

# Archaeological Ochres of the Rock Art Site of Leopard Cave (Erongo, Namibia): Looking for Later Stone Age Sociocultural Behaviors

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**Abstract** The use of ochre has been documented in many Middle Stone Age sites of Southern Africa. However, the literature on the exploitation of ochre within the archaeological contexts of Later Stone Age (LSA) rock art sites is scarce. Despite the discovery of several painted shelters within the Erongo Mountains (Namibia), no archaeological study of ochre assemblages has been conducted in the region. Here, we present the archaeological ochre assemblage recovered from a LSA sequence at the rock art shelter of Leopard Cave (Erongo, Namibia), spanning ca. 5,700 to 2,100 cal. BP. The use-wear traces present on some ochre fragments and the stone tools bearing red residues are indicative of different stages of ochre processing at the site. The presence of other artifacts, such as ostrich eggshell and bone beads with red residues, and the existence of rock paintings in the cave are pointers to the importance of ochre for understanding the sociocultural behaviors of the LSA populations in central Namibia.

**Résumé** Bien que de nombreux sites du Middle Stone Age d'Afrique australe documentent l'utilisation de matières colorantes ferrugineuses, la littérature existante sur leur utilisation dans des contextes archéologiques de sites d'art rupestre du Later Stone Age (LSA) est rare. Malgré la découverte de plusieurs abris ornés riches de nombreux blocs de matières colorantes ferrugineuses dans les monts Erongo (Namibie), aucune étude n'a été menée sur ces matières premières dans cette région. Nous présentons dans cet article l'assemblage archéologique de matières colorantes ferrugineuses récupérées dans l'abri orné de Leopard Cave (Erongo, Namibie) au sein d'une séquence LSA, s'étendant d'environ 5700 à 2100 cal. a. BP. Les traces d'utilisations présentes sur certains blocs de matières colorantes ferrugineuses et la présence d'outils en pierre portant des traces de résidus rouges à leur surface attestent de l'existence de différentes « chaînes opératoires » de traitement des matières colorantes ferrugineuses sur le site. La présence d'autres artefacts portant des traces de résidus rouges tels que des perles en coquille d'oeuf d'autruche ou en os et l'existence dans l'abri de peintures rupestres soulignent l'importance d'étudier les matières colorantes pour comprendre les comportements socio-culturels des populations LSA en Namibie centrale.

**Keywords** Later Stone Age · Ochre · Rock art · Erongo · Namibia · chaîne opératoire

## Introduction

Ochre is the common archaeological name of ferruginous rocks and iron oxides with a high tinting strength. Such materials appear in different geological settings, with varying amounts of iron oxides or iron oxyhydroxides (Hodgskiss 2010, 2020; Rifkin 2011, 2012). The study of the collection and use of ochre during the Middle Stone Age is well documented in the archaeology of Southern Africa (see Hodgskiss 2020 for a synthesis of this study). Henshilwood and others have noted the symbolic use of ochre in the evolution of modern human behaviors (Henshilwood 2002; Henshilwood et al. 2018). Hence, many studies have been conducted to analyze ochre pieces recovered within MSA layers (e.g., Barham 2002; Bernatchez 2008; Dayet et al. 2013; d'Errico et al. 2012; Hodgskiss 2012, 2013; Moyo et al. 2016; Rifkin et al. 2016). In contrast, the use of ochre in LSA contexts is understudied, especially given the large number of rock art sites where ochre has been discovered (Fig. 1; see Online Resource 1). As synthesized by Le Quellec (2018), Southern African rock art studies have long focused on the Drakensberg paintings. Innovative approaches have led to a renewal of rock painting studies in other regions, and these have highlighted the diversity of rock art traditions in Southern Africa (Challis 2012, 2016; Le Quellec 2018; Ouzman 2005). Significant works have been carried out to characterize the pictorial layers of these paintings (Bonneau et al. 2012, 2014; Hughes and Solomon 2000; Mauran et al. 2019; Prinsloo et al. 2008; Tournié et al. 2011; Van Rijssen 1990) and date them directly or indirectly (Bonneau et al. 2014, 2017; Mazel 1993; Mazel and Watchman 1997; Watchman and Mazel 2003). Others sought to identify the regional specificities of the different South-ern African rock art clusters (Challis 2012, 2016; Eastwood and Smith 2005; Smith et al. 2004). Some studies have analyzed the paintings' scenic narratives and explored the interactions between the rock arts and their environment (Breunig 2019; Breunig et al. 2018; Lenssen-Erz 2004; Holl 2017; Nankela 2015, 2017).

The discovery of ochre within LSA archaeological layers below rock paintings has often led researchers to consider that ochre was used only for rock paintings and that the discarded ochre pieces are waste materials. Therefore, these materials remain understudied (e.g., Breunig 2003; Kinahan 1990; Richter 1991; Vogelsang 1998; Vogelsang and Eichhorn 2011; Wendt 1972). As a result, only four multianalytical studies have been conducted on the ochre finds from Southern African LSA contexts (Bernatchez 2008; Hahndiek 2014; Hughes and Solomon 2000; Steele et al. 2016), despite the large number of sites where LSA ochres have been recovered. During their preliminary work on LSA ochres from four rock art sites in KwaZulu-Natal, Hughes and Solomon (2000) pointed to the lack of knowledge about ochre resources. Their preliminary work demonstrated that the ochres from these sites were of high diversity and might be correlated to the rock art in the area. But they could not go further with their study due to the diversity of sites they studied, both chronologically (1,290–9,180 years BP) and geographically.

To our knowledge, only a doctoral thesis correlates ochre from LSA layers and rock paintings at Andriesgrond, Diepkloof, and De Hangen (Hahndiek 2014). This study noted that it is difficult to ascertain the relationship between the rock paintings and the ochre fragments found below them. Two noteworthy studies have been carried out by Bernatchez (2008) at Nelson Bay Cave (Western Cape, South Africa) and Steele et al. (2016) at Varshe River 003 (Western Cape, South Africa). Both are unpainted LSA-MSA sites that have delivered some ochre fragments. In her study, Bernatchez (2008) identified different groups of archaeological ochres, pointing to the exploitation of different sources at the same time. Thanks to her diachronic approach, she also demonstrated some procurement changes during the Later Stone Age Wilton, Albany, and Robberg occupations of Nelson Bay Cave. In her conclusion, she called for the continuation of this study through provenience studies of Nelson Bay Cave ochres and of other sites in the region. This task was recently completed by Steele et al. (2016), who excavated Varshe River 003 and conducted geological surveys in the region. The authors noticed diversity in the lithology of the ochre fragments at the site. They considered that this diversity was pointing to the exploitation of numerous sources. For them, it could reflect either high mobility

of the population or a high level of exchange activity. But the connection with other sites and the nature of their use are uncertain. Moreover, ochre provenience studies have not been carried out.

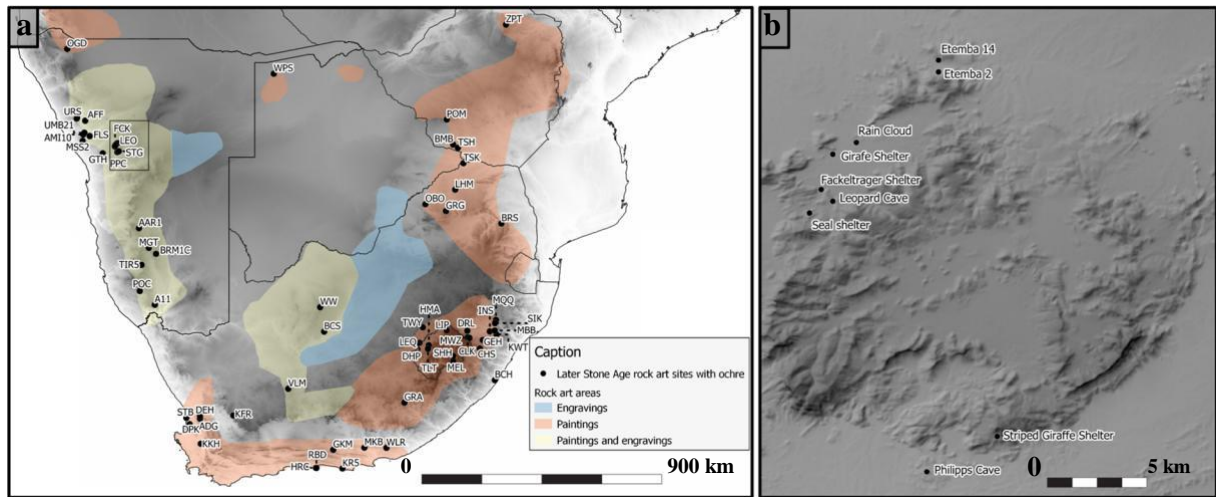


Fig. 1 Southern African rock art sites with archaeological ochre assemblage: a regional context; b Erongo Mountains (Namibia)

Archaeologists have extensively surveyed many sites in Central Namibia for several decades and recorded thousands of rock art sites in different massifs, including the Brandberg, the Erongo, and the Spitzkoppe (Breuil 1955; Breuil et al. 1960; Breunig et al. 2018; Börner 2013; Holl 2017; Hollmann and Steyn 2003; Kinahan 1990, 2000, 2010; Nankela 2017; Pager and Breunig 1989; Pager 1993, 1995, 1998, 2001, 2005, 2006; Scherz 1970; Vallverdu et al. 1979). Excavations have also been carried out to provide archaeological contexts for the various rock art sites and to identify the different phases of human occupation in the region (Breunig 2003, 2019; Breunig et al. 2018; Kinahan 1990; Pleurdeau et al. 2012; Richter 1991; Wendt 1972). These studies provide valuable insights for understanding central Namibian rock art. However, no investigation was carried out on the ochre assemblages discovered at the different rock art sites in the region (Table 1, Fig. 1, and Online Resource 1). Nevertheless, some of these studies have discussed the sociocultural contexts of the rock art sites, thanks to the discovery of exfoliated painted flakes within archaeological layers dated to 3,000 BP at Amis 10 (Breunig 2003; Pager and Breunig 1989) and the discovery of what could be interpreted as evidence of ritual practices at Falls Rock Shelter (FLS, Brandberg; Kinahan 2018). The chronology of these Namibian rock arts rests mainly on stylistic analyses and comparison with the other Southern African rock arts (Kinahan 2000, 2010; Nankela 2017; Richter 1988, 1995, 2002; Richter and Vogelsang 2008). Despite the attempts made by Conard et al. (1988), no direct dating has so far been performed on Namibian rock art due to the scarcity of dating materials.

The Erongo Mountains, a circular volcanic and in-trusive rock complex of Jurassic to Cretaceous age (Blümel et al. 1979), located at the edge of the Namib Desert, are known to host numerous rock paintings and engravings attributed to LSA hunter-gatherers (Breuil et al. 1960; Börner 2013; Hollmann and Steyn 2003; Nankela 2017; Scherz 1970; Vallverdu et al. 1979). The rock complex is regarded as a critical area for understanding LSA hunter-gatherers' behavior in semi-arid environments. It contains numerous archaeological rock art sites where ochre fragments have been found in LSA contexts, and in association with rock art paintings (Online Resource 1). These sites include Fackelträger (Richter 1991; Wendt 1972), Etimba 2 (Richter 1991), Etimba 14 (Richter 1991), Rain Cloud, Giraffe Shelter, and Seal Shelter (Pleurdeau, personal communication), and Leopard Cave (LC - Pleurdeau et al. 2012; Table 1, Fig. 1).

The LSA assemblages from the Erongo Mountains attest to the presence of human occupations all over the massif during the past 6,000 years. The LSA occupation levels have been divided into three technocomplexes—Wilton preceramic, Wilton ceramic, and post-Wilton (Richter 2002). They provided exceptional ochre-related assemblages in the form of numerous grinding and crushing stone tools with red residues on their surface, as well as hematite and “ochre stones”. These artifacts raised the possibility of understanding the relationships between rock art paintings and human occupations and called for more excavations that seek to recover ochre-related artifacts in their cultural contexts (Richter 1991; Wendt 1972).

Table 1 List of the rock art sites in the Erongo Mountains cited in the text

Site	Ochre description	Dating of the archaeological layers containing traces of pigments processing	References
Rain Cloud	Hematite and red traces on grinding stones	2,500–2,000 cal BP	Unpublished data
Fackelträger	Hematite, red traces on grinding stones, pestles and beads	3,000–2,500 cal BP	Wendt 1972; Richter 1991
Leopard Cave	Hematite, ferruginous rocks, red traces on grinding stones, pestles and beads	3,000–2,000 cal BP	Pleurdeau et al. 2012
Etemba 2	Lumps of pigment	Around $1,850 \pm 50$ cal BP	Wendt 1972; Richter 1991
Etemba 14	Lumps of pigment	Around $190 \pm 60$ cal BP	Wendt 1972; Richter 1991
Giraffe Shelter	Hematite and red traces on grinding stones	No data available	Unpublished data
Philipps Cave	Hematite and red « ochre »	Around $3,368 \pm 200$ cl BP	Martin and Mason 1954
Seal Shelter	Hematite, red traces on grinding stones, pestles and beads	No data available	Unpublished data
Striped Giraffe	Small red, brown and yellow pieces	Before $2,640 \pm 100$ cal BP	Sandelowsky & Viereck 1969

The excavations carried out since 2014 at the rock art shelter of Leopard Cave led to the discovery of numerous artifacts that indicate intensive use of ochre. These diverse remains document a unique archaeological context within a painted shelter attributed to LSA hunter-gatherers in Southern Africa. They provide crucial insights into the cultural-economical behaviors of these communities and the origins of rock paintings in the region. This article presents the artifacts relating to ochre processing in Leopard Cave and makes some inferences about the sociocultural behaviors of the LSA populations who occupied the cave. We will also show the existence of intense ochre processing activity at the site.

## Leopard Cave

Leopard Cave is a painted rock shelter located within a Cretaceous granitic spur. It lies in the Omaruru region in the northwestern part of the Erongo Mountains (Fig. 1b). Located on Omandumba West Farm, the shelter stands at an altitude of 1,256 m above sea level and 1.7 km south of the archaeological site of Fackelträger excavated by Wendt in the 1960s (Richter 1991; Wendt 1972). Leopard Cave opens towards the south, facing the hills of the Erongo Mountains. The site consists of a small rock shelter of approximately 60 m<sup>2</sup> (about 8 m long), mostly covered by the overhang of a granite boulder (Fig. 2a–c).

Leopard Cave was discovered in 2006 during a pedestrian survey. The initial coring highlighted the archaeological potential of the site, and excavations took place over several years (2007–2009, 2011–2012, and 2014–2018). Currently, 16 m<sup>3</sup> of sediments have been excavated from nine squares (M6–7, N6–8, O7–8, and P7–8; Fig. 2d). The excavation revealed a 1.8-m-deep stratigraphic sequence documenting a succession of human occupations. The archaeological assemblage is comprised of quartz and basalt lithic artifacts, faunal remains, bone points, link shafts and needles, pendants, and ostrich eggshells (OES) beads, among others. All artifacts point to an LSA hunter-gatherers tradition that was based on opportunistic stone tool production (Pleurdeau et al. 2012). The archaeological assemblage also includes ochre fragments (n = 366), grinding and crushing stone tools (active and passive, n = 15), and ornamental artifacts with red pigment traces on their surface (OES beads, n = 61; bone pendants, n = 1; bone bead, n = 1). Following the discovery of numerous ochres and tools bearing pigment traces in 2014, the excavation of Leopard Cave was expanded towards the eastern wall of the shelter (squares O7–8, Fig. 2b) to investigate the possible connection between the archaeological assemblage and the rock art. In 2015, the excavation revealed red traces on the wall.

## Stratigraphic Sequence

The sequence was subdivided into three stratigraphic complexes. There is evidence of some localized burrows cutting through the stratigraphic profiles. The archaeological materials found within these burrows are excluded in the present study. The upper complex I spans between – 120 and – 250 cm (Fig. 2d). Granitic “arena,” silt, and an ash mixture of anthropic origin with abundant vegetable remains and charcoals are the main components of the nine subhorizontal layers of this complex, labeled from “a” to “j” (Fig. 2d and Table 2). The texture of the upper complex I derived from the powdered silts resulting from the breakdown of the granite. The presence of ash/charcoal and a large number of artifacts recovered from this stratigraphic complex demonstrate the existence of intense anthropic activities.

Complex II, between – 250 and – 280 cm, constitutes deliquescent granite that probably corresponds to a phase of collapse. The few artifacts discovered within these layers appear to be downward infiltration and infilling between the collapsed granitic blocks. Finally, complex III, starting from – 280 cm, is made of an indurated arenaceous matrix, deprived of any ash or organic material. The substratum has not been reached, and a test-core indicates that at least 20 cm of artifact-bearing sediment remains unexcavated.

## Chronology

The chronology of the Leopard Cave shelter stratigraphic sequence has been determined, based on 18 radiocarbon dates from charcoal samples. Table 2 lists all of these radiocarbon dates and provides information about their location at the site. Radio-carbon ages were calibrated using the OxCal 4.3 software (Bronk Ramsey 2009) with the SHCal13 calibration curve (Hogg et al. 2013). The infilling was deposited between  $13,600 \pm 230$  cal. BP (complex III, layer m) and  $2,000 \pm 150$  cal. BP (complex I, layers c–e). The chronology tends to point to the existence of three significant periods of human occupations in complex I: between 5,700 and 3,200 cal BP (layer g), around 2,300–2,500 cal BP (layer f), and after 2,100 cal BP (layers c–e). Three dates obtained for samples SacA51308, SacA51309, and SacA51311 appear to be out of the chronological range of the site occupation. They are likely localized postdepositional events and resulted from intrusions from the upper layers.

Samples CA-DAT\_AD36A and CA-DAT\_AD36C provided important chronological data. The sample was obtained from a concretion covering the east wall of the shelter, a *terminus ante quem* for the covering of the wall by sediments. Archaeological layers located at the same levels, but deposited before the formation of this concretion, are dated to 3,200 cal BP. The C14 dates from CA-DAT\_AD36A and CA-DAT\_AD36C suggest 2,200 cal BP as the *terminus ante quem* for the covering of the wall by sediments.

## Methods

### Rock Painting Documentation

To study the parietal paintings and red traces on the walls of Leopard Cave, we photographically documented the walls and roof of the shelter with a Nikon D3300 with 105 mm focal distance. These pictures were then treated with Dstretch® (Harman 2008), according to the method published by Le Quellec et al. (2013). Descriptions and analysis of these paintings can be found in Nankela (2017) and Mauran et al. (2019).

### Ochre Description

Archaeological pieces were first observed visually before any treatment to evaluate their fragility and the possibility of washing them. The washing was performed with deionized water and ultra-sonication for 3 min for the hardest pieces. Only deionized water was used for the weaker ones, and a few were not cleaned at all in order not to destroy them. Once cleaned, the objects were observed with a binocular microscope (LEICA), and photos were taken with a Nikon D3300 with 105 mm focal distance. The description of the samples is presented



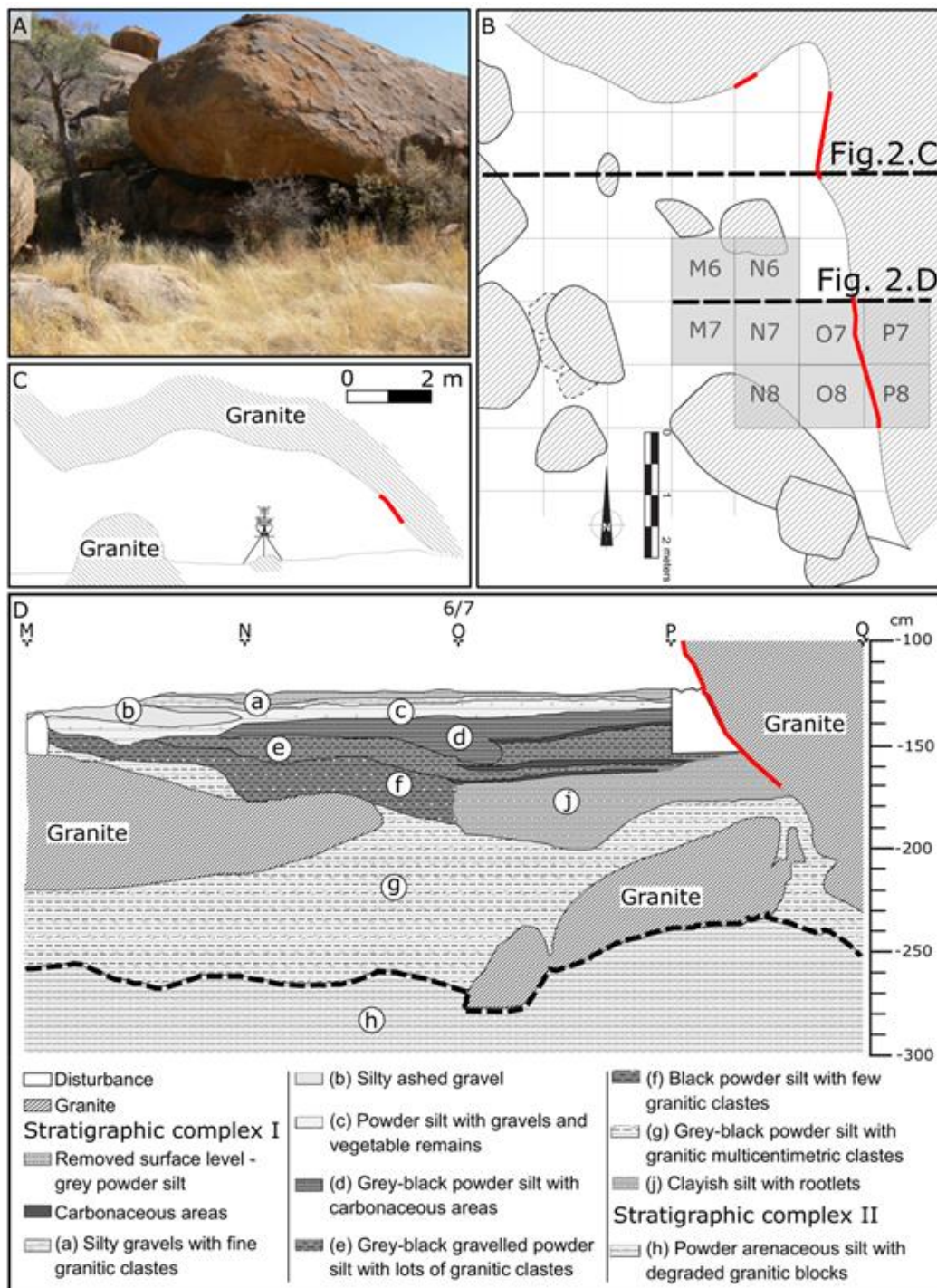


Fig. 2

Leopard Cave (a), showing (b) excavated squares within the shelter—red lines indicate the location of the paintings in the shelter; (c) shelter profile; and (d) stratigraphic sequence of cut 6/7

in Online Resource 2, based on the following characteristics (see Dayet 2012; Hodgskiss 2010; Pradeau 2015; Salomon 2009):

- & Block weight: measured to the milligram
- & Block dimensions: measured with a caliper to the millimeter
- & Main block hue: observed on natural surfaces
- & Powder hue: observed on microsample

- & Tinting strength: estimated during manipulation of the block—gentle (not tinting the skin at seizing) to strong (tinting the skin at seizing) handling
- & Block cohesion: estimated during manipulation of the block—gentle (the block breaks off at seizing) to strong (the block does not present any structural weakness) handling
- & Block hardness: estimated during manipulation of the block, ranging between gentle (a copper coin can scratch the block) and strong (the block can scratch a copper coin) handling
- & Matrix homogeneity: estimated with the observation of a fresh break on the block, between homogenous and heterogeneous
- & Matrix structure: described from a fresh break on the block
- & Porosity of the block: estimated from the observation of the block between low (no pore visible with binocular microscope) to high (presence of macropores visible at bare eyes)
- & Granulometry of the block: estimated from the observation of the block and described as being between fine and coarse grain size
- & Block luster: description of the luster (metallic, submetallic, greasy, or no luster)
- & Presence of inclusion: inclusion description from binocular microscope observations of the block
- & Magnetization: estimated from a magnet test between low (no reaction to a magnet) to high (strong reaction to a magnet)

These observations and descriptions permitted us to assess the diversity of the ochre found at Leopard Cave.

Table 2 Radiocarbon dates at Leopard Cave

Lab ID	Laboratory	Stratigraphic complex	Square	Layer	Depth (cm)	Nature	Conventional radiocarbon age, BP	Age cal BP (2 sigma)
SacA3262	LMC14	I	N6	c	143.5	Charcoal	2,150 ± 30	2,100 ± 100
Beta-270163	Beta analytic	I	N7	e	157.5	Tooth	2,190 ± 40	2,100 ± 100
SacA34261	LMC14	I	M6	i	159	Charcoal	2,565 ± 30	2,600 ± 150
Beta-270,164	Beta analytic	I	N7	f	163	Tooth	2,270 ± 40	2,200 ± 100
Beta-236,963	Beta analytic	I	N7	f	166–176	Charcoal	2,430 ± 50	2,500 ± 200
CA_DAT_AD63C	CARAA	I4	P8	In concretion over the wall	168	Charcoal	2,105 ± 45	2,100 ± 100
UBA-30945	14OCHRONO	I	P7	f	175.5	Charcoal	2,209 ± 33	2,200 ± 150
UBA-30946	14OCHRONO	I	P7	g	192	Charcoal	3,064 ± 32	3,200 ± 150
Beta-236,964	Beta analytic	I	N7	g	196–206	Charcoal	3,250 ± 40	3,500 ± 100
CA_DAT_AD63A	CARAA	I	P8	In concretion over the wall	203	Charcoal	2,267 ± 45	2,200 ± 150
SacA51308	LMC14	I	O8	Displaced (f)	224	Charcoal	2,105 ± 30	2,000 ± 150
SacA42295	LMC14	I	N7	g	263.5	Charcoal	3,465 ± 30	3,700 ± 150
CA_DAT_AD63B	CARAA	II	P8	g	240–250	Charcoal	4,508 ± 45	5,100 ± 200
SacA42299	LMC14	II	N7	g	271.5	Charcoal	3,000 ± 30	3,100 ± 150
SacA51309	LMC14	II	N7	Displaced (f)	281	Charcoal	2,330 ± 30	2,300 ± 100
SacA51311	LMC14	II	O8	Displaced (f)	285	Charcoal	2,345 ± 30	2,300 ± 100
SacA53511	LMC14	II	O7	h	290	Charcoal	49,45 ± 30	5,700 ± 100
SacA51310	LMC14	III	O7	m	300	Charcoal	13,040 ± 70	13,600 ± 230

## Anthropic Modification of Ochre Fragments

The experimental studies performed on ochre allowed inferences to be made on the existence and nature of anthropogenic modifications (Dayet 2012; Hodgskiss 2010; Rifkin 2012; Rosso et al. 2017; Salomon 2009).

'After visual examination, we classified the ochre fragments from Leopard Cave into two groups: unmodified and possibly modified. The modifications were considered according to the presence of striations, facets, fracturing edges, polished surfaces, and flake scars. According to the previous works of Hodgskiss (2010) and Rifkin (2012), we divided the potential anthropic modifications into two main groups: fragmentation and grinding. However, as no experimental study has been carried out on pure iron oxides or single fragmentation scars, we considered all the fragmentation scars as potential traces of anthropic modifications. These observations were coupled with the ones made on grinding and crushing tools, all stone items that have been intentionally modified through the pounding and grinding of other materials (Dubreuil and Savage 2014; Ebeling and Rowan 2004; Hayes et al. 2017). The two anthropic modifications are described below.

1. Fragmentation aims at decreasing the volume of the blocks. It can be achieved through various actions: knapping, pounding, or crushing. These actions leave distinct marks on the blocks. Knapping, pounding, and crushing are often continuous actions to reduce the initial blocks into small shards and pigment powder (Dayet 2012; Salomon 2009). The small shards that were not reduced to powder bear traces of “fresh” sharp edge and “fresh” fracturing surfaces. Traces on the tools used to crush and grind are more evident as they correspond to percussion pits, and the saddle shape of the grinding slabs bear red residues on their surface. Knapping performed on ochre leaves scar traces, although these are sometimes hard to observe (Henshilwood et al. 2009; Salomon 2009).
2. Grinding aims at shaping, altering the surface of the blocks, and producing pigment powder (Henshilwood et al. 2009; Hodgskiss 2010; Rifkin 2012; Salomon 2009). Grinding use-wear is more evident on ochre fragments than traces of fragmentation. It consists of facets and multiple groups of parallel striations on the surface of both the ochre piece and the grindstone on which the blocks were rubbed. On the tools, ochre grinding use-wear patterns mainly consist of red tint, ochre grain residues, and leveling or smoothing of the microrelief on the active surface of the tool (Hayes et al. 2017). Other possible anthropic modifications consist of ochre thermic treatment (Dayet 2012; Pomiès et al. 1999; Salomon et al. 2014). Only the archaeological context allows the differentiation of intentional treatment from accidental or postdepositional heating (Salomon et al. 2012, 2015; Wadley 2009). The large charcoal beds and the extensive number of heat-exploded lithics found at Leopard Cave prevent us from considering the potential thermic treatment intended for the ochre fragments at the site.

## Description of Ochre Residues on Artifacts

The residues on artifacts were described according to the methodology proposed by Pradeau (2015). All tools and ornaments were first observed with the naked eye to spot the presence of red residues and determine the part of the artifact on which they are present. All artifacts with residues on one of their surfaces were documented through various photographs with a Nikon D3300 with 105 mm focal distance. To enhance the visibility of the red residues present on the tools, the pictures were treated with Dstretch® (Harman 2008). All pictures were treated with the YRD filter. We then documented the presence of pits, smoothed edges, striations, and their relations with the red residues found on these artifacts.

## Results

### The Parietal Pigment Residues: Red Representations and Their Weathering

Eastern and northern walls of Leopard Cave bear red parietal representations or pigment traces (Figs. 2b and 3). Differential erosion and weathering caused large granitic slabs to detach from their bedrock. Paintings seem to have been performed after the collapse of these large granitic slabs. Today, these representations are all located



in the lowest parts of the walls. But given the recent sedimentation experienced in the shelter, the former surface levels must have been much lower, placing the paintings at about the eye level during the LSA occupations. Twelve figures and one area of diffuse red flat tint have been recorded and described (Nankela 2017). Among the 12 motifs identified, four are anthropomorphic, while four are zoomorphic (a headless giraffe, an antelope, a duiker, and a giraffe head). Another four figures are classified as indeterminable. All paintings exhibit fine-line appearance, a characteristic of the rock paintings in the Erongo region (for example, see the back legs of the antelope displayed in Fig. 3b; Nankela 2017; Richter 1991). Only red monochromes were observed at this site. Most of the paintings are in a poor state of conservation, as a result of natural weathering and anthropogenic activities resulting in dust coating. Substantial black residues covering the ceiling prevent us from assessing the possibility for the presence of paintings in this part of the cavity. Only the headless giraffe is still clearly visible (Fig. 3a), while all other paintings vanished under white crusts, such as the back legs of the antelope (Fig. 3b), or as the result of both water and sandy wind erosions—the headless giraffe (Fig. 3c).

The 2015 excavation of the subsquares lying next to the eastern wall (squares P7–P8) allowed us to clear the wall from the sediment covering it, and red traces were observed on the wall (Fig. 3f–h) between levels at  $z = -162$  cm (27 cm below the surface) and  $z = -189$  cm (54 cm below the surface) (Fig. 3f). These red traces could have resulted from the natural red tint of the granite, the presence of vanished red painting, or the leaking of pigments from wall sections above this area. The *in situ* pXRF analyses confirmed that the origin of the red tint was from the anthropogenic presence of iron pigment (Mauran et al. 2019).

## Ochre Fragments and Pigment Traces on the Archaeological Material

Ochre fragments ( $n = 366$ ), tools (grinding slabs and handstones,  $n = 15$ ), and ornaments (OES, bone beads, and bone pendant) bearing traces of pigments were discovered in stratigraphic complex I at the bottom of the painted wall (squares O/P; Fig. 2b). The presence of a grinding slab (T-LC-01) and a handstone (T-LC-07)—both bearing traces of use and an ochre piece with an abraded surface (LC-030, Fig. 4a)—are convincing evidence of the mechanical transformation of ochre at the site.

## Nature of the Ochre Fragments

The blocks of raw ochre that we studied were recovered from the 2014–2018 excavations. They are 366 pieces, representing a total mass of about 1.1 kg. They could be divided into two main macroscopic groups: black metallic iron oxides and red ferruginous rocks (Table 3 and Fig. 5). The first group corresponds to well-crystallized iron oxides and includes 171 elements for a total weight of 0.7 kg, representing 47% of the collection in the number of samples and 68% in mass. The pieces present a gray to black nodule aspect with a submetallic to metallic brilliance. They have the attributes of high cohesion and hardness with a homogenous matrix and a massive structure (Fig. 5). Their external surface is smooth without any sharp edges but with a metallic

glow, as exemplified in samples LC-047, LC-049, LC-189, and LC-301 in Fig. 5. Within the matrix, various inclusions are present. The predominant ones correspond to millimetric to centimetric quartz inclusions.

The second group is made up of different ferruginous rocks and comprises 195 specimens (53% of the total number) and totaling 0.4 kg (36% in mass). The characteristics of these pieces are the following: red to yellow hues, no brilliance, medium to low cohesion and hardness, and heterogeneous matrix (Fig. 5). However, this ferruginous rock group also comprises pieces of various textures ranging from granular (LC-255, LC-283, LC-248, LC-030) to well-stratified (LC-298) or heterogeneous (Fig. 5). Therefore, this group comprises ferruginous sandstones ( $n = 65$ ), banded ironstone ( $n = 59$ ), ferruginous mudstones ( $n = 26$ ), and other ferruginous altered rocks ( $n = 45$ ). Since we did not observe any difference in their spatial distribution or potential treatment, we decided to gather them into a single group of ferruginous rocks.

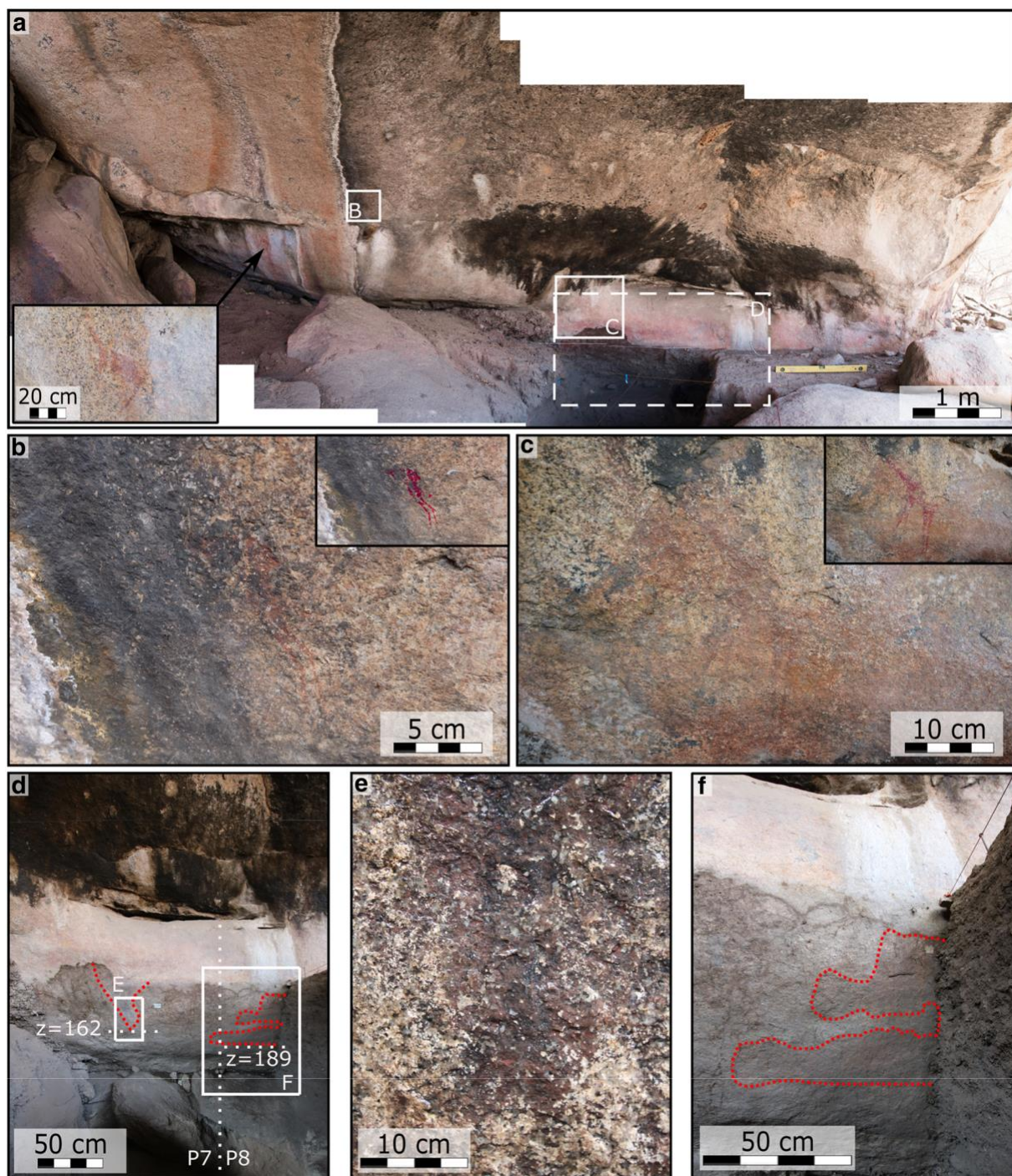


Fig. 3 Red pigment traces and paintings on the eastern wall of Leopard Cave



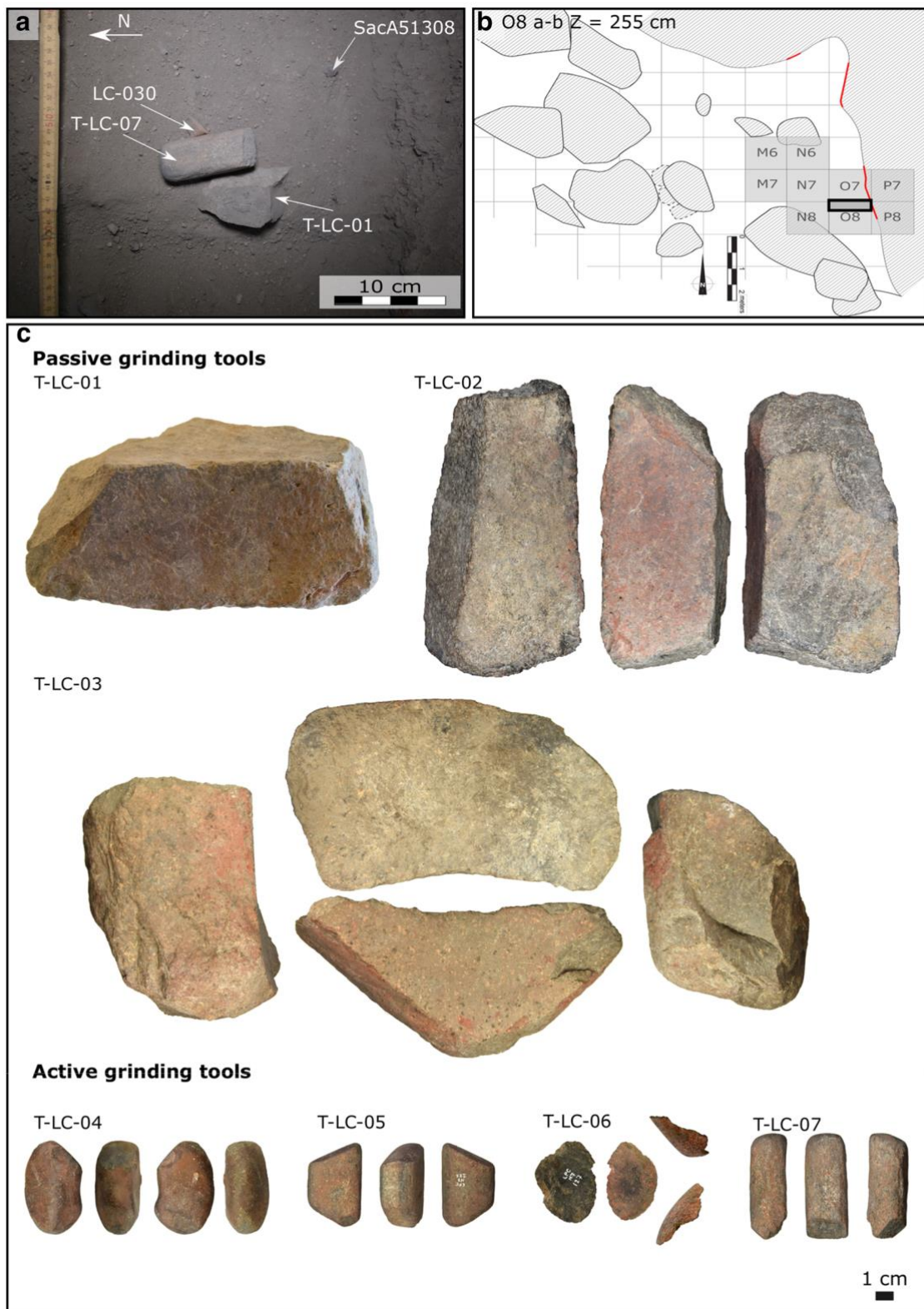


Fig. 4 Grinding and crushing tools in relation with abraded ochre

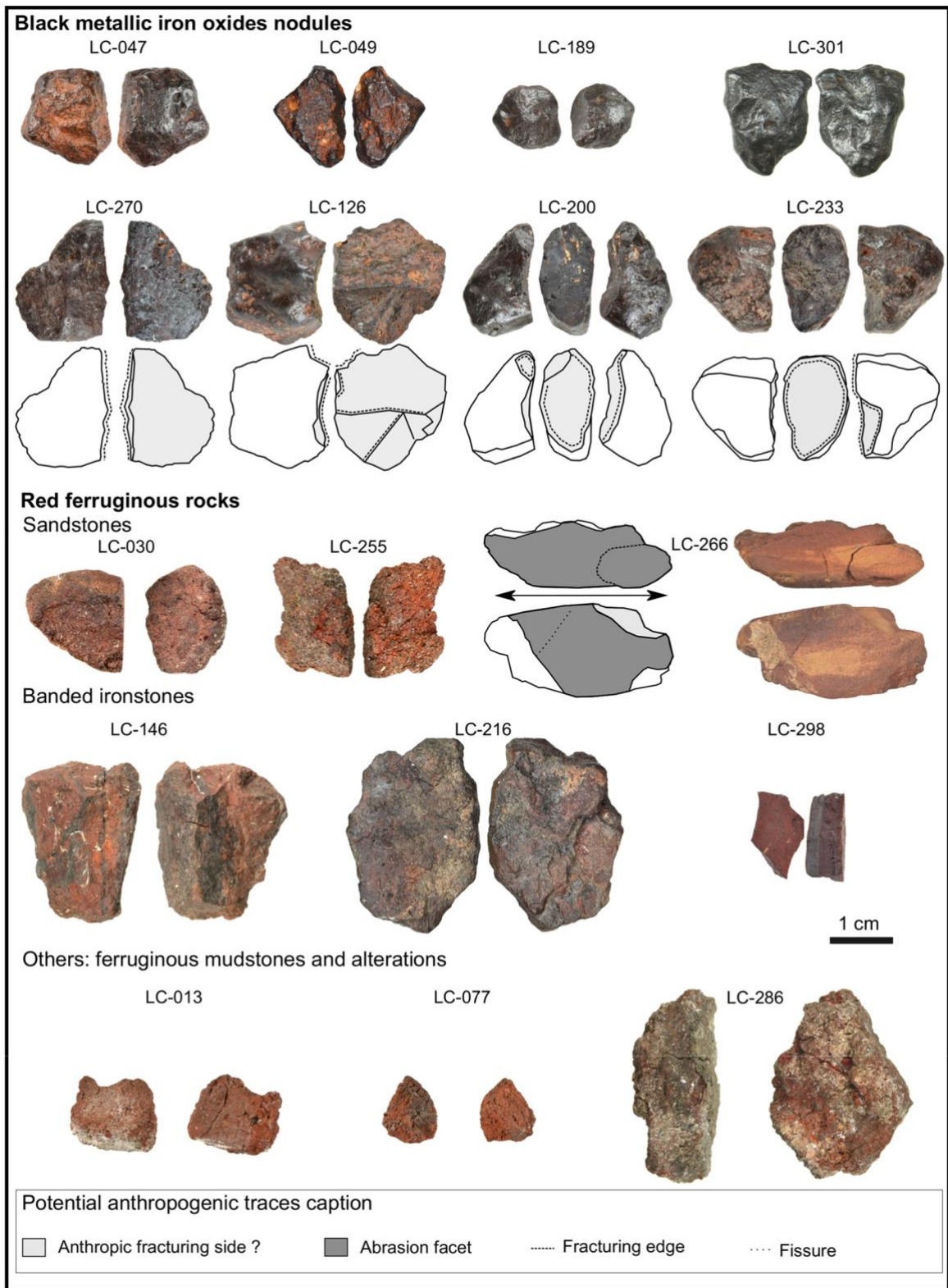


Fig. 5 Selection of ochre fragments with and without potential anthropic transformations, Leopard Cave



## Potential Anthropogenic Modifications of the Ochre Fragments

At Leopard Cave, 63% of the iron oxides blocks ( $n = 109$ ) exhibit potential marks of anthropogenic fragmentation in the form of fracturing surfaces and flake scars. Fracturing surfaces are the most prominent marks and correspond to net breaks of the pieces, such as those exemplified in Fig. 5 for LC-126, LC-200, LC-233, and LC-270. Flake scars were also identified through the presence of impact points (LC-200 and LC-270 on Fig. 5). The anthropic origin of these potential fragmentation traces is reinforced by the discovery of numerous small sherds of ochre (less than 1 mm), close to the blocks with those scars.

Among the ferruginous rocks, only three pieces out of 195 have striated facets (LC-030, LC-265, and LC-266; Fig. 5). While LC-030 exhibits only one facet of abrasion (Fig. 5), LC-265 and LC-266 exhibit several sides that bear four and two facets of abrasions with unidirectional microstriations (Fig. 5). As these flat surfaces do not exhibit sharp grooves or extremely pronounced microstriations, they are consistent with the grinding procedure of ochre, as published by Hodgskiss (2010). Other possible use-traces consisted of fragmentation marks on numerous pieces ( $n = 160$ ), as exemplified by LC-298 (Fig. 5).

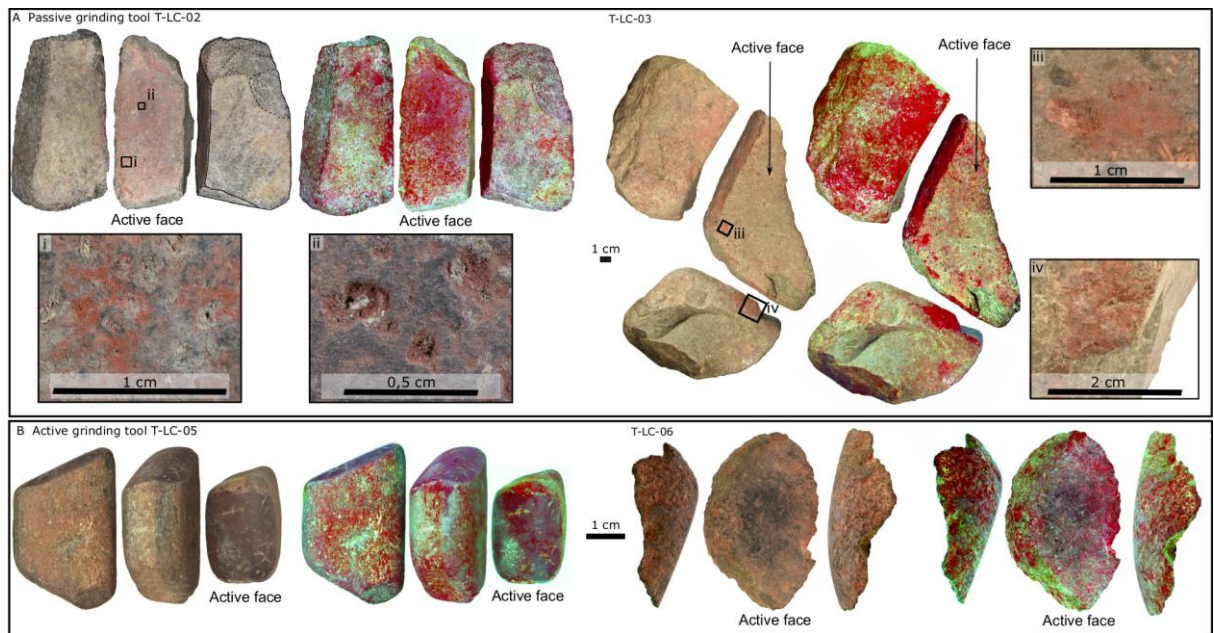


Fig. 6 Distribution and selection of red residues found on the crushing and grinding tools: natural light photos on the left and yrd Dstretch® (Harman 2008) treatments on the right

## Ochre Residues on Stone Tools

Crushing and grinding tools of Leopard Cave were divided into two groups, according to the morphological classification system of Wright (1992): (1) grinding slabs (passive tools,  $n = 6$ ) and (2) handstones (active tools,  $n = 9$ ). Figures 4 and 6 present some of these active and passive tools. Grinding slabs are the largest tools of the Leopard Cave assemblage, measuring at least 20 cm long. All six grinding slabs with red residues have an active face identifiable by their smoothed microrelief and flattened aspect (e.g., T-LC-01 and T-LC-02; Figs. 4 and 6) and their saddle shape (e.g., T-LC-03; Figs. 4 and 6). They are made either from granite ( $n = 4$ ) or basalt ( $n = 2$ ), both readily available in the vicinity of Leopard Cave. Five of the slabs appear intact (e.g., T-LC-01 and T-LC-02), while one is broken on its active surface (T-LC-03). One of the basaltic grinding slabs, T-LC-02, has been shaped on one of its pas-sive surfaces by knapping (Fig. 6a). High concentrations of red residues are found on these grinding slabs, suggesting their use to produce pigment powder, either by grinding or by fragmentation.



The grinding slabs can be divided into two groups: the grinding slabs with a red tint on their active surfaces and the ones solely presenting red residues on the edges of their active surfaces.

Within the first group of grinding slabs ( $n = 4$ ), the active surface presents a clear to diffuse red tint, and red ochre grains are visible macroscopically in the smoothed asperities of the granite and basalt slabs (Figs. 4 and 6). The presence of a red-tinted smoothed active surface, bearing grains of ochre in its asperities, is characteristic of ochre processing by grinding (Ebeling and Rowan 2004, 2004; Hayes et al. 2017). As for the second group ( $n = 2$ ), the smoothed active surface did not present any clear red tint, and red residues could only be spotted at the edges of this surface (Figs. 4 and 6). The red residues present on these artifacts might result from incidental contact with ochre pieces or ochred surfaces such as human skin or animal hide. Unfortunately, no other material was identified on the active surface, preventing us from determining the use of these stone tools.

Handstones are smaller tools, measuring around 10 cm long and all made of basalt. All these nine active tools with red residues present a single convex smoothed side with some pitting marks, corresponding to the active surface of the tools (Figs. 4 and 6b). Although all have some red residues on at least one of their lateral passive surfaces, only a few (T-LC-05, T-LC-06, T-LC-08) exhibited red tint or red ochre residues within the smoothed pits and microstriations on their active surface. These wear traces demonstrate the use of some of the tools to process ochre. Handstone T-LC-06 is broken but is still identifiable, thanks to the presence of an active surface covered by red residues and percussion pits. Its breakage might be related to the intensive crushing of hard materials such as iron oxides. The absence of residues on the active surfaces of some of the handstones could be due to the reuse of these tools to grind other materials, such as plants, or due to low adhesion of the ochre on the surface. The residues found only on the lateral faces could be the result of contact with an ochre-stained tool, an ochred artifact, or human skin. The modified ochre pieces, grinding tools bearing red pigment traces, a modified ochre piece, and the crushing and grinding tools with red residues over their active surface (4 grinding slabs and 4 handstones) all serve as evidence of the on-site mechanical transformation of ochre to produce pigment powder.

### Ochre Residues on Ornaments

The artifacts with red residues on their surfaces are not only restricted to crushing and grinding tools at Leopard Cave but also include ornamental pieces, especially beads and pendants ( $n = 63$ ). Schists, ostrich eggshells, bone shafts, and bone ornaments were found at Leopard Cave (Pleurdeau et al. 2012), but red residues are solely observed on ostrich eggshell (OES) beads ( $n = 61$ ), one bone bead, and one bone pendant. The OES beads diameter lies between 3 and 7 mm, and there are two categories of these based on the color: white to cream, and gray to black (Fig. 7). Among the 61 OES beads with red residues, the first group, comprising 57 pieces, is the most prominent. Only a few of them have small areas covered by thick layers of red residues ( $n = 12$ ). These areas are located on the lateral side (OES-LC-002, Fig. 7), in the central perforation (OES-LC-313, Fig. 7), and on inner and outer sides (OES-LC-305, OES-LC-313, OES-LC-313, Fig. 7) of the beads. On a few beads (e.g., OES-LC-305), specific use-wear patterns could be identified (Si Ammour 2016). These consist of light depressions filled with red residues on both sides.

There is also an ornate bird bone tube bead measuring 5 cm long and 0.5 cm in diameter with 15 notches of ca. 1 mm deep (Fig. 7). These 15 notches present similar profiles and manufacturing techniques. They most probably were made with the same tool during a single episode. It is similar to the bone tube beads discovered at other Namibian archaeological sites (Vogelsang and Eichorn 2011). Unfortunately, the animal species to which this bone belongs could not be identified, as it is only a fragment of diaphysis with no other diagnostic features. Eight other undecorated bird bone fragments were found in the same layer, again too fragmented to be assigned to one taxon. A few red residues are still trapped within the notches. These red residues consist of packs of granular red clay, mixed with micrometric angular hematite particles. Tiny red unidirectional striations can be

seen on these bone fragments. These tiny striations are not deep and represent hematite particles barely visible with an optical microscope; they could potentially be the result of bone polishing with some ochre.

The red residues found on the beads and pendant could be the result of the coloring of the beads or taphonomic processes. But as for most of the beads, the red residues are sporadic. Therefore, it is more likely that they resulted from indirect coloration due to contact with a colored surface, such as a colored string, cloth, or body. That is, the red residues on the beads could have derived from the ochre used to paint body or clothes, both possibly connected to identity markers (Rigaud et al. 2014; Vanhaeren and d’Errico 2003, 2005; Vanhaeren et al. 2006).

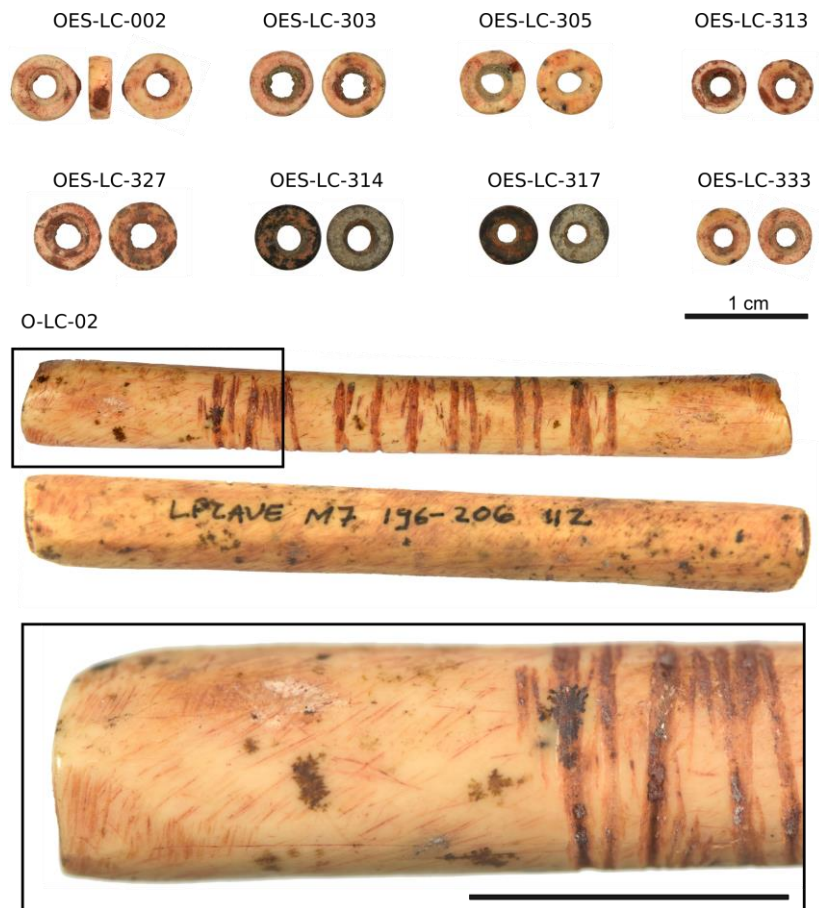


Fig. 7 Selection of beads from Leopard Cave displaying ochre residues. Scales, 1 cm

### Distribution of the Material Within the Stratigraphic Sequence

Table 3 and Fig. 8 sum up the distribution of the ochre fragments and associated grinding stones, beads, and quartz and basalt lithic industries in the stratigraphic complexes and layers. The artifacts were recovered from complex I in layers g and f, spanning from – 125 to – 260 cm (Fig. 8). Complex II and the upper part of complex III are almost sterile of archaeological remains. Layer f presents a few ochre pieces, some showing possible anthropogenic modifications, and there are also tools and beads with red residues. However, the highest concentration of artifacts is in the “oldest” layer g, located between – 185 and – 250 cm (Fig. 8 and Table 3). This is also where the decorated bone bead was found. While layer f has delivered one ceramic sherd, possibly due to sediment disturbance, no ceramic sherd was recovered from layer g.

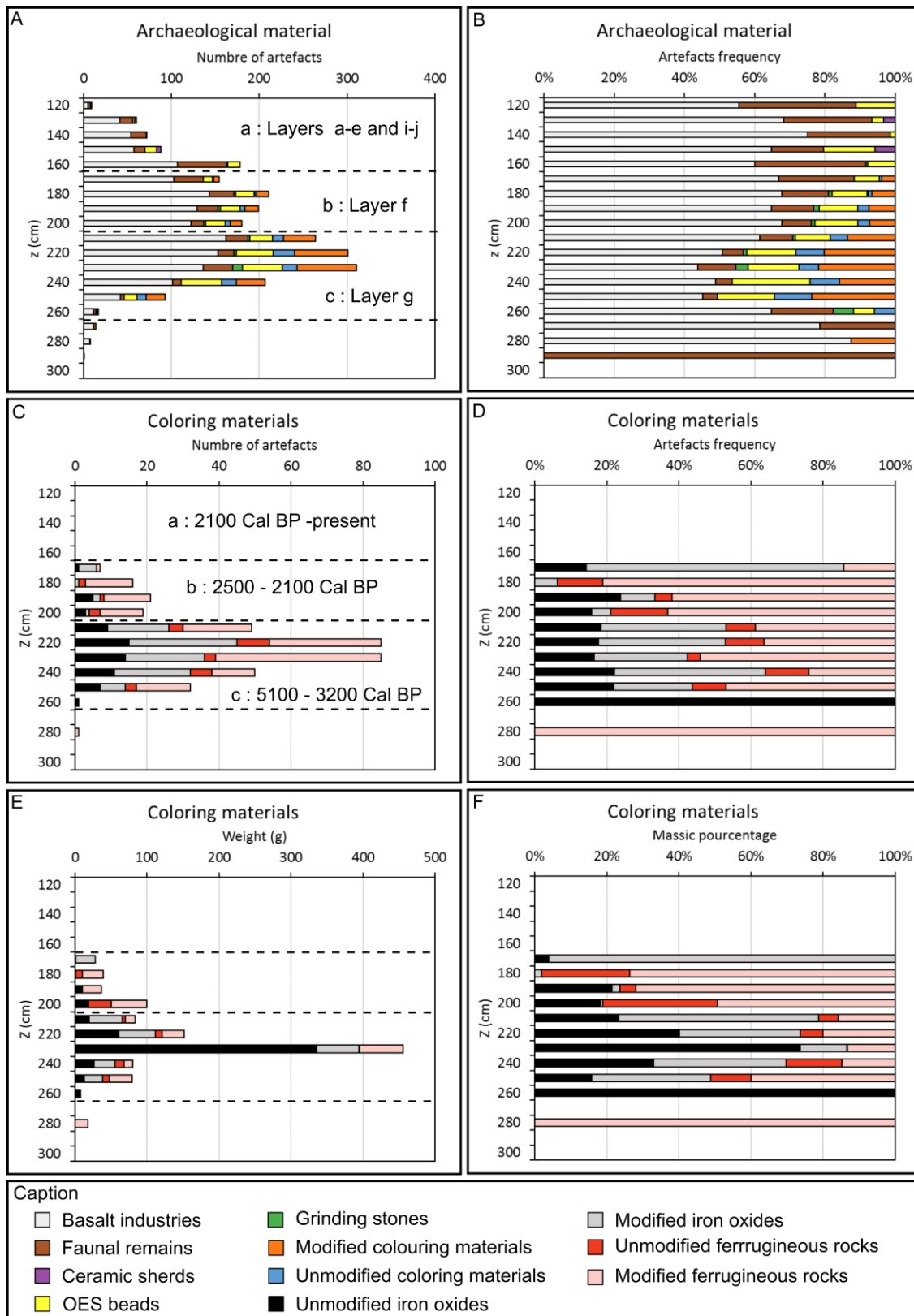


Fig. 8 Stratigraphic distribution of the materials mentioned in the text at Leopard Cave. a Numerical distribution of various selected archaeological materials. b Frequency distribution of various selected archaeological materials. c, d Numerical and frequency distribution of ochres. e, f Mass distribution and mass percentage of ochres

When considering the mass distribution of ochre in this stratigraphic complex, it is noteworthy that an iron oxide block weighing 310 g (LC-130) biased this distribution. Indeed, most of the ochre fragments weighed less than 10 g, with a median weight of 0.8 g. This low value reflects the high fragmentation of the ochre assemblage at Leopard Cave. Moreover, in layer g, potential anthropogenic modifications were identified in over 73% (220 out of 302) of the ochre fragments recovered (Table 3), confirming the intensive ochre exploitation at the site.

Both kinds of ochre fragments—iron oxides and ferruginous rocks—were recovered in the stratigraphic units f and g, with no apparent time differentiation. However, rich iron oxides are more abundant in layer g than in f, although both layers have delivered similar frequencies of lithic industries and faunal remains (Table 3). This difference could indicate either a change of activities performed at the site between the two occupation phases, or a shift in the deposition rate. Nevertheless, from the data gathered, ochre-processing appears to have been an important activity during the occupation phase corresponding to the two archaeological layers.

According to the chronology of the stratigraphic sequence, layer g is dated between 5,700 and 3,000 BP, despite the unexpected dates of ca 2,100 BP from three charcoal samples (Table 2). Postdepositional activities were most probably responsible for this unexpected young age. Hence, the 2,100 BP date must be considered as the minimum age of the layer and most of the materials above it. This should also be considered as the minimum age of the oldest rock paintings at Leopard Cave (see further discussions below).

Table 3 Stratigraphic distribution of the archaeological material of Leopard Cave within the 3 complexes of the stratigraphic sequence. \* Complex III remains largely unexcavated

Stratigraphic complex	Layers	Iron oxide		Ferruginous rock		Grinding tools		OES beads		Ceramic sherds	Lithic industries		Faunal remains
		Total	With potential anthropogenic modifications	Total	With potential anthropogenic modifications	Total	With red residues	Total	With red residues		Basalt	Quartz	
I	a-e	0	0	0	0	1	1	31	9	7	148	116	104
I	f	18	9	45	39	7	2	76	8	1	360	137	100
I	g	154	97	148	123	17	11	175	43	0	448	137	94
II	k-l	0	0	1	1	1	1	0	0	0	9	9	4
Total		172	106	194	163	26	15	283	61	8	965	399	302

## Discussion

The technical processes for the production of pigments seem to have five main steps: (1) exploitation/collection of raw materials (ochre) and their subsequent storage; (2) transformation of ochre for the production of coloring powders; (3) storage of the ochre powder; (4) possible mixing with binders and extenders; and (5) use of the powder/mixture (Dayet 2012; Rifkin 2011; Salomon 2009). At Leopard Cave, at least three of this five-step chaîne opératoire have been identified: collection and storage of raw materials, ochre transformation for the production of coloring powders, and their use.

## Collection and Storage of the Raw Material

Leopard Cave is not near a natural outcrop of ochre, and these materials could not have been formed from pedo-genetic alterations. Hence, the large number of ochre fragments found at the site ( $n = 366$ ) indicates that the raw materials were collected from elsewhere and stored at the site. The diversity of ochres recovered, with a large collection of ferruginous rocks and iron oxides, could be the result of an opportunistic procurement strategy or an important activity of ochre trade from distinct outcrops, as hypothesized by Steele et al. (2016). In the case of an opportunistic procurement strategy, ochre might have been collected during expeditions for other vital goods, with minimum effort to extract them and with a few materials obtained at a time (Couraud 1988, cited by Salomon 2009). The raw material collected came from different places. But these outcrops must be mostly local as they should fall within the region covered by hunter-gatherer populations for their economic activities. In such a procurement strategy, it seems unlikely that ochres would have been collected and transported over very long distances. The fact that many blocks of iron oxides found at Leopard Cave exhibit a smooth outer surface, without any scars from extraction (Fig. 5), supports the hypothesis of an opportunistic collection of the iron oxides at their original ore outcrops. At Leopard Cave, the lithic industries are made mainly of quartz and basalt, also supporting an opportunistic strategy for the use of local raw materials for tool manufacture (Pleurdeau et al. 2012).

As iron oxides and ferruginous rocks might have had different values and natural availability near Leopard Cave, the efforts undertaken to collect these various ochres might have been different. The provenience study of the different ochre fragments recovered at Leopard Cave could help us to understand the mobility pattern of the LSA communities in the area, the territory they exploited for raw materials, and the efforts expended to collect these ochre fragments (Dayet 2012). It will also help us to understand the possible changes in ochre procurement strategies during the Late Stone Age, a topic pioneered by Bernatchez (2008) at Nelson Bay Cave (Western Cape, South Africa). The provenience study of ochre promises to bring new insights on the economic behaviors of the LSA populations who occupied Leopard Cave, as well as their social organization.

## Ochre Transformations

The presence of several grinding slabs ( $N = 6$ ) and handstones ( $N = 9$ ), as well as the occurrence of red residues and use-wear (e.g., scars) on their surface, demonstrate the intensive pigment processing at Leopard Cave during the LSA. These grinding tools might have also been used to grind other materials such as plants, explaining the conservation of red residues in anfractuosités located on the passive faces of the tools. Our observation of the assemblage revealed two distinct chaînes opératoires for producing the pigment powder: fragmentation and grinding, as described above. The recovery of small fragments (less than 1 mm) and larger ochre blocks testify to the fragmentation process at the site. The presence of fracturing surfaces on different types of ochre indicates that fragmentation was a common technique for ochre powder production at the Leopard Cave. This is in agreement with Southern African ethnological data, according to which grinding and pounding are the usual treatments of ochre (How 1962; Rudner 1982).

The facets observed on three ferruginous rocks also relate to the grinding technique (Fig. 5). Traces of this technique were only observed on ferruginous rocks that are of soft materials and not on harder iron oxide blocks, an indication of differential ochre treatments based on the degree of hardness. The question then is whether the apparent differential ochre treatment was due to anthropogenic choices or related to a taphonomic bias such as gelifraction and intense heating? The experimental tests on geological iron oxides lead us to support the idea of anthropogenic choice. We noticed that the fragmentation method for iron oxides was based on their hardness. Such a differential treatment raises further questions. Why were all ochres not treated the same way and pounded? The answer to this question may relate to whether the choice to grind some pieces was linked to some kind of symbolic consideration instead of being purely oriented towards technical needs.



## Ochre Uses at Leopard Cave

The ochre-related artifacts at Leopard Cave could be connected to various cultural, social, technical, and economic purposes, not all linked to the rock paintings present on the site or in the surroundings (Cristiani et al. 2014; Dayet et al. 2017; d'Errico et al. 2005; Orton 2008). Therefore, the sequence of occupations found at Leopard Cave offers the opportunity to examine whether there were changes in the production and use of the pigments over time.

Some of the ochre fragments and ochre-related artifacts were found just at the bottom of the painted wall (Fig. 3). And, the minimum age for creating the paintings is consistent with the radiocarbon ages for the layers where the ochre-processing artifacts were found (Table 2). It is tempting, therefore, to say that the ochres were likely used to create the paintings in the shelter. Given the large numbers of rock painting sites around Leopard Cave, it is also possible that ochres found at Leopard Cave were used to produce paintings at some of these other sites (Breuil et al. 1960; Börner 2013; Hollman and Steyn 2003; Nankela 2017; Scherz 1970). It appears that ochres were primarily used for their tinting strength and might have conveyed a magical value, as mentioned in the literature for both ethno-graphic and archaeological contexts (Bleek and Lloyd 1911; How 1962; Rudner 1982; Van der Ryst 1998). In bearing such a magical value, ochres should be considered as a precious raw material. Its treatment, therefore, followed specific steps, as described in Rudner's (1982) review of ethnographic data. The fragmentation and grinding processes, identified at Leopard Cave, could relate to these steps. Identifying the nature of the ochre used to perform the rock paintings could bring new insights regarding rock art production at Leopard Cave and the surrounding area.

However, several other uses should be considered for ochre at Leopard Cave, given the presence of red residues on a wide range of archaeological materials. For example, the red residues present on the beads could have resulted from contact with body paintings, a well-known practice for both social and technical reasons in Southern Africa (How 1962; Rifkin 2012; Rifkin et al. 2015a, b; Rudner 1982); ochred strings on which beads were glued; ochred strings on which the beads were arranged; or clothes on which ochred strings/beads were sewn (Dayet et al. 2017; Vanhaeren et al. 2013). Ethno-graphic data about the ornaments used by !Kung hunter-gatherers from Botswana attest to the extensive use of OES beads, adhesive, and strings to form complex ornaments (Marshall 1976). Authors have demonstrated the existence of similar personal ornaments within archaeological assemblages of LSA and MSA sites, at Bushman Rock Shelter (Dayet et al. 2017) and Blombos Cave, respectively (Vanhaeren et al. 2013). At Leopard Cave, beads with red residues on their ventral and dorsal sides (e.g., OES-LC-313, OES-LS-314, and OES-LC-317; Fig. 7) could have been glued together to form rigid lines or ring-shaped ornaments. Beads with residues within their inner lateral sides could have been similarly arranged and glued on a string (e.g., OES-LC-303 and OES-LC-313). Likewise, the bone tube (O-LC-02) bead could have been part of a larger ornament arranged on a string. The red residues on the external sides of the beads may have resulted from contacts with an ochred body. In all cases, the red residues on the ornaments are indicative of the past cultural, social, and technical practices of ochre exploitation at Leopard Cave.

Indeed, body paintings and personal ornaments generally convey complex social information (Vanhaeren and d'Errico 2003, 2005; Vanhaeren et al. 2006, 2013; Rigaud et al. 2014). They could be markers of status or individual/community identity in everyday life or during specific events of high symbolic importance (Rudner 1982). The use of ochre for body paintings possibly also served technical purposes, such as insect repellent or sun protection (Rifkin 2012; Rifkin et al. 2015a, b). All of these further highlight the difficulty of discussing ochre uses at an inhabited rock art site. This difficulty of interpretation is further intensified by other possible ochre uses that do not leave archaeological traces but are known from ethnographic studies (e.g., hide tanning; Kewanwytewa and Bartlett 1946; Webley 2005). Ethnographic data allow us to consider the existence of such use in LSA populations (Blauer 1999), but the Leopard Cave ochres do not bear direct evidence for such use since treated skin, like most organic materials, are not preserved in the archaeological context.

## Chronological Constraints

From a stylistic point of view, the paintings at Leopard Cave are similar to the other Namibian rock art paintings. Such monochrome fine-lines paintings are encountered in various sites in Namibia, especially at other excavated sites of the northwestern Erongo Mountain, such as Fackelträger (Richter 1991; Wendt 1972), Rain Cloud (Breuil et al. 1960), and Etemba (Wendt 1972). The paintings found at Leopard Cave seem to be of the same cultural tradition as those of these other sites in the Erongo area (Nankela 2017).

Although archaeological raw blocks of ochres were found at Leopard Cave in levels ranging from – 140 to – 300 cm, their highest concentration was observed between – 190 and – 230 cm (Fig. 8). The latter corresponds to archaeological layers f and g, dated between  $3,500 \pm 100$  cal BP (Beta-236964) and  $2,000 \pm 150$  cal BP (SacA51308). The youngest date of these layers was obtained from a charcoal sample located near a grinding slab and a handstone showing red traces that might have been displaced vertically into older layers due to post-depositional biologic agents; for example, the localized burrows. The age obtained from it should be considered as the minimum age for the use of the in situ grinding slab and handstone.

The red pigment on the wall of the cave at levels previously buried under the sediment provides a *terminus ante quem* for the creation of some of the paintings. As demonstrated by Maura et al. (2019), the red traces found on the wall are not from the stains of sediment; neither are they a natural coloration of the granite. Rather, they correspond to the anthropogenic use of iron oxide pigments. These traces of pigments on the wall are either the remains of a red painting that is completely altered or traces of weathered pigments from paintings drawn above (Fig. 3). Therefore, the dating of this archaeological layer to  $2,100 \pm 100$  cal BP provides an age for the covering of these traces by sediments, not for the creation of the painting.

The present findings at Leopard Cave indicate a tradition of ochre processing between 3,500 and 2,000 BP, during the Wilton pre pottery period known at other Namibian sites for the extensive use of ochres (Richter 1991, 2002). The highest number of ochre fragments was discovered in layer g, where no ceramic sherd was present (Fig. 8 and Table 3). This layer is dated between 3,100 and 5,100 cal BP, corresponding to the Wilton preceramic period (Richter 2002). These dates are similar to those obtained at other sites in the Erongo Mountains such as Fackelträger and Etemba (Richter 1991; Wendt 1972), Rain Cloud (Pleurdeau, personal communication), Striped Giraffe (Sandelowsky and Viereck 1969), and Phillips Cave (Martin and Mason 1954) in which archaeological ochres have also been recovered (Table 1, Fig. 1, and Online Resource 1). All of these confirm the existence of a long tradition of ochre processing in the Erongo Mountains, and more generally, in northcentral Namibia. Some of these were related to the execution of rock art paintings in the region. The minimum age of Leopard Cave paintings ( $2,100 \pm 100$  cal BP) is slightly younger than the minimum age obtained in the Brandberg at Amis 10/Riesenhöhle (Breunig 2003; Pager and Breunig 1989), but it still falls in the pre pottery period proposed by Richter (1991, 2002).

Based on stylistic considerations of the rock art paintings and the archaeological artifacts recovered from the Namibian painted sites, Richter (1991, 2002) proposed 6,000–1,000 cal BP as the main period for the creation of the Namibian paintings. He divided this into two periods: pre pottery (6,000–2,000 cal BP) and post pottery (2,000–1,000 cal BP). According to the assemblages recovered at different rock art sites, the pre pottery stage corresponds to the period with most intensive activities for ochre processing and the execution of most of the Namibian LSA rock art (Richter 1991, 2002). The sole *terminus ante quem*, coming from the Brandberg site of Amis 10 (Riesenhöhle), falls within this period. Indeed, at this site, the exfoliated fragment of paintings derived from a layer dated to  $2,760 \pm 50$  cal BP (Breunig 2003; Pager and Breunig 1989). The remaining challenge is to more securely link the rock art paintings of Leopard Cave in relation to the ochre of the archaeological contexts.

## Future Directions

Leopard Cave is unique because of the documentation of the different *chaîne opératoire* for ochre processing and usage (raw blocks, tools bearing red residues, colored OES beads, and paintings) in the archaeological contexts. Although severely altered, the paintings at the cave still present characteristics similar to the rock

paintings already studied in western Namibia (Breuil et al. 1960; Nankela 2017; Scherz 1970; Vallverdu et al. 1979). Their alteration is mainly caused by water leakages that led to the dissolution of the pigments and the formation of authigenic crusts identified as calcium sulfate, such as gypsum and calcium oxalate (Mauran et al. 2019). These leakages all originate from various cracks found in the granite bedrock. Experiments are currently in progress to radiocarbon date the alterations covering the paintings at Leopard Cave, as one of the steps needed to overcome some of the chronological constraints in the present study (Dumoulin et al. in press). The ongoing effort to correlate the chemical attributes of the pigments in the rock paintings and on the archaeological tools promises to shed more light on the processes for the creation of the paintings and their subsequent alterations. Indeed, if the coloring agents discovered in the archaeological layers and the rock paintings correlate in terms of chemical composition, this would provide strong evidence for indirect dating of the rock paintings (Beck et al. 2012; Bednarik 2002; Lebon et al. 2014, 2018, 2019). Research about this correlation is partly hardened by the semantic discrepancies of the term “ochre” for the different actors involved in this research. Such issue calls for moving to less problematic terms, carefully selected in agreement with all disciplines involved in the study of these materials.

There is also an ongoing study of the microsamples of the rock art paintings, red residues found on the tools, and the ochre fragments using scanning electron microscopy (SEM), particle-induced X-ray emission (PIXE), and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). These analyses will provide new insights on the technical processes for the production and use of pigments at Leopard Cave (see Hahndiek 2014; Hughes and Solomon 2000). We plan to include other Erongo LSA rock art sites in our future studies. These include Rain Cloud, Giraffe Shelter, and Seal Shelter (Table 1, Fig. 1), where test pits already show the promise of documenting pigment production activities. This multisite study will provide critical insights into the pattern of LSA population mobility, their interactions with the environment, and the values they placed on ochre.

## Conclusion

Our study presents an exceptional archaeological assemblage connected to the processing of ochres at Leopard Cave in the Erongo Mountains, Namibia. The richness of this assemblage derives from the number of blocks of raw ochre and the traces of red residues on artifacts, tools, and ornaments. There is strong evidence for a long tradition of ochre processing at the site of Leopard Cave, and this was possibly connected to the rock paintings at the site. At least two distinct *chaînes opératoires* for ochre processing were documented, and these were possibly used for various purposes, including the creation of rock paintings, body painting, and abrading agents. The study also presents a new chronological framework for the rock art paintings at Leopard Cave, showing that the paintings were rendered between 3,600 and 2,000 cal BP, during the pre pottery LSA period.

This study is part of the renewed rock art studies in Southern Africa. It paves the way for new ochre and rock art analyses, to understand the technological, sociocultural, and chronological development of LSA rock art and ochre usage in the Erongo Mountains of Namibia. The study also calls for more investigations on ochre uses at other Southern African LSA rock art sites.

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**Compliance with Ethical Standards**

**Conflict of Interest** The authors declare that they have no conflict of interest.

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