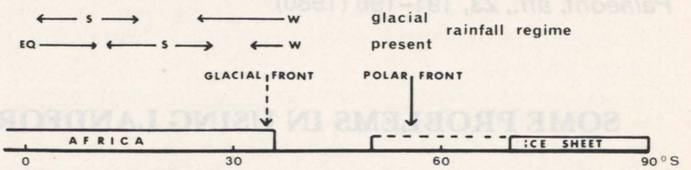


Figure 3. Present and glacial climatic relationships over southern Africa. (S = summer rainfall, W = winter rainfall, EQ = equatorial all year rainfall)

LANDFORM EVIDENCE

Landforms that have been used to deduce past climatic conditions are either erosional or depositional (sedimentary). My own karst research has provided both types of examples. The erosional cone and tower karst is believed to develop only with precipitation in excess of 1 500 mm p.a. (Verstappen 1960). In the Eastern Transvaal cone karst is located in an area that now has only 900 to 1 000 mm p.a. Cave sedimentary sequences of alternate mud layers and re-solution and carbonate speleothems have been elucidated to show seven alternations from wet to dry (fig. 4). Similar sequences have been identified in Cango Cave. Tufa deposits also show alternations of deposition under wet conditions and erosion or sand deposition under arid conditions. In the Namib the former position of the Tsondab river's end point (Seely and Sandelowsky 1974), karst dolines and river terraces all indicate former wetter conditions.

In Lesotho glacial-type hollows have been identified concentrated above 3 000 m along the northeastern border where precipitation and exposure are greatest (fig. 5). Solifluction deposits have also been recorded in association with the hollows (Marker and Whittington 1971) and elsewhere at high altitudes (Hastenrath and Wilkinson 1973). Recently, hard fragipans in high altitude soils have been interpreted as the product of periglacial conditions (Fitzpatrick 1978). Coastal marine terraces attributed to eustatic effects have also been equated with climatic events. However, the tectonic instability of the coastal belt and adjacent sea floor makes such a line of evidence dangerous to pursue.

SOME PROBLEMS

Landforms as climatic change indicators pose many problems. These can be classed as recognition, interpretation, application, correlation and chronology.

Climate		DRIEKOP-DRY TIGER CREEK	WOLKBERG		HOOGENOEG	MAKWENS	SUDWALA	ECHO
			First Chamber	*Second Chamber*				
		DRIEKOP						
	?WET	Phreatic	Phreatic					
I	DRY	1st $CaCO_3$						
I	WET	Vadose at 3660 m					Phreatic	Phreatic
II	DRY	$CaCO_3$	Large $CaCO_3$					1st $CaCO_3$
II	WET	Resolution with aragonite	Resolution with aragonite		Phreatic	?Phreatic	Vadose	Vadose associated with terrace at 1048m
III	DRY		Seasonal $CaCO_3$		$CaCO_3$		2 Calcite & earth fill layers	
		DRY TIGER CREEK						
III	WET	Phreatic		Phreatic	Vadose			
IV	DRY	$CaCO_3$		Major $CaCO_3$	$CaCO_3$	Major $CaCO_3$	Major $CaCO_3$	Major $CaCO_3$
IV	WET	Resolution with aragonite	Resolution			Resolution with aragonite	Resolution	Resolution
V	DRY			Recent small formations		$CaCO_3$	Crystals & rimstone formation	Minor speleothems Formation of cave at Bushman Rock Shelter
V	WET					Resolution		
VI	DRY					crystal growth		Middle Stone Age
VI	WET							
VII	DRY							
VII	WET							
VIII	DRY							Late Stone Age

Vertical arrows denote periods of rejuvenation.

Figure 4. Correlation of Transvaal cave depositional sequences.

Recognition

Recognition of the actual landform, perhaps in an unexpected context, is the first step. Fragipan soils have been known for many years, but knowledge of their link with a specific past climate is recent. The fragipan in the B horizon of some Natal soils has now been attributed to the action of freeze-thaw cycles at the base of the thaw layer (Fitzpatrick 1978). In the Eastern Cape the clay hardpans of the Sterkspruit soil type are recognised as having formed under much wetter conditions sufficient to elluviate the clay particles (Laker pers. comm.). Tufa deposits have been quarried for lime along the Kaap Plateau escarpment for many years. Only after investigations of tufa formation, however, was it recognised that wetter conditions than today were necessary to dissolve sufficient calcium from the dolomite rock and to permit springs to flow at sites that are now dry. The tufa deposits, then, are wet phase indicators. Recognition and recording of depositional sequences underground awaited the advent of serious karst research.

Interpretation

Having recorded significant landforms, the next problem is one of interpretation. There is first the basic problem of convergent development. Could the landform have developed by any other more plausible process? Linton (1970) reported transported masses of boulders in an earth matrix from regions as far apart as the Natal Drakensberg, the highveld near Kempton Park, and Simonstown. He attributed the sludge deposits to solifluction, or soil flow, an interpretation with which none would quibble. Solifluction, however, does not necessarily require freeze-thaw cycles for mobilisation as Linton presumed. Soil saturation after heavy rain would be equally effective and more probable under South African conditions.

The high altitude cirque-like hollows in Lesotho are presently being investigated. They are too large for nivation hollows, but there is no other evidence for glaciation (Marker and Dyer 1979). Fluvial terraces are another landform that requires careful interpretation. Fluvial terraces record alternate aggradation and degradation. They are normally attributed to ineffective fluvial transport and to renewed fluvial incision as a result of climatic variation, but there are alternative explanations. Terraces may form upstream of a blockage such as a landslide and be incised when normal flow is resumed (Partridge 1969). Flood plains may be incised into terraces after a knick point retreats. Terraces may also form following a change in the river channel regime. At the Klingbeil archaeological

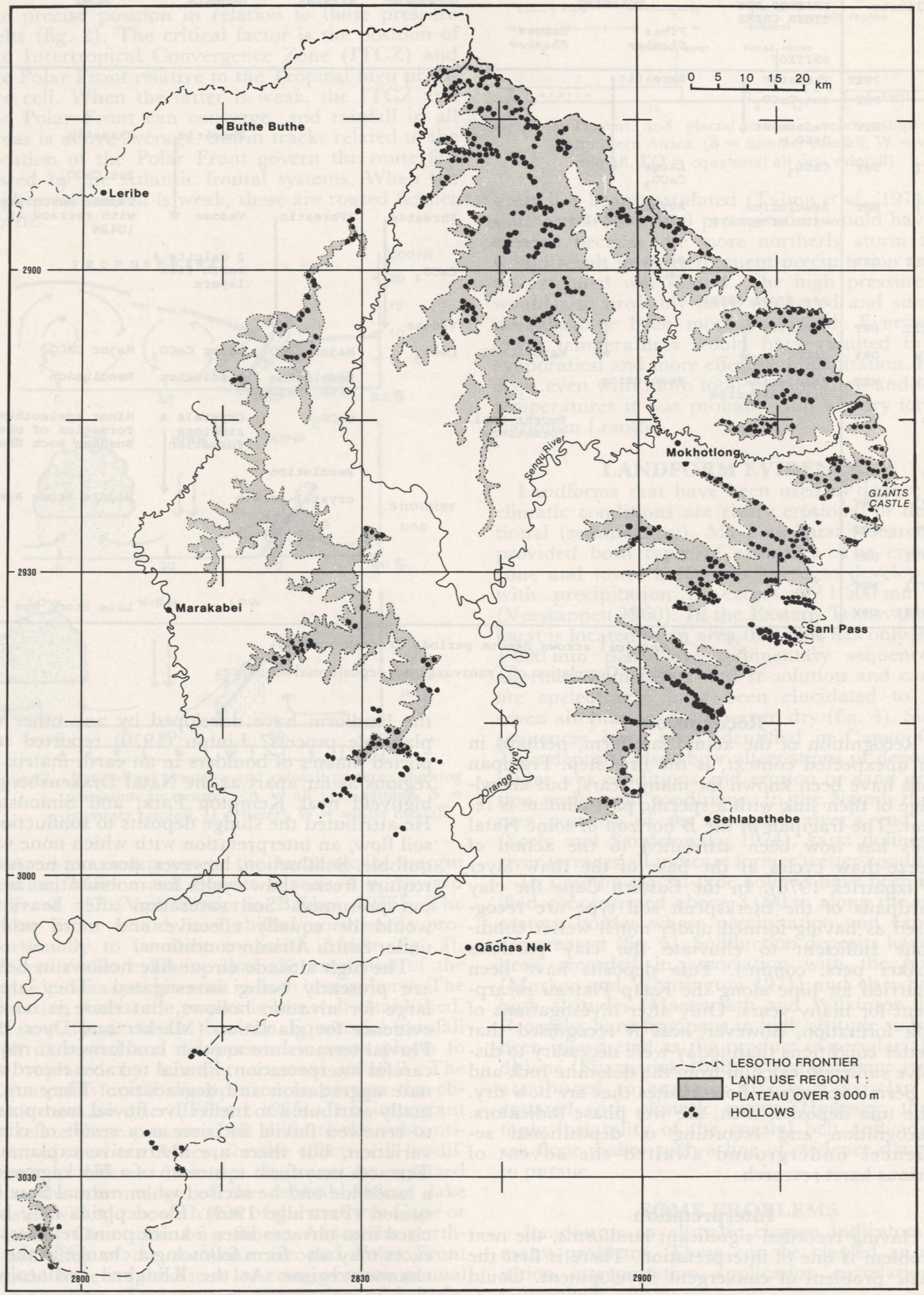


Figure 5. The distribution of high level hollows in Lesotho.

site near Lydenburg a Later Iron Age settlement was established on a gravel fan built up by braided channel flow. The fan has since been terraced following the replacement of braided flow by higher efficiency single channel flow with a lower gradient. The change is likely to have been induced by an alteration in land use, since it is too recent to be attributed to climatic change (Marker and Evers 1976) (fig. 6).

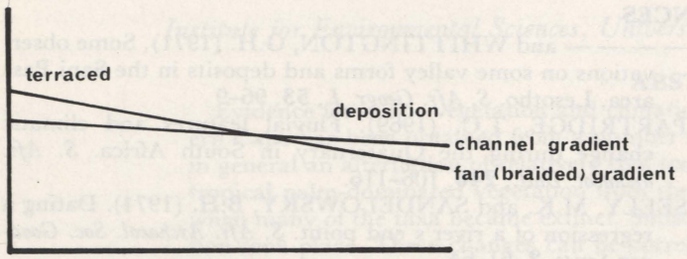


Figure 6. Gradients of braided and meandering channels.

Application

Application of landform evidence to problems of archaeology and climatic change is based on the Principle of Uniformitarianism: that the processes in operation now are the same as those in the past. The new view that effective long-return events cause change is in direct opposition. According to that model, pronounced changes in landforms occur at discrete periods of time far removed from one another.

Nevertheless, even if the basic principle of Uniformitarianism is still accepted, problems remain. Climatic evidence is derived by reverse reasoning from landform to process to climate. But process is never directly dependent on the specific climatic parameters that are sought (fig. 7). For example, the change in river regime at the Klingbeil site is attributed to increased runoff following overgrazing combined with a fine sediment load derived from soil erosion.

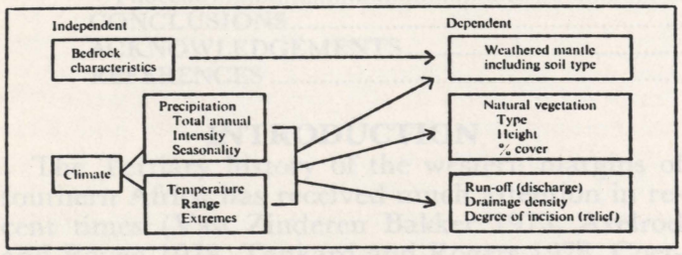


Figure 7. Environmental parameters affecting landform development.

Correlation

Having ensured the sound geomorphological basis of the evidence, the problem of correlation has still to be faced. Is the event or sequence only of local significance or has it wider application? My own work on the north-eastern Transvaal karst demonstrated cave sedimentary sequences that could be correlated over 300 km between Potgietersrus and Carolina (Fig. 4). The sequence showed cyclic climatic fluctuations from wet to dry. These were correlated one with another on the basis of cave age and the position of one particular phase of massive speleothem deposition (Marker 1972). Since similar sequences have been recorded from areas as far apart as Cango (Marker 1975) and Drotsky's Caves in western Botswana (Cooke 1975), the evidence is accruing that these fluctuations were of more than local significance. However, the evidence remains circumstantial only, since Cango and Botswana are both too far removed from the north-eastern Transvaal for direct correlation. It is vital that the distinction is made between correlations that are direct and those that are merely hypothesised. It is equally essential that the geomorphological evidence on which such correlations or postulations of climatic change are based be fully reported so that all users are in a position to form their own judgement. A further essential is that all correlations, especially those drawing evidence from a variety of sources, still fit into the climatic pattern controlled by the pressure systems. The discussion of the apparent contradictions over evidence drawn from East and Southern Africa in part arose because this basic constraint was ignored. There can be no direct correlation between East and Southern African climatic events because the evidence applies to different latitudinal belts.

Chronology

The first problem in the use of geomorphological evidence is that of dating. Relative dating at one site is secure provided the Law of Superposition is followed and lateral correlation is restricted. Correlation over distance is possible only so long as the sites are relatively close to one another and in similar geomorphological situations, as is the case for the north-eastern Transvaal cave sequences. Before incorporating evidence from more remote areas, it must be assessed critically and rejected if the actual evidence is not described in sufficient detail for it to be judged independently.

Some landform evidence can be dated isotopically. This aspect has been aired previously (Marker 1974). Apart from the inherent hazards of the method and those of material contamination, there remains the fact that the southern African environment is short of suitable datable material. Those that are generally available have a high contamination risk and a half life too short for effective dating. In other words most landforms are too old to be dated by current techniques. This is the attraction of the East African evidence.

A tufa sequence with interbedded red blown sands at Ulco west of Kimberley showed four wet and four dry cycles, yet the whole sequence was found to lie beyond the dating limit of about 40 000 years B.P. In fact it has now been established that the major unequivocal climatic fluctuations of sufficient amplitude to have had an impact on geomorphology are all older than 40 000 years ago.

CONCLUSION

The problems that have to be faced when using geomorphological evidence to adduce climatic changes have been emphasised, and the dangers appear to outweigh the merits. Nevertheless, certain landforms stand as unequivocal evidence for past change. The doline karst of the central Namib is one example, and the tufa deposits of the Kaap Plateau are another. Throughout this paper the premise has been that geomorphological evidence must be used with care. The evidence will always tend to be circumstantial rather than direct. An individual landform does not prove climatic change, but an entire landform assemblage might. Complementary evidence from adjacent regions makes the hypothesis stronger still.

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