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Abstract

Sehonghong rock shelter is situated in the eastern Lesotho highlands, a climatically extreme region of southern Africa. The site is one of a handful in southern Africa that preserve human occupations before, during, and after the Last Glacial Maximum (LGM). The site's long and well-preserved sequence makes it relevant to addressing questions of human mobility, subsistence, and technology in relation to broader environmental change. Here we present a Bayesian-modelled radiocarbon chronology for the LGM and terminal Pleistocene occupations at Sehonghong. Our model incorporates previously published radiocarbon dates and new accelerator mass spectrometry ages. We also present archaeological evidence to test the hypothesis that Sehonghong was occupied in a series of punctuated events, and that some of these occupations were more intensive than others. Previous chronological and archaeological data were insufficient for testing these hypotheses. The new dates and archaeological data confirm that the site was occupied intensively in the early LGM and immediately thereafter. The site was otherwise occupied sporadically. We find that greater site occupation density is not always correlated with intensified use of local resources as measured by increased bipolar reduction and fish consumption. The new dates further confirm that Sehonghong contains some of the oldest evidence for systematic freshwater fishing in southern Africa. The availability of fish, a high fat protein source, probably stimulated human occupation, however sporadic, of such montane environments during cooler and drier periods. These findings suggest behavioural variability in response to shifting mobility and subsistence strategies. Our brief discussion informs upon hunter-gatherer occupation of southern African montane environments more broadly and human behavioural variability during the LGM.

Keywords	Montane environments; late Pleistocene; Last Glacial Maximum; AMS; bipolar reduction; Lesotho
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Title:
New ages from Sehonghong rockshelter: Implications for the late Pleistocene occupation of highland Lesotho

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Abstract:

Sehonghong rock shelter is situated in the eastern Lesotho highlands, a climatically extreme region of southern Africa. The site is one of a handful in southern Africa that preserve human occupations before, during, and after the Last Glacial Maximum (LGM). The site's long and well-preserved sequence makes it relevant to addressing questions of human mobility, subsistence, and technology in relation to broader environmental change. Here we present a Bayesian-modelled radiocarbon chronology for the LGM and terminal Pleistocene occupations at Sehonghong. Our model incorporates previously published radiocarbon dates and new accelerator mass spectrometry ages. We also present archaeological evidence to test the hypothesis that Sehonghong was occupied in a series of punctuated events, and that some of these occupations were more intensive than others. Previous chronological and archaeological data were insufficient for testing these hypotheses. The new dates and archaeological data confirm that the site was occupied intensively in the early LGM and immediately thereafter. The site was otherwise occupied sporadically. We find that greater site occupation density is not always correlated with intensified use of local resources as measured by increased bipolar reduction and fish consumption. The new dates further confirm that Sehonghong contains some of the oldest evidence for systematic freshwater fishing in southern Africa. The availability of fish, a high fat protein source, probably stimulated human occupation, however sporadic, of such montane environments during cooler and drier periods. These findings suggest behavioural variability in response to shifting mobility and subsistence strategies. Our brief discussion informs upon hunter-gatherer occupation of southern African montane environments more broadly and human behavioural variability during the LGM.

INTRODUCTION

This paper presents an updated and improved ^{14}C-based chronological framework for Sehonghong rock shelter in highland Lesotho. Its goals are to examine patterning in evidence for human occupational density at the site, and to relate this patterning to a suite of newly derived accelerator mass spectrometry (AMS) ages for the site's LGM and terminal Pleistocene sequence. Our results have implications for the understanding of hunter-gatherer occupation of Afromontane environments more broadly.

African hunter-gatherers are typically seen as desert/savannah/forest dwelling, warm climate-adapted humans (Kusimba, 2003). These depictions derive in large part from classic twentieth-century ethnographies conducted in the Kalahari Desert, Central African rainforests, and the grasslands of eastern Africa (see Mitchell, 2016a for a discussion). Most contemporary models for prehistoric hunter-gatherer behaviour are defined in some way by the ethnographic research conducted in these often resource-marginal regions (Kelly, 2013). However, the African archaeological record provides examples of foraging populations occupying a wide-range of habitats beyond those depicted in these classic ethnographies (Sealy, 2016). These include groups occupying coastal and near coastal contexts and Afromontane environments.

Coastal environments provide a range of rich and predictable resources including fish, molluscs, and terrestrial resources. In southern Africa, stable coastal resources may have catalysed the evolution of hyper pro-sociality and intergroup territoriality amongst hunter-gatherers by providing stable, reliable, and defensible resources (Marean, 2016). While historically more archaeological research in southern Africa has focused on these rich coastlines, there is now also a growing realisation of the potential of interior montane regions (Stewart, et al., 2016). In fact, many of southern Africa's late Pleistocene archaeological sites are found in its peripheral mountains (Mitchell, 1990). These montane regions experience higher precipitation and lower evaporation rates than the rest of the sub-continent and are thus likely to have been insulated from periods of greater aridity across the wider region. Montane regions are also favourable to hunter-gatherers because of their ecological and topographic diversity, which provides a range of plants and animals within a relatively small range including dense and predictable resources in the form of freshwater and fish (Mitchell, 2016a). Fishing has a significant effect on the mobility and subsistence strategies of hunter-gatherer groups, allowing them to remain in one place for longer and to greater effect (Kelly, 2013).

FIGURE 1

Nevertheless, montane environments place unique demands on human behaviour. These environments are generally more rugged and more prone to extreme and unpredictable weather conditions. Montane resources, while diverse, tend to be more sparsely distributed, making resource scheduling less predictable and more challenging (Aldenderfer, 1999). Relatively rapid climate change during the LGM (22.3 ± 3.6 ka; Shakun and Carlson, 2010) would have exacerbated these uncertainty factors. Humans living under such conditions typically find themselves under greater pressure to implement reliable and flexible strategies, such as more structured patterns of seasonal movement, group aggregation, and a focus on specialised resource procurement activities, such as fishing (Stewart and Mitchell, In Press). Sehonghong is one of only a handful of southern African sites with human occupations before, during and after the LGM. This, and its good organic preservation, provide a unique window on montane-adapted hunter-gatherers and warrant the renewed chronological framework in this paper.

BACKGROUND TO SEHONGHONG AND ITS REGIONAL CONTEXT

Eastern Lesotho is one of the most climatically extreme and variable regions in southern Africa. The Thaba Tseka District, within which Sehonghong is situated, currently receives an average annual rainfall of 620 mm (mostly during the summer), with a standard deviation of 115 around this mean (weather data for 1976–2004 from the Thaba Tseka weather station, Moeletsi, 2004). Precipitation values of 578 mm from the Sehonghong weather station and >1500 mm from the nearby escarpment demonstrate the high degree of rainfall variability in this montane region (Carter et al. 1988). The Thaba Tseka District and the Senqu River Valley are drier than more easterly regions of Lesotho, but are also less prone to flash flooding during periods of high intensity rainfall (Moeletsi, 2004).

Temperatures in this region fluctuate between average monthly maximum/minimum values of 22/9 °C in the summer and 14/-0.25 °C in the winter (weather data for 1976–2004 from the Thaba Tseka weather station, Moeletsi, 2004). Extreme winter temperatures with minima as low as -10 and -21 °C can occur (Moeletsi, 2004). Effective temperature (ET), a measure that incorporates the difference between average temperatures in the coldest and warmest months, and which reflects ecosystem productivity and the length of the growing season, is 13 °C (Bailey, 1960). Effective temperatures above 15 °C represent environments with more abundant and predictable food sources (Johnson, 2014). Hunter-gatherers living near aquatic resources with ETs below c. 12 °C are expected to rely on hunting and especially fishing to a greater degree than on plant food resources for their subsistence (Binford, 2001).

Palaeoenvironmental indicators show that the LGM in the Lesotho highlands was highly variable, but markedly cooler than present. Periglacial conditions are recorded in small niche-glaciers, glacial moraines, and organic-poor colluvium deposits dated to 27–23 kcalBP (Grab and Mills 2011). Temperature estimates for the LGM based on the occurrence of glaciers and periglacial features range from 6 °C (Mills, et al., 2012) to as low as 8–10 °C below current mean annual values (Lewis and Illgner, 2001). Cool-adapted C_3 plants dominated the local vegetation around Sehonghong until c. 15 ka, indicating average temperatures at least 5 °C below today (Loftus et al., 2015). With such a temperature reduction, ET would have dropped to c. 12 °C, placing eastern Lesotho below Binford's (2001) threshold for an expected subsistence strategy focused on plant foods. Today, regions with effective temperatures below 12.75 °C include Alaska, northern Canada, much of Northern Asia, and Patagonia (Johnson, 2014).

Sehonghong is a large west-northwest facing rock shelter (280 m^2) at c. 1800 m.a.s.l. The site lies on the south bank of the Sehonghong River, 3 km upstream of the latter's confluence with the Orange (Senqu) River. Following Pat Carter's pioneering work in the 1970s that employed 10-cm-thick spits cross-cutting the stratigraphy (Carter, et al., 1988), Mitchell (1996) undertook further excavations in 1992 to collect organic and inorganic materials in a manner related to the natural depositional history of the shelter. His excavations revealed a complex stratigraphy of 161 units grouped together into 10 larger layers across a 12 m^2 grid. Mitchell's excavations revealed a rich sequence of late Pleistocene and Holocene human occupations containing abundant faunal, macrobotanical, and aquatic resources. Brian Stewart and Genevieve Dewar are currently directing excavations and the re-dating of underlying deposits (Stewart, et al., 2012; Loftus et al., 2015).

Mitchell and Carter obtained an initial series of conventional ^{14}C dates, which suggested that Sehonghong was occupied in a series of pulses across the LGM and terminal Pleistocene (**see Table 1**). Three dates from layer BAS dated it to the early LGM (c. 24 – 23 ka: Pta-918; Pta-6077; Pta-6281), but the overlying levels contained an apparently discontinuous sequence with ages at c. 21 ka (Q-1452) and c. 19 ka (Pta-6060) (**see Table 1**). The site was only intensively reoccupied in layers RBL-CLBRF and RF, dated to the terminal Pleistocene, c. 15–14 ka (**see Figure 2, Table 1**). However, difficulties in precisely matching the Carter and Mitchell depositional sequences and the large errors of the conventional radiocarbon ages have meant that it has hitherto been impossible to establish whether Sehonghong was continuously occupied throughout the LGM, completely abandoned over much of this time, or only sporadically occupied.

TABLE 1

Mitchell's excavations produced further data from which to build a model for the patterning and density of human occupations at the site. Layers RFS, MOS, and OS consist largely of extensively weathered deposits, thin hearths, and small sandstone roof spalls that may represent frost shattering because of increased cold associated with the LGM (Mitchell, 1994). Excavation of unit 140 in layer MOS revealed a large 150 mm deep pit filled with charcoal (Mitchell, 1994), while similarly extensive charcoal features in layers BAS and RBL-CLBRF were interpreted as 'roasting pits' (Mitchell, 1995). These features suggest more intensive use of the site at these times relative to the overlying layers RF and BARF, which lack such evidence. We hypothesize that more intensive site occupation in layers MOS, BAS and RBL-CLBRF may, in turn, have encouraged the intensified use of other resources, such as stone raw materials for tool production.

Sehonghong contains the largest assemblage of Pleistocene freshwater fish remains in southern Africa (Plug and Mitchell, 2008; cf. data in Marean 2016). Layers BAS and RF contain the highest number of identifiable fish specimens present (NISP) (**see Table 2**), normalized for the volume of excavated deposit. Lower fish frequencies occur in layers RFS, MOS, OS, RBL-CLBRF, and BARF (Plug and Mitchell, 2008). These patterns suggest that increased use of aquatic resources occurred during the lead up to the LGM and during the Antarctic Cold Reversal (ACR) (~14.7 to 13 ka), a sharp turnaround during the warmer post-LGM period (Pedro, et al., 2015). These patterns possibly indicate people adapted subsistence behaviors in order to remain in these montane environments. The absence of a sizable fish assemblage in layer RBL-CLBRF, with an otherwise large artefact assemblage, suggests that fishing was not always associated with intensified site use (see Mitchell, 2016a for a discussion).

METHODS

RADIOCARBON DATING

To provide an improved and updated chronology for Sehonghong's late Pleistocene deposits, twelve new AMS radiocarbon dates on charcoal fragments were acquired. These targeted the early and post-LGM levels at Sehonghong, including layer OS, which had not previously been dated. The samples were selected from charcoals from Mitchell's excavation stored at the Institute of Archaeology, University of Oxford. Intact, twig-like fragments were preferentially selected to limit any possible "old wood" effect, although this is not expected to be a concern for this region over these timescales. No consolidates or chemicals had been used on the charcoal for conservation purposes.

The Oxford Radiocarbon Accelerator Unit (ORAU) acid-base-acid extraction method for charcoal was used (Brock, et al., 2010) with graphitised samples dated on the Oxford Radiocarbon Accelerator Unit's HVEE AMS system (Bronk Ramsey et al., 2004). The greater sensitivity of AMS systems permits measurement of considerably smaller samples than required for conventional beta-counting measurements, and typically produces more accurate and precise dates. The new AMS and previously published ^{14}C measurements were calibrated with the OxCal v 4.2 software (Bronk Ramsey, 2009a), using the latest SHCal13 calibration curve for the Southern Hemisphere (Hogg, et al., 2013). The dates were modelled according to Bayesian statistical principles in OxCal, using stratigraphic information from the Mitchell excavation.

Outliers were identified according to the indices method (Bronk Ramsey, 2009b) and discarded from the models.

SITE OCCUPATION DENSITY, LITHIC REDUCTION INTENSITY, AND FISHING

This paper tests the hypothesis that Sehonghong was occupied in a series of punctuated events, and that some of these occupations were more intensive than others. We use the number of buckets excavated per layer as a measure of excavated volume and to measure variability in site occupation density (**see Table 2**). We use this variable to normalise the three proxies for site occupation density listed below.

TABLE 2

We present three variables to measure site occupation density: total weight of flaked stone, bipolar (hammer and anvil) core frequencies, and the relative contribution of fish to the diet. By comparing these three assumed measures of site occupation density to our the volume of excavated deposit as well as other contextual data on occupational density (e.g. the presence of large charcoal features), we test whether periods of intensified site occupation were also associated with intensification of stone tool production and a greater dietary contribution of aquatic resources.

First, we measured the weight of knapped lithic material per layer. As occupation density increases so to should the weight of the associated lithic assemblage (but see Hiscock, 1981; Barton and Riel-Salvatore, 2014). However, shifts in raw material use can affect this measure. To control for this, we record only the weight of the most commonly knapped cryptocrystalline (CCS) rocks (chert, agate, chalcedony). We also include weights for quartz crystals for which newly derived technological information is available. Quartz crystals are generally small and they are unlikely to significantly alter the weight of reduced lithic materials (see Pargeter 2016 for average crystal quartz weights).

Elsewhere, archaeologists regard bipolar technology as a signal of the intensification of lithic reduction in response to increased occupation density in environments where suitable raw materials are relatively scarce (Parry and Kelly, 1987; Eren et al. 2013). As occupation density increases, the availability of suitable raw materials is expected to decrease. In such situations, people may choose to travel further for raw materials or to reduce local rocks more intensively. Bipolar reduction is unsurpassed in its ability to reduce nodules of rock down to small sizes, especially more problematic raw materials such as quartz (Pargeter and de la Peña, In Press). A drop in raw material availability is expected to result in greater economising behaviour and potentially greater bipolar reduction (see Eren, et al., 2013). To test this, we quantified the frequency of bipolar cores per excavation layer. To do so, we employed an attribute-based approach to identifying bipolar cores following procedures outlined in de la Peña (2015), Pargeter (2016), and de la Peña and Pargeter (In Press). Here, we focus on crystal quartz and CCS bipolar cores as these are rock types for which we have the most precise experimental models with which to identify bipolar reduction (de la Peña, 2015, Pargeter, Submitted).

Our third measure of occupation density is the relative contribution of fish to diet. Increased fish consumption is commonly thought to reflect increased subsistence intensification (see Hall, 1997). To test this, we measure the number of identifiable species present (NISP) for fish versus ‘other’ animals at Sehonghong (**see Table 2**). We present this relationship in terms of the asymmetry quotient (AQ) (see Fears et al., 2011). Asymmetry quotients are calculated by subtracting a first input value (i.e. fish NISP) from a second data value (i.e. ‘other’ NISP) and dividing the result by the average value of the two measurements:

$$AQfood = (\text{fish NISP} - \text{‘other’ NISP})/((\text{fish NISP} + \text{‘other’ NISP})/2))$$

The AQ is a dimensionless index that allows for any two linear measurements to be compared and for the relative contribution of each of them to the resulting value be determined. Asymmetry quotient values at zero indicate symmetry between the two input variables. Positive AQ values show asymmetry towards the first input measurement (i.e. greater contribution of fish to the diet). Negative AQ values show asymmetry towards the second data point (i.e. greater contribution of ‘other’ animals to the diet). Asymmetry quotients allow us to determine not just when fish frequencies increase, but when the relative contribution of fish to the diet increases.

RESULTS

RADIOCARBON DATES

The AMS ^{14}C measurements for Sehonghong are presented in **Table 3**, together with their calibrated ranges (at 2σ) and $\delta^{13}C$ values based on isotope ratio mass spectrometry measurements. OxA-32924 and OxA-32925 are repeat measurements undertaken on the same charcoal for quality assurance and their error margins overlap. The dates are stratigraphically coherent, except for OxA-32916 from OS, which is clearly out of sequence, and OxA-32921 from BAS, which is several hundred years older than the dates immediately underlying it from MOS. Our other date from OS, OxA-32917, overlaps almost completely with OxA-32920 from BAS at two standard deviations. Only OxA-32921 was therefore marked as an outlier, and this date was discarded in the model.

TABLE 3

Table 4 shows the modelled results for the previously published conventional ^{14}C dates and the new chronology for Sehonghong, which incorporates our AMS dates. The two plots of Figure 2 show the modelled *Phases* in *Sequence* models, with a single *Boundary* or double *Boundaries* (indicated by double lines in the plots) inserted between *Phases* to model hiatuses in the depositional sequence. Also shown are the age ranges at 2σ for each distribution.

FIGURE 2

There is some uncertainty about the associations of several previously published dates obtained from Carter's excavations at the site. Based on descriptions in Pat Carter's notebooks and in the stratigraphic section drawings, dates Q-3172; Pta-884 and Q-3173 in Carter's units 48, 50 and 52, respectively, are believed to correspond with Mitchell's layer RBL-CLRBF and are here included in this *Phase.* Dates Q-1452 and Pta-6060 together span several thousand years in the lower part of Carter's Layer IX (correlated with Mitchell's layer BAS), these results are shown as individual dates in **Figure 2**. Their validity has considerable implications for the occupation of the site during the terminal Pleistocene (discussed below). Two additional dates from Units 39 (Q-3175) and 42 (Q-3176) are similarly difficult to correlate with the stratigraphy recognised in the 1992 excavation and used here, but their inclusion in the model does not greatly affect the occupational interpretation.

To test for occupational hiatuses, *Intervals* were inserted between the double *Boundaries* (Bronk Ramsey 2009a). Modelled *Interval's* greater than zero confirm a break in the chronology of the length indicated (shown at the 2σ range in Table 4). The addition of the new AMS ages helps to conform two further hiatuses in the depositional sequence, between the MSA and layer RFS and between the possible ephemeral occupation indicated by the date Pta-6060 and layer RBL-CLRBF. A hiatus cannot be confirmed between BAS and the overlying deposits if date Q-1452 is included in the model.

SITE OCCUPATION DENSITY

Figure 3 plots the site occupation density measures: lithic weights, bipolar core frequencies, and fish to 'other' NISP AQs. As expected, levels with the highest excavated volumes and with evidence for extensive hearth features (layers BAS, RBL-CLBRF, and RF) also show the highest mass of knapped lithic material (1335 g, 1273 g, 979 g respectively). Layer BARF departs from this pattern in showing high amounts of knapped material (608 g), but a low volume of excavated deposit represented by a thin lens and only two excavated buckets. No substantial fire-pit features were excavated in layer BARF (Mitchell 1995).

Adjusted bipolar core frequencies occur at their lowest frequencies in layers BAS (1.6 %), RBL-CLBRF (1.2 %), and RF (3.8 %) (**see Table 2, Figures 3 & 4**). The highest adjusted bipolar core frequencies occur in layers RFS (9.5 %), OS (26.6 %), and BARF (15.8%). The pattern in layer BARF is attributed to a spike in the use of crystal quartz bipolar cores at this time (**see Figure 4**). Overall, these patterns indicate that periods of increased site occupation density and increased lithic reduction are inversely correlated with increased bipolar core frequencies. Stone tool makers at the site appear not to have employed bipolar reduction in a manner related to occupation density. The one possible exception to this is layer BARF where high amounts of knapped material (608 g) are associated with relatively high bipolar core frequencies (15.8 %) made predominantly on quartz crystals.

FIGURE 3

The relative contribution of fish to the diet increases in the lead up to the LGM with AQ values ranging from -1.78 in layer RFS (relatively less fish in the diet) to their highest value of 0.75 in layer BAS (relatively more fish in the diet). Fish decrease in relative importance in layer RBL-CLBRF (AQ: -1.34) only to increase again in layers RF (AQ: 0.56). They comprise a marginally more important food source in layer BARF (AQ: 0.05). Fish consumption patterns in layers BAS and RF match the expectation of increased fishing at times of increased site occupation density. The patterns in layers RBL-CLBRF (high occupation density: lower relative fish contribution) and MOS, OS, and RF (low occupation density: higher relative fish contribution) depart from these expectations. Humans appear to have strategically varied their use of aquatic resources during both high and low density occupation events.

FIGURE 4

DISCUSSION AND CONCLUSIONS

These results substantially revise the existing chronology for the late and terminal Pleistocene deposits at Sehonghong, confirming at least two, possibly three occupational hiatuses at the site. These are between the MIS 3 deposits and RFS, between RFS and MOS, and possibly between BAS and RBL-CLBRF. Previous dating of the site had suggested that Sehonghong was more or less continuously occupied across the LGM. The updated and modelled results instead indicate a period of abandonment c. 28–25 kcalBP, followed by consistent occupation c. 25–23 kcalBP from layer MOS to the initial part of layer BAS. This period coincides with climate changes marked globally by the LGM from c. 25.9 ka (Shakun and Carlson, 2010). The Cold Air Cave speleothem record, located in the Makapansgat Valley in South Africa's Limpopo province, records a marked decline in the proportion of C_4 grasses c. 23 kcalBP, which is indicative of a decrease in growing season temperatures after the onset of the LGM (**see Figure 3**) (Holmgren, et al., 2003). Such ecological shifts are likely to have occurred even earlier in the montane region around Sehonghong, affecting the structure and abundance of resources in this region. Charcoal, isotope, and phytolith signals from the nearby site of Melikane confirm a generally cold and sparse LGM landscape at c. 25 kcalBP (Stewart, et al., 2016).

Crucial for our interpretation of the occupational sequence is the validity of the two ^{14}C dates, Q-1452 and Pta-6060, which fill out the period between 23–17 kcalBP. These dates, if secure, suggest the site continued to be visited sporadically during the LGM, perhaps as a summer camp. Given the uncertain associations of these dates, and the considerable improvements in radiocarbon dating methodology since they were obtained, an arguably more secure reading of the chronology would exclude these dates. In this case, Sehonghong was likely unoccupied for most of the LGM between 23–16 kcalBP, probably because of significantly colder/harsher climatic conditions. Humans reoccupied the site at c. 15 kcalBP in layer RBL-CLBRF, only to resume a more ephemeral occupation pattern in the terminal Pleistocene layers RF and BARF. Layers RF and BARF coincide with the cooler conditions of the ACR event at c. 14.7–13 ka. Roberts and colleagues (2013) show widely fluctuating sediment $\delta^{13}C$ values between c. 14–9.5 kcalBP at the lowland Lesotho site of Ntloana Tšoana and similarly sudden shifts are evident from the sediment isotope record within Sehonghong (Loftus et al., 2015) (**see Figure 1**). These records suggest marked fluctuations in vegetation composition characterized the terminal Pleistocene in this region. Under such unpredictable subsistence conditions humans may have avoided long-term forays into the montane regions around Sehonghong.

Our occupational density data inform these chronological discussions. They show that although occupations were consistent across various chronological intervals, the occupations were not uniform in density. Intensified occupations are noted in layers BAS, but not in layers MOS and OS, which show lower occupation density. Our inability to tease apart more detail in the current structure of the BAS lithic and faunal assemblage makes it difficult to determine if most of this material derives from the lower component of this layer > 23 kcalBP (i.e. earlier in the LGM). Being able to do so would help us to address whether a genuine hiatus of several thousand years exists between layers BAS and RBL-CLBRF, or if occupation density was readjusted under peak LGM conditions to the greater use of the site as a short-term camp. Sehonghong witnessed a series of variably intensive human occupations during the terminal Pleistocene. Layer RBL-CLBRF ranks second highest in occupation density by weight of lithic material. Excavated volumes and the weight of lithic materials show a steady decline in layer RF and drop to their lowest values in layer BARF (c. 15-12 kcalBP). Incidentally, we see increased evidence for site occupation at the same time at the lowland sites of Ntloana Tšoana and Rose Cottage Cave c.

150 km west of Sehonghong (Mitchell & Steinberg, 1992; Wadley 1996; Arthur & Mitchell, 2009; Pargeter 2016) (**see Figure 1**). This broader patterning in site occupation density may reflect shifting use of lowland versus montane environments related to increasingly unpredictable climatic conditions during the terminal Pleistocene.

We cannot conclusively link the relative contribution of fish in the diet to site occupation density. The only three layers for which this pattern holds are BAS, RF, and BARF. These three layers all fall within cold periods of the LGM (layer BAS) and the ACR (layers RF and BARF), when subsistence resources are expected to have become more sparsely distributed and more unpredictable (Roberts, et al., 2013, Stewart, et al., 2016). Under such conditions, models based on ethnographic observations predict a readjustment of subsistence practices to focus on the greater use of aquatic resources (e.g. Binford, 2001). The fish remains at Sehonghong, although present, contribute relatively less to human diets in those layers outside of either the LGM or ACR. This pattern of the greater use of aquatic resources during colder periods matches those expected from ethnographic observations.

Our bipolar core frequencies show an opposite pattern to that predicted by the Parry and Kelly (1987) model, namely a positive relationship between indices of lithic reduction and site occupational density. We find that bipolar core frequencies are lowest in layers with evidence of increased site occupation densities (layers BAS, RBL-CLBRF, and RF). Bipolar core frequencies are highest in layers RFS, MOS, OS, and BARF with the lowest occupation densities. Factors other than raw material scarcity and occupation density must be driving this technology. One possible factor is that Sehonghong is located in a region rich in high-quality silicate raw materials. This context would reduce the need to use bipolar reduction to conserve raw material.

Most archaeologists agree that bipolar reduction is an expedient (time-efficient) strategy (e.g. Shott, 1999, Eren, et al., 2013, Morgan, et al., 2015). Experiments show how tool makers using bipolar reduction are able to produce cutting edge up to three times quicker than with freehand reduction, while at the same time maximizing the cutting edge to mass ratio of a nodule of rock (Pargeter and de la Peña, In Press). These observations are important when we consider that hunter-gatherers have limited time and energy to budget (Torrence, 1983, Bousman, 1993). Parry and Kelly (1986: 303) perceive bipolar reduction as expedient, but wasteful: “such a technology is not costly in terms of time or effort needed to manufacture or use tools, but it is wasteful of raw material.” Yet, modern experimental work shows how bipolar reduction, as a strategy for small flake and bladelet production, combines production expediency with production economy (Pargeter and de la Peña, In Press). The complex interplay of these two variables may explain why we find increased levels of bipolar reduction at times when Sehonghong was only ephemerally occupied, and decreased frequencies at times when occupation density increased. People occupying sites for longer periods are more likely to have time to collect raw materials and to produce and maintain their toolkits. People occupying sites for shorter intervals would have less time to collect materials, reduce them, and then to manufacture implements (see Jeske 1992). Time-saving technologies, such as bipolar reduction, are expected to increase in such contexts. In future work we will investigate other potential factors to explain these patterns, such as functional differences for bipolar flakes and the use of bipolar reduction to reduce particularly challenging rock types/nodule shapes. Ongoing survey work around Sehonghong is also investigating the raw material context for these patterns.

Our revised chronology for the late and terminal Pleistocene deposits at Sehonghong finds strong evidence that Sehonghong was variably occupied in relation to major climatic intervals such as the LGM and ACR. Fish contribute relatively more to hunter-gatherer diets in layers associated with these colder periods. These observations mirror expectations from hunter-gatherer ethnography. Our bipolar core frequencies do not match the expectations of North American models linking expedient core technologies to site occupation density. This is probably because these models are built on the perception of bipolar reduction as wasteful and because Sehonghong is not located in a raw material scarce environment. Modern experimental work shows this assumption is erroneous. Toolmakers likely used bipolar reduction to save time in contexts where it was more limited. Collectively, our data provide an example of strategic human behavioural variability in contexts of fluctuating climates.

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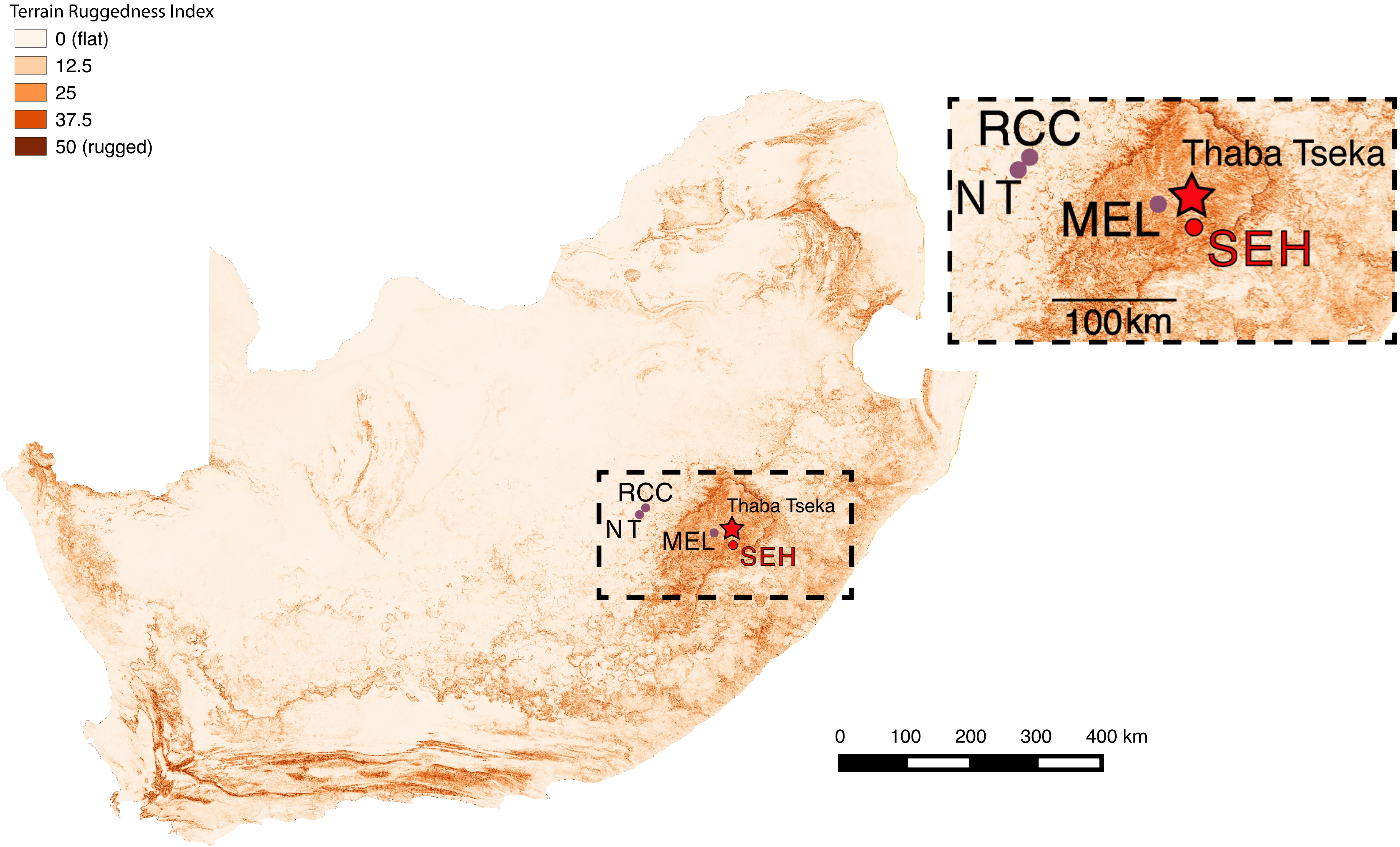
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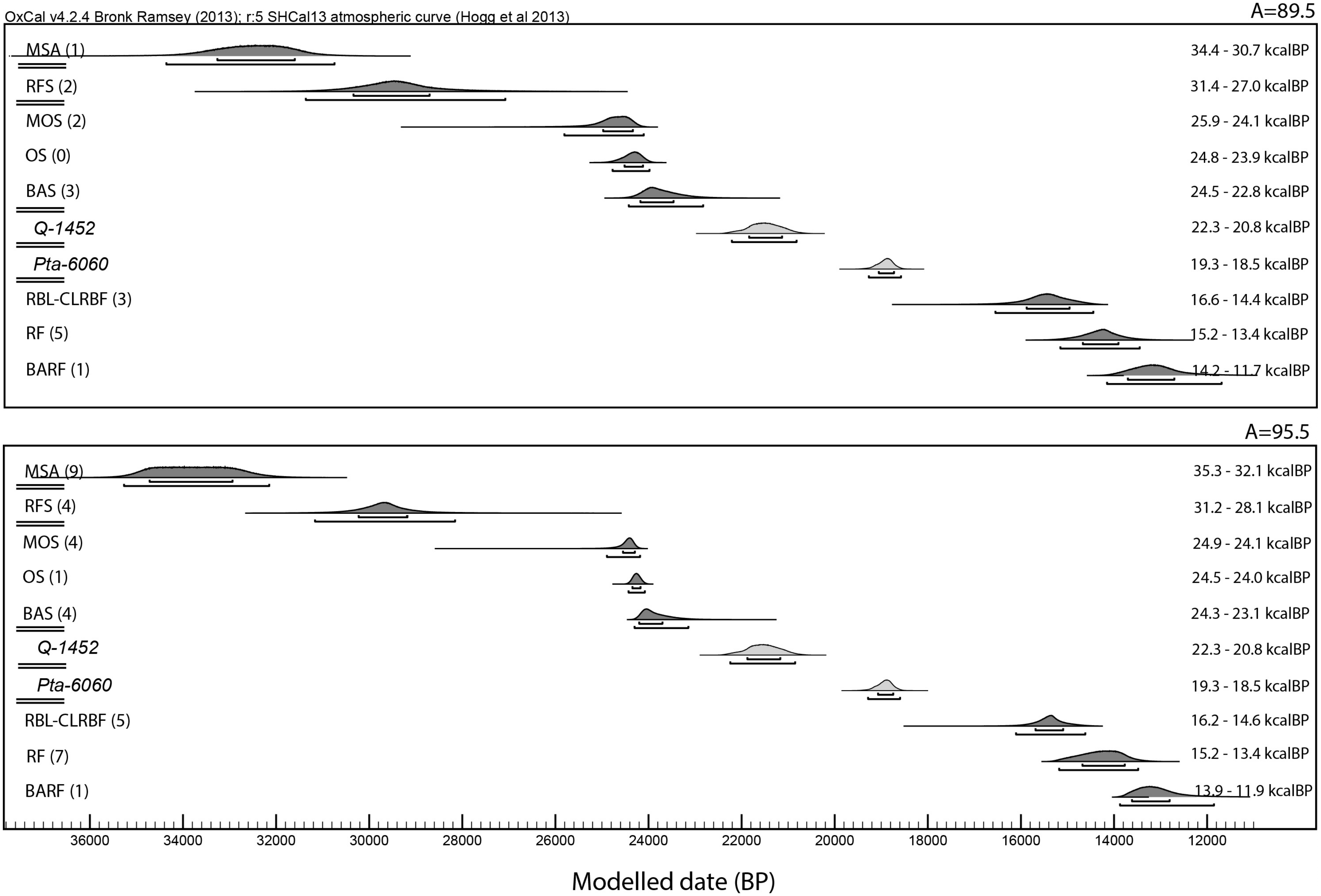
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BAS (3)
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Pta-6060
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BARF (1)
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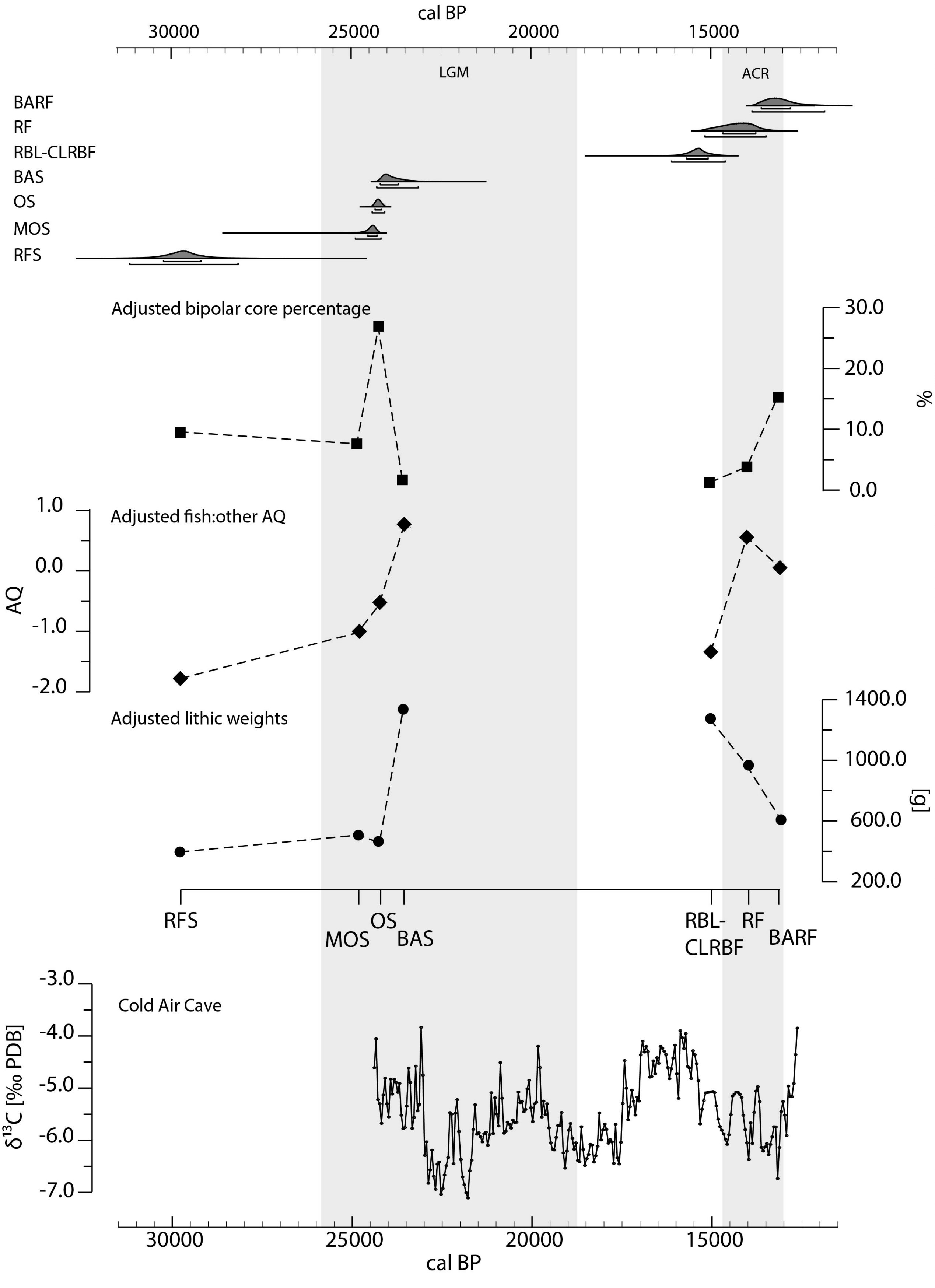
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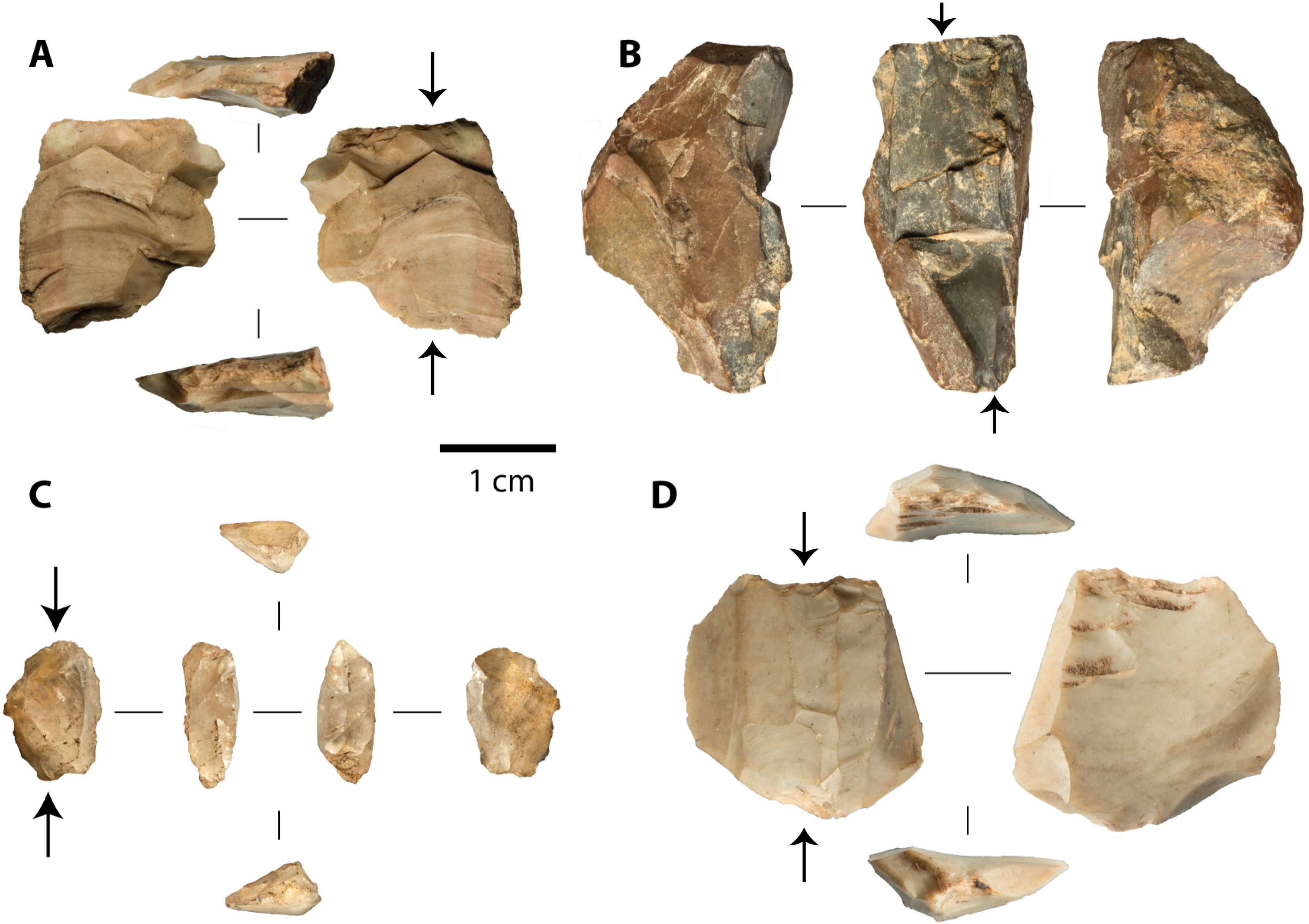
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FIGURE CAPTIONS

Figure 1. Map of southern African terrain ruggedness and sites mentioned in the text. RCC: Rose Cottage Cave; SEH: Sehonghong; MEL: Melikane; NT: Ntloana Tšoana; Thaba Tseka: marks the location of the weather station from which our modern climate data is sourced (see Moeletsi, 2004).

Figure 2. Comparison of modelled age ranges for Sehonghong sequence based on previously published dates (top) and incorporating new AMS ages (bottom). The age ranges are shown to 2σ, rounded outwards to 100 years, and the number of 14C dates included in each level is shown in brackets alongside the context name. Two dates, Q-1452 and Pta-6060, possibly representing ephemeral LGM occupations from Carter's units 48 – 54 are shown separately (white backgrounds). Each level is modelled as a *Phase*, with a *Boundary* or double *Boundary* (indicated by double lines between context names) between each. The agreement index for each model is shown in the upper right corner.

Figure 3. Bayesian modelled chronology for Sehonghong late Pleistocene levels (excluding dates from Units 48 – 54); B. Archaeological indicators of occupational intensity, including percentage of CCS bipolar cores (squares), lithic weights (circle) and asymmetry quotient of fish to all other fauna (diamond) (all adjusted for amount of deposit excavated); C. $\delta^{13}C$ values of Cold Air Cave speleothem, representative of proportions of C3 and C4 grasses (Holmgren, et al., 2003).

Figure 4. Sehonghong CCS (A,B,D) and crystal quartz (C) bipolar cores. A,B,C: Layer RBL-CLBRF; D: layer BAS. Black arrows indicate direction of bipolar reduction blows.

TABLES CAPTIONS

Table 1. Radiocarbon ages for the Last Glacial Maximum and terminal Pleistocene levels at Sehonghong from the Mitchell, Carter and Stewart and Dewar excavations, with sample context and the calibrated age estimate shown at the 2σ range (dates calibrated using Oxcal v. 4.2 and the SHCal13 curve for the Southern Hemisphere, rounded outwards to 5 years) (Carter and Vogel, 1974; Carter, 1976; Carter et al., 1988; Mitchell and Vogel, 1994.). All ages are conventional dates on charcoal, except Q-3175 and Q-3176 on bone and OxA-27689-97, which are AMS dates (Loftus et al., 2015).

Table 2. Sehonghong fish, fauna, lithic weights, bipolar core frequencies, and excavated number of buckets summary data. NISP: number of identifiable specimens present. AQ: asymmetry quotient. Other: faunal items other than fish. All values have been corrected by the number of excavated buckets.

Table 3. AMS dates on charcoal from Mitchell's excavation at Sehonghong, with $\delta^{13}C$. Dates are calibrated using the SHCal13 curve, and reported to 2σ, rounded outwards to 5 yr. *OS = date marked as outlier and discarded in the model.

TABLES AND CAPTIONS

Table 1. Radiocarbon ages for the Last Glacial Maximum and terminal Pleistocene levels at Sehonghong from the Mitchell, Carter and Stewart and Dewar excavations, with sample context and the calibrated age estimate shown at the 2σ range (dates calibrated using Oxcal v. 4.2 and the SHCal13 curve for the Southern Hemisphere, rounded outwards to 5 years) (Carter and Vogel, 1974; Carter, 1976; Carter et al., 1988; Mitchell and Vogel, 1994.). All ages are conventional dates on charcoal, except Q-3175 and Q-3176 on bone and OxA-27689-97, which are AMS dates (Loftus et al., 2015).

Mitchell association	**Carter association**				**Calibrated date**	
		Lab. ID.	**Date**	**±**	**From**	**To**
MSA		OxA-2769	35070	240	40175	38935
MSA		OxA-2769	31030	250	35485	34415
MSA		OxA-2769	30910	250	35335	34270
MSA		OxA-2769	28800	190	33520	32195
MSA		OxA-2769	29200	200	33800	32865
MSA		OxA-2769	29170	190	33770	32855
MSA		OxA-2769	29120	190	33740	32800
MSA		OxA-2769	28650	200	33330	31865
MSA	VII/VI/V	Pta-920	28870	520	33925	31575
RFS		Pta-6268	26000	430	30985	29240
RFS		Pta-6271	25100	300	29890	28465
MOS		Pta-6059	20500	230	25275	24060
MOS	VII (80)	Pta-919	20240	230	25015	23745
BAS	IX (60)	Pta-789	20900	270	25735	24430
BAS		Pta-6077	20200	200	24880	23745
BAS	IX (72)	Pta-918	19860	220	24405	23315
BAS		Pta-6281	19400	200	23855	22820
	IX (54)	Q-1452	17820	270	22250	20820
BAS		Pta-6060	15700	150	19300	18595
RBL_CLBRF	IX (52)	Q-3172	13200	150	16210	15300
RBL_CLBRF	IX (50)	Pta-884	13000	140	15950	15105
RBL_CLBRF	IX (48)	Q-3173	12800	250	15925	14180
RF		Pta-6058	12470	100	15040	14135
RF		Pta-6062	12410	45	14735	14125
RF	IX (39)	Q-3175	12250	300	15230	13470
RF	IX (42)	Q-3176	12200	250	15080	13495
RF		Pta-6282	12180	110	14470	13730
BARF		Pta-6065	11090	230	13395	12555

Table 2. Sehonghong fish, fauna, lithic weights, bipolar core frequencies, and excavated number of buckets summary data. NISP: number of identifiable specimens present. AQ: asymmetry quotient. Other: faunal items other than fish. All values have been corrected by the number of excavated buckets.

Layer	Fish NISP	Other NISP	Fish:Other NISP AQ	Lithic weights	Bipolar core %	Buckets excavated
RFS	17	296	-1.78	396.40	9.58	5.70
MOS	645	1996	-1.02	507.15	7.60	10.24
OS	285	510	-0.57	457.61	26.65	3.75
BAS	29046	13130	0.75	1335.85	1.69	17.86
RBL-CLBRF	3647	18461	-1.34	1273.72	1.24	17.53
RF	21052	11891	0.56	979.82	3.82	14.29
BARF	164	155	0.05	608.29	15.89	2.10

Table 3. AMS dates on charcoal from Mitchell's excavation at Sehonghong, with $\delta^{13}C$. Dates are calibrated using the SHCal13 curve, and reported to 2σ, rounded outwards to 5 yr. *OS = date marked as outlier and discarded in the model.

					Calibrated date				
Layer	**Context**	**Lab code**	**Date uncalibrated**	**+/-**	**from**	**to**	**δ13C**	**F14C**	**+/-**
RF	J12_069_hearth	OxA-32926	12010	50	14020	13745	-22.4	0.224	0.0014
RF	I12_065	OxA-32925	12355	50	14710	14115	-23.7	0.215	0.0014
RF	I12_065	OxA-32924	12420	50	14880	14185	-23.5	0.213	0.0014
RBL	K12_072_hearth	OxA-32923	12870	55	15600	15165	-23.9	0.201	0.0013
RBL	K12_072_hearth	OxA-32922	12960	55	15725	15275	-23.8	0.199	0.0014
BAS	K12_96	OxA-32921	20600	100	25180	24460	-23.6	0.077	0.0009
BAS	I12_126	OxA-32920	20270	100	24650	24020	-25.1	0.08	0.001
OS*	K13_127	OxA-32916	13240	55	16020	15813	-24.66	NA	NA
OS	K13_127	OxA-32917	20100	90	24420	23915	-25.8	0.082	0.001
MOS	J12_137_hearth	OxA-32919	20290	90	24655	24060	-23.2	0.08	0.0009
MOS	J12_137_hearth	OxA-32918	20460	100	25020	24290	-24	0.078	0.0009
RFS	K13_136	OxA-32915	25510	150	30190	29205	-24.2	0.042	0.0008
RFS	K13_136	OxA-32914	25870	160	30615	29595	-26.1	0.04	0.0008