

A multi-disciplinary review of late Quaternary palaeoclimates and environments for Lesotho

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Lesotho provides a unique context for palaeoclimatic research. The small country is entirely landlocked by South Africa, yet has considerable variation in topography, climate, and associated vegetation over an approximate east–west transect. The region has been of archaeological interest for over a century, and hosts many Early to Late Stone Age sites with occupation preceding 80 000 years before present. The eastern Lesotho highlands are of interest to periglacial and glacial geomorphologists because of their well-preserved relict landforms and contentious evidence for permafrost and niche glaciation during the late Quaternary. However, continuous proxy records for palaeoenvironmental reconstructions for Lesotho are scarce and hampered by a range of methodological shortfalls. These challenges include uncertain ages, poor sampling resolution, and proxies extracted from archaeological excavations for which there may be bias in selection. Inferences on palaeoclimates are thus based predominantly on archaeological and palaeogeomorphological evidence for discrete periods during the late Quaternary. This review paper presents a more detailed multidisciplinary synthesis of late Quaternary conditions in Lesotho. We simultaneously considered the varying data that contribute to the under-studied palaeoenvironmental record for southern Africa. The collective palaeoenvironmental data for eastern Lesotho were shown to be relatively contradictory, with considerable variations in contemporaneous palaeoclimatic conditions within the study area. We argue that although methodological challenges may contribute to this variation, the marked changes in topography result in contrasting late Quaternary palaeoenvironments. Such environments are characterised by similar contrasting microclimates and niche ecologies as are witnessed in the contemporary landscape. These spatial variations within a relatively small landlocked country are of importance in understanding broader southern African palaeoenvironmental change.

Introduction

Southern African palaeoenvironmental science has developed rapidly over recent decades, clarifying many key debates on environmental and climatic boundaries, and relating key climatic events with those of the northern hemisphere.¹ Whilst this work spans an increasing number of study sites, these are predominantly determined based on their accessibility and the availability of well-preserved proxies.^{1,2} To date, site selection for palaeoenvironmental research in southern Africa has been predominantly based on ease of access. Therefore, sites with highly vulnerable niche ecologies, heightened spatial ecological variation owing to rapid topographic changes, or which have particularly well established archaeological records are often neglected. Lesotho provides such a study region, yet relative to the surrounding southern African countries, the late Quaternary climatic and environmental record remains uncertain and at best undefined.^{3,4} Existing literature for Lesotho is based almost entirely on archaeological and geomorphological evidence that spans discrete periods of human occupation or glacial and periglacial activity (Figure 1). Such past research has offered numerous inferences on possible palaeoclimatic changes throughout the late Quaternary in Lesotho^{5,6}, but the chronological continuity and quantification of past climates lack both detail and objective confirmation^{7–9}.

A variety of Quaternary periglacial and glacial studies on Lesotho's eastern high mountain region have emphasised colder conditions during the late Pleistocene, including but not limited to the Last Glacial Maximum (LGM)^{6,10–13} and Holocene neoglacial episodes. The latter events are presumed to have occurred at ~4500 years before present (yr BP), 4000 yr BP, and 3000–2000 yr BP respectively.¹⁴ However, the absence of ages for most geomorphic phenomena studied, the lack of consistent chronologies, and the often disputed interpretation of landforms have limited their palaeoenvironmental value.^{4,8,13,15} The paucity of palaeoenvironmental work in the Lesotho region (Figure 1) stems largely from the difficulty in accessing sites in this mountainous country, and the considerable logistical challenges in extracting material¹⁶. However, these challenges provide tremendous impetus for such work in the region because of the unique high-altitude setting, with resultant vulnerable niche ecosystems^{3,15}.

We explore the current understanding of Lesotho's late Quaternary palaeoclimatic and palaeoenvironmental history, critically analysing the evidence published to date from archaeological, palaeogeomorphological and palaeoecological records. Our results highlight the importance of this region as a key site for Quaternary Science on the African sub-continent. The aim here is to provide a review of the three disciplines, followed by a synthesis of the palaeoclimatic data recorded to date. In so doing, we offer a robust framework for future research. This framework can guide palaeoenvironmental and palaeoclimatic research in the region, interrogate valuable proxies, extend studies into under-studied regions, and address outstanding questions and uncertainties.

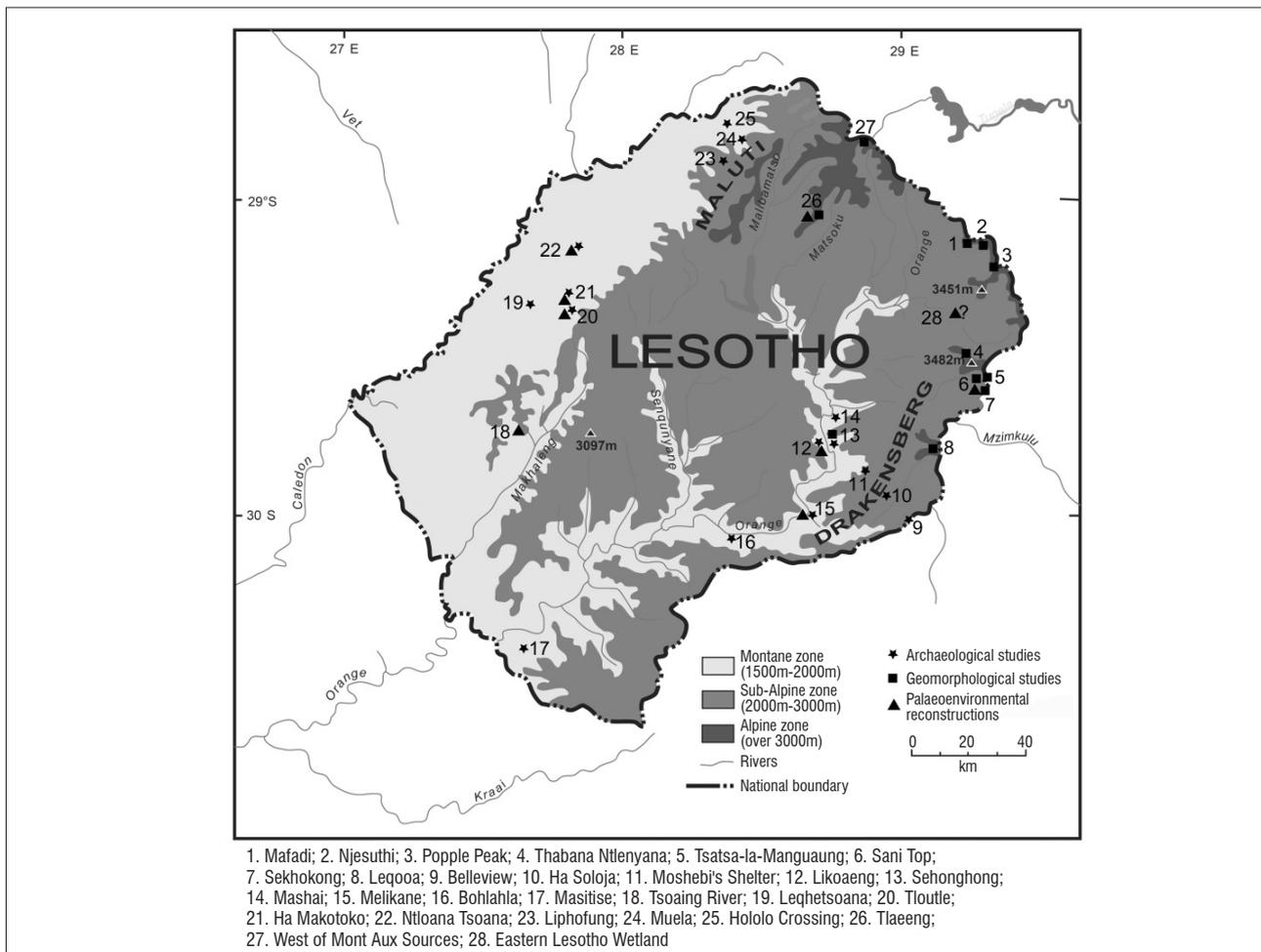


Figure 1: The location of archaeological, geomorphological and palaeoenvironmental study sites in Lesotho from which published palaeoclimatic inferences have been made.

Lesotho: A key site for palaeoenvironmental research

Considerable work has been undertaken to reconstruct palaeoenvironments for southern Africa, and in recent years reviews of such work have been published^{1,17}. However, there exists little synthesis of the research (albeit sparse) undertaken in Lesotho. Not only does the neglect of this country form a notable research gap, but as the highest altitude region in southern Africa, eastern Lesotho reflects a unique environment which has been significantly influenced by snow and ice throughout the late Quaternary¹⁸. Western Lesotho, by contrast, is situated at low elevation, consisting of lowlands and foothills.¹⁹ The contrast in elevation, topography, and resultant ecosystems across the country presents a valuable context for examining environmental lapse rates and topographic influences on the environment. Furthermore, synoptically this region is important as much of the moisture derives from the Indian Ocean, yet winter snow is a function of the passage of mid-latitude cyclones originating from the southwest of southern Africa¹⁸. A critical review of the existing palaeoenvironmental literature for this region is thus of importance in directing future research to more accurately address key research uncertainties.

Lesotho is located between the coordinates 28°30' S to 30°40' S and 27°00' E to 29°30' E, and covers a terrestrial area of 30 355 km².²⁰ The country is landlocked, entirely surrounded by provinces of the Republic of South Africa, namely Free State, KwaZulu-Natal and Eastern Cape. Lesotho is classified into four main physiographic zones: the western lowlands, ranging in elevation from 1500 masl to 1800 masl; the foothills, ranging from 2000 masl to 2500 masl; the Senqu River valley; and the

eastern highlands, which include elevations greater than 2500 masl.²⁰ The eastern highlands comprise 75% to 80% of the total land area, but the majority of the population lives in the lowlands, where the climate, soils and topography are most suitable for agriculture²¹. The high altitude and steep slopes contribute to a set of flora and fauna markedly different from those observed for much of southern Africa.

Eastern Lesotho accounts for a substantial portion of the Drakensberg Alpine Centre (DAC), a biome listed as a centre of endemism. Increasing efforts have been made to protect and understand the biodiversity of the region.²² The eastern Lesotho Drakensberg is a deeply dissected plateau, with elevations ranging from 2290 masl to 3482 masl²³, and all exposed and underlying rock in the eastern Lesotho Drakensberg forms part of the Karoo Supergroup¹⁶. This includes the Drakensberg Group flood basalts of Upper Triassic to Jurassic age, intruded by fine-grained dolerite dykes, underlain by the Stormberg Group of sandstone – including the Clarens Formation, which is exposed to an altitude of ~2500 masl, and the underlying Elliot and Molteno Formations²⁴. Climate data for Lesotho are insufficient relative to the varied climate across the region, and historical data represent an even more sparse set of locations of uncertain accuracy⁸. However, the contemporary climate of eastern Lesotho can broadly be described as a distinct seasonal alpine climate with cool wet summers and cold dry winters.²⁵ Spanning a trajectory from the eastern Lesotho highlands to the western lowlands, temperatures increase while rainfall and humidity decrease. The climate of eastern Lesotho, as well as the broader country, is influenced predominantly by altitude and distance from the rain-shadow of the Drakensberg Mountains, but there is considerable local variation arising from aspect and temperature inversions^{4,16}.

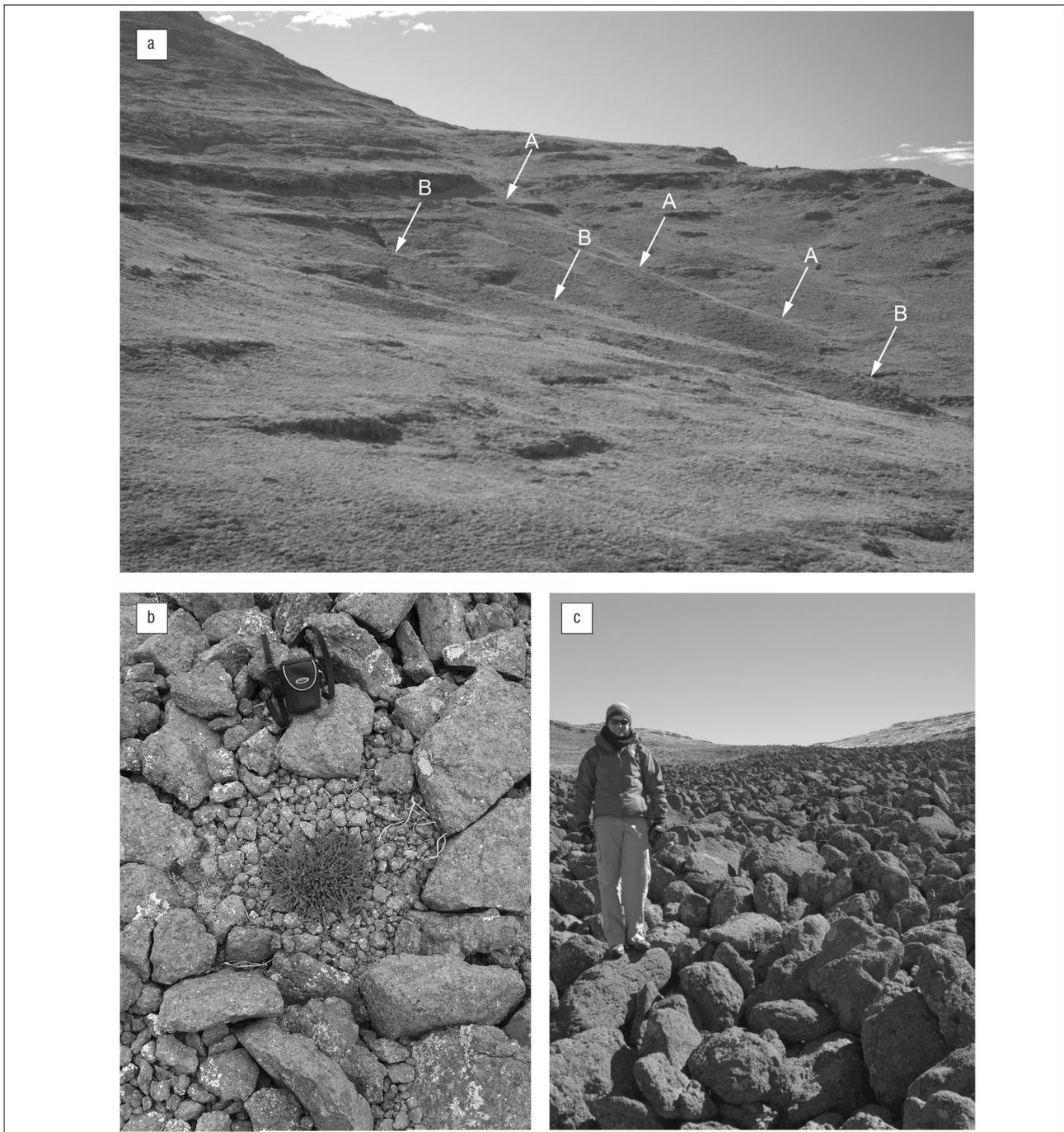


Figure 2: Examples of relict glacial and periglacial geomorphic features in eastern Lesotho: (a) glacial moraines on the south-facing slope of Leqooa Valley (ridges are marked A and B), (b) large sorted patterned ground at Mafadi summit (~40 cm in diameter), and (c) a blockstream near Sani Pass.

The palaeogeomorphological record

Many inferences on past climates for Lesotho have been made on the basis of periglacial and glacial palaeogeomorphological evidence. The eastern Lesotho highlands host an impressive array of relict glacial and periglacial geomorphic features (Figure 2), many of which are presumed to have developed during the LGM, and some periglacial features may have been reactivated during Holocene cold periods as recent as the Little Ice Age (LIA)^{8,11,14,26}. Owing to high altitudes, relatively cold temperatures persisted during interglacial periods. Palaeogeomorphological phenomena are thus relatively well preserved and provide evidence for discrete past cold events.²⁷ Given that these landforms are relatively unique to southern Africa, they have attracted considerable research attention in recent decades^{8,15}. However, many phenomena identified,

and their associated palaeoenvironmental and palaeoclimatic inferences, have been contentious.^{8,13,28}

The most contentious palaeogeomorphological features in eastern Lesotho are those interpreted to be of glacial origin.^{8,10,29} Many critiques of such glacial interpretations arise from the predominantly qualitative earlier approaches used, and difficulties in positive feature identification and age determinations^{8,15}. However, more recent quantitative approaches, including detailed mapping, macro- and micro-sedimentology, and obtaining ages for small moraines (Figure 2a), have provided more substantive evidence for Quaternary glaciation in eastern Lesotho. Such glaciation is dated to ~19 500–17 350 calibrated years before present (cal yr BP)^{6,12,13}, which coincides with the terminal stage of the LGM in southern Africa². While the accuracy of the term 'niche glaciation'

has been queried²⁹, evidence based on these moraines for small-scale, spatially restricted glaciation during the LGM is undisputed to date¹⁸.

Evidence for contemporary and relict periglacial features in the eastern Lesotho highlands (Figure 2) is more widely accepted^{6,15,30}. The contemporary alpine region of Lesotho is considered a marginal periglacial environment.^{8,31,32} Active features, including earth hummocks, sorted patterned ground (Figure 2b) and stone-banked lobes still develop as a result of diurnal and seasonal frost action¹⁴. Inactive periglacial landforms dating back to colder periods are generally larger in scale than their contemporary counterparts. In the case of stone-banked lobes, the older lobes are between 1.4 m and 4 m long and were formed in association with prolonged periods of sub-zero air and ground temperatures^{11,15}. Similar to the contested glacial evidence, greater insolation on north-facing slopes requires that the majority of such features are situated on south-facing slopes^{14,28,33-35}. Larger relict periglacial features (e.g. sorted patterned ground) could be indicative of sporadic permafrost during their genesis, most likely during the LGM¹¹. Such permafrost might have been highly localised and possibly of relatively short duration, spanning a few centuries at most.¹¹

The palaeo-periglacial phenomena indicate colder conditions than at present, with the size of landforms and their likely genesis providing some indication of relative temperature departures^{11,15,18}. However, palaeoenvironmental interpretations of associated precipitation levels during these cold periods are conflicting.^{6,8,15,31} Boelhouwers and Meiklejohn⁸ suggested that some periglacial features, including large patterned ground, solifluction mantles and blockstreams (Figure 2c) were indicative of dry, cold conditions at their time of formation, whereas typically erosional features, including nivation hollows, cirques and cryoplanation terraces are likely indicative of wetter conditions during cold periods³⁶. Other scholars^{11,26} have argued that similar periglacial features, including large sorted patterned ground near Mafadi Summit (Figure 2b) and at Thabana Ntlenyana, and pronival ramparts at Thabana Ntlenyana, imply relatively high moisture availability during their formation. In addition, small glaciers would have required sufficient snow cover during the LGM, implying a shift in the seasonality of precipitation, relative to contemporary conditions^{9,12,13,18}.

Glacier reconstructions from five sites in eastern Lesotho have enabled the calculation of equilibrium line altitudes and glacier viability under specific climatic conditions.¹⁸ From this, using the high-resolution HadAM3h climate model, Mills et al.¹⁸ demonstrate a likely decrease in summer precipitation during the LGM. Assuming temperatures of 6 °C during the LGM, this would be associated with a 28% increase in solid precipitation during the autumn, winter and spring months¹⁸. These models support a growing number of recent studies that posit relatively wet LGM conditions over parts of south-eastern Africa^{2,37,38}.

Relict periglacial features provide evidence for single discrete cold events. The restricted climatic requirements for such landform genesis can facilitate improved quantification of climatic change during these cold periods.^{11,18} Continued debates concerning these cold region landforms highlight many unresolved uncertainties as to their identification, processes and environmental drivers, oftentimes with an over-reliance on northern hemisphere analogues^{28,36,39,40}. The identification of features may become increasingly difficult to address as landscape disturbance increases in response to greater human and livestock pressure in the region²⁷. Temporal constraint for the period of landform formation is critical if such debates are ever to be resolved adequately. However, age-dating remains a challenge because of difficulties in precisely dating relict periglacial and glacial phenomena.^{8,15} Ages obtained for pronival ramparts and moraines have confirmed the timing during which these features developed, and interestingly coincide with a Holocene neoglacial event and the LGM respectively. This knowledge has improved the potential for palaeoenvironmental inferences to be drawn from such features.^{6,12,13} Accurate inferences could be achieved through the provision of corroborating environmental evidence, and by filling in the large temporal gaps between cold periods represented by these features^{6,8,18,36}.

The archaeological record

Archaeological work in Lesotho has been relatively slow in forthcoming, resulting from problems endemic to field-based research in the region: difficulty in accessing sites because of their remoteness in eastern Lesotho; the deeply dissected landscape; and a lack of institutional knowledge^{16,41}. The first significant contribution to understanding Stone Age occupation in the eastern Lesotho highlands was made by Carter^{42,43}, with the specific aim of understanding occupation patterns resulting from changes in the natural environment, driven by climatic changes^{5,16,43}. While some aspects of Carter's methodology have been critiqued, this work importantly confirmed that occupation dates back to the Early Stone Age at >80 000 yr BP, and that the highlands do not represent an enclave only recently inhabited^{7,16,44}.

From the late 1980s onwards, the development of the Southern Perimeter Road and the Lesotho Highlands Water Scheme initiated a more intensive developer-funded archaeological effort in the regions^{41,45}. This included further work on the timing and seasonal patterns of human occupation in the region, based on excavations at predominantly shelter sites^{4,5,7,16,19,43-48} and later work on open-air sites^{9,50-53}. These studies have largely supported Carter's initial findings and interpretations, and have improved the resolution of detail. The environmental inferences from these studies are explored in this section of our paper, beginning with long-term patterns of occupation and absence at these sites, followed by evidence for the seasonal occupation of sites, and finally evidence of human influence on the environment. A small body of archaeological work undertaken in the region has analysed palaeoecological proxies for the periods of settlement^{4,9,19,53}. This will be discussed predominantly in the palaeoecological section which follows.

The selection of locations for settlement by Early through to Late Stone Age communities in southern Africa necessarily involved considerations of the climate, natural environment and resource availability. These factors presented varied opportunities and threats at each location, particularly due to the reduced habitat adaptation measures available^{43,47,49,50}. It has been posited that Stone Age settlement in the eastern Lesotho highlands would have occurred under two dominant environmental conditions. The first is relatively arid conditions which would have forced people into the moist highlands in search of water, plants and animals.^{4,48,53,54} The second is a shift to temperatures warm enough to support varied vegetation, with a consequent range of animals, and with limited snow cover^{5,41,48,49}. Given the low capacity for improved warmth, settlement under more arid cold conditions could not have occurred at the highest altitudes, as temperatures would have been intolerably cold and would have prevented plant growth and deterred animals.^{7,41,47,49} Settlements could thus develop only during sufficiently warm periods and with enough moisture to support a varied ecology. Pulsed occupation throughout the Pleistocene and Holocene has commonly been observed for archaeological sites across Lesotho (Table 1). For many sites, periods of absence are greater than those of occupation.^{7,41,47,48} For the highest altitude sites, such as Belleview, Moshebi's Shelter and Ha Soloja (Figure 1), occupation ceases during known periods of very cold conditions, most recently the LGM^{16,47,50}. Occupation resumes during warm periods, as is most clearly noted for Likoeng^{16,47,50,52}. For lower altitude sites, including Sehonghong and Melikane (Figure 1), there remains evidence of occupation throughout very cold periods including the LGM, although some scholars suggest this evidence of occupation reflects visits of short duration for hunting purposes^{46,53}.

Although it would appear that occupation has been more intensive and prolonged since the mid-Holocene⁴⁹, notably, there are no clear overlaps in periods of occupation or absence between the Lesotho sites (Table 1), nor for the broader southern African sites⁵⁵. Therefore, microclimate and microtopography appear to have been important factors determining the selection of locations for occupation.⁴⁷ However, a far greater set of influencing factors is likely to be responsible for the selection of sites and timing of occupation than climate and associated environment alone.^{49,53} These pulses of occupation may critically involve climatically-driven seasonal movements between sites, both within Lesotho and from farther afield.^{43,47,48}

Table 1: Known periods of occupation at Stone Age sites in Lesotho

Author	Year	Site	Occupation Periods
Mitchell et al.	1994	Hololo	1660 AD (cal) 1640 AD (cal)
Mitchell et al.	1994	Bolahla	1885–1914 AD (cal) 1179 AD (cal)
Mitchell et al.	1994	Tloutle	1272–1305 AD (cal) 1446–1638 AD (cal)
Esterhuysen & Mitchell	1996	Ha Makotoko	10 000–8370 yr BP
Esterhuysen & Mitchell	1996	Ntloana Tsoana	12 100–8780 yr BP
Esterhuysen & Mitchell	1996	Tloutle	9000–5000 yr BP
Mitchell	1996a	Sehonghong	~6000 yr BP ~7000 yr BP ~10 000 yr BP ~11 000 yr BP ~12 000–12 500 yr BP ~20 000 yr BP ~25 000 yr BP
Mitchell	1996b	Sehonghong	850–1870 AD (cal)
Mitchell et al.	1998	Sehonghong	12 500–12 000 yr BP ~11 000 yr BP 9800–9300 yr BP
Mitchell et al.	2011	Likoaeng	1700–1000 BC (cal) 1000–200 BC (cal) 100 BC–250 AD (cal) 800–899 AD (cal)
Parker	2011	Likoaeng	>3380–2860 cal yr BP 2860–2440 cal yr BP 2510–2150 cal yr BP 2070–1600 cal yr BP 1260–1070 cal yr BP
Stewart et al.	2012	Melikane	~80 000 cal yr BP ~60 000 cal yr BP ~50 000 cal yr BP ~46 000–38 000 cal yr BP ~24 000 cal yr BP ~9000 cal yr BP ~3000 cal yr BP ~1800 cal yr BP
Roberts et al.	2013	Ntloana Tsoana	~61 000 cal yr BP 57 000 cal yr BP 14 200–9600 cal yr BP
Loftus et al.	2015	Sehonghong	35 000–32 000 cal yr BP 30 000–9000 cal yr BP 25 000–21 000 cal yr BP 19 000–18 500 cal yr BP 16 000–12 500 cal yr BP 11 500–10 000 cal yr BP 8000–7500 cal yr BP 7000–6500 cal yr BP 1700–1000 cal yr BP

Note: All dates are cited directly from the literature and have not been re-calibrated (owing to insufficient data).

Key: cal yr BP – calibrated years before present, yr BP – years before present

Carter⁴² originally suggested that evidence of occupation at sites in Lesotho may reflect periods of seasonal duration, with movement between two or more sites over an annual period. This hypothesis was supported by observations of seasonal movements between eastern Lesotho and low-altitude sites in KwaZulu-Natal in the late 19th century, with the highest altitude or coldest site being used in spring and summer and a warmer site used in winter each year^{47,56}. This in turn is supported by documentary records for the 19th century from eastern Lesotho, which record particularly cold conditions⁵⁷. There are three main examples of seasonal occupation shifts in eastern Lesotho: Sehonghong and Melikane^{43,47}; Belleview and lower-altitude sites in KwaZulu-Natal⁴²; and Likoaeng^{51,52}. Sehonghong and Melikane are both situated on the Senqu/Orange River, but Sehonghong has a considerably colder climate as it is west-facing, compared with the north-facing Melikane^{16,52}.

The synchronous dates of occupation at the two sites during climatically adverse periods are argued to be explained by seasonal migration between the two sites, using Sehonghong in summer and Melikane in the colder winter months during interglacial periods⁴⁷, whereas during the LGM it is likely that both sites were used only briefly in summer⁷. This seasonal pattern of use is supported by evidence of fish, flower-heads and grasses found at Sehonghong but not Melikane, indicating preferential occupation of Sehonghong in spring^{16,47,56}. At the higher altitude sites on the eastern escarpment, including Belleview, Moshebi's Shelter and Ha Soloja, a different system of seasonal movement appears to have occurred, across far greater distances, covering a transect from the eastern Lesotho highlands to the KwaZulu-Natal lowlands^{16,42}. High-altitude Lesotho sites would have been used only briefly in summer, with movement through the mist belt and tall-grassveld of KwaZulu-Natal, and coastwards to the thornveld during winter months^{16,42,43}. The larger distances travelled and more extreme cold temperatures at the escarpment sites explain the complete abandonment of high-altitude sites during the LGM.^{5,7,43}

Likoaeng is one of the few open-air sites in Lesotho for which archaeological records have been reported, with remains of mammals, birds, reptiles and molluscs, demonstrating a shift from hunting to fishing at the site at ~4000 cal yr BP^{9,50}. Higher resolution seasonal occupation is evident from Likoaeng, where fish bones provide evidence of deliberate occupation of a site timed by recurrent biological events^{9,50-52}. The late Holocene deposits at this site are dominated by very large numbers of fish bones (1.3 million counted), suggesting that the site was occupied specifically to intercept the spawning runs⁵². The species of fish from these deposits demonstrate a marked shift in dominance from smallmouth yellowfish (*Labeobarbus aeneus*) to Orange River mudfish (*Labeo capensis*) over time, with Orange River mudfish accounting for the majority of fish bones after 560 cal yr BP⁵¹. As these fish have different spawning times, centred in mid-summer for smallmouth yellowfish and early spring for Orange River mudfish, the timing of occupation of Likoaeng demonstrates preferences for different spawning groups – based most likely on the availability of food elsewhere^{51,52}. Over longer time periods, occupation at Likoaeng appears to have been interrupted primarily by periods of flooding rather than changes in temperature or snowfall.⁵²

The palaeoenvironmental significance of these occupation pulses identified in the archaeological record, together with evidence of seasonal movement between sites, implies that an ameliorating climate would have been necessary for these Stone Age occupants of high-altitude sites to survive⁷. Although it seems reasonable that these occupation pulses and seasonal movements were driven predominantly by climatic changes in the eastern Lesotho highlands, it is impossible to quantify the extent of any climatic influence or to account for all non-environmental drivers^{7,55}. Social interactions between different communities, and changes in food and landscape preferences, could alter settlement patterns and occupation pulses entirely, independent of changes in climate and vegetation^{4,49,51}. Where settlement location and consequent occupation pulses were driven by climate changes, it is difficult to determine whether these were shifts in temperature, precipitation, or both.^{4,43}

It is likely that occupation in the eastern Lesotho highlands occurred either during warmer periods, or during periods of lowland drought

when moisture available in the highlands was a valuable and necessary resource – which would surpass the detriments of having to endure the cold^{4,43,47}. For most sites there is insufficient evidence to interpret independently which of these drivers was dominant at any given period. Thus, many of the climate inferences based on occupation cycles are dependent on palaeoclimatic information from the site or from elsewhere in southern Africa.^{43,52} Consequently, there have been continued calls, and recent efforts made, to extract palaeobotanical climate proxies – including charcoal, faunal remains, phytoliths and stable isotopes – from material recovered at archaeological excavations in the region.^{4,7,9,19,48,59}

Palaeoenvironmental reconstructions

Detailed continuous palaeoenvironmental records from Lesotho are limited.^{3,5,7} For example, the only pollen reconstruction for the eastern Lesotho highlands⁶⁰ was sampled at poor resolution and lacks chronology, and no information on site location is provided. Fluctuations in Holocene climate have been reconstructed on the basis of sedimentary characteristics from gully exposures in eastern Lesotho^{61–63}, but without an analysis of biological proxies the palaeoenvironmental inferences made from such studies remain relatively generalised³. The majority of studies that have explored palaeoenvironmental changes using biological proxies have been conducted in the western Lesotho lowlands, and many have relied on archaeological evidence and hence provide environmental records only for periods of occupation^{3,4,19}. Archaeological material is further compromised by human bias, because material that was brought to shelters often did not directly reflect the broader spectrum of dominant regional vegetation but rather preferences for fuel, food and bedding material.^{9,19,53}

As part of a broader preliminary study of the wetlands in eastern Lesotho, van Zinderen Bakker⁶⁰ presents the results of pollen analysis from a sediment profile measuring 90–100 cm in length, extracted from an unidentified wetland. The pollen results reflect a shift from Cyperaceae-dominated samples at the bottom of the profile to a proportion of Poaceae (Gramineae) near the top. This pattern is argued to represent a regional decrease in moisture over the period represented by the profile.⁶⁰ The period during which this regional drying would have occurred remains unclear because of the absence of age-dating technology at the time of the study. In a later and more detailed vegetation analysis of eastern Lesotho wetlands, van Zinderen Bakker and Werger⁶⁴ present a bottom date for a peat bog in eastern Lesotho of 8020 ± 80 yr BP, which could potentially be related to this profile. However, the lack of site details for either study makes the inference impossible to confirm. The initial study was preliminary work in the region, which most likely was intended to lay a foundation for future studies given the availability of well-preserved pollen and diatoms in the many highland wetlands⁶⁰.

Sedimentary sequences with alternating layers of organic rich clays, peat and gravels, exposed along deep gully systems at Sani Top and Tlaeeng (Figure 1), were investigated to develop a regional late Quaternary palaeoclimatic and palaeoenvironmental history^{61–63}. Interpreting the sequence to represent dry periods through layers of orange-coloured gravels, and wet periods through organic rich clay and peat layers, a chronology of moisture fluctuations for eastern Lesotho was developed, constrained by radiocarbon dates^{61–63}. Results suggest cold conditions prior to 13 500 yr BP, a warm and wet period from 13 500–9000 yr BP, drier and potentially colder conditions from 9000–5000 yr BP, and warmer wet conditions from 5000–1000 yr BP⁶³. The methodology requires critical review, as the samples were not pre-dried, and organic material was determined by burning the samples at 105 °C rather than the standard 550 °C.⁶⁴ The low burning temperature accounts for percentage organic content measurements that were, by the researcher's own admission, exceptionally high.⁶¹ These measures of percentage organic content removed therefore rather reflect the percentage of moisture loss. Nonetheless, distinct differences in colour and texture between gravel and organic-rich sediments are recorded, and the temporal constraint of these shifts provides some understanding of Holocene precipitation changes in the highlands^{61,62}.

A further study³ focused on reconstructing palaeoenvironments of the western Lesotho lowlands, by examining a sedimentary sequence exposed along a 13-metre deep gully sidewall in the Tsoaing River Basin (Figure 1). Pollen and phytoliths were extracted for analysis

from nine visually distinct sedimentary layers within the sequence, with dates ranging from 12 000 to 4000 cal yr BP.³ Very little pollen was available for counting, with representative samples for only the bottom two layers of the sequence, possibly indicating oxidation under seasonal dry conditions for the remaining layers³. The environmental reconstruction was thus made primarily from the phytolith data, which indicate a rapid transition to dry conditions from 8600 to 8450 cal yr BP, with wetter conditions by 7000 cal yr BP and again after 4500 cal yr BP.³ The absence of pollen for much of the sequence, limited information available from the phytoliths, and low sampling resolution all restrict the palaeoclimatic value of this work. However, the study does indicate considerable potential for detailed future analysis.

Work undertaken on biological proxies from excavated sediments at archaeological sites provides some of the most valuable palaeoenvironmental information for Lesotho.^{4,9,19,53,59} Holocene charcoal assemblages were analysed from three shelters (Tloutle, Ha Makotoko and Ntloana Tsoana) along a tributary of the Caledon River in western Lesotho (Figure 1).^{19,66} Considerable differences in species composition were noted between Tloutle, which is closer to the river, and Ha Makotoko and Ntloana Tsoana throughout the periods of occupation; these findings highlight the influence of microclimates within small geographic areas in Lesotho¹⁹. Ha Makotoko and Ntloana Tsoana had charcoal evidence of species well adapted to cold and drought, including *Protea sp.*, *Leucosidea sericea*, *Rhamnus prinoides*, *Rhus sp.*, *Passerina montana* and *Erica sp.*, for the period 12 110–8370 yr BP. The species composition from Tloutle for the period 8680–5080 yr BP was indicative of more mesic woodland, including high percentages of *Olea africana*, *Celtis africana*, *Maytenus heterophylla*, *Rhus sp.* and small percentages of *Podocarpus*.¹⁹

Examining changes throughout the periods of occupation, two mesic periods were identified by the appearance of *Podocarpus* charcoal. The first was centred at 8700 yr BP, possibly the result of a continued increase in moisture from 10 000 yr BP; the second period, 6900–5000 cal yr BP, reflected an even wetter period^{19,66}. These wet periods were separated by dry conditions, characterised by the appearance of *Euphorbia sp.* and increases in charcoal from *Buddleia sp.* and *Passerina montana*.¹⁹

Analyses of stable carbon and oxygen isotopes from ungulates, and stable carbon isotopes from organic material, provide further palaeoenvironmental evidence for these three sites.^{4,59} The isotopic values for herbivore grazers reflect the proportion of C₃:C₄ vegetation consumed, from which the vegetation balance at the site can be inferred⁵⁹. Evidence for the three Caledon River sites in Lesotho indicate a progressive warming from 16 000 to 6000 cal yr BP, marked by considerable fluctuations.⁵⁹ The fluctuations notably include periods that were sufficiently cool to encourage the growth of C₃ plants during the periods 16 000–14 000 cal yr BP, 10 200–9600 cal yr BP and 8400–8000 cal yr BP.⁵⁹

A more recent study using stable carbon isotopes provides further environmental proxy data for Ntloana Tsoana and Tloutle for the period spanning the Pleistocene-Holocene transition.⁴ The δ¹³C values are distinct for C₃ and C₄ plants, and the ratio of C₃:C₄ plants is related to temperature and water availability. In Lesotho, temperature is altitudinally constrained, with C₃ plants found largely in the cold high-altitude regions, and C₄ plants dominating the vegetation in the warmer lowlands.⁴ Isotope analysis confirms predominantly C₃ vegetation during the LGM, followed by a progressive increase in the proportion of C₄ plants.⁴ Within this period of overall warming, the Pleistocene-Holocene transition was marked by rapid temperature fluctuations of as much as 4 °C from 11 200 cal yr BP to 9500 cal yr BP, with at least three cycles of warming and cooling reflected in the carbon isotope record⁴. More stable, warm conditions were attained by 9500 cal yr BP.⁴ In addition to providing valuable proxy evidence for the period preceding the charcoal record reported by Esterhuysen and Mitchell¹⁹, this record notably demonstrates the existence of very cold periods and extreme climatic fluctuations during longer periods of occupation, which, without proxy data, would have been assumed to reflect continuous moderate conditions⁴.

Caution must be used when interpreting environmental proxy data from archaeological sites, particularly in the case of shelters, as the species

composition depends on what people selectively brought into the shelter¹⁹. Depending on the intended use of the plant material, biases may exist, and species that were common in the area may be absent in the record.¹⁹

Evidence of environmental and climatic change from a 3-metre stratified sequence at Likoeng open air shelter is derived from phytoliths and stable carbon isotopes, spanning periods of both occupation and absence over the period 3400–1070 cal yr BP.⁹ Results suggest a warm period dominated by C₄ panicoid and chloridoid grass types from the beginning of the sequence to 2960 cal yr BP. This is followed by an abrupt neoglacial cooling period from 2960 to 2160 cal yr BP, dominated by C₃ pooid grassland, with the presence of *Erica* and *Euryops sp.*⁹ Thereafter, the environment is characterised by a mixture of C₃ and C₄ species until 1600 cal yr BP, followed by a return to the original environment dominated by C₄ panicoid and chloridoid.⁹ This proxy evidence complements findings on occupation pulses at the site based on mammal and fish remains.^{50–52} Although occupational hiatuses at the site resulted from flooding rather than unsuitable temperatures, unlike most archaeologically derived environmental reconstructions, the record spans both occupation and absence⁹.

Most recently, the analysis of stable isotopes derived from soil organic matter and faunal enamel from Sehonghong⁵³ greatly improves the temporal resolution of palaeoclimatic reconstructions for eastern Lesotho. Notably, that study provides evidence for the absence of C₄ plants at Sehonghong during the LGM.⁵³ With the isotope record reflecting the re-emergence of C₄ species in the early Holocene, and supporting evidence of C₄ species occurrence during the LGM at the lower-altitude western Lesotho sites⁹, a temperature depression of at least 5 °C is confirmed⁵³. The Sehonghong isotope records further indicate a sudden cooling at ~11 000 cal yr BP, argued to provide possible evidence for southern African cooling during the Younger Dryas⁵³.

Conclusions and research questions

Combining evidence from archaeological, geomorphological and palaeobiological archives highlights considerable variability in temperature and precipitation, biosystems, geomorphology and human occupation throughout the late Quaternary in Lesotho (Figure 3). Specific variables of interest include temperature and precipitation, biosystems, geomorphology and human occupation. Although there are some

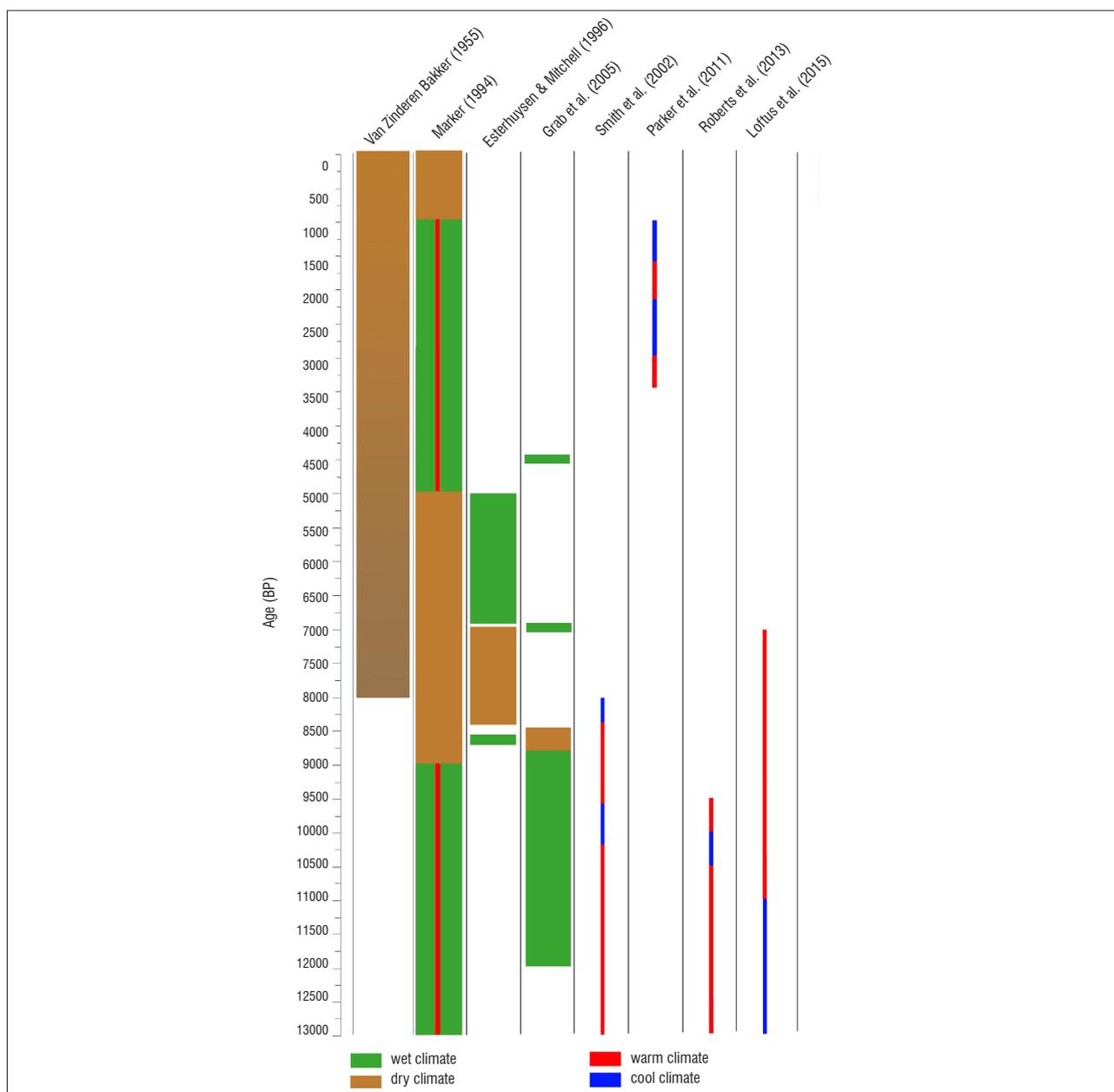


Figure 3: Palaeoclimatic inferences based on geomorphological, archaeological and palaeobiological studies in Lesotho from 13 000 cal yr BP to present. Graduated colour represents progressive drying.

conflicting interpretations of the available records, these often occur where coarse-resolution long-term records do not register the intricacies of higher-resolution records that span shorter time periods (Figure 3). Most notable is the absence of any high-resolution long-term record that can bridge the gap and resolve these apparent conflicts. Long-term temporally continuous palaeoenvironmental reconstructions, based on proxy data, would greatly improve the palaeoclimatic inferences made from such geomorphic features.^{8,18} Comparisons with higher resolution and more temporally continuous records from Braamhoek Wetland^{67,68} and Mahwaqa Mountain³⁷ in the adjacent South African Drakensberg indicate lags in temperature depressions and changes in moisture availability. These findings support the inference of topographical controls on lapse rates and orographic rainfall.

The reconstructed palaeoclimatic and palaeoenvironmental history of Lesotho relies predominantly on archaeological and geomorphic evidence. Both sources of evidence are produced through pulsed events. In the case of archaeology, these pulses are recurrent periods of usually warmer temperatures, whereas for cryogenic landforms, phenomena reflect development during what is usually a single pulse of cold conditions^{4,6,13}. Although such periglacial landforms may become reactivated (active) again after warmer climatic episodes terminate, it has thus far not been possible to ascertain their age and periods of past activity. When combined, palaeogeomorphological and archaeological evidence can be used to infer the timing of both cold and warm events. However, such data are collectively unable to provide a complete and continuous climatic and environmental history for the region, as the climatic extremes they represent are often short-lived and seldom overlap, and are influenced significantly by conditions leading into and out of the events they document^{4,9,26}. Thus, while potentially valuable for defining more extreme palaeoclimatic periods, and useful for reconstructing broad environmental conditions where no other data exist, these records are relatively limited in providing more precise palaeoclimatic and environmental information on the late Quaternary³.

Continuous, well dated palaeoecological records are thus essential for determining the nature of climatic and associated environmental changes, during which these extreme events took place, during the periods leading up to these events, and the smaller temporal fluctuations between them^{3,6}. Because of the complex relationships between temperature and precipitation in Lesotho, it would be beneficial to employ multiple proxies to quantify the relative effects of these two climate variables⁴. Finally, given the large differences in palaeoclimatic and palaeoenvironmental information gained from geomorphic features, human occupation, and present-day environments at sites in very close proximity to each other, these features highlight distinct microclimatic differences. Only once detailed analyses across many sites are forthcoming will it be possible to develop a high-resolution understanding of past climates at specific sites in Lesotho, and to integrate the findings of geomorphological and archaeological records.

Authors' contributions

J.F. was the team leader, collated the existing literature, and wrote the first draft. S.G., M.B. and A.M. supervised this process, contributed to the literature database, and assisted in the argumentation throughout the paper. S.G. provided photographs of geomorphological features.

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