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Evidence for large land snail cooking and consumption at Border Cave *c.* 170–70 ka ago. Implications for the evolution of human diet and social behaviour

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A B S T R A C T

Fragments of land snail (Achatinidae) shell were found at Border Cave in varying proportions in all archaeological members, with the exception of the oldest members 5 WA and 6 BS (>227,000 years ago). They were recovered in relatively high frequencies in Members 4 WA, 4 BS, 1 RGBS and 3 WA. The shell fragments present a range of colours from lustrous beige to brown and matt grey. The colour variability can occur when shell is heated. This possibility was explored here through experimental heating of giant land snail shell fragments (Achatinidae, *Metachatina kraussi* - brown lipped agate snail) in a muffle furnace from 200 to 550 °C for different lengths of time. Colour change, weight loss, and shattering of the heated samples were recorded. Transformation of aragonite into calcite and the occurrence of organic material was investigated by means of Infrared and Raman spectroscopy. Scanning electron microscopy was also used on selected specimens to help identify heat-induced transformation as opposed to taphonomic alteration. The identification on archaeological fragments of features produced by experimentally heating shells at high temperatures or for long periods has led us, after discarding alternative hypotheses, to conclude that large African land snails were systematically brought to the site by humans, roasted and consumed, starting from 170,000 years ago and, more intensively between 160,000 and 70,000 years ago. Border Cave is at present the earliest known site at which this subsistence strategy is recorded. Previous research has shown that charred whole rhizomes and fragments of edible *Hypoxis angustifolia* were also brought to Border Cave to be roasted and shared at the site. Thus, evidence from both the rhizomes and snails in Border Cave supports an interpretation of members of the group provisioning others at a home base, which gives us a glimpse into the complex social life of early *Homo sapiens*.

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1. Introduction

When, how, and why terrestrial molluscs became a constituent part of the diet of our ancestors are questions that are still largely unanswered and that puzzle researchers in many respects. Invertebrate animals represent more than 95% of earth's biodiversity (Herbert and Kilburn, 2004), but they are often not studied in archaeological assemblages because they are considered marginal for the understanding of past human behaviour (Mannino, 2019). In addition, most of them are small and have little chance of surviving in the archaeological record. One of the most common remains is from soft bodied animals with mineralised exoskeletons; molluscs.

Land snails may be present in archaeological sites because they occur naturally in the sediments or because they were introduced by the occupants to consume their flesh and/or to use their shells as raw materials or as body ornaments (Mannino, 2019). Although the

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shell was often used for bead-making in African Iron Age contexts in the late Holocene, older symbolic use may have occurred too, as evidenced by an *Achatina* shell fragment interpreted as engraved with a criss-cross pattern, recently found at Txina-Txina, southern Mozambique, in layers dated 27.4–26.8 ka cal BP (Bicho et al., 2018).

Many terrestrial molluscs bury themselves deep in the soil to avoid dehydration during dry winters (Herbert and Kilburn, 2004), so they can be found naturally in sediments, or they can be brought to a site by their numerous predators. Adverse climatic events can also cause the death of snails in their natural habitats and consequently their shells may be incorporated in cave and shelter deposits through geological processes. Multiple uses of land snail shell have been investigated from an ethnoarchaeological point of view: including use as tools for agricultural, fishing, hunting or household purposes, or as decorations or ritual implements (Lubell, 2004a; Mannino, 2019). Snail shells have been discovered in numerous African sites, including Border Cave, the subject of this volume.

At Haua Fteah Cave in Libya, North Africa, preliminary analysis suggests that small land snails were consumed occasionally from 40 to 15 ka cal BP, and more regularly from 14 to 10 ka cal BP (Barker et al., 2012). The site of Taforalt (Grotte des Pigeons) in Morocco, Northwest Africa, records land snail consumption from 13 to 11 ka BP (Taylor et al., 2011). In Beirut in the Levant the site of Ksar 'Aqil has yielded an accumulation of land snails dated 23–22 ka BP (Mellars and Tixier, 1989). In Europe, Klissoura Cave 1 in Greece records land snails with broken lips that are interpreted as evidence of human consumption, in levels dated between 36 and 28 ka cal BP (Kuhn et al., 2010). Nearby, Franchthi Cave documents land snail consumption between 15 and 12 ka cal BP (Stiner and Munro, 2011). The site of Cova de la Barriada in Spain preserves compelling evidence for land snail consumption in Europe from 31.3 to 26.9 ka cal BP (Fernández-López de Pablo et al., 2014). Here land snails were found in three different levels in association with combustion features, lithic and faunal assemblages. Charcoal analysis revealed that the snails were roasted in ambers of pine and juniper. X-Ray diffraction analysis showed that all specimens presented aragonite (CaCO3) as the only mineral phase, indicating that the heating temperature was insufficient to promote the formation of calcite (Parker et al., 2010). The site of Cueva de Nerja, also in Spain, records land snails throughout the stratigraphic sequence, including Gravettian (28–19 ka) and Solutrean (22–17 ka) deposits (Aura Tortosa et al., 2012; Jordá et al., 2011), while the Italian site of Grotta della Serratura evidences land snail consumption in Epigravettian layers dated 14.1–13.7 ka yrs cal BP (Martini et al., 2009). Edible land snails are often abundant in late Pleistocene and Holocene archaeological sites, and have been found in the Caribbean, Peru, parts of North America, East Africa, Sudan, Nigeria, the Philippines and throughout the Mediterranean region, where they become a substantial part of the human diet (Lubell, 2004b). The consumption of land snails continues today in the Mediterranean Basin in Spain, France, Italy, Portugal, Algeria, Morocco, and Tunisia. Land snails are also consumed in Nepal, Southeast Asia and Northeast India, and there is a growing demand in South America.

The above review of the evidence highlights, however, what can be perceived as a conundrum in the history of our lineage's adaptation. Terrestrial molluscs are an excellent source of nutrients, they are easy and not dangerous to collect, they can be stored for some time before being consumed, they are simple to prepare and to digest as long as one has a basic mastery of fire, certainly acquired by hominins at least 400,000 years ago. However, and contrary to what one might expect, the systematic consumption of terrestrial molluscs does not seem to date back to before 49 ka in Africa and 36 ka in Europe, and does not become an essential component of the diet of most human populations before 15–10 ka. Although terrestrial molluscs, especially those of small dimension, are subject in some sedimentary contexts to taphonomic processes that can damage or destroy them, it is difficult to attribute the recent exploitation of terrestrial molluscs to taphonomic causes. For this reason, the dramatic intrusion of this food source in the late Pleistocene or, depending on the region, early Holocene, has traditionally been interpreted as a consequence of an expansion of subsistence resources that would have developed at that time, probably due to demographic pressure. This "broad spectrum revolution" (Flannery, 1969) would have aimed at the systematic exploitation of all available resources, and in particular small prey such as small mammals, fish, reptiles and molluscs (Flannery, 1969; Stiner, 2001; Zeder, 2012). This vision has tended to attribute possible evidence of older exploitation of terrestrial molluscs to the many natural phenomena that can lead the remains of these animals to be incorporated into sedimentary sequences or, at most, to sporadic consumption that does not substantially change the classical vision of the evolution of the diet of our genus. It is quite possible, however, that this mainstream narrative reflects only the best-documented and archaeologically visible part of a more complex process that has involved, since the mastery of fire, the exploitation of certain nutritious species that were only available in certain ecological settings. It is also possible that these subsistence strategies were lost in some cases and reacquired in others. Because of its particular characteristics, *Achatina* (giant African land snail) may have been a continuously exploited species in certain regions of Africa, and may have been an important part of the diet of Middle Stone Age (MSA) populations long before the "broad spectrum revolution". This point of view is supported, but not really substantiated, by archaeological evidence that predates our work at Border Cave. The earliest possible habitual consumption of land snails in Africa, from Mumba-Höle Cave in Tanzania, East Africa, from level V upper (Lubell, 2004b), dated to 49.1 ± 4.3 ka (Gliganic et al., 2012) consists of *Achatina* sp. shells found in association with lithic artefacts (Mehlman, 1979), though a description of the snail assemblage is yet to be published. An even older possible consumption of this species comes from the Kenyan site of Panga Ya Saidi (Martinón Torres et al., 2021). These authors report large frequencies of *Achatina* sp. fragments, many of which bear traces of heating in the form of distinct blackening, in layers dated *c.* 78 ka, in which a burial of a three-year-old child was discovered. More recent evidence for possible MSA exploitation of *Achatina* comes from Sibudu Cave (Plug, 2004), Bushman Rock Shelter (Badenhorst and Plug, 2012) and Kuumbi Cave, Zanzibar (Faulkner et al., 2019; Shipton et al., 2016).

The Achatinidae family incorporates the largest land snails and KwaZulu-Natal has a relatively rich agate snail fauna, including 15 species (Herbert and Kilburn, 2004). They are herbivores, but also consume soil, calcareous rocks, the shells of other molluscs and bone from carcasses to form their own shells made of the aragonite calcium carbonate ($CaCO_3$) polymorph (Herbert and Kilburn, 2004). This large gastropod is still a popular food in West African countries including Cameroon, Ghana and Nigeria (Griveaud, 2016), but not in South Africa among rural people living in Nkungwini near Border Cave (personal communication by B. Vilane to L.W. in 2016). In some parts of Africa, *Achatina* snails are believed to contain various curative properties, and the bluish liquid (haemolymph) obtained from the shell reportedly helps with infant development (Ugwumba et al., 2016; Munywoki, 2022). Snail meat is highly nutritious; it is rich in protein, iron, potassium, phosphorous, magnesium, selenium, calcium, copper, sodium, zinc, Omega-3 and other essential fatty acids, and various vitamins, including vitamin A, Thiamine (B1), Riboflavin (B2), Niacin (B3), vitamin B6, B12, C, D, E and K, while being low in fat (Aboua, 1990; Fagbuaro et al., 2006).

An adult *Achatina* snail may have a mass of close to a kilogram, so it provides a substantial protein source. Recent studies (Dumidae et al., 2019) suggest that humans can contract a parasitic disease caused by a worm hosted by the giant African land snail. Careful handling may prevent disease. Of course, we do not know whether the parasite is a modern phenomenon or whether humans in the past were also vulnerable to disease when handling the snails.

The objective of this study is to use the results of new high-resolution excavations at Border Cave and appropriate analytical methods to test the hypothesis that *Achatina* snails were consumed systematically by human groups in Border Cave between about 170 ka and 70 ka ago (and occasionally thereafter) and discuss the role that this giant land snail may have played in early modern human cultural adaptations.

1.1. Background to the site

Border Cave is located on a cliff, at the border between KwaZulu-Natal in South Africa and eSwatini (Fig. 1). It occurs in the Lebombo mountain range at an elevation of *c.* 600 m above sea level. The shelter is semi-circular in shape, approximately 50 m wide by 35 m long, and faces West. The site has been extensively excavated: first, in 1934 by Dart, but his findings were never published. In 1940 Horton extracted a vast amount of deposit, supposedly for agricultural purposes, which left a large pit in the middle of the site. The following year Cooke and colleagues resumed archaeological excavations and discovered an infant burial (BC3) with a *Conus* shell originally covered in ochre (d'Errico and Backwell, 2016), and recovered additional human remains from Horton's dump, which they attributed to the Middle Stone Age (Cooke et al., 1945). Extensive excavations were conducted during the 1970s and 1980s by Beaumont and Todd and Miller (Beaumont, 1978, 1980; Beaumont et al., 1992), which led to the naming of brown sand (BS) and white ash (WA) members (Fig. 1) that make up the deposit (Butzer et al., 1978), and dating of the stratigraphic sequence (Vogel and Beaumont, 1972; Beaumont et al., 1978, 1992; Beaumont, 1980; Vogel et al., 1986; Grün and Beaumont, 2001; Grün et al., 2003; Bird et al., 2003; Millard, 2006). In recent years radiocarbon dating has been applied to archaeological finds (d'Errico et al., 2012; Villa et al., 2012; Backwell et al., 2018), and now Tribolo and colleagues (Tribolo et al., 2022) present optically stimulated luminescence ages for the sedimentary sequence and a suite of Bayesian model ages for the deposits. Bayesian model ages include all published electron spin resonance and ^{14}C ages. Results are given at 2 sigma (95%), and the highest posterior density is given at 95%. Member 5 WA ranges between ~250 and 160 ka; Member 5 BS ranges between ~176 and 149 ka; Member 4 WA ranges between 167 and 100; Member 4 BS ranges between ~93 and 69 ka; Member 1 RGBS ranges between ~79 and 67 ka; Member 3 WA ranges between ~74 and 62 ka; Member 3 BS ranges between ~69 and 56 ka; Member 2 WA ranges between ~61 and 53 ka; Member 2 BS ranges between ~57 and 43 ka; Member 1 WA ranges between ~45 and 41 ka and Member 1 BS ranges between 43 and 22 ka.

The most recent round of excavations started in 2015 under the direction of Backwell, Wadley and d'Errico (Backwell et al., 2018). Their research has confirmed that the cave records traces of

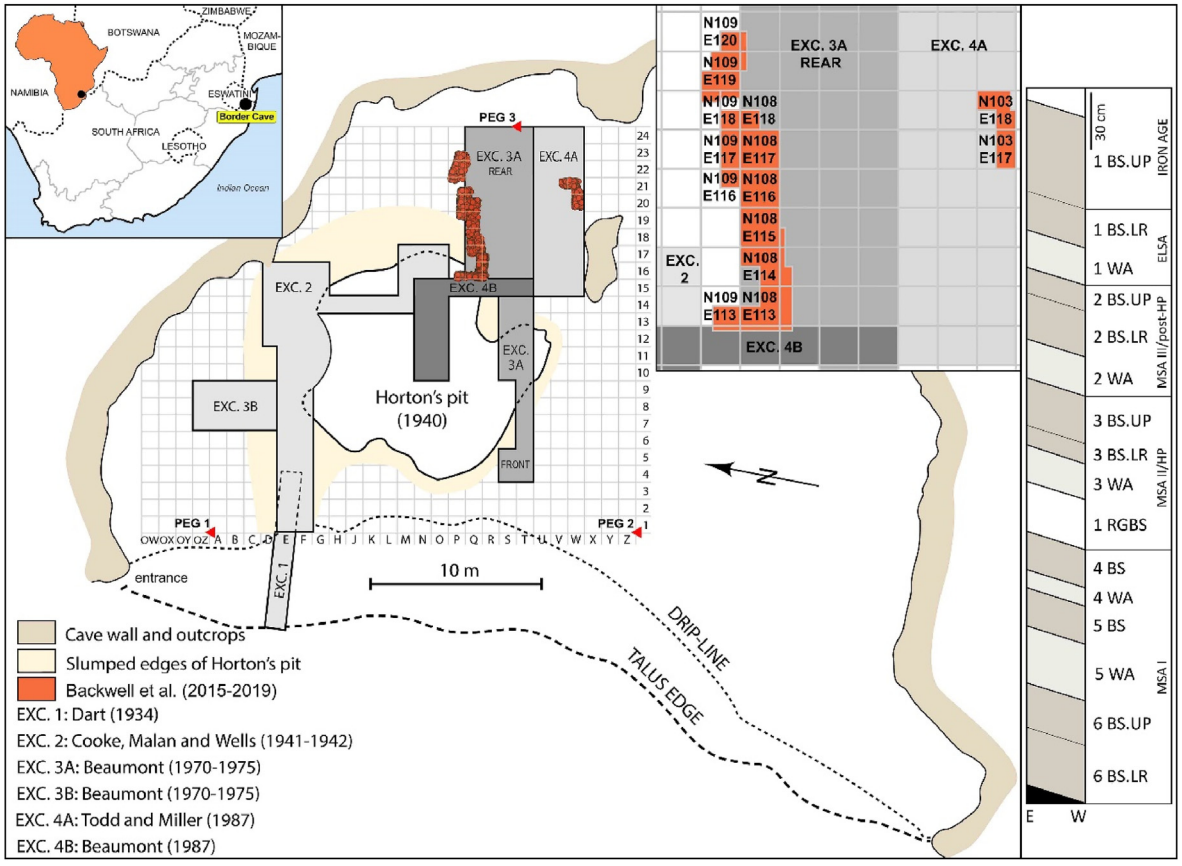

Fig. 1. Location of Border Cave and a site plan showing the position of the various excavations from 1934 to 2019. The orange overlay shows the position of point-plotted artefacts in excavations conducted from 2015 to 2019 along the North wall of excavation (EXC.) 3 A and South wall of EXC. 4 A. The inset (top right) provides the square names excavated according to North and East lines. Stratigraphic members and associated cultural attributions after Beaumont et al. (1992) are shown in the column on the right. The alternating tan and off-white colours denote Brown Sand and White Ash members, and the sloped dividing lines represent the dip of the deposit.

intermittent occupation from before 227 ka ago until 24 ka, capped by Iron Age occupation dated to about 600 BP. Their fine-scale approach identifies 10 layers where Beaumont saw one for Member 1 BS, and 15 in Member 1 WA. They identify 69 layers within his single Member 2 WA and 51 in 4 WA. As opposed to the 10 members identified by Beaumont, 237 stratigraphic layers have been identified and excavated to date (Backwell et al., 2022; Stratford et al., 2022). Beaumont (1978) originally reported remarkable preservation of organic remains and the new excavations have confirmed this, with 48 layers of grass mats/bedding identified (Sievers et al., 2022). Grass bedding in Member 5 BS dated at about 170 ka, and Member 5 WA, dated to >227 ka makes it the oldest known (Wadley et al., 2020a; Esteban et al., 2023). The same is true for whole cooked starchy rhizomes, identified as *Hypoxis angustifolia*, from layers dated to *c.* 170 ka ago (Wadley et al., 2020b). Charcoal is preserved throughout the sequence, providing a rare and comprehensive record of climate change in the region (Lennox et al., 2022). In addition to burning wood for cooking, warmth and protection against predators, the charcoal record suggests that plant species may have been selected for their latex, nutritional value, insecticidal, medicinal, and cosmetic properties (Zwane and Bamford, 2021; Lennox et al., 2022).

1.2. The Achatina record

During the latest excavations, from 2015 to 2019, shell fragments of giant land snails (Fig. 2) were found throughout the sequence, except in the oldest members 5 WA and 6 BS. They were found in relatively high frequencies in Members 4 WA, 4 BS, 1 RGBS and 3 WA. Beaumont's extensive excavation of the site yielded 3529 pieces of *Achatina* shell, representing a minimum number of 84 individuals (Beaumont, 1978), with the highest number in Member 4 BS (n = 1076), as is the case with recent excavations (see Backwell et al., 2022; Fig. 7). Backwell and colleagues (Backwell et al., 2022) postulate that between about 170 ka and 70 ka ago land snails may have been a regular part of the diet of visitors to the cave, and that more recent occupants ate them only occasionally. They acknowledge that the land snails may have buried themselves in the cave deposit, but consider human consumption as a more likely explanation for their presence in the deposits because the *Achatina* shell assemblage is extremely large and mono-specific, the pieces are often associated with grass mats, combustion features, lithic and faunal remains, and the shells are fragmented, with a mixture of what they consider to be burned and unburned pieces based on state of preservation and colour, though the differences may result from non-human taphonomic processes. The concentrated accumulation of shells in specific stratigraphic units (see Backwell et al., 2022; Fig. 7) does not conform to a random distribution of shells scattered at various depths, as would be the case if the snails had buried themselves in the deposit.



Fig. 2. Modern Achatinidae land snail. Such agate snails may reach a length of about 160 mm (Herbert and Kilburn, 2004).

The fragments vary in colour from lustrous beige to brown and matt grey. Accidental or deliberate heating of shells is said to account for changes observed in the colour and chemistry of excavated gastropods (Lange et al., 2008; Bonizzoni et al., 2009; d'Errico et al., 2015; Milano et al., 2016, 2018). In particular, the shell of *Achatina*, which is essentially composed of superimposed layers of aragonite, undergoes a mineralogical phase transition into calcite, associated with morphological changes at microscopic and macroscopic scale, if the shell is submitted to substantial heating. However, change in colour and chemical composition can also be produced by non-human taphonomic processes (d'Errico et al., 2015), and this deserves further enquiry. In order to test the hypothesis that people at Border Cave cooked and consumed land snails, we used an experimental approach to explore colour and chemical changes to modern *Metachatina kraussi* shell fragments heated in a muffle furnace at various temperatures and for different lengths of time. The chemical reaction through heating was studied using vibrational spectroscopy. The macroscopic and microscopic appearance of the heated shells was documented using photographs, optical and scanning electron microscopy. The results were compared to a sample of land snail shells from Border Cave in an attempt to match the features and chemical signatures resulting from heat, and to establish whether the archaeological specimens might have been similarly modified.

2. Material and methods

2.1. Experimental sample

For the experimental sample, a modern brown-lipped agate snail (Achatinidae, *Metachatina kraussi*) shell from the Verulum region in KwaZulu-Natal was used. It was chosen because it represents the same family of snails preserved in the archaeological deposits at Border Cave. The shell ranges in colour from off-white, to beige to brown (Herbert and Kilburn, 2004). It was broken into multiple pieces using a chunk of rhyolite found on the path leading to Border Cave. Pieces with many different shapes, sizes and colours were obtained and 41 of them were selected and used to perform heating experiments. Fig. S1 shows photographs of the giant snail shell before and after crushing as well as the rhyolite used to break it.

2.2. Archaeological sample

The archaeological sample studied comes from the recent excavations conducted by Backwell and colleagues, and more precisely from the 2017 excavation. The shell fragments are attributed to the Family Achatinidae. The attribution was made based on the relatively large size of the pieces, their curvature, and pattern made of wavy brown axial lines or stripes. Even though the sample is fragmented, we attribute the shells to *Metachatina kraussi* because of the pale wavy axial lines that are distinct from the bold straight ones characteristic of *Achatina immaculata*, the only other agate snail found in the region (Herbert and Kilburn, 2004). From the 87 ziplock bags containing 1654 shell fragments, 27 pieces showing a range of colours and state of preservation were selected for analysis using Raman spectroscopy. Fig. 3 shows photographs of a sample of

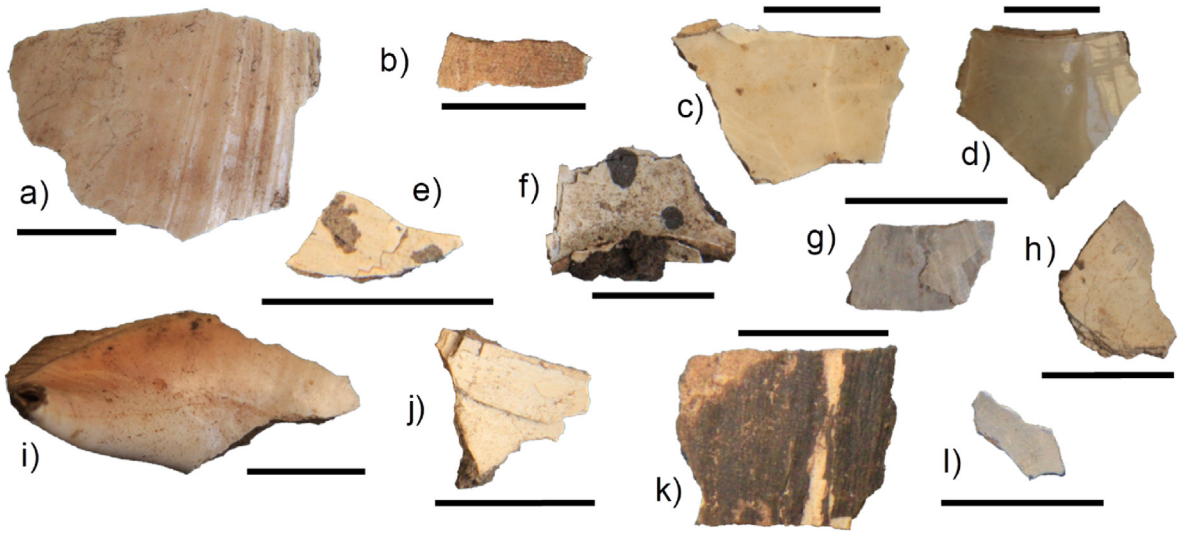

Fig. 3. Examples of Border Cave shell fragments and their stratigraphic context. a) Member 4 BS, layer Chocolate Brown Ena plan 1; b) Member 4 BS, layer Dark Brown Elmo plan 1 (Combustion Feature base) sample 3; c) Member 4 BS, layer Chocolate Brown Ena (Combustion Feature 1); d) Member 4 BS, layer Chocolate Brown Ena plan 2; e) Member 5 BS, layer Very Dark Greyish Brown Jim plan 4 (Combustion Feature) sample not selected for analysis; f) Member 4 BS, layer Dark Brown Elmo plan 1 (Combustion Feature base) sample 1; g) Member 5 BS, layer Very Dark Greyish Brown Jan sample 4; h) Member 5 BS, layer Very Dark Greyish Brown Jim sample 3 (Combustion Feature); i) Member 4 BS, layer Grass mat Ega sample 1 (lip); j) Member 5 BS, layer Very Dark Greyish Brown Jim plan 4 (Combustion Feature) sample 1 (Combustion Feature base); k) Member 4 BS, layer Dark Grey Eduardo plan 2 (Combustion Feature) sample 2; l) Member 5 BS, layer Very Dark Greyish Brown Jan plan 4 sample 1. All scale bars represent 1 cm.

the selected specimens from Members 4 BS (93.5–69.8 ka) and 5 BS (176.8–149.1 ka).

Of the 27 samples selected, six specimens did not yield spectra, or the spectra recorded did not allow for carbonate polymorph discrimination using the non-invasive Raman analysis and these were subjected to invasive (but non-destructive) Infrared analysis. Table 1 lists the selected ziplock bags with the number of fragments, their colours, specific features (such as the presence of a lip) and the results of the analyses. A preliminary identification of heated specimens was based on the sample colour and state (cracks, if it was brittle, etc.) The full table of samples from the 2017 excavation can be found in Table S1.

2.3. Heating experiments

Three experiments were performed with a muffle furnace. The temperature varied from 200 to 550 °C and the heating time from 5 min to 36 h. The first experiment was performed to determine at which temperature the mineralogical transformation from aragonite to calcite and colour change start when heated for a short period of time (5 min) from 200 °C to 550 °C with a 50 °C increment. For each temperature step three fragments of different colour were used. The fragments also exhibited different thicknesses, which can also influence the transformation. The second experiment explored heat exposure for an increased period of time (20 min) starting from 300 °C (since the lower temperatures showed limited change during the first experiment) to 550 °C. Two fragments per temperature step were heated to check reproducibility. The last experiment focused on heat exposure time at a set temperature (350 °C) ranging from 1 h to 36 h. The rationale being that if archaeological fragments of shell were present around a fire, they could have been exposed to heat for long periods of time. The fragments were inserted when the furnace reached the desired temperature. Different shell fragments were used depending on their colour (white, beige, or brown) and some of them were cleaned with water and a soft brush to clearly see the colour change of the shell. Not all were cleaned since shell was unlikely to have been cleaned in the past. The weight loss, established at a precision of 0.001 g, and the colour change were recorded, and the specimens were photographed before and after heating. Table 2 lists the different experiments (temperature, duration, initial colour and if the sample was cleaned or not) with their respective results (colour and appearance after heating, weight loss, if the sample shattered or not and the Raman and FTIR results).

2.4. Optical microscopy

Optical microscopic observations were conducted using an Olympus BX63 upright microscope with reflected light and CellSem Dimension software. The z-stacking option of the software was used with magnification objectives of 4 × and 10 × .

2.5. Raman micro-spectroscopy

Raman spectroscopy can help to determine the molecular composition of the samples. Here, all experimental samples (n = 45) and archaeological specimens (n = 27) were analysed on both sides, on multiple spots with a green laser covering a very localised surface area of around 1 μm. Raman spectra were recorded using a LabRam HR 800 spectrometer (Horiba Jobin–Yvon), with a 514.5 nm line of a Lexel argon ion laser, equipped with an Olympus BX41 microscope attachment. A charge coupled detector cooled with liquid nitrogen collected the spectra with a spectral resolution <2 cm^{-1} using the 600 lines/mm grating. The spectrometer was set to save the 80–1800 cm^{-1} spectral range, and the laser beam power directed at the sample was kept under 0.8 mW to avoid inducing thermal transformation. The spectra were acquired with a 100x long working distance giving a spatial resolution of around 1 μm for 8–350 s, repeated at least twice.

2.6. Infrared spectroscopy

Fourier Transform Infrared spectroscopy (FTIR) was performed with a Bruker Alpha spectrometer equipped with an Attenuated Total Reflectance (ATR) module. A small piece (few millimetres wide) of the selected specimen was broken and finely ground in an

Table 1
List of archaeological shell fragments excavated in 2017 and selected for the analysis. Each line refers to a ziplock bag, from which one to four specimens were selected for study. Cultural attributions according to Beaumont et al. (1992). ATR-FTIR: Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy; AC: amorphous carbon; BS: brown sand; CF: combustion feature; MnOx: manganese oxide; Orga: organic matter; WA: white ash; ELSA: Early Later Stone Age.

Cultural attribution	Member	Layer	Plan	Number of fragments	Colour	Signs of heating	Note/Samples selected	Raman	ATR-FTIR
ELSA	1 WA	Grass Mat Betty	1	1	beige	possibly	Lip	Calcite	–
MSA III	2 WA	Very Dark Brown Dax	1	1	beige	possibly	–	Fluorescence	Bone (Apatite)
MSA II	1 RGBS	Very Dark Brown Eba	2	2	grey	possibly	Sample 1	Calcite, AC	–
							Sample 2	Calcite, Gypsum	–
MSA I	4 BS	Dark Grey Eduardo (CF)	2	15	beige	possibly	Sample 1	Aragonite, MnOx, Gypsum	–
							Sample 2	Aragonite, AC	–
							Sample 3	Aragonite	–
	4 BS	Dark Grey Eduardo	2	3	1 grey, 2 beige	possibly	Sample 1 (beige)	Aragonite	–
							Sample 2 (grey)	Calcite, AC	–
							Sample 3 (beige)	Aragonite	–
	4 BS	Grass Mat Ega	1	2	beige	no	–	Aragonite	Aragonite, Orga, Apatite, silicates
	4 BS	Grass Mat Ega	1	1	beige/ brown	possibly	Lip	Aragonite, Carotenoid	Aragonite, Orga, Apatite, Silicates
	4 BS	Dark Brown Elmo (CF base)	1	19	10 grey, 9 beige	possibly	Sample 1 (grey/black)	Aragonite, Calcite, MnOx, AC	–
							Sample 2 (grey)	Calcite, AC	–
							Sample 3 (beige)	Aragonite	–
	4 BS	Chocolate Brown Ena	1	1	beige	no	Scratches, striations on the outer part, shiney both sides	Aragonite	–
	4 BS	Chocolate Brown Ena (CF1)	1	1	beige	no	Cracks visible macroscopically on the inner part	Aragonite, AC	–
	5 BS	Very Dark Greyish Brown	?	1	beige	possibly	–	Aragonite	–
	5 BS	Very Dark Greyish Brown Jan	1	1	grey	?	–	Calcite	–
	5 BS	Very Dark Greyish Brown Jan (CF1)	3	1	beige	possibly	–	Carbonate	Calcite, Silicates (sediments)
	5 BS	Very Dark Greyish Brown Jan	4	2	grey	possibly	Sample 1	Bone	–
							Sample 2	Calcite, AC	–
	5 BS	Very Dark Greyish Brown Jim (CF)	3	1	beige	possibly	–	Calcite	–
	5 BS	Very Dark Greyish Brown Jim (CF)	4	6	2 grey, 4 beige	possibly	Sample 1 (beige)	Carbonate	Calcite, Silicates, Gypsum
							Sample 2 (grey)	Calcite, AC	–
							Sample 3 (grey)	Fluorescence	Bone (Apatite), Gypsum
							Sample 4 (beige)	Aragonite	–

agate mortar to obtain a homogeneous and fine powder that was pressed onto the diamond crystal. Spectra were acquired in the mid-IR range between 400 and 4000 cm^{-1} (Deuterated TriGlycine Sulfate detector) with 64 scans and a 4 cm^{-1} resolution. An atmospheric compensation was applied to the spectra using OPUS 7.5 software.

2.7. Scanning electron microscopy

Scanning electron microscope (SEM) observations were made and images captured with a Phenom Pure generation 5 instrument from Thermo Fisher Scientific. The samples were placed on adhesive carbon tape. The backscattered images were acquired at a working distance of ~10 mm at 5 kV. SEM observations were performed on the inner and outer parts of a white experimental control specimen not heated, a grey piece heated at 500 °C for 20 min, and on the inner part of three archaeological samples with different compositions. These samples are a beige sample composed of aragonite from Member 5 BS, layer Very Dark Greyish Brown Jan, not showing any signs of heating macroscopically (accession number 3038), another beige sample from Member 5 BS (accession number 5256) composed of calcite and thus likely heated, and sample 1 (grey/black) from Member 4 BS, layer Dark Brown Elmo (combustion feature base) exhibiting a mixture of calcite and aragonite.

3. Results

3.1. Experimental heating and macroscopic observations

The weight loss for samples heated at the lower temperature (200–300 °C) and for a short period of time oscillated around 0.5% that likely corresponds to the loss of water. For samples heated for longer periods and at higher temperatures, the weight loss was around 1–2% and probably entailed the entire or partial loss of organic matter (Table 2). In the case of land snails, the carbonate crystals that constitute the shell are bound in an organic framework of tanned proteins that protect the shell against humic acids present in the soil (Herbert and Kilburn, 2004). Starting from 450 °C, some samples shattered and/or there was a separation of the different layers comprising the shell (Fig. S2). The effect of heat on colour was that the originally white specimens became a more snow white, while the beige and brown samples lost their colour (Table 2, Fig. 4). Starting from 500 °C for at least 20 min, the samples turned grey. After heating, most of the specimens lost their initial gloss and became matt. This is because the organic matter present

Table 2
List of heating experiments in terms of parameters and results. ATR-FTIR: Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy; AC: amorphous carbon; bh: before heating; ah: after heating; MnOx: manganese oxide; Orga: organic matter; N: no; Y: yes; ?: indeterminate compound; min: minutes; h: hours. The weight loss could not be measured for the samples which shattered (since many fragments were scattered).

Temperature (°C)	Heating time	Sample colour bh	Cleaned	Sample colour & appearance ah	Weight loss (%)	Shattered	Raman	ATR-FTIR
200	5 min	white	x	white	0.00	N	Aragonite, Carotenoid	Aragonite
		beige		beige	0.13	N	Aragonite	Aragonite, Orga
		brown		brown	0.12	N	Aragonite, Carotenoid, ?	Aragonite, Orga
250		white		white	0.47	N	Aragonite, Carotenoid, AC, Feldspar, Romanéchite	Aragonite
		beige		beige	0.07	N	Aragonite, Carotenoid, AC, ?	Aragonite, Orga
		brown		light brown	0.27	N	Aragonite, Carotenoid	Aragonite, Orga
300		white		white	0.50	N	Aragonite, Haematite	Aragonite
		beige		beige	0.28	N	Aragonite, AC	Aragonite, Orga
		brown		light brown	0.28	N	Aragonite, Carotenoid, AC	Aragonite, Orga
350		white		white with darkening of brown areas	0.47	N	Aragonite, AC	Aragonite
		beige		beige with darkening of brown areas	0.70	N	Aragonite, AC	Aragonite, Orga
		brown		brown became grey & darkening of brown areas	0.46	N	Aragonite	Aragonite, Orga
400		white		white	0.43	N	Aragonite, AC	Aragonite
		beige (a bit of brown)		beige & brown became black	0.49	N	Aragonite, AC, ?	Aragonite, Orga
		brown		brown became beige & is black on some areas	0.47	N	Aragonite, AC, ?	Aragonite, Orga
450		white		white	0.51	N	Aragonite, AC, ?	Aragonite
		beige		white (darkening on some areas)	0.83	N	Aragonite, AC, ?	Aragonite, Orga
		brown		white	0.73	N	Aragonite, AC	Aragonite, Orga
500		white		whiter	1.49	N	Aragonite, Calcite, AC, MnOx, Anatase	Calcite, Aragonite
		beige (a bit of brown)		white (brown became black)	–	Y	Aragonite, Calcite, AC, Haematite, ?	Calcite
		brown		white (brown became black)	–	Y	Aragonite, Calcite, AC	Calcite, Aragonite
550		white		whiter	–	Y	Calcite	Calcite
		beige		white (bit of brown left)	–	Y	Aragonite, Calcite	Calcite, Aragonite
		brown		white/grey	–	Y	Aragonite, Calcite, AC	Calcite, Aragonite
300	20 min	beige	x	darker outside, whiter inside	0.00	N	Aragonite, AC, Maghemite	Aragonite
		beige/brown & green spots	–	darker & green became brown	0.00	N	Aragonite, AC, MnOx	Aragonite, Orga
350		beige (a bit of brown)	x	whiter, brown became black	0.35	N	Aragonite, Carotenoid, AC, ?	Aragonite
		white & green spots	–	whiter, green became black/brown	0.53	N	Aragonite, AC, ?	Aragonite, Orga
400		white	x	whiter	0.21	N	Aragonite, AC, ?	Aragonite, Calcite
		white/brown	–	whiter, brown became black	0.31	N	Aragonite, AC, ?	Aragonite, Orga
450		beige	x	very white, separation of layers (at least 3 layers)	1.43	N	Aragonite, MnOx	Calcite
		beige/brown	–	white, brown became black, layer separation (at least 4)	1.29	N	Aragonite, Calcite, AC	Calcite, Aragonite
500		white	x	whiter, layer separation & cracking	1.90	N	Aragonite, Calcite, MnOx	Calcite, Aragonite
		beige/brown	–	white, slightly grey outside, layer separation, cracking	1.63	N	Calcite, MnOx, Maghemite	Calcite + Aragonite
550		white	x	grey/white	1.22	N	Calcite, MnOx	Calcite, Aragonite
		white	–	grey/white	–	Y	Calcite, AC	Calcite, Aragonite
350	1 h	beige/brown	–	whiter, brown became black	0.49	Y	Aragonite, AC, MnOx, ?	Aragonite, Orga
	3 h	beige/white	–	beige/whiter, outer layer detached from the inner ones	1.35	N	Aragonite, AC, Haematite, Quartz, Anatase	Aragonite, Orga
	6 h	beige/brown	–	whiter, brown became black	1.40	Y	Aragonite, AC, Anatase, ?	Aragonite, Calcite
	12 h	beige/brown	–	very white inner part, sample broke & layers bent in opposite directions	1.04	N	Aragonite, Calcite, AC	Aragonite, Calcite
	36 h	beige/brown	–	disappearance of many brown areas, the colour became matt, cracks, outer layer detached from the inner ones	1.19	N	Calcite, AC, MnOx	Aragonite, Calcite

in the shell structure is responsible for the glossy appearance (Nouet, 2014). Hence, the loss of gloss corresponds with the loss of organic matter, as confirmed by vibrational spectroscopy, which did not detect organic matter in matt samples.

Of the 1654 archaeological fragments unearthed in 2017, 82.6% exhibit a beige colour, 15.3% are grey, 1.9% brown and only 0.2% are black (Table S1 and Fig. 3). Several samples show some black staining which could be due to manganese oxides and many display cracks. Some of the beige specimens appear very glossy, while others are matt. The grey, brown, and black ones are always matt. The loss of organic matter that makes shell appear glossy may be attributed to heat, although microbial attack of organic matter and diagenesis could also be possible causes.

3.2. Microscopic observations

At a microscopic scale it is possible to observe in detail the ridges present on the in- and outside of the modern shell fragments (Fig. 5a). These correspond to the successive growth increments of the shell (Nouet, 2014). The same growth ridges are clearly visible

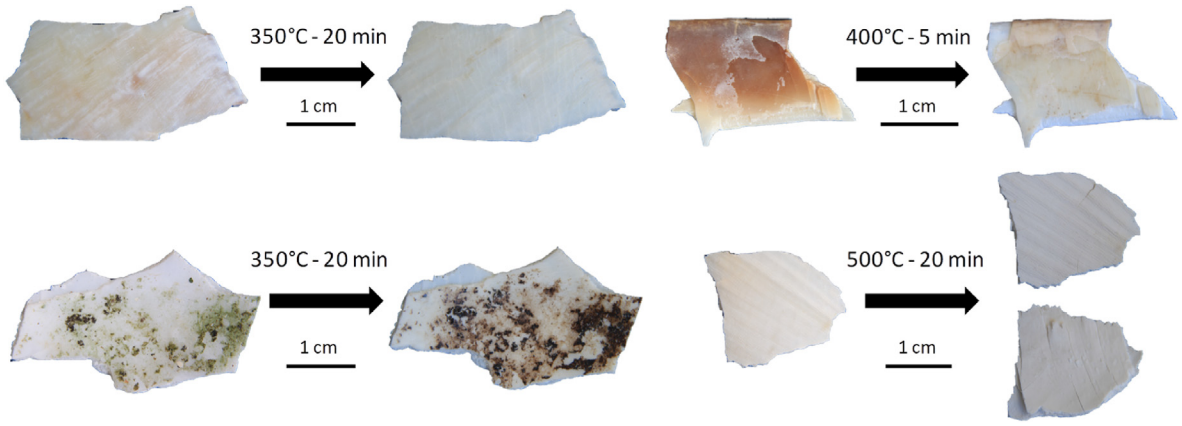

Fig. 4. Representative colour change of the experimental *Metachatina kraussi* shell fragments through heating. The top left specimen was cleaned and considered as beige before heating. The bottom left specimen was not cleaned, and the adhering organic matter turned black and stained the shell pale brown. The top right specimen was considered brown before heating and lost its colour, and the bottom right specimen was white before heating and turned matt grey.

on the archaeological specimens (Fig. 5b) and they help to confirm our identification of the snail shell. Cracks can be observed on the modern heated specimens, which also lack gloss and have a matt surface (Fig. 5c). The same features are observed on the archaeological specimens, which are similarly cracked with a matt surface (Fig. 5d). Scanning electron microscope analysis of modern heated shells reveals a plethora of desiccation cracks resulting from rapid water loss (Fig. 5e). Similar microscopic cracking of the surface was observed on archaeological specimen (Fig. 5f). SEM also revealed fusion of a shell's original microstructure after it was heated at high temperatures such as 500–700 °C (Milano et al., 2016, 2018). Other taphonomic processes caused by localised dissolution, fusion and recrystallization processes can also be observed with SEM (Toffolo, 2021) but were not observed on the Border Cave specimens.

Microscopic analysis of the modern heated shells and archaeological specimens from Border Cave shows that they share features resulting from exposure to heat, namely micro-cracking and a matt surface appearance. This finding, and the fact that most of the archaeological specimens derive from combustion features (see Table 1) demonstrates that these shell fragments were most likely heated.

3.3. Raman micro-spectroscopy

The spectra of compounds detected on the experimental and archaeological specimens are presented in Fig. 6, and Tables 1 and 2 list the compounds obtained for each specimen analysed. Before heating, only the calcium carbonate polymorph of aragonite was detected on the fragments of the brown-lipped agate snail shell (Table 2). It is one of the polymorphs of calcium carbonate ($CaCO_3$) with characteristic Raman peaks located around 152, 179, 189, 212, 272, 282, 702 and 1086 cm^{-1} (Urmos et al., 1991). On the brown parts of the shell fragments before heating, carotenoids were identified with vibrational bands located around 875, 958, 1004, 1156, 1191, 1285, 1355, 1392, 1447 and 1514 cm^{-1} (Maguregui et al., 2012). Spectra of amorphous carbon, quartz, haematite, maghemite, feldspar and manganese oxides (Mernagh, 1991; Chamritski and Burns, 2005; Prinsloo et al., 2013; Bernardini et al., 2019; Wojcieszak and Wadley, 2019) were also recorded on the experimental shell before the heating experiment. These minerals likely come from soil particles present on the surface of the shell fragments. After heating (Table 2), carotenoids were still detected on shell fragments heated for less than 20 min at 350 °C. They disappeared after this threshold. The transformation of aragonite into calcite was detected only in fragments heated for 5 min at 500 °C, in those heated for 20 min above 450 °C, and those heated for 12 h at a temperature of 350 °C. Similar transition ranges in temperature and time were obtained on marine mollusc shells (Lange et al., 2008; Parker et al., 2010; d'Errico et al., 2015; Milano et al., 2016; Müller et al., 2017; Milano et al., 2018). Calcite is the most stable form of calcium carbonate at ambient conditions and can be distinguished from aragonite by the lower intensity bands in the wavenumber range below 720 cm^{-1}. Calcite characteristic Raman bands are located around 155, 282, 713 and 1086 cm^{-1} (Urmos et al., 1991). The aragonite to calcite transformation through heating depends on the temperature and the type of aragonite, it can take a few days at low temperature (~100 °C) or a few minutes at higher temperatures (>470 °C). For biogenic aragonite, the presence of intracrystalline molecules intercalated in the atomic structure influence the temperature of transition (Parker et al., 2010).

For the archaeological samples (Table 1), only amorphous carbon, gypsum, manganese oxide, aragonite and calcite were detected. Amorphous carbon probably comes from the absorption of carbon from organic material surrounding the shell during the heating process (d'Errico et al., 2015) and from sediment particles. Gypsum could come from the sedimentary deposit and taphonomic processes that lead to the breakdown of organic matter, such as the introduction of fresh plant material like grass used for bedding, wood used for fuel and guano from birds and bats (Schiegl and Conard, 2006). Manganese oxides may correspond to black stains present on the surface of some fragments (Fig. 3). Dendritic structures, typical of manganese oxides (Potter and Rossman, 1979), were observed on an archaeological specimen using SEM-Energy Dispersive Spectroscopy (EDS) (Fig. S3). Of the 27 archaeological specimens analysed, 12 contained aragonite. One specimen found in a layer dated to *c.* 60 ka still contains carotenoids. Calcite was recorded on nine specimens, often in combination with amorphous carbon; one was a mixture of both, and another was identified as bone. Because of high fluorescence, two samples produced spectra with no identifiable features and two others only produced spectra identifying calcium carbonate, with peaks around 1084 cm^{-1}, but no bands distinguishing calcite from aragonite.

3.4. ATR-FTIR spectroscopy

FTIR spectroscopy provides information on the molecular composition of the main compounds present in a sample; compounds present in low proportion will not be detected because they

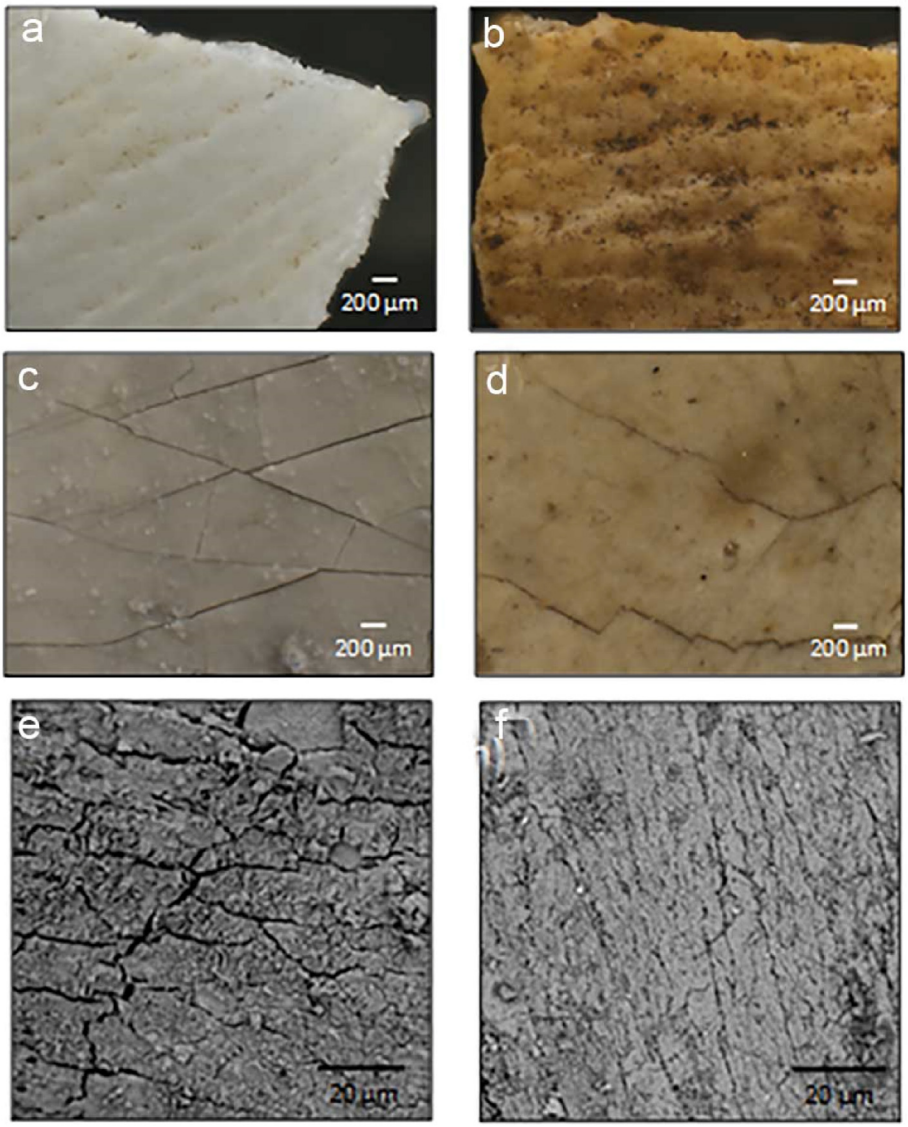

Fig. 5. Microscopic images of modern (left) and archaeological (right) land snail shells. a) Growth ridges on a modern unmodified shell fragment, and b) similar growth ridges on an archaeological specimen from Member 3 BS, layer Dark Brown Elmo, plan 1 combustion feature base. c) Cracks observed on a cleaned modern shell fragment heated at 550 °C for 20 min, and d) similar irregular cracks recorded on an archaeological specimen from Member 5 BS, layer Very Dark Greyish Brown Jim, plan 3 (combustion feature). e) Uncleaned modern shell fragment heated at 500 °C for 20 min showing extreme micro-cracking of the desiccated surface, and f) archaeological specimen from Member 5 BS, layer Very Dark Greyish Brown Jim, plan 3 (combustion feature - accession number 5256) showing similar fine cracking over the entire surface of the piece. Scales in a-d = 200 µm; scales in e, f = 20 µm.

are covered by the more intense signal of the main compounds. For the experimental specimens (Fig. 7a, Table 2), only two compounds were detected on unheated samples: aragonite with characteristic bands around 700, 712, 857, 1083, 1459, 1786, 2523, 2947 and 2978 cm^{-1} (Tomić et al., 2010) and organic matter with the CH stretching vibration at 2914 cm^{-1}. A mixture of aragonite and calcite was recorded on samples experimentally heated for 5 min at 500 °C, on samples heated for 20 min at 400 °C, and for 6 h at 350 °C. The spectra with both aragonite and calcite signals exhibit a more pronounced asymmetry of the more intense vibrational band around 1400 cm^{-1} in addition to a doublet at 859 and 874 cm^{-1}, clearly indicating the presence of both compounds. The characteristic band of organic matter was detected in coloured (beige or brown) samples heated at the lowest temperatures and/or for the shortest times. Carotenoids could therefore be responsible for this signal. One white sample also showed evidence of organic matter, but it was an uncleaned specimen, so the reading could be due to organic matter adhering to the surface of the shell. Only three specimens out of the 41 heated pieces identified only calcite, with bands around 712, 873, 1403, 1795, 2511, 2872 and 2977 cm^{-1} (Shillito et al., 2009; Tomić et al., 2010). These fragments were relatively thin. The above results suggest that the transformation of aragonite into calcite through heating depends on several parameters, such as the dimension and shape of the specimens, and the duration and temperature of heating, as previously mentioned. It also depends on the species analysed (Yoshioka and Kitano, 1985), hence the need for species-specific reference samples.

The four archaeological specimens (see above) that did not provide identifiable Raman spectra, and two additional ones, were analysed by means of ATR-FTIR (Fig. 7b). Two of them were identified as bone. Two others revealed the presence of aragonite and organic matter (CH vibrations at 2916 cm^{-1} - data not shown) in

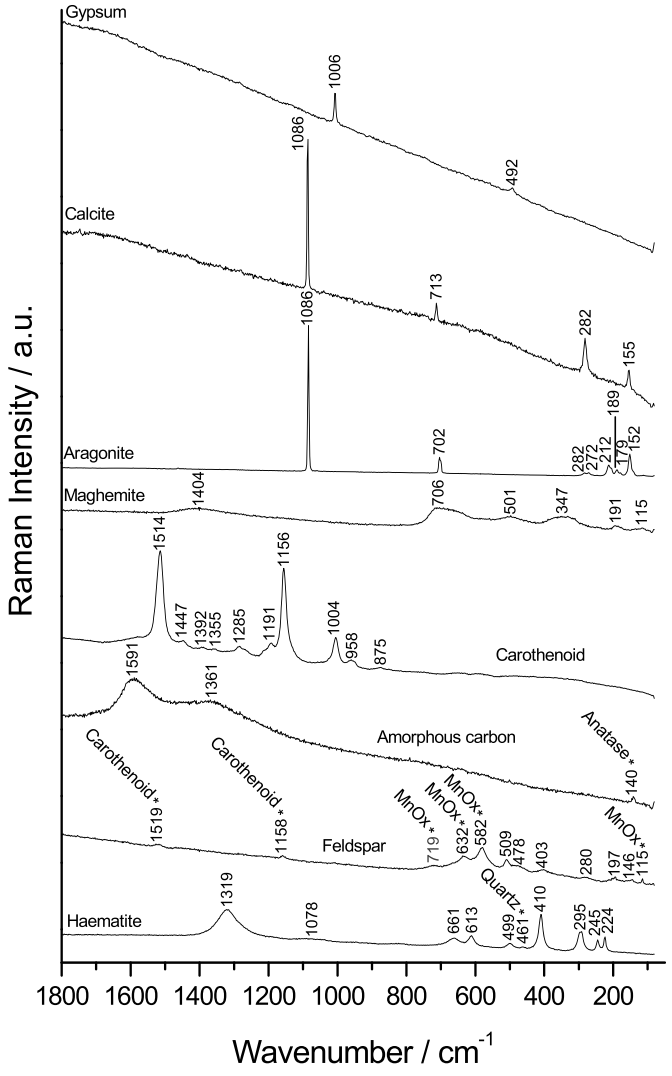

Fig. 6. Representative Raman spectra recorded on *Metachatina kraussi* experimental shell fragments and Border Cave archaeological shell fragments. Tables 1 and 2 list the spectra obtained for each specimen analysed. Most of the spectra presented were recorded on heated experimental pieces, except for the spectrum of aragonite (centre), which was obtained from an unheated experimental specimen, and the spectrum of gypsum (top), which was acquired on an archaeological specimen.

addition to apatite and silicates, likely originating from sediment. The last two specimens contained calcite and silicates, and one of them gypsum.

3.5. The stratigraphic distribution of Achatinidae fragments

During the excavations conducted between 2015 and 2019 snail fragments were found in all archaeological members with the exception of the deepest ones (Members 5 WA and 6 BS). The fragments are particularly abundant in Member 4 BS and, to a lesser extent, in adjacent Members 4 WA, and 1 RGBS (Fig. 8). The more recent archaeological deposits (Members 2 WA, 2 BS, 1 WA), on the other hand, show a significant reduction in number, and here most of the pieces were found on grass mats. Shell fragments from the older members are abundant in layers with combustion features. In Member 5 BS two thirds of the fragments found in 2017 came from combustion features, while a quarter of the pieces found in Member 4 BS were found in them. In this member the highest number of fragments (n = 252) found in one layer derive from a grass mat. This

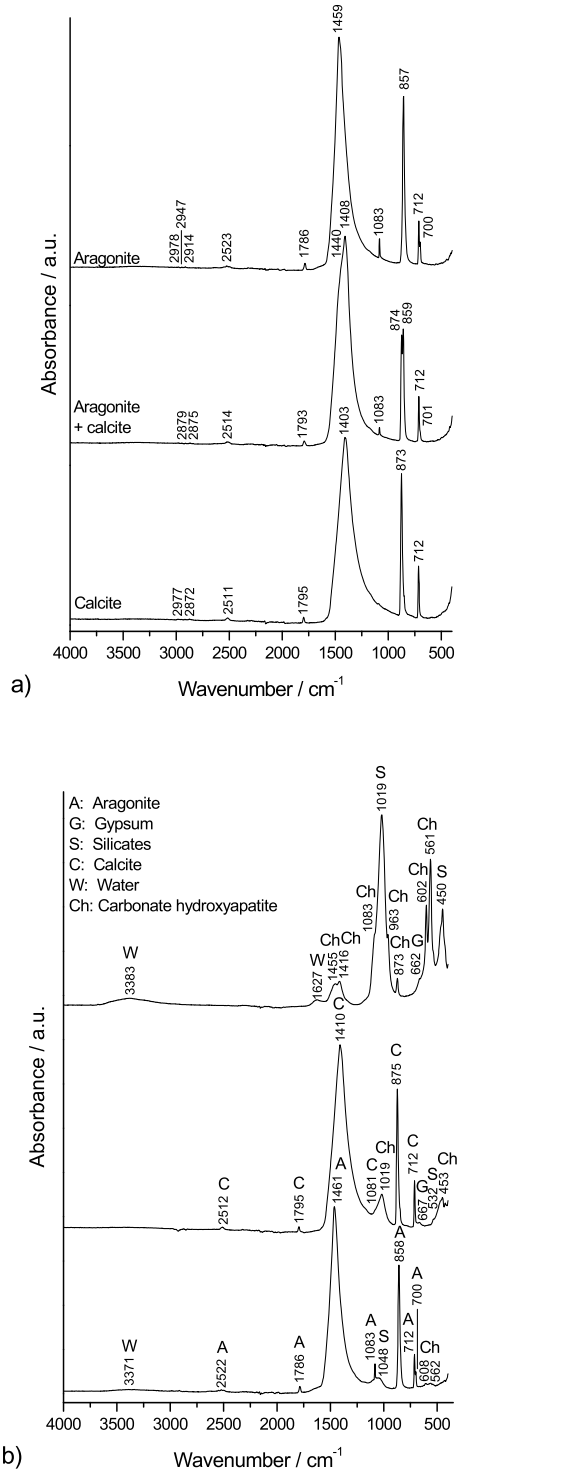

Fig. 7. Representative ATR-FTIR spectra recorded on a) modern *Metachatina kraussi* experimental shell fragments. The spectrum at the bottom corresponds to a white fragment heated at 550 °C for 5 min; the spectrum in the middle to a fragment heated at 350 °C for 6 h, and the top one to a fragment heated at 350 °C for 1 h, b) spectra obtained from Border Cave shell fragments of giant land snails.

supports the hypothesis that the snails were cooked in combustion features and associated with human activity but does not eliminate the possibility that the observed variations are also related to the availability of the resource in the environment or to cultural changes.

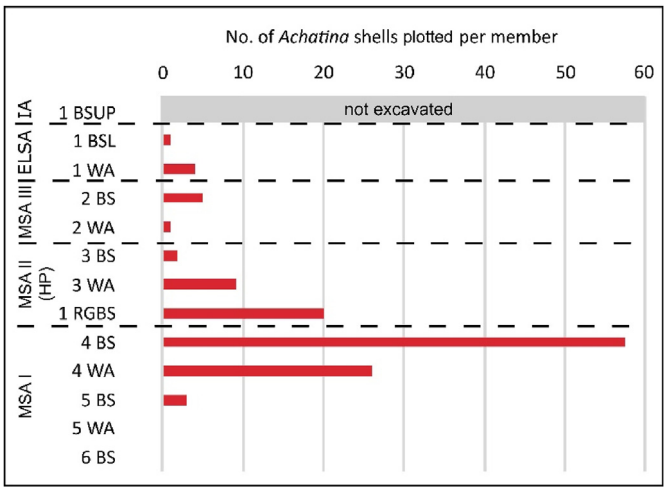

Fig. 8. Bar chart showing the number of *Achatina* shells plotted *in situ* per member from 2015 to 2019.

4. Discussion and conclusion

Our experimental results and those from previous studies indicate that shells of gastropods composed of aragonitic layers undergo a change of mineral phase when heated at high temperature or for a long time. The transformation of aragonite into calcite is generally associated with change in colour, the appearance of microscopic cracks, the loss of water and shell organic component, weight loss, and, at microscopic scale, the recrystallization of calcium carbonate from aragonite to calcite. Land snail heating for consumption does not necessarily produce a mineral phase change and the above listed features. Experiments with large edible *Helix* sp. indicate that roasting them on embers for 5–8 min was the most plausible technique carried out at Pupićina cave, Croatia. This technique leaves barely visible traces of burning (Rizner et al., 2009) and no mineral phase change when the shells were analysed using XRD (Fernández-López de Pablo et al., 2014). However, the samples analysed presented some changes in the texture of aragonite, detectable from the relative intensities of the peaks in the diffractograms.

No complete or almost complete *Achatina* shells were recovered at Border Cave, including in the layers with few combustion features. This contradicts the possibility that live snails buried themselves in the sediments and were accidentally heated when humans made fireplaces at the site. Shells were not brought to the site to be used as raw material, for example for the production of beads or tools. No personal ornaments and artefacts made of these shells, nor production waste have been found at Border Cave. The hypothesis that *Achatina* were brought alive to the site to be cooked and consumed is consistent with the fact that fragments of this family are abundant in layers with combustion features. The presence of fragments made of aragonite, a mixture of aragonite and calcite, and calcite, is also consistent with the consumption contention (although diagenesis cannot be excluded): the large size of the *Achatina* is such that once put to cook on embers some parts of the shell may not reach the temperature necessary for the transformation of the aragonite into calcite. In addition, as mentioned above, the Pupićina Cave record shows that land snails can be satisfactorily cooked at temperatures lower than those involving a mineral phase change. It is likely that, considering its larger size, to fully cook an *Achatina* the mollusc must be exposed to heat for longer periods of time, which leads to a transformation into calcite of only the lower part of the shell in contact with embers. This would explain the mixture of burned and unburned shell fragments encountered in the same area during excavation, but add that this may be a result of diagenesis, which can be extremely localised. Combustion experiments have shown that the sediment below a fire can reach 300+°C through vertical heat transfer (Werts and Jahren, 2007; Sievers and Wadley, 2008; Aldeias et al., 2016). This means that land snail shells in archaeological deposits, separated by thousands of years from fires made above them may be thermally altered, and exhibit the same features as intentionally roasted snail shells. We acknowledge that no distinction can be made between intentional or fortuitous heating, as was the case for the blackened *Helix cincta* land snail shells dating from the Mesolithic Italian site of Edera Cave (Bonizzoni et al., 2009), and this may well have occurred with some pieces at Border Cave. However, baking of the sediment caused by overlying hearths made years later would have altered all of the fragments in a localised area, which is not the case; at Border Cave we find a mixture of transformed, partially transformed and unaltered shell fragments in close proximity. Heat transfer subsequent to deposition, which has probably had the effect of increasing the number of fragments made of calcite, does not explain how the snails arrived at the site in the first place, and why they are more abundant in layers with more combustion features. The most parsimonious explanation for the frequent presence of land snail shells in combustion features is that they were intentionally placed on coals, to cook them. Their occurrence in combustion features throughout the sequence, from about 170 ka ago, implies regular consumption of land snails at the site, with occupants of the shelter habitually eating them from 170 to 70 ka ago, and only occasionally thereafter, which makes Border Cave the earliest site at which the frequent consumption of land snails is recorded.

This finding has implications for our view of the evolution of diet within our lineage. Our results suggest that long before the broad spectrum revolution, human populations may have consumed terrestrial molluscs and for long periods. At Border Cave, as at other Middle and Later Stone Age sites in southern and eastern Africa, it would appear that they chose a species of particular nutritional value. However, the search for and consumption of this species, with such particular characteristics, did not necessarily imply a reorganization of the subsistence strategies of the human groups that exploited it, as was certainly the case with the advent of the broad spectrum revolution. The time dedicated to the collection of these molluscs did not impinge on that dedicated to hunting or other subsistence activities and did not require the development of new technologies. Furthermore, snails could be easily collected by all mobile members of a band, regardless of their age or gender. Future research should apply the research strategy followed at Border Cave to other African sites that have yielded *Achatina* fragments, in order to gain a clearer picture of the regions and periods in which this species was exploited. It would be particularly important to establish whether *Achatina* fragments appear in other archaeological records of about 170 ka ago. There is growing evidence for consumption of marine molluscs at coastal sites from southern Africa (Marean et al., 2007; Jerardino and Marean, 2010) and Europe (Zilhão et al., 2020) dated to MIS 6 and MIS 5. Evidence for the consumption of land snails in those and subsequent periods has however been scant. This introduces the possibility that different populations, living in different environments, developed distinct cultural adaptations, including or not the consumption of molluscs, with inland cultural adaptations crossing the tipping point for consumption of molluscs later than some coastal populations. These scenarios need to be tested in the future by research focusing on the shell fragments found at inland sites. This may shed light on whether changes in the quantities of snail remains may be due to differential preservation, environmental changes probably

reducing the availability of this resource during periods of increased aridity, or cultural change.

It may be no coincidence that between about 170 and 100 ka ago, we also found many charred whole rhizomes and fragments of the edible *Hypoxis angustifolia* in Border Cave (Wadley et al., 2020b). The implications of this discovery reach far beyond the interesting fact that people so far back in time cooked starchy foods. The cave is perched on a cliff where *Hypoxis* spp. do not grow, so collectors of the edible rhizomes would have dug them elsewhere and transported them to the home base for cooking and sharing. If sharing had not been intended, the food could have been eaten in the field where it was recovered. Ethnographic records of hunter-gatherer food collection, such as those made by Marshall (1976), clearly illustrate that people eat a great many plants directly where they find them, and that hunters will also cook and eat some hunted meat in the field before carrying portions home. Thus, evidence from both the rhizomes and snails in Border Cave supports an interpretation of people in an economically active stage of life provisioning others (perhaps infirm band members and very young children) at a home base. The evidence therefore reaches beyond subsistence strategies and gives us a glimpse into the potentially complex social life of early *Homo sapiens.*

Author contributions

M.W. and L.W. conceived the research. M.W. acquired and analysed the data and wrote the paper, with input from L.W., F.d'E. and L.B. L.W., F.d'E. and L.B. revised versions of the manuscript and made improvements to the text. Figures were produced by M.W. and L.B. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.quascirev.2023.108030.

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