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Caracterización físico-química y análisis tecnológico de los pigmentos del *Middle Stone Age* de la Cueva de Porc-Epic (Dire Dawa, Etiopía)

Caractérisation physico-chimique et analyse technologique des pigments *Middle Stone Age* de la Grotte du Porc-Épic (Dire Dawa, Éthiopie)

Daniela Eugenia Rosso

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Facultat de Geografia i Història

Departament d'Història i Arqueologia

Programa de doctorado *Societat i Cultura*

UNIVERSITÉ DE BORDEAUX

ÉCOLE DOCTORALE Sciences et Environnements

SPÉCIALITÉ Préhistoire

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Tesis doctoral presentada por:

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RESUMEN - Caracterización físico-química y análisis tecnológico de los pigmentos del *Middle Stone Age* de la cueva de Porc-Epic (Dire Dawa, Etiopía)

El uso sistemático de colorantes, interpretado como la prueba de una cognición compleja y en algunos casos de una conducta simbólica, es uno de los rasgos culturales más controvertidos en prehistoria. Los estudios detallados de las diferentes fases de tratamiento de este material son escasos, especialmente en África Oriental, a pesar de la importancia de esta zona en el estudio del origen de los Humanos anatómicamente modernos. La finalidad de la presente tesis es reconstruir la cadena operativa del tratamiento de los colorantes de la cueva de Porc-Epic (Dire Dawa, Etiopía), yacimiento clave del *Middle Stone Age* (MSA) del Cuerno de África, para averiguar su función y significado en las poblaciones MSA. Nuestros resultados demuestran que esta colección de colorantes es la más amplia jamás hallada en un yacimiento MSA, con sus 40 kg de colorantes (n = 4213 piezas), 21 útiles para su tratamiento y dos cantos con residuos rojos encontrados en niveles de ca. 40 ka cal BP. El análisis de la distribución espacial de los colorantes ha permitido determinar que la secuencia no ha sido perturbada significativamente. Se han identificado zonas de acumulación de colorantes, interpretadas como áreas especializadas para el procesado de este material. El análisis tecnológico de los fragmentos de colorantes y de los útiles para su procesado nos ha permitido identificar diferentes tipos de marcas de uso. A través de análisis por espectroscopia µ-Raman, MEB-EDS y DRX hemos comprobado que los molinos y machacadores fueron empleados para procesar diferentes tipos de colorantes. La variedad de materias primas y técnicas de procesado parecen indicar que los habitantes de la cueva producían polvos de colorantes de diferentes colores y texturas, adaptados a diferentes funciones. Se ha observado una continuidad a lo largo de la secuencia en el tratamiento de este material, que hemos interpretado como la expresión de una adaptación cultural transmitida a lo largo del tiempo. Los análisis rugosimétricos nos han permitido determinar que los colorantes se procesaban para producir cantidades reducidas de polvo. Esto, y la presencia de un canto posiblemente usado como tampón parecen sugerir un uso para actividades simbólicas. A través de un análisis etnoarqueológico del uso de colorantes en la sociedad Hamar (Etiopía) hemos valorado la complejidad de la cadena operativa de este material y destacado su función a la vez simbólica y funcional en las sociedades tradicionales.

Palabras clave: ocre, pigmentos, molinos, modernidad cognitiva, complejidad cultural, *Middle Stone Age*, África Oriental.

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RÉSUMÉ - Caractérisation physico-chimique et analyse technologique des pigments *Middle Stone Age* de la grotte du Porc-Épic (Dire Dawa, Éthiopie)

L'utilisation de l'ocre, interprétée comme la preuve d'une cognition complexe et dans certains cas d'un comportement symbolique, est l'un des traits culturels les plus controversés en contexte paléolithique. Les analyses systématiques de ses différentes phases de traitement sont rares, particulièrement en Afrique de l'Est, malgré l'importance de cette région pour l'étude de l'origine de l'homme moderne. Le but de cette thèse est de reconstruire la chaîne opératoire du traitement de l'ocre à la grotte du Porc-Epic (Dire Dawa, Ethiopie), site clef de la Corne de l'Afrique, afin de déterminer sa fonction et son rôle au sein de populations MSA. Nos résultats montrent que cette collection d'ocre est la plus abondante connue jusqu'à présent dans un site paléolithique, avec 40 kg d'ocre (n = 4213 pièces), 21 outils de traitement et deux galets ocrés trouvés dans des niveaux de ca. 40 ka cal BP. L'analyse de la distribution spatiale a permis de déterminer que la séquence n'a pas été perturbée significativement. Nous avons identifié des zones d'accumulation d'ocre interprétées comme des aires consacrées au traitement de ce matériel. L'analyse technologique a permis d'identifier une grande variété de traces d'utilisation. A travers une analyse par µ-Raman, MEB-EDS et DRX nous avons démontré que les meules et broyeurs ont été utilisés pour traiter différentes types d'ocre. La variété de matières premières et des techniques de traitement indiquent une production de poudres de différentes couleurs et textures, adaptées à des fonctions diverses. Une continuité dans le traitement de l'ocre a été mise en évidence le long de la séquence et interprétée comme le reflet d'une adaptation culturelle transmise au cours du temps. Des analyses rugosimétriques ont montré que l'ocre était traitée pour produire des quantités réduites de poudre. Cela, ainsi que la présence d'un galet possiblement utilisé comme tampon, semblent indiquer une utilisation de l'ocre pour des activités symboliques. Une analyse ethnoarchéologique de l'ocre chez les Hamar (Ethiopie) nous a permis d'évaluer la complexité du traitement de ce matériel et de souligner sa fonction à la fois utilitaire et symbolique.

Mots-clef: ocre, pigments, meules, modernité comportementale, complexité culturelle, *Middle Stone Age*, Afrique de l'Est.

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ABSTRACT - Physicochemical and technological analysis of Middle Stone Age pigments from Porc-Epic Cave, Dire Dawa, Ethiopia

Ochre is one of the most controversial features found at Palaeolithic sites. It is often interpreted as proof of behavioural complexity and, in some cases, as a marker of symbolically mediated behaviour. Detailed reconstructions of ochre processing techniques are rare, particularly in East Africa, despite the fact that it is one of the most significant areas for the study of the emergence of *Homo sapiens*. The aim of this thesis is to conduct a detailed reconstruction of the ochre *chaîne opératoire* at Porc-Epic Cave (Dire Dawa, Ethiopia), key site for the East African Middle Stone Age (MSA). Our approach permits the function of ochre and its significance for late MSA groups to be explored.

Our results show that this site has yielded the largest known MSA ochre collection, comprising 40 kg of ochre (n = 4213 pieces), 21 ochre processing tools and two ochre-stained artefacts from levels dated to ca. 40 ka cal BP. The analysis of the spatial distribution suggests that no major post-depositional reworking occurred at the site and allowed us to identify ochre accumulations, interpreted as areas devoted to ochre processing. Different types of modification marks were identified. SEM-EDS, µ-Raman and XRD analyses conducted on ochre residues from the processing tools suggest that these tools were used to process different types of ochre. The variety of raw materials and processing techniques indicates that ochre powder of different coarseness and shades was used for a variety of functions. Our results identify patterns of continuity in ochre acquisition, treatment and use, interpreted as the expression of a cohesive cultural adaptation, consistently transmitted through time. Rugosimetric analyses show that ochre was probably processed to produce small amounts of ochre powder. Additionally, a pebble possibly used as a stamp was identified. This seems to suggest a use of ochre for symbolic activities. An ethnoarchaeological analysis of ochre use among the Hamar, Ethiopia, allowed us to evaluate the complexity of the ochre *chaîne opératoire* and to highlight its use in both functional and symbolic activities.

Keywords: ochre, pigment, grindstones, behavioural modernity, cultural complexity, Middle Stone Age, East Africa.

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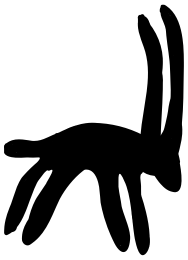
Introducción



La percepción y la categorización del color son parte inherente de las culturas humanas. Nuestra visión del mundo e incluso nuestro lenguaje están estrechamente ligados a éstas (Berlin y Kay, 1969; Davidoff et al., 1999; Roberson et al., 2000). Por la misma razón, los colorantes han suscitado un gran interés entre arqueólogos, prehistoriadores y etnólogos.

Existen algunas pruebas del uso de colorantes antes de la aparición de los Humanos anatómicamente modernos. Este uso se observó durante el Paleolítico medio y el *Middle Stone Age* (MSA) y ha persistido hasta nuestros días. Aunque numerosos investigadores consideren que su empleo es el reflejo de una conducta compleja (McBrearty y Brooks, 2000; Henshilwood y Marean, 2003; d'Errico, 2008), la función de los colorantes es actualmente objeto de debate. Algunos autores consideran que su uso implica una actividad simbólica (Bordes, 1952; Pomiès y Vignaud, 1999; Watts, 1999, 2009; Hovers et al., 2003) y otros defienden la interpretación utilitaria (Wadley et al., 2004, 2009, Wadley, 2005b, 2010b, Lombard, 2007, 2008, Rifkin, 2011, 2015a; Zipkin et al., 2014; Rifkin et al., 2015b; Kozowyk et al., 2016). Sin embargo, la frontera entre lo funcional y lo simbólico no está claramente definida en muchas culturas, como lo demuestran numerosos casos etnográficos (d'Errico y Stringer, 2011).

Aunque la presencia de colorantes se haya detectado en numerosos yacimientos *Middle Stone Age* (McBrearty y Brooks, 2000; d'Errico et al., 2001, 2012c; Barham, 2002; Watts, 2010; Henshilwood et al., 2011; Hodgskiss, 2012; Dayet et al., 2013), existen pocas reconstrucciones detalladas de las técnicas de tratamiento de este material. Esto se debe en primer lugar al hecho de que las metodologías para el estudio de este tipo de materiales se han desarrollado recientemente (Henshilwood et al., 2009; Watts, 2010; d'Errico et al., 2012c; Rifkin, 2012; Dayet et al., 2013; Hodgskiss, 2013) y en segundo lugar a la falta de colecciones de colorantes lo suficientemente amplias como para obtener resultados significativos. Por otra parte, el estudio de colorantes se ha concentrado en determinadas áreas geográficas, en especial el sur del continente africano. Otras zonas, en cambio, nunca se han estudiado desde esta perspectiva. Es el caso por ejemplo de África Oriental, zona esencial para nuestro conocimiento de los primeros *Homo sapiens* (McDougall et al., 2005, 2008) y para el estudio del origen de la modernidad.

La cueva de Porc-Epic es el marco ideal para desarrollar un estudio sistemático del uso de colorantes. En este yacimiento clave para el conocimiento del MSA en el Cuerno de África se han encontrado 40 kg de colorantes rojos, amarillos y marrones asociados a veintiún útiles de tratamiento de colorantes y dos cantos con residuos rojos. Esta es actualmente la colección de colorantes más amplia que se haya encontrado en un contexto paleolítico y la primera en ser estudiada de forma sistemática en esta área geográfica.

1.1 Marco teórico y estado de la cuestión

1.1.1 La emergencia de la complejidad cultural

La cuestión del origen de la complejidad cultural o modernidad cognitiva es el objeto de un intenso debate en prehistoria y arqueología (McBrearty y Brooks, 2000). La conducta moderna se define como una sofisticación cognitiva (McBrearty y Brooks, 2000) caracterizada por pensamientos y acciones formados espontáneamente por mentes equivalentes a las del *Homo sapiens* actual (Henshilwood y d'Errico, 2011). El concepto de "modernidad" ha sido ampliamente criticado por la dificultad de definirlo y aplicarlo a culturas materiales, por la arbitrariedad de los criterios usados para identificar culturas "modernas" en sociedades prehistóricas o por la dificultad que supone el establecer uno o más grados evolutivos de la cultura humana (d'Errico, 2003; Henshilwood y Marean, 2003; Barham, 2007; Shea, 2011; Zilhão, 2011; d'Errico y Banks, 2013).

Hasta muy recientemente la complejidad cultural se asociaba a los Humanos anatómicamente modernos y al Paleolítico superior europeo, y se aceptaba la idea de una emergencia repentina (Mellars y Stringer, 1989). Un nuevo modelo fue propuesto tras el descubrimiento del origen africano de los Humanos anatómicamente modernos (Trinkaus, 2005; Weaver y Roseman, 2008; Henn et al., 2011). Según este modelo, la modernidad fue el resultado de una evolución progresiva comenzada durante el *Middle Stone Age* africano (~ 300–40 ka) como consecuencia de la aparición de nuestra especie. Prueba de ello son las innovaciones culturales observadas en niveles fechados en el *Middle Stone Age* (McBrearty y Brooks, 2000; Marean et al., 2007).

Sin embargo, si la complejidad cultural se hubiese desarrollado únicamente como consecuencia de la emergencia del *Homo sapiens*, se habría observado un cambio importante en las adaptaciones culturales de poblaciones humanas que vivieron en África hace alrededor de 200.000 o 160.000 años. Ya que esto no se ha observado, algunos investigadores se preguntaron si otros factores como la geografía (Compton, 2011), la demografía y la transmisión cultural (Shennan, 2001; Henrich, 2004; Powell et al., 2009) hubiesen podido influenciar la difusión y el mantenimiento de innovaciones culturales de los Humanos anatómicamente modernos. Según estos autores, la demografía, la densidad de población, la tasa de reproducción y la intensidad de información intercambiada entre grupos humanos fueron factores determinantes para la difusión, la preservación o la desaparición de una cultura.

Un último modelo sugiere un origen de la conducta moderna como resultado de un camino evolutivo discontinuo comenzado durante el *Middle Stone Age* africano y en el Paleolítico medio eurasiático. Factores sociales y demográficos probablemente provocados por cambios climáticos serían la causa de la aparición, la desaparición y la reaparición de innovaciones culturales en poblaciones en diversos puntos del planeta. Según este modelo, la cognición compleja de la humanidad actual no es propia del *Homo sapiens*, sino que se ha heredado de diversos homíninos de nuestra línea evolutiva (Deacon y Wurz, 2001; Zilhão, 2001, 2007; d'Errico, 2003; Hovers y Belfer-Cohen, 2006; Conard, 2008; Langley et al., 2008; Nowell, 2010; Zilhão et al., 2010; d'Errico y Henshilwood, 2011; d'Errico y Stringer, 2011; Lombard y Parsons, 2011). Una prueba de ello son las innovaciones culturales desarrolladas por los neandertales, como por ejemplo los enterramientos, las tecnologías líticas complejas, la ornamentación personal, la industria ósea, la producción de adhesivos para enmangar o el uso de colorantes. Esta visión multirregional parece estar de acuerdo con el reciente descubrimiento de los intercambios genéticos que se produjeron entre poblaciones denisovianas, neandertales y *sapiens* de origen africano (Green et al., 2010; Reich et al., 2010; Alves et al., 2012; Meyer et al., 2012; Sánchez-Quinto et al., 2012; Yang et al., 2012) y de las introgresiones de genes arcaicos y neandertales en poblaciones africanas de *Homo sapiens* (Hammer et al., 2011; Sánchez-Quinto et al., 2012).

Con el fin de comprobar la coherencia de los modelos propuestos para explicar la aparición de la cognición compleja y frente a los nuevos descubrimientos en el campo de la genética, los investigadores siguen explorando los posibles factores desencadenantes del desarrollo de innovaciones culturales entre las poblaciones del pasado. Se preguntan en que momento aparecieron las características que podrían definir la humanidad actual. Las expresiones artísticas, las creencias religiosas, el uso de un lenguaje complejo y sintáctico (Bickerton, 1990; Dunbar, 2003), el altruismo (Bowles, 2009), el incremento de la memoria (Wynn y Coolidge, 2010) y de la capacidad de aprendizaje (Tomasello, 1994; Mesoudi et al., 2006; Richerson et al., 2009), la creación de ambientes de aprendizaje específicos (Sterelny, 2011), la jerarquización de las construcciones mentales (Gibson, 2007) son algunas de éstas.

Ya que la mayor parte de estas características no dejan pruebas materiales y que podemos basarnos únicamente en restos arqueológicos para evaluar los modelos de aparición de las conductas modernas, se han establecido un cierto número de criterios indicativos de una complejidad cultural, que varían según los autores (d'Errico, 2003; Henshilwood y Marean, 2003). Existe un consenso sobre el hecho de que la capacidad de crear y transmitir sistemas simbólicos e incorporarlos a una cultura material represente una prueba definitiva de cognición compleja. Por pensamiento simbólico, nos referimos a la capacidad de atribuir un significado específico a signos establecidos arbitrariamente (d'Errico y Stringer, 2011). Esta característica se observa en todas las sociedades humanas actuales y materialmente se manifiesta de diferentes formas: los enterramientos, la ornamentación personal, las representaciones abstractas o figurativas y el uso de colorantes.

1.1.2 Los colorantes y el debate sobre el origen de la complejidad cultural

Los colorantes minerales, a menudo modificados por abrasión o raspado para producir polvo, representan una de las innovaciones culturales más controvertidas en el contexto paleolítico. Por "colorante" nos referimos a materiales que pueden dar color, pero que a veces no son utilizados para esa función. Aunque el término "colorante" abarque una variedad de materiales, aquí nos referimos específicamente a rocas de color rojo o amarillo formadas mayoritariamente por óxidos de hierro, a veces asociadas a otros compuestos (cuarzo, arcillas, yeso o micas). Su color amarillo deriva generalmente de la goethita (α-FeOOH) y su color rojo de la hematites (α-Fe_2O_3) (Jercher et al., 1998; Popelka-Filcoff et al., 2008). Se trata del término inglés "*ochre*" (el término castellano "ocre" es ambiguo ya que se asocia a los colorantes amarillos).

El uso intensivo de colorantes se interpreta como el reflejo de una complejidad cognitiva (McBrearty y Brooks, 2000; Henshilwood y Marean, 2003; d'Errico, 2008) y muchos autores consideran que esta utilización es también la prueba de una conducta simbólica (Watts, 2002, 2009, 2010; Zilhão, 2007; d'Errico, 2008; Zilhão et al., 2010; d'Errico et al., 2012c). Diversos argumentos se usaron en favor de esta interpretación: la adquisición de colorantes en áreas de aprovisionamiento alejadas de las zonas de hábitat, la selección de determinadas tonalidades, su calentamiento para modificar el color o la presencia de residuos de colorantes sobre elementos de ornamentación personal (Bordes, 1952; Pomiès y Vignaud, 1999; Watts, 1999, 2009; Hovers et al., 2003). Sin embargo otros investigadores, sin negar una posible relación entre este material y actividades simbólicas, subrayan la dificultad de demostrar una conducta simbólica basándose únicamente en pruebas materiales. Así, sugieren un uso de colorantes para funciones utilitarias que apoyan con numerosos ejemplos etnográficos. Los colorantes pueden usarse para curtir pieles (Rifkin, 2011), conservar alimentos, proteger la piel contra el sol o los insectos (Rifkin et al., 2015a; 2015b), para fines médicos (Velo, 1984) o incluso para producir adhesivos para enmangar útiles líticos (Wadley et al., 2004, 2009; Wadley, 2005b, 2010b; Lombard, 2007, 2008; Zipkin et al., 2014; Kozowyk et al., 2016).

Hoy en día se está abandonando progresivamente esta visión polarizada de la función de los colorantes que opone lo funcional y lo simbólico, ya que crea una falsa dicotomía. Etnográficamente se ha observado que la frontera entre lo simbólico y lo funcional no está claramente definida (d'Errico y Stringer, 2011). Actividades que en la cultura occidental se definirían cómo puramente funcionales están en la mayor parte de las sociedades tradicionales ligadas a actividades simbólicas.

1.1.3 La explotación de colorantes durante el Paleolítico

Las pruebas más antiguas del uso de colorantes se hallaron en niveles fechados alrededor de 250-300 ka, en los yacimientos de Terra Amata (Francia) Hunsgi (India) Ambrona (España), Achenheim, (Francia) y en Tuff K4, Kapthurin Formation (Kenia) (Howell, 1966; de Lumley, 1969; Paddayya, 1976; Thévenin, 1976; Bednarik, 1990b; McBrearty y Brooks, 2000; Deino y McBrearty, 2002). Sin embargo se encontraron posibles restos de pigmentos sin marcas de uso antrópicas en Gadeb (Etiopía) y Olduvai Gorge (Tanzania) en niveles fechados alrededor de 1,5–1 Ma, en Isernia la Pineta (Italia) en niveles fechados hacia 610 ka, y en Garba I, Melka Kunture (Etiopía) en niveles de ca. 500 ka (Leakey, 1958; Desmond Clark y Kurashina, 1979; Cremaschi y Peretto, 1988; Chavaillon y Berthelet, 2004; Coltorti et al., 2005).

En Europa, existen pruebas de que los Neandertales usaban colorantes rojos y amarillos antes del Chatelperroniense y de la llegada de los Humanos anatómicamente modernos (Demars, 1992; Beyries y Walter, 1996; Soressi y d'Errico, 2007; Cârciumaru y Ţuţuianu-Cârciumaru, 2009; Zilhão et al., 2010). Uno de los ejemplos más significativos es el del yacimiento de Maastricht-Belvedere (Holanda), en el que se encontraron fragmentos de colorantes en niveles fechados a >200-250 ka BP (Roebroeks et al., 2012). Le Moustier (Peyrony, 1930) y Pech-de-l'Azé I (Soressi y d'Errico, 2007; d'Errico, 2008; Soressi et al., 2009; Heyes et al., 2016) son también algunos de los numerosos ejemplos de yacimientos musterienses con restos de pigmentos. En algunos casos, como en Les Bossats, Ormesson (Francia) se ha identificado un uso intensivo de este material en niveles Musterienses (Bodu et al., 2014). Los últimos Neandertales usaban intensivamente pigmentos rojos y negros (manganeso), como en el caso de la Grotte du Renne (Caron et al., 2011; Salomon et al., 2014), o en Roc-de-Combe (Dayet et al., 2014), en Francia. En el Próximo Oriente también se encontraron pruebas de empleo de colorantes. Éstas aparecen en niveles de 100 ka, en Qafzeh y Es-Skhul (Israel). Algunos de los fragmentos parecen haber sido sometidos a un tratamiento térmico (Hovers et al., 2003; Godfrey-Smith y Ilani, 2004; d'Errico et al., 2010; Salomon et al., 2012).

Mucha información de la que disponemos sobre el uso de colorantes proviene del continente Africano. El empleo de este material se generaliza progresivamente en esta área geográfica y aparece en numerosos yacimientos *Middle Stone Age*. En Twin Rivers (Zambia) se encontraron fragmentos de colorantes con marcas de uso en niveles de >200 ka BP (Barham, 2002). En Sai Island (Sudán) se han encontrado fragmentos de colorantes rojos y amarillos con facetas de abrasión en niveles fechados alrededor de 180 ka BP (Van Peer et al., 2003). Otros ejemplos de yacimientos en los que se encontraron restos de pigmentos son Nooitgedacht (Sudáfrica), Kabwe (Zambia), Charama (Zimbabwe), y Mumbwa (Zambia) (Barham, 2000). A partir de 100 ka BP el uso de colorantes se transforma en una característica recurrente (McBrearty y Brooks, 2000). Algunos de los ejemplos más conocidos son los de Klasies River Mouth (Wurz, 2008; d'Errico et al., 2012c), Hollow Rock Shelter (Högberg y Larsson, 2011) o Border cave (Watts, 2002), así como Apollo 11 cave en Namibia (Wendt, 1974; Vogelsang et al., 2010). En yacimientos como Die Kelders (Grine et al., 1991; Avery et al., 1997; Thackeray, 2000), Yserfontein (Avery et al., 2008), Umhlatuzana Rock Shelter (Kaplan, 1990), Bushman Rockshelter en Sudáfrica (Louw, 1969; Kraybill, 1977; de Beaune, 1993, 2002), Sehonghong, en Lesotho (Carter et al., 1988), ≠Gi, Botswana (McBrearty y Brooks, 2000), Songona I en Mali (Huysecom et al., 2008, 2009) y en Nswatugi y Pomongwe en Zimbabue (Walker, 1995; Larsson, 1996; McBrearty y Brooks, 2000) se encontraron útiles para el tratamiento de colorantes.

Sin duda alguna los yacimientos mejor documentados en cuanto a uso de colorantes se encuentran en Sudáfrica. Blombos Cave (Henshilwood et al., 2001, 2002, 2009; Moyo et al., 2016), Diepkloof Rockshelter (Dayet, 2012; Dayet et al., 2013, 2016), Pinnacle Point Cave (Barham, 1998; Marean et al., 2007; Watts, 2010) y Sibudu Rockshelter (Wadley, 2005a, 2007, 2010a; Lombard, 2008; Soriano et al., 2009; Hodgskiss, 2012, 2013, 2014; Villa et al., 2015) son los ejemplos más significativos.

Blombos Cave es probablemente uno de los yacimientos más interesantes en cuanto al uso de colorantes. Se encontraron más de 8000 fragmentos de colorantes rojos, con un peso total de 5,8 kg, en niveles *Middle Stone Age* fechados alrededor de 100–72 ka (Henshilwood et al., 2001, 2002, 2009; Moyo et al., 2016). Se identificaron diferentes marcas de uso: estrías de abrasión o de raspado, impactos realizados por percusión, así como grabados con motivos abstractos (Henshilwood et al., 2001, 2002, 2009; Rifkin, 2012). En niveles fechados alrededor de 100 ka, se hallaron dos equipos de útiles para la producción y almacenamiento de un compuesto rico en colorante (Henshilwood et al., 2011). Incluyen fragmentos de colorante modificados, huesos, molinos y machacadores y dos conchas de *Haliotis midae* con residuos de pasta de colorante.

En Pinnacle Point Cave se analizaron 380 fragmentos de colorante (1.08 kg) de niveles fechados hacia 164–91 ka (Watts, 2010). Fue identificada una preferencia por ciertas tonalidades, además de posibles modificaciones del color provocadas por calentamiento, lo que nos indica un posible empleo para actividades simbólicas.

En Diepkloof Rockshelter se hallaron miles de fragmentos de colorantes en niveles fechados alrededor de 110–55 ka, de diferentes materias primas (pizarra, ferricreta, pizarra/ferricreta, caliza ferruginosa, cuarcita ferruginosa) (Dayet, 2012; Dayet et al., 2013). La naturaleza exógena de algunas de estas materias primas, la selección de ciertos tipos de colorantes y la ausencia de colorante en los residuos de adhesivos para el enmangue de herramientas (Charrié-Duhaut et al., 2013) parecen apoyar en Diepkloof la idea de un uso para fines simbólicos.

Sibudu Cave es otro yacimiento clave para el estudio de colorantes. En sus niveles *Middle Stone Age*, fechados entre 77.2 ± 2.6 ka y 37.6 ± 2.6 ka (Wadley y Jacobs, 2006; Wadley, 2007; Jacobs, et al., 2008a, 2008b; Hodgskiss, 2010, 2012, 2013, 2014) se encontraron 5449 fragmentos de colorantes de distintas materias primas (Hodgskiss, 2012) caracterizados por la presencia de modificaciones producidas por abrasión, fricción contra materiales blandos y raspado (Hodgskiss, 2010, 2013). Hogares con restos importantes de colorantes fueron identificados en niveles de ca. 50 ka, y se interpretaron cómo recipientes o zonas de trabajo (Wadley, 2010a). Se encontraron también losas de caliza u otros artefactos líticos con residuos amarillos y rojos (Wadley et al., 2004; Williamson, 2004; Wadley, 2005b; Soriano et al., 2009). La presencia de residuos en el plano de percusión de algunas lascas indica un posible uso de nódulos de colorantes como percutores (Soriano et al., 2009). Además de esto, mezclas de colorantes y resina identificadas en algunos artefactos demuestran su uso para el enmangue. Recientemente, un residuo compuesto de una mezcla de colorante y leche ha sido identificado en un fragmento de dolerita hallado en niveles fechados en 49 ka BP (Villa et al., 2015).

En África Oriental se hallaron numerosas pruebas del uso de colorantes (Tryon y Faith, 2013) con evidentes marcas de uso antrópicas en yacimientos *Middle Stone Age*. Algunos ejemplos son Enkapune Ya Muto (Ambrose, 1998) y GvJm-11 (Lukenya Hill, Kenia) (Tryon et al., 2015) en Kenia, Mumba y Nasera Rock Shelters (Mehlman, 1989) en Tanzania, Mochena

Borago Rock Shelter (Brandt et al., 2012, 2017), Gorgora Rock Shelter (Leakey, 1943; Moysey, 1943; Desmond Clark, 1988) y Aduma (Yellen et al., 2005) en Etiopía. Sin embargo, los colorantes de estos yacimientos nunca fueron estudiados de forma sistemática. Los datos de los que disponemos sobre el uso de colorantes en África Oriental por lo tanto son escasos, a diferencia de ciertas zonas geográficas, como por ejemplo Sudáfrica. La cueva de Porc-Epic (Desmond Clark y Williamson, 1984), que estudiamos en la presente tesis, es el primer yacimiento en el Cuerno de África cuya colección de colorantes ha sido analizada sistemáticamente (Rosso et al., in press, 2014, 2016).

1.2 Contexto arqueológico

1.2.1 El *Middle Stone Age* en África Oriental

Definido por primera vez por Goodwin (1928) a partir de características tecnológicas y tipológicas de industrias líticas sudafricanas, el *Middle Stone Age* (MSA) es el período que se extiende aproximadamente entre 300 y 30 ka. Es una fase clave para la evolución humana ya que se caracteriza por importantes innovaciones tecnológicas y culturales. Poco a poco los atributos que definían el MSA se fueron ampliando y este término actualmente abarca el conjunto del continente africano.

En África Oriental, se hallaron los restos más antiguos de *Homo sapiens* conocidos a día de hoy (Tryon y Faith, 2013) incluyendo a los de la formación Kibish, Herto, Aduma y Porc-Epic en Etiopía, Upper Ngaloba Beds en Laetoli, Mumba Rockshelter y Lake Eyasi Beds en Tanzania (Braüer, 1984; Mehlman, 1987, 1991; Desmond Clark, 1988; Grün y Stringer, 1991; McDermott et al., 1996; McBrearty y Brooks, 2000; Desmond Clark et al., 2003; White et al., 2003; Haile-Selassie et al., 2004; McDougall et al., 2005, 2008). Se considera por lo tanto fundamental para la comprensión del desarrollo cognitivo de poblaciones humanas modernas y para el estudio de la expansión de los Humanos anatómicamente modernos fuera de África (Watson et al., 1997; Tishkoff et al., 1998; Kittles y Keita, 1999; Satta y Takahata, 2002; Dugoujon et al., 2004; Hawks, 2006; Kivisild, 2007; Stringer, 2007). Por “África Oriental”, nos referimos a la zona que incluye los actuales países de Tanzania, Kenia, Uganda, Etiopía, Somalia, Yibuti y Eritrea. Esta área geográfica se caracteriza por un medioambiente variado en el que interactúan un mosaico de hábitats y zonas de refugio. Tiene una situación geográfica privilegiada, conectada con las principales regiones del continente Africano: el Sahara y Sahel, los bosques tropicales del oeste a lo largo del Gran Valle del Rift y el sur del continente (Mirazón Lahr y Foley, 2016).

Los yacimientos MSA en África Oriental están repartidos de forma irregular (Basell, 2008) en parte por la naturaleza discontinua de las investigaciones *in loco* y en parte por la geografía de la zona (Tryon y Faith, 2013): se concentran mayoritariamente en el Gran Valle del Rift y muchos son yacimientos al aire libre. Además de esto, uno de los principales problemas del MSA de esta región es la falta de información cronológica. Las secuencias estratigráficas bien fechadas son extremadamente escasas: sólo unos 60 yacimientos MSA están en contextos estratificados y entre éstos, menos de 40 tienen algún tipo de control cronológico (Basell, 2008).

Desde una perspectiva paleoantropológica, el MSA del África Oriental se caracteriza por una gran variabilidad anatómica. Aunque uno de los hechos más destacables de este período sea la presencia del *Homo sapiens*, éste no es el único autor de la industria MSA (Tryon y Faith, 2013). Se ha señalado una posible coexistencia de diferentes formas del género Homo (*Homo rhodesiensis*, *Homo louisleakey*, *Homo erectus*, y *Homo helmei*, *Homo idaltu* y *Homo sapiens*).

La industria lítica ha sido uno de los aspectos más estudiados para el MSA de la zona. Se caracteriza por una gran variabilidad, tanto tipológica como tecnológica. Sin embargo, a pesar de un uso de términos como *Early* MSA (EMSA: ca. 300 ka–126 ka) y *Late* MSA (LMSA: ca. 126 ka–30 ka), no se han identificado fases tecno-tipológicas claramente diferenciadas (Basell, 2008; Douze, 2011; Tryon y Faith, 2013). La falta de dataciones precisas y el hecho de que ciertas técnicas para la manufactura de útiles (percusión, *façonnage*, retoques, etc.) se usen a partir del Achelense, hacen aún más difícil la identificación de fases diferenciadas (Tryon y Faith, 2013). El uso del percutor duro es predominante, pero la percusión blanda está documentada ya desde inicios del MSA (Douze, 2011). Se observan diversos métodos de talla: Levallois, discoide o laminar. Los útiles retocados son escasos pero a veces se encuentran raederas, puntas, buriles o raspadores. Las puntas, intensamente retocadas, unifaciales, bifaciales y triangulares, con una extremidad distal redondeada, foliáceas o de tipo Levallois, presentan una gran variabilidad y se caracterizan por su carácter ubicuo en el MSA de África Oriental (Douze, 2011). Rose et al. han demostrado una gran similitud tecnológica con industrias de la península arábiga (tecnología Nubia tipo 1), especialmente en cuanto a la preparación de los núcleos y de las puntas Levallois (Rose et al., 2011). Por lo general se observa una presencia cada vez menos importante de piezas de tipo Achelense (grandes lascas bifaciales, *core-axes*…) a principios del MSA y una progresiva reducción del tamaño de las piezas líticas e incluso en algunos casos (como en la cueva de Porc-Epic, Etiopía, o en Mumba, Tanzania) la presencia de hojitas de borde abatido (Douze, 2011). Se ha también destacado un aumento durante el LMSA de la presencia de núcleos bipolares, hojas y otros útiles como molinos o machacadores (Tryon y Faith, 2013).

En África Oriental, como en el resto del continente, el MSA es el período durante el cual aparecen posibles pruebas de conductas simbólicas, prácticas mortuorias, uso de ornamentación personal y empleo de colorantes, y éstas parecen desarrollarse progresivamente. Se identificaron *cut marks* o posibles zonas pulidas en los cráneos de homíninos de Herto (Bouri Formation, Etiopía) fechados alrededor de 154–167 ka, interpretados como tratamientos *perimortem* o *postmortem* (Desmond Clark et al., 2003; White et al., 2003). La ornamentación personal es relativamente escasa y tardía: se hallaron perlas de huevo de avestruz asociadas a industrias MSA/LSA en Mumba Rockshelter en niveles fechados alrededor de 30–60 ka (Gliganic et al., 2012) y en Enkapune Ya Muto en niveles fechados alrededor de 40 ka (Ambrose, 1998). En cuanto a los colorantes, su empleo aumenta claramente durante el LMSA. La cueva de Porc-Epic (Rosso et al., 2014), cuyos niveles contenían la más amplia colección de colorantes jamás hallada en un yacimiento MSA, es un ejemplo representativo de este aumento.

1.2.2 La cueva de Porc-Epic

La cueva de Porc-Epic (Fig 1) es uno de los primeros yacimientos paleolíticos encontrados en Etiopía y es clave para nuestro conocimiento del MSA en África Oriental. Situado a 3 km al sur de Dire Dawa, entre la depresión del Afar y el altiplano de Somalia, la cueva se encuentra en un acantilado calcáreo jurásico, 140 metros sobre el uadi Laga Dächatu (Fig 2).

En 1929, Pierre Teilhard de Chardin y Henry de Monfreid descubrieron el yacimiento y llevaron a cabo un sondeo que les permitió identificar niveles paleolíticos (Teilhard de Chardin, 1930) y arte parietal caracterizado por un “estilo esquemático tardío” (Breuil, 1934). En 1933, Henri Breuil y Paul Wernert extendieron la excavación (Teilhard de Chardin et al., 1940). En 1974, John Desmond Clark llevó a cabo una nueva excavación (Desmond Clark y Williams, 1978; Desmond Clark y Williamson, 1984) y en 1975–1976, Kenneth D. Williamson la amplió, cubriendo un área de aproximadamente 49 m^2. En 1998, un trabajo de campo llevado a cabo por un equipo del *Muséum National d’Histoire Naturelle,* Paris, y la *Authority for Research* *and Conservation of Cultural Heritage* (ARCCH) de Etiopía (Pleurdeau, 2004) permitió aportar nuevos datos en cuanto a la secuencia estratigráfica del yacimiento.

Fig 1. La cueva de Porc-Epic.

La estratigrafía del yacimiento, que describimos detalladamente en el capítulo 2, muestra una sucesión de niveles arcillosos, arenosos y brecha, que se dividieron en siete unidades estratigráficas (Desmond Clark y Williamson, 1984; Rosso et al., 2014). Los niveles MSA se encontraban entre -60 y -220–230 cm (niveles 2–4B). Los niveles 4A y 4B estaban sellados por un nivel estalagmítico y eran perfectamente diferenciables estratigráficamente (Desmond Clark y Williamson, 1984). Únicamente en la entrada y hacia el centro de la cueva hubo posibles perturbaciones post-deposicionales (Assefa, 2006). Por encima de esta zona se depositaron niveles donde se encontraron artefactos atribuidos al LSA y al Neolítico (entre 0 y 60 cm).

La cueva de Porc-Epic ha sido fechada con diversos métodos, pero la fiabilidad de los resultados es dudosa. Se fecharon tres artefactos atribuidos al MSA (de procedencia estratigráfica desconocida) por hidratación de la obsidiana en 61.202 ± 958 BP, 61.640 ± 1083 BP, y 77.565 ± 1575 BP (Michels y Marean, 1984). Recientemente, una revisión de este método se ha llevado a cabo en útiles de niveles entre -60 y 120 cm y entre -160 y 180 cm de profundidad y ha permitido obtener fechas de 50–59 ka y 95–107 ka respectivamente (Taffere et al., 2016). Sin embargo este método no se considera fiable (Ridings, 1996; Anovitz et al., 1999). La mandíbula humana encontrada en 1933 se fechó hacia 50 ka por espectrometría de rayos gamma de alta resolución (Leplongeon, 2014). Tres opérculos de gasterópodos terrestres de la especie *Revoilia* se fecharon por radiocarbono (espectrometría de Masas con

Aceleradores), proporcionando fechas de 33,700 ± 300 (Beta–193517), 35,600 ± 350 (Beta–193516), y >43,200 (Beta–193518). En fechas calibradas, éstas corresponden a 38,800–37,049 cal BP, y 41,084–39,421 cal BP, IntCal13; OxCal 4.2; (Bronk Ramsey, 1995). Se fecharon fragmentos de carbón encontrados en la brecha superior en 5700 ± 110 BP. J. C. Vogel fechó la estalagmita que cubre los principales niveles MSA obteniendo resultados de 4590 ± 60 BP y 6270 ± 1020 BP por ^{14}C y U–Th (Desmond Clark y Williamson, 1984). Según Desmond Clark y Williamson, la estalagmita se formó probablemente durante un período húmedo a principios del Holoceno.

Fig 2. Vista del uadi Laga Dächatu desde la cueva de Porc-Epic.

El análisis de la industria lítica de los niveles MSA de Porc-Epic reveló que los materiales usados con más frecuencia eran el sílex, el basalto, la obsidiana y la arenisca/cuarcita (Perlès, 1974; Desmond Clark y Williamson, 1984; Pleurdeau, 2003, 2004, 2005a, 2005b; Vogel et al., 2006; Leplongeon, 2013, 2014). Se observó la producción de lascas, hojas, hojitas y puntas (Fig 3) con los métodos Levallois, Discoide y Laminar, por percusión dura directa. Según Desmond Clark y Williamson, los niveles LSA se diferencian claramente de los niveles MSA por la presencia de microlitos, raspadores y *outils écaillés*. Sin embargo, Pleurdeau identificó la presencia de un número reducido de microlitos y hojitas de borde abatido en los niveles MSA (Pleurdeau, 2004) que interpreta como el reflejo de una evolución gradual del MSA al LSA. Por otra parte, estudios recientes indican que la presencia de microlitos podría en realidad ser el resultado de perturbaciones tafonómicas o de una reducción intensiva de ciertas materias primas como la obsidiana (Leplongeon, 2014).

Fig 3. Ejemplos de industria lítica de la cueva de Porc-Epic (foto: F. d'Errico).

Los restos de fauna incluyen una gran variedad de mamíferos entre los cuales se encuentran los *Reduncinae* y *Alcelaphinae* que reflejan una proximidad a praderas y acceso al agua (Assefa, 2006). En los niveles MSA se observó una explotación de animales de tamaño pequeño o mediano. Además, se ha observado una más alta representación de huesos largos, particularmente los fémures. Esto podría ser el reflejo de un transporte selectivo de porciones más nutritivas al yacimiento, que se interpreta como un campamento base (Assefa, 2006).

Un análisis del esmalte de dientes de ungulados fósiles hallados en los niveles MSA de la cueva de Porc-Epic ha sido llevado a cabo para identificar posibles cambios ambientales o climáticos en la secuencia (Robinson, 2017). Sin embargo, la mayor parte de los taxones (por ejemplo, *Equus quagga/grevyi*, *Aepyceros melampus*, *Damaliscus lunatus*, *Syncerus caffer*) muestran valores bajos de $\delta^{13}C$ y valores altos de $\delta^{18}C$, indicativos de un clima árido, sin cambios significativos en la secuencia. Otros taxones, como *Phacochoerus* sp., mostraron una mayor variabilidad en los valores de $\delta^{13}C$ y $\delta^{18}C$, pero no se ha observado ningún cambio significativo en la secuencia (Robinson, 2017).

Los restos humanos consisten en fragmentos de cráneo y un fragmento de mandíbula. Se encontraron en 1933 hacia la entrada de la cueva, en niveles MSA. Según Vallois, presentan una combinación de caracteres modernos y arcaicos (Vallois, 1951).

Durante la excavación de 1975–1976 se encontraron aproximadamente 420 opérculos de gasterópodos terrestres de la especie *Revoilia guillainopsis* en los niveles MSA (Fig 4). Según Assefa et al., esta acumulación no puede ser el resultado de procesos naturales y por ello ha sido interpretada como el reflejo de una actividad simbólica (Assefa et al., 2008). Cabe destacar que estos opérculos no presentan marcas de una modificación antrópica y que sus perforaciones parecen naturales.

Fig 4. Opérculos de gasterópodos terrestres de la cueva de Porc-Epic.

Breuil identificó en las paredes de la cavidad 20 figuras humanas, 37 animales y 5 signos pintados en rojo, marrón y amarillo (Breuil, 1934) que calificó cómo convencionales y difíciles de atribuir a un período específico (Fig 5). Por otra parte, Desmond Clark describió su estilo cómo tardío y esquemático (Desmond Clark y Williamson, 1984). Las capas de calcita que cubren las pinturas fueron interpretadas por Breuil como la prueba de que el arte de Porc-Epic era más antiguo que la formación de la estalagmita más reciente de los niveles arqueológicos (Breuil, 1934).

La presencia de fragmentos de colorantes y útiles para el tratamiento de colorantes en los niveles MSA ha sido mencionada por Breuil et al. (1951). Desmond Clark y Williamson también hacen referencia al hallazgo de 214 fragmentos de colorantes rojo y amarillo (de los cuales 34 presentaban marcas de uso) y un molino en los niveles situados por encima de -200 cm (Desmond Clark y Williamson, 1984), así como 84 fragmentos de colorantes (de los cuales 6 estaban modificados) en el sedimento que rellenaba la zona excavada en 1933. Sin embargo, este material nunca ha sido estudiado de forma sistemática.

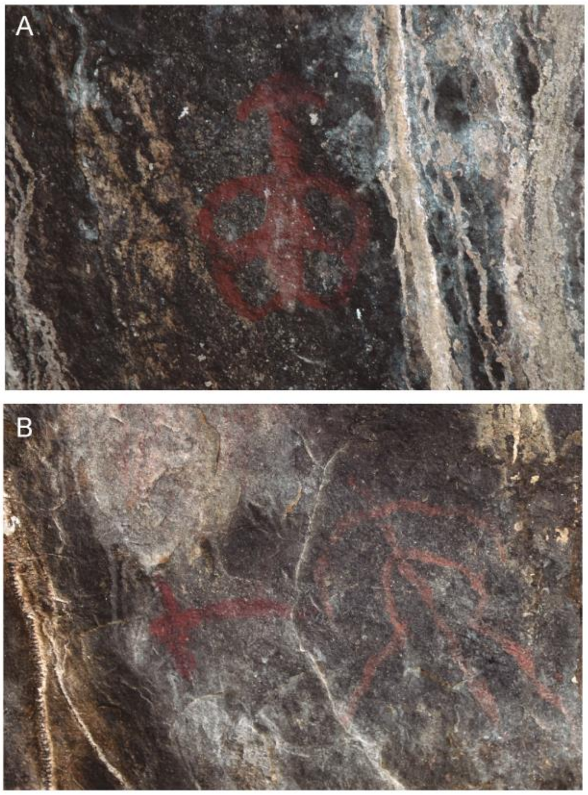


Fig 5. Pinturas de la cueva de Porc-Epic. (A: signo; B: figura antropomorfa).

1.3 Objetivos

Una de las principales motivaciones de la presente investigación fue la constatación de un vacío geográfico en el estudio del uso de colorantes. La mayor parte de los análisis sistemáticos de este tipo de material en yacimientos MSA se concentran en Sudáfrica. El hecho de que el Cuerno de África, zona indispensable para el conocimiento del origen de la modernidad, no haya sido nunca estudiado desde esta perspectiva, hace de la cueva de Porc-Epic un excelente contexto de estudio.

El interés de este yacimiento clave para el MSA de África Oriental no reside únicamente en su situación geográfica. La cantidad de colorantes (40 kg) caracterizados por una gran variedad de materias primas, la diversidad de marcas de uso y la presencia de útiles para el tratamiento de colorantes, nos proporcionan una oportunidad única para llevar a cabo un análisis completo de la adquisición, el tratamiento y el uso de este material.

El objetivo principal en esta tesis es, por tanto, reconstruir las acciones que resultaron en la acumulación, transformación y uso de colorantes en este yacimiento, con el fin de comprender cual pudo haber sido la función de dicho material, y qué significado tenía para los habitantes de la cueva. Esto se ha realizado siguiendo la lógica de la "*chaîne opératoire*" (cadena operativa), teniendo en cuenta posibles cambios diacrónicos en las materias primas, en el tratamiento y uso de los colorantes. Para llevar a cabo este estudio hemos analizado los fragmentos de colorantes, los útiles empleados para procesarlos y los cantos con residuos rojos, combinando diferentes métodos de análisis. La importancia de los colorantes en el debate del origen de la modernidad nos llevó también a explorar la distribución espacial de este material con el fin de verificar su proveniencia estratigráfica y evaluar la integridad de la secuencia. Además, hemos llevado a cabo comparaciones con material experimental y etnográfico (usado por las mujeres Hamar, en Etiopía) para entender mejor las implicaciones del uso de este material.

1.4 Métodos

En esta sección de la tesis presentamos nuestras estrategias metodológicas y explicamos el porqué de ciertas decisiones tomadas a la hora de establecer nuestro protocolo de análisis. Las variables estudiadas, las especificaciones técnicas de los equipos empleados, las muestras analizadas y el tratamiento de resultados están detallados en las secciones de "materiales y métodos" de cada artículo y por ello no los presentaremos en esta parte.

El material estudiado en esta tesis consiste en 4213 fragmentos de pigmentos, 21 útiles destinados a su tratamiento (molinos y machacadores con residuos de pigmentos) y dos cantos con residuos rojos. Descubierto en las excavaciones de 1975-1976, actualmente se encuentra en el *National Museum of Ethiopia* (Addis Abeba).

1.4.1 Estudio preliminar y selección de variables

El proyecto de la presente tesis fue elaborado tras un estudio preliminar de la colección de colorantes de la cueva de Porc-Epic llevada a cabo en el marco del trabajo de fin de Máster de la autora de la presente tesis (Rosso, 2011). Las bases de nuestra estrategia de estudio fueron establecidas durante una estancia en Addis Abeba (en el *National Museum of Ethiopia* en marzo de 2011) llevada a cabo con uno de los directores de esta tesis (Francesco d'Errico) y Renata García Moreno, investigadora postdoctoral en la Universidad de Burdeos. Como se ha indicado anteriormente, en las publicaciones sobre la cueva de Porc-Epic se mencionaba la presencia de colorantes pero fue durante la estancia de 2011 que la autora de esta tesis identificó los 40 kg de colorantes, 21 útiles de tratamiento de colorantes y dos cantos con residuos de colorante. Esto nos permitió valorar el potencial de esta colección para desarrollar un proyecto de tesis de doctorado. Hemos examinado detalladamente una muestra del material durante esta estancia (aproximadamente 1000 fragmentos de colorantes y todos los útiles de tratamiento de colorantes) y hemos decidido cuáles eran las variables que debían de tenerse en cuenta en la elaboración de la base de datos. Hemos registrado la información contextual, caracterizado la materia prima en base a criterios visuales y registrado informaciones relativas a las marcas de uso. Más concretamente, hemos tenido en cuenta variables cuantitativas (medidas, peso, número de facetas, medidas de las facetas) y cualitativas (color, morfología, tipos de materia prima y de marcas de uso, orientación de las estrías, forma de las facetas, disposición de las facetas…) que describimos detalladamente en el capítulo 3. Durante esta estancia previa a la realización del proyecto de tesis, hemos transportado un espectrómetro de fluorescencia de rayos X y un colorímetro para llevar a cabo los primeros análisis sobre el material de forma rápida y eficaz. Una prospección por los alrededores de la cueva de Porc-Epic (Dire Dawa) nos ha permitido recoger el material que fue empleado posteriormente para la experimentación llevada a cabo en la presente tesis doctoral, presentada detalladamente en el capítulo 3.

1.4.2 Registro de datos

Gracias a nuestra primera evaluación de la colección de Porc-Epic, al comenzar el proyecto de doctorado ya conocíamos las características principales del material estudiado y ya se habían determinado gran parte de las variables que iban a tenerse en cuenta en nuestro estudio.

Una de las primeras decisiones que tomamos fue la de incluir en nuestra base de datos todos los fragmentos de colorantes hallados en la cueva, en vez de seleccionar una muestra. Esta estrategia ha permitido aportar datos sobre la secuencia del yacimiento, identificar las áreas de acumulación de colorantes y de útiles de tratamiento, y llevar a cabo un análisis tecnológico exhaustivo de la colección de colorantes. Por esta razón, durante la elaboración de la tesis, hemos llevado a cabo una parte de la investigación en el museo Nacional de Etiopía, en Addis Abeba: en abril de 2012, desde noviembre de 2012 hasta enero de 2013 y de noviembre de 2013 hasta enero de 2014.

Ya que aproximadamente 3000 fragmentos de colorantes no habían sido examinados durante nuestro estudio preliminar, una parte del tiempo ha tenido que invertirse en la organización del material (Fig 6). Éste se encontraba todavía en las bolsas de la excavación de 1975-1976, mezclado con el material lítico (exceptuando las 1000 piezas examinadas en 2011). Ha sido por tanto necesario buscar los fragmentos de colorante en cientos de bolsas para colocarlos en bolsas individuales, en las que se ha indicado toda la información contextual disponible. Hemos registrado las variables mencionadas anteriormente en nuestra base de datos para todos los fragmentos de colorantes y útiles de tratamiento de colorantes. Para ello, cada objeto ha sido observado macro y microscópicamente. Una gran parte del material ha sido fotografiado durante esta fase.

Fig 6. Estado de conservación (A, B) y organización (C) del material.

Durante el período transcurrido en Etiopía, nos trasladamos a Turmi (región de las Naciones, Nacionalidades y Pueblos del Sur, en la zona Debub Omo, Etiopía) para llevar a cabo un trabajo de campo de corta duración, durante el cual hemos documentado el uso de colorantes en la sociedad Hamar, adoptando una estrategia de observación (Fig 7). Esta primera aproximación al estudio etnoarqueológico del uso de colorantes nos ha permitido interactuar con dos informantes especializadas, Buno Goffa y Ballo Aysire, que nos han mostrado la cadena operativa del tratamiento del material. Aunque en arqueología usemos la experimentación como herramienta para familiarizarnos con un tipo de material, no tenemos las competencias que aporta un uso tradicional de dicho material. La observación del procesado de colorantes por las mujeres Hamar ha sido sin duda una estrategia enriquecedora para llevar a cabo nuestro trabajo como arqueólogos.

Fig 7. Aplicación de colorante para la realización del peinado tradicional de las mujeres Hamar (Turmi, Etiopía).

1.4.3 Análisis del material exportado

Considerando la falta de laboratorios de análisis en Addis Abeba, ha sido necesario llevar a cabo los trámites administrativos para muestrear y exportar una parte del material. Las autoridades etíopes (ARCCH, *Authority for Research and Conservation of Cultural Heritage*) nos han concedido los permisos necesarios para:

- Extraer y exportar muestras residuos de colorante de los útiles de tratamiento de colorantes y de los cantos con residuos rojos. La extracción de residuos se ha llevado a cabo sobre zonas de 2 mm^2 y no ha dejado ninguna marca visible sobre estos objetos.
- Exportar 20 microfragmentos de colorantes (de 1-2 mm de largo) desprendidos de piezas de colorante. Los microfragmentos procedían de fracturas previas a nuestro trabajo y por lo tanto no dañaron las piezas arqueológicas.
- Exportar temporalmente una parte del material: 80 fragmentos de colorantes.

Las analíticas fueron llevadas a cabo en Burdeos (Francia). La caracterización de la materia prima se realizó combinando diferentes técnicas analíticas (Tabla 1), que indicamos a continuación.

- Hemos determinado la composición elemental de los **residuos de colorante** por microscopía electrónica de barrido con sistema de análisis (MEB-EDS). Asimismo, la composición mineralógica de dichos residuos se ha caracterizado por espectroscopia µ-Raman (µ-RS) y difracción de rayos X (DRX). Presentamos la metodología de forma detallada y los resultados de estos análisis en el capítulo 4 de la presente tesis.
- Hemos determinado la composición elemental de los **fragmentos de colorantes** mediante el uso de MEB-EDS, fluorescencia de rayos X por dispersión de energías (EDXRF) y PIXE (Particule-Induced X-Ray Emission Spectrometry). Hemos caracterizado su composición mineralógica por espectroscopia µ-Raman. La composición mineralógica de los **microfragmentos de colorantes** ha sido llevada a cabo por DRX. El empleo de un colorímetro nos ha permitido además cuantificar el color de los fragmentos. Ya que hemos optado por realizar un análisis tecnológico exhaustivo de los fragmentos de colorantes, los resultados de la caracterización químico-mineralógica de los fragmentos y microfragmentos de colorantes no han podido ser incluidos en las publicaciones que forman parte de la presente tesis y serán el objeto de una futura publicación. En el capítulo 3, hemos caracterizado la materia con criterios visuales que probablemente coinciden con aquellos que tenían en cuenta los habitantes de Porc-Epic a la hora de seleccionar los colorantes.

¿Por qué hemos elegido estos métodos? En primer lugar, hemos combinado técnicas que se complementan, ya que nos permiten determinar por un lado la composición elemental y por otro lado la composición mineralógica. En segundo lugar, algunos de los métodos fueron elegidos porque no conllevaban ninguna alteración de la superficie: los análisis llevados a cabo sobre los fragmentos de colorante debían ser no destructivos. Sin embargo, los microfragmentos de colorantes han podido ser molturados con un mortero de ágata para obtener mejores resultados. Hemos optado por no molturar los residuos de colorante para no modificar la morfología de las partículas, esencial para diferenciar los diferentes tipos de residuos. Otro elemento determinante a la hora de elegir los métodos de análisis, especialmente en el caso de los residuos de colorante, fue el hecho de que debían realizarse sobre cantidades de muestras reducidas. Además, el coste y acceso a los equipos fueron elementos fundamentales para la elección de los métodos de análisis. A continuación, describimos las ventajas y desventajas de cada uno de éstos métodos, y las razones por las que los hemos seleccionado.

- El MEB-EDS presenta la ventaja de ser un método no destructivo. Además, permite determinar la composición elemental y aportar datos sobre la morfología de las partículas analizadas a través de la observación. Este método fue fundamental a la hora de diferenciar los diferentes tipos de materia prima, especialmente en el caso de los residuos. Sin embargo, presenta la desventaja de tener un coste económico relativamente elevado. Por esta razón, las muestras y los fragmentos analizados con este método fueron escasos. Otra desventaja es que los análisis requieren sesiones relativamente largas para obtener buenos resultados.
- El PIXE y la EDXRF presentan la ventaja de ser no destructivos. El primer método fue llevado a cabo sobre pocas muestras por dificultades relacionadas con el acceso al equipo. El segundo método, en cambio, fue usado para caracterizar todos los fragmentos de colorantes exportados ya que el acceso al equipo era libre. Además, la EDXRF presenta la ventaja de ser un método rápido. El inconveniente en este caso es el hecho de que para una correcta cuantificación de los elementos presentes en la muestra objeto de estudio es necesaria una calibración previa del equipo.
- La espectroscopia µ-Raman presenta la ventaja de ser no destructiva. Además el acceso al equipo era libre y por ello hemos analizado todo el material exportado con este método. Sin embargo, presenta el inconveniente de que los análisis se hacen sobre partículas individuales, por lo que no se obtiene una visión de conjunto de la composición mineralógica del fragmento o muestra analizada. Así, en ocasiones los resultados no reflejan la variabilidad de la materia prima. Además, los espectros obtenidos muchas veces son de difícil interpretación por problemas relacionados con la fluorescencia.
- La DRX presenta la ventaja de dar una visión más general de la composición mineralógica de los fragmentos o muestras analizadas (con respecto al µ-Raman). Sin embargo, pocas muestras han sido analizadas por DRX ya que estos análisis presentaban un coste económico elevado.
- La colorimetría presenta la ventaja de ser no destructiva. Además, el equipo usado para llevar a cabo estos análisis es portable y las medidas se adquieren rápidamente. Sin embargo, los valores colorimétricos dependen de la granulometría y por ello debemos ser prudentes a la hora de interpretar estos datos.

Hemos también llevado a cabo análisis para cuantificar las marcas de uso. Del material exportado, 20 fragmentos han sido analizados con un microscopio confocal. Esto nos permitió cuantificar la rugosimetría de las facetas de abrasión. Hemos llevado a cabo sesiones de experimentación durante las cuales hemos tratado fragmentos de colorantes recogidos en el uadi Laga Dächatu con molinos de diferentes materias primas. Los fragmentos de colorantes experimentales también han sido analizados con el microscopio confocal para compararlos a los fragmentos arqueológicos.

Además de esto, los polvos de colorante producidos experimentalmente y dos muestras de polvo producido por las mujeres Hamar han sido el objeto de análisis granulométricos.

En el capítulo 3 presentamos detalladamente los equipos utilizados para llevar a cabo los análisis de rugosimetría y granulometría, así como los resultados obtenidos.

Método de análisis	**Fragmentos de colorantes**	**Residuos de colorantes (útiles para el tratamiento de colorantes)**
SEM-EDS	22 fragmentos	12 muestras
EDXRF	80 fragmentos	-
PIXE	6 fragmentos	-
μ-Raman	80 fragmentos	20 muestras
DRX	9 microfragmentos	11 muestras
Colorimetría	42 fragmentos	-
Rugosimetría	19 fragmentos	-

Tabla 1. Análisis realizados sobre el material exportado, el experimental y el etnográfico.

1.5 Organización y desarrollo de la tesis

1.5.1 Estructura

El cuerpo principal de esta tesis está constituido de cuatro artículos publicados o aceptados con fecha posterior a la aprobación del proyecto de tesis doctoral. Los capítulos 2 y 4 (Rosso et al., 2014, 2016) están publicados en revistas científicas incluidas en el *Journal Citation Reports (ISI)* de Thomson Reuters (*Quaternary International* y *PLOS ONE*). El capítulo 3 (Rosso et al., in press) fue aceptado en *PLOS ONE* y el capítulo 5 (Rosso, in press) fue aceptado en *Pyrenae*, revista incluida en *el European Reference Index for Humanities* (ERIH). En esta tesis se ha respetado el formato de los artículos exigido por cada una de las revistas. En cada uno se incluye su propia bibliografía y en dos de ellos (cap. 3 y 4) se encuentran documentos con informaciones suplementarias. En el capítulo 6 presentamos la discusión de nuestros resultados, las conclusiones finales y las perspectivas. La relación bibliográfica final comprende todas las referencias citadas en los seis capítulos que forman el cuerpo principal de la tesis. Las figuras y las tablas de los capítulos de esta tesis que no se presentan en forma de artículo se recogen en el índice de figuras y tablas. En los anexos hemos incluido dos artículos (d'Errico y Rosso, 2016; Rosso, 2016) publicados durante la redacción de esta tesis y relacionados con nuestra investigación. El primero, publicado en la revista de la *Accademia dei Lincei*, Roma, y el segundo publicado en la revista *Annales de la Fondation Martine Aublet*. Siguiendo la normativa de la Universidad de Burdeos relativa a las tesis en idiomas extranjeros, hemos añadido en la sección de anexos un resumen largo de la tesis en francés. Además de esto, en los anexos hemos adjuntado las cartas de aceptación de los artículos aceptados pero todavía no publicados (en la fecha del depósito de la tesis).

1.5.2 Presentación de los artículos y unidad temática

Los artículos que forman el cuerpo principal de la tesis tienen una unidad temática: todos tienen como finalidad el aportar nuevos datos en cuanto al uso de colorantes. Los tres primeros se centran en el caso de la cueva de Porc-Epic, y el último permite ampliar este tema a sociedades actuales.

El artículo presentado en el capítulo 2 analiza el contexto arqueológico de nuestra tesis y tiene como finalidad el estudio de la distribución espacial de los colorantes en la cueva de Porc-Epic. Este artículo nos ha permitido obtener el máximo de información sobre la estratigrafía del yacimiento y a través de esta primera evaluación del material poder establecer una estrategia de estudio.

En el capítulo 3 presentamos el análisis tecnológico de los fragmentos de colorantes de la cueva de Porc-Epic, con el fin de comprender la función de este material durante el MSA. Hemos podido reconstruir los gestos y los procedimientos técnicos utilizados para tratar este material. Teniendo en cuenta los datos presentados en el artículo del capítulo 2 sobre la distribución vertical, hemos podido verificar si hubo una evolución en la cadena operativa de los colorantes en la secuencia de Porc-Epic.

El artículo presentado en el capítulo 4 nos permite aportar un elemento clave para la reconstrucción de la cadena operativa de los colorantes. A través del análisis de los útiles que sirvieron para tratarlos hemos podido corroborar las observaciones hechas en el capítulo 3 en cuanto a técnicas de tratamiento. Además, la presencia de cantos con residuos de colorantes nos ha permitido documentar sus posibles funciones en este yacimiento.

Considerando la dificultad de llegar a conclusiones definitivas en cuanto a la función de los colorantes y su significado en poblaciones del pasado, hemos decidido estudiar un caso etnográfico. En el capítulo 6 presentamos los primeros resultados del análisis de la cadena operativa de los colorantes usados por las mujeres Hamar (Etiopía) para la elaboración de su peinado tradicional, con el fin de verificar si existen paralelismos en el tipo de procesado. Este estudio etnoarqueológico nos ha permitido comprobar la complejidad de la cadena operativa de este material y la dificultad que supone el establecer una frontera clara entre una función utilitaria y una función simbólica. Utilizamos el presente para poder comprender el pasado.

1.5.3 Contexto global de la investigación

La presente tesis de doctorado se ha realizado en el marco de una cotutela de tesis doctoral entre la Universidad de Barcelona y la Universidad de Burdeos. El trabajo presentado se ha llevado a cabo en estas dos universidades como establecido por el convenio de cotutela y por lo tanto esta tesis se adscribe a dos grupos de investigación:

- El Seminari d'Estudis i Recerques Prehistòriques (SERP). El SERP está vinculado al Departamento de Historia y Arqueología de la Universidad de Barcelona. Este grupo de investigación se dedica a la reconstrucción paleoambiental y el estudio de la evolución cultural en la Prehistoria partiendo de la premisa de la interdisciplinariedad. Dos de los directores de esta tesis, el Dr. José María Fullola Pericot y el Dr. João Zilhão forman parte de este grupo.
- El laboratorio UMR-CNRS 5199 de la Préhistoire à l'Actuel: Culture, Environnement et Anthropologie (PACEA), vinculado a la Universidad de Burdeos y al Centre National de Recherche Scientifique (CNRS). Las investigaciones llevadas a cabo en este grupo de investigación se integran en diferentes temáticas: la diversidad biológica y la bioarqueología, la arqueotanatología, la arqueología de los ritos y de los símbolos, así como los medioambientes, poblamientos y modos de vida del pasado. Uno de los directores de esta tesis, el Dr. Francesco d'Errico, pertenece a este grupo de investigación.

Nuestro trabajo se ha realizado en el marco de dos proyectos de investigación, gestionados respectivamente por la Universidad de Barcelona y la Universidad de Burdeos.

- El proyecto HAR2011-26193 (El Paleolítico superior y el Epipaleolítico en el NE peninsular: una aproximación socio-económica, cultural y paleoambiental, Ministerio de

Ciencia e Innovación, MICINN), que tiene continuidad en el vigente HAR2014-55131, cuyo principal investigador es uno de los directores de la presente tesis, José María Fullola Pericot.

- El proyecto TRACSYMBOLS (European Research Council Advanced Grant, TRACSYMBOLS No. 249587 awarded under the FP7 program), co-dirigido por uno de los directores de la presente tesis (Francesco d'Errico) junto con Christopher Henshilwood (Universidad de Bergen, Noruega).

El trabajo de la autora de esta tesis ha sido financiado por la Generalitat de Catalunya (*Ajuts per a la contractació de personal investigador novell*, FI-DGR) entre mayo de 2014 y abril de 2017 y por el Ministerio de Asuntos exteriores y del Desarrollo Internacional Francés (*Bourse d'Excellence Eiffel*) entre septiembre de 2012 y junio 2013. La autora de la tesis ha obtenido financiaciones de la fundación Martine Aublet (*Bourse de recherche doctorale*) y la Fundación Wenner-Gren (Gr. 8786) para llevar a cabo el trabajo de campo en Etiopía y para la realización de analíticas. Los costes de publicación, así como una parte de los costes del trabajo de campo y de las analíticas ha sido financiado por el European Research Council (Advanced Grant, TRACSYMBOLS No. 249587, FP7 program).

Algunos de los artículos se han realizado en colaboración con coautores afiliados a los dos grupos de investigación mencionados previamente, pero la parte fundamental de los artículos fue realizada por la autora de la presente tesis. Los coautores son: Francesco d'Errico y João Zilhão, codirectores de esta tesis, de la Universidad de Burdeos y de la Universidad de Barcelona (ICREA) respectivamente; así como Àfrica Pitarch Martí y Alain Queffelec, afiliados al laboratorio PACEA de la Universidad de Burdeos.

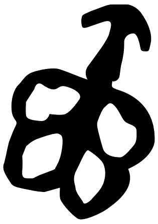
Los permisos para muestrear, estudiar y exportar el material fueron concedidos por el *Authority for Research and Conservation of Cultural Heritage* (ARCCH).

Las analíticas presentadas en este trabajo se llevaron a cabo en diferentes laboratorios. Los análisis por espectroscopia µ-Raman, EDXRF, colorimetría, rugosimetría y granulometría se realizaron en el laboratorio PACEA (UMR 5199 CNRS, Université de Bordeaux). Los análisis por MEB-EDS se llevaron a cabo en el *Bordeaux Imaging Center* (UMS 3420 CNRS, Université de Bordeaux/Inserm US4) con la colaboración de Isabelle Svahn. En el *Institut de Chimie de la Matière Condensée de Bordeaux* (UPR 9048 CNRS, Université de Bordeaux) se llevaron a cabo los análisis por DRX con la colaboración de Eric Lebraud. En el Centre d'Études Nucléaires de Bordeaux Gradignan (AIFIRA: Applications Interdisciplinaires de Faisceaux d'Ions en Région Aquitaine) se efectuaron los análisis por PIXE.

CAPÍTULO 2

La cueva de Porc-Epic: contexto y análisis espacial

Rosso D. E., d’Errico F., Zilhão J. 2014. Stratigraphic and spatial distribution of ochre and ochre processing tools at Porc-Epic Cave, Dire Dawa, Ethiopia. *Quaternary International* 343: 85–99.



2.1 RESUMEN

A través del análisis del material excavado por Kenneth D. Williamson en la cueva de Porc-Epic en 1975-1976, se ha demostrado la presencia de la colección de colorantes más amplia jamás hallada en un yacimiento MSA. En este estudio analizamos la distribución vertical y horizontal de los fragmentos de colorantes (n=3792, 40 kg) y de los útiles para el procesado de colorantes (n=20) cuya información contextual se ha conservado, comparándola con la distribución espacial de otras categorías de artefactos (industria lítica y opérculos de gasterópodos terrestres).

Nuestros resultados indican que gran parte de los colorantes fueron hallados en los niveles MSA y que la presencia de este material en los niveles superiores, atribuidos al LSA y al Neolítico es escasa. En los niveles MSA, se han identificado dos zonas de acumulación de colorantes, en las que se hallaron la mayor parte de los útiles para el procesado. Éstas se interpretaron como posibles áreas dedicadas al tratamiento de colorantes. Su localización cambia significativamente en función del nivel arqueológico.

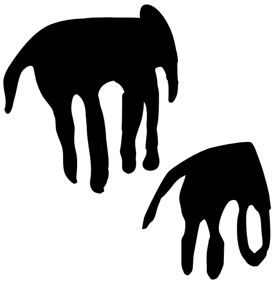
La comparación de la distribución vertical de los colorantes y de la industria lítica indica que en la mayor parte de los casos, estas dos categorías de objetos siguen las mismas tendencias. La distribución vertical de los colorantes y de los opérculos también coincide, pero se observan diferencias en la distribución horizontal. Esto sugiere que las acumulaciones de colorantes no son el resultado de perturbaciones post-deposicionales.

Las fechas ^{14}C indican que los principales niveles MSA se acumularon como mínimo durante 4500 años y sitúan los niveles con la más alta frecuencia en colorantes hacia 40 ka cal BP.

CAPÍTULO 3

Análisis tecnológico de los fragmentos de colorantes

Rosso, D. E., d’Errico, F, Queffelec, A., in press. Patterns of change and continuity in ochre use during the late Middle Stone Age of the Horn of Africa: the Porc-Epic Cave record. *PLOS ONE* 12(5): e0177298.



3.1 RESUMEN

Los colorantes son materiales ubicuos en los yacimientos MSA y tienen un papel esencial en los estudios sobre los primeros Humanos anatómicamente modernos. En este artículo analizamos la colección más amplia de colorantes jamás hallada en niveles MSA, procedente de la cueva de Porc-Epic (Dire Dawa, Etiopía). Ésta incluye 40 kg de colorantes rojos, amarillos y marrones, encontrados en niveles acumulados durante ca. 4500 años.

Hemos llevado a cabo una caracterización visual, una identificación microscópica de las marcas de uso, un análisis morfológico y morfométrico de las piezas. Hemos combinado los resultados de estos análisis con un análisis de granulometría de polvos de colorantes experimentales y polvos producidos actualmente por mujeres Ovahimba (Namibia) y Hamar (Etiopía). Asimismo, hemos realizado un estudio rugosimétrico de las facetas arqueológicas y experimentales producidas por abrasión. El objetivo fue reconstruir la cadena operativa de los colorantes e identificar posibles cambios en el tratamiento y uso de este material en la secuencia, con el fin de explorar la función y el significado de este material en las poblaciones MSA del Cuerno de África.

Nuestros resultados nos han permitido identificar una continuidad en la adquisición, el tratamiento y el empleo de colorantes que refleja un uso persistente de las mismas técnicas de procesado. Teniendo en cuenta la cantidad de colorantes presentes por nivel arqueológico, esta continuidad puede ser interpretada como la expresión de una adaptación cultural compartida por todos los habitantes de la cueva y transmitida de forma constante. Las paulatinas variaciones observadas en las técnicas de procesado se han interpretado como una deriva cultural. Por otra parte, los resultados de nuestros análisis indican que la abrasión se utilizaba probablemente para producir pequeñas cantidades de polvo de colorante. Esto se considera más compatible con actividades simbólicas, como la pintura corporal o la realización de diseños abstractos. Sin embargo, no debemos descartar posibles usos funcionales que a veces no requieren grandes cantidades de polvo, como usos medicinales o una utilización para producir adhesivo para enmangar útiles líticos.

Patterns of change and continuity in ochre use during the late Middle Stone Age of the Horn of Africa: the Porc-Epic Cave record

Ochre use in the Middle Stone Age in the Horn of Africa

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Abstract

Ochre is found at numerous Middle Stone Age (MSA) sites and plays a key role in early modern human archaeology. Here we analyse the largest known East African MSA ochre assemblage, comprising 40 kg of ochre, found at Porc-Epic Cave, Ethiopia, spanning a period of at least 4,500 years. Visual characterisation of ochre types, microscopic identification of traces of modification, morphological and morphometric analysis of ochre pieces and modified areas, experimental reproduction of grinding processes, surface texture analysis of archaeological and experimentally ground ochre facets, laser granulometry of ochre powder produced experimentally on different grindstones and by Hamar and Ovahimba women from Ethiopia and Namibia respectively, were, for the first time, combined to explore diachronic shifts in ochre processing technology. Our results identify patterns of continuity in ochre acquisition, treatment and use reflecting both persistent use of the same geological resources and similar uses of iron-rich rocks by late MSA Porc-Epic inhabitants. Considering the large amount of ochre processed at the site, this continuity can be interpreted as the expression of a cohesive cultural adaptation, largely shared by all community members and consistently transmitted through time. A gradual shift in preferred processing techniques and motions is interpreted as reflecting cultural drift within this practice. Evidence for the grinding of ochre to produce small quantities of powder throughout the sequence is consistent with a use in symbolic activities for at least part of the ochre assemblage from Porc-Epic Cave.

Introduction

Ochre pieces, often modified by grinding and scraping to produce red powder, and ochre-stained objects (grindstones, ochre containers, lithic and bone tools, personal ornaments) represent one of the most controversial features found at Middle Stone Age (MSA) and Middle Palaeolithic sites. It is often argued that such innovation reflects cognitive complexity [1], and many consider ochre as a marker of symbolically mediated behaviour [2–13]. Some authors consider that body painting in the earliest group rituals were primarily indexical and that only once ochre use became ubiquitous, such use was part of “symbolic culture” [5,14–18]. However, some have argued that inferring symbolism from such an equivocal archaeological feature is risky, preferring functional explanations such as hide tanning, adhesive production, insect repellent, antiseptic treatments, or sun protection as viable alternative interpretations [1,19–30]. Still others contend that there has been an unnecessary polarisation around the distinction between symbolic and utilitarian activities that fails to account for the complex interplay between functional and symbolic activities in traditional human cultures [31].

Although numerous African MSA sites yielded ochre pieces [3–6,15,16,32–37], in some cases associated with coloured artefacts [38,39], detailed reconstructions of MSA ochre processing techniques are rare, particularly in East Africa. This is due to the fact that effective methodologies for addressing technological aspects of modified ochre pieces have only been developed recently [3,4,21,33,34,40] and that few multistratified sites from Africa have yielded ochre collections large enough to produce reliable results.

Here we present the first technological analysis of ochre pieces from Porc-Epic Cave, Dire Dawa, Ethiopia. This site has yielded the largest collection of ochre currently known in East Africa, weighting 40 kg (n=4213 pieces), found during excavations of 49 m^2 over a depth of approximately 3 m. Previous work has shown that, while found throughout the stratigraphic sequence, ochre pieces are concentrated in different locations and depths [38,41]. Analysis of 23 associated ochre processing tools and ochre-stained artefacts has demonstrated that different types of rocks, sometimes exogenous, were used to process ochre. Additionally, it was shown that a variety of ochre types were processed and that different processing techniques were involved, suggesting that different shades and colours of ochre were possibly intended for variety of activities. This study focuses on reconstructing the sequence of actions that led to the accumulation, transformation and use of iron-rich rocks at this site. Such an approach permits the function of these objects and, ultimately, the significance of ochre use for late MSA groups of the Horn of Africa to be explored. We equally address to what extent these practices changed through time and for what reasons by combining morphometric, technological, and roughness analyses with experimental and ethnographic data.

Background

The term “ochre” refers to a variety of rocks characterised by a red or yellow colour or streak, from soil lumps to ore minerals, containing a high proportion of iron oxides [21,42,43]. Yellow ochres usually derive their colour from goethite (α -FeOOH), red ochre from hematite (α-Fe_2O_3), and often contain other components such as quartz, clays, gypsum, or mica [44]. Ochre is frequently found at Middle Stone Age sites, particularly after 100 ka BP, when it becomes ubiquitous [37,39]. Numerous MSA sites from East Africa have yielded ochre, including the Kapthurin Formation [37,45], Enkapune Ya Muto [46] in Kenya, Mumba and Nasera Rock Shelters [47] in Tanzania, Mochena Borago Rock Shelter [48], Gorgora Rock Shelter [49–51] and Aduma [52] in Ethiopia. However, none of these ochre collections have been analysed, and comprehensive studies of MSA ochre pieces, with the exception of Twin Rivers and Mumbwa in Zambia [32,53], are currently limited to material from South African sites (e.g. Blombos Cave, Pinnacle Point Cave, Diepkloof Rock Shelter and Sibudu Cave).

Blombos Cave is probably one of the richest sites with respect to ochre use. Dated to ca. 100–72 ka, the site’s MSA levels yielded a collection of more than 8000 ochre pieces weighing approximately 5.8 kg [5,33,54–56]. Elemental and mineralogical analysis of pieces from different layers show clear differences in composition, suggesting they come from different geological sources, and that ochre procurement patterns changed through time [5,56]. Colour profiles, identified using the Natural Color System Index, detected a variety of shades, with a clear preference for saturated red ochre [5]. Striations, grooves, scraping, percussion pits, possible traces of handling, as well as abstract engravings, were identified on numerous pieces [5,21,33,54,55]. Watts [5] concluded that the reddest and more saturated pieces were overrepresented among the most intensively ground pieces, and that ochre was ground to produce small quantities of powder, a behaviour consistent with a use for symbolic activities. This is supported by the presence of numerous intensively ground pieces, as well as twelve "definite" and twelve "probable" ochre pieces used as "crayons", following the definition according to which a crayon is an ochre piece characterised by three or more facets converging to a point [5,20,55]. Differences were observed in the sequence: harder forms of ochre (highly ferruginous types of ochre from distant sources), and intensively ground pieces ("crayons") were better represented in younger levels. The latter, according to Henshilwood et al. [55], were probably the result of a more protracted processing, consistent with curation. This appears to be in accordance with changes in procurement of raw material, which shift to more distant sources [55]. Two toolkits for the production and storage of ochre-rich compounds were also recovered from layers dated to 100 ka [35]. These toolkits comprise modified ochre pieces, bones, upper and lower grindstones, and two abalone shells still containing an ochre-rich compound.

The analysis of 380 ochre pieces (1.08 kg) from layers dated to ca. 164–91 ka at Pinnacle Point Cave 13B [4] highlighted the use of raw materials of different types and colours (e.g. mudstone, shale, siltstone, sandstone, iron oxide), and modifications produced by grinding, flaking, notching and, to a lesser degree, scraping. An engraved piece and a piece that shows marks indicating that it may have been suspended were also identified. Possible evidence for the heating of ochre, and a preference for dark red shades has been advanced in support of symbolic activities, such as body painting.

Several thousand ochre pieces were recovered from the MSA levels of Diepkloof Rockshelter dated to 110–55 ka. The analysis of 558 pieces (1.9 kg) [34,57] identified different types of rocks (shale, ferricrete, shale/ferricrete, ferruginous sandstone, ferruginous quartzite), with the presence of exogenous raw materials suggesting complex mobility patterns [58]. Modifications were identified on 16% of the analysed assemblage, including striations produced by grinding, and to a lesser extent, smoothed areas. A number of pieces appear to have been intentionally shaped, and one is engraved. Flaking is rare, and scraping apparently absent. Quartzite slabs and silcrete flakes bearing ochre residues may have been used as processing tools. According to Dayet et al. [58], the exogenous nature of the ochre, the selection of particular ochre types, and the absence of ochre in adhesives used for tool hafting [59] are consistent with the symbolic interpretation.

The MSA levels of Sibudu, South Africa, dated between 77.2 ± 2.6 ka – 37.6 ± 2.6 ka [60–63], yielded 5449 pieces of ochre (>8mm, 15,4 kg), as well as 3837 small pieces. Various raw materials [36] were identified by visual inspection (shale, siltstone, snuffbox shale, sandstone, iron oxide, hardened clay, mudstone, weathered dolerite). Microscopic observations [40], supported by experimental data [64], allowed the identification of a variety of modifications produced by grinding, rubbing and scoring on 682 pieces [40]. Most of the modified pieces concern bright red shale. Clayey ochre appears in higher frequencies in the lower levels and silty ochre in the upper levels. This is interpreted by Hodgskiss as a shift in ochre use over time [36]. A few pieces, mostly from layers dated to between 77–58 ka, are interpreted as engraved [65]. Although others bear facets and a pointed morphology, the author questions, on experimental grounds, their interpretation as “crayons” [66]. Cemented hearths with substantial ochre deposits in layers dated to ca. 58 ka have been described as receptacles for ochre powder or work surfaces [67]. Sandstone slabs and other lithic artefacts with yellow or red residues were also recovered from the site [26,27,68,69]. The presence of ochre residue on the striking platform of flakes suggests large ochre lumps to have been used as soft hammers [68]. Ochre mixed with a possible resin identified on stone tools has been advanced as support for the presence of hafting adhesives. Finally, the production of a compound composed of ochre and milk has been identified on residue adhering to a dolerite flake in layers dated to 49 ka BP [70].

Archaeological context

Porc-Epic Cave is located between the Afar Depression and the Somali Plateau, 3 km south of Dire Dawa in Ethiopia (Fig 1). The cave opens at the base of a Jurassic limestone cliff, 140 m above the wadi Laga Dächatu near the top of the Garad Erer hill.

Pierre Teilhard de Chardin and Henry de Monfreid discovered the cave in 1929, with a test pit conducted the same year to test the archaeological potential of the site [71]. The excavation was enlarged by Henri Breuil and Paul Wernert in 1933 [72]. Rock art of a "later schematic style" identified on the cave’s walls was also described [73,74]. New excavations directed by John Desmond Clark in 1974 [73,75] were followed in 1975–1976 by fieldwork led by Kenneth D. Williamson over an approximately 49 m^2 surface. More recently, fieldwork conducted by a team from the *Muséum National d’Histoire Naturelle*, Paris, France, and the Authority for Research and Conservation of Cultural Heritage (ARCCH) of Ethiopia helped clarify the Porc-Epic stratigraphy [76].

Fig 1. Location of Porc-Epic Cave. *(A) Location of the site. (B) View of the cliff where the site is located. The arrow indicates the cave entrance. (C) View of the cave (photo A. Herrero). Modified after [38] under a CC BY license, with permission from PLOS ONE, original copyright 2016.*

Divided into seven units (Fig 2), the stratigraphy comprises a succession of clayish levels, sandy levels and breccia (see [41,73] for details). MSA material was recovered from levels 2, 3C/D and 4A/B [73], approximately 60 to 220–230 cm below datum. Above these layers, layers 6, 7A and 7B are all composed of fine sands and loam with interstratified hearth material containing LSA and Neolithic artefacts [77].

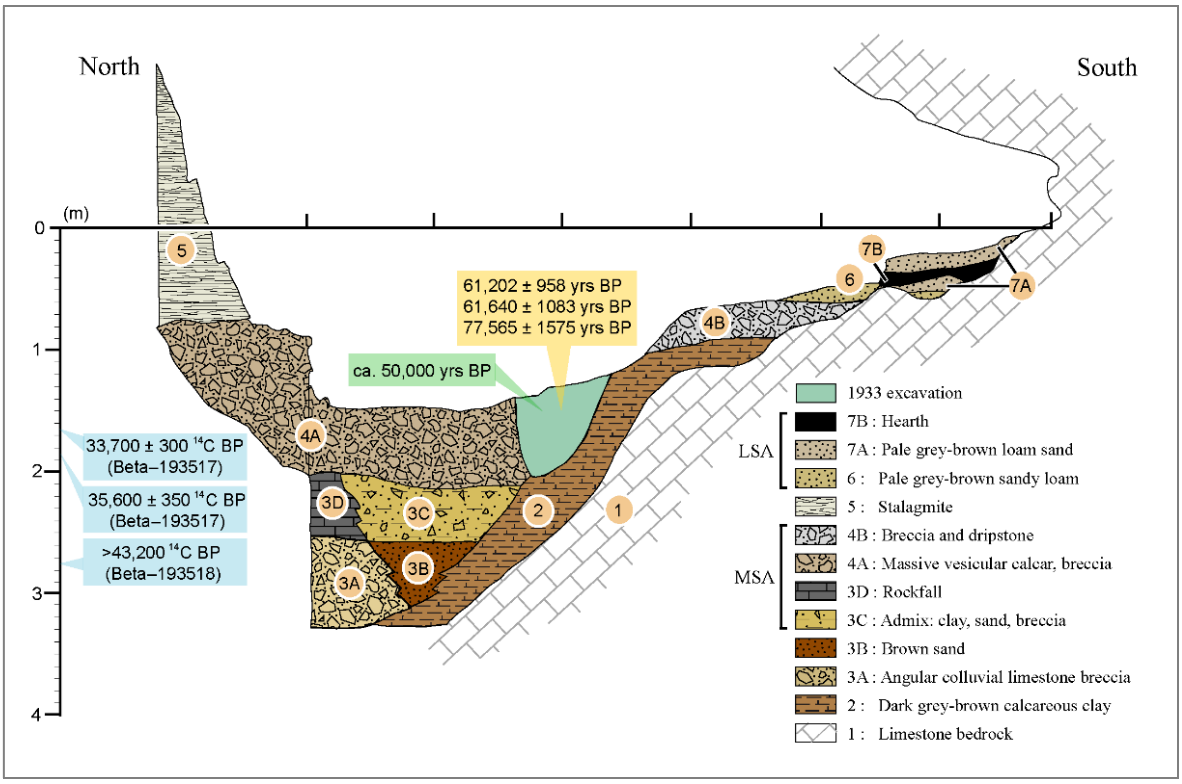

Fig 2. Porc-Epic Cave's stratigraphy. *Eastern profile (09W-10W) at the end of the 1974 excavation. The gamma-spectrometry age of a human mandible and the obsidian hydration ages for artefacts recovered during the 1933 excavation are indicated in green and orange, respectively.* ^{14}*C ages obtained from gastropod opercula are indicated in blue. Their stratigraphic position is approximate, as only the depth and square from which these objects were recovered is known, and therefore cannot be correlated with a specific layer. Reprinted from [38] under a CC BY license, with permission from PLOS ONE, original copyright 2016.*

Three artefacts found during the 1933 excavation [78] were dated by obsidian hydration to 61,202 ± 958, 61,640 ± 1083, and 77,565 ± 1575. However, this dating method is now considered unreliable [79,80] and, although the samples come from MSA levels, the exact stratigraphic provenance of these tools is unknown. High-resolution, low-background gamma-ray spectrometry analyses of a human mandible produced a date of ca. 50 ka [81]. Accelerator mass spectrometry (AMS) radiocarbon determinations for three samples of *Revoilia* gastropod opercula from the MSA layers [77] returned uncalibrated ^{14}C ages of 33,700 ± 300 (Beta–

193517), 35,600 ± 350 (Beta–193516), and >43,200 (Beta–193518). The 95.4% probability range of the two finite ages are 38,800–37,049 cal BP, and 41,084–39,421 cal BP (IntCal13; OxCal 4.2; [82]). The stalagmite that seals the breccia containing the main MSA levels yielded ^{14}C and U–Th ages of, respectively, 4,590 ± 60 BP and 6,270 ± 1020 BP [73]. Charcoal fragments recovered in the uppermost breccia have been dated to 5,700 ± 110 BP. Overall, radiocarbon ages obtained from *Revoilia* opercula at Porc-Epic Cave seem to indicate the sequence to have accumulated over at least 4,500 years [41,83]. However, given the uncertainty surrounding ages obtained at the site, we cannot exclude that Porc-Epic's sequence may be longer than suggested by radiocarbon ages.

At Porc-Epic Cave, the study of lithic artefacts showed that flakes, blades, bladelets and points were produced using Levallois, Discoid and laminar reduction methods by direct hard-hammer percussion [73,76,81,84–88]. Flint, basalt, obsidian [89,90] and sandstone/quartzite were the main raw materials exploited. Various interpretations have been advanced for the microliths from Porc-Epic Cave. Desmond Clark and Williamson suggested that their presence in the upper levels differentiates the LSA from MSA levels [73]. More recently, Pleurdeau [76,86–88] identified a small number of microliths and backed bladelets in the MSA assemblage, which he interpreted as a gradual evolution from the MSA to the LSA. It was later suggested, however, that the presence of microliths may be result either from mixing with the overlying LSA layers or the intense reduction of raw materials such as obsidian [81]. Several human cranial fragments and a partial mandible showing both modern and archaic features [91] were found at the site. The identification of different mammal taxa in the MSA levels suggests a nearby water source and widespread grasslands. The skeletal element profile reveals a selective transport of high-ranking nutritional elements, leading the site to be interpreted as a base camp [77]. Fossil ungulate enamel isotope data from teeth recovered in the MSA levels of Porc-Epic Cave was analysed to identify possible shifts in climatic and environmental conditions [92]. However, most taxa (for example, *Equus quagga/grevyi*, *Aepyceros melampus*, *Damaliscus lunatus*, *Syncerus caffer*) yielded low $\delta^{13}C$ and high $\delta^{18}C$ values, with little or no changes throughout the sequence, suggesting dry grass feeding and high aridity. Other taxa, such as *Phacochoerus* sp. yielded a greater variability in $\delta^{13}C$ and $\delta^{18}C$ values, but no significant changes were observed throughout the stratigraphy among mixed feeders [92]. The MSA levels yielded more than 419 perforated gastropod opercula belonging to the terrestrial species *Revoilia guillainopsis*. Given that their presence cannot be attributed to natural processes and despite the lack of visible anthropogenic modifications on the perforations, they have nevertheless been interpreted as possible evidence for symbolic behaviour [83].

Ochre at Porc-Epic Cave

Ochre was reported at Porc-Epic Cave by Breuil, and later by Desmond Clark and Williamson [73,93]. The latter described 214 ochre pieces and one limestone grindstone recovered during the 1974 excavations. The ochre assemblage from the 1975–1976 excavations comprises 4213 pieces (ca. 40 kg) of red, brown and yellow iron-rich minerals [41], as well as 21 ochre processing tools and 2 ochre-stained artefacts [38]. Although the size of the mesh used during sieving is unknown, many ochre pieces are smaller than 1 cm, indicating a fairly exhaustive recovery (see below).

Ochre pieces are present between 30 and 280 cm below datum [41], with the highest frequency (83.15% of the total number of pieces) concentrated between 60–160 cm and peaking at 110–120 cm. The number of ochre pieces decreases gradually towards both the top and the bottom of the sequence. Analysis of the spatial and stratigraphic distribution identified two main ochre concentrations (Fig 3).

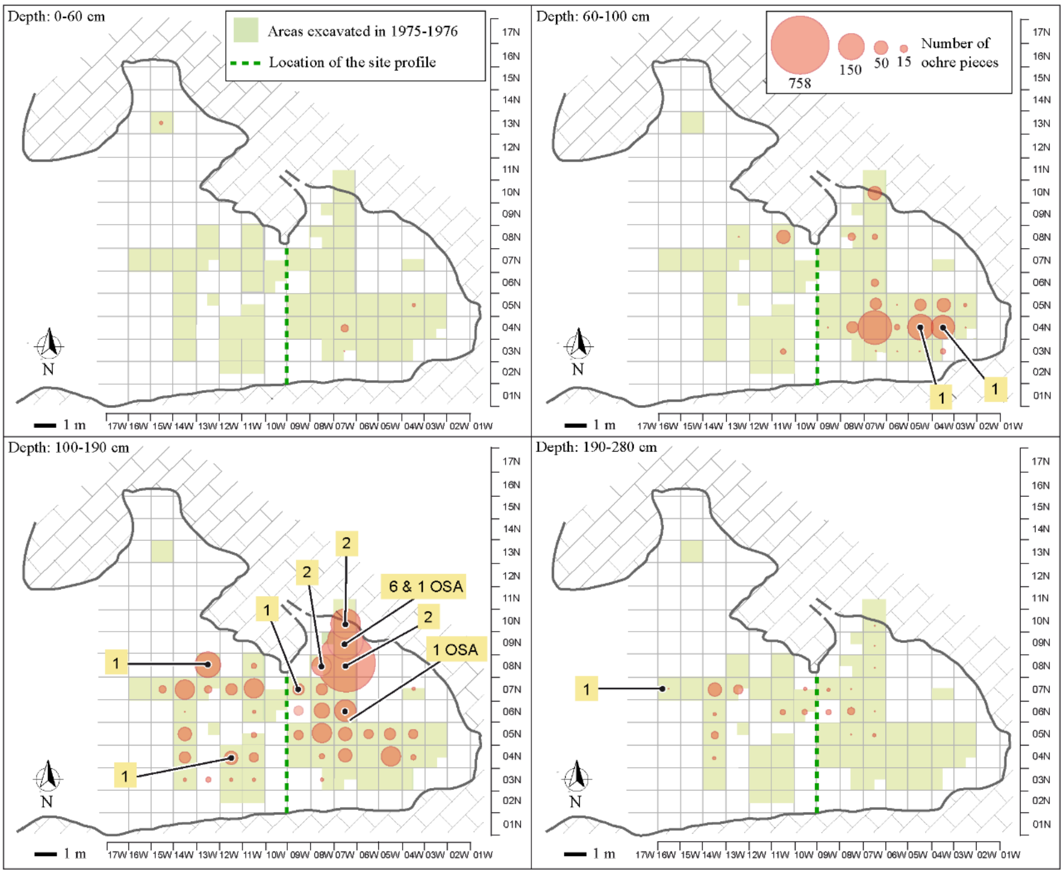

Fig 3. ***Spatial distribution of ochre pieces, ochre processing tools and ochre-stained artefacts.*** *Bubble sizes reflect the frequency of ochre pieces per grid unit. Numbers indicate ochre processing tools and ochre-stained artefacts (OSA) when indicated. Modified after [38] under a CC BY license, with permission from PLOS ONE, original copyright 2016.*

The first (NEA) is located at 100 to 190 cm below datum in the northeastern squares (squares 08N-07W, 08N-08W, 09N-07W, 10N-07W) and accounts for 50.73% (n=1373) of the ochre pieces present at this depth. Twelve ochre processing tools and one ochre-stained artefact were equally found in this area. The second concentration (SEA), accounting for 62.27% (n=558) of the ochre pieces recovered within this depth, lies between 60 and 100 cm below datum in the southeastern area of the site (squares 04N-04W, 04N-05W and 04N-07W). Two processing tools were also recovered in the SEA. Concomitant changes in the location of ochre concentration areas and ochre processing tools suggest areas devoted to ochre processing to have shifted spatially over time. Additionally, by comparing the distribution of ochre pieces and gastropod opercula dated by ^{14}C, ochre use at Porc-Epic appears to have begun around or before 45 cal kyr BP, becoming particularly intense at ca. 40 cal kyr BP [41].

The technological analysis of the upper and lower grindstones from Porc-Epic Cave [38] revealed different types of modifications associated with ochre residues. The analysis of ochre residues showed that different types of ferruginous rocks were processed for the production of ochre powders of different coarseness and shades. It has been proposed that these powders probably met a variety of utilitarian and/or symbolic needs. A round pebble with half its surface covered with ochre and no use-wear related to ochre processing seems to have been dipped in a liquid medium. Possibly used as a stamp to create patterns or apply pigment to soft materials, this object supports the hypothesis that ochre was involved at Porc-Epic Cave in symbolic practices.

Material and methods

The material analysed here includes all ochre pieces recovered at Porc-Epic Cave during Williamson's excavation (1975–1976). Currently housed in a permanent repository at the National Museum of Ethiopia in Addis Ababa, the collection comprises 4213 ochre pieces (39.97 kg, specimen numbers Porc-Epic ochre n. 2–3965) studied by one of us (DR) between 2011 and 2014. A permit to study the archaeological material and to export it temporarily was granted by the Authority for Research and Conservation of Cultural Heritages of Ethiopia (ARCCH). Around 10% of the pieces (n=421) lack contextual information and were excluded from the analysis.

A number of contextual, technological and morphometric variables were recorded for each of the 3792 analysed pieces, including the square and 10 cm spit in which the object was found, the length, width, thickness and weight of complete objects (n=3659), raw material and colour. Raw materials were identified based on their colour, texture, inclusions, hardness and density (Table 1). These visual criteria likely coincide with those considered by Middle Stone Age groups when selecting ochre. When possible, we recorded the original morphology of the piece (small slab, pebble, nodule, irregular). Streak or hardness analyses were not conducted in order to avoid damaging the archaeological specimens. Colour was characterised by visual inspection, and hardness determination was based on pulverulence and hand staining while manipulating the pieces. Light grey pieces were characterised as ochre when they showed red microscopic grains, and ambiguous pieces were not taken into account.

Raw material type	Colour	Texture		Inclusions	Hardness	Density
Soft fine-grained (SFG)	G, Y, BR, BL, O, R, DR	VF	Hom	None or few	Soft to hard	Light
Banded fine-grained (BFG)	Layers of Y, O, R, DR, G, BR	VF	Hom	None or few	Soft to hard	Light
Hard fine-grained (HFG)	G, Y, BL, O, R, DR, BR	VF	Hom	None	Very hard	Heavy
Coarse-grained (CG)	G, Y, BR, O, R, DR	C	Het	Subcirc / irreg	Soft to hard	Normal
Ferruginous sandstone (FS)	G, Y , BR, O, R, DR	C	Hom	Subcirc / irreg	Soft to hard	Normal
Platy fine-grained (PFG)	G, R	F + C	Het	Platelets	Soft	Light

Table 1. Criteria for the determination of ochre types. *G: grey; Y: yellow; BR: brown; BL: black; O: orange; R: red; DR: dark red; VF: very fine; C: coarse; F: fine; Hom: homogeneous; Het: heterogeneous; subcirc: subcircular; irreg: irregular.*

Anthropogenic modifications were identified macro- and microscopically, and photographed with a Leica Z6 APO macroscope (Fig 4). We recorded traces of flaking, striations, facets, smoothed areas, incisions, and pits. Pieces bearing traces of flaking include objects with simple or multiple flake scars and flakes. Striations (Figs 4A and 4B) produced by grinding the piece against an abrasive surface are present as linear parallel marks arranged in groups [21,64,65]. Facets refer to areas flattened by grinding and covered with striations. Facet size and cross-section (convex, flat, concave) were recorded in addition to the orientation of the striations with respect to the facet lengths. Incisions (Figs 4C and 4D) are present as sub-parallel, slightly curved marks displaying multiple grooves (or micro-striations defined as microscopically visible parallel striations) produced by the asperities of lithic cutting edges or other sharp tools during scraping or scoring [21,40,64]. Smoothed areas (Fig 4E) refer to homogeneous surfaces lacking irregularities and projections in comparison to neighbouring unmodified areas or those on which modification marks have been partially or fully erased [64]. Percussion pits (Fig 4F) take the form of depressions produced by a pounding action [38,94,95].

Fig 4. Modifications on ochre pieces. *(A, B) Striations produced by grinding PE102 and PE987. (C, D) Incisions produced by scraping/scoring PE306 and PE1419. (E) Smoothed areas on PE3067. (F) Pits produced by a pounding action on PE931 (OPT21).*

Experimental and ethnographic data

Three ochre pieces were ground on three different grindstones, applying the same pressure until a distinct facet was produced. Grindstones were made of sandstone (G1, Fig 5A), quartzite (G2, Fig 5B), and limestone (G3, Fig 5C), which are among the rock types used at Porc-Epic Cave for grinding ochre [38]. The sandstone grindstone (G1) and ochre pieces used in the experiments (EXP1, EXP2, EXP3) were collected from the wadi Laga Dächatu and are comparable to ochre types found at the site (SFG, CG –see below). EXP1 is made of a soft, clayish, fine-grained homogeneous ferruginous rock. EXP2 and EXP3 are slightly harder. The first is more heterogeneous and contains a few well cemented coarse grains. The second is highly heterogeneous and rich in well cemented coarse grains.

The nine powder samples produced during the experiments were kept in separate sampling tubes and submitted to granulometric analyses described below. Two samples of ochre powder produced by Hamar women [96–98] to coat their hair and six samples of ochre ground by Ovahimba women to cover their body, hair and attire were also submitted to granulometric analyses. Both Ovahimba and Hamar women produce pigment powder by crushing ochre lumps with upper grindstones and grinding the resulting fragments between upper and lower grindstones. The Hamar samples were collected by one of us (DR) in Turmi and Dombo, Southern Ethiopia. Results of the analysis of Ovahimba samples, collected during fieldwork conducted by one of us (FD), have been presented elsewhere [30].

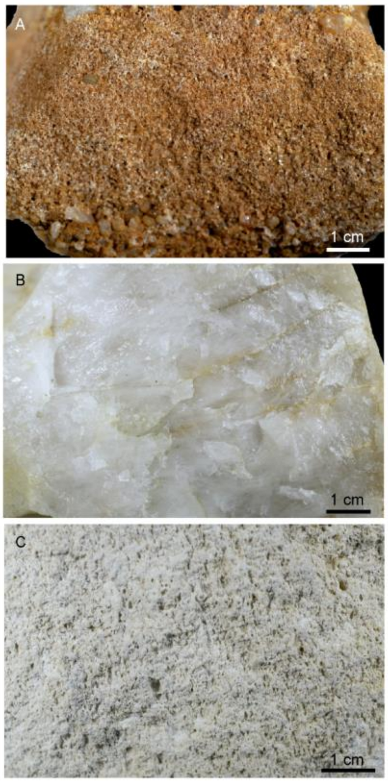

Fig 5. Experimental grindstones.
Experimental grindstones G1 (A), G2 (B) and G3 (C).

Surface texture analysis

Different surface textures result from material loss due to abrasion [99]. This is the case with facets created by grinding ochre pieces on grindstones. Confocal microscopy allowed the surface topography of experimental and archaeological facets to be quantitatively compared in order to explore whether the type of grindstone can be identified.

Rugosimetric analysis was conducted with a Sensofar S-Neox confocal microscope driven by the SensoScan 6 software (Sensofar, Barcelona) on facets present on nineteen SFG (see below) ochre pieces from Porc-Epic Cave and nine facets produced experimentally. The archaeological ochre pieces vary in texture and show features intermediate between EXP1 and EXP2. Depending on the facet surface, one to three 4 x 3 mm² areas were captured per facet. We used a 20x objective (N.A. 0.45) with green light illumination and a measurement step of 1 µm. These parameters allow for a spatial sampling of 0.65 µm and a vertical resolution of 8 nm. Only surfaces with more than 95% of measured points were retained for analysis.

Data was processed with SensoMap 7.3. Form was removed by subtracting a second-degree polynomial, and isolated or around edge outliers were removed and non-measured points filled. A Gaussian filter was applied to these areas to separate roughness and waviness with a 0.25 mm cut-off value, and captured areas were subsequently divided into four 2 x 1.5 mm^2 sub-areas. ISO 25178 international standards were used to calculate different 3D area surface texture parameters for roughness [100–102]. We selected one height parameter (Sq: Root Mean Square Roughness, i.e. standard deviation of the height distribution) for further analysis and one hybrid parameter (Sdr: developed interfacial area ratio, i.e. the increase in surface when flattening the measured area). Sq quantifies the statistical distribution of height values around the mean plane and Sdr the complexity of the surface [103].

Particle-size analysis

A Horiba LA950 laser scattering particle sizer was used to analyse experimental and ethnographic ochre powder. *Mie* solution to Maxwell's equations [104], which provides the basis for measuring the size of particles through the scattering of electromagnetic radiation, was used to calculate the particle size distribution in aqueous solution (refractive index 1.333). Calculations were made with the refractive index of hematite (2.94i–0.01i). The pre-treatment of samples included suspension in sodium hexametaphosphate (5 g/L) for 12 hours and 60 seconds of ultrasonification to achieve optimal dispersion.

Results

Raw material types and colour

The ochre pieces display a variety of colours and shades (Fig 6, Figs A–E in S1 Figs). Three quarters (n=2700; 71%) have a single colour, followed by smaller numbers with either two (n=1063) or three (n=29) (Fig 7, Tables A–E in S1 Tables). While yellow, orange, red, dark red, brown, grey and black shades were identified, red and dark red shades are most common, accounting, respectively, for 37.6% and 26% of the total number of pieces. Pieces combining either red and grey (12.5%) or red and yellow (4.88%) are also relatively frequent.

Due to the high degree of fragmentation and reduction intensity, it was possible to determine the original morphology of pieces for only 29% of the pieces (Table 2). Ochre was most frequently imported to the site in the form of slabs (n=401, Fig 6A), followed by irregular pieces (n=265, Figs 6C, 6D, 6G), nodules (n=260, Fig 6B) and pebbles (n=166, Fig 6H).

Fig 6. Ochre pieces from Porc-Epic Cave. *(A) Ochre piece PE1699, SFG. (B) Ochre piece PE2104, BFG. (C) Ochre piece PE1752, HFG. (D) Ochre piece PE436, PFG. (E) Ochre piece PE1577, FS. (F) Ochre piece PE809, CG. (G) Ochre piece PE962, HFG. (H) Ochre piece PE2563, SFG. (I) Ochre piece PE420, SFG. (J) Ochre piece PE2063, SFG. (K) Ochre piece PE3358, SFG. (L) Ochre piece PE312, SFG. (M) Ochre piece PE1806, BFG. (N) Ochre piece PE987, SFG. (O) Ochre piece PE3067, SFG. (P) Ochre piece PE1862, SFG. (Q) Ochre piece PE1677, SFG. (R) Ochre piece PE1493, SFG. (S) Ochre piece PE102, BFG. (T) Ochre piece PE306, BFG. (U) Ochre piece PE1419, HFG. (V) Ochre piece PE931, OPT21, BFG.*

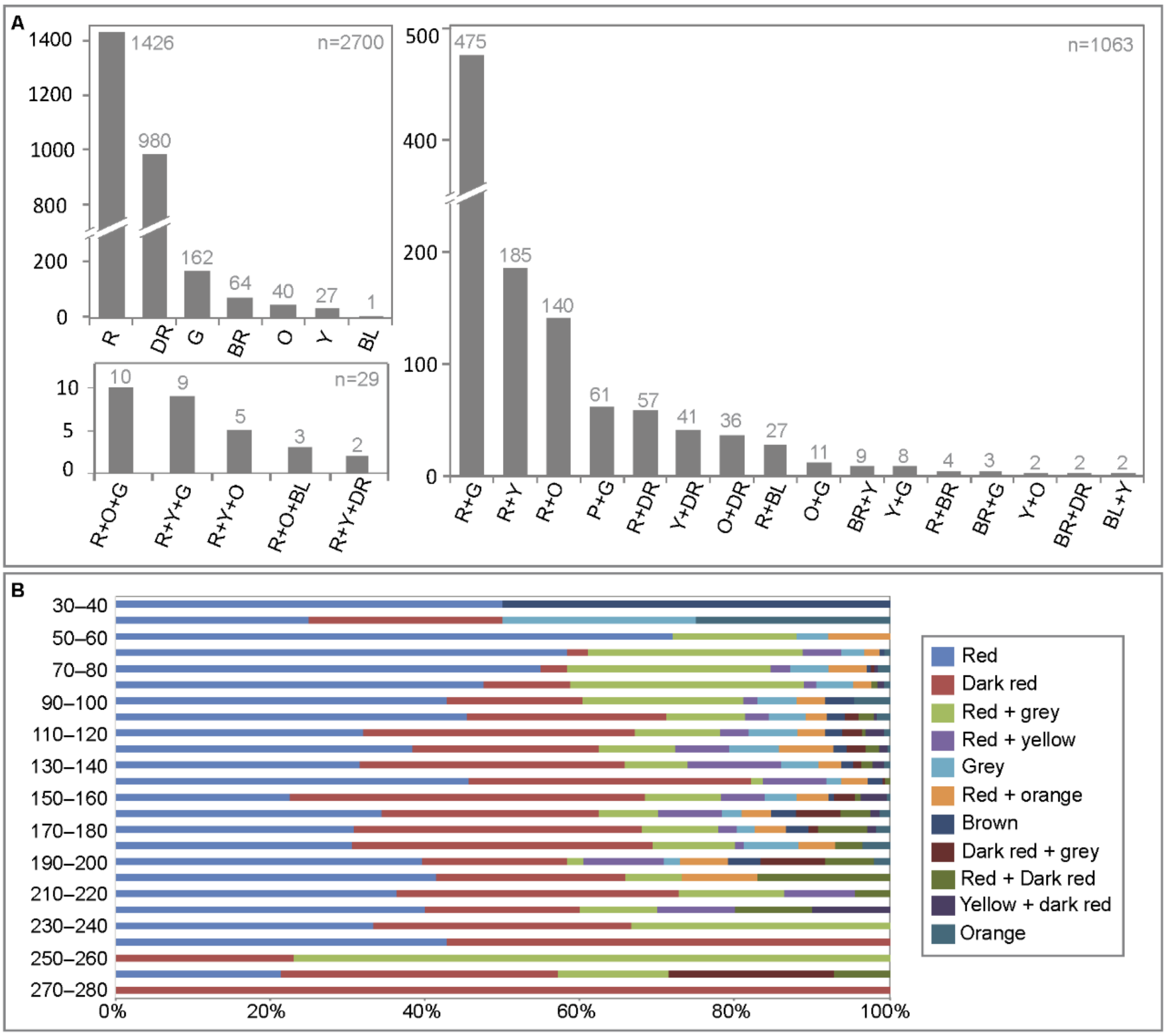

Fig 7. Colours of ochre pieces from Porc-Epic Cave. *(A) Grey numbers represent the number of pieces. Colours per ochre piece are represented in separate histograms. R: red. DR: dark red; G: grey; BR: brown; O: orange; Y: yellow; BL: black. (B) Vertical distribution of main colours and colour associations on ochre pieces. Data is presented in percentages for 10 cm spits. (C) Main colours and colour associations on modified and unmodified ochre pieces by weight. (D) Main colours and colour associations on ochre pieces by raw material type. (E) Main colours and colour associations on ochre pieces by modification type.*

Morphology	Unmod	%Unmod	Mod	%Mod	TOTAL	%TOTAL
Undetermined	1426	69.46	1274	73.26	2700	71.20
Slab	263	12.81	138	7.94	401	10.57
Pebble	64	3.12	102	5.87	166	4.38
Nodule	115	5.60	145	8.34	260	6.86
Irregular	185	9.01	80	4.60	265	6.99
Total	2053	100	1739	100	3792	100

Table 2. Morphology of unmodified and modified ochre pieces. *Number and percentages of ochre pieces. Unmod: unmodified; Mod: modified.*

Six types of raw material were identified (Fig 8, Table 1).

- Soft, fine-grained ferruginous rocks (SFG, Figs 8A and 8B): homogeneous, fine-grained, clayish rocks with very few or no inclusions that are mostly red and dark red, but also grey, brown, orange or yellow in colour and only rarely bear small black spots (Fig 7D). Most are slabs (n=339) or irregular pieces (n=218), although nodules (n=117) and pebbles (n=107) are also observed. Several examples have a compact structure; others are laminated or show small cavities. These raw materials are generally light.
- Banded, fine-grained ferruginous rocks (BFG, Figs 8C and 8D): rocks with the same texture and appearance as type SFG but with clearly differentiated layers of colours, that are mostly red and yellow, or red and orange but also dark red, grey or brown (Fig 7D). These rocks are mostly found as nodules (n=90), followed by smaller numbers of slabs (n=23) and irregular pieces (n=19) or pebbles (n=14). Generally light, these materials usually have a compact structure.
- Hard, fine-grained ferruginous rocks (HFG, Figs 8E and 8F): very hard and heavy iron oxides characterised by dark colours, mostly grey and red, but also black. They rarely show brown, yellow, dark red, grey and orange spots (Fig 7D). These materials usually occur as nodules (n=51) and pebbles (n=45) and more rarely as slabs (n=33) and irregular pieces (n=24).
- Coarse-grained ferruginous rocks (CG, Figs 8G and 8H): heterogeneous agglomerates of mostly red, dark red and grey grains, and more rarely yellow, orange, and brown grains (Fig 7D). They are generally irregular in shape (n=49) or occur in the form of nodules (n=42) and, to a lesser degree, pebbles (n=25) or slabs (n=28).
- Ferruginous sandstone (FS, Figs 8I and 8J): agglomerates of translucent grains (probably quartz) in a fine iron oxide matrix. They are mostly red and orange, sometimes with dark red, grey, brown and yellow spots (Fig 7D). Although commonly found as slabs (n=5), nodules (n=2) or pieces with irregular morphologies (n=2) were also recorded.
- Platy fine-grained ferruginous rocks (PFG, Figs 8K and 8L): agglomerates of platelets (probably micas) characterised by a shiny or metallic-like appearance. They are usually greyish with red veins (Fig 7D), and can be irregular (n=2) or flat in shape (n=1).

SFG is the most frequent type (68.2%, n=2588), followed by CG (12.8%, n=486), BFG (9.78%, n=371) and HFG (8.14%, n=309). The FS and PFG are rare (n=30 and 8), accounting, respectively, for only 0.79% and 0.21% of the assemblage (Table F in S1 Tables).

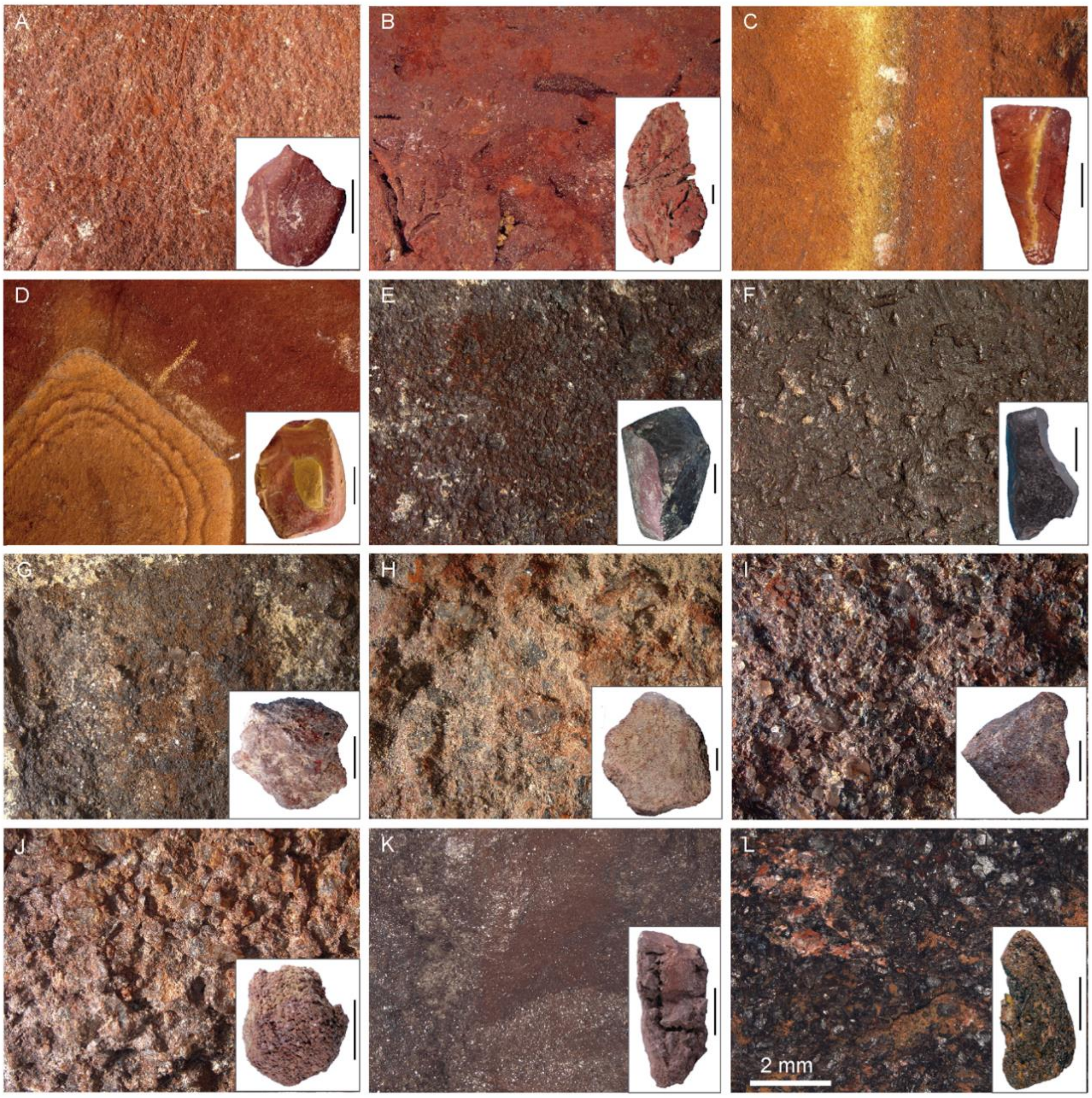

Fig 8. Ochre raw material types. *(A, B) Soft fine-grained (SFG): PE725 and PE1942. (C, D) Banded fine-grained (BFG): PE1806 and PE2104. (E, F) Hard fine-grained (HFG): PE1734 and PE2282. (G, H) Coarse-grained (CG): PE809 and PE1666. (I; J) Ferruginous sandstone (FS): PE965 and PE1577. (K, L) Platy fine-grained (PFG): PE436 and PE1812. Scales of overall photos of the pieces = 1 cm.*

Raw material and colour changes through time

The proportion of the six raw materials remains relatively stable throughout the sequence (Fig 9, Table F in S1 Tables). Variations observed at the top (-30–60 cm) and bottom (-210–280 cm) of the sequence are not substantial due to small sample size. More than half of the ochre pieces in all levels are of the SFG type; the proportion of type CG oscillates between 10% and 15%, and types BFG and HFG range between 5% and 15%, and 3% and 20%, respectively. Type FS is systematically present, but in very low proportions. Type PFG is only recorded sporadically in levels in which ochre is abundant. The only noticeable change concerns type HFG, which is more abundant at depths between -60–140 cm. HFG type increases consistently from 140 to 80 cm and then declines slightly from 80 to 60 cm. The two areas with concentrations of ochre and ochre processing tools (Fig 3) follow the same pattern of the levels in which they occur. By weight (Tables G and H in S1 Tables), the proportion of each raw material does not differ substantially from what we described above for their numbers. SFG is still the most frequent raw material type, oscillating between 76% and 40% per level, followed by CG (8–42%). BFG and HFG range between 3% and 20% and 5% and 27% respectively. FS and PFG are still present in low proportions.

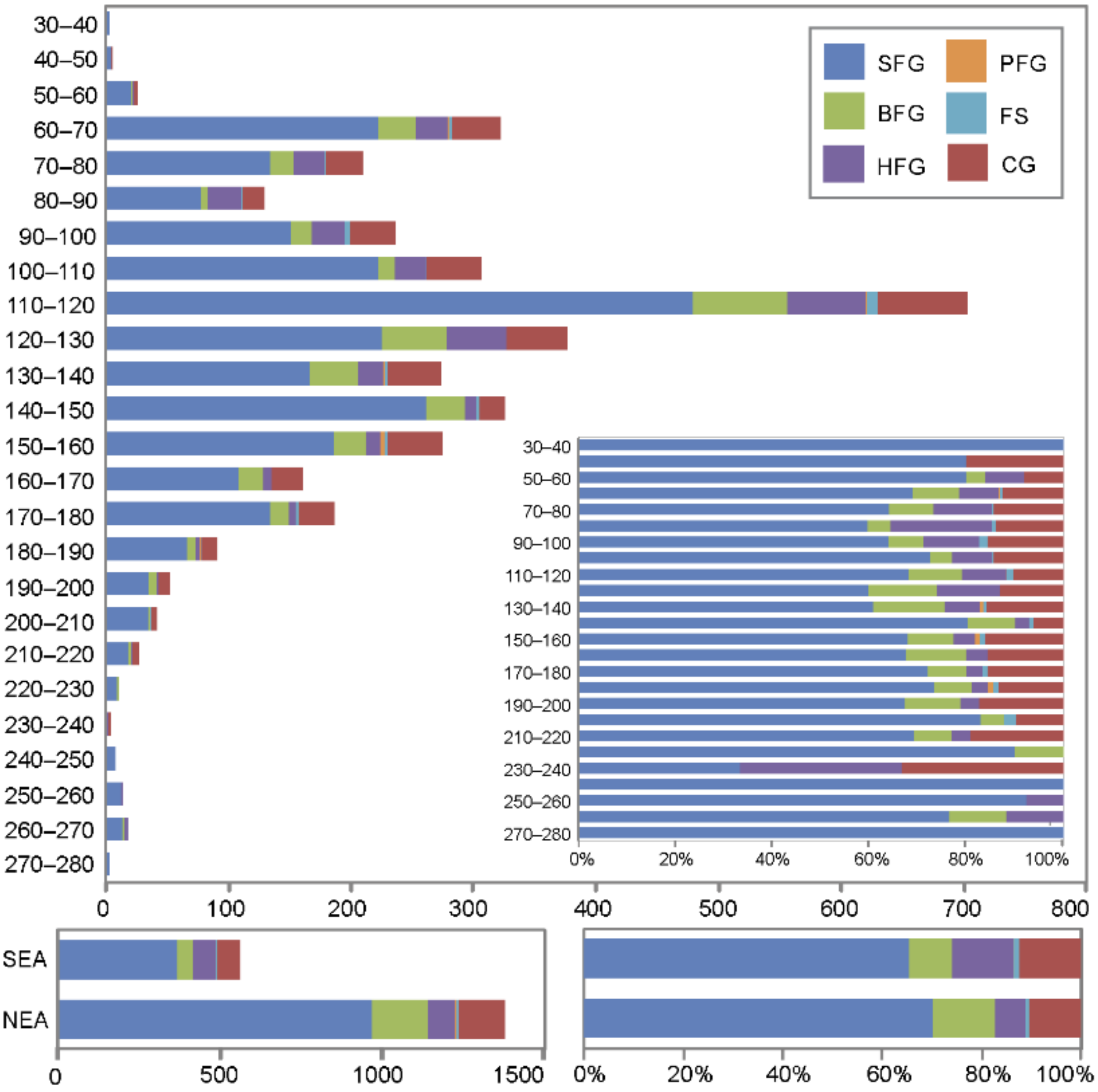

Fig 9. Vertical distribution of ochre pieces per raw material type. *Data is presented in number of pieces and percentages. Separate histograms are presented for ochre from the northeastern (NEA) and southeastern (SEA) accumulations. SFG: Soft fine-grained; BFG: banded fine-grained; HFG: hard fine-grained; PFG: platy fine-grained; FS: ferruginous sandstone; CG: coarse-grained.*

Interesting differences can be seen in the proportion of ochre colours over time (Fig 7B, Tables A and B in S1 Tables). Although red and dark red shades are dominant in all levels, they become proportionally less well represented in levels in which ochre is more abundant (-60–160). These levels are richer in grey, brown, orange, and yellow pieces and pieces of multiple colours. We also observe a decline in dark red, and red+yellow, and an increase in red, and red+grey between 100 cm and 60 cm.

Diachronic changes are also observable in terms of piece morphology. Slabs gradually increase in proportion towards the upper levels while irregular pieces follow the opposite trend (Fig 10). The same pattern can be seen with the two ochre concentrations (Figs 3 and 10).

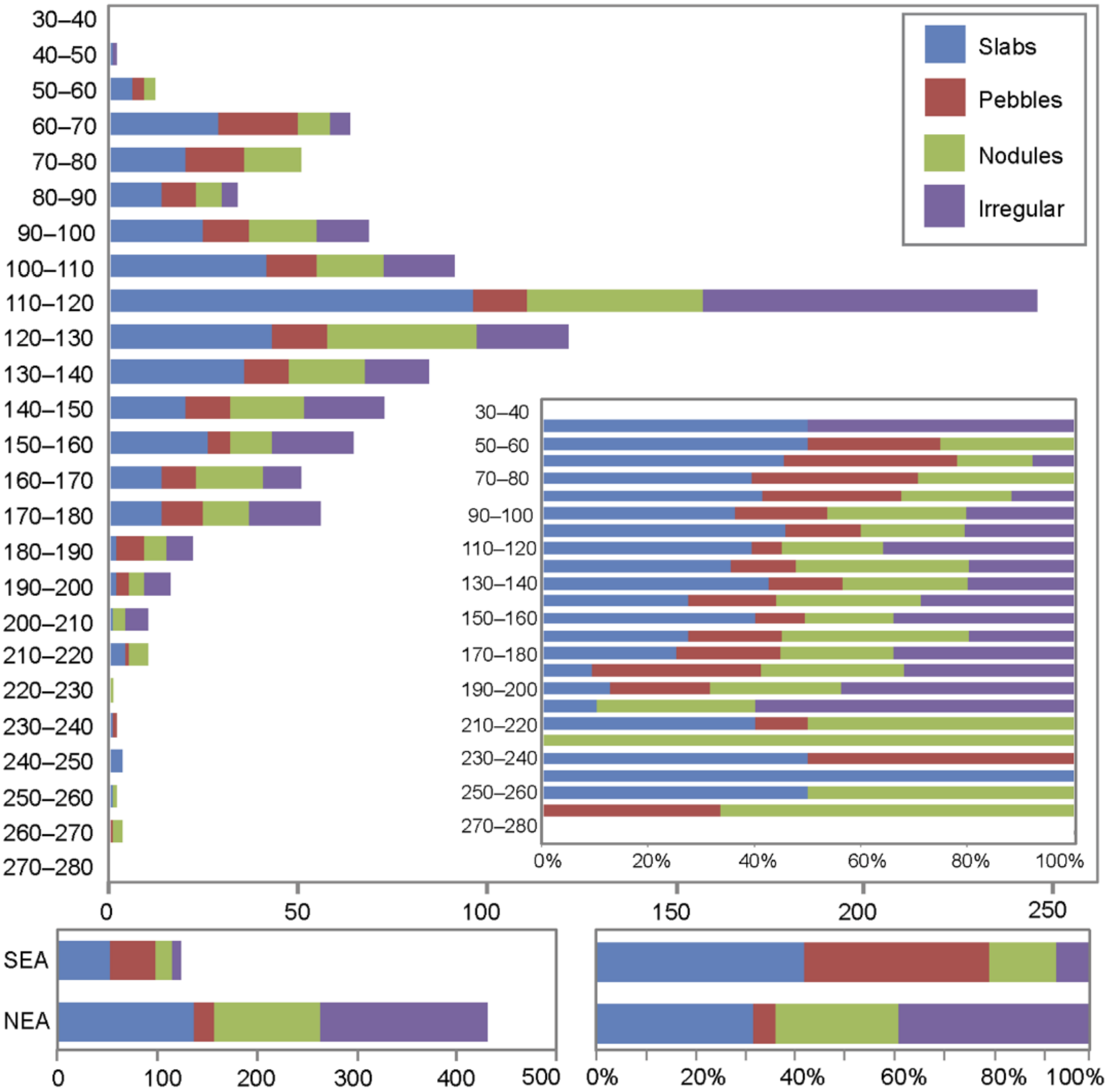

Fig 10. Vertical distribution of ochre piece morphology. *Data is presented in number of pieces and percentages. Pieces with undetermined morphologies were not included. Separate histograms are presented for ochre pieces from the northeastern (NEA) and southeastern (SEA) accumulations.*

Technological analysis

Traces of modification

Almost half (n=1739; 45.8%) of the 3792 analysed ochre pieces bear anthropogenic modifications (Table I in S1 Tables), accounting for 63.2 % (25.3 kg) of the total weight of the analysed assemblage (Table J in S1 Tables).

Traces of flaking are most frequent (Table 3, Table K in S1 Tables), recorded on 1242 (71.4%) of the modified pieces or 45.1% (18 kg) of the total ochre analysed, in the form of flake scars (n=1006, 57.8%, Fig 6H, Fig A in S1 Figs) and flakes (n=236, 13.5%, Fig 6J, Fig A in S1 Figs). The latter include 17 bladelets (Fig 6I, Fig A in S1 Figs) and a number of retouched pieces, two of which resemble transverse scrapers (Figs 6K and 6L, Fig A in S1 Figs). Fourteen pieces bearing multiple, adjacent flake scars were clearly used as cores to produce ochre flakes. Lumps with traces of grinding (n=913, 52.5%; 14.3 kg, 35.8% of the total ochre analysed; Figs 6B, 6C, 6L–6S, Figs B and C in S1 Figs) comprise either pieces with clear facets (n=821, 42.2%) or areas covered by parallel striations that do not flatten the surface (n=92, 5.2%). A relatively small proportion of pieces (n=161, 17.6%) bear traces of grinding over more than 50% of their surface, a third (n=334, 36.6%) half of their surface, and almost half (n=418, 45.7%) less than 50% of their surface.

While the number of facets on ground ochre varies between 1 and 18, more than half only have one facet (51.8%, n=426). Pieces with two of more facets gradually decrease in proportion, with only six examples having 8 or more facets (Table 3). In cases of pieces with more than one facet (n=395), facets are usually adjacent (n=343, 86.8%). Facets on distinct areas are rare (n=34, 8.6%) and very few pieces bear both isolated and adjacent facets (n=18, 4.5%). Juxtaposed facets producing a geometric or pointed morphology are present on less than a hundred examples (n=96, Figs 6N, 6P–6S, Fig B in S1 Figs). Of complete identifiable facets (n=1665, 99 % Figs 6B, 6C, 6M–6S, Figs B and C in S1 Figs), most are convex (n=1184, 71.1%) or flat (n=429, 25.8), rather than concave (n=19, 1.1%) or irregular (n=16, 0.9%) (Table L in S1 Tables). Striations are in most cases oriented obliquely to the main axis of the facet (n=898; 53.9%, Table L in S1 Tables) although they can also be longitudinal (n=437, 26.2%) or perpendicular (n=78, 4.7%). Overlapping striations include combinations of oblique and longitudinal (n=167, 10%), oblique and perpendicular (n=12, 0.7%), longitudinal and perpendicular (n=3, 0.2%) and random (n=41, 2.4%) orientations. The orientation could not be determined in only 29 cases (1.7%).

MODIFICATIONS	OCHRE TYPES						Total (n)	OCHRE TYPES (kg)						Total (kg)
	SFG	CG	BFG	HFG	FS	PFG		SFG	CG	BFG	HFG	FS	PFG	
FLAKING	**827**	**96**	**163**	**151**	**4**	**1**	**1242**	**8.14**	**4.18**	**2.16**	**3.45**	**0.05**	**0.01**	**18.01**
Flake scars	*641*	*84*	*136*	*141*	*3*	*1*	*1006*	*7.35*	*4.11*	*2.04*	*3.26*	*0.05*	*0.01*	*16.82*
Flakes	*186*	*12*	*27*	*10*	*1*	*0*	*236*	*0.8*	*0.07*	*0.12*	*0.2*	*0*	*0*	*1.19*
GRINDING	**635**	**73**	**109**	**90**	**4**	**2**	**913**	**7.93**	**2.61**	**1.55**	**2.2**	**0.04**	**0.02**	**14.37**
1 facet	*293*	*34*	*60*	*37*	*1*	*1*	*426*	*2.59*	*0.74*	*0.68*	*0.62*	*0.02*	*0.01*	*4.67*
2 facets	*141*	*16*	*17*	*15*	*1*	*0*	*190*	*2.2*	*0.66*	*0.31*	*0.34*	*0*	*0*	*3.51*
3 facets	*78*	*8*	*5*	*9*	*0*	*1*	*101*	*0.75*	*0.54*	*0.13*	*0.18*	*0*	*0.01*	*1.60*
4 facets	*20*	*5*	*6*	*6*	*1*	*0*	*38*	*0.45*	*0.4*	*0.09*	*0.24*	*0.02*	*0*	*1.20*
5 facets	*19*	*1*	*6*	*4*	*0*	*0*	*30*	*0.43*	*0.01*	*0.09*	*0.12*	*0*	*0*	*0.65*
6 facets	*12*	*1*	*1*	*5*	*0*	*0*	*19*	*0.43*	*0*	*0.02*	*0.46*	*0*	*0*	*0.90*
7 facets	*8*	*1*	*1*	*1*	*0*	*0*	*11*	*0.11*	*0.07*	*0.03*	*0.01*	*0*	*0*	*0.22*
8 facets	*1*	*0*	*1*	*0*	*0*	*0*	*2*	*0.01*	*0*	*0.02*	*0*	*0*	*0*	*0.02*
9 facets	*1*	*0*	*1*	*0*	*0*	*0*	*2*	*0.02*	*0*	*0.02*	*0*	*0*	*0*	*0.05*
11 facets	*0*	*0*	*0*	*1*	*0*	*0*	*1*	*0*	*0*	*0*	*0.02*	*0*	*0*	*0.02*
18 facets	*0*	*0*	*1*	*0*	*0*	*0*	*1*	*0*	*0*	*0.01*	*0*	*0*	*0*	*0.01*
SCRAPING	**76**	**8**	**21**	**6**	**0**	**0**	**111**	**1.28**	**0.78**	**0.32**	**0.57**	**0**	**0**	**2.95**
SMOOTHING	**41**	**19**	**7**	**4**	**0**	**0**	**71**	**0.91**	**1.06**	**0.17**	**0.11**	**0**	**0**	**2.24**
PITTING	**8**	**4**	**1**	**1**	**0**	**0**	**14**	**0.62**	**0.72**	**0.11**	**0.36**	**0**	**0**	**1.81**
1 end	*6*	*1*	*0*	*0*	*0*	*0*	*7*	*0.21*	*0.07*	*0*	*0*	*0*	*0*	*0.28*
2 ends	*2*	*1*	*1*	*1*	*0*	*0*	*5*	*0.42*	*0.28*	*0.11*	*0.36*	*0*	*0*	*1.17*
Entire surface	*0*	*2*	*0*	*0*	*0*	*0*	*2*	*0*	*0.36*	*0*	*0*	*0*	*0*	*0.36*

***Table 3. Number of modified ochre pieces and weight per modification type and raw material.** SFG: Soft fine-grained; CG: coarse-grained; BFG: banded fine-grained; HFG: hard fine-grained; FS: ferruginous sandstone; PFG: platy fine-grained. Notice that each modification type is considered independently. The total for pieces with ground facets is less than the total of ground pieces because some show striations due to grinding that was not intensive enough to create a flat surface.*

Incisions produced by scraping and scoring (Figs 6A, 6N, 6T, 6U, Fig D in S1 Figs) were identified on 111 pieces (6.4%; 2.9 kg or 7.2 % by weight). Smoothed areas (Fig 6O, Fig D in S1 Figs) were detected on 71 pieces (4%; 2.2 kg or 5.5 % by weight). Percussion pits (Fig 6V, Fig C in S1 Figs) were recorded on 14 (0.8%; 1.8 kg or 4.5 % by weight) and are located on one end (n=7), two ends (n=5), or the entire surface of the piece (n=2).

Most pieces only bear one type of modification (n=1192, 68.5%), a third associate two (n=489, 28.2%), and only a few examples produced evidence for three (n=51, 2.9%) or four (n=5, 0.3%) types (Table 4, Table M in S1 Tables). Flaking is the only modification present on 756 pieces, (43.5%) grinding the only recorded on 403 pieces (23.2%), with 397 (22.8%) bearing evidence for both. Pieces with traces of scraping and grinding (n=38, 2.2%), flaking, grinding and scraping (n=35, 2%), or flaking associated with smoothed areas (n=21, 1.2%) are less frequent and only a single object shows all types of identified modifications. Pieces bearing multiple modifications are found in all levels with large ochre assemblages (-60–190 cm) and combinations of different modifications remain relatively stable across the sequence (Table M in S1 Tables, Fig 11B).

Num of pieces	SM	GR	SC	FK	P
14	■				
16	■	■			
403		■			
1	■	■	■		
2	■		■		
12	■	■		■	
4	■	■	■	■	
38		■	■		
21	■			■	
17			■		
35		■	■	■	
397		■		■	
1	■	■	■	■	■
10			■	■	
1		■	■	■	■
4		■			■
2		■		■	■
1			■	■	■
756				■	
2				■	■
2					■

***Table 4. Combinations of modification types on single ochre pieces.** Num.: number; SM: smoothing; GR: grinding; SC: scraping; FK: flaking; P: pitting.*

Modifications by raw materials

Of the four best represented raw materials (SFG, CG, BFG, HFG), almost 60% of HFG and BFG pieces bear traces of intentional modification. This is considerably more than what is observed for SFG (46%) and CG (29%). By weight, modified ochre represent 67% and 68% of HFG and BFG respectively, 65% of SFG, and 58% of CG. The five identified types of modification (flaking, scraping, grinding, smoothing, pitting) were all observed (Fig 12, Table 3) on these four raw materials. Regardless of raw material type, half bear traces of flaking, 35–40% traces of grinding, 2.4–7% evidence of scraping. On the other hand, traces of smoothing (9.5 %) and pitting (2%) are clearly more abundant with the CG. Scraping is barely represented in the HFG category, which is consistent with the hardness of this material. Single or multiple facets were observed on all types of raw materials with evidence for grinding. However, pieces with multiple facets are comparatively overrepresented in HFG, particularly in the range of 4–6 facets. More than half of pieces with facets in this raw material present more than one facet and 34% more than two, whereas facet frequencies are lower than 50% and 25%, respectively, for the other types of raw material. By weight, HFG pieces with more than two facets represent

51% of pieces with facets in this material, while this is the case in only 31%, 42% and 29% for the SFG, CG and BFG categories respectively.

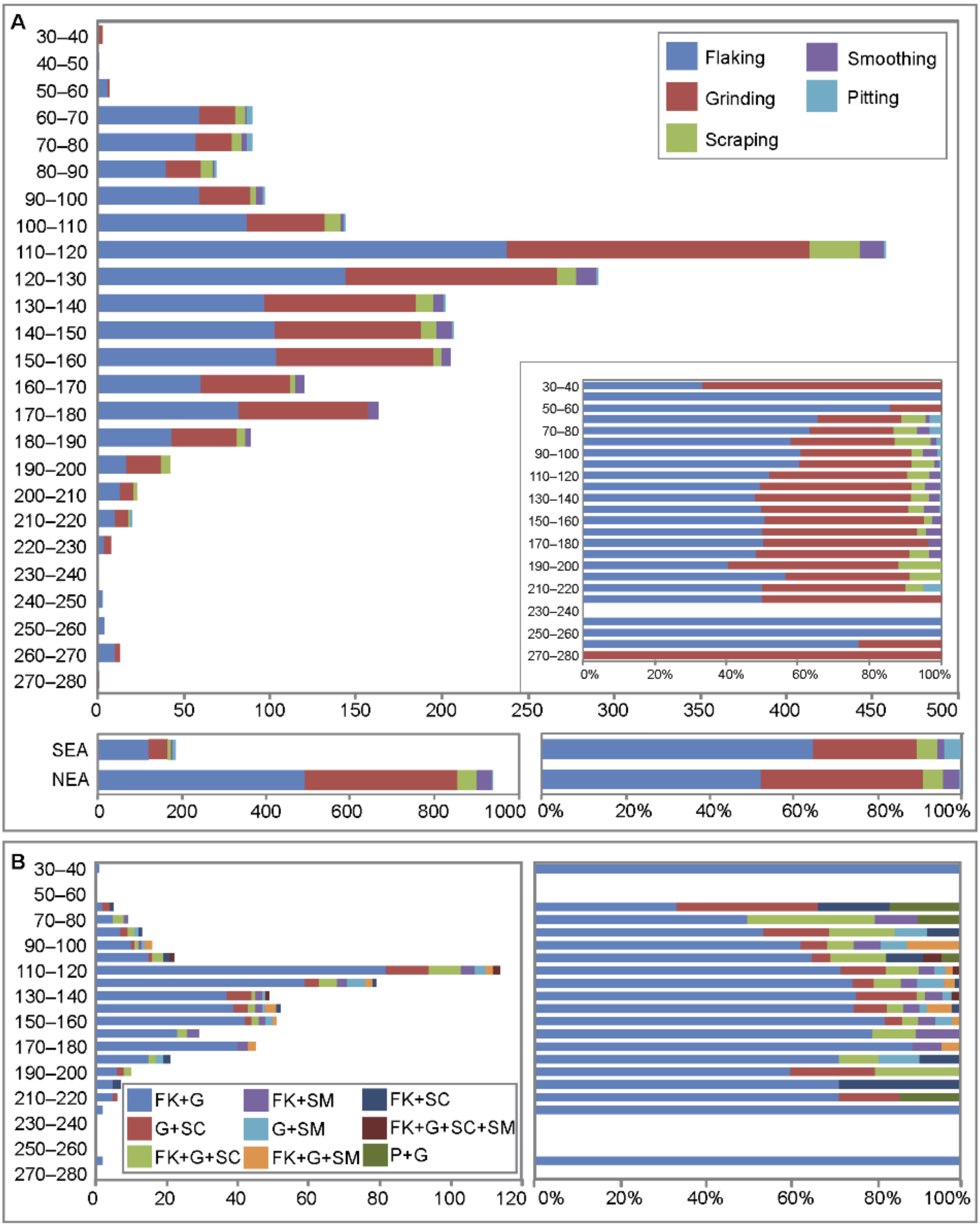

Fig 11. Vertical distribution of modifications identified on ochre lumps. *Data is presented in number of pieces and percentages. (A) Occurrence of each modification type throughout the sequence. Separate histograms are presented for ochre pieces from the northeastern (NEA) and southeastern (SEA) accumulations. (B) Occurrence of main combinations of modifications. Ochre pieces with only one modification or combinations that appear on less than 4 pieces were excluded. FK: flaking, GR: grinding; SC: scraping; SM: smoothing; P: pitting.*

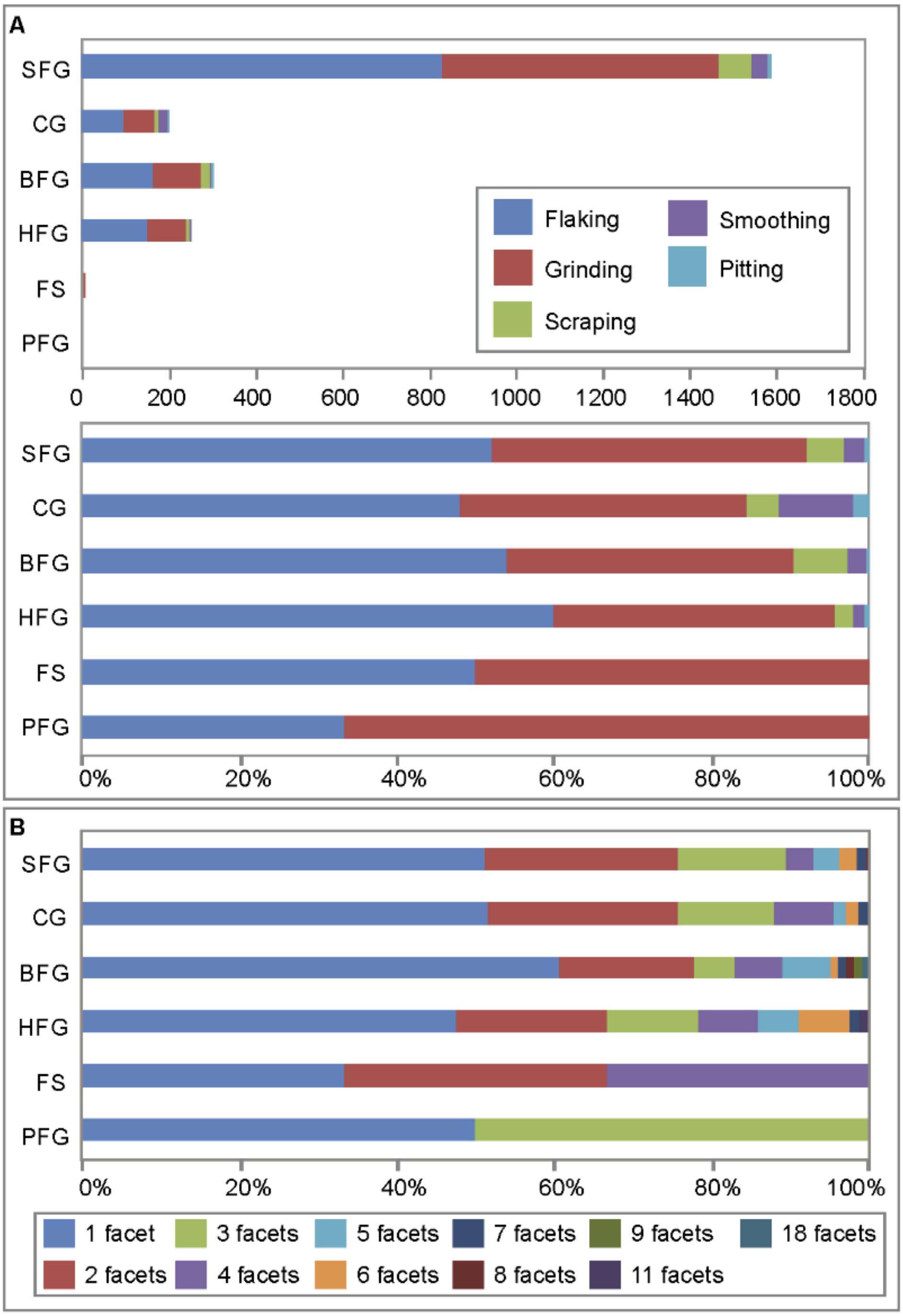

Fig 12. Modifications and number of facets per ochre raw material type. *(A) Modifications by raw material. Data is presented in number of pieces and percentages. (B) Number of facets resulting from grinding by raw material. Data is presented in percentages.*

All types of modification are found in similar proportions on ochre pieces of different colour. In other words, the type of techniques applied to the ochre was not dependent on their colour (Fig 7E, Table E in S1 Tables). The only possible difference is the overepresentation of pits on red and grey ochre pieces. However, this is probably linked to the fact that pitting is more common in the CG, a raw material that is often red and grey, as indicated above.

Changes in ochre treatment

The proportion of modified ochre pieces decreases progressively from -200–210 cm to -60–70 cm spits (Fig 13, Table I in S1 Tables) when analysed by number of pieces, and from -140–150 to -40–50 when analysed by weight (Table J in S1 Tables). This trend is worth noticing, considering the large number of ochre pieces recovered in these levels.

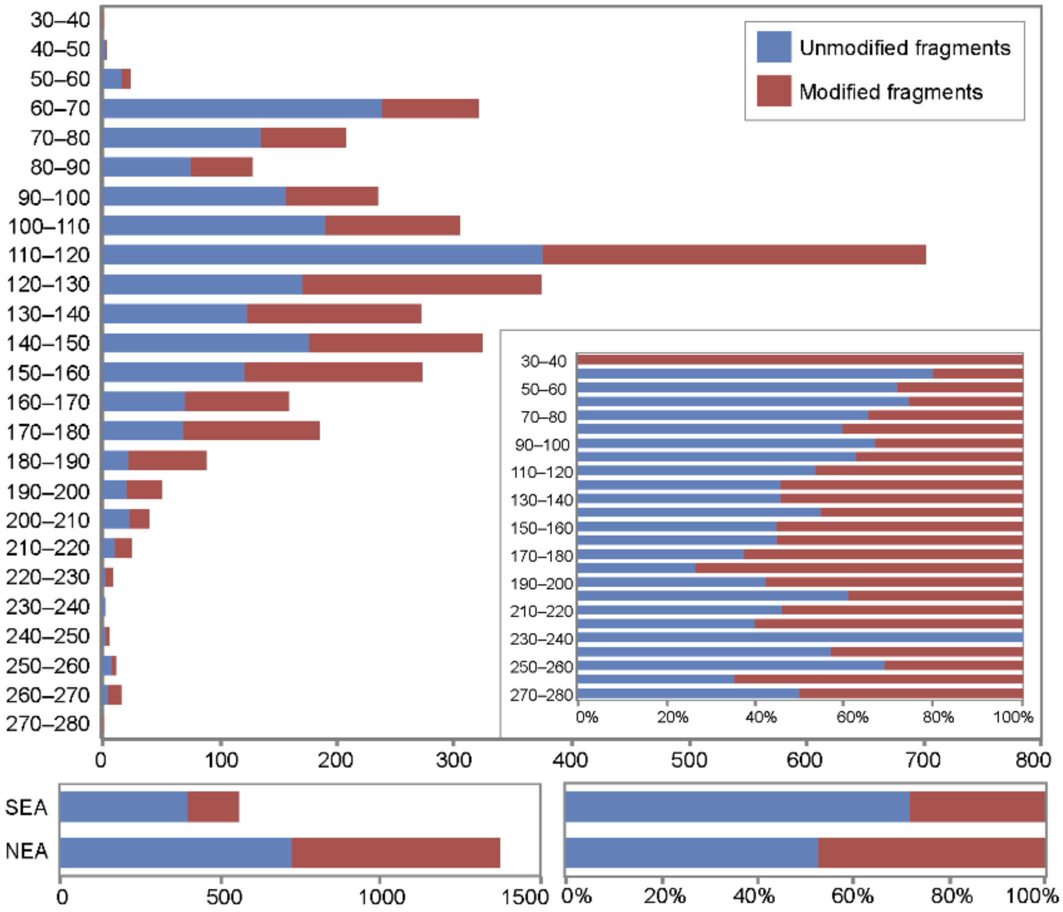

Fig 13. ***Vertical distribution of modified and unmodified ochre lumps.*** *Data is presented in number of pieces and percentages. Separate histograms are presented for ochre pieces found in the northeastern (NEA) and southeastern (SEA) accumulations.*

Ochre recovered from accumulations SEA and NEA reveal the same proportion of modified and unmodified ochre pieces recorded in the other squares of their respective levels. Interesting diachronic changes are also observable in the way ochre was modified (Fig 11, Table K in S1 Tables). There is a general gradual increase of flaking, scraping and pitting from the bottom to the top of the sequence. Flaking is fairly constant at about 50% between -220 and 120, and progressively increases between -120 cm to the top of the sequence (except for a slight decrease at -80–90), from around 60% to more than 80% at -50–60. Evidence for scraping progressively augments from 2.5% in the 160–170 spit to 7% in the -60–70 cm spit. Practically absent in levels between -200 cm and 110 cm, pitting accounts for 3.3% of all modifications in the -60–70 spit. In contrast, grinding becomes increasingly rare; evident on 48% of pieces in the -190–200 spit and only to 23% in the -60–70 spit. The levels in which evidence for grinding is more frequent (-90–190 cm) are also those where this type of modification is most intense, as indicated by the high number of facets per piece at these depths (Fig 14A).

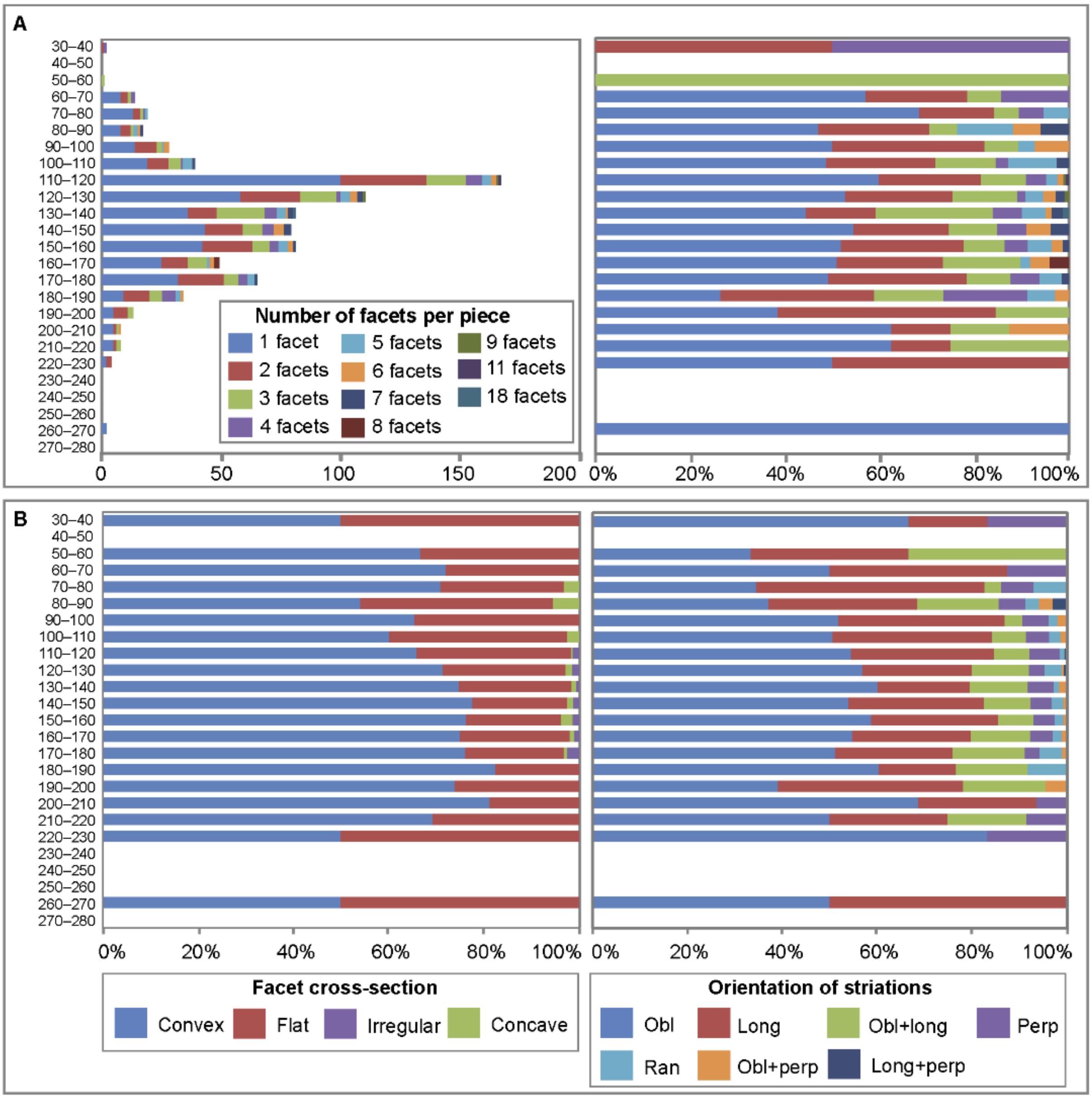

Fig 14. Vertical distribution of ochre lumps with facets, facet cross-sections and orientation of striations. *(A) Distribution of ochre pieces with facets produced by grinding, per number of facets. Data is presented in number of pieces and in percentages. (B) Distribution of facets by cross-section type and orientation of striations with respect to the main axis of the facet. Facets with undetermined cross-sections or orientation of striations were excluded. Data is presented in percentages.*

In levels between -160–130 cm, there is a consistent increase in the proportion of more intensively ground pieces moving up the sequence. Facet cross-sections (Fig 14B, Table L in S1 Tables) remain stable throughout the stratigraphy, with convex facets always more frequent than flat facets. Concave or irregular facets appear only between -70 and 180 cm and -110–180 cm, respectively. The orientation of striations (Fig 14B, Table L in S1 Tables) on the facets changes slightly and gradually throughout the stratigraphy, with oblique striations decreasing from 83.3% in the -220–230 spit to 33.3% in the -50–60 spit and longitudinal striations increasing from 23.1% in the -210–220 spit to 45.2% in the -70–80 spit. Facets with oblique and longitudinal or uniquely perpendicular striations remain relatively stable. Facets with random striations or oblique and perpendicular striations appear, respectively, between 70 and 190 cm and between 80 and 200 cm below datum. Ochre accumulations SEA and NEA do not differ from what was observed in the other squares of their respective levels in terms of the proportion of techniques observed (Figs 11A and 13).

Size and weight of ochre pieces

Ochre pieces vary considerably in terms of size and weight (Figs 15 and 16, Tables 5 and 6). They can reach 12 cm in length (mean= 24.6 mm), 9 cm (mean=17.2 mm) in width, 6,6 cm in thickness (mean=10.7 mm), and 678 gr in weight (mean=10.6 gr). No significant changes in size and weight are observed throughout the sequence (Table G in S1 Tables). This suggests that the higher number of ochre pieces in layers -180–60 cm is not due to a higher fragmentation occurring in these layers. When observing mean sizes of pieces of SFG, it appears that they are slightly smaller and lighter than what is observed with the other raw materials (Fig 15, Table 5). The opposite is seen with CG, with modified pieces of this raw material being on average three times heavier than unmodified examples. Moreover, in three categories (SFG, CG, and BFG), modified pieces are substantially larger and heavier than their unmodified counterpart. Red, dark red, orange and brown pieces tend to be lighter than grey pieces. This is consistent with the fact that pieces of SFG are generally lighter than pieces of CG (Table C in S1 Tables). No substantial differences in size and weight are recorded between pieces modified by grinding, scraping and pitting (Fig 16, Table 6). On the other hand, examples with traces of smoothing are larger and heavier than those modified with the other three techniques. Pieces bearing flake scars are similar in size to those modified by the other techniques but considerably larger and heavier than flakes (Fig 16). This implies that the size of most flakes rendered them unsuitable for grinding, scraping, pitting, and smoothing. Contrary to what one may expect, the size of the pieces does not decrease with the number of facets produced by grinding. We observe an increase in length with an increase in the number of facets, particularly in pieces with 1 to 4 facets (Fig 16). These differences are statistically significant (Table N in S1 Tables). However, pairwise comparisons are only significant when pieces with one facet are compared with pieces with 2, 4, 5 and 6 facets (Table O in S1 Tables). A slight increase in facet length on pieces with more than 3 facets is observed, and appears statistically significant (Table P in S1 Tables). Pieces with 1–3 facets show a mean facet length ranging from 19.3 to 20.6 mm, and pieces with 4–6 facets, ranging from 22.2 to 22.8 (Table 7); these two groups differ significantly from one another (Table Q in S1 Tables). All of these general trends remain stable throughout the sequence.

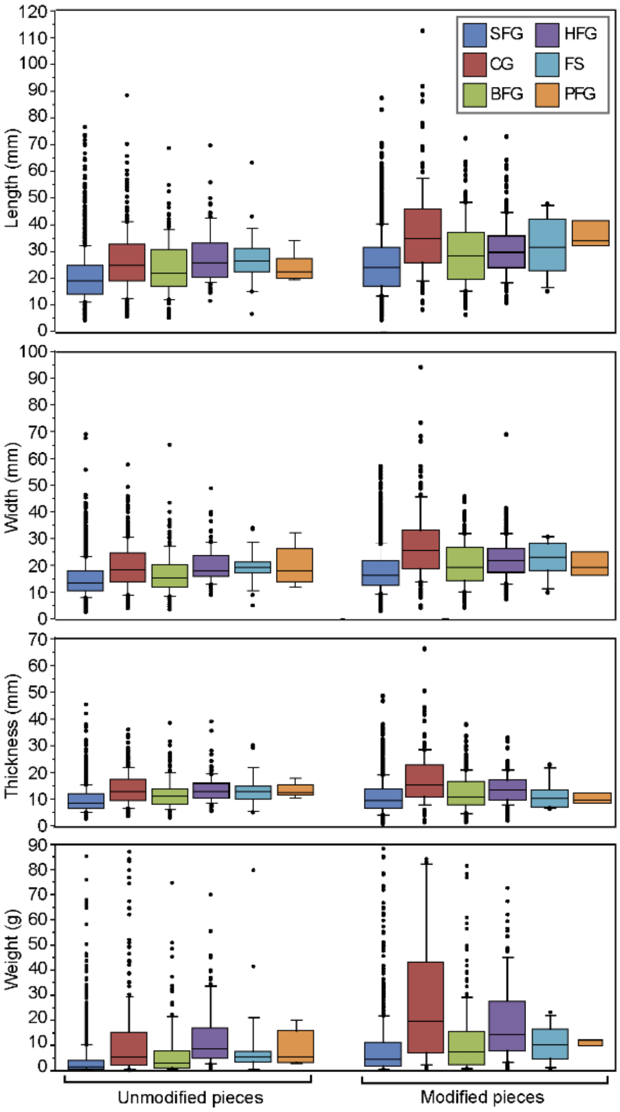

Fig 15. ***Size and weight of unmodified and modified ochre pieces by raw material type.*** *SFG: soft fine-grained; CG: coarse-grained; BFG: banded fine-grained; HFG: hard fine-grained; FS: ferruginous sandstone; PFG: platy fine-grained.*

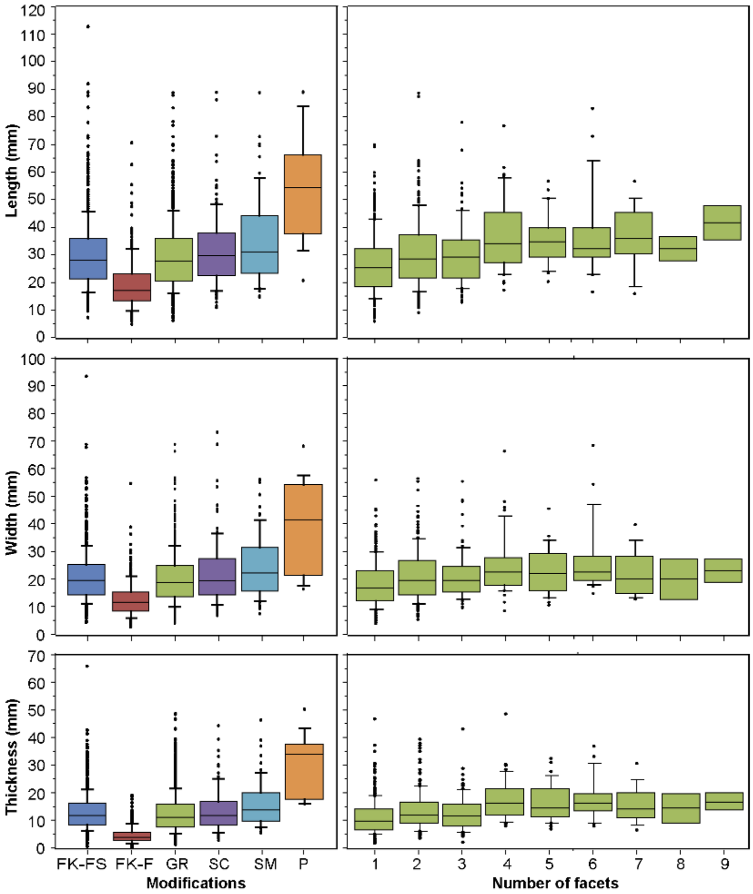

Fig 16. Size of modified pieces by modification type and number of facets. *FK-FS: flaking, flake scars; FK-F: flaking, flakes; GR: grinding; SC: scraping; SM: smoothing; P: pitting.*

Size		Unmod						Mod						All pieces
		SFG	CG	BFG	HFG	FS	PFG	SFG	CG	BFG	HFG	FS	PFG	
Length (mm)	Min	1.8	3.8	2.9	9.9	4.9	18.4	5.1	8.8	6.9	11	15.8	31.8	1.8
	Max	78.6	91.3	70.2	71.2	64.5	33.8	87.7	112.7	72.7	73	48.4	44.1	112.7
	Mean	19.6	25.8	23.1	27.5	26.8	36.8	26	37.8	30	31.2	32.5	36.8	24.6
	St dev	10.2	12.6	11.4	10.3	11.9	6.5	11.3	17	12.8	10.5	11.8	6.5	12.2
Width (mm)	Min	0.8	2.2	1.5	7.1	3.1	10.3	3.2	4.3	4.2	7.6	9.7	15.2	0.77
	Max	71.0	58.9	66.8	49.5	33.6	32	56.9	93.8	45.4	68.9	30.8	26.4	93.8
	Mean	13.5	18.5	16.0	19	18.5	20.4	18.1	27.8	20.6	22.3	22.7	20.4	17.2
	St dev	7.3	9.3	9	7.4	7	5.7	8.5	13.8	8.5	7.8	7.4	5.7	9.1
Thickness (mm)	Min	0.4	1.4	0.8	3.5	3.1	8.8	1	1.6	1.7	2.4	6.7	8.1	0.4
	Max	45.8	36.2	38.5	39	29.8	16.8	48.5	66.1	37.9	33.2	23.4	13.2	66.1
	Mean	8.1	12.4	10.4	12.5	11.8	10.5	11.1	17.9	12.8	14	11.9	10.5	10.7
	St dev	5.1	6.7	6.3	5.6	7	2.6	6.4	9.8	6.5	5.5	5.8	2.6	6.5
Weight (g)	Min	0.1	0.1	0.1	0.8	0	2.9	0.1	0.4	0.1	0.4	0.8	8.7	0.1
	Max	320.4	229.9	172	192.4	79.8	19.9	27.8	678	124.3	364.5	23.3	12.6	678
	Mean	4.8	13	8.7	15.8	10.3	11.2	10.5	41.6	12.9	21.8	11.3	11.2	10.6
	St dev	13.7	21.8	19.5	25.4	17.3	2.1	21.2	77.2	17.6	31.3	7.9	2.1	25.272
Total weight (kg)		6.7	4.4	1.3	2.0	0.2	0.05	12.4	6.0	2.8	4	0.1	0.03	39.97
% total weight		16.7	11.1	3.4	4.9	0.6	0.1	30.9	15	7	10.1	0.2	0.08	100
Num of pieces		**1404**	**342**	**155**	**124**	**23**	**5**	**1184**	**144**	**216**	**185**	**7**	**3**	**3792**

Table 5. Size and weight of modified and unmodified ochre lumps per raw material. *Unmod: unmodified; mod: modified; min: minimum; max: maximum; st dev: standard deviation; num: number; SFG: soft fine-grained; CG: coarse-grained; BFG: banded fine-grained; HFG: hard fine-grained; FS: ferruginous sandstone; PFG: platy fine-grained.*

Size		All unmod	All mod	Modifications					SEA		NEA		All frag
				FK	GR	SC	SM	P	Unmod	Mod	Unmod	Mod	
Length (mm)	Min	1.8	5	5.06	6.3	11.15	14.72	20.75	6.2	10.8	1.8	5.1	1.8
	Max	91.2	112.7	112.7	88.8	88.84	88.84	88.84	74.8	88.8	55.9	87.7	113
	Mean	21.5	28.1	28.025	29.5	32.211	35.269	54.317	22.8	28	17.4	26.7	24.6
	St dev	11.1	12.5	12.564	12.3	14.408	15.78	19.753	10.5	11.5	9.6	13.2	12.2
Width (mm)	Min	0.7	3.2	3.23	4.3	7.2	8.03	16.41	4.2	6.6	0.8	3.2	0.77
	Max	71	93.7	93.78	68.9	73.26	56.18	68.93	47.0	56.8	45	56.9	93.8
	Mean	14.9	19.7	19.715	20.57	22.736	25.064	40.968	15.8	19.3	11.8	18.5	17.2
	St dev	8.1	9.4	9.379	9.3	12.059	11.762	16.701	7.3	8	6.8	9.3	9.1
Thickness (mm)	Min	0.4	1.04	1.04	1.7	3.03	5.75	16.42	1.8	1.9	0.4	1	0.4
	Max	45.8	66.09	66.09	48.4	44.22	46.62	50.48	29.6	50.5	36.2	46.6	66.1
	Mean	9.3	12.21	12.144	12.8	13.846	16.167	31.226	9.9	12	7.2	11.2	10.7
	St dev	5.8	6.942	6.774	6.9	7.891	8.455	10.764	5.5	7	4.9	7	6.5
Weight (g)	Min	0.1	0.1	0.1	0.1	0.51	0.93	9.78	0.1	0.2	0.1	0.1	0.1
	Max	320.4	678	678	678	402.1	279.47	364.5	90.2	279.5	84.3	277.8	678
	Mean	7.2	14.6	14.51	10.571	26.552	31.618	129.5	7.5	14.2	3.4	12.9	10.6
	St dev	17.098	31.9	32.061	25.272	61.172	51.518	110.97	12.0	30.7	7.8	25.1	25.3
Total weight (kg)		14.6	25.3	18.0	14.3	2.9	2.2	1.8	3.0	2.2	2.4	8.3	39.9
% total weight		36.5	63.2	45.1	35.8	7.3	5.5	4.5	7.5	5.5	6	20.8	100
Num of pieces		**2053**	**1739**	**1242**	**913**	**111**	**71**	**14**	**650**	**159**	**723**	**399**	**3792**

Table 6. Size and weight of ochre pieces by modification type and ochre accumulation area. *Unmod: unmodified; mod: modified; FK: flaking; GR: grinding; SC: scraping; SM: smoothing; P: pitting; SEA: southeastern ochre accumulation; NEA: northeastern ochre accumulation; min: minimum; max: maximum; st dev: standard deviation; num: number.*

	Size (mm)	Min	Max	Mean	St dev
Pieces with 1 facet	Length	3.5	46.7	19.3	8.9
	Width	0.9	37.4	11.1	6.6
Pieces with 2 facets	Length	3.7	77.9	20.6	11.2
	Width	0.9	39.1	10.7	7.0
Pieces with 3 facets	Length	2.1	47.8	19.4	8.9
	Width	1.0	36.9	9.8	6.4
Pieces with 4 facets	Length	4.8	97.3	22.7	12.7
	Width	1.5	35.3	11.2	6.7
Pieces with 5 facets	Length	5.0	52.0	22.2	9.6
	Width	1.4	29.9	10.4	5.8
Pieces with 6 facets	Length	7.0	77.9	22.8	11.5
	Width	0.8	46.0	11.9	7.7
Pieces with 7 facets	Length	3.0	44.1	21.7	11.1
	Width	1.3	28.3	9.6	6.1
Pieces with 8 facets	Length	4.6	30.3	14.5	8.2
	Width	2.5	18.9	6.8	3.8
Pieces with 9 facets	Length	3.2	42.9	20.0	12.3
	Width	1.2	17.7	9.6	5.5
Piece with 11 facets	Length	14.4	26.7	21.3	4.2
	Width	2.9	16.4	10.0	4.5
Piece with 18 facets	Length	5.3	27.5	14.4	5.7
	Width	4.2	20.7	8.6	4.3
All facets	Length	2.1	97.9	20.4	10.3
	Width	0.8	46.0	10.6	6.6

Table 7. Size of facets per number of facets present on the piece. *Min: minimum; max: maximum; st dev: standard deviation.*

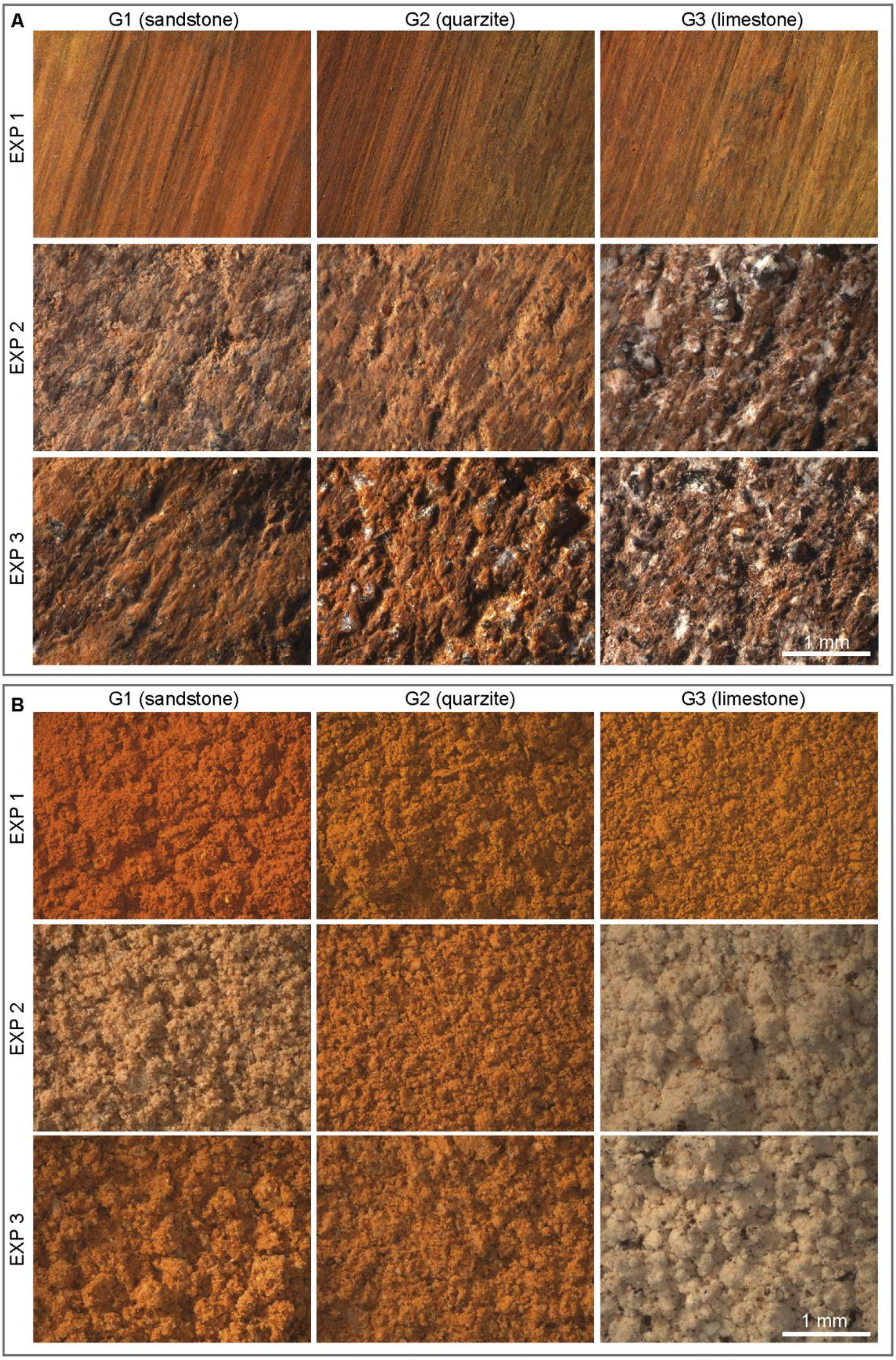

Fig 17. Facets and powder produced experimentally. *Photos of facets (A) and experimental powder (B) produced from EXP1, EXP2 and EXP3 with sandstone, quartzite and limestone grindstones.*

Surface texture analysis

Grinding three ochre pieces of different textures on sandstone, quartzite and limestone grindstones (Figs 17 and 18) produces facets characterised by clearly different roughness values (Figs 19 and 20).

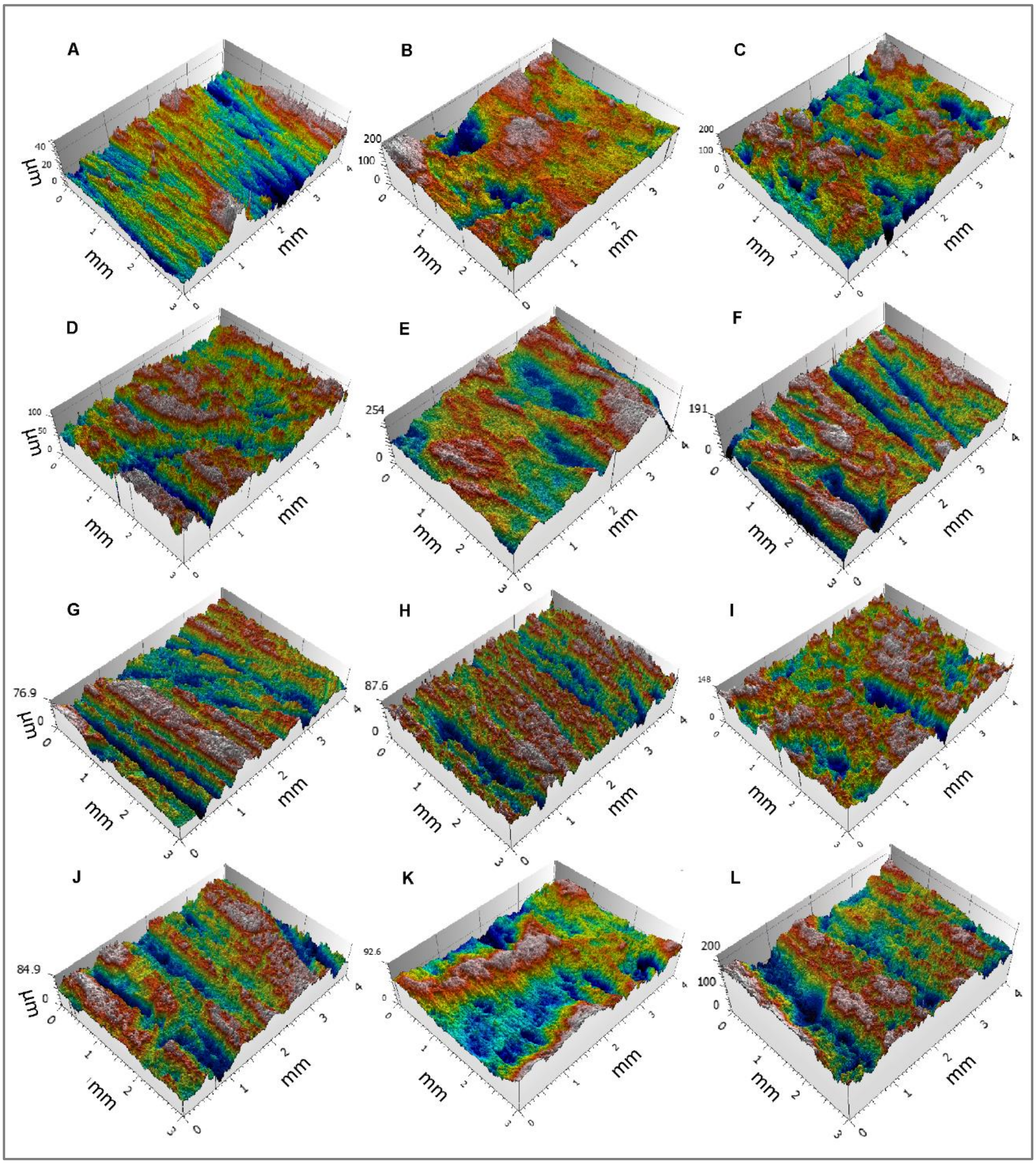

Fig 18. 3D images produced by confocal microscopy of experimental and archaeological facets. *(A) Facet on EXP1 produced with a limestone grindstone. (B) Facet on EXP2 produced with a quartzite grindstone. (C) Facet on EXP3 produced with a quartzite grindstone. (D, E) Facets on ochre piece PE102. (F) Facet on ochre piece PE987. (G) Facet on ochre piece 1491. (H) Facet on ochre piece 1493. (I) Facet on ochre piece 1499. (J) Facet on ochre piece 1677. (K) Facet on ochre piece 1700. (L) Facet on ochre piece 1806.*

The lowest values (Fig 19), reflecting a smoother, less complex surface texture, were obtained with fine-grained ochre (EXP1) irrespective of the grindstone used. Medium and very high values are associated, respectively, with coarse (EXP2) and very coarse (EXP3) ochre pieces. In addition, EXP1 features considerable differences in roughness according to the grindstone used, with low, medium and high values associated with limestone, quartzite and sandstone, respectively (Fig 19). Such a clear trend is not observed with EXP2 and EXP3. In EXP2, the highest Sq values (Fig 19) are observed on the facet produced on limestone with lower values for quartzite and sandstone. The highest values from EXP3 were obtained on quartzite with comparable lower values obtained for sandstone and limestone (Fig 19). The above pattern can be explained by the properties of the grindstones and the ochre pieces used. Roughness on fine-grained ochre (EXP1) is primarily determined by the texture and hardness of the grindstone. On harder and coarser ochre (EXP2), only the hardest grindstone is able to flatten the ochre surface, resulting in lower roughness values than those obtained with softer grindstones such as limestone. The roughness produced by limestone grindstones mostly depends on the ochre’s natural texture and grain hardness, rather than the properties of the grindstone itself. With the coarsest ochre (EXP3), none of the grindstones are able to flatten the natural internal texture of the material, producing high roughness values. This implies that roughness measurements can identify the type of grindstone used only when homogeneous and very fine-grained ochre is ground.

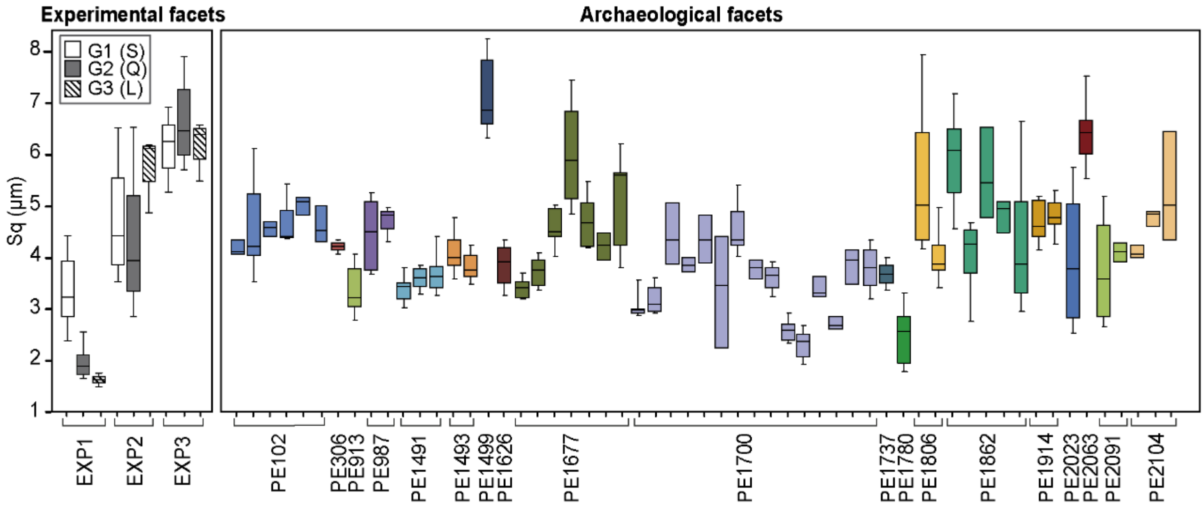

Fig 19. Sq values for experimental and archaeological facets. *Sq values of experimental facets are presented by ochre pieces (EXP1, EXP2 and EXP3) and grindstone on which they were processed (S: sandstone; Q: quartzite; L: limestone). Colours of boxplots representing Sq values of archaeological facets represent facets from single ochre pieces.*

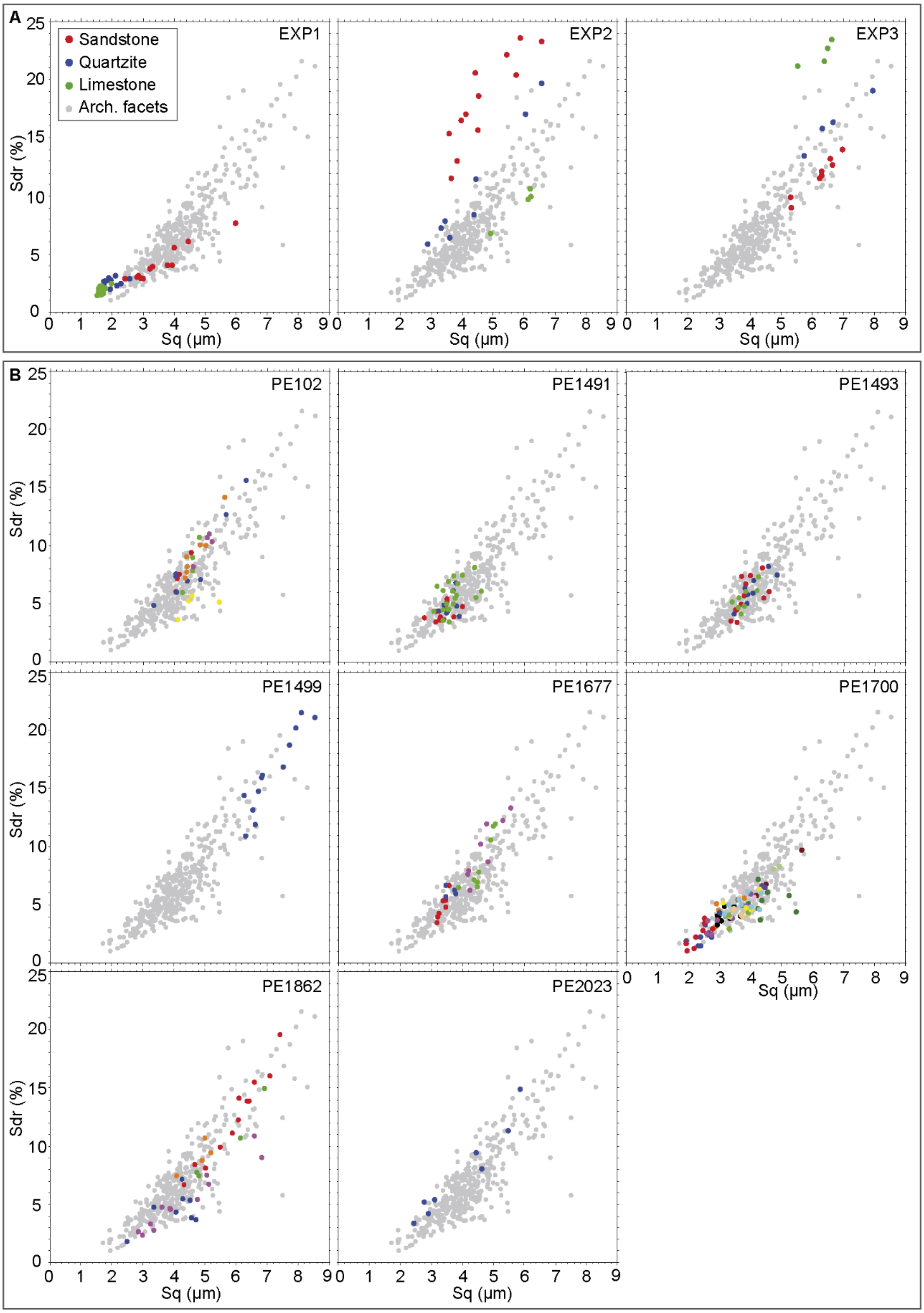

Fig 20. Sq and Sdr values in experimental and archaeological facets. *(A) Results of rugosimetric analysis on experimental facets from EXP1, EXP2 and EXP3. (B) Results of rugosimetric analysis on archaeological pieces. Dots of the same colour identify measurements taken on the same facets. Grey dots identify the overall variability of the archaeological sample.*

Sq values recorded on archaeological facets roughly overlap with those produced experimentally, with most ranges being comparable to those of EXP1 on sandstone and EXP2 on quartzite and sandstone (Fig 19). Extremely low values produced by grinding EXP1 on limestone were not observed on archaeological facets, suggesting that this ochre type was not or only rarely ground on limestone. Alternatively, taphonomic processes may also be responsible for texture modification, leading to increased Sq values for some archaeological specimens. This hypothesis needs to be tested experimentally in the future. As most of the analysed archaeological ochre pieces are composed of raw materials with textures between EXP1 and EXP2, their roughness values likely reflect both the hardness of the grindstone used and the texture/hardness of the pieces themselves.

Sdr and Sq values show that EXP2 processed on sandstone and EXP3 processed on limestone have facets that are rougher than the archaeological facets (Fig 20). Roughness values recorded on facets belonging to the same ochre piece (Figs 19 and 20) identify cases in which facets show similar values (PE102, PE 987, PE1491, PE1493, PE1914) and others in which some facets show clearly different values (PE1677, PE1700, PE1806, PE1862, PE2104). Our experimental results suggest the first pattern likely reflects cases in which several facets were ground on the same type of grindstone, with the second resulting from facets ground on different grindstones, possibly during different grinding sessions.

Particle size analysis

Between 40 and 390 mg of ochre powder per facet were produced during grinding experiments. Granulometric analysis shows that regardless the grindstone used, powders produced with EXP1 are finer than those produced by EXP2, which is finer than EXP3 (Fig 21). The particle size distributions are very similar in the case of EXP2 and EXP3, while EXP1 is characterised by a very fine mode indicating a clayish composition (Fig 21). Powders produced by grinding EXP2 and EXP3 on quartzite and sandstone are respectively composed of two and three main modes comparable to those observed in powders produced by Ovahimba women. Hamar powder is instead mainly composed of fine sand and small amounts of silt and clay (Fig 21). In addition, it is observed that ochre powder produced with sandstone is coarser than that produced with quartzite.

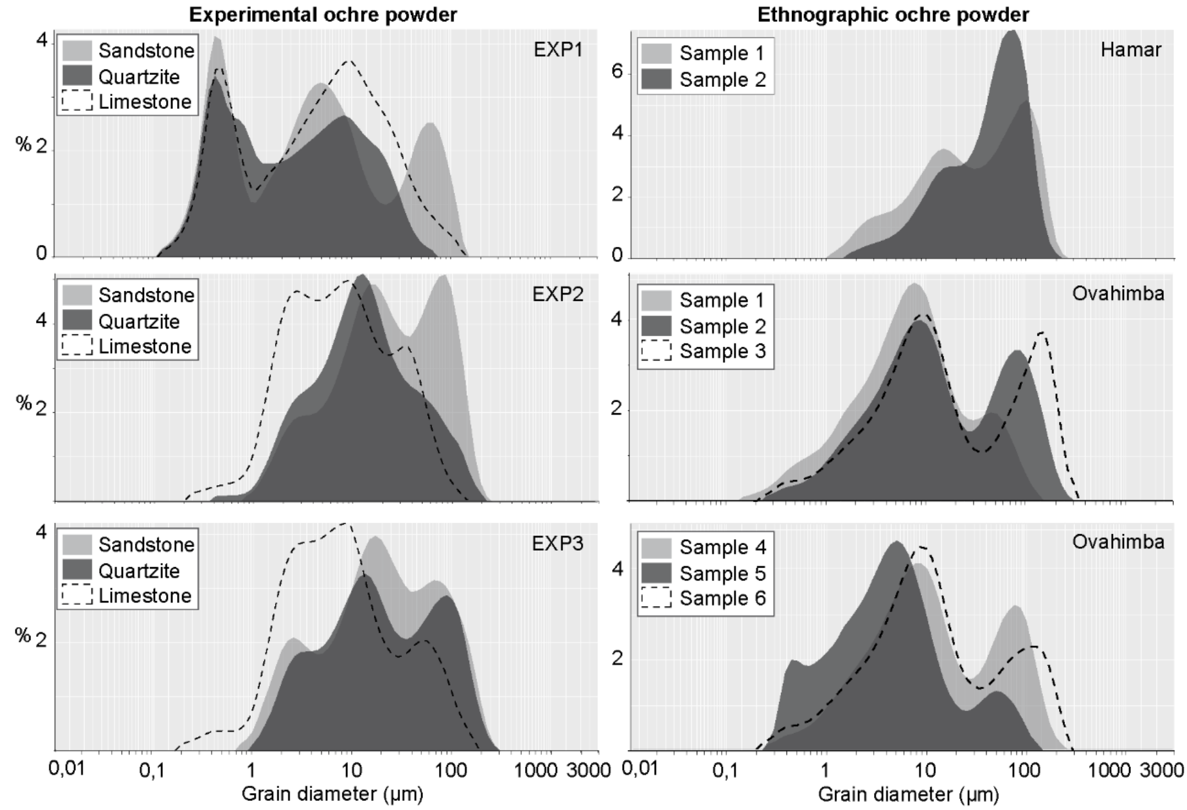

Fig 21. Results of granulometric analysis on experimental and ethnographic ochre powder. *Grain size distribution of nine experimental ochre powder samples produced with EXP1, EXP2 and EXP3, using sandstone, quartzite and limestone grindstones, two samples produced by Hamar women, and six samples produced by Ovahimba women.*

Discussion and conclusion

Archaeologists working on the Middle Stone Age have primarily relied on lithic technology to identify evolutionary trends in regional cultural trajectories. Data accumulated over the last two decades have broadened our understanding of the Middle Stone Age by providing insights into a variety of cultural adaptations beyond those related to lithic technology and typology. Newly acquired data on, for example, bone tool and mastic production, personal ornamentation or graphic expressions demonstrate the complexity of Middle Stone Age cultures. However, the majority of information concerning these cultural innovations remains sporadic in nature, suggesting that while new cultural traits likely emerged at some sites during different periods they are insufficient to reliably and accurately track diachronic changes. This shortcoming is mainly due to the sparsity of sites at which these innovations have been documented, as well as the small sample sizes and relatively limited occurrences of pertinent artefacts. Documenting the pace and nature of such changes is however key to producing a comprehensive view of individual MSA cultural trajectories, reconstructing the rate of cultural change, and inferring mechanisms of cultural transmission specific to these societies. Although almost ubiquitous at cave or rockshelter MSA sites (particularly in Southern African sites after ca. 170 ka [4,16]), only few sites with long stratigraphic sequences that have yielded a continuous record of ochre use have been studied in detail [4,35,40,56,58]. Porc-Epic is the only one at which, with the exception of the lower and upper-most layers, behavioural trends are identified based on a very high density of modified pieces per 10 cm spit.

Although uncertainties still surround the exact chronology of the Porc-Epic sequence, radiocarbon ages suggest it covers at least 4,500 years, and indicate that ochre use probably begun around or before 45 cal kyr BP, and was intense at ca. 40 cal kyr BP [41].

In this respect, it is noteworthy that our results identify continuity or gradual changes rather than any abrupt shifts in the way ochre was acquired and treated during the accumulation of the site's late MSA layers. The robustness of these trends is supported by the parallel analysis of the two areas (SEA and NEA) with the highest ochre concentrations. In all recorded variables, these two areas systematically show results comparable to those obtained for the overall ochre assemblage.

With the exception of an increase of the HFG type approximately from 2% to 20% at -80–150, the proportions of the different raw material types does not change substantially throughout the sequence. This probably reflects the persistent function of different types of ochre through time. Even though proportions of raw material are relatively stable, concomitant gradual changes in the morphology of ochre pieces were identified. The proportion of slabs increases with time, that of irregular pieces decreases, and that of nodules and pebbles does not considerably change throughout the stratigraphy. Slabs and irregular pieces include pieces with fresh edges that show little or no signs of water transport. This suggests that Porc-Epic MSA inhabitants searched in and around the wadi for the same raw materials, regardless of their morphology. In this respect, it is noteworthy that each raw material category used at Porc-Epic is characterised by a range of colours (Table D in S1 Tables). Continuity in raw material choice through time supports the hypothesis that Porc-Epic late MSA inhabitants provisioned themselves over a considerable duration with ochre types featuring different textures, hardness, density, colouring power, and shades. Although most of the colour types fall within the broad category of "red", a small proportion of pieces show colour features that appear to fall outside this category. This raises the question of whether different shades of "red" and other colours were perceived as distinct categories by Porc-Epic inhabitants.

Continuity in raw material use equally tracks gradual changes in the way ochre pieces were processed. Porc-Epic ochre record features an exceptionally high proportion of modified pieces, with flaking and grinding representing the most common techniques applied. Modified ochre pieces progressively decrease from the bottom to the top of the sequence with flaking, scraping and pitting becoming increasingly frequent, smoothing remaining stable, and grinding progressively dropping. This trend indicates that grinding ochre pieces against lower grindstones gradually becomes less prevalent and is partially replaced by flaking. It has been shown at a number of sites (for example Blombos, see [35]) that ochre was flaked and subsequently crushed to produce ochre powder. Since ochre pieces showing evidence for flaking often bear other types of modifications at Porc-Epic, this interpretation seems likely. In very few cases (17 ochre bladelets and 2 transverse scrapers), iron-rich rocks may not have been part of a reduction sequence leading to the production of ochre powder, but this appears as anecdotal. Noteworthy gradual changes through time are observed in the way the ground facets were produced. While the proportion of convex and flat facets does not change meaningfully through time, the orientation of striations progressively evolve from oblique to longitudinal with respect to the main axis of the facet. The fact that concave and irregular facets, and facets with random or overlapping oblique and perpendicular striations only appear in levels with the highest occurrences of ochre may indicate the work of apprentices. However, pieces with facets showing these characteristics are not significantly different from the others in terms of raw material and size. If the less precise motions that produced the irregular facets present in these layers results from training, the trainees were given the same type of ochre routinely used at the site by “expert” ochre producers.

The gradual shift through time between the two most frequently used techniques at the site, flaking and grinding, does not correspond to a shift in the weight of ochre processed with these techniques nor in the type and amount of raw materials processed. Contrary to expectation that flaking would have been more frequently applied to the coarse ochre type CG to produce coarse powder, and grinding or scraping to the SFG, BFG or HFG types to produce fine powder, the three techniques were applied in a comparable way to all types of raw material. The fact that HFG is comparatively more represented among the intensively utilised pieces is probably meaningful (see below), as it may be linked to the fact that this raw material is the most likely to produce a fine-grained and bright red powder. The higher frequency of smoothing and pitting on the CG type may be due to the fact that grinding does not always produce diagnostic striations on coarse-grained raw materials and is therefore more difficult to identify, and that pitting on these heavy pieces results from attempts of breaking them or use for crushing more friable ochre.

Results of the rugosimetric analysis of the ground facets and the size of ground pieces with more than one facet suggests curation of ground objects. The former shows that some pieces bear facets produced with different grindstones, arguably at different times. The latter indicates that pieces with just one facet are significantly smaller than those with more facets and that a trend towards bigger pieces is observed with the increase in the number of facets. This finding is consistent with the idea that large pieces were ground a number of times to produce small quantities of ochre powder. Alternatively, it may be argued that smaller pieces only bear one facet because they are more difficult to manipulate. The latter is contradicted by differences in the number of facets on pieces of different raw materials. Pieces of the fine-grained HFG type display, comparatively, a higher number of facets than ochre pieces made of the other raw materials. This implies that Porc-Epic inhabitants more intensively ground ochre pieces when they were made of the best available raw material. The small size of some of the HFG ochre pieces did not prevent their intense modification.

It is likely that crushing ochre was also not applied to produce substantial amounts of ochre powder. Evaluating the amount of ochre powder produced with this technique is of course difficult, as it leaves behind little tangible evidence, i.e. small fragments produced by crushing and pits on the grindstones. However, the application of these techniques by Hamar [96] or Ovahimba women [22] shows that in order to produce large quantities of powder with this technique, ochre is crushed on large lower grindstones, and then ground with upper grindstones. Most lower grindstones at Porc-Epic Cave are relatively small in size, only few show traces of pitting [38], and no upper grindstones show facets or striations referable to grinding ochre against a lower grindstone. It therefore appears that unless this action was carried out on grinding tools left outside the excavated area, which is contradicted by the spatial co-occurrence of processing tools and ochre concentrations, this technique was also employed to produce small quantities of powder.

The production of small amounts of ochre powder is usually considered more consistent with symbolic activities, such as body painting, the production of patterns on different media, or for signalling [4,5,21]. However, small quantities of ochre powder can also be used for medicinal purposes [24] or hafting. It has been shown that only 5 g of ochre powder are required to produce an adhesive compound for hafting a tool [25]. Some functional activities involve larger quantities of ochre powder. Tanning hides, for instance, require more than 2 kg of ochre powder for a medium-sized antelope [21]. Use of ochre as a sun-block requires 60 g of red ochre powder every 2 or 3 days [30], and use as an insect repellent [105] would presumably require a similar quantity. Our experimental grinding of ochre suggests, however, that many facets present on the Porc-Epic pieces result from grinding episodes that produced less than 0.4 g of powder and that, as indicated by rugosimetry, pieces with multiple facets were in some cases curated and ground at different times to produce small amounts of powder. Unless powder obtained from grinding different pieces and perhaps powder obtained by crushing pieces was mixed together, some grinding episodes recorded at Porc-Epic better fit the hypothesis that ochre powder was used for symbolic rather than for functional purposes. This observation is valid for the entire Porc-Epic sequence considering that the number of facets shows no meaningful changes throughout the stratigraphy. The discovery of an ochre-stained pebble half covered with ochre residues as if dipped in an ochre-rich liquid medium to paint the object or to use it as a stamp to apply pigment to soft materials further supports the symbolic hypothesis [38]. Of course this conclusion does not imply that all ochre powder produced at the site was used for symbolic activities. Particle size analysis of experimentally ground ochre demonstrates that the use of different grindstones and ochre types produce ochre powders of different coarseness. This implies that ochre pieces presenting facets with clearly different roughness values produced ochre powder of different granulometry. The use of powder of different coarseness for distinct purposes is supported by particle size analysis of ethnographic samples. Powder produced by Ovahimba women for body painting is finer than that produced by Hamar women for their hairdress.

The above trends have clear implications for the interpretation of changes in the amount of ochre processed at the site. Considerable inter-layer variation in ochre quantities, which peaks in the spits between 100 and 130 cm below datum, does not correspond to any marked change in raw material, size and weight of the ochre pieces, or processing technique. Continuity in weight throughout the stratigraphy contradicts the hypothesis according to which the increase in ochre pieces in layers -180–60 would be result of a higher fragmentation occurring in those layers. The observed trend supports the interpretation that the larger amount of ochre found in those layers results from an increased need for ochre powder in order to fulfil the same types of functions. This observation, and the fact that there are no major changes in lithic technology throughout the sequence [41,73,76], supports the hypothesis that the site was either more frequently visited during the accumulation of the richer layers or visited by a larger group. Alternative interpretations seem less likely. Increase of ochre pieces in some archaeological layers of MSA sites has been attributed to better availability of local ochre sources during a relatively short lapse of time that would have motivated people to be less discriminating in the choice of the raw material brought to the site [5]. This hypothesis seems contradicted in our case by continuity in the proportion of the different raw materials brought to the site. Increase in some activities, for example body painting, would have likely resulted in the prominence of one type of raw material over the others, which is not the case.

Refining the dating of the sequence and the acquisition of more precise environmental data may allow us to establish whether an increase in occupation intensity coincided with, and was perhaps in some way triggered by environmental changes that created favourable conditions for demographic expansion.

Patterns of continuity observed at Porc-Epic in ochre acquisition, processing and use reflect persistence through time in the exploitation of available geological resources, and the functions in which iron-rich rocks were used by late MSA groups of the Horn of Africa. A gradual shift was, however, documented in the preferred processing techniques and motions. Understanding the mechanisms behind the transmission of cultural practices related to ochre use is only at its beginning, and a solid record, such as that from Porc-Epic Cave, is needed to draw informed, testable hypotheses. Considering the large amount of ochre used at the site, patterns of continuity and change likely reflect a cohesive behavioural system shared by all community members and consistently transmitted through time.

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Supporting information

S1 Figs. Ochre pieces from Porc-Epic Cave.

Photos of the pieces and modifications.

S1 Tables. Detailed results of the technological analysis of ochre pieces.

Colour, raw material and modifications of ochre pieces.

Patterns of change and continuity in ochre use during the late Middle Stone Age of the Horn of Africa: the Porc-Epic Cave record

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S1 Figures. Ochre pieces from Porc-Epic Cave.

Photos of the pieces and modifications.

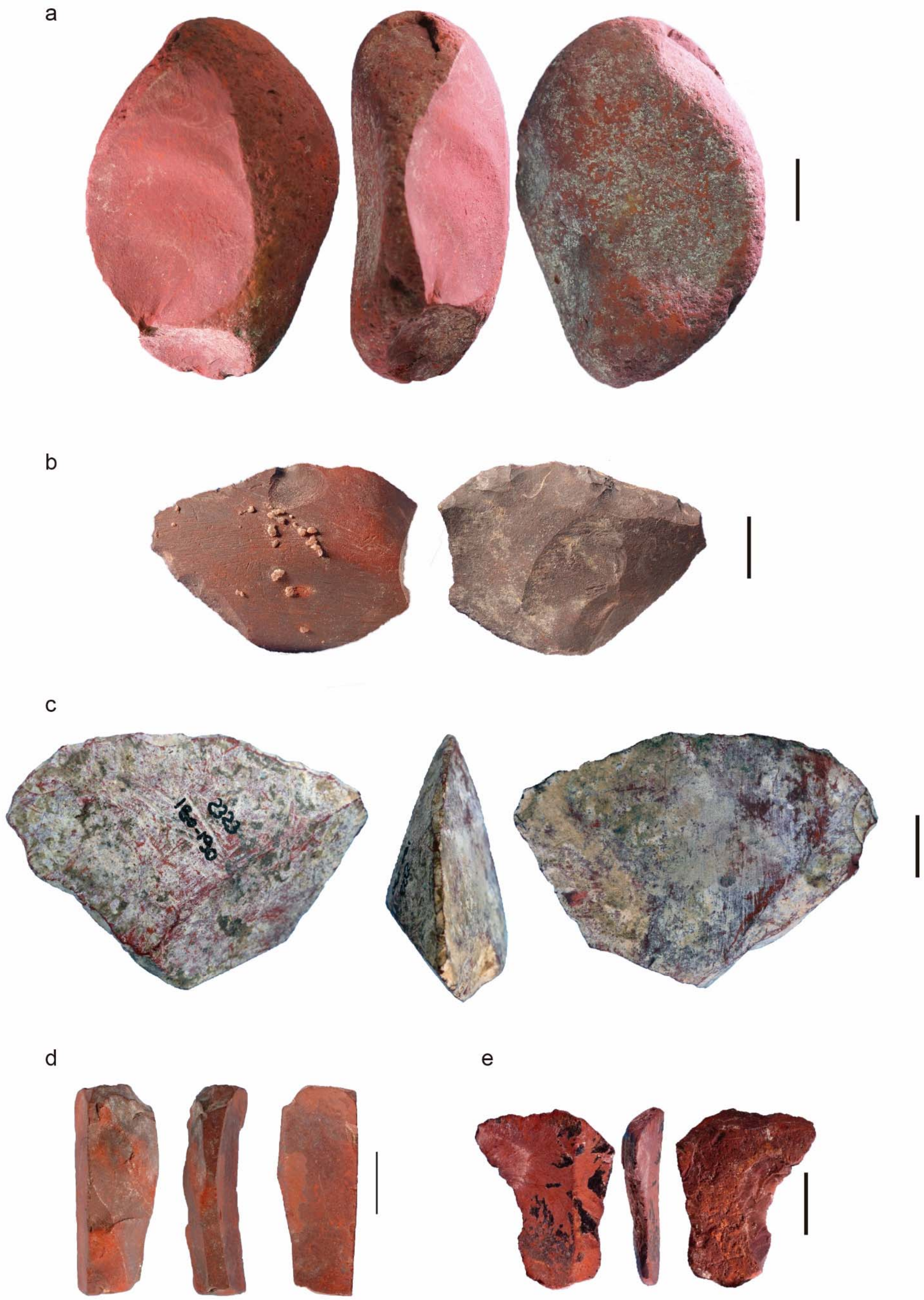

Fig A. Flaked ochre pieces. (a) Flake scar, ochre piece PE2563, SFG. (b) Scraper, ochre piece PE312, SFG. (c) Scraper, ochre piece PE3358, SFG. (d) Bladelet, ochre piece PE420, SFG. (e) Flake, ochre piece PE2063, SFG.

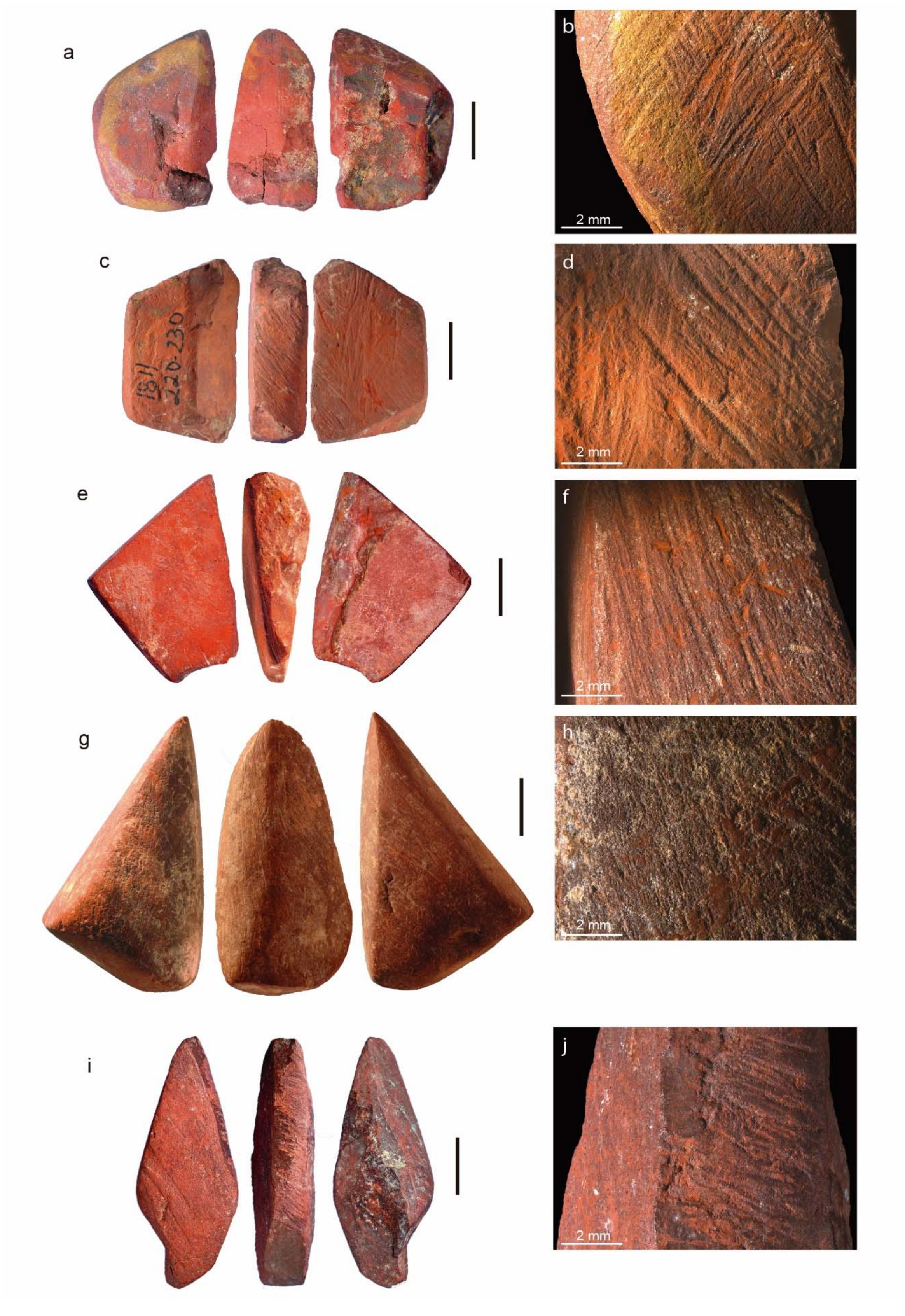

Fig B. Ochre pieces with traces produced by grinding. (a, b) Ochre piece PE102 and photo of striations produced by grinding on the same piece, BFG. (c, d) Ochre piece PE987 and photo of striations produced by grinding on the same piece, SFG. (e, f) Ochre piece PE1493 and photo of striations produced by grinding on the same piece, SFG. (g, h) Ochre piece PE1677 and photo of striations produced by grinding on the same piece, SFG. (i, j) Ochre piece PE1862 and photo of striations produced by grinding on the same piece, SFG.

Fig C. Ochre pieces with traces produced by grinding and pitting. (a, b) Ochre piece PE1806 and photo of striations produced by grinding on the same piece, BFG. (c, d) Ochre piece PE2104 and photo of striations produced by grinding on the same piece, BFG. (e, f) Ochre piece PE1752 and photo of striations produced by grinding on the same piece, HFG. (g, h) Ochre piece PE931 (also OPT21) and photo of pits on the same piece, BFG.

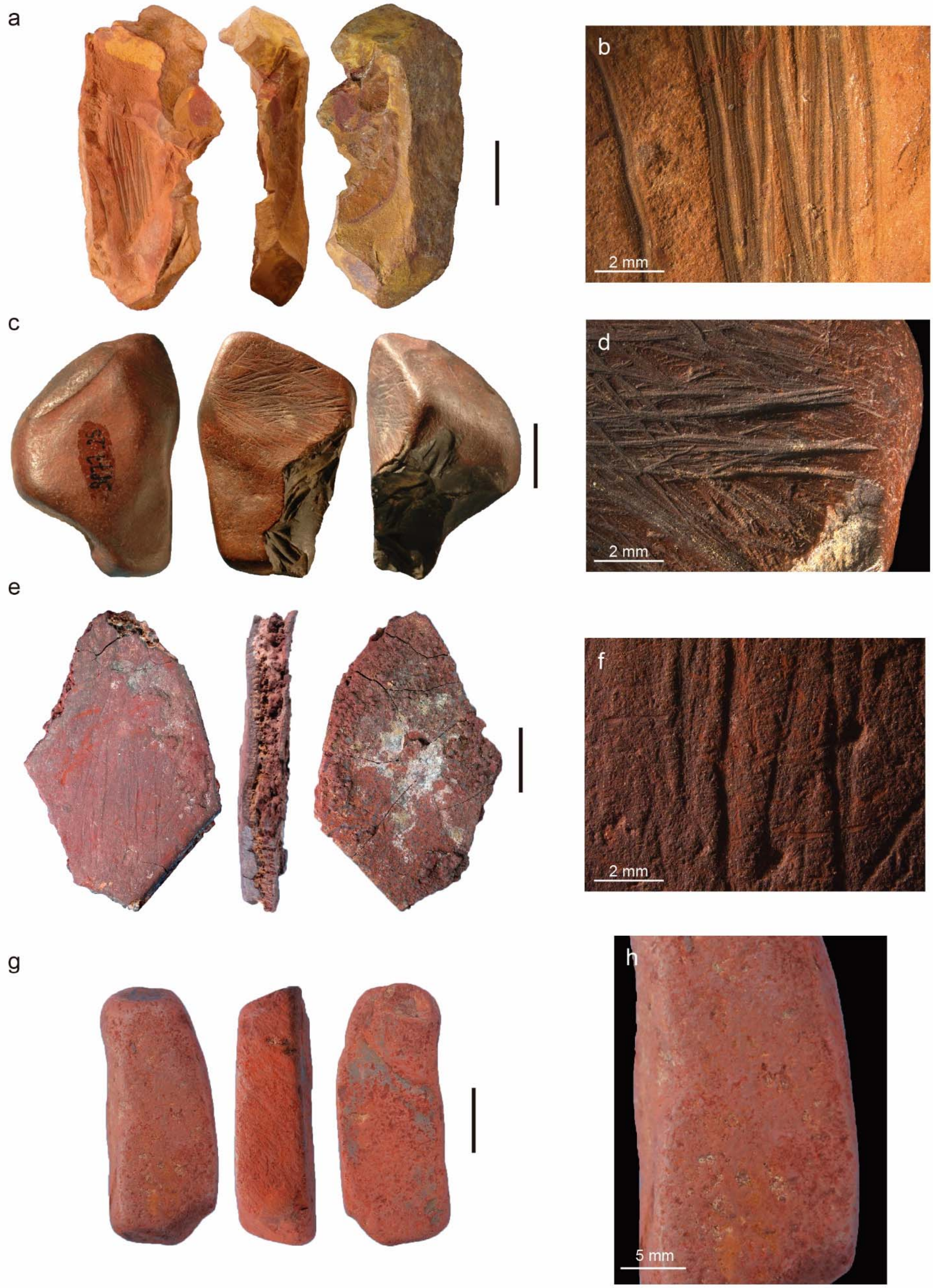

Fig D. Ochre pieces with traces produced by scraping and smoothed areas. (a, b) Ochre piece PE306 and photo of incisions produced by scraping on the same piece, BFG. (c, d) Ochre piece PE1419 and photo of incisions produced by scraping on the same piece, HFG. (e, f) Ochre piece PE1699 and photo of incisions produced by scraping on the same piece, SFG. (g, h) Ochre piece PE3067 and photo of smoothed areas, SFG.

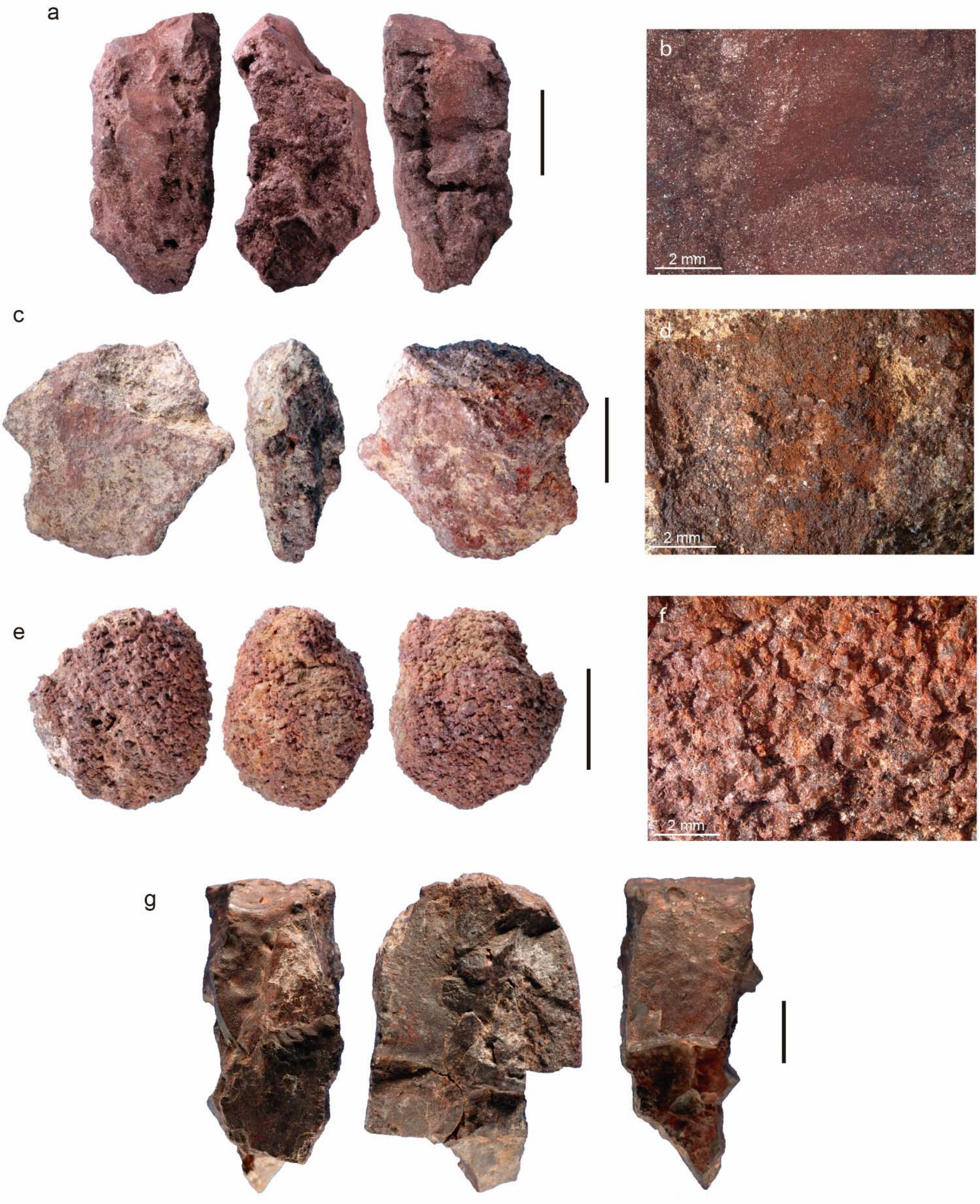

Fig E. Unmodified ochre pieces. (a, b) Ochre piece PE436, PFG. (c, d) Ochre piece PE809, CG. (e, f) Ochre piece PE1577, FS. (g) Ochre piece PE962, HFG.

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S1 Tables. Detailed results of the technological analysis of ochre pieces.

Colour, raw material, and modifications of ochre pieces.

Table A. Vertical distribution of colours for ochre piece.

Levels (cm)	Colours																											
	R	DR	R+G	R+Y	G	R+O	BR	DR+G	R+DR	Y+DR	O	O+DR	Y	R+BL	O+G	R+O+G	BR+Y	R+Y+G	Y+G	+Y+	R+BR	BR+G	R+O+BL	Y+O	BR+DR	BL+Y	R+Y+DR	BL	TOT
30-40	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
40-50	1	1	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
50-60	18	0	4	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
60-70	177	8	84	15	9	6	2	0	0	0	2	0	2	6	2	2	0	1	0	5	0	0	0	1	0	0	0	0	322
70-80	111	7	53	5	10	10	1	1	0	1	3	0	0	4	0	1	0	0	1	0	0	0	0	0	0	0	1	0	209
80-90	60	14	38	2	6	3	0	0	1	1	1	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	129
90-100	93	38	45	4	11	8	8	0	0	0	10	3	2	3	2	5	0	2	0	0	0	0	1	0	0	0	0	1	236
100-110	134	76	30	9	14	8	7	5	6	1	5	0	0	5	0	0	1	1	0	0	1	0	0	0	1	1	1	0	306
110-120	215	235	74	25	42	24	15	17	3	16	5	6	8	2	1	0	7	3	2	0	1	0	1	0	0	1	0	0	703
120-130	137	86	35	25	23	25	6	9	6	4	1	4	2	4	2	1	0	1	2	0	0	3	0	0	0	0	0	0	376
130-140	86	93	22	33	13	8	4	3	4	4	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	273
140-150	145	116	5	26	6	11	6	1	2	0	0	1	1	1	2	0	1	0	0	0	1	0	0	0	0	0	0	0	325
150-160	60	122	26	15	11	11	2	7	2	9	1	1	3	0	1	0	0	0	0	0	1	0	0	1	1	0	0	0	274
160-170	54	44	12	13	4	6	5	9	6	2	2	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	160
170-180	53	64	17	4	4	7	5	2	11	2	3	10	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	186
180-190	26	33	9	1	6	4	0	0	3	0	3	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90
190-200	19	9	1	5	1	3	2	4	3	0	1	2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	52
200-210	17	10	3	0	0	4	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41
210-220	8	8	3	2	0	0	0	0	1	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	26
220-230	4	2	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
230-240	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
240-250	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
250-260	0	3	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
260-270	3	5	2	0	0	0	0	3	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
270-280	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2
TOTAL	**1426**	**980**	**475**	**185**	**162**	**140**	**64**	**61**	**57**	**41**	**40**	**36**	**27**	**27**	**11**	**10**	**9**	**9**	**8**	**5**	**4**	**3**	**3**	**2**	**2**	**2**	**2**	**1**	**3792**

R: red; DR: dark red; G: grey; Y: yellow; O: orange; BR: brown; BL: black; TOT: total.

Table B. Proportion of colours for ochre pieces.

Levels (cm)	Colours																											
	R	DR	R+G	R+Y	G	R+O	BR	DR+G	R+DR	Y+DR	O	O+DR	Y	R+BL	O+G	R+O+G	BR+Y	R+Y+G	Y+G	R+Y+	R+BR	BR+G	R+O+BL	Y+O	BR+DR	BL+Y	R+Y+DR	BL	TOT
30-40	50	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
40-50	20	20	0	0	20	0	0	0	0	0	20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
50-60	72	0	16	0	4	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
60-70	55	2.5	26.1	4.7	2.8	1.9	0.6	0	0	0	0.6	0	0.6	1.9	0.6	0.6	0	0.3	0	1.6	0	0	0	0.3	0	0	0	0	100
70-80	53.1	3.3	25.4	2.4	4.8	4.8	0.5	0.5	0	0.5	1.4	0	0	1.9	0	0.5	0	0	0.5	0	0	0	0	0	0	0	0.5	0	100
80-90	46.5	10.9	29.5	1.6	4.7	2.3	0.0	0	0.8	0.8	0.8	0	0.8	1.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
90-100	39.4	16.1	19.1	1.7	4.7	3.4	3.4	0	0	0	4.2	1.3	0.8	1.3	0.8	2.1	0	0.8	0	0	0	0	0.4	0	0	0	0	0.4	100
100-110	43.8	24.8	9.8	2.9	4.6	2.6	2.3	1.6	2.0	0.3	1.6	0	0	1.6	0	0	0.3	0.3	0	0	0.3	0	0	0	0.3	0.3	0.3	0	100
110-120	30.6	33.4	10.5	3.6	6	3.4	2.1	2.4	0.4	2.3	0.7	0.9	1.1	0.3	0.1	0	1.0	0.4	0.3	0	0.1	0	0.1	0	0	0.1	0	0	100
120-130	36.4	22.9	9.3	6.6	6.1	6.6	1.6	2.4	1.6	1.1	0.3	1.1	0.5	1.1	0.5	0.3	0	0.3	0.5	0	0	0.8	0	0	0	0	0	0	100
130-140	31.5	34.1	8.1	12.1	4.8	2.9	1.5	1.1	1.5	1.5	0.7	0	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	100
140-150	44.6	35.7	1.5	8.0	1.8	3.4	1.8	0.3	0.6	0	0	0.3	0.3	0.3	0.6	0	0.3	0	0	0	0.3	0	0	0	0	0	0	0	100
150-160	21.9	44.5	9.5	5.5	4	4	0.7	2.6	0.7	3.3	0.4	0.4	1.1	0	0.4	0	0	0	0	0	0.4	0	0	0.4	0.4	0	0	0	100
160-170	33.8	27.5	7.5	8.1	2.5	3.8	3.1	5.6	3.8	1.3	1.3	0	0.6	0	0	0	0	0.6	0.6	0	0	0	0	0	0	0	0	0	100
170-180	28.5	34.4	9.1	2.2	2.2	3.8	2.7	1.1	5.9	1.1	1.6	5.4	1.6	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	100
180-190	28.9	36.7	10	1.1	6.7	4.4	0	0	3.3	0	3.3	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
190-200	36.5	17.3	1.9	9.6	1.9	5.8	3.8	7.7	5.8	0	1.9	3.8	1.9	0	1.9	0	0	0	0	0	0	0	0	0	0	0	0	0	100
200-210	41.5	24.4	7.3	0.0	0	9.8	0	0	17.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
210-220	30.8	30.8	11.5	7.7	0	0	0	0	3.8	0	0	0	11.5	0	0	0	0	0	3.8	0	0	0	0	0	0	0	0	0	100
220-230	40	20	10	10	0	0	0	0	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
230-240	33.3	33.3	33.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
240-250	42.9	57.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
250-260	0	23.1	76.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
260-270	17.6	29.4	11.8	0	0	0	0	17.6	5.9	0	0	17.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100
270-280	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	100
TOTAL	**37.6**	**25.8**	**12.5**	**4.9**	**4.3**	**3.7**	**1.7**	**1.6**	**1.5**	**1.1**	**1.1**	**0.9**	**0.7**	**0.7**	**0.3**	**0.3**	**0.2**	**0.2**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0**	**100**

Numbers are presented in percentages. R: red; DR: dark red; G: grey; Y: yellow; O: orange; BR: brown; BL: black; TOT: total.

Table C. Colours by weight.

Colour	Minimum	Maximum	Mean	St. dev.	Total weight	Number of pieces
R	0.1	678	10.049	29.398	14249.21	1426
DR	0.1	258.39	6.449	16.281	6313.155	980
R+G	0.13	364.5	14.914	26.438	7084.09	475
R+Y	0.1	172.2	14.492	24.656	2680.945	185
G	0.1	402.1	17.729	35.988	2872.13	162
R+O	0.18	87.03	12.698	16.745	1777.75	140
BR	0.1	110.88	6.191	14.716	396.205	64
DR+G	0.1	229.89	19.237	35.79	1173.48	61
R+DR	0.41	175.76	16.457	28.328	938.03	57
Y+DR	0.1	30.45	8.156	8.733	334.41	41
O	0.1	76.89	9.288	15.831	362.225	40
O+DR	0.12	89.3	9.117	15.187	328.2	36
Y	0.1	33.85	4.624	6.521	124.86	27
R+BL	0.7	33.05	9.305	7.8	251.24	27
O+G	0.5	36.88	7.61	10.216	83.71	11
R+O+G	1.71	79.57	23.812	28.857	238.12	10
BR+Y	0.1	12.07	2.691	5.161	24.215	9
R+Y+G	1.93	28.38	9.411	8.4	84.7	9
Y+G	1.09	123.44	28.365	40.518	226.92	8
R+Y+O	6.48	24.92	17.106	7.284	85.53	5
R+BR	5.9	15.35	10.453	4.561	41.81	4
BR+G	1.63	45.19	16.4	24.936	49.2	3
R+O+BL	3.16	48.62	18.883	25.767	56.65	3
Y+O	0.48	19.66	10.07	13.562	20.14	2
BR+DR	4.5	10.53	7.515	4.264	15.03	2
BL+Y	18.24	34.47	26.355	11.476	52.71	2
R+Y+DR	11.26	78.05	44.655	47.228	89.31	2
BL	24.46	24.46	24.46	-	24.46	1
All pieces	0.1	678	10.571	25.272	39978.4	3792

Data is in grams. R: red; DR: dark red; G: grey; Y: yellow; O: orange; BR: brown; BL: black; St. dev: standard deviation.

Table D. Colours by raw material types.

Colours	Raw material (n)						Num of pieces
	SFG	CG	BFG	HFG	FS	PFG	
R	1225	119	29	45	8	0	1426
DR	847	100	0	30	3	0	980
R+G	220	115	9	121	3	7	475
R+Y	32	5	147	1	0	0	185
G	25	55	0	80	1	1	162
R+O	37	6	92	2	3	0	140
BR	40	22	0	0	2	0	64
DR+G	27	22	0	12	0	0	61
R+DR	45	10	1	1	0	0	57
Y+DR	2	1	37	1	0	0	41
O	22	7	6	0	5	0	40
O+DR	13	2	21	0	0	0	36
Y	10	5	11	0	1	0	27
R+BL	14	3	0	10	0	0	27
O+G	4	5	0	0	2	0	11
R+O+G	5	3	1	1	0	0	10
BR+Y	0	1	7	1	0	0	9
R+Y+G	5	1	2	1	0	0	9
Y+G	2	3	2	1	0	0	8
R+Y+O	1	0	4	0	0	0	5
R+BR	2	0	0	0	2	0	4
BR+G	2	1	0	0	0	0	3
R+O+BL	2	0	1	0	0	0	3
Y+O	1	0	1	0	0	0	2
BR+DR	2	0	0	0	0	0	2
BL+Y	1	0	0	1	0	0	2
R+Y+DR	2	0	0	0	0	0	2
BL	0	0	0	1	0	0	1
Total	**2588**	**486**	**371**	**309**	**30**	**8**	**3792**

R: red; DR: dark red; G: grey; Y: yellow; O: orange; BR: brown; BL: black; SFG: Soft fine-grained; CG: coarse-grained; BFG: banded fine-grained; HFG: hard fine-grained; FS: ferruginous sandstone; PFG: platy fine-grained.

Table E. Colours by modification types.

Colours	FK	GR	SC	SM	P	Number of facets											Unmod	Num of pieces
						1	2	3	4	5	6	7	8	9	11	18		
R	465	361	56	34	5	157	78	45	16	15	11	6	1	0	1	0	744	1426
DR	306	227	14	13	1	120	44	26	7	3	3	3	0	1	0	0	563	980
R+G	132	86	7	2	5	31	21	8	5	4	3	1	0	0	0	0	293	475
R+Y	89	60	12	3	1	30	11	4	4	2	1	1	1	1	0	0	69	185
G	63	35	4	4	0	20	8	0	1	0	0	0	0	0	0	0	84	162
R+O	55	42	5	4	1	17	8	2	2	3	1	0	0	0	0	1	59	140
BR	16	16	0	1	0	6	4	4	0	1	0	0	0	0	0	0	41	64
DR+G	29	20	1	3	0	7	4	9	0	0	0	0	0	0	0	0	21	61
R+DR	17	18	3	0	0	10	2	2	0	1	0	0	0	0	0	0	27	57
Y+DR	17	14	1	2	0	9	3	0	1	0	0	0	0	0	0	0	16	41
O	13	4	1	1	0	2	0	1	0	0	0	0	0	0	0	0	26	40
O+DR	16	12	2	0	0	6	3	0	0	1	0	0	0	0	0	0	13	36
Y	6	4	3	2	0	4	0	0	0	0	0	0	0	0	0	0	18	27
R+BL	3	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	24	27
O+G	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	8	11
R+O+G	2	2	0	0	0	1	0	0	1	0	0	0	0	0	0	0	7	10
BR+Y	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	8	9
R+Y+G	2	2	2	0	0	1	1	0	0	0	0	0	0	0	0	0	6	9
Y+G	2	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	5	8
R+Y+O	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	5
R+BR	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	4
BR+G	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3
R+O+BL	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	3
Y+O	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2
BR+DR	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2
BL+Y	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
R+Y+DR	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	2
BL	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total	**1242**	**913**	**111**	**71**	**14**	**426**	**190**	**101**	**38**	**30**	**19**	**11**	**2**	**2**	**1**	**1**	**2044**	**3792**

R: red; DR: dark red; G: grey; Y: yellow; O: orange; BR: brown; BL: black; FK: flaking; GR: grinding; SC: scraping; SM: smoothing; P: pitting; unmod.: unmodified; Num.: number.

Table F. Vertical distribution of ochre raw material types.

Levels (cm)	**Raw material types**					
	SFG	**CG**	**BFG**	**HFG**	**FS**	**PFG**
30–40	2	0	0	0	0	0
40–50	4	1	0	0	0	0
50–60	20	2	1	2	0	0
60–70	222	40	31	26	2	1
70–80	134	30	19	25	1	0
80–90	77	18	6	27	1	0
90–100	151	37	17	27	4	0
100–110	222	44	14	25	1	0
110–120	479	73	77	64	9	1
120–130	225	49	53	49	0	0
130–140	166	43	40	20	2	2
140–150	261	20	32	9	3	0
150–160	186	44	26	12	3	3
160–170	108	25	20	7	0	0
170–180	134	29	15	6	2	0
180–190	66	12	7	3	1	1
190–200	35	9	6	2	0	0
200–210	34	4	2	0	1	0
210–220	18	5	2	1	0	0
220–230	9	0	1	0	0	0
230–240	1	1	0	1	0	0
240–250	7	0	0	0	0	0
250–260	12	0	0	1	0	0
260–270	13	0	2	2	0	0
270–280	2	0	0	0	0	0
Total	**2588**	**486**	**371**	**309**	**30**	**8**

SFG: soft fine-grained; CG: coarse-grained; BFG: banded fine-grained; HFG: hard fine-grained; FS: ferruginous sandstone; PFG: platy fine-grained.

Table G. Vertical distribution of ochre raw material types by weight.

Levels (cm)	SFG (g)					CG (g)					BFG (g)					HFG (g)					FS (g)					PFG (g)				
	Min	Max	Mean	St. dev.	Tot	Min	Max	Mean	St. dev	Tot	Min	Max	Mean	St. dev.	Tot	Min	Max	Mean	St. dev.	Tot	Min	Max	Mean	St. dev.	Tot	Min	Max	Mean	St. dev.	Tot
30–40	9.8	13	11.3	2.086	22.59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40–50	0.9	11	5.7	4.784	22.8	43.2	43.2	43.22	-	43.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50–60	0.5	67	7.101	14.67	142	2.97	3.42	3.195	0.318	6.39	4	4	4.02	-	4.02	14	17	15.46	1.683	30.92	-	-	-	-	-	-	-	-	-	-
60–70	0.2	168	6.161	14.439	1355	1.03	402	21.21	63.63	848.2	0.5	25	6.235	6.933	193.3	0.8	62	15.47	17.867	402.3	9.7	80	44.77	49.547	89.5	20	20	19.89	-	19.9
70–80	0.1	106	8.831	16.986	1183	1.17	279	31.05	61.05	931.5	0.3	48	13.59	13.436	258.3	0.6	101	18.75	20.827	468.7	16	16	16.09	.	16.1	-	-	-	-	-
80–90	0.2	188	10	21.986	770.3	2.33	36.5	12.94	11.03	233	3.2	10	6.905	2.897	41.43	1.3	56	14.46	13.653	390.4	4.8	4.8	4.82	.	4.82	-	-	-	-	-
90–100	0.1	320	9.276	28.825	1401	1.77	90.2	17.6	20.77	651.3	0.2	45	8.449	13.529	143.6	3.1	40	15.79	9.904	426.4	3.3	8.1	5.23	2.038	20.9	-	-	-	-	-
100–110	0.1	126	6.487	14.934	1434	0.2	230	24.23	41.16	1066	0.1	78	15.05	21.565	210.7	1.4	46	13.4	11.739	334.9	5.7	5.7	5.68	.	5.68	-	-	-	-	-
110–120	0.1	151	4.733	9.797	2267	0.04	87	16.33	19.9	1192	0.1	75	8.658	13.623	666.7	0.8	365	22.71	50.139	1453	0.4	17	6.708	4.736	60.4	14	14	14.4	-	14.4
120–130	0.1	109	8.464	14.064	1896	0.03	84.1	17.26	22.05	845.7	0	172	17.56	32.32	930.5	2	111	16.19	17.639	793.5	-	-	-	-	-	-	-	-	-	-
130–140	0.1	275	7.24	22.633	1202	0.07	188	14.89	37.4	640.5	0.1	27	6.427	6.91	257.1	0.9	53	18.1	16.978	362	0.8	13	6.83	8.57	13.7	2.9	8.7	5.81	4.13	11.6
140–150	0.1	278	7.618	24.989	1958	0.1	258	32.21	63.9	644.1	0.1	61	13.98	14.536	447.5	0.4	56	23.76	20.072	213.9	0	23	10.38	11.865	31.2	-	-	-	-	-
150–160	0	153	7.165	15.252	1318	0.1	678	31.89	102.6	1403	0.1	32	6.774	9.392	176.1	3.6	95	33.54	25.321	402.5	0.6	15	5.657	8.398	17	3.2	12	6.963	4.709	20.9
160–170	0.1	117	8.841	15.78	954.8	0.55	103	17.15	26.06	428.7	0.6	124	25.78	32.446	515.5	7.4	28	17.08	8.494	119.5	-	-	-	-	-	-	-	-	-	-
170–180	0.2	100	7.692	13.419	1031	0.1	91.4	26.91	26.93	780.4	1	26	5.231	6.192	78.47	4	73	29.22	25.081	175.3	4.5	7	5.73	1.782	11.5	-	-	-	-	-
180–190	0.4	187	12.32	26.121	813	2.49	132	25.19	34.5	302.2	1.1	23	7.134	8.846	49.94	9.5	36	20.52	14.119	61.57	4	4	4.03	-	4.03	13	13	12.64	-	12.6
190–200	0.2	111	13.77	21.408	481.9	3	36.7	12.2	11.12	109.8	2.5	11	7.268	3.69	43.61	19	23	21.11	2.758	42.22	-	-	-	-	-	-	-	-	-	-
200–210	0.3	42	7.255	9.766	246.7	1.58	15	6.453	5.877	25.81	1.7	7.9	4.815	4.391	9.63	-	-	-	-	-	42	42	41.59	-	41.6	-	-	-	-	-
210–220	0.2	15	5.582	4.937	100.5	0.37	176	54.25	74.04	271.2	36	49	42.49	8.768	84.98	70	70	70.13	-	70.13	-	-	-	-	-	-	-	-	-	-
220–230	1.3	90	16.38	28.894	147.4	-	-	-	-	-	20	20	20.03	-	20.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
230–240	8.5	8.5	8.5	-	8.5	3.58	3.58	3.58	-	3.58	-	-	-	-	-	192	192	192.4	-	192.4	-	-	-	-	-	-	-	-	-	-
240–250	1.2	13	6.399	4.527	44.79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
250–260	0.3	13	3.682	3.363	44.18	-	-	-	-	-	-	-	-	-	-	7.7	7.7	7.68	-	7.68	-	-	-	-	-	-	-	-	-	-
260–270	0.4	94	13.59	25.504	176.7	-	-	-	-	-	0.7	5.7	3.19	3.564	6.38	19	20	19.6	0.375	39.19	-	-	-	-	-	-	-	-	-	-
270–280	3.2	7.3	5.23	2.927	10.46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

SFG: Soft fine-grained; CG: coarse-grained; BFG: banded fine-grained; HFG: hard fine-grained; FS: ferruginous sandstone; PFG: platy fine-grained. Min: minimum; Max: maximum; st. dev: standard deviation.

Table H. Vertical distribution of ochre raw material types by weight in percentages.

Levels (cm)	SFG	CG	BFG	HFG	FS	PFG	Total
30–40	100	-	-	-	-	-	100
40–50	34.53	65.47	-	-	-	-	100
50–60	77.46	3.485	2.193	16.86	-	-	100
60–70	46.6	29.16	6.645	13.83	3.078	0.684	100
70–80	41.4	32.59	9.037	16.4	0.563	-	100
80–90	53.49	16.18	2.877	27.11	0.335	-	100
90–100	53	24.64	5.435	16.13	0.792	-	100
100–110	46.99	34.94	6.906	10.98	0.186	-	100
110–120	40.1	21.08	11.79	25.7	1.068	0.255	100
120–130	42.46	18.94	20.84	17.77	-	-	100
130–140	48.33	25.76	10.34	14.56	0.549	0.467	100
140–150	59.43	19.55	13.58	6.492	0.946	-	100
150–160	39.49	42.04	5.276	12.06	0.508	0.626	100
160–170	47.3	21.24	25.54	5.922	-	-	100
170–180	49.64	37.58	3.779	8.444	0.552	-	100
180–190	65.38	24.31	4.016	4.952	0.324	1.017	100
190–200	71.12	16.21	6.437	6.231	-	-	100
200–210	76.2	7.974	2.975	-	12.85	-	100
210–220	19.07	51.49	16.13	13.31	-	-	100
220–230	88.04	-	11.96	-	-	-	100
230–240	4.156	1.751	-	94.09	-	-	100
240–250	100	-	-	-	-	-	100
250–260	85.19	-	-	14.81	-	-	100
260–270	79.5	-	2.871	17.63	-	-	100
270–280	100	-	-	-	-	-	100

Data is presented in percentages. SFG: Soft fine-grained; CG: coarse-grained; BFG: banded fine-grained; HFG: hard fine-grained; FS: ferruginous sandstone; PFG: platy fine-grained.

Table I. Vertical distribution of unmodified and modified ochre.

Levels (cm)	Unmodified	Modified	Total
30–40	0	2	2
40–50	4	1	5
50–60	18	7	25
60–70	240	82	322
70–80	137	72	209
80–90	77	52	129
90–100	158	78	236
100–110	192	114	306
110–120	377	326	703
120–130	172	204	376
130–140	125	148	273
140–150	178	147	325
150–160	123	151	274
160–170	72	88	160
170–180	70	116	186
180–190	24	66	90
190–200	22	30	52
200–210	25	16	41
210–220	12	14	26
220–230	4	6	10
230–240	3	0	3
240–250	4	3	7
250–260	9	4	13
260–270	6	11	17
270–280	1	1	2
Total	**2053**	**1739**	**3792**

Table J. Vertical distribution of unmodified and modified ochre by weight.

Levels (cm)	Unmodified ochre (g)					Modified ochre (g)					All pieces (kg)
	Min	Max	Mean	St. dev.	Total	Min	Max	Mean	St. dev.	Total	
30–40	-	-	-	-	0	9.82	12.77	11.3	2.086	22.59	0.02
40–50	0.86	43.22	15.81	18.79	63.23	2.79	2.79	2.79	-	2.79	0.07
50–60	0.49	67.32	7.297	15.49	131.34	2.26	16.65	7.43	5.68	52.01	0.18
60–70	0.21	168.5	7.185	14.92	1710.12	0.24	402.1	14.62	45.96	1198.42	2.91
70–80	0.05	105.6	9.947	16.92	1362.72	0.29	279.5	20.77	42.54	1495.19	2.86
80–90	0.24	55.63	8.909	10.88	686.01	0.4	188	14.5	25.95	753.87	1.44
90–100	0.07	320.4	10.03	27.93	1584.65	0.18	89.3	13.57	18.17	1058.21	2.64
100–110	0.1	229.9	7.341	20.48	1402.165	0.12	128.3	14.46	23.09	1648.85	3.05
110–120	0.1	181.9	6.707	16.21	2528.56	0.02	364.5	9.586	22.93	3125.18	5.65
120–130	0.1	172.2	7.611	18.37	1309.09	0.13	111.5	15.55	19.88	3156.56	4.47
130–140	0.1	27.2	3.356	4.726	419.475	0.04	275.1	13.97	31.33	2067.2	2.49
140–150	0.1	58.1	3.032	7.082	530.57	0.005	277.8	18.93	40.01	2763.855	3.29
150–160	0.1	76.89	5.334	11.48	650.78	0.06	678	17.92	58.29	2687.29	3.34
160–170	0.1	90.8	6.867	12.64	494.42	0.18	124.3	17.32	24.77	1524.12	2.02
170–180	0.1	61.95	5.712	9.913	399.82	0.64	100.3	14.45	20.68	1676.59	2.08
180–190	0.41	132.2	13.55	28.75	325.21	0.66	187.2	13.91	25.28	918.19	1.24
190–200	0.82	31.76	10.6	8.962	233.1	0.16	110.9	14.81	22.81	444.43	0.68
200–210	0.28	41.71	7.738	11.58	193.46	0.34	28.15	8.139	9.036	130.23	0.32
210–220	0.24	70.13	9.895	19.74	118.74	0.81	175.8	29.15	47.13	408.08	0.53
220–230	3.83	89.69	32.49	39.77	129.96	1.27	20.03	6.25	7.652	37.5	0.17
230–240	3.58	192.4	68.17	107.6	204.51	-	-	-	-	0	0.20
240–250	1.51	13.09	7.153	5.177	28.61	1.23	9.85	5.393	4.317	16.18	0.04
250–260	0.32	4.84	2.182	1.353	19.64	5.86	12.56	8.055	3.109	32.22	0.05
260–270	0.88	94.35	23.22	35.61	139.3	0.35	23.88	7.54	8.986	82.94	0.22
270–280	7.3	7.3	7.3	-	7.3	3.16	3.16	3.16	.-	3.16	0.01
Total	**0.005**	**320.4**	**7.171**	**17.1**	**14672.78**	**0.005**	**678**	**14.58**	**31.9**	**25305.66**	**39.9**

Min: minimum; max: maximum; st. dev: standard deviation.

Table K. Occurrence of each modification throughout the stratigraphy.

Levels (cm)	Modifications (n)						Modifications (%)					
	FK	**G**	**SC**	**SM**	**P**	**Tot**	**FK**	**G**	**SC**	**SM**	**P**	**Tot**
30–40	1	2	0	0	0	3	33	67	0	0	0	100
40–50	1	0	0	0	0	1	100	0	0	0	0	100
50–60	6	1	0	0	0	7	86	14	0	0	0	100
60–70	59	21	6	1	3	90	66	23	6.7	1.1	3.3	100
70–80	57	21	6	3	3	90	63	23	6.7	3.3	3.3	100
80–90	40	20	7	1	1	69	58	29	10	1.4	1.4	100
90–100	59	30	3	4	1	97	61	31	3.1	4.1	1	100
100–110	87	45	9	2	1	144	60	31	6.3	1.4	0.7	100
110–120	238	176	29	14	1	458	52	38	6.3	3.1	0.2	100
120–130	144	123	11	12	1	291	49	42	3.8	4.1	0.3	100
130–140	97	88	10	6	1	202	48	44	5	3	0.5	100
140–150	103	85	9	9	1	207	50	41	4.3	4.3	0.5	100
150–160	104	91	5	5	0	205	51	44	2.4	2.4	0	100
160–170	60	52	3	5	0	120	50	43	2.5	4.2	0	100
170–180	82	75	0	6	0	163	50	46	0	3.7	0	100
180–190	43	38	5	3	0	89	48	43	5.6	3.4	0	100
190–200	17	20	5	0	0	42	40	48	12	0	0	100
200–210	13	8	2	0	0	23	57	35	8.7	0	0	100
210–220	10	9	1	0	1	21	48	43	4.8	0	4.8	100
220–230	4	4	0	0	0	8	50	50	0	0	0	100
230–240	0	0	0	0	0	0	0	0	0	0	0	0
240–250	3	0	0	0	0	3	100	0	0	0	0	100
250–260	4	0	0	0	0	4	100	0	0	0	0	100
260–270	10	3	0	0	0	13	77	23	0	0	0	100
270–280	0	1	0	0	0	1	0	100	0	0	0	100
Total	**1242**	**913**	**111**	**71**	**14**	**2351**	**53**	**39**	**4.7**	**3**	**0.6**	**100**

FK: flaking; G: grinding; SC: scraping; SM: smoothing; P: pitting, tot: total.

Table L. Vertical distribution of cross-section of facets and orientation of striations.

Levels (cm)	Facet cross-section					Orientation of striations								Total (n)
	Conv	Flat	Conc	Irreg	Undet	O	L	O+L	P	R	O+P	L+P	Undet	
30–40	3	3	0	0	0	4	1	0	1	0	0	0	0	6
40–50	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50–60	2	1	0	0	0	1	1	1	0	0	0	0	0	3
60–70	18	7	0	0	0	12	9	0	3	0	0	0	1	25
70–80	22	8	1	0	0	10	14	1	2	2	0	0	2	31
80–90	20	15	2	0	5	13	11	6	2	1	1	1	7	42
90–100	36	19	0	0	0	28	19	2	3	1	1	0	1	55
100–110	50	31	2	0	0	42	28	6	4	2	1	0	0	83
110–120	195	96	1	4	4	161	89	22	19	3	0	1	5	300
120–130	155	56	3	3	5	123	50	26	7	8	1	1	6	222
130–140	148	47	2	1	0	118	38	24	11	2	3	0	2	198
140–150	125	32	2	2	3	87	46	16	7	4	1	0	3	164
150–160	122	32	4	2	0	94	43	12	7	3	1	0	0	160
160–170	78	24	1	1	0	57	26	13	5	2	1	0	0	104
170–180	96	26	1	3	0	64	31	19	4	6	1	0	1	126
180–190	71	15	0	0	0	52	14	13	0	7	0	0	0	86
190–200	17	6	0	0	0	9	9	4	0	0	1	0	0	23
200–210	13	3	0	0	0	11	4	0	1	0	0	0	0	16
210–220	9	4	0	0	0	6	3	2	1	0	0	0	1	13
220–230	3	3	0	0	0	5	0	0	1	0	0	0	0	6
230–240	0	0	0	0	0	0	0	0	0	0	0	0	0	0
240–250	0	0	0	0	0	0	0	0	0	0	0	0	0	0
250–260	0	0	0	0	0	0	0	0	0	0	0	0	0	0
260–270	1	1	0	0	0	1	1	0	0	0	0	0	0	2
270–280	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**1184**	**429**	**19**	**16**	**17**	**898**	**437**	**167**	**78**	**41**	**12**	**3**	**29**	**1665**

Conv: convex; Conc: concave; irreg: irregular; undet: undetermined; O: oblique; L: longitudinal; P: perpendicular; R: random.

Table M. Vertical distribution of combinations of modifications.

Levels (cm)	Modifications																				
	FK	G	FK+G	G+SC	FK+G+SC	FK+SM	SC	G+SM	SM	FK+G+SM	FK+SC	FK+G+SC+SM	P+G	P	SC+SM	FK+G+P	FK+P	G+SC+SM	FK+G+P+SC	FK+G+P+SC+SM	FK+P+SC	TOT
30–40	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
40–50	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**5**
50–60	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**25**
60–70	54	16	2	2	0	0	3	0	1	0	1	0	1	0	0	0	2	0	0	0	0	**322**
70–80	47	11	5	0	3	1	1	0	1	0	0	0	1	1	0	0	0	0	0	1	0	**209**
80–90	29	8	7	2	2	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	**129**
90–100	45	15	10	1	1	1	1	1	0	2	0	0	0	1	0	0	0	0	0	0	0	**236**
100–110	66	23	15	1	3	0	1	0	0	0	2	1	1	0	0	0	0	1	0	0	0	**306**
110–120	138	66	82	12	9	4	4	3	2	2	0	2	0	0	1	0	0	0	1	0	0	**703**
120–130	74	48	59	4	5	3	1	5	2	2	1	0	0	0	0	0	0	0	0	0	0	**376**
130–140	55	40	37	7	1	2	1	1	2	0	0	1	0	0	0	1	0	0	0	0	0	**273**
140–150	55	35	39	4	2	2	1	1	2	3	1	0	0	0	1	1	0	0	0	0	0	**325**
150–160	57	42	42	2	2	2	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	**274**
160–170	31	26	23	0	3	3	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	**160**
170–180	37	33	40	0	0	3	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	**186**
180–190	24	19	15	0	2	0	1	2	1	0	2	0	0	0	0	0	0	0	0	0	0	**90**
190–200	9	10	6	2	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**52**
200–210	6	3	5	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	**41**
210–220	5	2	5	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	**26**
220–230	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**10**
230–240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**3**
240–250	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**7**
250–260	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**13**
260–270	8	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**17**
270–280	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Total	**756**	**403**	**397**	**38**	**35**	**21**	**17**	**16**	**14**	**12**	**10**	**4**	**4**	**2**	**2**	**2**	**2**	**1**	**1**	**1**	**1**	**3792**

FK: flaking; G: grinding; SC: scraping; SM: smoothing; P: pitting; TOT: total.

Table N. One-way ANOVA test on length of pieces by number of facets per piece.

	Sum of squares	DF	Mean squares	F	Significance
Between groups	8283.757	6	1380.626	9.622	**0.000**
Within groups	110769.952	772	142.484		
Total	119053.709	778			

We took into account pieces with one to 7 facets, as pieces with 8, 9, 11 and 18 facets have less than three specimens. The analysis was conducted with IBM SPSS Statistics for Macintosh, Version 21.0.

Table O. Pairwise comparison for length of pieces by number of facets with Bonferroni correction on length.

		1 Facet	2 facets	3 facets	4 facets	5 facets	6 facets	7 facets
Mean squares			**-4.00439**	-3.79588	**-10.37742**	**-8.79108**	**-10.25618**	-9.67493
Standard error	**1 facet**		**1.07023**	1.38745	**2.05578**	**2.30130**	**2.81071**	3.65955
P-value			**0.004**	0.134	**0.000**	**0.003**	**0.006**	0.176
Mean squares		**4.00439**		0.20851	-6.37303	-4.78669	-6.25179	-5.67055
Standard error	**2 facets**	**1.07023**		1.54074	2.16220	2.39685	2.88945	3.72037
P-value		**0.004**		1.000	0.069	0.970	0.647	1.000
Mean squares		3.79588	-0.20851		-6.58153	-4.99520	-6.46029	-5.87905
Standard error	**3 facets**	1.38745	1.54074		2.33553	2.55431	3.02135	3.82371
P-value		0.134	1.000		0,104	1.000	0.689	1.000
Mean squares		**10.37742**	6.37303	6.58153		1.58634	0.12124	0.70248
Standard error	**4 facets**	**2.05578**	2.16220	2.33553		2.97081	3.38079	4.11363
P-value		**0.000**	0.069	0,104		1.000	1.000	1.000
Mean squares		**8.79108**	4.78669	4.99520	-1.58634		-1.46510	-0.88386
Standard error	**5 facets**	**2.30130**	2.39685	2.55431	2.97081		3.53547	4.24167
P-value		**0.003**	0.970	1.000	1.000		1.000	1.000
Mean squares		**10.25618**	6.25179	6.46029	-0.12124	1.46510		0.58124
Standard error	**6 facets**	**2.81071**	2.88945	3.02135	3.38079	3.53547		4.53826
P-value		**0.006**	0.647	0.689	1.000	1.000		1.000
Mean squares		9.67493	5.67055	5.87905	-0.70248	0.88386	-0.58124	
Standard error	**7 facets**	3.65955	3.72037	3.82371	4.11363	4.24167	4.53826	
P-value		0.176	1.000	1.000	1.000	1.000	1.000	

We took into account pieces with one to 7 facets, as pieces with 8, 9, 11 and 18 facets have less than three specimens. In bold, statistically significant differences between pairs. The analysis was conducted with IBM SPSS Statistics for Macintosh, Version 21.0.

Table P. One-way ANOVA test on length of facets by number of facets per piece.

	Sum of squares	DF	Mean squares	F	Significance
Between groups	4116.710	10	411.671	3.942	**0.000**
Within groups	164887.406	1579	104.425		
Total	169004.117	1589			

The analysis was conducted with IBM SPSS Statistics for Macintosh, Version 21.0.

Table Q. Post-hoc Tamhane T2 test on pairwise comparison of length of facets by number of facets per piece.

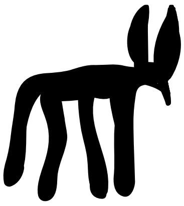
		1 Facet	**2 facets**	**3 facets**	**4 facets**	**5 facets**	**6 facets**	**7 facets**	**8 facets**	**9 facets**	**11 facets**	**18 facets**
Mean squares	**1 facet**		-1.28484	-0.08871	**-3.46324**	**-2.97576**	**-3.51013**	-2.41593	4.76353	-0.70633	-2.00204	**4.86700**
Standard error			0.73960	0.79276	**0.96946**	**1.00205**	**1.08488**	1.26847	2.60373	2.46054	3.12187	**2.46054**
P-value			0.083	0.911	**0.000**	**0.003**	**0.001**	0.057	0.068	0.774	0.521	**0.048**
Mean squares	**2 facets**	1.28484		1.19613	**-2.17841**	-1.69092	**-2.22529**	-1.13109	**6.04837**	0.57851	-0.71720	**6.15184**
Standard error		0.73960		0.81840	**0.99054**	1.02246	**1.10375**	1.28465	**2.61165**	2.46892	3.12848	**2.46892**
P-value		0.083		0.144	**0.028**	0.098	**0.044**	0.379	**0.021**	0.815	0.819	**0.013**
Mean squares	**3 facets**	0.08871	-1.19613		**-3.37454**	**-2.88705**	**-3.42142**	-2.32723	4.85224	-0.61762	-1.91333	**4.95571**
Standard error		0.79276	0.81840		**1.03084**	**1.06155**	**1.14006**	1.31598	2.62720	2.48536	3.14147	**2.48536**
P-value		0.911	0.144		**0.001**	**0.007**	**0.003**	0.077	0.065	0.804	0.543	**0.046**
Mean squares	**4 facets**	**3.46324**	**2.17841**	**3.37454**		0.48749	-0.04689	1.04731	**8.22678**	2.75692	1.46121	**8.33025**
Standard error		**0.96946**	**0.99054**	**1.03084**		1.19928	1.26930	1.42940	**2.68581**	2.54724	3.19064	**2.54724**
P-value		**0.000**	**0.028**	**0.001**		0.684	0.971	0.464	**0.002**	0.279	0.647	**0.001**
Mean squares	**5 facets**	**2.97576**	1.69092	**2.88705**	-0.48749		-0.53437	0.55983	**7.73929**	2.26943	0.97372	**7.84276**
Standard error		**1.00205**	1.02246	**1.06155**	1.19928		1.29436	1.45170	**2.69775**	2.55982	3.20070	**2.55982**
P-value		**0.003**	0.098	**0.007**	0.684		0.680	0.700	**0.004**	0.375	0.761	**0.002**
Mean squares	**6 facets**	**3.51013**	**2.22529**	**3.42142**	0.04689	0.53437		1.09420	**8.27366**	2.80380	1.50809	**8.37713**
Standard error		**1.08488**	**1.10375**	**1.14006**	1.26930	1.29436		1.51006	**2.72960**	2.59336	3.22759	**2.59336**
P-value		**0.001**	**0.044**	**0.003**	0.971	0.680		0.469	**0.002**	0.280	0.640	**0.001**
Mean squares	**7 facets**	2.41593	1.13109	2.32723	-1.04731	-0.55983	-1.09420		**7.17946**	1.70960	0.41390	**7.28294**
Standard error		1.26847	1.28465	1.31598	1.42940	1.45170	1.51006		**2.80762**	2.67536	3.29384	**2.67536**
P-value		0.057	0.379	0.077	0.464	0.700	0.469		**0.011**	0.523	0.900	**0.007**
Mean squares	**8 facets**	-4.76353	**-6.04837**	-4.85224	**-8.22678**	**-7.73929**	**-8.27366**	**-7.17946**		-5.46986	-6.76557	0.10347
Standard error		2.60373	**2.61165**	2.62720	**2.68581**	**2.69775**	**2.72960**	**2.80762**		3.51112	4.00247	3.51112
P-value		0.068	**0.021**	0.065	**0.002**	**0.004**	**0.002**	**0.011**		0.119	0.091	0.976
Mean squares	**9 facets**	0.70633	-0.57851	0.61762	-2.75692	-2.26943	-2.80380	-1.70960	5.46986		-1.29571	5.57333
Standard error		2.46054	2.46892	2.48536	2.54724	2.55982	2.59336	2.67536	3.51112		3.91083	3.40629
P-value		0.774	0.815	0.804	0.279	0.375	0.280	0.523	0.119		0.740	0.102
Mean squares	**11 facets**	2.00204	0.71720	1.91333	-1.46121	-0.97372	-1.50809	-0.41390	6.76557	1.29571		6.86904
Standard error		3.12187	3.12848	3.14147	3.19064	3.20070	3.22759	3.29384	4.00247	3.91083		3.91083
P-value		0.521	0.819	0.543	0.647	0.761	0.640	0.900	0.091	0.740		0.079
Mean squares	**18 facets**	**4.86700**	**-6.15184**	**-4.95571**	**-8.33025**	**-7.84276**	**-8.37713**	**-7.28294**	-0.10347	5.57333	-6.86904	
Standard error		**2.46054**	**2.46892**	**2.48536**	**2.54724**	**2.55982**	**2.59336**	**2.67536**	3.51112	3.40629	3.91083	
P-value		**0.048**	**0.013**	**0.046**	**0.001**	**0.002**	**0.001**	**0.007**	0.976	0.102	0.079	

In bold, statistically significant differences between pairs. The analysis was conducted with IBM SPSS Statistics for Macintosh, Version 21.0.

CAPÍTULO 4

Análisis tecnológico y caracterización de residuos de los útiles para el tratamiento de colorantes

Rosso, D. E., Pitarch Martì, A., d'Errico, F., 2016. Middle Stone Age Ochre Processing and Behavioural Complexity in the Horn of Africa: Evidence from Porc-Epic Cave, Dire Dawa, Ethiopia. *PLOS ONE* 11(11): e0164793.



4.1 RESUMEN

En contexto arqueológico, la presencia de colorantes se interpreta como la prueba de una complejidad cultural siendo su análisis esencial para el conocimiento del origen de la modernidad cognitiva. Sin embargo, son escasos los estudios que se focalizan en los útiles de procesado, los contenedores y los artefactos con residuos de colorantes, con la finalidad de reconstruir las diferentes etapas de la cadena operativa del tratamiento de este material.

En este artículo, analizamos veintiún útiles de tratamiento de colorantes (14 molinos, 6 machacadores un útil posiblemente usado como molino y machacador) y dos cantos con residuos de colorante, todos ellos hallados por Kenneth D. Williamson en 1975-1976, en los niveles MSA de la cueva de Porc-Epic.

Nuestro objetivo ha sido evaluar el grado de complejidad cultural que refleja el tratamiento y uso de colorantes y aportar datos para un área geográfica inexplorada desde este punto de vista: el Cuerno de África.

Estos útiles, así como una parte importante de los 40 kg de colorantes hallados en los mismos niveles, estaban concentrados en áreas probablemente dedicadas al procesado de colorantes. Los molinos incluyen diversos tipos de materias primas, en algunos casos exógenas. El estudio de las marcas de uso nos ha permitido detectar una variedad de técnicas empleadas para procesar los colorantes. Hemos llevado a cabo análisis de los residuos de colorante por microscopía óptica, por difracción de rayos X, por espectrometría μ-Raman y microscopía electrónica de barrido con sistema de detección de energía acoplada (MEB-EDS). Hemos podido comprobar que estos útiles fueron usados para procesar una gran variedad de colorantes, de texturas y colores diversos, seguramente usados para diferentes funciones.

El caso particular de un canto con residuos rojos repartidos en la mitad de su superficie de forma homogénea parece sugerir un uso para actividades simbólicas: hemos interpretado este objeto o bien como canto pintado o bien como tampón utilizado para aplicar colorante sobre materiales blandos.

RESEARCH ARTICLE

Middle Stone Age Ochre Processing and Behavioural Complexity in the Horn of Africa: Evidence from Porc-Epic Cave, Dire Dawa, Ethiopia

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Abstract

Ochre is a common feature at Middle Stone Age (MSA) sites and has often been interpreted as a proxy for the origin of modern behaviour. However, few ochre processing tools, ochre containers, and ochre-stained artefacts from MSA contexts have been studied in detail within a theoretical framework aimed at inferring the technical steps involved in the acquisition, production and use of these artefacts. Here we analyse 21 ochre processing tools, i.e. upper and lower grindstones, and two ochre-stained artefacts from the MSA layers of Porc-Epic Cave, Dire Dawa, Ethiopia, dated to ca. 40 cal kyr BP. These tools, and a large proportion of the 4213 ochre fragments found at the site, were concentrated in an area devoted to ochre processing. Lower grindstones are made of a variety of raw materials, some of which are not locally available. Traces of use indicate that different techniques were employed to process ochre. Optical microscopy, XRD, μ-Raman spectroscopy, and SEM-EDS analyses of residues preserved on worn areas of artefacts show that different types of ferruginous rocks were processed in order to produce ochre powder of different coarseness and shades. A round stone bearing no traces of having been used to process ochre is half covered with residues as if it had been dipped in a liquid ochered medium to paint the object or to use it as a stamp to apply pigment to a soft material. We argue that the ochre reduction sequences identified at Porc-Epic Cave reflect a high degree of behavioural complexity, and represent ochre use, which was probably devoted to a variety of functions.

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Introduction

Evidence for systematic exploitation of ochre has been reported at several Middle Stone Age (MSA) sites from North and South Africa [1–9], as well as Mousterian and Châtelperronian sites in Europe [10–16] and the Middle East [17,18]. Here, we define "ochre" as rocks containing a high proportion of iron oxides, often mixed with silicates and other mineral substances, which are red or yellow in colour, or are streaked with such shades [19]. The use of these iron-rich minerals has often been interpreted to reflect high cognitive functions and symbolic thinking [1,3,9,20,21]. However, this view has been contested, as some evidence indicates that ochre may have also been used for functional purposes [19,22–29].

With the exception of a few sites in Sub-Saharan and North Africa, information on the way ochre was selected, processed, stored, and used is still scarce. This complicates the detection of behavioural similarities and what such behaviours may represent in terms of cognition and cultural complexity. Analysis of artefacts stained with ochre and involved, to varying degrees, in the treatment, storage and use of ochre have been conducted on Middle Stone Age and Mousterian knapped lithics (possibly stained by hafting or ochre processing) [27,28,30,31], shell containers [5,16], and personal ornaments [16,32–35]. Such analyses remain few in number due to the rarity of these objects in the archaeological record and the methodological challenges associated with the analysis of microscopic ochre residues.

In order to gain a better understanding of ochre processing and use in the East African MSA, and to evaluate the degree of behavioural complexity reflected by these activities, we present the first detailed analyses of ochre processing tools (OPT), namely upper and lower grindstones, and ochre-stained artefacts (OSA), consisting of stained pebbles and cobbles, recovered by Kenneth D. Williamson [36] in 1975 and 1976 from the MSA layers of Porc-Epic Cave (Dire Dawa, Ethiopia). The interest of these objects lies in their number, variety, excellent state of preservation of surface modifications, consistent presence of ochre residues, and the fact that they are associated with the most abundant collection of ochre pieces ever found at a Palaeolithic site [37]. In addition, research on the spatial distribution of pigment lumps and ochre processing tools has shown that concentrations of these artefacts are present at the site. The location of these concentrations shift through time, thereby offering the possibility of documenting temporally changing behavioural patterns. Thus, one has a unique opportunity to comprehensively reconstruct technical processes involved in the treatment and use of ochre in an area of the African continent virtually unexplored in this respect and for a key period for hominin cultural and biological evolution.

Early ochre processing tools and ochre containers

Ochre processing tools, ochre containers, and ochre-stained artefacts from MSA and Middle Palaeolithic contexts are, in most cases, only briefly mentioned in the literature and have rarely been analysed in detail [5]. Additionally, they often present a poor state of preservation, with little or no trace of residue.

In Africa, the earliest tools that may have been used to process ochre are found in early MSA contexts. At the site of GnJh-15, in the Kapthurin formation, Kenya, possible grindstones stained with ochre were found in layers dated to 500–284 ka [8,38]. A quartzite cobble with ochre stains, interpreted as an ochre processing tool, was recovered at Twin Rivers, in Zambia [1,39]. At Sai 8-B-11, Sai Island, Sudan, sandstone mortars shaped by knapping and small chert pebbles with residues of red and yellow ochre are reported from levels dated to ca. 180 ka [40,41].

At Blombos Cave, South Africa, two toolkits used for the production and storage of ochre-rich compounds were recovered from layers dated to 100 ka [5]. These toolkits include two large abalone shells containing an ochre-rich compound composed of ochre powder and microflakes of two types of ferruginous siltstone (composed of quartz, hematite, muscovite/illite, and goethite), fragments of crushed trabecular bone, crushed compact bone, charcoal, and fragments of grindstones made of quartz, quartzite and silcrete. The two shells were found in close proximity to utilized ochre lumps, bones, as well as upper and lower grindstones. Two rhyolite grinders, and a faceted quartz mortar with ochre residues are reported from Ngalue Cave, in Mozambique, in levels dated between >42 ka and 105 ka. One of these shows the presence of possible starch residues [42,43]. At Klasies River, South Africa, a piece of tabular quartzite, battered on one edge, and bearing possible ochre residues, was found in shelter 1A in levels dated to 80–65 ka [44]. Two ochre-stained upper grindstones (one of which is quartzitic sandstone) and several ochre-stained artefacts are reported from middle–late MSA layers at Die Kelders, South Africa [45–47]. Nine backed tools with ochre on the cutting edges were found at Rose Cottage Cave in layers dated to 68–60 ka [31]. At Sibudu, South Africa, the presence of cemented hearths with ochre powder deposits was observed in layers dated to ca. 58 ka, suggesting that they were used as receptacles for ochre powder or as work surfaces on which grindstones were placed during the processing of ochre pieces [48]. Sandstone slabs, dolerite and hornfels tools with yellow or red residues were also recovered at the site [49]. Scrapers and flakes from late MSA layers with ochre residues on their working edges were interpreted as ochre processing tools [26,28,30]. Two diorite chunks and one diorite cobble with pigment residues that suggest grinding or scoring were found in MSA layers (dated to ca. 119–46 ka) at Yserfontein, South Africa [50]. Six broken pieces of quartzite with ochre residues, interpreted either as bearing paint or as "ochre-smeared slabs of non-artefactual stone" were found in MSA layers at Umhlatuzana Rock Shelter, South Africa [51]. At Bushman Rockshelter, South Africa, several broken grindstones, some with traces of ochre, were found both in MSA (ca. 47–43 ^{14}C kyr BP) and LSA levels [52–55].

One sandstone fragment coated with red ochre was found in the MSA layers of Sehonghong, Lesotho [56]. Grindstones stained with ochre were also reported in Botswana, in the late MSA levels of ≠Gi [8]. In Mali, MSA levels of Songona I, dated to 55–35 ka, yielded sandstone artefacts with smoothed areas interpreted as possible ochre processing tools [57,58]. In Zimbabwe, granite slabs with ochre residues are found at Nswatugi and Pomongwe, in late MSA layers [8,59,60]. In East Africa, two flakes with traces of red ochre and one small ochre-stained lower grindstone were found at Enkapune Ya Muto, Kenya [61]. Grindstones have been recovered from other East African late MSA sites where the presence of ochre lumps is reported. However, it is not specified whether these tools bear ochre residues. Cases in point are Mochena Borago Rockshelter, in Ethiopia [62], and Mumba and Nasera rockshelters, in Tanzania [38,63].

In the Middle East, a possible ochre processing tool was found at Qafzeh cave, Israel, in layers dated to 100–90 ka. A centripetal recurrent mode Levallois core displays a concentration of ochre residues in the concavity of a large negative scar. This is interpreted as a core recycled into an ochre receptacle [18]. *Glycymeris* shells found in the same layers [64] have been interpreted as possible receptacles for ochre by some authors [35], or as ochered shell beads by others [65].

In Europe, grindstones found in early Mousterian levels (250–200 ka) at Beçov I, Czech Republic, were apparently used to process pigments [66,67]. In Germany, sandstone slabs with modifications attributed to the grinding of mineral material are reported in late middle Pleistocene levels of Rheindahlen [13,68]. At Cioarei-Boroşteni Cave, Romania, eight concave fragments of stalagmites and stalagmite crusts, showing ochre residues in concave areas, as well as scraping and polishing marks, were found in levels dated to ca. 52–45 ka BP are thought to be ochre containers [69–71]. In the same site was found an apparently painted geode, in levels dated to ca. 48 ka BP [70]. Grinding stones possibly used for mineral processing were also reported at Barakaevskaya Cave, in southern Russia [72,73].

In Spain, grindstones possibly used for ochre processing are reported from Mousterian levels at Cueva del Castillo and Cueva Morín [8,54], but the presence of ochre residues on these objects is not documented. At Cueva de los Aviones, Spain [16], in levels dated to ca. > 50 cal kyr BP, ochre residues were found on the inner side of an upper valve of a *Spondylus gaederopus* shell and have been interpreted as evidence for use of this shell as an ochre container. A use as ochre containers was also suggested for a *Callista chione* and two lower valve fragments of *Pecten maximus*. However, it has been argued that *S. gaederopus* upper valves have a limited volumetric capacity, which is insufficient for use for ochre processing and storing. A perforated *Glycymeris* shell with red residues identified as hematite was also found. In addition to these finds, an unmodified ancillary metatarsal of *Equus* sp. with orange residues on one extremity is reported from this site, suggesting that it functioned as a tool for the preparation or application of ochre [16].

At Pech-de-l'Azé I, France, a sandstone slab with black residues and diagnostic use-wear of grinding was found in Mousterian of Acheulean Tradition (MTA) levels, which are older than 43 cal kyr BP [15,74–76]. A limestone slab with pigment residues was also found in MTA levels at Le Moustier, France [12]. The absence of smoothed areas or homogenous pigment stains, suggested to the excavator that it was a painted rock rather than a grindstone. At Grotte de Néron, also in France, a limestone block interpreted as an ochre receptacle, possibly modified along its base by knapping and characterized by a central pit with ochre residues, was found in late Mousterian context [53,77]. The Châtelperronian levels of Grotte du Renne, France, have yielded an abundant collection of grindstones with red and black residues [14,53,78].

The earliest evidence of ochre processing tools in Sahul may date back to more than 50 kya. At Madjedbebe (Malakunanja II), in northern Australia, grindstones that sometimes show streaks of red residues were recovered in layers dated to ca. 55–45 ka [79]. At Nauwalabila I, also in northern Australia, levels dated to ca. 53 ka yielded a grindstone made of quartzite with flaked edges and abrasion marks on one face [80,81]. It shows no traces of pigment, but was stratigraphically associated with a large piece of worked hematite.

Ochre processing tools and ochre containers become ubiquitous at LSA and Upper Palaeolithic sites, including rock art contexts [53,82–84]. However relatively few artefacts and associated residues have been subjected to detailed analyses.

Archaeological context

Porc-Epic Cave is a key Palaeolithic site located between the Afar Depression and the Somali Plateau (Fig 1). It is situated 3 km south of Dire Dawa (Ethiopia), near the top of the Garad Erer hill, 140 m above the wadi Laga Dächatu, and opens at the base of a Jurassic limestone cliff. In 1929, Pierre Teilhard de Chardin and Henry de Monfreid discovered the site and carried out an initial survey that identified the presence of Palaeolithic levels [85] and rock art of a "later schematic style" [36,86]. The excavation was extended by Henri Breuil and Paul Wernert in 1933 [87] and by John Desmond Clark in 1974 [36,88]. In 1975–1976, the trench excavated by Desmond Clark was enlarged by Kenneth D. Williamson, covering an area of approximately 49 m^2. In 1998, new data on Porc-Epic's stratigraphic sequence were collected during fieldwork conducted by a team from the *Muséum National d'Histoire Naturelle*, Paris, and the Authority for Research and Conservation of Cultural Heritage (ARCCH) of Ethiopia [89].

The stratigraphy of the site (Fig 2) shows a succession of clayish, sandy levels and breccia, which were divided into seven stratigraphic units [36,37]. MSA artefacts were present between 60 and 220–230 cm below datum. According to Desmond Clark and Williamson [36], the

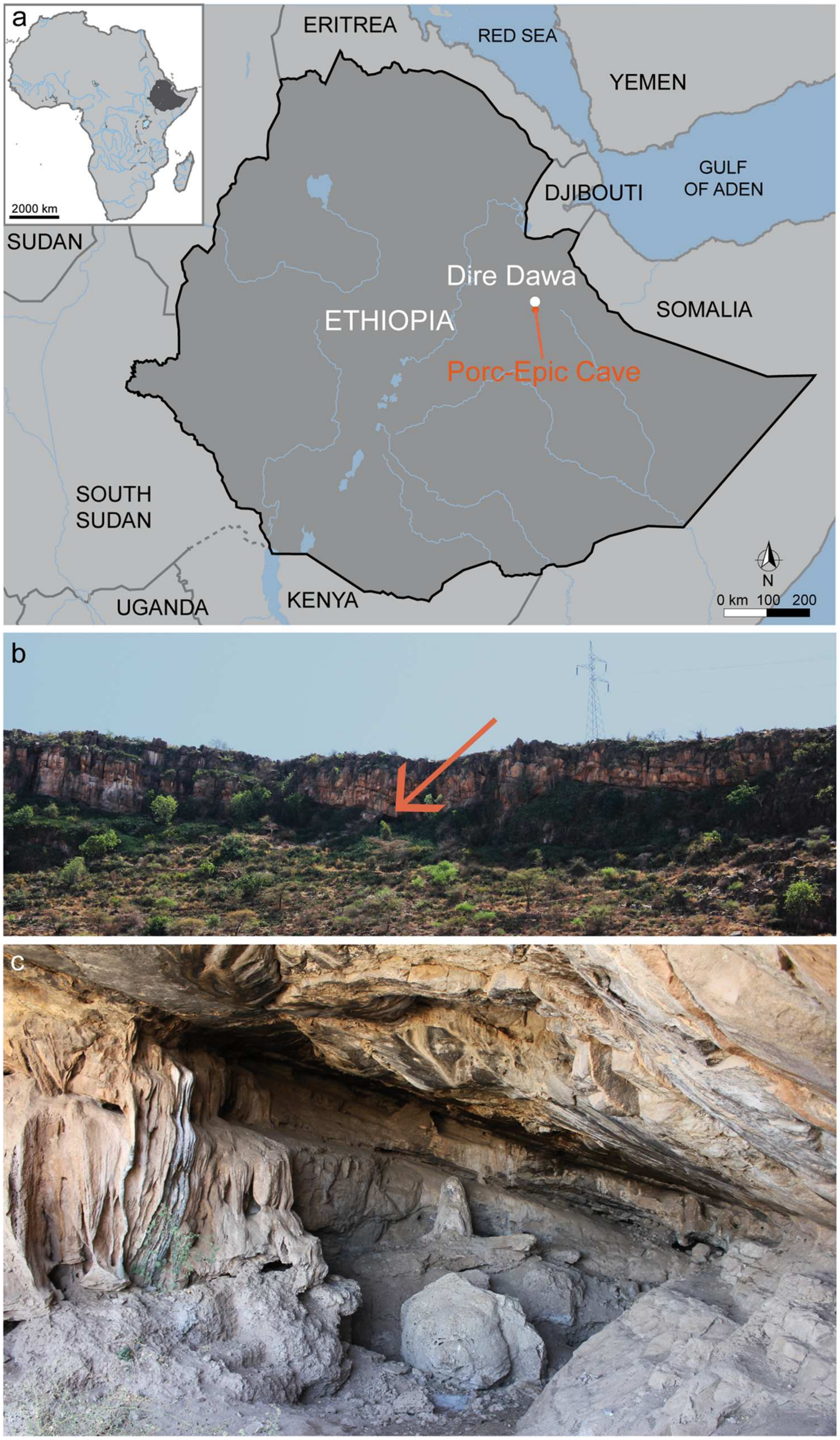
a
2000 km
ERITREA
RED SEA
YEMEN
GULF OF ADEN
DJIBOUTI
SUDAN
Dire Dawa
ETHIOPIA
SOMALIA
Porc-Epic Cave
SOUTH SUDAN
UGANDA
KENYA
N
0 km 100 200
b
c

Fig 1. Location of Porc-Epic Cave. a: map of Ethiopia with location of the site; b: view of the cliff where the site is located. The arrow indicates the entrance of the cave; c: view of the cave from its entrance (photo A. Herrero).

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earliest MSA artefacts were found in a layer of calcareous clay with angular rubble and a wedge of sand (level 2), and in layers of sand, clay and calcareous breccia with roof-fall deposits of limestone rubble (levels 3C and 3D). The main MSA assemblage was collected in levels consisting of calcareous breccia deposits (levels 4A and 4B) and sealed by the main dripstone. Post-dripstone activity and erosion removed deposits to a depth of approximately one meter at the entrance and towards the centre of the cave, where brown loam accumulated. LSA and Neolithic artefacts were found at the top of these poorly consolidated sediments, between 0 and 60 cm below datum. In these levels, consisting of fine sands and loam with interstratified hearth material, some post-depositional mixing may have occurred [90]. However, with the exception of the cave entrance, the main MSA assemblage was sealed and stratigraphically distinct [36].

Analysis of the lithic artefacts from the MSA levels of Porc-Epic Cave [36,89,91–96] revealed that the main raw materials exploited at the site were flint, basalt, obsidian [97,98] and

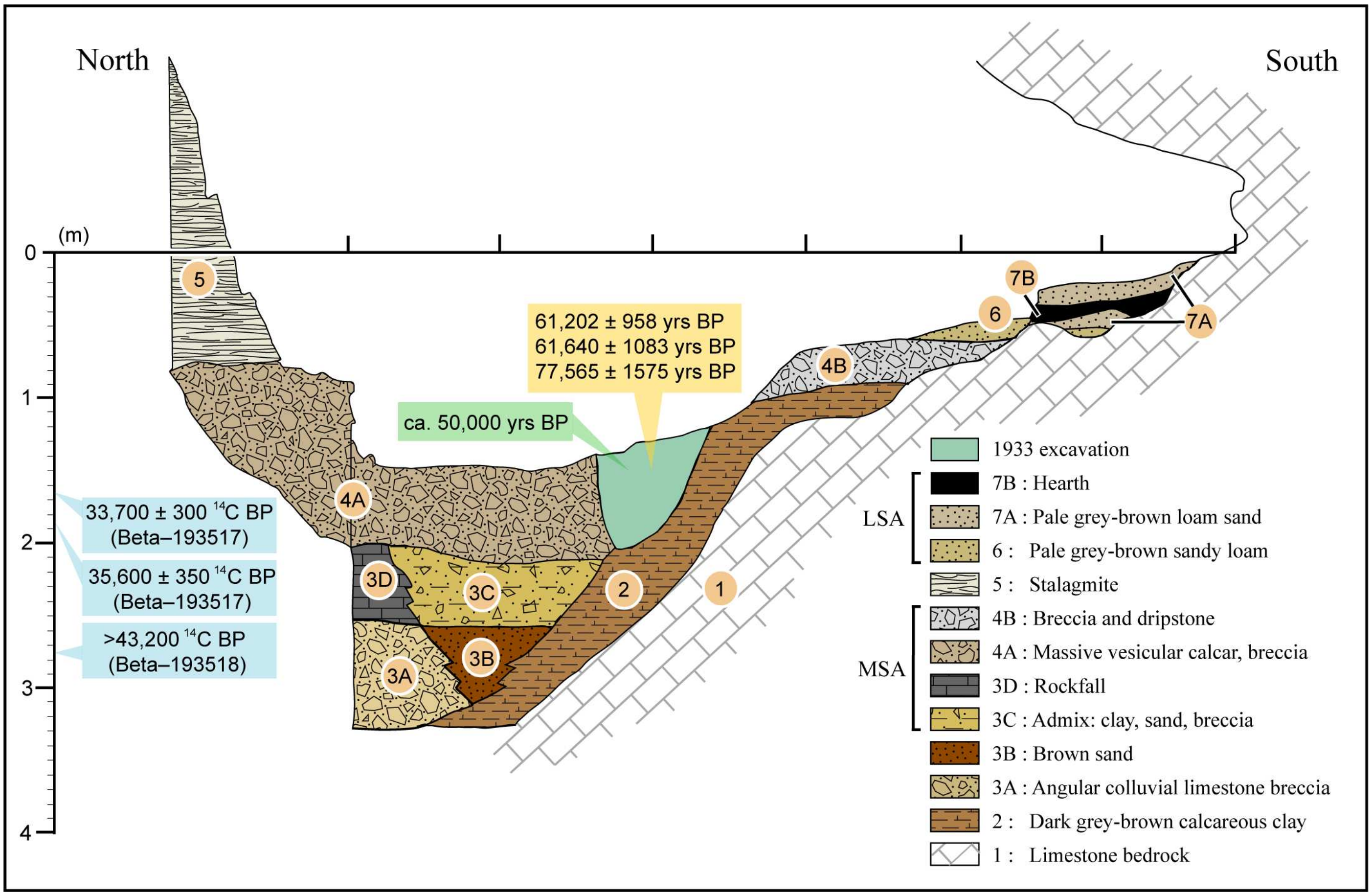

Fig 2. Porc-Epic Cave's stratigraphy. Eastern profile (09W-10W) at the end of the 1974 excavation. The gamma-spectrometry age of the human mandible and the obsidian hydration ages for artefacts recovered during the 1933 excavation are indicated in green and orange respectively. ^{14}C ages obtained from gastropod opercula are indicated in blue. Their position within the stratigraphy is approximate, as only the depth and square at which these objects were found is known, and cannot be correlated to a specific layer. This figure is similar but not identical to the image from [37], and is therefore for illustrative purposes only.

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sandstone/quartzite. Levallois, Discoid and Laminar reduction methods, employing direct hard-hammer percussion were used in the production of flakes, blades, bladelets and points. According to Desmond Clark and Williamson [36], the LSA levels can be clearly differentiated from the MSA levels due to the presence of microliths, small scrapers and *outils écaillés*. This, though, is not supported by Pleurdeau [89,94–96], who identifies the presence of a small number of microliths and backed bladelets in the MSA assemblage. According to this researcher, the presence of LSA features in levels attributed to the MSA may reflect a gradual evolution from the MSA to the LSA. However, recent studies [91] suggest that the presence of microliths may be the result of mixing with the overlying LSA layers, or of an intensive reduction of raw materials such as obsidian, which may occasionally produce micro-laminar blanks.

The analysis of the faunal remains showed the presence in the MSA levels of a variety of mammal taxa, suggesting the proximity of a water source and widespread grasslands. According to Assefa [90], the skeletal element profile suggests a selective transport of nutritional high-ranking elements to the site, which may have been a residential base during the MSA.

The MSA levels of the site also yielded a few human cranial fragments and a partial mandible, which exhibits a combination of modern and archaic features [99].

An accumulation of more than 400 gastropod opercula belonging to the terrestrial species *Revoilia guillainopsis* was found in the MSA levels. According to Assefa [100], this accumulation cannot result from natural processes and may be interpreted as evidence for symbolic behaviour, even though the analysis of the perforations shows no evidence of anthropogenic modifications.

A number of attempts have been made to radiometrically date the MSA layers (for a summary, see [37]). Three artefacts attributed to the MSA found during the 1933 excavation [101] were dated by obsidian hydration to 61,202 ± 958, 61,640 ±1083, and 77,565 ± 1575. However, this dating method is now considered unreliable [102,103]. The human mandible found in 1933 [99] provided a date of ca. 50 ka through high-resolution low-background gamma-ray spectrometry [91]. Accelerator mass spectrometry (AMS) radiocarbon determinations for three samples of gastropod opercula from the MSA layers [90] yielded ^{14}C ages of 33,700 ± 300 (Beta–193517), 35,600 ± 350 (Beta–193516), and >43,200 (Beta–193518). The 95.4% probability range of the two finite ages are 38,800–37,049 cal BP, and 41,084–39,421 cal BP (IntCal13; OxCal 4.2; [104]).

Ochre processing and use at Porc-Epic Cave

Ochre fragments and ochre processing tools were mentioned by Breuil et al. [105], and according to Desmond Clark and Williamson [36], 214 ochre fragments and "one sub-rectangular lower grindstone fragment of limestone showing one well-smoothed face and reddish alteration due to having been burnt" were recovered during the 1974 excavation. Analysis of the material from the 1975–1976 excavation has recently identified a hitherto unknown ochre assemblage comprising 4213 lumps (40 kg) of red, brown and yellow iron rich minerals (Fig 3) often modified by grinding (Fig 3A, 3B and 3D), as well as 23 possible ochre processing tools [37].

The analysis of the spatial and stratigraphic distribution of these artefacts [37] clearly shows concomitant changes in the location of concentrations of ochre processing tools and ochre fragments (Fig 4). Between 60 and 100 cm below datum, an accumulation of ochre, accounting for 62,27% of the ochre pieces recovered within this depth interval, and two ochre processing tools, are observed in the southeastern area of the site (squares 04N-04W, 04N-05W and 04N-07W). Another concentration, accounting for 1373 ochre fragments (50,73% of the ochre fragments present at that depth interval), comes from a depth of 100 to 190 cm below datum, and

Fig 3. Ochre fragments from Porc-Epic Cave. a, b, d: fragments modified by grinding; c: fragment showing no modifications. Scale = 1 cm.

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is found in northeastern squares (squares 08N-07W, 08N-08W, 09N-07W, 10N-07W). Most of the ochre processing tools (n = 17) and two ochre-stained artefacts occur between 110 and 180 cm below datum. Among those tools, 76,4% (n = 13) were found in the same squares where the ochre fragment concentration occurs. The abundance of both ochre processing tools and ochre fragments in the same excavation units suggests that there were areas devoted to ochre processing, whose location shifted through time. The lower levels (190–280 cm below datum) yielded only one ochre processing tool at the northwestern area of the cave, towards the entrance.

Comparison of the distribution of ochre fragments and gastropod opercula dated by ^{14}C suggests that the MSA deposits accumulated over a relatively short period of time and that the transport and use of ochre pieces at Porc-Epic most likely started around, or slightly before, 45 ka cal BP, and was particularly intense ca. 40 cal kyr BP [37]. However, the low number of ^{14}C determinations and the fact that the dated samples come from three different areas of the site make it difficult to precisely establish for how long ochre was used.

Materials and Methods

Data collection, macroscopic and microscopic analysis

The material analysed in this study is curated at the National Museum of Ethiopia, in Addis Ababa. It includes twenty-three artefacts (OPT 1–4, 6–14, 16–23, OSA 5, 15; Fig 5 and S1 and S2 Figs) identified by one of us (DR) when examining the material from Williamson's excavations [37]. Chipped stone tools bearing ochre residues were identified in the 1975–1976 material, but were excluded from this study. A permit to study the archaeological material and to export it temporarily was granted by the Authority for Research and Conservation of Cultural Heritages of Ethiopia (ARCCH). Material recovered during Teilhard de Chardin and de

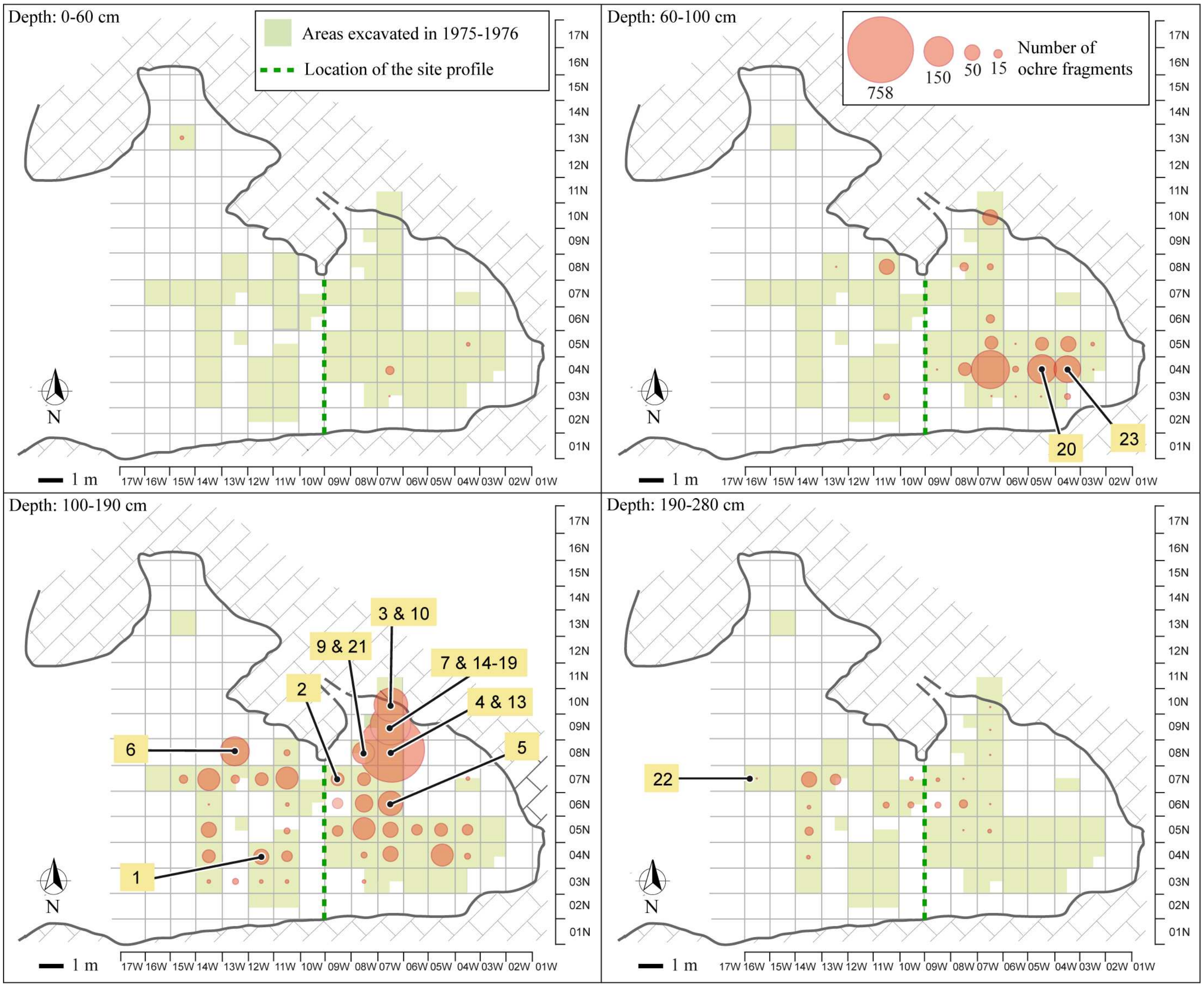

Fig 4. Spatial distribution of ochre fragments, ochre processing tools and ochre-stained artefacts. Bubble sizes reflect the frequency of ochre fragments per grid unit. Numbers refer to ochre processing tools and ochre-stained artefacts. The objects' identification number is the same as presented in Figs 5–11, Tables 1–5, S1 and S2 Figs, S1 Table, S1 Text. This figure is similar but not identical to the image from [37], and is therefore for illustrative purposes only.

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Monfreid's survey (1929), Breuil and Wernert's excavation (1933), and Desmond Clark's excavation (1974) are not analysed in this paper.

Contextual, mineralogical, technological and morphometric variables were recorded for each object, and samples of residues were collected on a number of them (see below). In particular, we collected information on the spatial and stratigraphic provenance of the artefact, type of raw material, as well as object length, width, and thickness. The location and type of modifications, as well as the location of residue were also recorded.

Characterisation of the raw material was based on macroscopic and microscopic observation of the objects.

Fig 5. Ochre processing tools and ochre-stained artefacts found at Porc-Epic Cave. The objects' identification number is the same as presented in Figs 4 and 6–11, Tables 1–5, S1 and S2 Figs, S1 Table, S1 Text.

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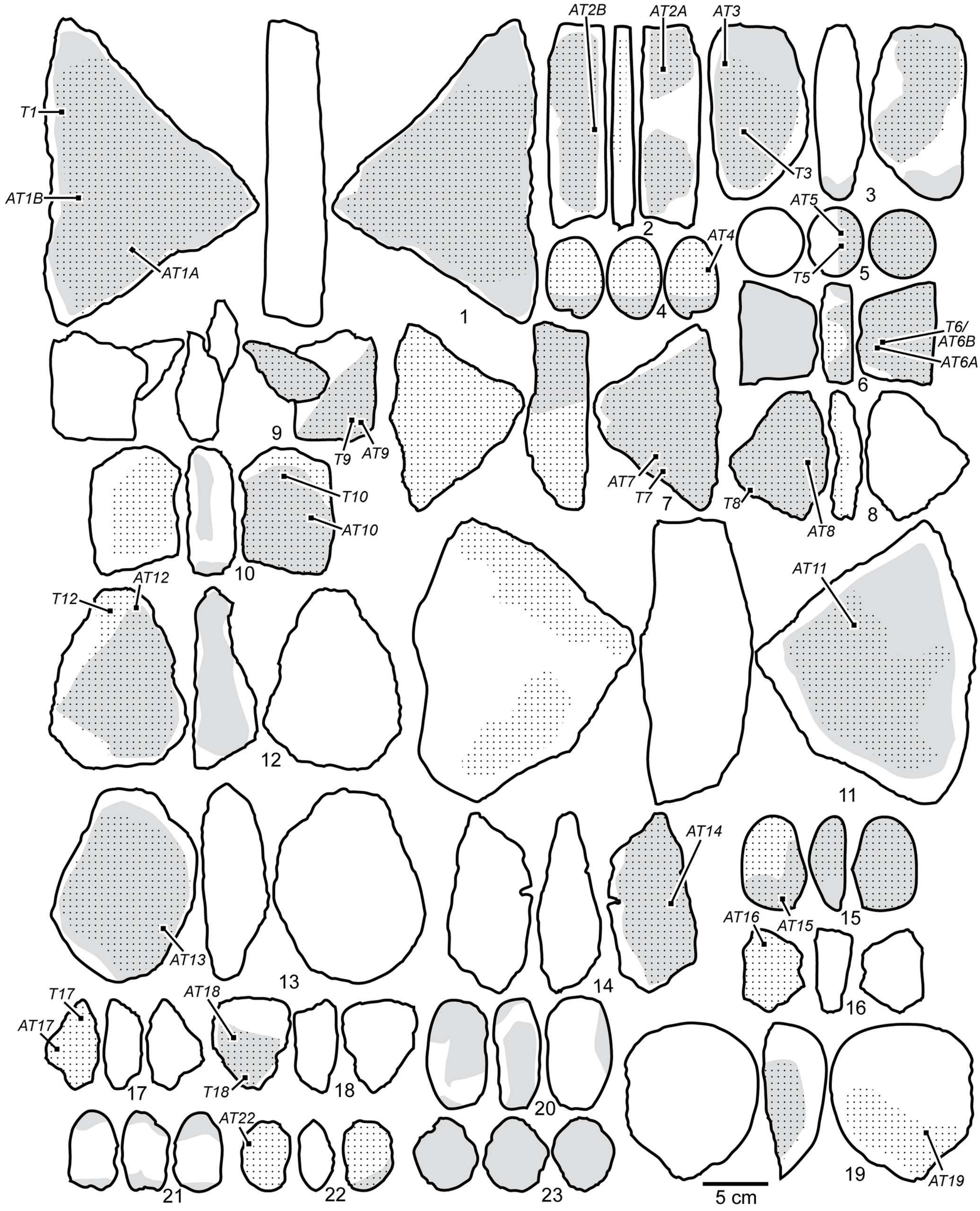
AT2B
AT2A
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1
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15
16
T17
AT17
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T18
17
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5 cm
19
AT19

Fig 6. Drawings of the ochre processing tools and ochre-stained artefacts from Porc-Epic Cave. Ochre residues (dotted areas), traces of modification (gray areas), and location of the samples are indicated. The objects' identification number is the same as presented in Figs 4, 5 and 7–11, Tables 1–5, S1 and S2 Figs, S1 Table, S1 Text.

doi:10.1371/journal.pone.0164793.g006

Anthropogenic (Fig 6) and natural modifications were also analysed and photographically documented using a Leica Z6 APO macroscope. We recorded the presence of flake scars (Fig 7A), pits (Fig 7B and 7C), linear impressions (Fig 7D and 7E), smoothed/levelled areas (Fig 7F–7I), microstriations (Fig 7G–7I), deep composite grooves (Fig 7J), and striations (Fig 7E). We define pits as depressions produced by a pounding action [82,106–108]. Linear impressions are elongated, irregular marks produced by a lithic edge impacting the stone surface during retouching [82]. Smoothing is the state of a surface that has lost, comparatively to neighbouring areas, irregularities and projections through abrasive action [82,106,109–111]. Smoothed areas may be covered in some cases by groups of superficial microstriations [107,109,112,113] not exceeding a width of 50 μm. Deep grooves are sub-parallel, slightly curved marks displaying on their walls multiple striae produced by the asperities of a lithic cutting edge vigorously scraping the object's surface [19,114]. Striations are produced by the punctual tangential contact of a sharp tool, such as a lithic cutting edge or a bone artefact, with a pebble surface [82].

Ochre residue sampling and analysis

Residues from twenty artefacts were sampled with a scalpel under the microscope, on areas of approximately 2 mm^2. The sampling (Fig 6) did not produce any visible damage to the objects. Sampling was easy to conduct on OPT 1–4, 6–8, 11, 16–19 and OSA 15 due to the abundance and softness of the residue, but was more difficult on OPT 9, 10, 12–14, 22 and OSA 5, due to the small amount and hardness of the identified residues.

Sampled residues were collected following two protocols: (1) by applying carbon adhesive tabs to residues loosened by scalpel blades (samples AT1–19, AT22; Fig 8); or (2) by placing loosened residues in sample tubes (samples T1, T3, T5–10, T12, T17, T18). The second sampling method was carried out only when residues were abundant.

Residues were examined and photographed with a motorised Leica Z6 APOA macroscope equipped with a DFC420 digital camera. Images were treated with Leica Application Suite (LAS) equipped with a Multifocus module, and Leica Map DCM 3D computer software, which allowed for images with extended depths of field.

Micro-Raman spectroscopy (μ-RS), X-ray diffraction (XRD) and scanning electron microscopy coupled with energy dispersive X-ray spectroscopy (SEM-EDS) were used to characterise the composition of the residues (Table 1). The combined application of these three methods allows for the identification of the mineralogical and elemental composition of inorganic residues [5,16] such as those present on the studied objects. These techniques are complementary in that XRD provides an overall assessment of the minerals phases present in the sample, and μ-RS identifies the mineral composition of specific particles, which may in parallel be analysed with SEM-EDS for their elemental composition, morphology and distribution. Micro-RS was applied to all samples, XRD only when the quantity of residue was sufficient for obtaining reliable results, SEM-EDS when examination of the residue under optical microscopy indicated that the sample was not or less contaminated by sediment and/or tool fragments.

Mineralogical analyses were carried out using a SENTERRA Dispersive Raman Microscope (Bruker), equipped with an internal calibration system. The working area was examined through the integrated colour camera. Spectra were acquired with a 785 nm laser, in a spectral range from 50 to 1500 cm^{-1}, a laser power of 1 mW necessary to avoid thermal transformation of mineral phases, an integration time of 20 s, and with a number of co-additions ranging


a
b
c
d
e
f
g
h
i
j

Fig 7. Modifications and use-wear on Porc-Epic Cave's ochre processing tools and ochre-stained artefacts. a: flake scar on OPT 3; b, c: pits on OPT 1 and 21; d: linear impressions on OSA 5; e: linear impressions and striations on OSA 15; f: smoothed areas on OPT 9; g-i: smoothed areas and microstriations on OPT 3, 11 and 13 respectively; j: deep grooves on OPT 20. Scales = 5 mm.

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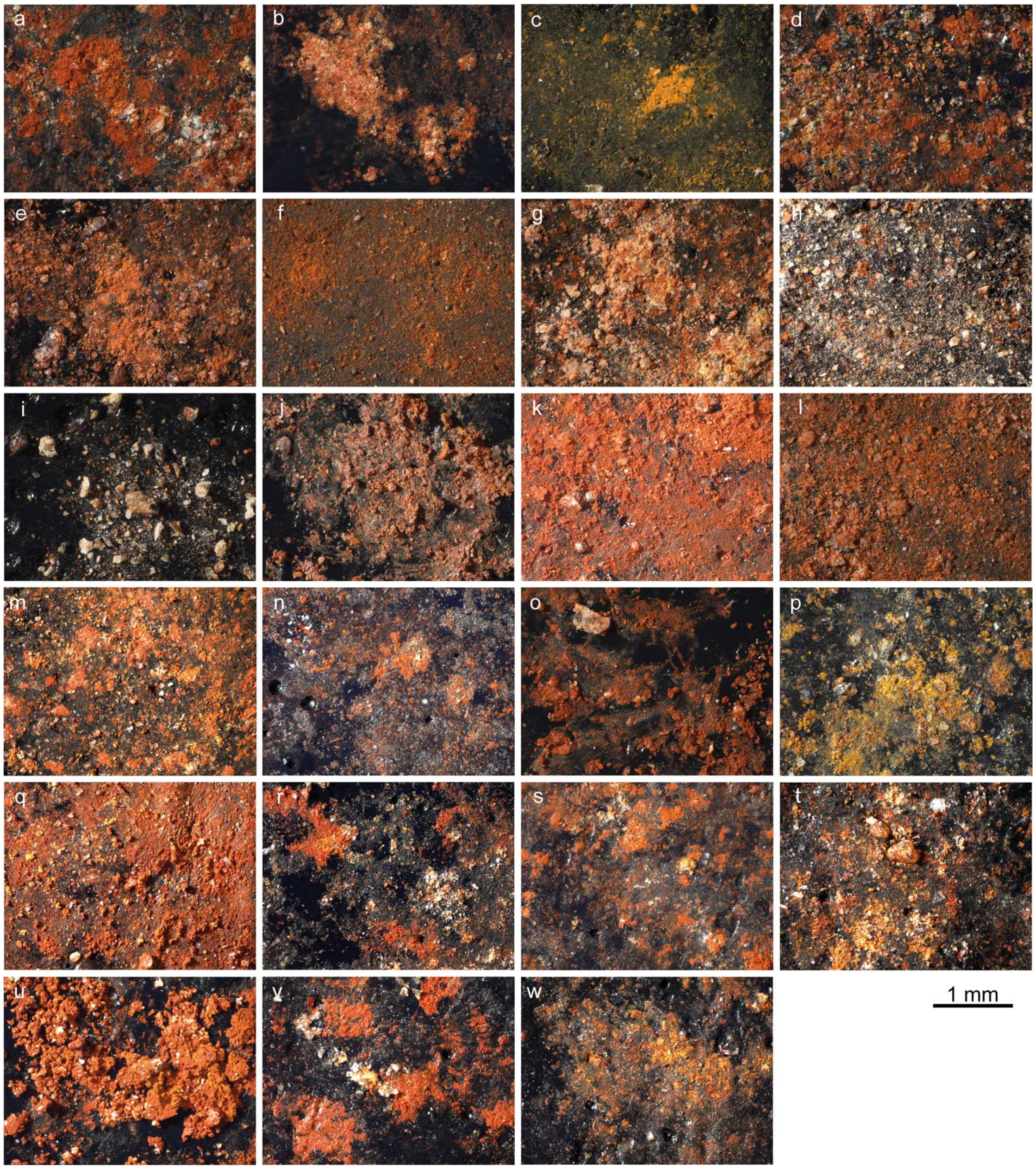

Fig 8. Ochre residues on carbon adhesive tabs. a: sample AT1A (OPT 1); b: sample AT1B (OPT 1); c: sample AT2A (OPT 2); d: sample AT2B (OPT 2); e: sample AT3 (OPT 3); f: sample AT4 (OPT 4); g: sample AT5 (OSA 5); h: sample AT6A (OPT 6); i: sample AT6B (OPT 6); j: sample AT7 (OPT 7); k: sample AT8 (OPT 8); l: sample AT9 (OPT 9); m: sample AT10 (OPT 10); n: sample AT11 (OPT 11); o: sample AT12 (OPT 12); p: sample AT13 (OPT 13); q: sample AT14 (OPT 14); r: sample AT15 (OSA 15); s: sample AT16 (OPT 16); t: sample AT17 (OPT 17); u: sample AT18 (OPT 18); v: sample AT19 (OPT 19); w: sample AT22 (OPT 22).

doi:10.1371/journal.pone.0164793.g008

Table 1. Analyses conducted on ochre residue samples.

	SEM-EDS		µ-RS		XRD	
Num	**Sample***	**Num of an**	**Sample***	**Num of an**	**Sample***	**Num of an**
1	AT1A	14	AT1A, B	5	T1	1
2	AT2A, B	14	AT2A, B	7	-	-
3	AT3	12	AT3	5	T3	1
4	AT4	8	AT4	6	-	-
5	AT5	11	AT5	4	T5	1
6	AT6B	9	AT6A	3	T6	1
7	AT7	13	AT7	12	T7	1
8	-	-	AT8	5	T8	1
9	AT9	15	AT9	8	T9	1
10	-	-	AT10	8	T10	1
11	-	-	AT11	9	-	-
12	AT12	6	AT12	5	T12	1
13	AT13	9	AT13	4	-	-
14	-	-	AT14	7	-	-
15	AT15	9	AT15	7	-	-
16	-	-	AT16	6	-	-
17	-	-	AT17	9	T17	1
18	-	-	AT18	7	T18	1
19	-	-	AT19	7	-	-
20	-	-	-	-	-	-
21	-	-	-	-	-	-
22	AT22	18	AT22	2	-	-
23	-	-	-	-	-	-

Num: number; An: analyses; SEM-EDS: Scanning electron microscopy coupled with energy dispersive X-ray spectroscopy; µ-RS: micro-Raman spectroscopy; XRD: X-ray diffraction. The objects' identification number is the same as presented in Figs 4–11, Tables 2–5, S1 and S2 Figs, S1 Table, S1 Text.

* Samples AT1–AT19, AT22 refer to residues stuck on carbon adhesive tabs, and samples T1, T3, T5–T10, T12, T17, T18 refer to loose residues kept in sample tubes.

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between 20 to 40 depending on the presence of fluorescence radiation and signal-to-noise ratio. Spectra were collected with the OPUS 7.2. software, and compared to those of the RRUFF spectra library [115] in order to identify mineral phases.

Mineralogical composition was also established by XRD using PANalytical X'pert MPD-PRO diffractometer (Bragg Brentano Theta-Theta geometry), with a copper anticathod (mean lambaKalpha = 15,418 Å). The working tension and intensity were set at 45 kV and 40 mA, respectively, and the time of analysis was of 19.30 h and 9.30 h, depending on the sample. Mineralogical phases were identified by using the routine DIFFRAC.SUITE™ EVA software package (Bruker AXS GmbH, Germany), combined with the specific powder diffraction file (PDF2) database (International Centre for Diffraction Data—ICDD, Pennsylvania, USA).

Elemental analyses were performed through SEM-EDS by using a FEI Quanta 200 with SiLi detector, and SDD-EDAX detector. The EDS analyses were performed at the same working distance (10 mm) and with the same acquisition time (100 s). Backscattered electron images (BSE) and elemental analyses were obtained under a low vacuum mode with an accelerating voltage of 10 kV and 15 kV.

Results

Artefact analysis

We identify artefacts displaying areas covered with ochre residues, associated with use-wear, as ochre processing tools (OPT). However, three ferruginous rock nodules on which no ochre residues could be identified were also included in this category. The shape and size of these objects, as well as the presence of use-wear (pits on the extremities or on the entire surface of the objects, and in one case smoothed areas) are consistent with a use for ochre processing. Among the ochre processing tools, we distinguish lower grindstones (i.e., flat or concave slabs used as passive tools to crush, pulverize, and grind iron-rich minerals) from upper grindstones (i.e., pebbles, cobbles or blocks used as active implements to facilitate the crushing or grinding of iron-rich minerals) [53,54,116–118]. One tool shows modifications indicative of a use as both an upper and lower grindstone. In addition, our collection includes a number of ochre-stained artefacts (OSA) that carry ambiguous or no use-wear traces.

Lower grindstones. Fourteen tools are interpreted as lower grindstones (Fig 5 no. 1, 2, 6–14, 16–18, Table 2, Figs A, B, F–K in S1 Fig, Figs A–C, E–G in S2 Fig). They are predominantly made of quartzite (n = 5) and sandstone (n = 3), with basalt, conglomerate, granite, granitoid, limestone and schist only used occasionally. Eight show recent fractures (Table 2).

Table 2. Contextual and descriptive data of ochre processing tools and ochre-stained artefacts from Porc-Epic Cave.

Num	Square	Subsq	Depth	OCA	Preserv	Length*	Width*	Thick*	Rock type	Tool type	Supp inf
1	04N-12W	SE	130–140	-	C	245.0	165.0	46.4	Limestone	LG	Fig A in S1 Figs
2	07N-09W	NE	170–180	-	C	159	46.43	15.63	Schist	LG	Fig B in S1 Figs
3	10N-07W	SW	160–170	NEA	C	138.02	77.02	33.18	Sandstone	LG/UG	Fig C in S1 Figs
4	08N-07W	-	150–160	NEA	RF	65.83	46.51	42.39	Limestone	UG	Fig D in S1 Figs
5	06N-07W	NW	110–120	-	C	52.45	50.26	41.65	Limestone	OSA	Fig E in S1 Figs
6	08N-13W	-	150–160	-	OF	77.08	58.32	28.94	Quartzite	LG	Fig F in S1 Figs
7	09N-07W	SW	110–120	NEA	RF	(141,72)	(99,32)	(39,75)	Conglomerate	LG	Fig G in S1 Figs
8	-	NW	120–130	-	C	108.43	84.06	21.76	Sandstone	LG	Fig H in S1 Figs
9	08N-08W	NE	110–120	NEA	RF	(82,02)	-	(31,15)	Granite	LG	Fig I in S1 Figs
10	10N-07W	NE	120–130	NEA	RF	(100,67)	(80,07)	(26,9)	Quartzite	LG	Fig J in S1 Figs
11	-	-	-	-	C	220	170	56.73	Basalt	LG	Fig K in S1 Figs
12	-	-	150–160	-	C	142.19	107.52	53.45	Quartzite	LG	Fig A in S2 Figs
13	08N-07W	NW	150–160	NEA	RF	(152,56)	(109,09)	(43,16)	Granitoid**	LG	Fig B in S2 Figs
14	09N-07W	SE	120–130	NEA	RF	141.86	58.75	41.02	Quartzite	LG	Fig C in S2 Figs
15	09N-07W	SE	120–130	NEA	OF	71.49	50.12	28.06	Limestone	OSA	Fig D in S2 Figs
16	09N-07W	SE	120–130	NEA	RF	(66,99)	(49,63)	(29,4)	Quartzite	LG	Fig E in S2 Figs
17	09N-07W	SE	120–130	NEA	RF	(71,07)	(42,36)	(29,97)	Sandstone	LG	Fig F in S2 Figs
18	09N-07W	SE	120–130	NEA	RF	(72,36)	(62,47)	(28,4)	Sandstone	LG	Fig G in S2 Figs
19	09N-07W	SE	120–130	NEA	OF	123.34	105.74	46.81	Granite	UG	Fig H in S2 Figs
20	04N-05W	SW	70–80	SEA	C	88.84	55.75	39.39	Ferruginous rock	UG	Fig I in S2 Figs
21	08N-08W	SE	120–130	NEA	C	62.59	38.02	37.86	Ferruginous rock	UG	Fig J in S2 Figs
22	07N-16W	SW	210–220	-	C	52.14	37.06	27.02	Andesite	UG	Fig K in S2 Figs
23	04N-04W	SW	70–80	SEA	C	59.76	56.75	50.48	Ferruginous rock	UG	Fig L in S2 Figs

Num: number; subsq: subsquare; OCA: ochre concentration area; NEA: northeastern area; SEA: southeastern area; preserv: preservation; C: complete; RF: recent fracture; OF: old fracture; thick: thickness; LG: lower grindstone; UG: upper grindstone; OSA: ochre-stained artefact; supp inf: supporting information. The objects' identification number is the same as presented in Figs 4–11, Tables 1 and 3–5, S1 and S2 Figs, S1 Table, S1 Text.

* In brackets, measurements on objects bearing recent fractures.

** Uncertain identification.

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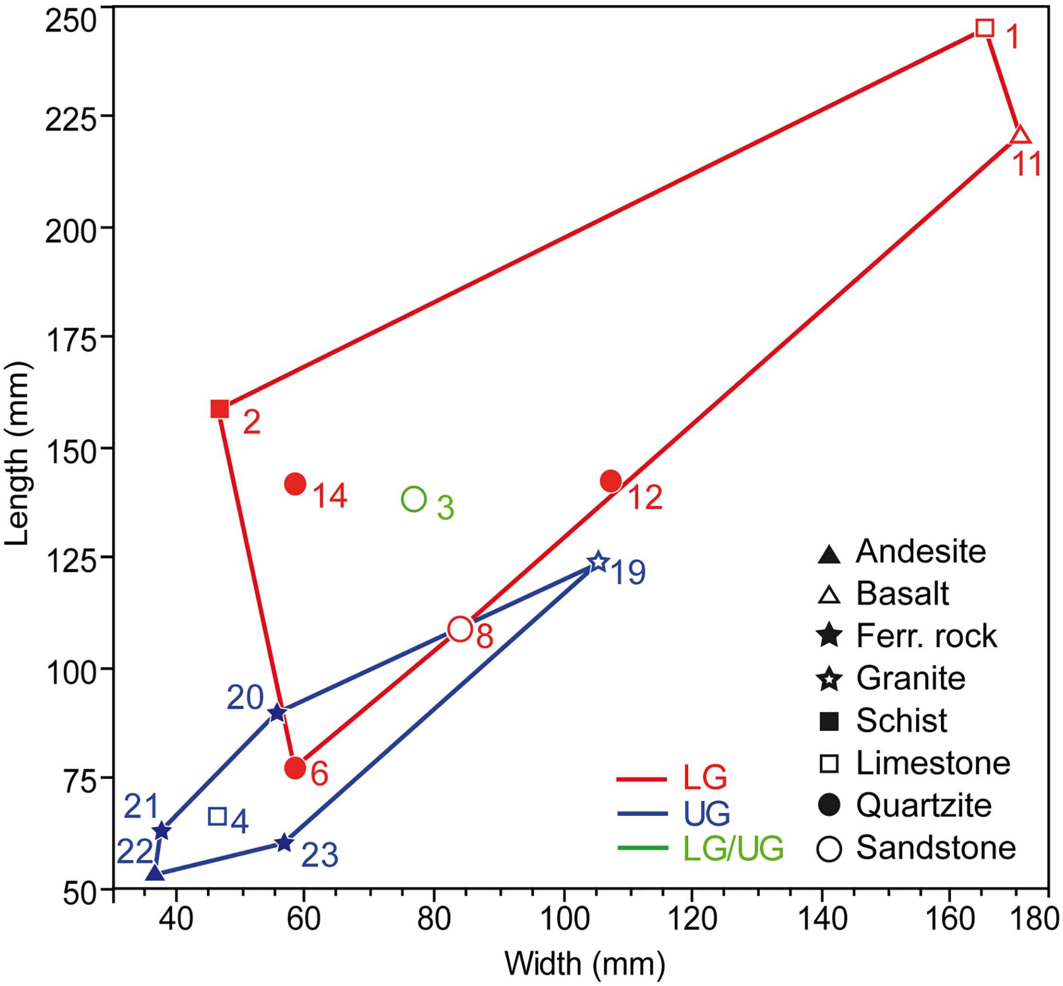

Fig 9. Biplot of length and width of Porc-Epic grindstones of different raw materials. LG: lower grindstone; UG: upper grindstone; ferr. rock: ferruginous rock. The objects' identification number is the same as presented in Figs 4–8, 10 and 11, Tables 1–5, S1 and S2 Figs, S1 Table, S1 Text.

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Undamaged lower grindstones are generally larger than upper grindstones (Fig 9), and two exceed 200 mm in length (OPT 1 and 11).

Lower grindstones display smoothed areas (Fig 7F, 7H and 7I, Table 3, Figs A, B, F–K in S1 Fig, Figs A–C and G in S2 Fig), identified on all pieces except OPT 16 and 17. On nine tools, smoothed areas are present on one flat surface (OPT 7–14, 18), on three, on both flat surfaces (OPT 1, 2, 6). In OPT 6, 7 and 12, smoothing is also observed on the lateral aspect. This is consistent with an abrasion, which requires large flat surfaces. On three lower grindstones (OPT 11, 13, 14), smoothed areas are covered by microstriations (Fig 7H and 7I, Table 3, Fig K in S1 Fig, Figs B, C in S2 Fig) oriented randomly (OPT 11, 14) or along the main axis of the artefact (OPT 13). Only on one artefact (OPT 1), the largest of the collection, smoothed areas also display pits (Fig 7B, Table 3, Fig A in S1 Fig), probably indicating a use for both abrading and pounding ochre lumps.

Lower grindstones show residues ranging in colour from yellow to dark brownish red. In nine cases (OPT 6, 8, 9, 12–14, 16–18; Figs F, H, I in S1 Fig, Figs A–C, E–G in S2 Fig), residues are present on one flat face, on four (OPT 1, 2, 10, 11; Figs A, B, J, K in S1 Fig) they are detected on both flat faces (Fig 6, Table 3). Three also show residues laterally (OPT 2, 6, 8; Fig 6,

Table 3. Modifications and residues on Porc-Epic Cave's ochre processing tools and ochre-stained artefacts.

Num	FS	Pits	LI	Sm	Micr	DG	Str	Residue colour*	Residue loc
1	-	2F	-	2F	-	-	-	R + (Y)	2F
2	-	-	-	2F	-	-	-	R + Y	2F, L
3	2E	2E	-	2F	1F	-	-	R	2F
4	-	1E	-	-	-	-	-	R + (Y)	ES
5	-	-	1F	-	-	-	-	R + B	1F
6	1E, L	-	-	2F, L	-	-	-	R + (Y)	1F, L
7	-	-	-	1F, L	-	-	-	R + (Y)	ES
8	-	-	-	1F	-	-	-	R + (Y)	1F, L
9	-	-	-	1F	-	-	-	R + (B +Y)	1F
10	L	-	-	1F	-	-	-	R + (Y)	2F
11	-	-	-	1F	1F	-	-	R	2F
12	-	-	-	1F, L	-	-	-	R	1F
13	-	-	-	1F	1F	-	-	BRR + Y	1F
14	-	-	-	1F	1F	-	-	R + (Y)	1F
15	L	-	1F	-	-	-	2F, L	R + (Y)	ES
16	-	-	-	-	-	-	-	R + (Y)	1F
17	-	-	-	-	-	-	-	R + (Y)	1F
18	-	-	-	1F	-	-	-	R + (Y + O)	1F
19	-	L	-	-	-	-	-	R + (Y)	1F, L
20	2E	2E	-	1F, L	1F	1F	-	-	-
21	2E	2E	-	-	L	-	-	-	-
22	-	1E	-	-	-	-	-	R + (Y)	2F
23	-	ES	-	-	-	-	-	-	-

Num: number; FS: flake scars; LI: linear impressions; sm: smoothing; micr: microstriations; DG: deep grooves; str: striations; loc: location; 1E: one end; 2E: two ends; 1F: one face; 2F: two faces; L: lateral face(s); ES: entire surface; R: red; Y: yellow; B: brown; BRR: brownish red; O: orange. The objects' identification number is the same as presented in Figs 4–11, Tables 1, 2, 4 and 5, S1 and S2 Figs, S1 Table, S1 Text.

* In brackets, coloured residue visible under optical microscope.

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Table 3, Figs B, F, H in S1 Fig). OPT 7 (Fig 6, Table 3, Fig G in S1 Fig) is the only artefact that shows ochre residues across the entire surface. Residues are systematically found on smoothed areas, but also on areas with no use-wear (Fig 6).

In OPT 13 (Fig B in S2 Fig) and 10 (Fig J in S1 Fig), residues homogenously cover one (OPT 13) or two (OPT 10) larger surfaces. Two layers of residue are identified on OPT 13: a thin brown-red layer overlying a yellow layer, visible in areas in which the former is eroded, and along its perimeter. This is likely due to the successive treatment of two ochre types. It cannot be attributed to heating of the residue, leading to a transformation of goethite into hematite, since no traces of such an event (rubefaction, cracks, etc) are detected on the tool.

In two cases (OPT 2 and 7; Figs B, G in S1 Fig), patchy residues of different colour or texture are associated on the same face. On OPT 2, a few spots of yellow residue are observed in areas covered by red residue. On OPT 7, patchy ochre residues coexist with small accumulations of homogenous residue.

OPT 11 (Fig K in S1 Fig) represents a special case. A dark and defined ring-like deposit runs along the edge of both faces, reflecting a "coffee-ring effect" [119]. During the evaporation of a liquid substance, suspended particles are pushed to the edges of the area covered by the mixture, creating a ring-like deposit [120]. Residues of a different colour, resulting from a more recent use of the same surface, are also present in the centre of this artefact's face.

Continuous flake scars on the edges of two lower grindstones (OPT 6 and 10; Figs F, J in S1 Fig) suggest a use of these tools as hammerstones after their use for ochre treatment, since no traces of ochre are found on the flake scars.

Upper grindstones. The six tools interpreted as upper grindstones are made of limestone, andesite, granite and ferruginous rocks (Fig 5 no. 4, 19–23, Table 2, Fig D in S1 Fig, Figs H–L in S2 Fig). They are often smaller than lower grindstones (Fig 9).

Pits produced by pounding (Fig 7C, Table 3) are generally present on one or both ends (OPT 4, 20–22; Fig D in S1 Fig, Figs I–K in S2 Fig), and in two cases on a margin (OPT 19; Fig H in S2 Fig) and across the entire surface (OPT 23; Fig L in S2 Fig). They are in some cases associated with tangential small flake scars resulting from fractures produced during pounding (OPT 20, 21; Table 3, Figs I, J in S2 Fig). OPT 19 (Fig H in S2 Fig) is a fragment of a tool that accidentally split during use.

With the only exception of one object (OPT 19; Fig H in S2 Fig), which has only one area homogeneously covered with ochre, ochre residues appear on these tools in the form of individual spots, often present on the pitted areas (Fig 6). On the tools made of ferruginous rocks, they cannot be differentiated from the tools' raw material (Figs I, J, L in S2 Fig). Deep grooves produced by a longitudinal scraping (Fig 7J, Table 3) and flat facets produced by abrasion are also present on one upper grindstone made of ferruginous rock (OPT 20; Fig I in S2 Fig). The facets may be due to extraction of pigment powder by rubbing the object against a lower grindstone or by using it to finely powder more friable iron-rich rocks. Striations due to abrasion (Table 3) are also visible on another grindstone made of ferruginous rock (OPT 21; Fig J in S2 Fig).

Upper and lower grindstone. An elongated sandstone cobble (OPT 3) displays modifications indicating use as both a lower and upper grindstone (Fig 5 no. 3; Table 2; Fig C in S1 Fig). Smoothed areas covered by longitudinally oriented microstriations (Fig 7G), with respect to the main axis of the artefact, are detected on both faces (Table 3). They are homogeneously covered with ochre. Pits are identified at both ends, along with a large flake scar created by the use of the tool in a pounding action posterior to its use as a lower grindstone (Fig 7A).

Ochre-stained artefacts. Two limestone artefacts (OSA 5, 15) display ochre residues with traces of modification unrelated to ochre treatment (Fig 5 no. 5 and 15, Table 2, Fig E in S1 Fig, Fig D in S2 Fig).

OSA 15 (Fig 5 no. 15, Fig D in S2 Fig) is a flat cobble homogeneously stained with ochre, which displays linear impressions produced by its use as a retoucher and groups of subparallel individual thin striations, resulting from scraping, or use of the cobble to retouch a lithic edge (Fig 7E, Table 3). In this artefact, the homogeneity of the residues associated with linear impacts and striations, suggests an unintentional staining during its use as a retoucher. This may have been produced either by it being used by a person covered in ochre, or with ochre-stained hands, or by close contact with ochre powder or ochre fragments, for example by carrying them in the same container. This is consistent with the analysis of ochre residues (see below), which suggests the presence of two different ochre types.

OSA 5 (Fig 5 no. 5; Fig E in S1 Fig) is a subspherical pebble. Half of its surface is homogeneously covered by an ochre stain, which is removed at one spot by linear impressions due to its use as a retoucher (Fig 7D; Table 3). The location and appearance of the stain suggests that the artefact was dipped in a liquid ochered medium, which was absorbed by the limestone. The pattern is consistent with a single production or use. Multiple uses would have probably left pigment residue of different shades and traces of pigment on the half of the surface that is not covered in ochre.

Rock type and spatial distribution. The depth (110–130 cm below datum) and area within the cave (northeastern zone [37]) where most of the processing tools are found (Fig 4,

Table 2), also features the highest variety of rock types used (conglomerate, granite, quartzite, limestone, sandstone, and ferruginous rock). Two ochre processing tools (Fig 4, Table 2) made of andesite and schist (OPT 22 and 2) were found in lower levels (210–220 cm and 170–180 cm below datum respectively). No spatial information is available for the only object made of basalt (OPT 11; Table 2).

Residue analysis

Under optical microscopy most residues from the ochre processing tools and ochre-stained artefacts appear as agglomerates of fine-grained powder (Fig 8). These agglomerates are particularly compact in the case of residues from OPT 9, 12 and 18 (Fig 8L, 8O and 8U, Fig I in S1 Fig, Figs A, G in S2 Fig). Residues sampled on OPT 6 (Fig 8H and 8I, Fig F in S1 Fig) are instead composed of isolated coarse grains, and those from OPT 7 (Fig 8J, Fig G in S1 Fig) take the form of small homogenous accumulations.

Even though macroscopically only two processing tools (OPT 2, 13; Table 3, Fig B in S1 Fig, Fig B in S2 Fig) show the presence of yellow residues, microscopically, samples display in most cases a majority of fine red grains associated with few yellow grains (Fig 8; Table 3). Four samples (from OPT 3, 11, 12 and OSA 5; Fig 8E, 8G, 8N and 8O, Figs C, E, K in S1 Fig, Fig A in S2 Fig) only feature red grains and two others (one of the samples from OPT 2 –AT2A– and the sample from OPT 13; Fig 8C and 8P, Fig B in S1 Fig, Fig B in S2 Fig) only contain yellow grains with rare red grains. All residues also contain translucent, white and black coarse particles in variable proportions (Fig 8).

Elemental (Figs 10 and 11, Figs A–G, I in S1 Fig, Figs A, B, D, K in S2 Fig, Table A in S1 Table, Texts A–G, I, L, M, O, T in S1 Text) and mineralogical (Tables 4 and 5; Figs A, C, E–J in S1 Fig, Figs A, F, G in S2 Fig; Table B in S1 Table; S1 Text) analyses indicate that the residues are composed of numerous minerals, including several types of oxides, aluminosilicates (clays, micas, and feldspars), silicates, carbonates, sulphates, and phosphates.

SEM-EDS and mineralogical analysis (Figs 10 and 11, Tables 4 and 5, Figs A–G, I in S1 Fig, Figs A, B, D, K in S2 Fig, S1 Table, S1 Text) of the residues from twelve ochre processing tools reveals that six (OPT 3, 6, 7, 9, 12, 13; Fig 10E, 10H, 10I, 10J, 10K and 10L, Figs C, F, G, I in S1 Fig, Figs A, B in S2 Fig) include element associations and morphological features indicating the presence of a single type of ochre per tool; five (OPT 1, 2, 4 and OSA 5, 15; Fig 10A, 10B, 10C, 10D, 10F, 10G and 10M, Figs A, B, D, E in S1 Fig, Fig D in S2 Fig) display associations suggesting the presence of two types of ochre. A single tool (OPT 22; Fig 10N and Fig 11, Table 4, Fig K in S2 Fig, S1 Table, Text T in S1 Text), made of an iron-rich rock, shows residues that come either from surface alteration or from use. Components interpreted as contamination from the tool, surrounding sediment and post-depositional processes are discussed in more detail in S1 Text.

Among those from the first group, samples from OPT 7 and 9 (Fig 10I, 10J and Fig 11, Tables 4 and 5, Fig G, I in S1 Fig, S1 Table, Texts G, I in S1 Text) are very similar and almost exclusively composed of a pure earthy hematite characterised by agglomerates of iron oxide platelets. Goethite is also found on both samples. The only difference lies in the size of the platelets, smaller in OPT 7 (2–4 μm) than in OPT 9 (5–10 μm), and the presence of lepidocrocite in the sample from OPT 7. Ca and Na-rich feldspars, quartz grains, iron oxide particles in OPT 7, and plagioclase feldspars (albite, anorthite), alkali feldspars (probably microcline), quartz grains, clays from the smectite group (probably montmorillonite), iron oxide particles, and gypsum in OPT 9 probably derive from the grinding tool and the surrounding sediment.

The sample from OPT 3 (Fig 10E and Fig 11, Tables 4 and 5, Fig C in S1 Fig, S1 Table, Text C in S1 Text) contains exogenous iron-rich submicrometric particles identified as hematite

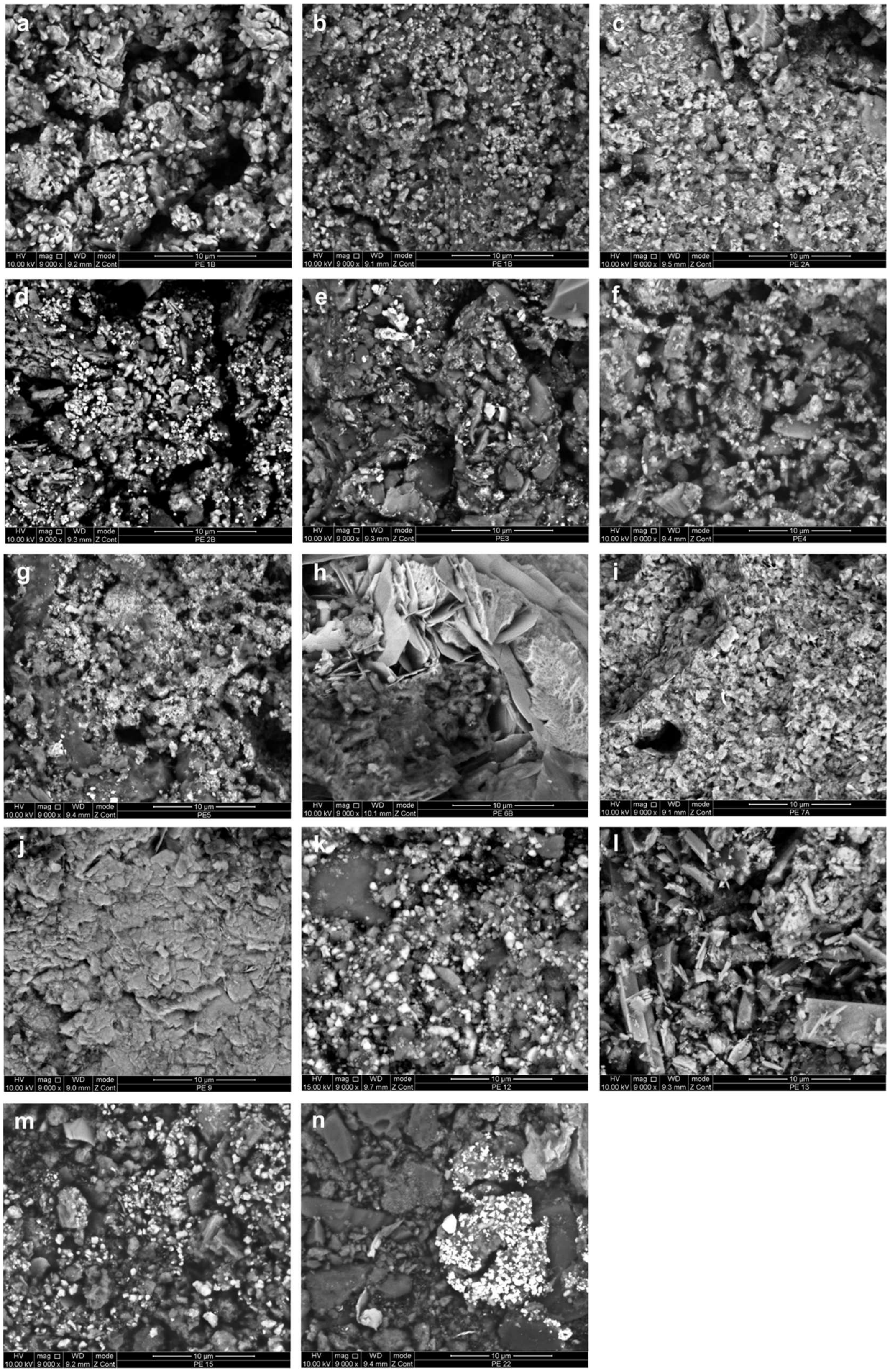
a
b
c
d
e
f
g
h
i
j
k
l
m
n
10 µm
PE 1B
PE 1B
PE 2A
PE 2B
PE3
PE4
PE5
PE 6B
PE 7A
PE 9
PE 12
PE 13
PE 15
PE 22

Fig 10. SEM images of ochre residues from Porc-Epic Cave's ochre processing tools and ochre-stained artefacts. All figures are in BSE mode. a: OPT 1, sample AT1 zone 1; b: OPT 1, sample AT1 zone 2; c: OPT 2, sample AT2A; d: OPT2, sample AT2B; e: OPT 3, sample AT3; f: OPT 4, sample AT4; g: OSA 5, sample AT5; h: OPT 6, sample AT6; i: OPT 7, sample AT7; j: OPT 9, sample AT9; k: OPT 12, sample AT 12; l: OPT 13, sample AT13; m: OSA 15, sample AT15; n: OPT 22, sample AT22. Scales = 10 μm.

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associated with clay minerals from the kaolinite-serpentine group (Si, Al, Ca, K, Mg and traces of Ti) and quartz grains–cemented by iron oxides–, which probably derive from the grinding tool. Fragments of quartz grains with clean edges (5–10 μm) may be interpreted as an additive or resulting from fragmentation of grains originating from the tool.

The residue from OPT 12 (Fig 10K and Fig 11, Tables 4 and 5, Fig A in S2 Fig, S1 Table, Text L in S1 Text) features subcircular iron-rich particles, 1–2 μm in width, with Mn traces, identified as hematite and goethite, consistently associated with micrometric platelets of clay minerals (Si, Al, K, Ca, Mg), a few K-rich platelets interpreted as micas (Si, Al, K, Na), and Ca-rich feldspar particles (possibly albite). Quartz grains certainly derived from the OPT were also detected.

The sample from OPT 13 (Fig 10L and Fig 11, Table 4, Fig B in S2 Fig, S1 Table, Text M in S1 Text) contains agglomerates of submicrometric acicular and irregular iron oxide particles with traces of Mn, identified as goethite and hematite, associated with clays (Si, Al, Na, with low contents of K, Ca, Mg, and traces of Ti). Large tabular Na-rich feldspars (possibly albite), quartz grains, and rare earth elements (La, Ce, Nd) are interpreted as originating from the tool stone.

Ochre residues from OPT 6 (Fig 10H and Fig 11, Tables 4 and 5, Fig F in S1 Fig, S1 Table, Text F in S1 Text) include grains of 55–134 μm in length containing thin platelets composed of Fe and Ti. Hematite and goethite were identified by mineralogical analysis. Agglomerates of submicrometric grains interpreted as clay minerals (Si, Al, Mg, K), possibly saponite and halloysite, coat, in places, the large oxide grains. Clay minerals do not appear to originate from the iron rich ground rock, nor from the processing tool, which make of them good candidates for being additives. Angular, coarse grains (Si, Ca, Mg, Fe, Al, Ti, with traces of Na; approximately 194 μm in length) identified as mineral phases from chlorite and pyroxene groups (probably clinochlore and augite) were also detected in the sample. These grains, commonly found in metamorphic rocks, as well as quartz and plagioclase feldspars (such as albite and anorthite), probably originate from the processing tool.

Among the samples containing two ochre types, that from OSA 5 (Fig 10G and Fig 11, Tables 4 and 5, Fig E in S1 Fig, S1 Table, Text E in S1 Text) is composed of individual, large (17–38 μm in length), and numerous small (1–2 μm in length) iron-rich particles, identified as hematite. The latter, which occasionally present an acicular morphology, are embedded in a clay matrix (Si, Al, K, Ca, with traces of Mg, Na and Ti) identified as montmorillonite. Calcite and laumontite originate from the tool. Gypsum may have grown post-depositionally. Manganese oxides (ramsdellite), alkali feldspars (possibly sanidine) and quartz grains could either come from the tool or could be part of the ochre residue.

OPT 4 (Fig 10F and Fig 11, Table 4, Fig D in S1 Fig, S1 Table, Text D in S1 Text) includes octahedral undetermined Fe-Ti oxides with a length of 58–63 μm, and agglomerates of submicrometric grains made of hematite and goethite that are probably naturally associated with clay minerals (Si, Al, Ca, and traces of K, Mg, Na). Quartz grains are interpreted as part of the ochre residue since such grains are rare in the rock composing this tool. They could come from the processed ochre fragments or represent an additive intentionally mixed to the ochre powder. The presence of gypsum is likely due to post-depositional processes.

The sample from OPT 1 (Fig 10A, 10B and Fig 11, Tables 4 and 5, Fig A in S1 Fig, S1 Table, Text A in S1 Text) is composed of two different mineral associations. The first shows

Num	SEM observations and EDS analysis			
	Clay-sized particles (<4µm)		Silt and sand-sized particles (>4µm)	
	Shape	Composition*	Shape	Composition*
1	Aggl Plat	Fe *(iron oxide)* Si, Al, Ca, K *(clay minerals)*	Irreg Plat Ang Irreg	Fe, Mn *(iron oxide)* Si, Al, K, Na *(K-rich mica)* Ca, Mg *(carbonate)* Ba, S *(Ba-rich sulphate)*
2	Aggl Plat	Fe *(iron oxide)* Si, Al, Ca, K, Mg *(clay minerals)*	Irreg Ang Irreg	Fe, Cr, Ni (*undet*) Si *(silicate)* Si, Al, Ca, K, Na *(Ca-rich feldspar)*
3	Aggl Plat	Fe *(iron oxide)* Si, Al, Ca *(clay minerals)*	Irreg Subcirc Irreg/ang	Fe, Cr, Ni (*undet*) Fe *(iron oxide)* Si *(silicate)*
4	Aggl Plat	Fe, Si, Al, Ca, K, Mg, Na, Ti *(mixture of iron oxides and aluminosilicates)* Si, Al, Ca *(clay minerals)*	Oct Ang	Fe, Ti *(undet oxide)* Si *(silicate)*
5	Irreg/ acic Aggl	Fe *(iron oxide)* Si, Al, K, Ca *(clay mineral)*	Irreg Irreg Irreg	Fe *(iron oxide)* Si, Al, Na, K *(feldspar)* Si *(silicate)*
6	Aggl	Si, Al, Mg, K *(clay mineral)*	Irreg/plat Ang	Fe, Ti *(undet oxide)* Si *(undet silicate)*
7	Aggl	Fe *(iron oxide)*	Irreg Aggl Aggl Irreg	Fe (*iron oxide*) Si, Al, Ca, Na *(Ca, Na-rich feldspar)* Si, Al, Ca *(undet aluminosilicate)* Si *(silicate)*
9	Aggl Aggl	Fe *(iron oxide)* Si, Al, Ca, K, Na *(clay minerals)*	Irreg Irreg	Si *(silicate)* Si, K, Al *(feldspar)*
12	Irreg Plat	Fe *(iron oxide)* Si, Al, Ca, K, Mg *(clay minerals)*	Irreg Subcirc Plat	Fe, Si, Al, Mg, K, Cl, Ca (*undet*) Si, Ca, Al, K *(Ca-rich feldspar)* Si, Al, K *(K-rich mica)*
13	Aggl	Fe, Si, Al, Ce, La, Nd, Na *(mixture of iron oxides and clay minerals)*	Tab	Si, Na, Al, K *(Na-rich feldspar)*
15	Aggl Aggl	Ba, S *(Ba-rich sulphate)* Si, Fe, Al, Ca, K, S (*mixture of iron oxides and clay minerals*)	Irreg	Fe, Ti *(undet oxide)*
22	Aggl	Fe, Si, Al *(mixture of iron oxides and aluminosilicates)*	Ang Irreg Irreg/ang	Fe *(iron oxide)* Fe, Si, Al *(Fe-rich silciate)* Si, Al *(undet aluminosilicate)*

Fig 11. Results of SEM-EDS analyses on residues from Porc-Epic Cave's ochre processing tools and ochre-stained artefacts. Num: number; aggl: agglomerate; irreg: irregular; plat: platy; ang: angular; subcirc: subcircular; oct: octahedral; acic: acicular; tab: tabular. (*) Interpretation in brackets. The objects' identification number is the same as presented in Figs 4–10, Tables 1–5, S1 and S2 Figs, S1 Table, S1 Text.

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Table 4. Results of μ-RS analyses on residues from Porc-Epic Cave's ochre processing tools and ochre-stained artefacts.

Num	Sample	ab	an	aug	cal	dol	gth	gp	hem	kln	lep	mag	man	mnt	ms	qz	un. alum.	un. Mn ox.	C
1	AT1A,B						•		•						•		•		
2	AT2A,B						•		•						•	•	•	•	
3	AT3								•							•			
4	AT4						•	•	•							•	•		
5	AT5				•				•							•			
6	AT6A						•		•										
7	AT7						•		•		•					•			•
8	AT8						•	•	•							•			
9	AT9						•	•	•							•			
10	AT10				•		•		•				•			•	•		
11	AT11		•					•	•			•				•	•		
12	AT12	•							•							•	•		
13	AT13	•					•		•							•			•
14	AT14				•		•		•					•		•	•		•
15	AT15					•	•		•					•			•		
16	AT16						•	•	•							•			
17	AT17						•	•	•	•						•			
18	AT18						•	•	•			•				•			
19	AT19			•			•		•							•			
22	AT22						•		•					•		•			

Num: number; un: undetermined; alum: aluminosilicate; ox: oxide; C: carbon; abbreviations of minerals are based on the nomenclature suggested by [121], except for lepidocrocite (lep), and manganite (man). The objects' identification number is the same as presented in Figs 4–11, Tables 1–3 and 5, S1 and S2 Figs, S1 Table, S1 Text.

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aggregates of submicrometric iron oxides (Fe) identified as hematite and goethite mixed with clay minerals (Si, Al, Ca, K, Mg, and traces of Ti and Na) from the kaolinite group, as well as micas consisting of muscovite (Si, Al, K, Na). The second is more compact, features submicrometric and large aggregates (approximately 39 μm in length) of iron oxides (Fe, Mn),

Table 5. Results of XRD analyses on residues from Porc-Epic Cave's ochre processing tools and ochre-stained artefacts.

Num	Sample	ab	an	ant	aug	ber	cal	clc	gth	gp	hal	hem	kln	lmt	mc	mgh	mnt	or	qz	ram	sa	sap
1	T1		•				•					•	•						•			
3	T3					•						•	•						•			
5	T5									•		•		•			•		•	•	•	
6	T6	•	•		•			•			•	•							•			•
7	T7											•							•			
8	T8			•								•	•			•			•			
9	T9	•	?									•			?		•		•			
10	T10						•					•		•					•		•	
12	T12								•			•							•			
17	T17						•					•	•					?	•			
18	T18											•	•						•			

Num: number; abbreviations of minerals are based on the nomenclature suggested by [121], except for bernalite (ber), halloysite (hal) and ramsdellite (ram). The objects' identification number is the same as presented in Figs 4–11, Tables 1–4, S1 and S2 Figs, S1 Table, S1 Text.

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plagioclase feldspars (probably anorthite), absent in the former, and does not contain titanium in the clay minerals. Calcite, and quartz are probably part of the rock composing the tool. Detected barium sulphates and carbonates could derive from surrounding sediment or post-depositional processes.

A different type of iron oxide is detected on each of the two samples collected on OPT 2 (Fig 10C, 10D and Fig 11, Table 4, Fig B in S1 Fig, S1 Table, Text B in S1 Text). Yellow in colour, sample AT2A (Fig 10C) contains compact agglomerates of submicrometric acicular grains made of goethite and, occasionally hematite, with traces of Ti mixed with platy particles of clay minerals (Si, Al, Ca, K, with traces of Mg, Ti, Na). Red in colour, the second sample (AT2B, Fig 10D) is composed of submicrometric grains of hematite (Fe, with traces of Ti) associated with platy grains of clay minerals (Si, Al, Ca, K, and traces of Mg, Na), taking the form of less compact agglomerates. Angular silicate grains (approximately 42–156 μm in length) identified as quartz, and undetermined Mn-rich minerals detected in both residues probably come from the OPT. This is also the case for irregular Ca-rich grains corresponding to plagioclase feldspars (Si, Al, Ca, K, Na; approximately 62 μm in length), and K-rich micas (muscovite), observed in AT2A.

Of the two ochre components identified in the sample from OSA 15 (Fig 10M and Fig 11, Table 4, Fig D in S2 Fig, S1 Table, Text O in S1 Text), the first includes submicrometric grains of hematite and goethite (Fe with traces of Ti) associated with clay minerals (Si, Al, Ca, K, with traces of Na, Mg) from the smectite group (probably montmorillonite). The consistent combination of iron oxides and clay minerals suggests that they come from the same rock. The second type of ochre displays large particles of Fe oxides richer in Ti, with traces of Mn (approximately 20–79 μm in length). Fine-grained agglomerates composed of submicrometric to micrometric Ba-rich sulphates (Ba, S) and dolomite were also identified, but probably originate from the tool.

In summary, SEM-EDS and mineralogical analyses identify three main ochre groups:

- (1) ferruginous clay rocks (OPT 1–4, 12, 13, and OSA 5 and 15);
- (2) pure earthy hematite with a low content of goethite (OPT 7, 9);
- (3) isolated coarse iron oxide particles (OSA 5) sometimes containing titanium (OPT 4, 6, and OSA 15).

Differences between groups 1 and 2 are most likely due to the fact that two types of rock were processed. Group 3 is more difficult to interpret, as it may represent either an extreme in variation of ferruginous clay rocks or a different rock type.

In addition, these three categories may contain quartz, feldspars and other silicates, clays, calcite, and calcium or barium sulphates. They may originate from the processed ochre, the grindstone, loading agents, surrounding sediments, or be the result of post-depositional processes.

XRD (Table 5) and μ-RS analysis (Table 4, Table B in S1 Table) of samples not studied with SEM-EDS identified the same minerals found on the samples also studied with SEM-EDS (Texts H, J, K, N, P–S in S1 Text).

Processing tools and processed ochre

No obvious relationship is observed between the type of processed ochre and the raw material from which the ochre processing tools are made (Table 2). Ferruginous clay powder was detected on limestone, schist, sandstone, granitoid and quartzite tools. Isolated iron oxide particles were found on limestone and quartzite tools. Earthy hematite was identified on conglomerate and granite tools. Cases in point are the ochre type identified on OPT 1 and OPT 12 (Fe and Mn oxides, clay minerals, K-rich micas and Ca-rich feldspars), and samples from OPT 7 and 9 (earthy hematite). Ochre types identified on OSA 15 also show similarities with ochre residues from one of the samples from OPT 2 (AT2B, submicrometric iron oxides with traces of Ti, associated with clay minerals), and the sample from OPT 6 (Fe-Ti oxides).

Discussion

Results of the analysis of ochre-stained artefacts and ochre processing tools from Porc-Epic Cave provide a means of identifying technical preferences, evaluating the behavioural complexity behind these activities and understanding, to some extent, their goals. The appearance, granulometry and colour of ground ochre powder depends on the grinding/pounding technique, the nature and state of freshness of the grinding tools, the composition, texture and hardness of the processed iron-rich rock, the pressure applied, the duration of the grinding/pounding actions, and the eventual presence of loading or binding agents [6,14,19].

Porc-Epic's MSA inhabitants used a variety of rock types as grindstones. The time and effort necessary to locate and transport these rocks to the site is difficult to evaluate since the only available information comes from geological maps [122], and studies on the provenance of rocks used for knapped lithics [94]. We know that limestone, sandstone, and conglomerate are found locally. Basalt sources are located approximately 5–10 km to the north and the northeast. Quartzite and schist sources are found 30–50 km to the south. Granite occurrences are not signalled in the geological map. However, it can be found in Precambrian to Ordovician formations present in the region [89]. Allochthonous rocks displaced by fluvial transport may have been collected along the wadi Laga Dächatu. However, collection from such deposits implies transport of the raw materials from the wadi floor to the site, an uphill transport of 400 m with a slope of 140 m. Furthermore, twelve grindstones (OPT 1, 2, 6, 7, 9–12, 14, 16–18), including some made of raw material not available locally, display clean edges–a characteristic incompatible with prolonged fluvial transport. The diversified nature of the rock types, the distant origin of some of them, and the fact that tools made of different rocks were found in the same area and at the same depth, indicates that ochre reduction sequences carried out at Porc-Epic required grindstones made of different rocks, which the site inhabitants acquired when moving across the landscape or through exchange with neighbouring groups. Porc-Epic represents the earliest known case in which the use of diversified rock types for ochre treatment is documented.

How was ochre powder produced? Iron-rich rock clasts may have been first crushed to reduce their size. The resulting fragments were probably abraded directly on lower grindstones, or reduced into powder by pounding/grinding them with upper grindstones. The latter is the technique used at present, for example, by Ovahimba women [123]. At Porc-Epic, all objects identified as upper grindstones display percussion pits reflecting pounding but virtually no facets or striations indicating their actual use to grind ochre. This suggests that ochre clasts were in some instances fragmented to reduce their size before being individually rubbed against lower grindstones rather than ground between lower and upper grindstones. This is consistent with preliminary analyses conducted on ochre fragments, which identify abrasion facets on numerous pieces [124]. Additionally, smoothed areas on lower grindstones made of hard rocks such as quartzite or basalt suggest a long-term use of these tools for rubbing ochre. The fact that only one lower grindstone (OPT 1), made of limestone, shows percussion pits associated with ochre residues does not contradict the hypothesis that ochre was in some instances crushed by pounding it on lower grindstones before being abraded. This activity may have been carried elsewhere, only on a reduced number of ochre fragments, or may have left little or no trace on lower grindstones made of hard rocks [125].

Why did Porc-Epic inhabitants use different rocks for their grindstones? The coarseness and hardness of grinding tools conditions the granulometry, shade, and composition of the ochre powder [19]. A grindstone made of a relatively soft rock such as limestone or sandstone releases a powder that is incorporated into the ochre powder produced by the grinding process [126]. The colour of the powder is generally lighter when using those tools. The same technique using grindstones made of hard rocks such as schist, quartzite, basalt, granitoid, or fine-grained ferruginous rocks, results in little or virtually no release and incorporation of particles derived from the tool. When using these rocks, the granulometry of the powder mostly depends on the roughness of the tool surface, as well as the pressure exerted during the work.

The above considerations, and the variety of rock types used for grindstones suggest that the MSA inhabitants of this site may have produced, according to their needs, ochre powders of different shades, consistency, composition, granulometry and colour. This is confirmed by the analysis of the residues collected on the grindstones, which reveals the use of different ochre types and, in many cases, the presence of more than one type on the same processing tool. The number of processed ochre types per tool is probably underestimated as sampled residues represent a minimal part of the ochre present on each processing tool, which is not necessarily representative of all iron-rich rocks processed on it. Such palimpsests of ochre types may result either from intentional grinding and mixing of different types of ochre at the same time, or, more probably, different ochre processing episodes. Whatever the case, the elemental and mineralogical analysis of the residues clearly indicates that different iron-rich minerals, with different properties, iron oxides types, and iron contents were sought after and processed.

What are the reasons behind such a high behavioural variability? Recent studies [19] have reached the conclusion that differences in granulometry, consistency and colour intensity of ochre powder can be related to its function. Fine, clayish sorted ochre powder is more suitable for cosmetic or symbolic activities such as body painting, whereas mixed grain size ochre would be more adapted to utilitarian activities such as hafting [6]. The use of grinding tools made of different raw materials, allowing the production of powders of different granulometries, the identification of different types of ochre in the residues collected on the ochre processing tools and among the ochre fragments recovered at the site [124] indicate that ochre was processed at Porc-Epic Cave to perform a variety of activities. Analysis of OSA 5 suggest that some of these activities may have been symbolic in nature. Considering the absence on this object of use-wear related to ochre processing, two hypotheses account for the red spot present on its surface: decoration of the pebble with red paint or use as a stamp or "pintadera" [127] to produce a subcircular print on soft surfaces such as human or animal skin. Both uses better fit symbolic rather than utilitarian functions. Supplementary evidence that, in some instances, a small quantity of a liquid binder was added to ground ochre powder comes from OPT 11, which displays a ring-like deposit resulting from the drying of such mixture. Toolkits to produce and store ochered liquid compounds were recovered at Blombos Cave in layers dated to 100 ka BP [5]. The use of ochre to change the appearance of personal ornaments is known at MSA sites from Northern and Southern Africa dated to ca. 80–70 ka BP [33,128]. The production of ochre and milk paint has been recently identified on residue adhering to a stone flake found at Sibudu Cave, South Africa, in layers dated to 49 ka BP [129]. Apart from the colouring of ornaments, however, virtually nothing is known about other non-utilitarian activities in which ochre may have been involved in the MSA. OSA 5 represents the earliest known example of a painted object from an MSA context or evidence that pigment powder was mixed with a liquid binder to produce a paint used to print red spots, perhaps arranged to create recognizable and meaningful visible patterns. Future experiments may clarify which of these two possibilities is the most likely. They may also document the elemental and mineralogical composition of powder produced by grinding different iron-rich rocks on grindstones made of a variety of raw materials. This would allow a better characterisation and quantification of the grindstone contribution to the resulting powder.

In conclusion, Porc-Epic is at present the only Palaeolithic site from the Horn of Africa that has yielded a collection of ochre pieces and processing tools allowing comprehensive documentation of practices related to ochre acquisition, processing, and use. The analysis of the processing tools and ochre-stained artefacts conducted in this study needs to be complemented in the future by the analysis of the ochre fragments found in the same layers. However, the results presented here already reveal an original, hitherto unknown, behavioural complexity. This complexity is evidenced by the diversity and exogenous provenance of the raw material used for the processing tools, the techniques and motions applied to modify iron-rich rocks, the variety of rocks chosen to produce ochre powder of different colour, composition, consistency and shade, and their probable involvement in utilitarian as well as symbolic activities.

To counter the notion that ochre was symbolically used in the MSA and the Mousterian, it has been argued that utilitarian functions suffice to explain the evidence. The opposition symbolic vs. functional represents, however, a false dichotomy, as, firstly, symbolic behaviour is more often than not embedded in what, to the western eye, would seem to be purely functional activities and, secondly, ochre may have been used in the context of both "symbolic" and “utilitarian” actions. The detailed analysis of the tools used to process ochre and the ochre residues still attached to them has the potential to advance the debate beyond this false either/or dichotomy.

Supporting Information

S1 Fig. Results of analyses conducted on ochre processing tools 1–4; 6–11 and ochre-stained artefact 5. Photos of the artefacts, modification marks and residues, SEM-EDS images and XRD diffractograms. The objects' identification number is the same as presented in Figs 4–11, Tables 1–5, S2 Fig, S1 Table, S1 Text.
(PDF)

S2 Fig. Results of analyses conducted on ochre processing tools 12–14; 16–23 and ochre-stained artefact 15. Photos of the artefacts, modification marks and residues, SEM-EDS images and XRD diffractograms. The objects' identification number is the same as presented in Figs 4–11, Tables 1–5, S1 Fig, S1 Table, S1 Text.
(PDF)

S1 Table. Detailed results of elemental and mineralogical analyses conducted on ochre processing tools and ochre-stained artefacts. SEM-EDS and μ-RS analyses. The objects' identification number is the same as presented in Figs 4–11, Tables 1–5, S1 and S2 Figs, S1 Text.
(PDF)

S1 Text. Results of residue analysis on ochre processing tools and ochre-stained artefacts from Porc-Epic Cave. SEM-EDS, μ-RS and XRD analyses. The objects' identification number is the same as presented in Figs 4–11, Tables 1–5, S1 and S2 Figs, S1 Table.
(PDF)

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Middle Stone Age Ochre Processing and Behavioural Complexity in the Horn of Africa: Evidence from Porc-Epic Cave, Dire Dawa, Ethiopia

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S1 Figures. Results of analyses conducted on ochre processing tools 1–4; 6–11 and ochre-stained artefact 5.

Photos of the artefacts, modification marks and residues, SEM-EDS images and XRD diffractograms. The objects' identification number is the same as presented in Figs 4–11, Tables 1–5, S2 Figs, S1 Tables, S1 Texts.

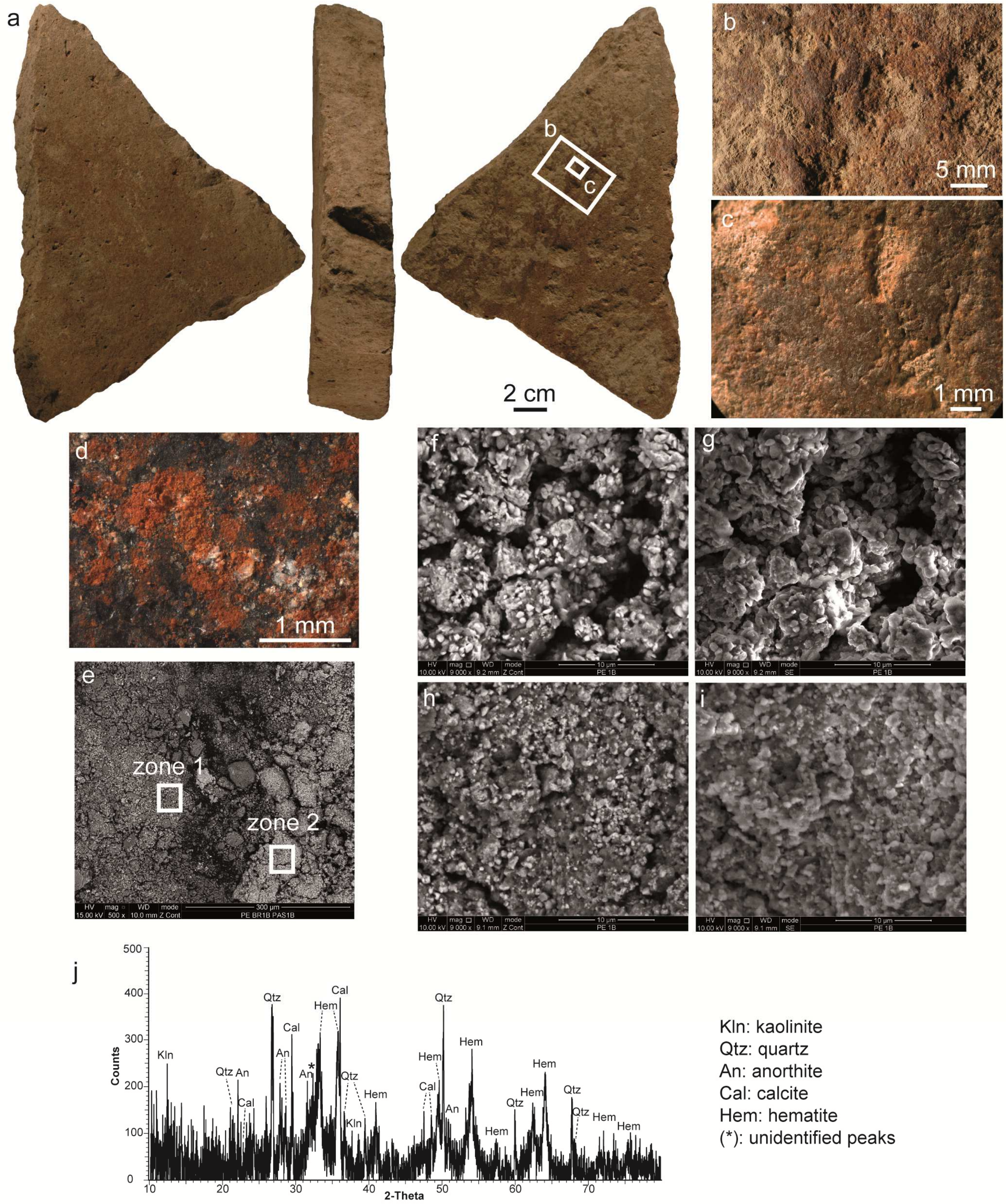

Fig A. Results of analyses conducted on ochre processing tool 1 (lower grindstone).

a: Photo of the object. Squares indicate the location of macro photos b and c; b, c: macro photos of smoothed area associated with pits and red residues; d: photo of the sampled ochre residue (sample AT1A); e: SEM image in BSE mode of sample AT1A (zones 1 and 2 indicate areas represented in f, g and h, i respectively); SEM images in BSE (f) and SE (g) modes of sample AT1A zone 1; SEM images in BSE (h) and SE (i) modes of sample AT1A zone 2; j: X-ray diffractogram of sample T1.

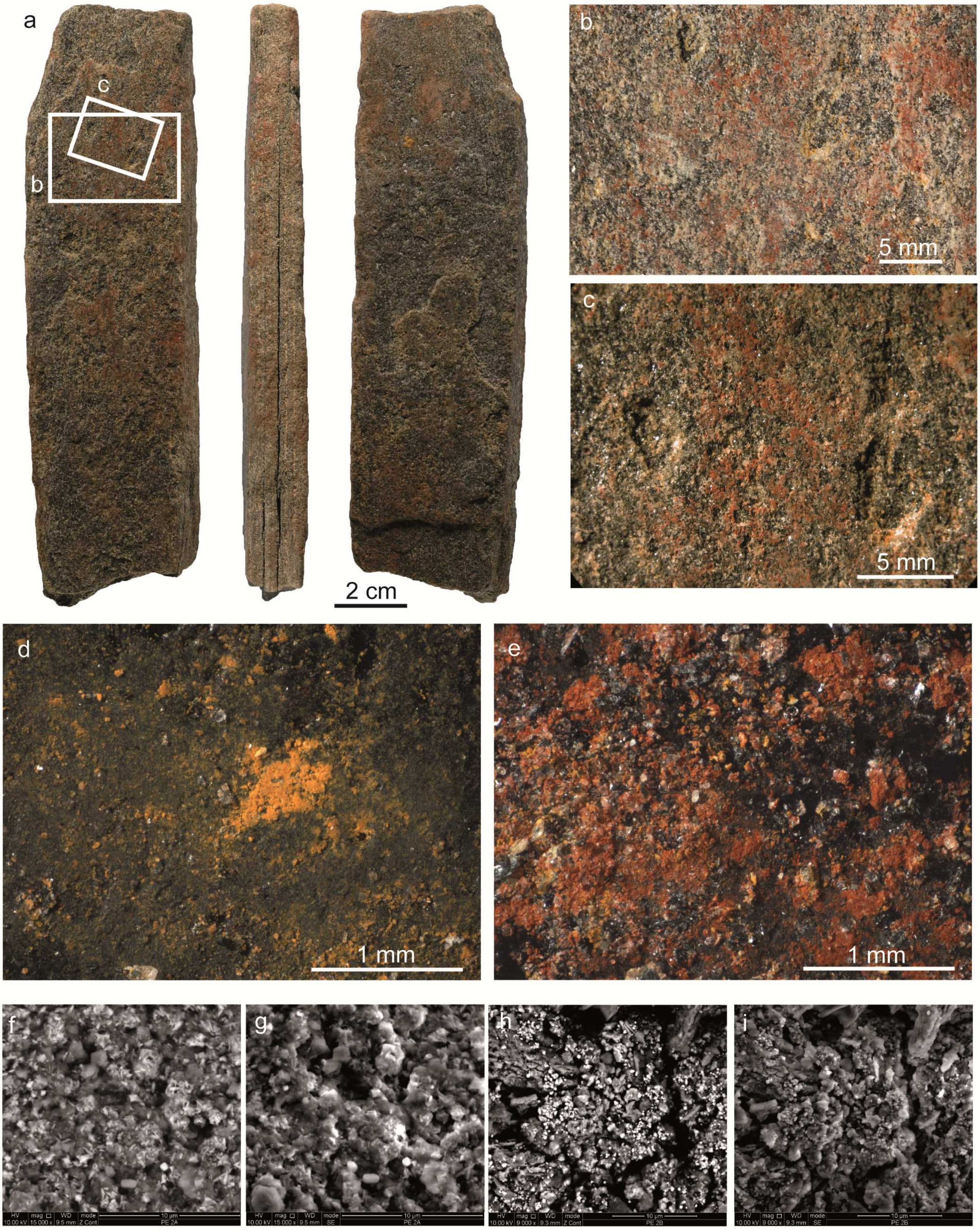

Fig B. Results of analyses conducted on ochre processing tool 2 (lower grindstone). a: Photo of the object. Squares indicate the location of macro photos b and c; b, c: macro photos of smoothed area associated with red and yellow residues; d, e: photos of the sampled ochre residues (samples AT2A and AT2B); SEM images in BSE (f) and SE (g) modes of sample AT2A; SEM images in BSE (h) and SE (i) modes of sample AT2B.

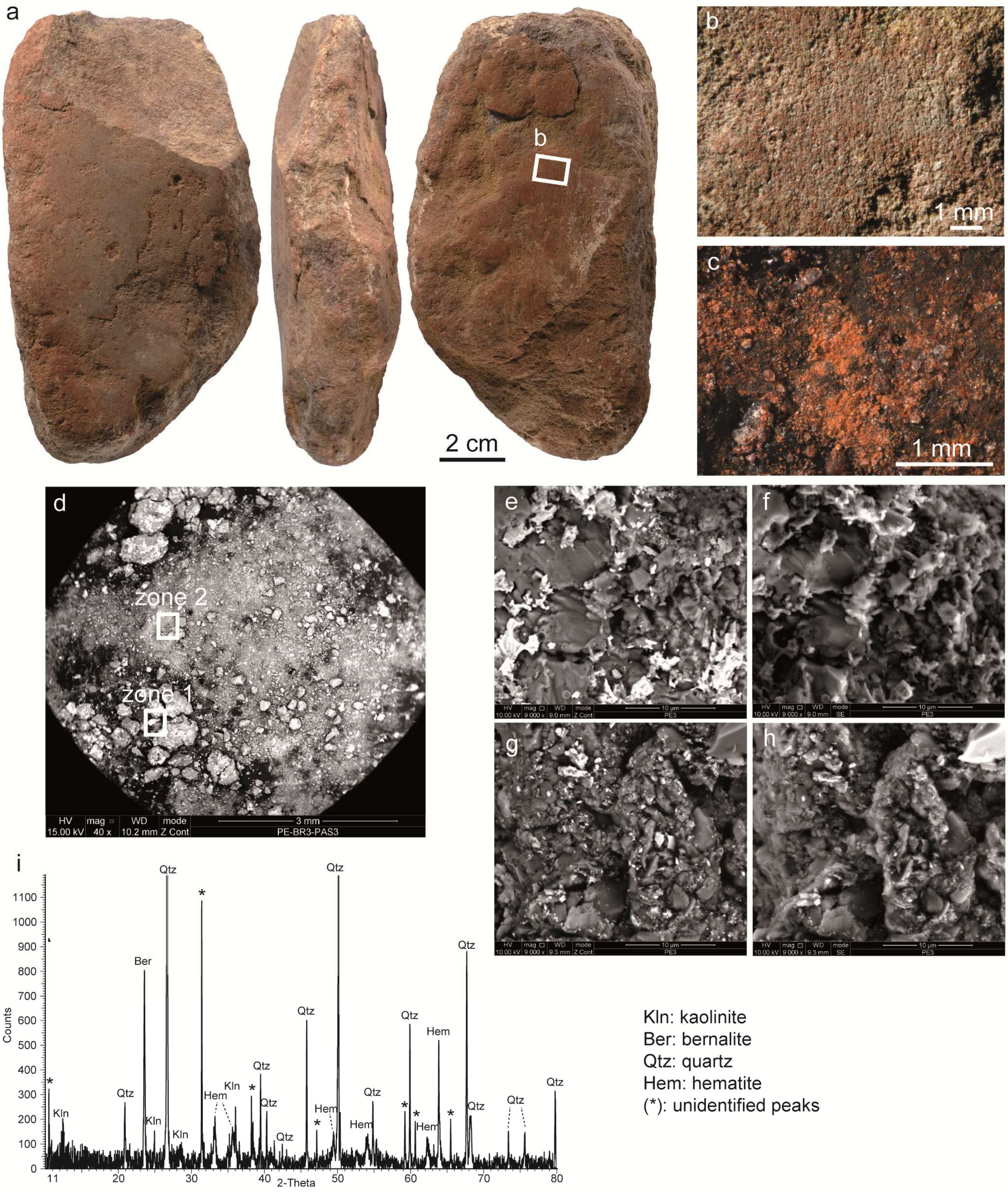

Fig C. Results of analyses conducted on ochre processing tool 3 (upper/lower grindstone).

a: Photo of the object. Square indicates the location of macro photo b; b: macro photo of smoothed areas associated with microstriations and red residues; c: photo of the sampled ochre residue (sample AT3); d: SEM image in BSE mode of sample AT3 (zones 1 and 2 indicate areas represented in e, f, and g, h respectively); SEM images in BSE (e) and SE (f) modes of sample AT3 zone 1; SEM images in BSE (g) and SE (h) modes of sample AT3 zone 2; i: X-ray diffractogram of sample T3.

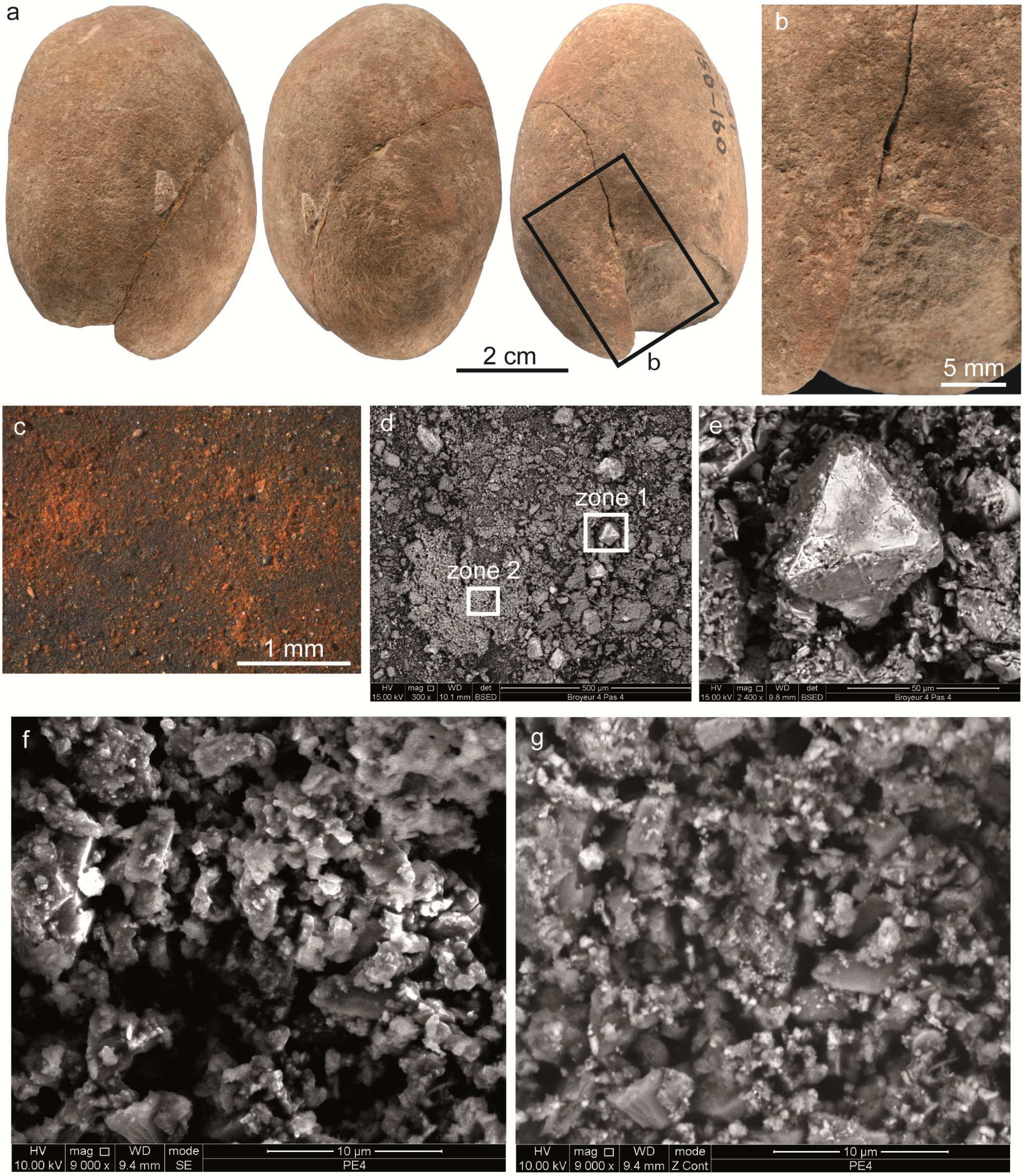

Fig D. Results of analyses conducted on ochre processing tool 4 (upper grindstone). a: Photo of the object. Square indicates the location of macro photo b; b: macro photo of pits associated with red residues; c: photo of the sampled ochre residue (sample AT4); d: SEM image in BSE mode of sample AT4 (zones 1 and 2 indicate areas represented in e and f, g respectively); e: SEM image in BSE mode of sample AT4 zone 1; SEM images in SE (f) and BSE (g) modes of sample AT4 zone 2.

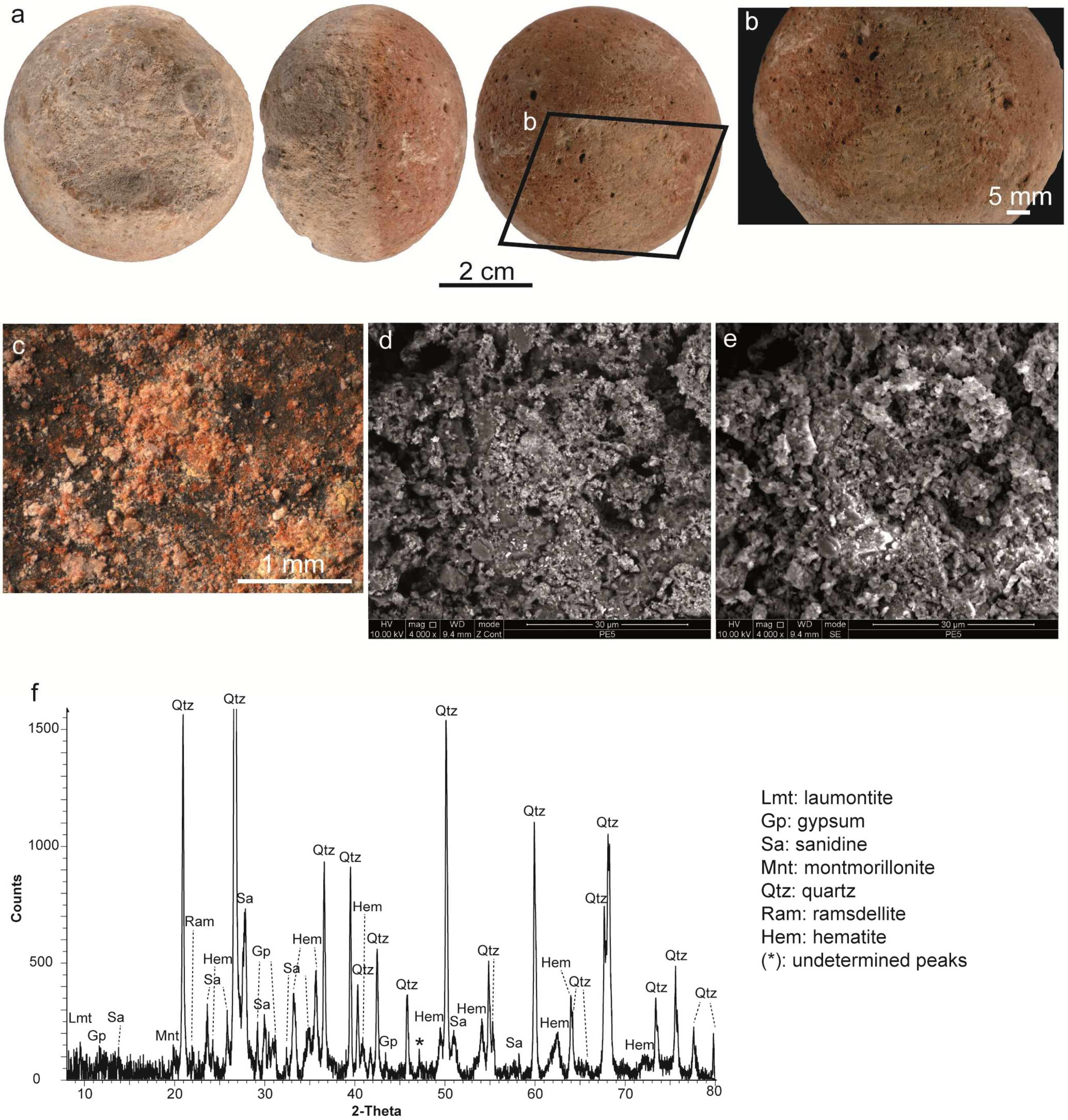

Fig E. Results of analyses conducted on ochre-stained artefact 5.
a: Photo of the object. Square indicates the location of macro photo b; b: macro photo of linear impressions associated with red residues; c: photo of the sampled ochre residue (sample AT5); SEM images in BSE (d) and SE (e) modes of sample AT5; f: X-ray diffractogram of sample T5.

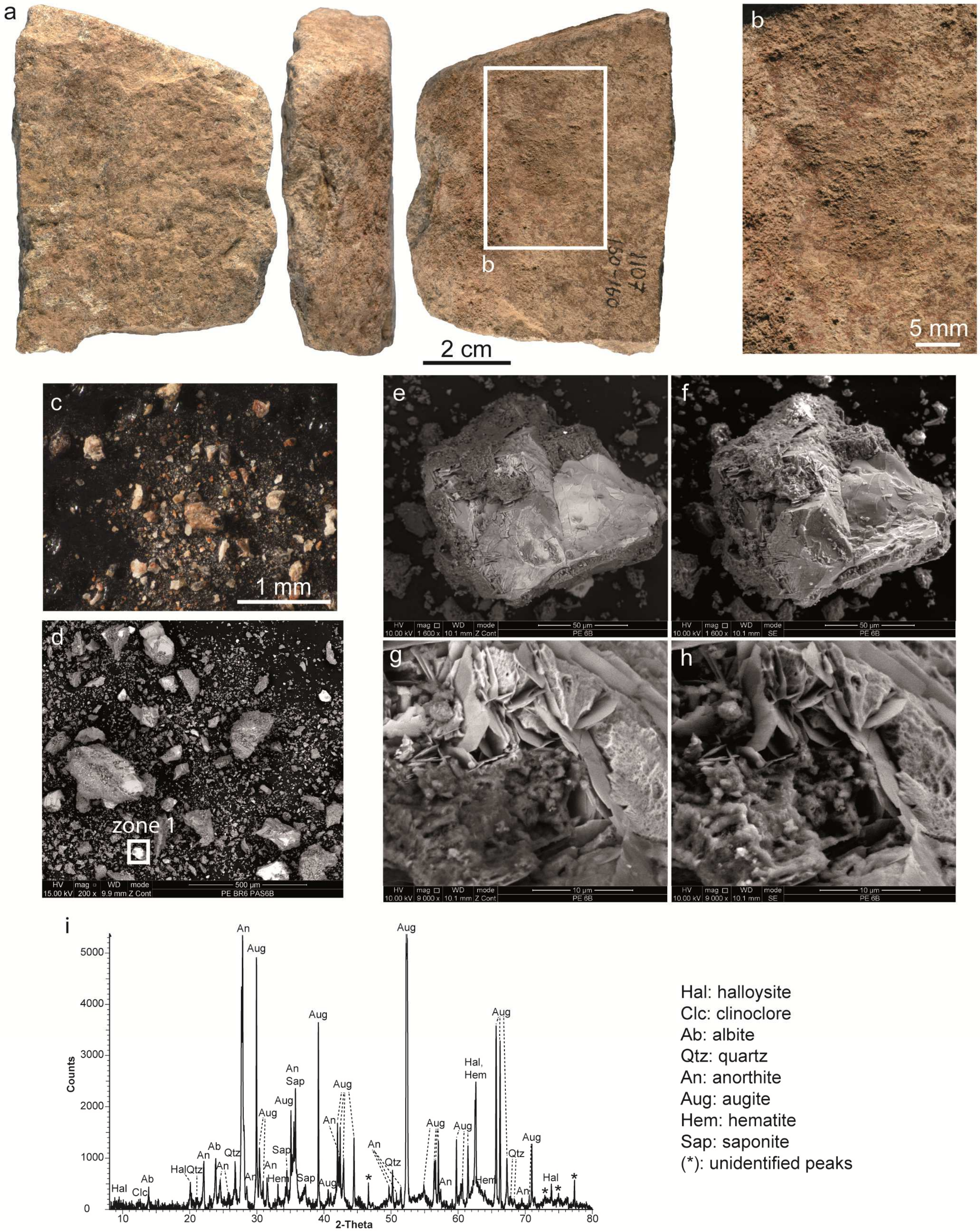

Fig F. Results of analyses conducted on ochre processing tool 6 (lower grindstone). a: Photo of the object. Square indicates the location of macro photo b; b: macro photo of smoothed area associated with red residues; c: photo of the sampled ochre residue (sample AT6); d: SEM image in BSE mode of sample AT6 (zone 1 indicates area represented in e–h); SEM image in BSE (e, g) and SE (f, h) modes of sample AT6 zone 1; i: X-ray diffractogram of sample T6.

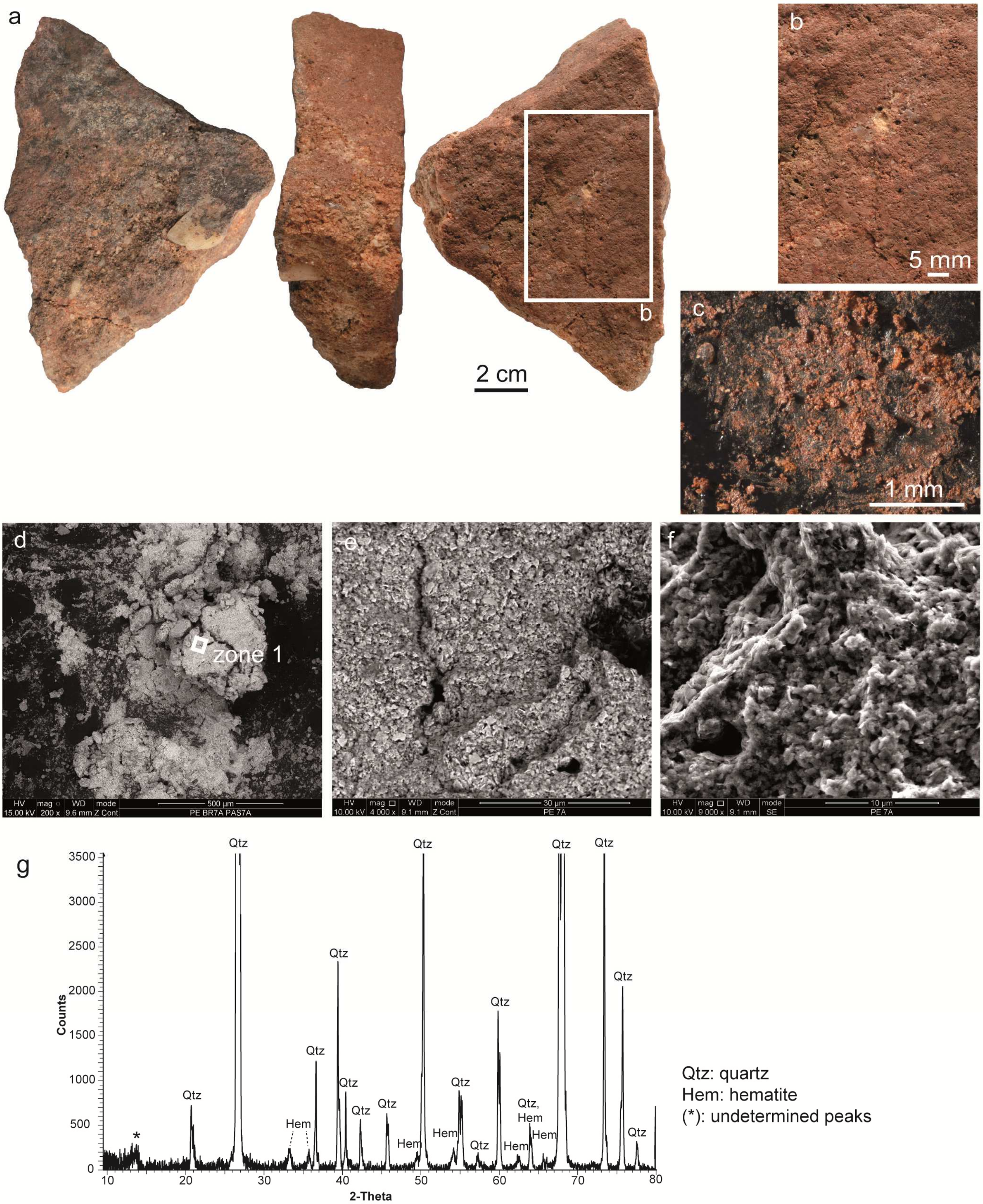

Fig G. Results of analyses conducted on ochre processing tool 7 (lower grindstone). a: Photo of the object. Square indicates the location of macro photo b; b: macro photo of smoothed area associated with red residues; c: photo of the sampled ochre residue (sample AT7); d: SEM image in BSE mode of sample AT7 (zone 1 indicates area represented in e, f); SEM images in BSE (e) and SE (f) modes of sample AT7 zone 1; j: X-ray diffractogram of sample T7.

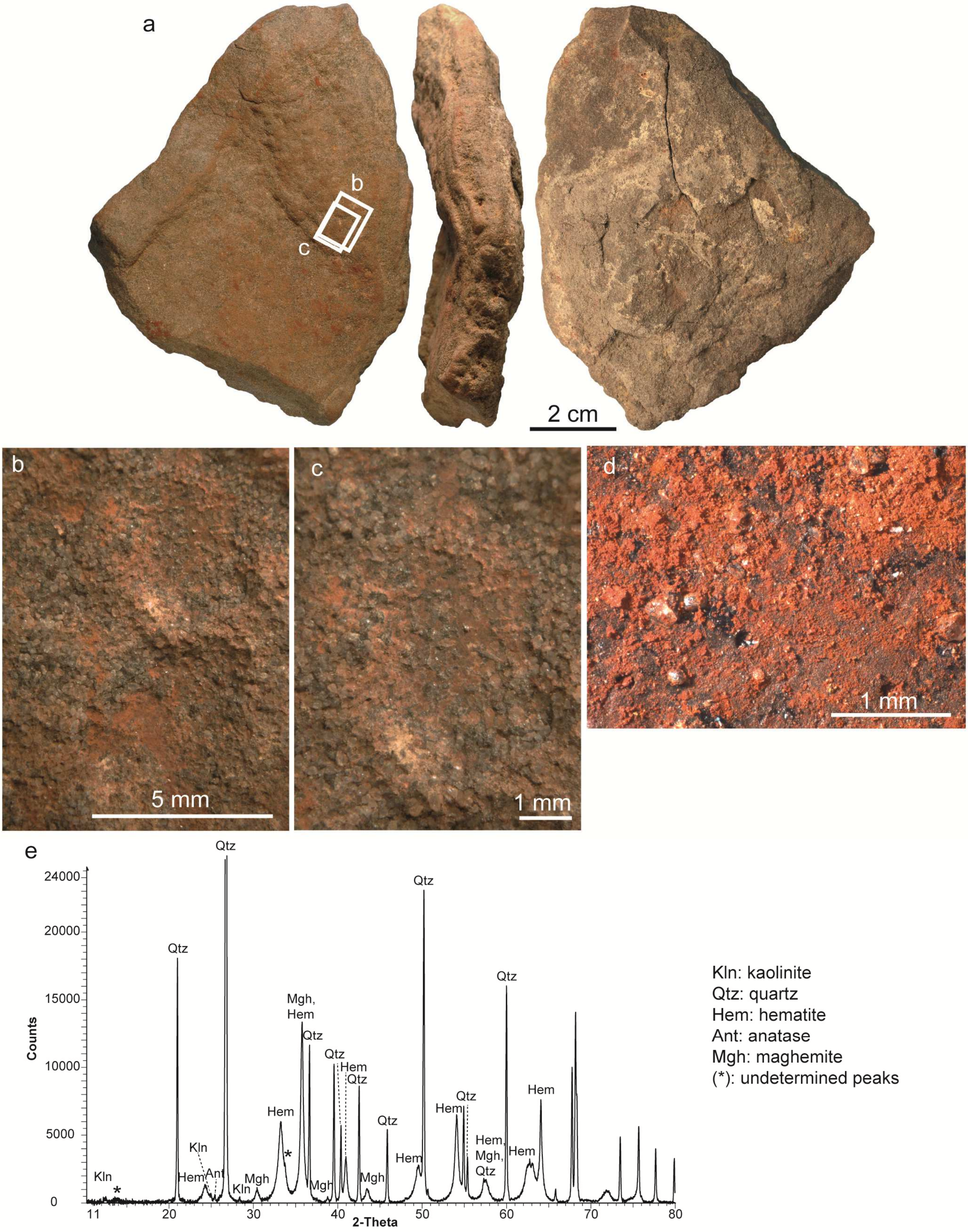

Fig H. Results of analyses conducted on ochre processing tool 8 (lower grindstone). a: Photo of the object. Squares indicate the location of macro photos b and c; b, c: macro photos of smoothed area associated with red residues; d: photo of the sampled ochre residue (sample AT8); e: X-ray diffractogram of sample T8.

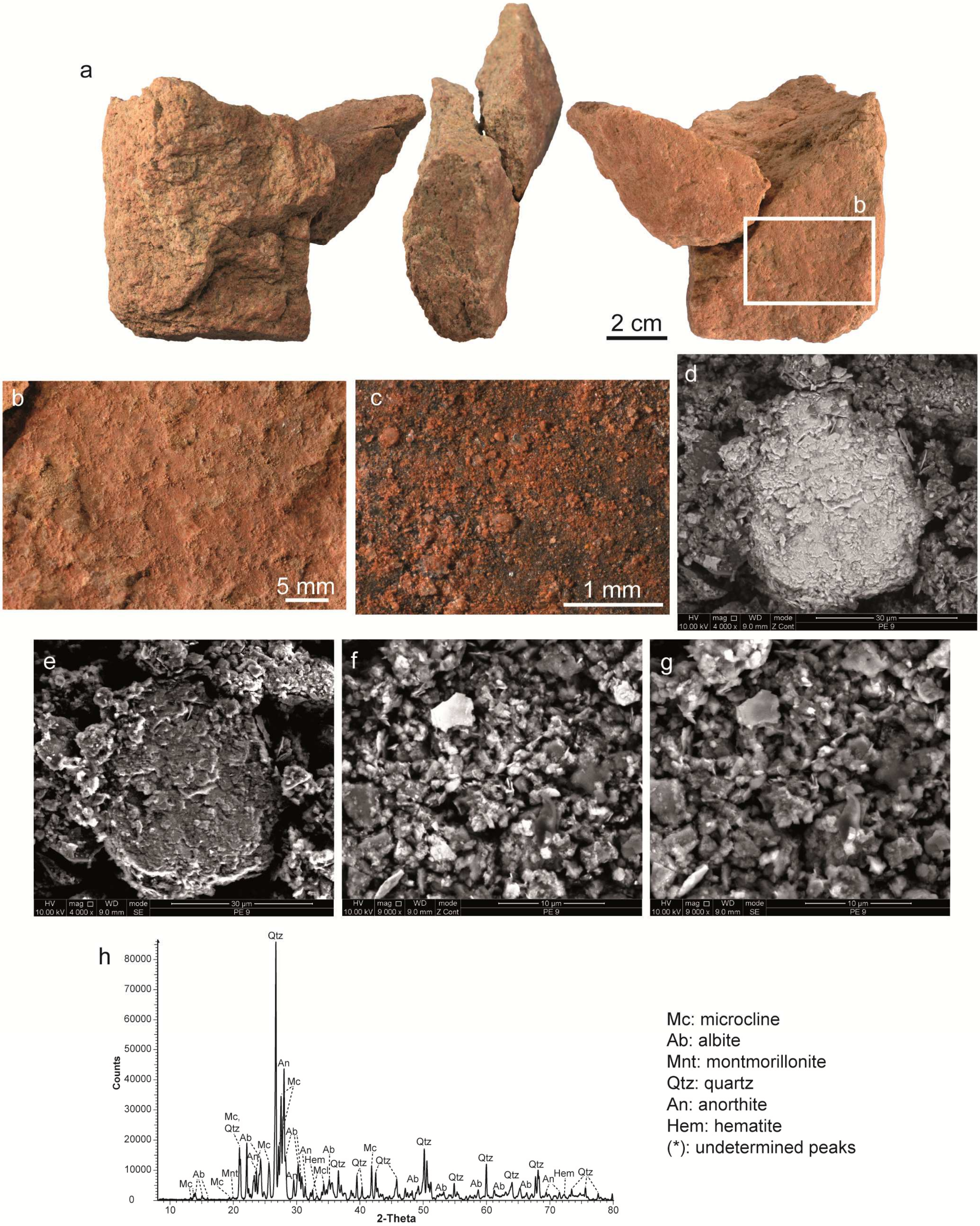

Fig I. Results of analyses conducted on ochre processing tool 9 (lower grindstone). a: Photo of the object. Square indicates the location of macro photo b; b: macro photo of smoothed areas associated with red residues; c: photo of the sampled ochre residue (sample AT9); SEM images in BSE (d) and SE (e) modes of sample AT9 zone 1; SEM images in BSE (f) and SE (g) modes of sample AT9 zone 2; h: X-ray diffractogram of sample T9.

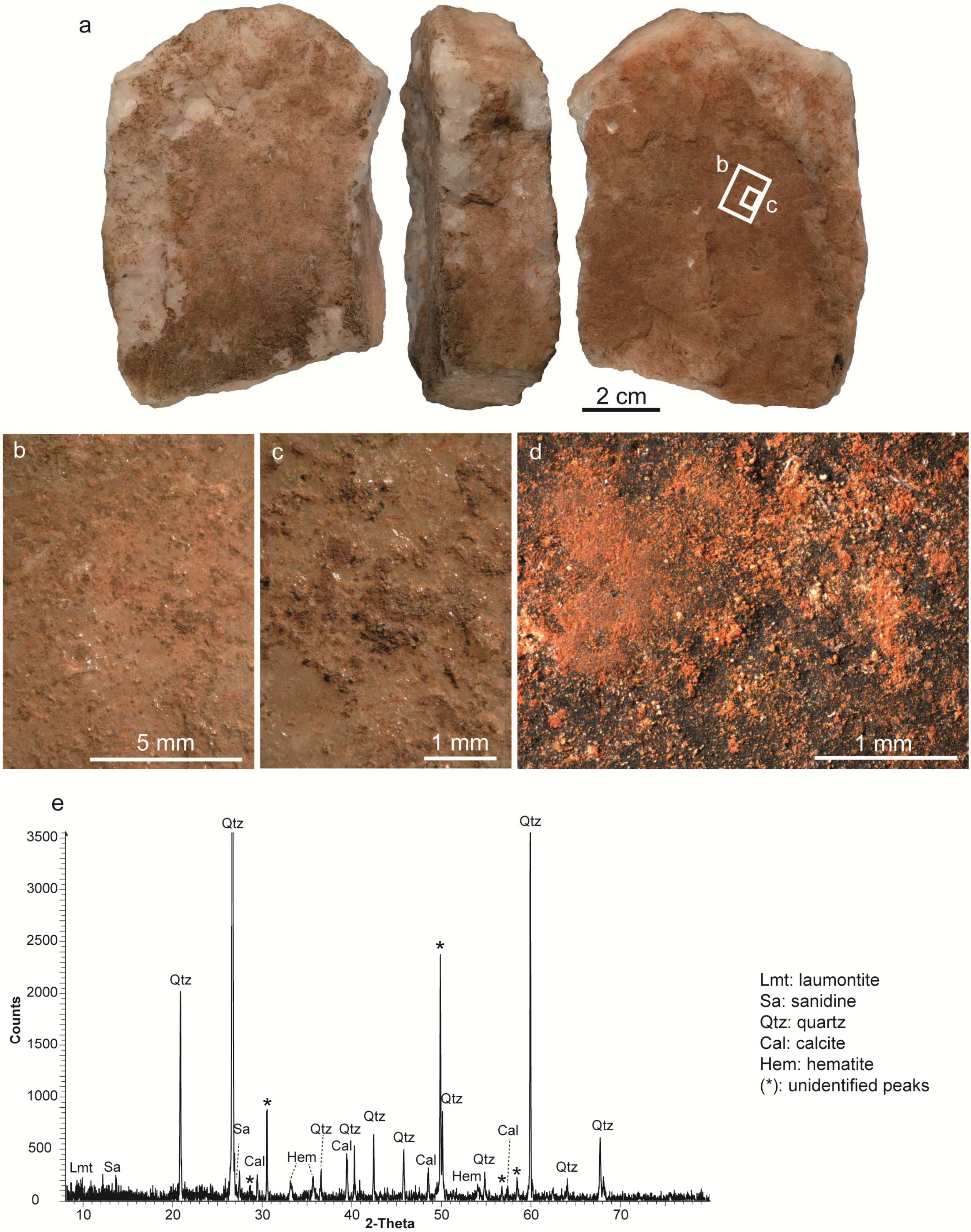

Fig J. Results of analyses conducted on ochre processing tool 10 (lower grindstone).

a: Photo of the object. Squares indicate the location of macro photos b and c; b, c: macro photos of smoothed area associated with red residues; d: photo of the sampled ochre residue (sample AT10); e: X-ray diffractogram of sample T10.

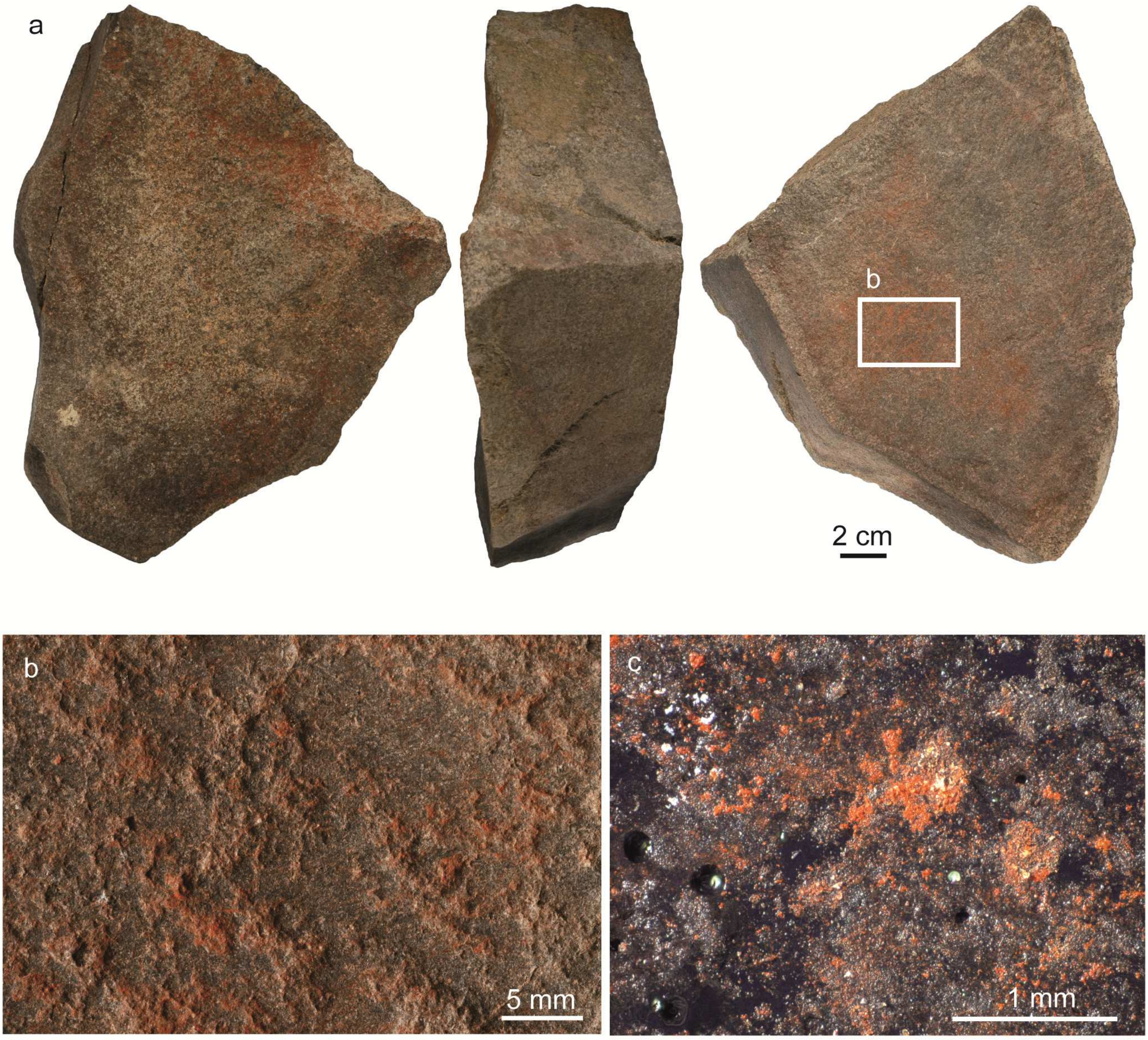

Fig K. Results of analyses conducted on ochre processing tool 11 (lower grindstone).

a: Photo of the object. Square indicates the location of macro photo b; b: macro photo of smoothed areas associated with microstriations and red residues; c: photo of the sampled ochre residue (sample AT11).

Middle Stone Age Ochre Processing and Behavioural Complexity in the Horn of Africa: Evidence from Porc-Epic Cave, Dire Dawa, Ethiopia

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S2 Figures. Results of analyses conducted on ochre processing tools 12–14; 16–23 and ochre-stained artefact 15.

Photos of the artefacts, modification marks and residues, SEM-EDS images and XRD diffractograms. The objects' identification number is the same as presented in Figs 4–11, Tables 1–5, S1 Figs, S1 Tables, S1 Texts.

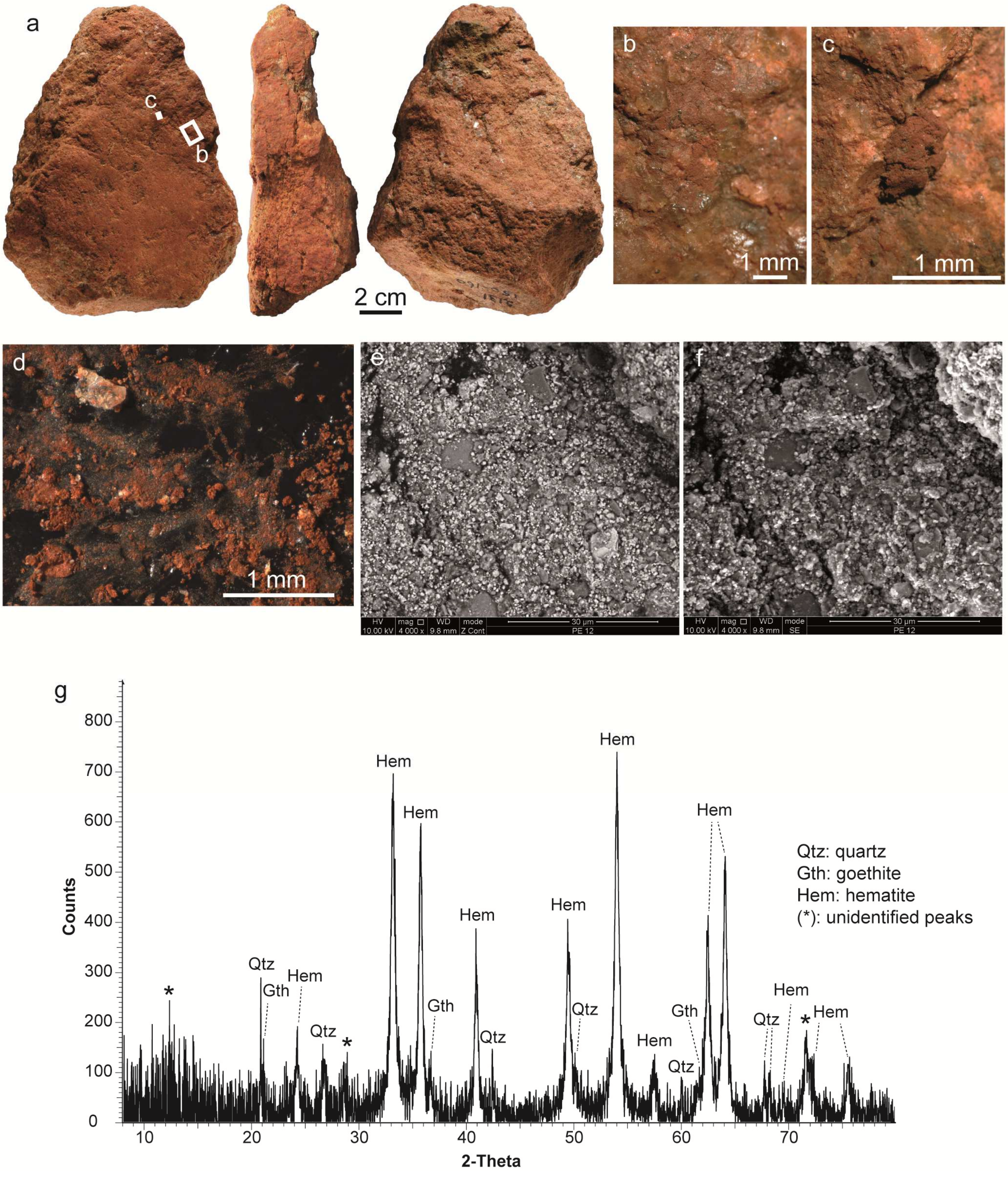

Fig A. Results of analyses conducted on ochre processing tool 12 (lower grindstone). a: Photo of the object. Squares indicate the location of macro photos b and c; b, c: macro photos of smoothed areas associated with red residues; d: photo of the sampled ochre residue (sample AT11); SEM images in BSE (e) and SE (f) modes of sample AT12; g: X-ray diffractogram of sample T12.

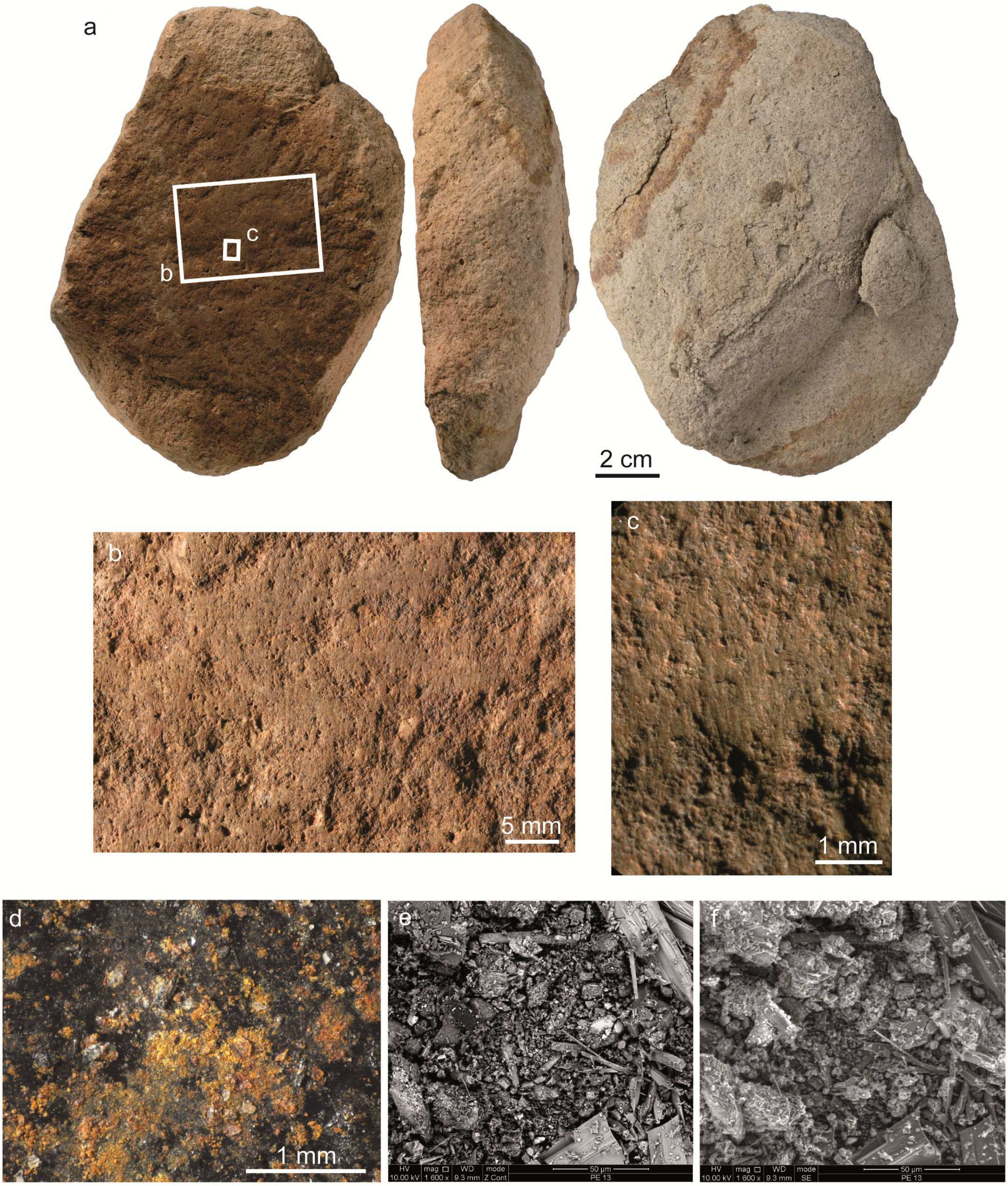

Fig B. Results of analyses conducted on ochre processing tool 13 (lower grindstone). a: Photo of the object. Squares indicate the position of macro photos b and c; b, c: macro photos of smoothed areas associated with microstriations and red residues; d: photo of the sampled ochre residue (sample AT13); SEM images in BSE (e) and SE (f) modes of sample AT13.

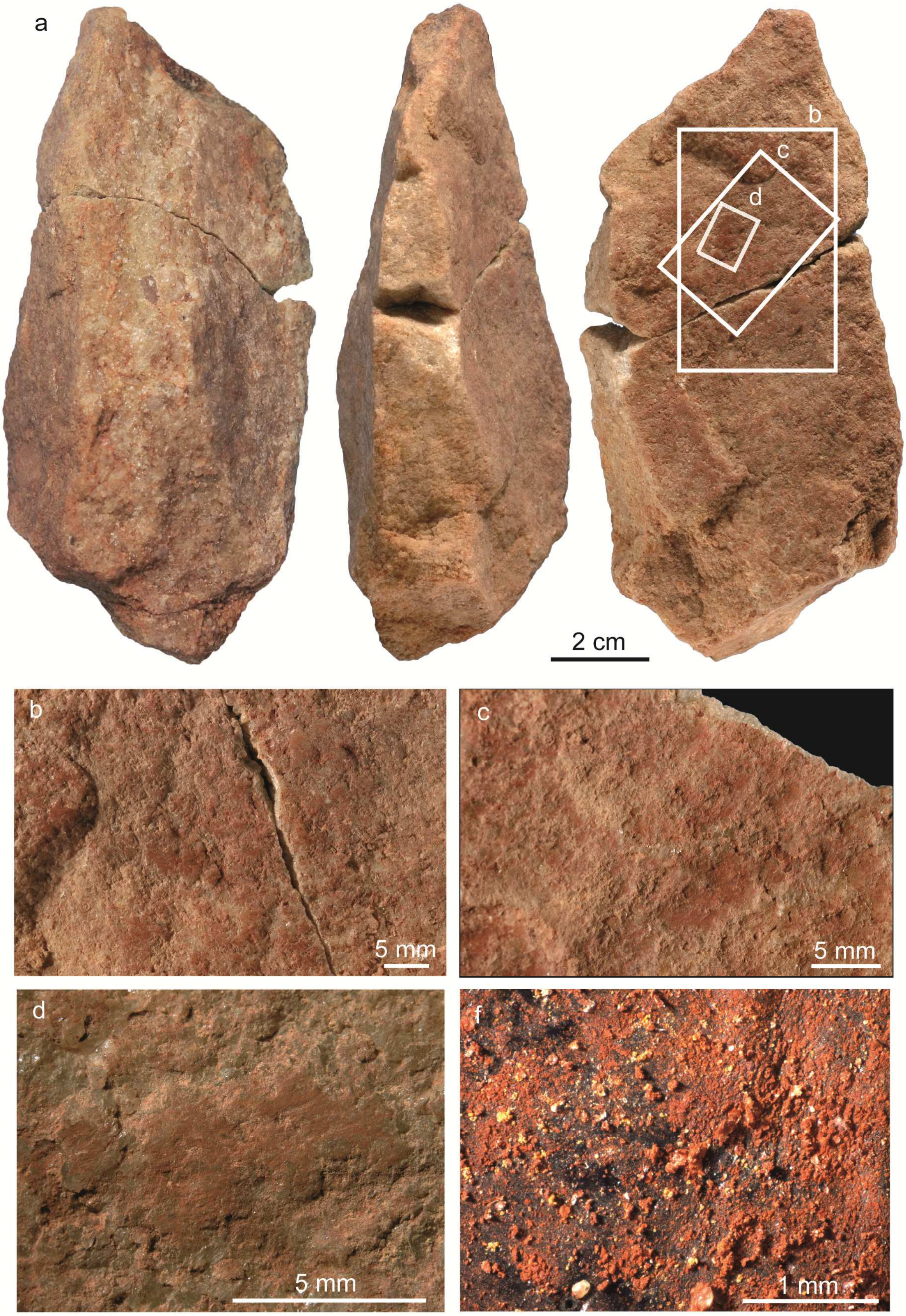

Fig C. Results of analyses conducted on ochre processing tool 14 (lower grindstone). a: Photo of the object. Squares indicate the position of macro photos b–d; b–d: macro photos of smoothed areas associated with microstriations and red residues; f: photo of the sampled ochre residue (sample AT14).

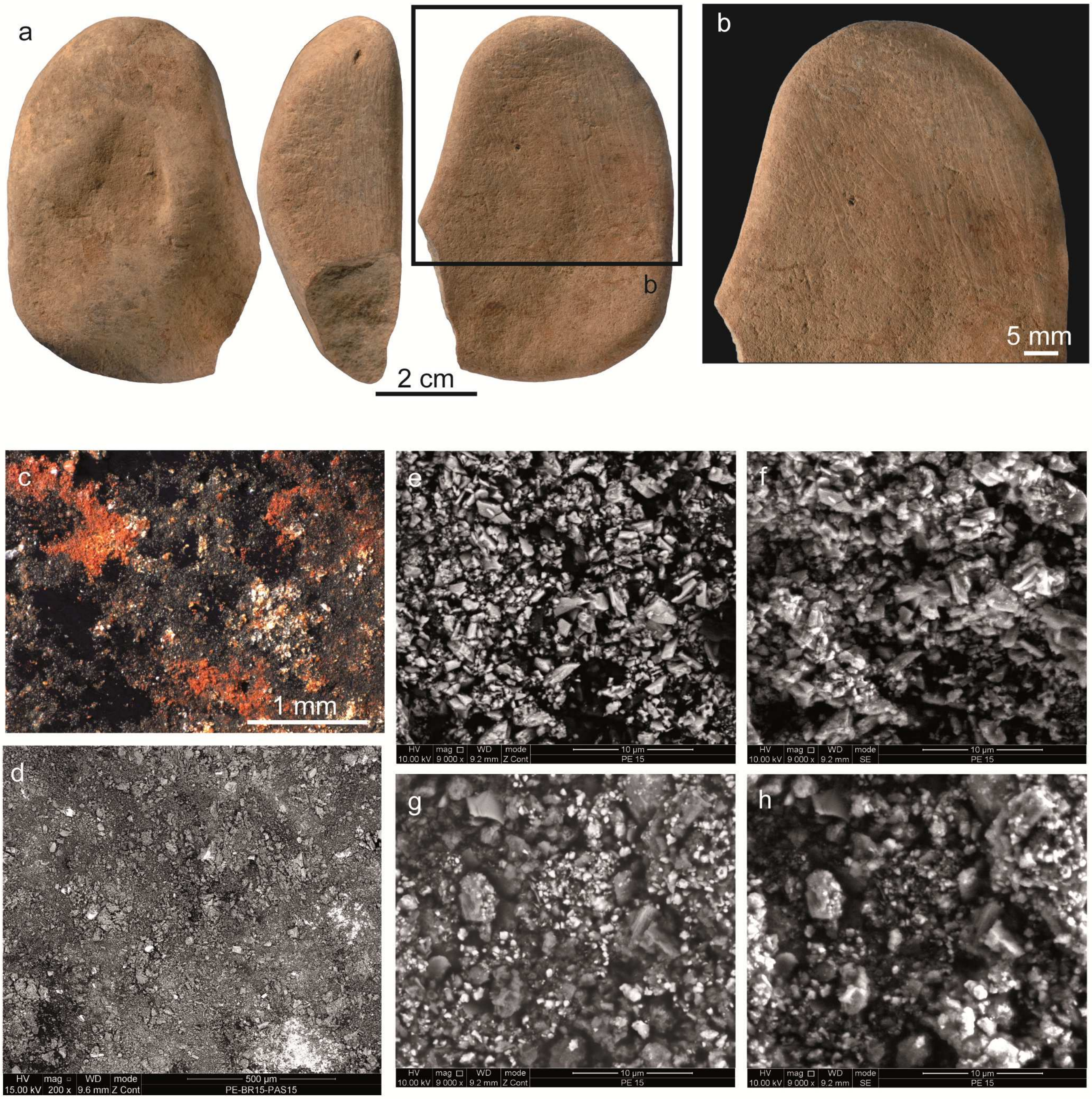

Fig D. Results of analyses conducted on ochre-stained artefact 15.
a: Photo of the object. Square indicates the position of macro photo b; b: macro photo of linear impressions associated with striations and red residues; c: photo of the sampled ochre residue (sample AT15); d: SEM image in BSE mode of sample AT15; SEM images in BSE (e) and SE (f) modes of sample AT15 zone 1; SEM images in BSE (g) and SE (h) modes of sample AT15 zone 2.

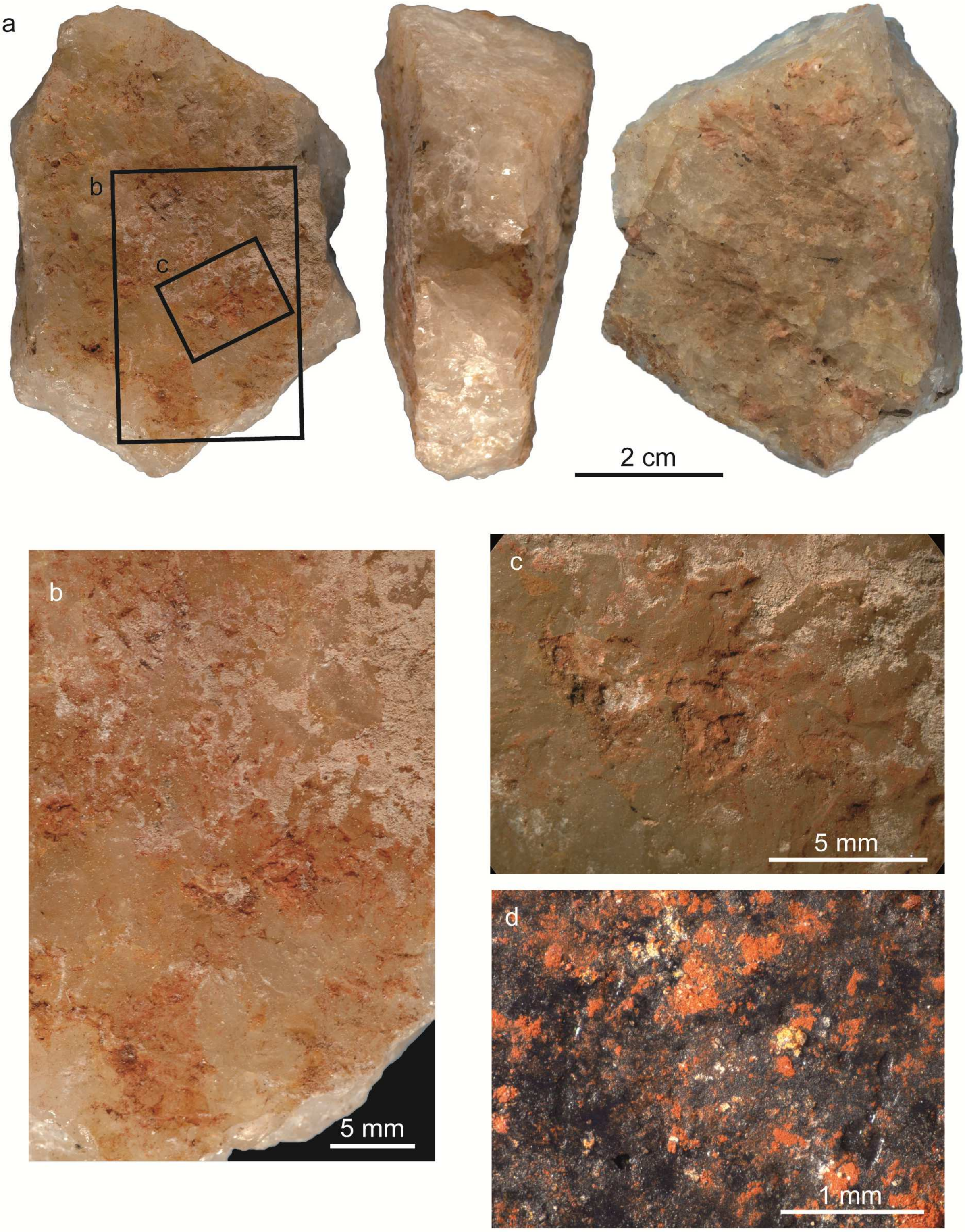

Fig E. Results of analyses conducted on ochre processing tool 16 (lower grindstone). a: Photo of the object. Squares indicate the location of macro photos b and c; b, c: macro photos of red residues; d: photo of the sampled ochre residue (sample AT16).

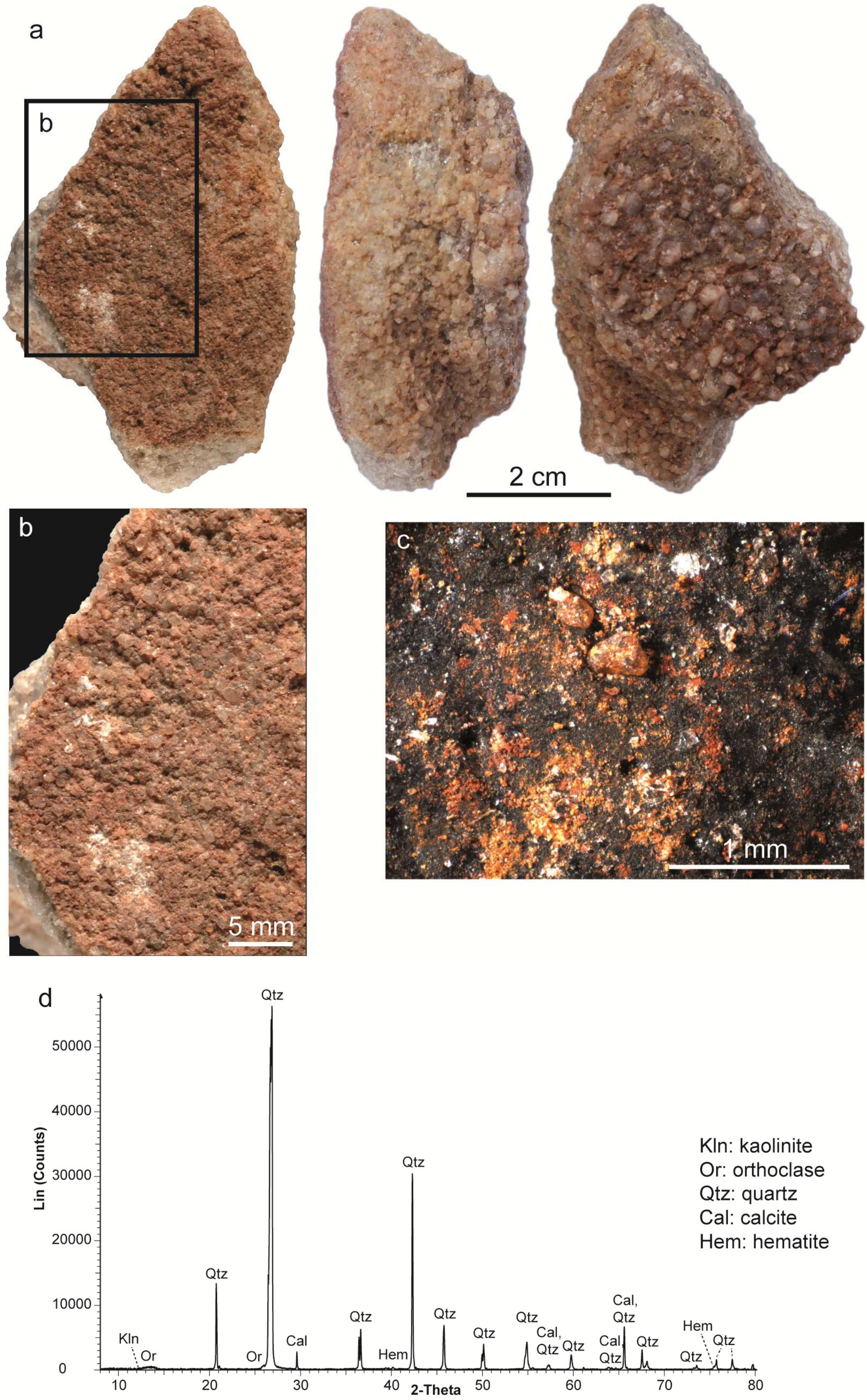

Fig F. Results of analyses conducted on ochre processing tool 17 (lower grindstone). a: Photo of the object. Square indicates the position of macro photo b; b: macro photo of red residues; c: photo of the sampled ochre residue (sample AT17); d: X-ray diffractogram of sample T17.

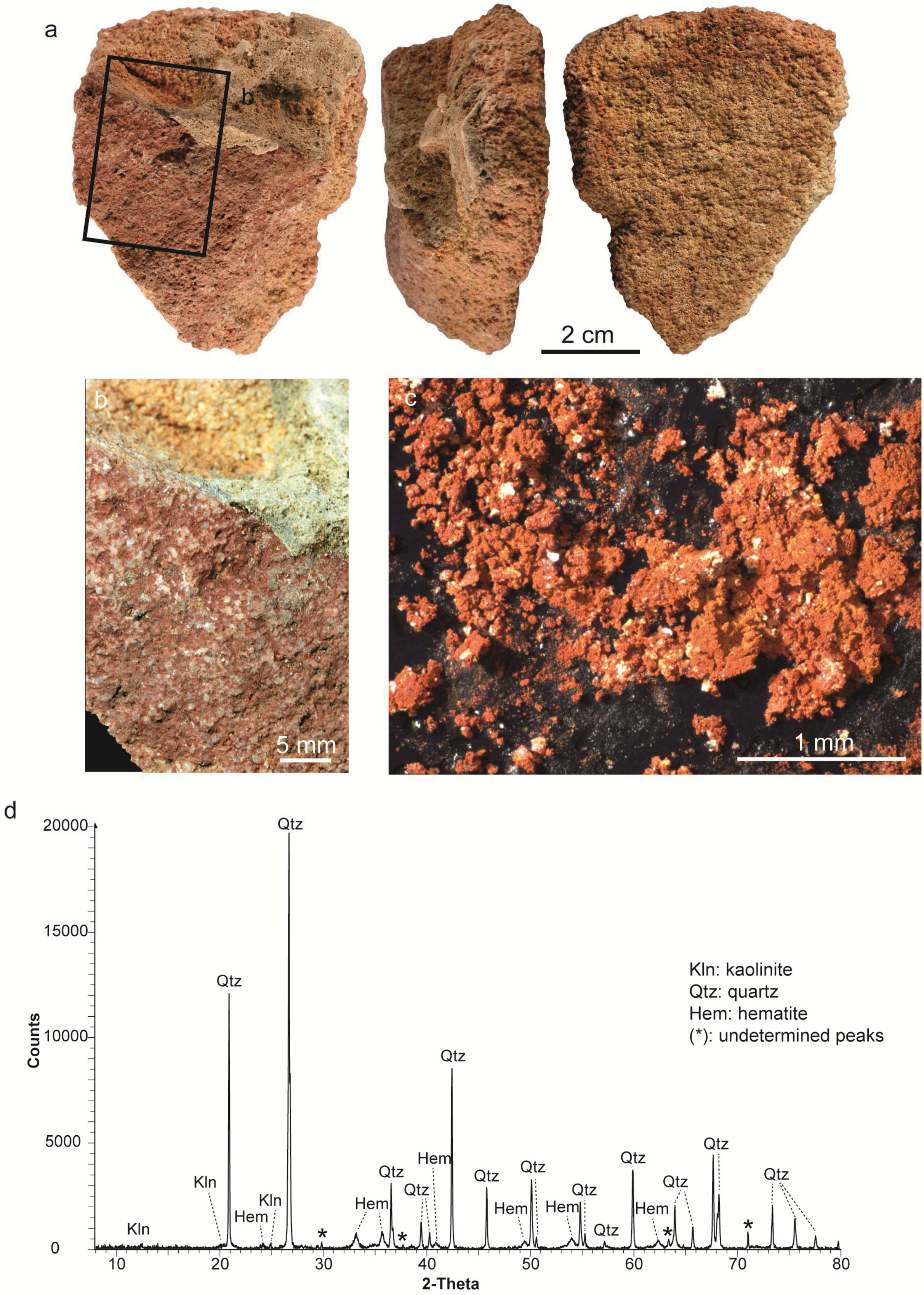

Fig G. Results of analyses conducted on ochre processing tool 18 (lower grindstone). a: Photo of the object. Square indicates the position of macro photo b; b: macro photo of red residues; c: photo of the sampled ochre residue (sample AT18); d: X-ray diffractogram of sample T18.

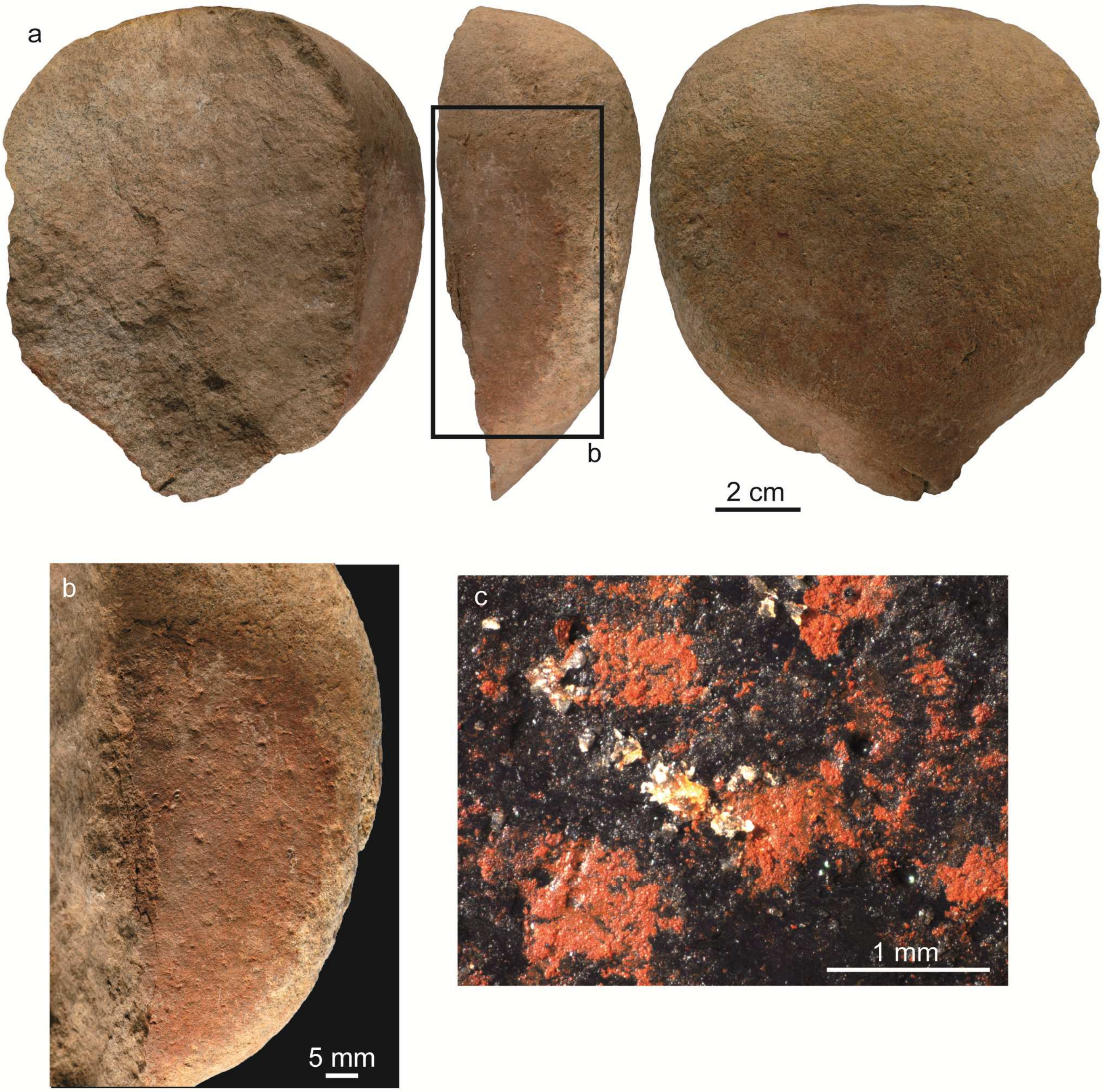

Fig H. Results of analyses conducted on ochre processing tool 19 (upper grindstone).
a: Photo of the object. Square indicates the position of macro photo b; b: macro photo of pits associated with red residues; c: photo of the sampled ochre residue (sample AT19).

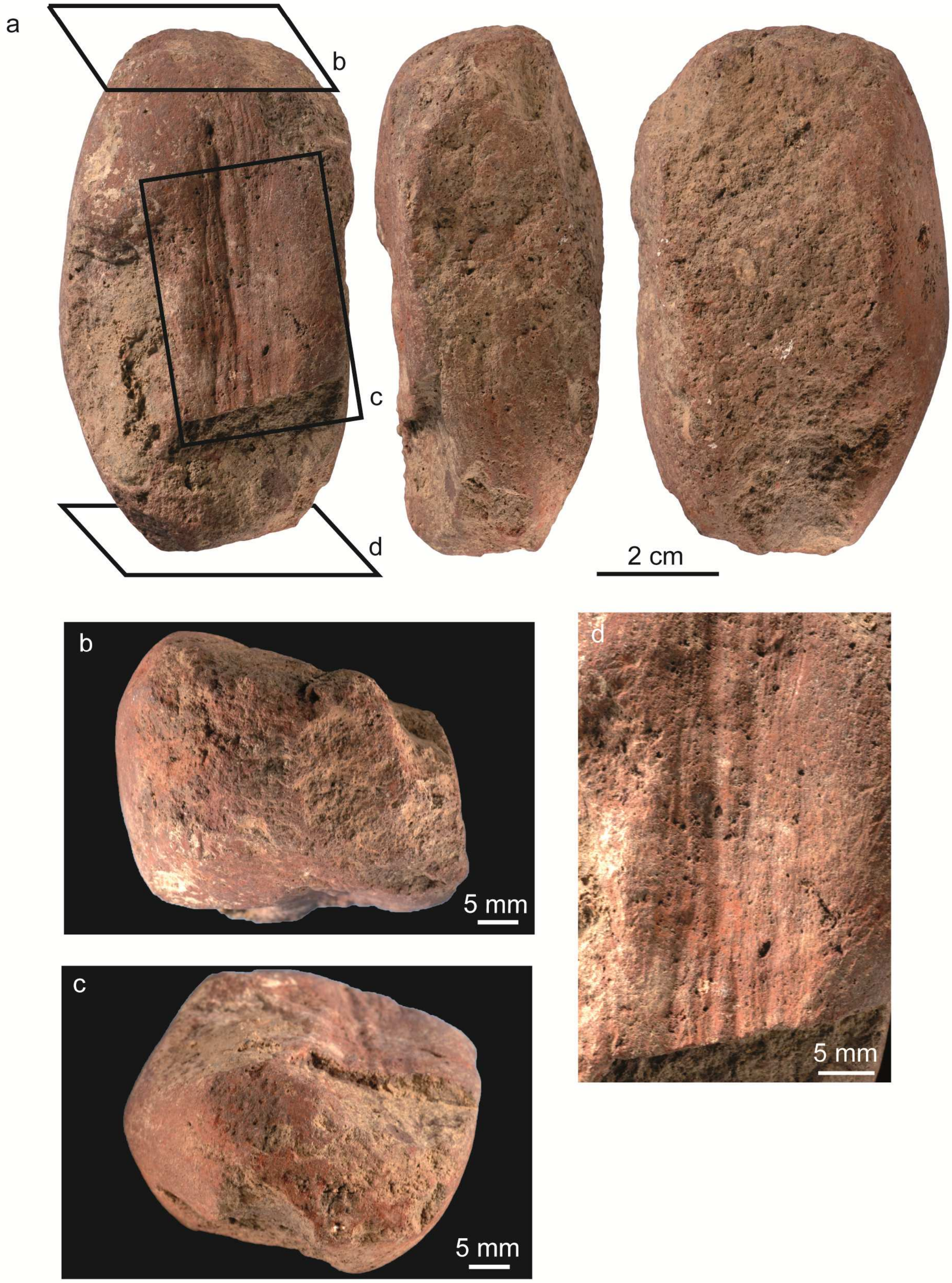

Fig I. Results of analyses conducted on ochre processing tool 20 (upper grindstone). a: Photo of the object. Squares indicate the location of macro photos (b–d); macro photos of pits associated to smoothed areas (b, c), flake scar (c), and deep grooves (d).

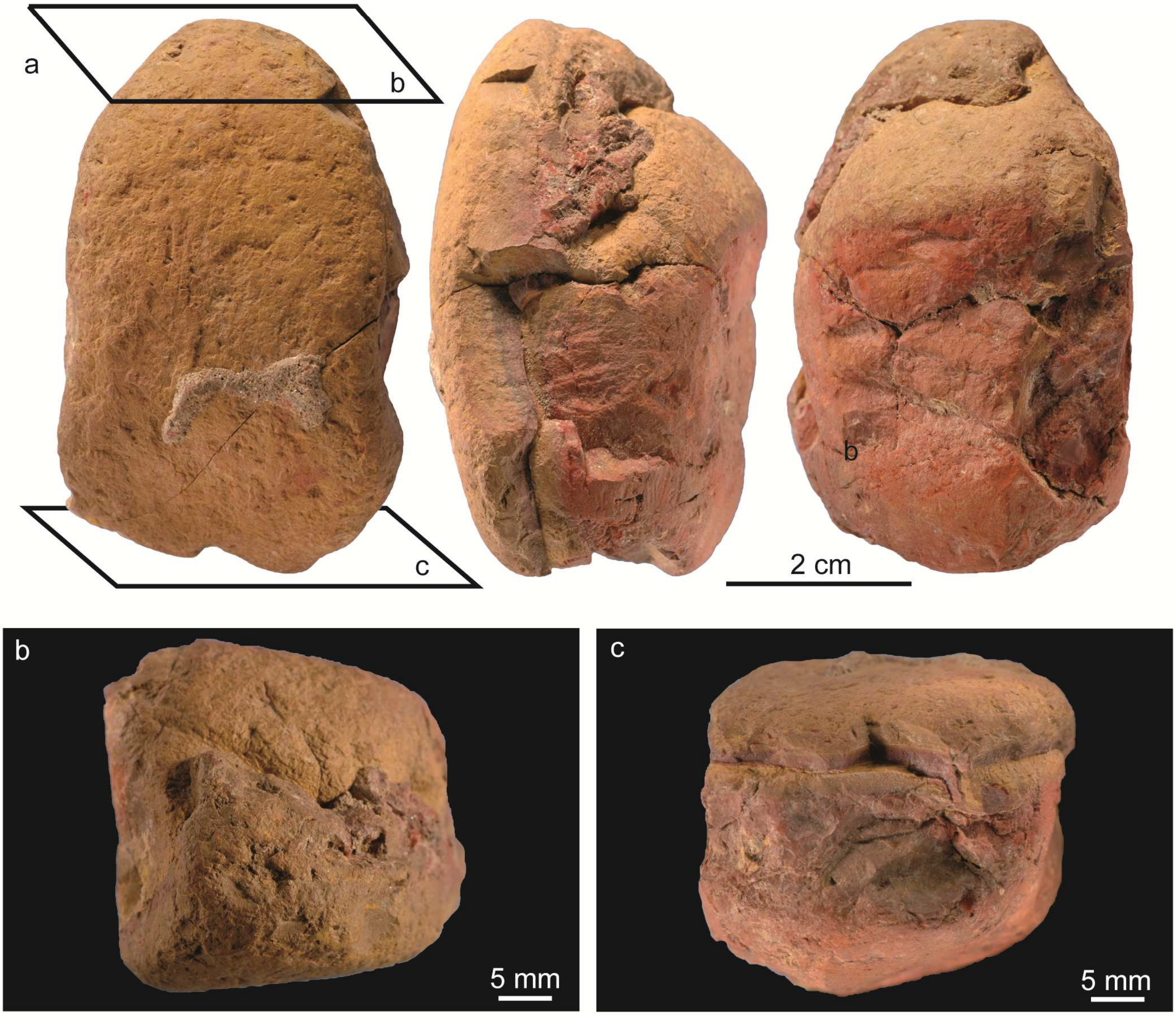

Fig J. Results of analyses conducted on ochre processing tool 21 (upper grindstone). a: Photo of the object. Squares indicate the location of photos b and c; photos of pits (b, c) and flake scars (c).

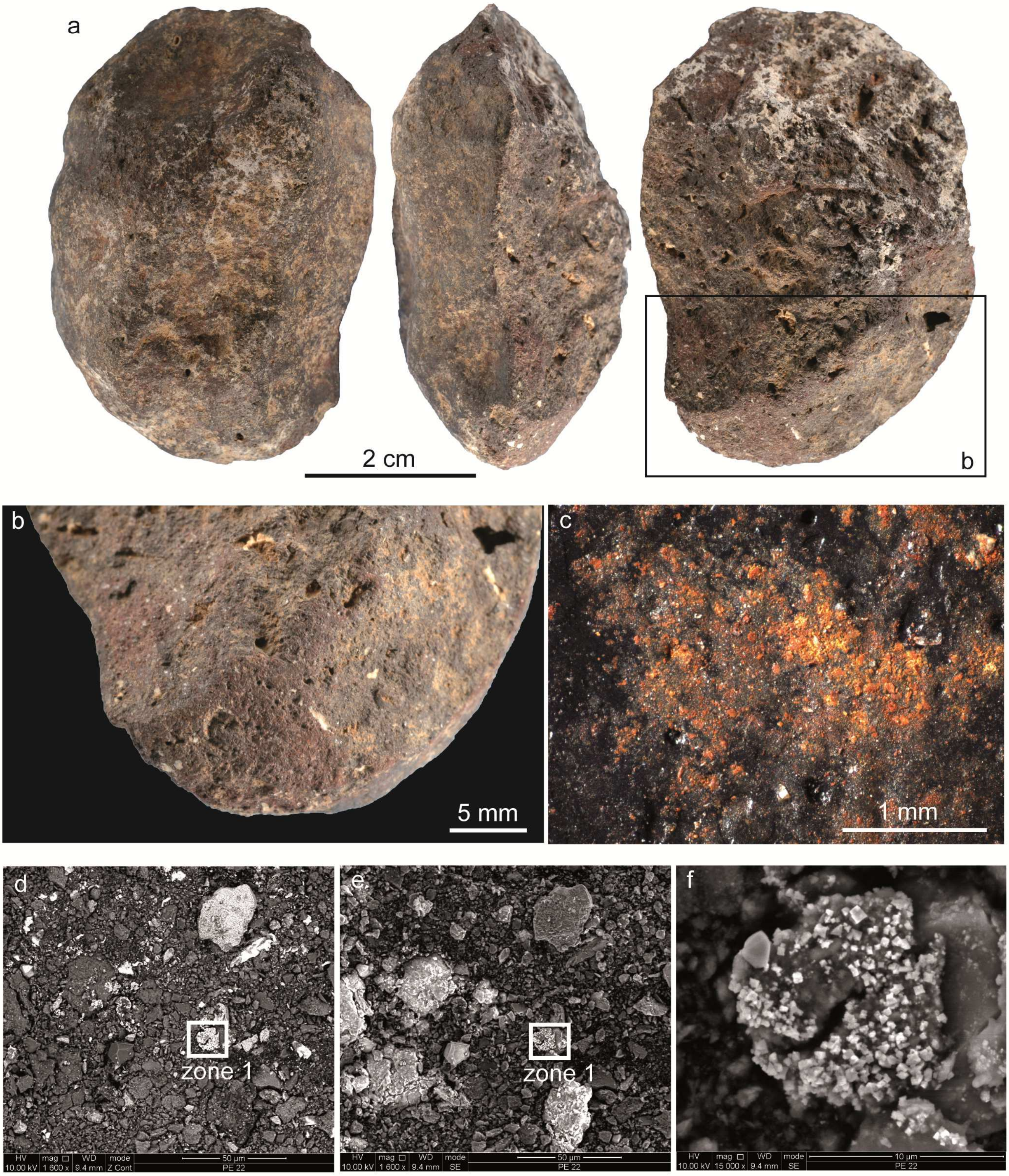

Fig K. Results of analyses conducted on ochre processing tool 22 (upper grindstone).

a: Photo of the object. Square indicates the location of macro photo b; b: macro photo of pits; c: photo of the sampled ochre residue (sample AT22); SEM images in BSE (d) and SE (e) modes of sample AT22 (zone 1 indicates the area represented in c); SEM image in SE mode of sample AT22 zone 1.

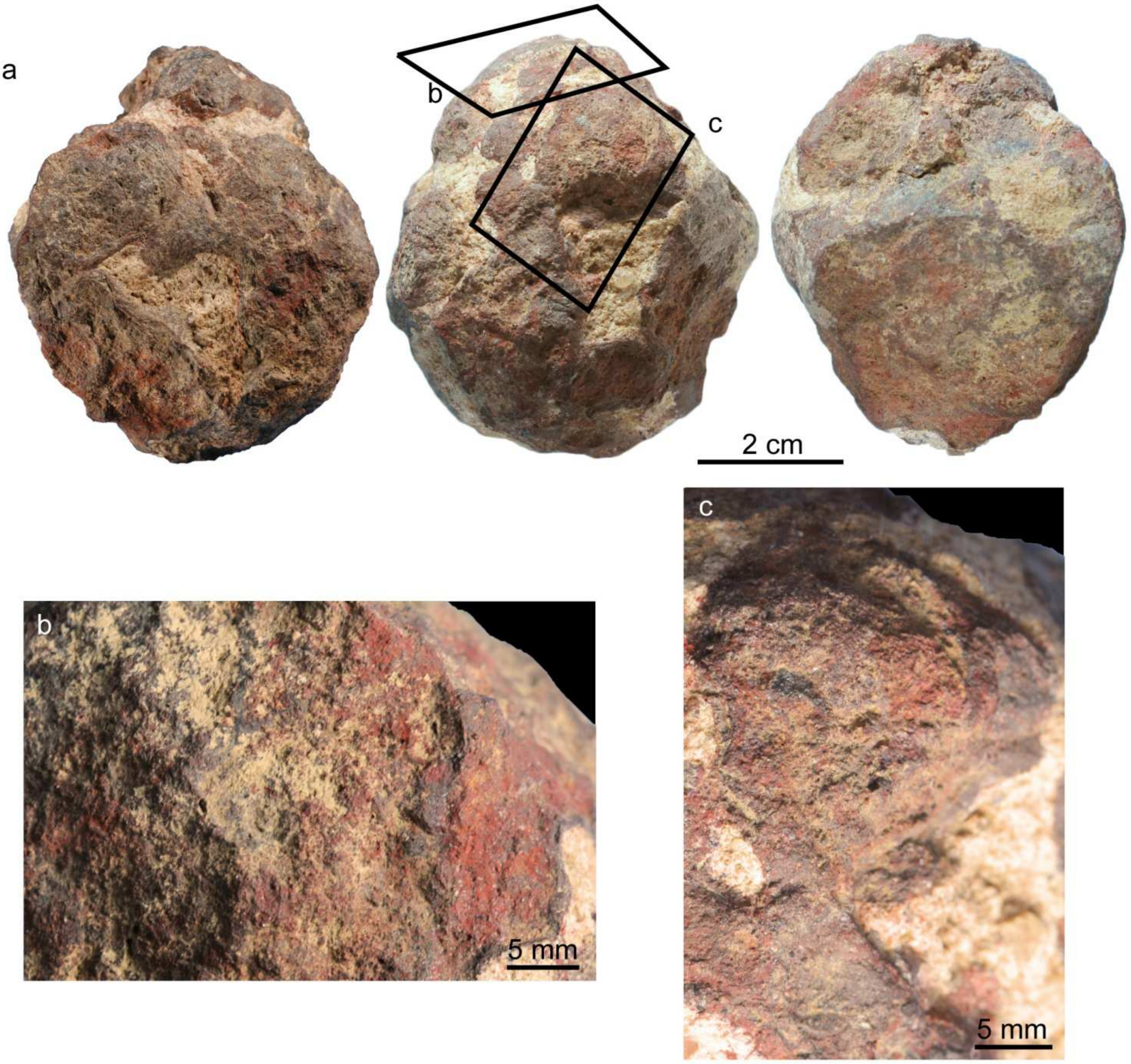

Fig L. Results of analyses conducted on ochre processing tool 23 (upper grindstone). a: Photo of the object. Squares indicate the position of macro photos b and c; b, c: macro photos of pits.

Middle Stone Age Ochre Processing and Behavioural Complexity in the Horn of Africa: Evidence from Porc-Epic Cave, Dire Dawa, Ethiopia

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S1 Tables. Detailed results of elemental and mineralogical analyses conducted on ochre processing tools and ochre-stained artefacts.

SEM-EDS and μ-RS analyses. The objects' identification number is the same as presented in Figs 4–11, Tables 1–5, S1 and S2 Figs, S1 Texts.

Table A. Results of SEM-EDS analyses.

Num	Sam	Num of an	Description of analysed item				Semi-quantitative EDX analyses **				Interpretation***
			Grain morph	BSE cont*	Length range (µm)	Width range (µm)	>10%	10-3%	3-1%	<1%	
1	AT1A	1	Irreg	W	39	26	**Fe**	Mn, (Si)	(Ca, Al, K)	(Cl, Mg, Ti, Na, P)	Iron ox (+ clay min)
1	AT1A	4	Aggl	W	Submicr	Submicr	**Fe**	(Si, Al)	(Ca, K)	(Mg), Mn, (Ti, P, Cl, Na)	Iron ox (+ clay min)
1	AT1A	2	Plat	G	34	26	Si, (Fe)	Al, K, Na	(Ca)	(Mg)	K-rich mica (+ iron ox)
1	AT1A	1	Ang	G	30	19	Ca, Mg	(Fe, Si)	(P, Al, K)	(Mn)	Carbonate (+ clay min)
1	AT1A	1	Irreg	W	24	10	**Ba**	S, (Si, Fe)	(Al, Ca, K)	(Mg, Na, Mn, P)	Ba-rich Sulphate (+ clay min + iron ox)
1	*AT1A*	*3*	*-*	*W*	*-*	*-*	***Fe**, Si*	*Al, Ca, K*	*-*	*Mg, (Cl), Ti, P, Mn, Na, Cr*	*Mixture of iron ox and aluminosil*
1	*AT1A*	*2*	*-*	*G*	*-*	*-*	*Fe, Si*	*Al, Ca, K*	*Mg*	*P, Ti, (Cl) ,Na, S*	*Mixture of iron ox and aluminosil*
2	AT2A	2	Irreg	W	21-34	13	**Fe**, Cr	(Si), Ni, (Al)	(Ca, Cl)	(K, Mg, P, S, Na, Ti)	Undet
2	AT2A	1	Ang	LG	42	42	Si, (Fe)	(Ca, Al, Mg)	(K)	(Cl, Na, Ti, S, P)	Silicate (+ Ca-rich aluminosil)
2	AT2A	1	Irreg	G	62	35	(Fe), Si	Al, Ca, K	(Cl, S), Na, (Ti)	Mg, P	Ca-rich feldspar (+ iron ox)
2	*AT2A*	*3*	*-*	*G*	*-*	*-*	*Fe, Si*	*Al, Ca*	*K, (Cl), S*	*Mg, Ti, P, Na*	*Mixture of iron ox and clay min*
2	*AT2A*	*1*	*-*	*W*	*-*	*-*	*Fe, (Si)*	*(Cl, Al, Ca, K)*	*(Mg)*	*(S, Na), Ti, (P)*	*Iron ox (+ clay min)*
2	AT2B	1	Aggl	W	Submicr	Submicr	**Fe**, (Si)	(Ca, Al, Cl)	(K)	(Mg), Ti, (Na, P)	Iron ox (+ Ca-rich feldspars)
2	AT2B	2	Ang	G	96-156	54-90	Si, (Fe)	(Al, Ca, Mg)	(Cl, K)	(Na)	Silicate (+ aluminosil)
2	*AT2B*	*3*	*-*	*W*	*-*	*-*	*Fe, Si*	*Ca, Al, (Cl)*	*Mg, K, Na*	*Ti, P, S*	*Mixture of iron ox and clay min*
3	AT3	2	Subcirc	W	15-17	12	**Fe**	(Si)	(Al)	(Cl, Ca, S, K, Mg, P)	Iron ox (+ silicates + clay min)
3	AT3	2	Aggl	W	Submicr	Submicr	**Fe**	(Si, Al)	-	(Ti, Cl, Ca, S, P, K, Mg)	Iron ox (+ silicates + Ti-rich clay min)
3	AT3	2	Irreg	W	18-19	12-14	**Fe**, Cr	Ni, (Si)	(Al)	(Mn, Ca, Cl, Ti, S, K)	Undet
3	AT3	2	Irreg	G	522-807	413-531	**Si**	(Fe)	(Al)	(Ca, Cl, Ti)	Silicate (+ iron ox + Ti-rich clay min)
3	AT3	1	Ang	G	5-10	5-10	**Si**	(Fe)	(Al)	-	Silicate (+ iron ox)
3	*AT3*	*3*	*-*	*G*	*-*	*-*	*Si, Fe*	*Al, (Cl), Ca*	*-*	*K, Ti, Mg, P, (Cr), S*	*Mixture of iron ox and Ti-rich clay min*
4	AT4	4	Oct	G	58-63	41-51	Fe, (Si), Ti	(Al)	(Ca, K, Mg, Na)	(P, Cl), Mn, (S)	Undet ox (+ silicates + clay min)
4	*AT4*	*4*	*-*	*G*	*-*	*-*	*Fe, Si*	*Al*	*Ca, K, Mg, Na, Ti*	*(Cl), P*	*Mixture of iron ox and aluminosil*
5	AT5	4	Irreg	W	17-38	13-27	**Fe**, (Si)	(Al)	(Cr, K)	(Ca, Cl, Mg, Na, Ti, S, P)	Iron ox (+ feldspars + clay min)
5	AT5	1	Irreg/acic	W	1-2	1-2	Fe, (Si)	(Al, K)	(Ca, Cr, Cl)	(Mg, Na, Ti)	Iron ox (+ feldspars + clay min)
5	AT5	1	Irreg	G	24	15	Si	Al, Na, K	(Fe)	(Cl), P	Feldspar (+ clay min)
5	AT5	1	Aggl	G	Submicr	Submicr	(Fe), Si	Al, (Cr), K	Ca, (Cl)	Mg, Ti, Na	Clay min (+ iron ox)
5	AT5	1	Irreg	G	30	25	Si, (Fe)	(Al)	(K, Ca)	(Cl, Mg, S, Na)	Silicate (+ clay min)
5	*AT5*	*3*	*-*	*G*	*-*	*-*	*Si, Fe*	*Al*	*K, Ca, (Cl)*	*Mg, S, Ti, Na*	*Mixture of iron ox and aluminosil*
6	AT6B	3	Irreg/plat	W	55-134	39-113	**Fe**, Ti	(Si, Al)	(Mg)	(Cr), Mn, (Ca, K, Cl, Na, P)	Undet ox (+ aluminosil)
6	AT6B	2	Aggl	G	Submicr	Submicr	Si, Al	(Fe)	Mg, K, (Cl, Ti)	Ca, Na, P, S	Clay min (+ iron ox)
6	AT6B	1	Ang	G	194	111	Si, Ca	Mg, Fe, Al	Ti	Na,(K, Cl)	Undet silicate (+ clay min)
6	*AT6B*	*3*	*-*	*G*	*Submicr*	*Submicr*	*Si, Fe*	*Al*	*Ca, Ti, Mg, K, (Cl)*	*Cr, Mn, Na, P*	*Mixture of iron ox and aluminosil*

7	AT7	2	Irreg	W	20-29	9-20	**Fe**	-	(Si, Al, Cl, Ca)	(Ti, K, Mg, P)	Iron ox (+ aluminosil)
7	AT7	1	Irreg	G	56	34	Si, Al	(Fe), Ca	Na, (Cl)	K, Mg, Mn, Ti	Ca, Na-rich feldspar (+ iron ox)
7	AT7	2	Aggl	W	2-4	2-4	Fe, (Si)	(Cl, Ca, Al)	-	(K, Mg), Mn, (Ti, P)	Iron ox (+ aluminosil)
7	AT7	1	Aggl	G	211	131	(Fe)	Si, Al	(Cl), Ca	Mg, K, Ti, Mn, Na, P	Undet Aluminosil (+ iron ox)
7	AT7	1	Irreg	G	326	241	Si, (Fe)	(Al)	(Cl, Ca)	(K, Mg, Ti, P)	Silicate (+ iron ox + aluminosil)
7	*AT7*	*3*	*-*	*W*	*-*	*-*	*Fe*	*Si, Al, (Cl), Ca*	*-*	*K, Mg, Ti, P, Na, S*	*Mixture of iron ox and aluminosil*
7	*AT7*	*3*	*-*	*W*	*-*	*-*	***Fe***	*(Cl, Ca, Al, Si)*	*-*	*(P, K, Mg, S, Ba, Ti, Na, Cr)*	*Iron ox (+ aluminosil)*
9	AT9	5	Aggl	W	5-10	5-10	**Fe**	(Si, Cl)	(Al, Ca)	(K, Na, Mg, P, Ti)	Iron ox (clay min)
9	AT9	2	Irreg	G	131-153	109-129	**Si**	**-**	(Al, Fe)	(Ca, Cl, K, Mg, Na)	Silicate (+ iron ox + clay min)
9	AT9	3	Irreg	G	27-194	21-150	Si, K, Al	(Fe)	**-**	Na, Mg, (P)	Feldspar (+ iron ox + clay min)
9	*AT9*	*1*	*-*	*G*	*-*	*-*	*Si, Fe*	*Al, K*	*Ca, (Cl), Na*	*Mg, (P)*	*Mixture of iron ox and aluminosil*
9	*AT9*	*3*	*-*	*W*	*-*	*-*	*Si, Fe*	*Al, Ca*	*K, (Cl), Na*	*Mg, (P), Ti*	*Mixture of iron ox and aluminosil*
12	AT12	1	Subcirc	W	1-2	1-2	**Fe**	(Si, Al, Ca)	(Cl, K)	Mn, (Mg, P, Ti)	Iron ox (+ aluminosil)
12	AT12	1	Plat	G	2	1	(Fe), Si	Al, (Cl), Ca	K, Mg	P, Ti	Clay min (+ iron ox)
12	AT12	1	Subcirc	G	23	19	(Fe), Si, Ca	(Cl), Al	K	P, Ti, Mg, Na	Ca-rich feldspar (+ iron ox)
12	AT12	1	Plat	G	50	26	Si, Al	(Fe), K	-	(Cl), Ti, Ca, Mg, Na	K-rich mica (+ iron ox)
12	AT12	1	Irreg	G	8	8	Fe, Si	Al, Mg, K	Cl, Ca	Ti, P	Undet
12	*AT12*	*1*	*-*	*G*	*-*	*-*	***Fe**, Si*	*Cl, Al, Ca*	*K*	*Ti, P, Mg*	*Mixture of iron ox and aluminosil*
13	AT13	3	Aggl	W	Submicr	Submicr	Fe, Si	Al, Ce, La, Nd	Na	K, Ca, (P), Mg, Cl, Ti, (S), Mn	Mixture of iron ox and clay min
13	AT13	3	Tab	LG	113-202	30-48	(Fe), Si	Na	Al, K	Ca, Ti, (Mn), Mg, Cl	Na-rich feldspar (+ iron ox + clay min)
13	*AT13*	*3*	*-*	*G*	*-*	*-*	*Fe, Si*	*Al*	*Na*	*Ca, K, (Cl), Mg, P*	*Mixture of iron ox and aluminosil*
15	AT15	4	Irreg	W	20-79	14-66	**Fe**, Ti	(Si, Al)	-	(Ca, Mg, K), Mn, (Na, Cl, P, Cr, S)	Undet ox (+ clay min)
15	AT15	2	Aggl	W	Submicr-micr	Submicr-micr	**Ba**, S	(Si)	(Fe, Al)	(Ca, K, Na, Mg)	Ba-rich sulphate (+ clay min)
15	*AT15*	*3*	*-*	*G*	*-*	*-*	*Si, Fe*	*Al, Ca*	*K, S*	*Na, Mg, (Cl), Ti, P*	*Mixture of iron ox and clay min*
22	AT22	5	Ang	W	20-64	6-20	**Fe**	(Si)	(Al)	Mn, (Ti, Ca, K, Cl, P, Mg, S)	Iron ox (+ aluminosil)
22	AT22	1	Irreg	W	36	14	**Fe**, Si	-	Al	Ti, K, Mg, (Cl), Na	Fe-rich silicate
22	AT22	6	Irreg/ang	LG	28-70	19-61	(Fe), Si, Al	-	-	Ti, Ca, (Cl), K, P, Mg, S	Undet aluminosil (+ iron ox)
22	*AT22*	*6*	*-*	*G*	*-*	*-*	*Fe, Si*	*Al*	*-*	*K, Ca, Ti, (Cl), Mg, P, Na*	*Mixture of iron ox and aluminosil*

Num: number; sam: sample; an: analyses; morph: morphology; cont: contrast; irreg: irregular; aggl: agglomerate; plat: platy; ang: angular; subcirc: subcircular; oct: octahedral; acic: acicular; tab: tabular; W: white; G: gray; LG: light gray; submicr: submicrometric; micr: micrometric; ox: oxide; min: minerals; aluminosil: aluminosilicates; undet: undetermined.

(*): BSE cont. refers to the contrast observed on backscattered electron (BSE) images.

(**): Weight percentages including C and O, normalised to 100 %. Elements in brackets play no role in the mineralogical composition of the analyzed items, elements in bold are present in a proportion equal or higher than 40 %.

(***) Text in italic indicates analyses conducted on areas of 4 μm2 instead than on points.

Table B. Results of μ-RS analyses.

Num	Sample	Num of an	Grain morph	Grain colour	Identified compounds*
1	AT1A	4	Elo, amo	B	gth + (ms + undet aluminosil)
1	AT1B	1	Aggl	R	hem
2	AT2A	2	Aggl	Y	gth
2	AT2A	1	Irreg	B	gth + (ms + undet Mn oxide)
2	AT2A	1	Aggl	R	hem
2	AT2B	3	Aggl	R	hem + (qz + undet Mn oxide + undet aluminosil)
3	AT3	4	Aggl	R + G	hem + (qz)
3	AT3	1	Aggl	B + W	qz + hem
4	AT4	1	Aggl	R	gp + hem + (qtz + undet aluminosil)
4	AT4	5	Aggl	R + Y	gth + hem + (undet aluminosil)
5	AT5	4	Aggl	R	hem + (qz + cal)
6	AT6A	1	Tab	B	hem + gth
6	AT6A	2	Aggl	R + W	hem + (gth)
7	AT7	1	Irreg	B	C
7	AT7	2	Aggl	R + G	hem + qz
7	AT7	1	Tab	B	hem
7	AT7	3	Subcirc	B	hem
7	AT7	2	Aggl	Y	lep, (gth)
7	AT7	1	Subcirc	Y	gth
7	AT7	1	Angular	W	qz + (hem)
7	AT7	1	Subcirc	B	qz
8	AT8	3	Aggl	B	hem + (gp)
8	AT8	1	Angular	B	qz + (gth)
8	AT8	1	Subcirc	B	qz + (gp)
9	AT9	4	Aggl	B	hem
9	AT9	2	Subcirc	B	hem + (gp)
9	AT9	1	Angular	W + R	qz + (hem)
9	AT9	1	Irreg	G	qz + (hem + gp + gth)
10	AT10	6	Aggl	R	hem + (cal + man + undet aluminosil)
10	AT10	1	Irreg	B	hem + (qz)
10	AT10	1	Subcirc	Y	gth
11	AT11	6	Aggl	R + B	hem + (an + gp + qz + undet aluminosil)
11	AT11	2	Angular	B	mag + (gp)
11	AT11	1	Elo, amo	W	qz + (hem + gp)
12	AT12	1	Irreg	W	ab + (hem)
12	AT12	3	Aggl	R	hem
12	AT12	1	Subcirc	G	qz + (hem + undet aluminosil)
13	AT13	3	Aggl	Y	gth + (ab + hem)
13	AT13	1	Angular	G	qz + (hem + gth + C)
14	AT14	1	Aggl	Y	gth + (hem + mnt)
14	AT14	1	Irreg	B	hem
14	AT14	3	Aggl	R	hem + (cal + gth + qz + undet aluminosil)
14	AT14	2	Angular	B + G	qz + (C + gth + hem)
15	AT15	1	Irreg	B	hem + (gth + dol)
15	AT15	2	Aggl	R	hem + (mnt + undet aluminosil)
15	AT15	1	Subcirc	Y	gth
15	AT15	3	Irreg	T	dol
16	AT16	2	Irreg	Y	gth + (gp + hem)
16	AT16	3	Aggl	R	hem
16	AT16	1	Subcirc	B	qz + (hem)

17	AT17	2	Aggl	R	hem
17	AT17	2	Subcirc	Y	gth
17	AT17	1	Aggl	Y	kln
17	AT17	1	Angular	G	qz + (gp)
17	AT17	2	Irreg	B	qz + (gp + hem)
17	AT17	1	Tab	W	qz + kln + (gp + hem)
18	AT18	3	Irreg	B	hem + (gp)
18	AT18	3	Aggl	R	hem + (gth)
18	AT18	1	Irreg	G	qz + (mag)
19	AT19	6	Aggl	R	hem + (aug)
19	AT19	1	Ang	G	qz + gth
22	AT22	1	Aggl	Y	gth + (mnt)
22	AT22	1	Aggl	R	hem + (qz)

Num: number; an: analyses; morph: morphology; elo: elongated; amo: amorphous; aggl: agglomerate; irreg: irregular; tab: tabular; subcirc: subcircular; ang: angular; B: black; R: red; Y: yellow; G: gray; W: white; T: translucent. Abbreviations of minerals are based on the nomenclature suggested by [121], except for lepidocrocite (lep), and manganite (man); C: carbon.

(*) Minerals in brackets reflect the composition of area located outside the analysed spot.

Middle Stone Age Ochre Processing and Behavioural Complexity in the Horn of Africa: Evidence from Porc-Epic Cave, Dire Dawa, Ethiopia

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S1 Texts. Results of residue analysis on ochre processing tools and ochre-stained artefacts from Porc-Epic Cave.

SEM-EDS, µ-RS and XRD analyses. The objects' identification number is the same as presented in Figs 4–11, Tables 1–5, S1 and S2 Figs, S1 Tables.

Text A. Results of residue analysis from ochre processing tool 1

Microscopic description and results of SEM-EDS, μ-RS and XRD analyses of samples AT1A, AT1B and T1.

Sample description

The ochre residue, relatively abundant in the irregularities of the tool's surface, was easy to remove with a scalpel. When observed through optical microscopy (Fig 8a, b, Fig A in S1 Figs), all sampled residues appear composed of aggregates of mostly red and, to a lesser degree, yellow fine-grained powder. Large white translucent and black grains, which probably come from the minerals composing the tool, are also present in the residue.

Sample composition

SEM-EDS analysis (Fig 10a, b, Fig 11, Fig A in S1 Figs, Table A in S1 Tables) shows that sample AT1A is composed of two different types of residue. Residue from zone 1 has a loose appearance and shows the presence of aggregates including what we interpreted as iron oxides (Fe) with clay minerals (Si, Al, Ca, K, Mg, and traces of Ti and Na), and K-rich micas (Si, Al, K, Na; approximately 34 μm in length). Residue from zone 2 has a compact appearance, and is composed of sub-micrometric and large (approximately 39 μm in length) irregular grains of iron oxides (Fe, Mn) and submicrometric platy grains (Si, Al, K, Ca, with traces of Mg and Na) interpreted as clay minerals. Irregular particles of barium sulphates (Ba, S; approximately 24 μm in length), and carbonates (Ca, Mg; approximately 30 μm in length) are also sporadically detected.

Micro-RS analyses (Table 4, Table B in S2 Tables) identify in sample AT1A the presence of goethite ($FeO(OH)$), muscovite (potassic mica, $KAl_2(AlSi_3O_{10})(OH)_2$) and other undetermined aluminosilicates. Sample AT1B shows the presence of hematite (Fe_2O_3). This is consistent with the results obtained through SEM-EDS.

XRD analyses (Table 5, Fig A in S1 Figs) confirm the presence in sample T1 of hematite, clay minerals (probably from the kaolinite group, $Al_2Si_2O_5(OH)_4$), and calcite ($CaCO_3$), and identify plagioclase feldspars (probably anorthite, $CaAl_2Si_2O_8$) and quartz (SiO_2).

Interpretation

Microscopic, elemental and mineralogical analyses suggest that this tool was used to process ochre lumps rich in iron oxides, clay minerals, and micas. The relationship between these components seems to indicate that they were naturally associated before being processed.

Differences in grain size and texture between two zones of sample AT1A analysed with SEM-EDS indicate the possible presence of two different types of ferruginous clay rocks. Iron oxides from zone 1 differ from those of zone 2, the first being submicrometric and composed of Fe, and the second being composed of larger grains, and composed of Fe and Mn. Additionally, clay minerals from zone 1 contain Ti, which is absent in zone 2.

Feldspar grains are detected through mineralogical analysis, but they were not directly analysed through SEM-EDS. However, SEM images from zone 2 seem to show some embedded irregular grains that could be interpreted as feldspars, absent in zone 1. Coarse quartz grains do not seem well blended with ochre residues, which may indicate that they originate from the limestone composing the processing tool. The low presence of barium sulphates suggests that they originate from surrounding sediments or post-depositional processes. This is also the case of carbonates detected by SEM-EDS.

Text B. Results of residue analysis from ochre processing tool 2

Microscopic description and results of SEM-EDS and μ-RS analyses of samples AT2A and AT2B.

Sample description

Small accumulations of ochre residues were detected in irregularities of the tool surface, making easy their extraction. Samples AT2A (Fig 8c, Fig B in S1 Figs) and AT2B (Fig 8d, Fig B in S1 Figs) are different macroscopically and microscopically. The former is yellow, the latter red, with very few yellow grains. In both cases, the ochre powder is fine-grained, and coarse translucent grains are present.

Sample composition

SEM-EDS analysis indicates that sample AT2A (Fig 10c, Fig 11, Fig B in S1 Figs, Table A in S1 Tables) contains compact agglomerates of submicrometric acicular grains of iron oxides (Fe, with traces of Ti), associated with platy submicrometric grains matching clay minerals (Si, Al, Ca, K, with traces of Mg, Ti, Na). Irregular Ca-rich grains, probably corresponding to plagioclase feldspars (Si, Al, Ca, K, Na; approximately 62 μm in length), and a few angular silicate grains (Si; approximately 42 μm in length) are also recorded.

Sample AT2B (Fig 10d, Fig 11, Fig B in S1 Figs, Table A in S1Tables) contains less compact agglomerates of fine submicrometric grains of iron oxides (Fe, Ti) associated with submicrometric platy grains corresponding to clay minerals (Si, Al, Ca, K, and traces of Mg, Na). Several large, angular silicate grains (approximately 42–156 μm) are present among the iron oxides.

Micro-RS analyses (Table 4, Table B in S1 Tables) show the presence in sample AT2A of goethite, and hematite. Manganese-rich minerals, muscovite and other undetermined aluminosilicates are also detected. In sample AT2B, hematite, quartz, undetermined aluminosilicates and manganese-rich minerals are recorded.

Interpretation

Microscopic, elemental and mineralogical analysis suggests that this tool was used to process two different types of ochre. The first type is a rock rich in fine-grained goethite (sample AT2A), and the second (sample AT2B) is almost exclusively composed of a fine-grained hematite.

In both cases, the blended appearance of iron oxides and clay minerals seems to indicate that they were naturally associated in origin. Both residues can be interpreted as ferruginous clay rocks.

Large quartz grains, identified in both samples, do not seem closely associated with the ochre powder. They seem more likely to be part of the minerals composing the schist tool. This is also the case with muscovite, undetermined manganese-rich minerals, and Ca-rich feldspars.

Text C. Results of residue analysis from ochre processing tool 3

Microscopic description and results of SEM-EDS, μ-RS and XRD analyses of samples AT3 and T3.

Sample description

Ochre residues on this tool are abundant, and were easy to remove. Samples AT3 and T3 are composed of fine red ochre powder, and translucent coarse grains (Fig 8e, Fig C in S1 Figs).

Sample composition

SEM-EDS analysis of sample AT3 (Fig 10e, Fig 11, Fig C in S1 Figs, Table A in S1 Tables) shows the presence of coarse silicate grains (Si, approximately 522–807 μm in length) cemented with iron oxides (Fe). Small subcircular grains probably corresponding to iron oxides, silicate grains (Si; approximately 5–10 μm in length), and submicrometric platy grains interpreted as clay minerals (Si, Al, Ca, K, Mg, and traces of Ti) are also identified.

Micro-RS analyses (Table 4, Table B in S1 Tables) identify hematite and quartz in sample AT3, which is consistent with the presence of iron oxides and silicates detected by SEM-EDS.

The presence of hematite and quartz is confirmed by XRD (Table 5, Fig C in S1 Figs) on sample T3. Clay minerals from the kaolinite-serpentine group (consistent with results of SEM-EDS analyses), and bernalite ($Fe(OH)_3$, –consistent with the presence of iron oxides– are also detected.

Interpretation

Results suggest the presence of two types of mineral associations. The first, characterized by large quartz grains cemented by iron oxides, probably originate from the ferruginous sandstone composing the tool. The second, made of fine-grained iron oxides associated with clay minerals such as kaolinite, correspond to a ferruginous clay rock processed on the tool. The small size and clean edges of quartz grains found in the residues, which differentiate them from those originating from the tool, indicate that they may have been added on purpose.

Text D. Results of residue analysis from ochre processing tool 4

Microscopic description and results of SEM-EDS and μ-RS analyses of sample AT4.

Sample description

Ochre residues were identified in small accumulations on the whole surface of the object, making the sample extraction relatively easy. Through optical microscopy (Fig 8f, Fig D in S1 Figs), sample AT4 shows the presence of a fine red powder, a few yellow grains, and translucent and black subcircular grains.

Sample composition

SEM-EDS analyses on sample AT4 (Fig 10f, Fig 11, Fig D in S1 Figs, Table A in S1 Tables) show the presence of octahedral grains (Fe, Ti; approximately 58–63 μm in length), agglomerates of submicrometric grains of iron oxides (Fe), clay minerals (Si, Al, Ca, with traces of K, Mg, Na), and coarse grains (Si) interpreted as silicates.

Micro-RS analyses on the same sample (Table 4, Table B in S1 Tables) show the presence of goethite, hematite, and quartz, which is consistent with the presence of iron oxides and silicates detected by SEM-EDS. Gypsum ($CaSO_4 \cdot 2H_2O$) is also detected.

Interpretation

Microscopic, elemental and mineralogical analyses suggest that this ochre processing tool was used to process two types of ochre: one rich in Fe/Ti oxides, and another type rich in submicrometric hematite and goethite grains associated with clay minerals and a few quartz grains. The blended appearance of submicrometric iron oxides and clay minerals seems to indicate that this second type of ochre was a ferruginous clay rock. Quartz does not appear to originate from the limestone of the tool, that shows a compact appearance, and is more likely to come from the processed ochre fragment, or from an additive mixed to the ochre powder.

Text E. Results of residue analysis from ochre-stained artefact 5

Microscopic description and results of SEM-EDS, μ-RS and XRD analyses of samples AT5 and T5.

Sample description

Ochre residues were abundant on this artefact but they were not easy to extract, as they appeared to be absorbed in the limestone, rather than disposed in accumulations. Through optical microscopy (Fig 8g, Fig E in S1 Figs), sample AT5 and sample T5 seem mostly composed of a light brown fine-grained powder, associated with an even finer bright red powder. Light brown and light gray coarse grains can be observed. A few black grains were also identified on sample T5.

Sample composition

When analysed through SEM-EDS (Fig 10g, Fig 11, Fig E in S1 Fig, Table A in S1 Tables), sample AT5 shows the presence of two ochre types. The first includes iron oxides in the form of small irregular grains (Fe; approximately 1–2 μm in length) embedded in a clay matrix (Si, Al, K, Ca, with traces of Mg, Na and Ti), and the second is composed of large irregular grains (Fe; approximately 17–38 μm). Larger irregular grains (Si, Al, Na K; approximately 24 μm in length) probably corresponding to feldspars, and irregular grains (Si; approximately 30 μm in length) interpreted as silicates are also observed.

Micro-RS analyses on the same sample (Table 4, Table B in S1 Tables) show the presence of hematite, quartz, and calcite.

XRD analyses on sample T5 (Table 5, Fig E in S1 Figs) confirm the presence of hematite and quartz. Manganese oxides, which were not detected through SEM-EDS or μ-RS, were also identified (ramsdellite, MnO_2). Analyses show the presence of other aluminosilicates, such as laumontite ($Ca(AlSi_2O_6)_2{\cdot}4H_2O$). Montmorillonite, $(Na,Ca)_{0,3}(Al,Mg)_2Si_4O_{10}(OH)_2{\cdot}nH_2O$, and alkali feldspars, possibly sanidine, $KAlSi_3O_8$, are detected, which is consistent with results from SEM-EDS analyses. Gypsum was also found.

Interpretation

Microscopic, elemental and mineralogical analyses suggest that this tool was used to process two types of ochre, among which at least one was a ferruginous clay rock. It is probable that a few grains originating from the limestone composing the artefact were included in the sample. The identification of calcite and laumontite supports this view. The presence of quartz, sanidine and ramsdellite could come either from the minerals composing the artefact or from the processed ochre. Gypsum may have grown post-depositionnaly.

Text F. Results of residue analysis from ochre processing tool 6

Microscopic description and results of SEM-EDS, μ-RS and XRD analyses of samples AT6A, AT6B and T6.

Sample description

Samples from OPT 6 were easily removed, as small ochre accumulations were present in the irregularities of the surface. The three sampled residues are composed of agglomerates of fine red and yellow grains associated with black, white, and brown grains of different coarseness and shape (Fig 8h, i, Fig F in S1 Figs).

Sample composition

SEM-EDS analyses carried out on sample AT6B (Fig 10h, Fig 11, Fig F in S1 Figs, Table A in S1 Tables) show the presence of large grains containing thin platelets rich in Fe and Ti (approximately 55–134 μm in length), coated by agglomerates of submicrometric grains interpreted as clay minerals (Si, Al, Mg, K), associated with angular, coarse grains (Si, Ca, Mg, Fe, Al, Ti, with traces of Na; approximately 194 μm in length) probably corresponding to silicates.

Micro-RS analyses on sample AT6A (Table 4, Table B in S1 Tables) show the presence of hematite and goethite.

XRD analyses on sample T6 (Table 5, Fig F in S1 Figs) confirm the presence hematite and detected plagioclase feldspars, possibly albite ($NaAlSi_3O_8$) and anorthite. The diffractogram also highlights the presence of minerals from the smectite group, possibly saponite, $Ca_{0.25}(Mg,Fe)_3((Si,Al)_4O_{10})(OH)_2 \cdot n(H_2O)$, and halloysite, $Al_2Si_2O_5(OH)_4$, which is consistent with the identification of clay minerals through SEM-EDS. Clinochlore, $(Mg,Fe^{2+})_5Al(AlSi_3O_{10})(OH)_8$, augite, $(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$, and quartz are also identified.

Interpretation

Microscopic, elemental and mineralogical analyses suggest that OPT 6 was used to process ochre composed of Fe-Ti oxides. The way in which clay minerals coat the Fe-Ti particles may indicate that they do not come from the same rock, and that they are part of additives, intentionally mixed during processing.

Albite, anorthite, clinochlore, augite and quartz, common in metamorphic rocks, are likely to come from the quartzite composing the processing tool.

Text G. Results of residue analysis from ochre processing tool 7

Microscopic description and results of SEM-EDS µ-RS and XRD analyses of samples AT7 and T7.

Sample description

All samples were very easily extracted, as they were disposed in small accumulations of residue on the surface of the tool. They are mostly composed of fine red grains and very few yellow agglomerates (Fig 8j, Fig G in S1 Figs). Translucent white subcircular grains can also be observed microscopically.

Sample composition

SEM-EDS analyses (Fig 10i, Fig 11, Fig G in S1 Figs, Table A in S1 Tables) show that sample AT7 contains agglomerates formed by platelets (approximately 2–4 µm in length) and larger irregular grains (approximately 20–29 µm in length), both interpreted as iron oxides (Fe). Other coarser, irregular grains are observed, and interpreted as Ca/Na-rich feldspars (Si, Al, Ca, Na; approximately 56 µm in length) and silicates (Si; approximately 326 µm in length).

Micro-RS on sample AT7 (Table 4, Table B in S1 Tables) and XRD analyses on sample T7 (Table 5, Fig G in S1 Figs) detected the presence of hematite, goethite, lepidocrocite ($Fe^{3+}O(OH)$), and quartz, which is consistent with SEM-EDS results. Carbon was also detected by μ-RS analysis.

Interpretation

Microscopic, elemental and mineralogical analysis suggest that OPT 7 was used to process an earthy hematite. Larger iron oxide grains, feldspars and quartz grains appear unrelated to the earthy hematite, and probably derive from the processing tool.

Text H. Results of residue analysis from ochre processing tool 8

Microscopic description and results of μ-RS and XRD analyses of samples AT8 and T8.

Sample description

Samples AT8 and T8 were easy to extract, as ochre residues were relatively abundant between the quartz grains composing the sandstone of which the processing tool is made. When observed through optical microscopy (Fig 8k, Fig H in S1 Figs), samples from this tool appear composed of a fine grained red powder, with a few yellow agglomerates. Rounded translucent grains are also part of the residues.

Sample composition

Micro-RS analyses on sample AT8 (Table 4, Table B in S1 Tables) show the presence of hematite, goethite, quartz and gypsum. Among these, only hematite and quartz are identified through XRD in sample T8 (Table 5, Fig H in S1 Figs), in addition to another iron oxide (maghemite, Fe_2O_3), as well as clay minerals (kaolinite) and anatase (TiO_2).

Interpretation

Mineralogical analyses confirm that residues from this tool contain hematite, goethite and kaolinite. This can either indicate that they come from a ferruginous clay rock, or that clay minerals were used as additives. The presence of quartz is likely to come from the minerals composing the sandstone tool. It is less likely that quartz grains were used as additives, or that they were part of a ferruginous sandstone processed on the tool.

Text I. Results of residue analysis from ochre processing tool 9

Microscopic description and results of SEM-EDS, μ-RS and XRD analyses of samples AT9 and T9.

Sample description

Samples AT9 and T9 were difficult to extract, as the surface of the OPT was covered by a patina. Both samples show the presence of coarse, rounded, translucent and brownish grains, surrounded by small agglomerates of fine red grains (Fig 8l, Fig I in S1 Figs). A few yellow grains are recorded in sample AT9.

Sample composition

SEM-EDS analyses on sample AT9 (Fig 10j, Fig 11, Fig I in S1 Figs, Table A in S1 Tables) show the presence of compact agglomerates composed of micrometric platelets (Fe, 5–10 μm in length) and irregular submicrometric iron-rich grains (Fe). Both are interpreted as iron oxides. The second type is associated with agglomerates of clay minerals (Si, Al, Ca, and traces of, K, Na Mg and Ti), irregular grains possibly corresponding to K-rich feldspars (Si, K, Al; approximately 27–194 μm in length), and large grains (Si; 131–153 μm in length) interpreted as silicates.

Micro-RS analyses on the same sample (Table 4, Table B in S1 Tables) show the presence of hematite, goethite and quartz, which is consistent with the presence of iron oxides and silicates detected through SEM-EDS. Gypsum is also found.

XRD analyses on sample T9 (Table 5, Fig I in S1 Figs) confirm the presence of hematite and quartz. Plagioclase feldspars, possibly albite and anorthite, and alkali feldspars (possibly microcline, $KAlSi_3O_8$) are detected. The presence of clay minerals from the smectite group, is also confirmed by the identification of montmorillonite.

Interpretation

Samples from this tool include compact agglomerates of iron-rich platelets interpreted as residues originating from the processing of earthy hematite. Adjacent to these agglomerates, but not blended to them, are the plagioclase and alkali feldspars, quartz grains, clay minerals and other iron oxide particles (unrelated to those characterised as earthy hematite). They are interpreted as part of the minerals composing the granite of which is made the tool. Gypsum probably originates from the surrounding sediments.

Text J. Results of residue analysis from ochre processing tool 10

Microscopic description and results of μ-RS and XRD analyses of samples AT10 and T10.

Sample description

Samples AT10 and T10 were difficult to extract, as the residue was diffuse and there were no ochre accumulations in the irregularities of the surface. Samples are mostly composed of a fine red and yellow powder, associated with translucent grains (Fig 8m, Fig J in S1 Figs).

Sample composition

Micro-RS analyses on sample AT10 (Table 4, Table B in S1 Tables) show the presence of hematite, goethite, manganite (MnO(OH)), calcite, quartz and undertermined aluminosilicates.

Hematite, calcite, quartz, sanidine and laumontite are identified through XRD (Table 5, Fig J in S1 Figs).

Interpretation

Hematite and goethite-rich rocks were processed on this tool. Aluminosilicates (sanidine and laumontite), silica (quartz) and carbonates (calcite) may originate from the quartzite composing the tool. However, the manganite cannot come from the tool, as its black colour would have been visible on the tool surface, which is white. It is more likely that the manganite derives from the processed ochre, an additive intentionally mixed to the ochre powder, or the cave sediment.

Text K. Results of residue analysis from ochre processing tool 11

Microscopic description and results of μ-RS analyses of sample AT11.

Sample description

The ochre residue, relatively abundant in the irregularities of the working surface of OPT 10, was easy to remove with the scalpel. When observed through optical microscopy (Fig 8n, Fig K in S1 Fig), sample AT11 is composed of a fine-grained red powder. Very few angular black and white grains are also observed.

Sample composition

Micro-RS analyses (Table 4, Table B in S1 Tables) show that sample AT11 contains hematite, magnetite ($FeO \cdot Fe_2O_3$), feldspars (anorthite), quartz, gypsum, and undetermined aluminosilicates.

Interpretation

Residues from this tool include a hematite-rich component. Other identified minerals (anorthite, quartz, and magnetite) probably come from the tool, which is made of a fine grained, mafic (dark-colored) igneous rock. The presence of gypsum is probably due to post-depositional processes.

Text L. Results of residue analysis from ochre processing tool 12

Microscopic description and results of SEM-EDS, μ-RS and XRD analyses of samples AT12 and T12.

Sample description

Sample AT12 was difficult to extract, as ochre residues were diffuse and there were no ochre accumulations on the irregularities of the surface. Microscopically, samples AT12 and T12 are composed of a fine-grained red powder (Fig 8o, Fig A in S2 Figs). Coarse angular translucent grains and a few black particles are also identified.

Sample composition

SEM-EDS analysis (Fig 10k, Fig 11, Fig A in S2 Figs, Table A in S1 Tables) shows that sample AT12 is composed of 1–2 μm long subcircular grains (Fe, with traces of Mn), probably corresponding to iron oxides, consistently associated with micrometric platelets interpreted as clay minerals (Si, Al, Ca, K, Mg), as well as coarser grains including platelets identified as micas (Si, Al, K, Na), and subcircular grains identified as plagioclase feldspars (Si, Ca, Al, K).

Results of μ-RS analysis in the same sample (Table 4, Table B in S1 Tables) are consistent with SEM-EDS results: hematite, albite and undetermined aluminosilicates are detected. Quartz is also found.

XRD analyses on sample T12 (Table 5, Fig A in S2 Figs) only allow us to confirm the presence of hematite and quartz. Goethite is also detected, even though yellow residues cannot be observed microscopically. However, SEM identifies a few acicular particles that are consistent with this type of iron oxide.

Interpretation

Microscopic, elemental and mineralogical analyses of sample AT12 suggest that OPT 12 was used to process one or more ochre fragments rich in hematite, and, to a lesser degree, goethite. The embedded appearance of clay minerals, feldspars and micas with respect to iron oxides seems to indicate that they come from the same ochre. Given the difference in granulometry and unblended appearance of quartz grains, we interpret them as originating from the processing tool.

Text M. Results of residue analysis from ochre processing tool 13

Microscopic description and results of SEM-EDS and μ-RS analyses of sample AT13.

Sample description

Sample AT13 was difficult to remove, as ochre residues on this piece are small and spread all over the surface. Under optical microscopy, sample AT13 reveals the presence of small agglomerates of fine-grained brown-red and yellow powder (Fig 8p, Fig B in S2 Figs). A few angular translucent grains are also observed.

Sample composition

SEM-EDS analyses (Fig 10l, Fig 11, Fig B in S2 Figs, Table A in S1 Tables) identify agglomerates of submicrometric acicular grains of iron oxides (Fe), associated with submicrometric grains interpreted as clay minerals (Si, Al, Na, with low contents of K, Ca, Mg, and Ti). Some areas show the presence of rare earth elements (La, Ce, Nd). Large tabular grains (Si, Na, Al, K, 113–202 μm in length) are also identified, and interpreted as Na-rich feldspars.

Micro-RS analyses (Table 4, Table B in S1 Tables) confirm the presence, in the same sample, of iron oxides (hematite and goethite), and plagioclase feldspars (albite). Quartz and traces of carbon are also detected.

Interpretation

Microscopic, elemental and mineralogical analyses of sample AT13 show that iron oxides (hematite and goethite) and clay minerals are consistently associated. It is therefore likely that a ferruginous clay rock was processed on this tool.

The granulometry and morphology of feldspars indicate that they do not originate from the same rock as the iron oxides and clay minerals, and suggest that these particles were not ground. They can be part of the minerals composing the tool, which is made of a granitoid rock. Quartz is probably part of the minerals composing the tool. La, Ce, Nd also probably come from the processing tool since granitoid rock may include rare earth elements.

Text N. Results of residue analysis from ochre processing tool 14

Microscopic description and results of μ-RS analyses of sample AT14.

Sample description

Residues from this tool were difficult to sample, as ochre residues were diffuse, and there were no ochre accumulations in the irregularities of the surface. Through optical microscopy (Fig 8q, Fig C in S2 Figs), sample AT14 appears composed of agglomerates of fine-grained red ochre powder, associated with a few agglomerates of yellow fine grains, fine irregular black grains and coarse angular translucent grains.

Sample composition

Micro-RS analyses (Table 4, Table B in S1 Tables) show that sample AT14 contains goethite, hematite, quartz, montmorillonite, calcite, carbon and undetermined aluminosilicates.

Interpretation

This tool was used to process ochre rich in hematite and goethite. The presence of montmorillonite could indicate that the processed ochre was a ferruginous clay rock. However, it could also indicate a use of clayish additives. Detected aluminosilicates and silicates could originate from the processed ochre, from the quartzite composing the tool, or be part of additives intentionally mixed to the ochre powder. Carbonates may originate from the quartzite, where they play the role of cementing material, or result from post-depositional processes.

Text O. Results of residue analysis from ochre-stained artefact 15

Microscopic description and results of SEM-EDS and μ-RS analyses of sample AT15.

Sample description

Sample AT15 was easy to extract. Under optical microscopy (Fig 8r, Fig D in S2 Figs), the sample is composed of agglomerates of a fine red powder including fine yellow grains. A fine white powder is also detected, in addition to a few angular translucent grains.

Sample composition

SEM-EDS analyses (Fig 10m, Fig 11, Fig D in S2 Figs, Table A in S1 Tables) show that sample AT15 is composed of submicrometric grains of iron oxides (Fe, with traces of Ti) consistently associated with submicrometric grains interpreted as clay minerals (Si, Al, Ca, K, with traces of Na and Mg). Large particles rich in Fe and Ti, with traces of Mn (approximately 20–79 µm in length) are also detected, as well as fine-grained agglomerates submicrometric to micrometric interpreted as Ba-rich sulphates (Ba, S).

Micro-RS analyses (Table 4, Table B in S1 Tables) show the presence on the same sample of hematite, goethite, montmorillonite, and other undetermined aluminosilicates, which is consistent with SEM-EDS results. Dolomite ($CaMg(CO_3)_2$) was also detected.

Interpretation

Microscopic, elemental and mineralogical analyses of sample AT15 identify two types of ochre: one composed of iron oxides and clay minerals, the other of iron oxides rich in titanium. Grain size, morphology and composition indicate that these two ochres do not come from the same rock. The dolomite and Ba-rich sulphates are more likely part of the minerals composing the limestone of the artefact.

Text P. Results of residue analysis from ochre processing tool 16

Microscopic description and results of µ-RS analyses of sample AT16.

Sample description

Sample AT16 was easy to remove. The irregularities of the working surface of the OPT were rich in ochre residue. The sample is composed of a very fine-grained bright red powder, with a few yellow agglomerates (Fig 8s, Fig E in S2 Figs).

Sample composition

Micro-RS spectroscopy (Table 4, Table B in S1 Tables) identifies hematite, goethite, quartz, and gypsum.

Interpretation

The brightness of the red powder may indicate that a pure iron oxide was processed. Clay minerals and other aluminosilicates are not detected by µ-RS, but this does not mean that they are not present. Quartz grains probably originate from the tool, made of quartzite. The presence of gypsum is attributed to post-depositional processes.

Text Q. Results of residue analysis from ochre processing tool 17

Microscopic description and results of µ-RS and XRD analyses of sample AT17 and T17.

Sample description

Samples AT17 and T17 were easy to remove, as ochre residues are abundant on the surface of this tool. They are mostly composed of fine red and yellow agglomerates (Fig 8t, Fig F in S2 Figs). Large subcircular translucent grains coming from the friable sandstone composing the tool are also incorporated in the sampled residue.

Sample composition

Micro-RS analyses on sample AT17 (Table 4, Table B in S1 Tables) show that the sample is rich in hematite and goethite. The most present mineral in the sample is quartz, but clay minerals (kaolinite) and gypsum are also detected.

XRD analyses on sample T17 (Table 5, Fig F in S2 Figs) confirm the presence of hematite, quartz and kaolinite. Calcite and possibly alkali feldspars (orthoclase, $KAlSi_3O_8$) are also identified.

Interpretation

The detection of hematite, goethite and kaolinite in sample OPT 17 indicates that a ferruginous clay rock may have been processed on this tool. Kaolinite, however, could also be present in the sandstone composing the tool. Orthoclase and calcite could also come from the tool, the former originating from the matrix, and the latter from the cement. The presence of gypsum could be due to a post-depositional contamination.

Text R. Results of residue analysis from ochre processing tool 18

Microscopic description and results of µ-RS and XRD analyses of sample AT18 and T18.

Sample description

Samples AT18 and T18 were easy to extract, as ochre residues are abundant on OPT 18. Through optical microscopy (Fig 8u, Fig G in S2 Figs), samples are composed of agglomerates of a bright red, yellow and orange powder. A few white and dark irregular grains are also present in the residue.

Sample composition

Micro-RS analyses on sample AT18 (Table 4, Table B in S1 Tables) show the presence of hematite, goethite, magnetite, quartz and gypsum.

XRD analyses on sample T18 (Table 5, Fig G in S2 Figs) confirm the presence of hematite and quartz, and detect the presence of kaolinite.

Interpretation

Microscopic observations and mineralogical analyses show the presence of different types of iron oxides associated with clay minerals that could indicate that this tool was used to process a ferruginous clay rock. However, this tool is made of a coarse sandstone cemented with different types of iron oxides, which makes it difficult to determine which are part of the minerals composing the tool, and which are part of the processed ochre. Quartz particles probably originate from the sandstone of the tool, and the presence of gypsum is likely due to post-depositional processes.

Text S. Results of residue analysis from ochre processing tool 19

Microscopic description and results of μ-RS analyses of sample AT19.

Sample description

Ochre samples were relatively easy to extract as a small ochre accumulation was identified on the surface of the tool. Sample AT19 is characterized by the presence of a fine-grained red residue, with agglomerates of fine yellow grains (Fig 8v, Fig H in S2 Fig). A few irregular white and translucent grains can also be observed.

Sample composition

Micro-RS analyses on sample AT19 (Table 4, Table B in S1 Tables) show the presence of hematite, goethite, quartz and augite.

Interpretation

Microscopic and mineralogical analyses indicate that OPT 19 was used to process hematite and goethite-rich rocks. Clay minerals are not detected with μ-RS, but this is no proof of their absence in the residue.

Quartz and augite can derive from the granite composing the tool. The fact that these minerals are not blended with the ochre powder supports this hypothesis.

Text T. Results of residue analysis from ochre processing tool 22

Microscopic description and results of SEM-EDS and μ-RS analyses of sample AT22.

Sample description

Sample AT22 was not easy to remove, as residues were not abundant on this tool. Microscopically (Fig 8w, Fig K in S2 Fig), the residue appears composed of agglomerates of very fine red and yellow grains. A few white irregular grains are also present in the residue.

Sample composition

SEM-EDS analyses of sample AT22 (Fig 10n, Fig 11, Fig K in S2 Fig, Table A in S1 Tables) identify agglomerates of submicrometric iron-rich cubic grains, larger, angular grains of iron oxides (Fe with traces of Mn, approximately 20–64 μm in length), irregular iron-rich silicate grains (Fe, Si, Al, approximately 36 μm in length), and undetermined aluminosilicates (Si, Al, 28–70 μm in length).

Micro-RS analyses detect (Table 4, Table B in S1 Tables) goethite and hematite. Clay minerals, identified as montmorillonite and quartz are also identified.

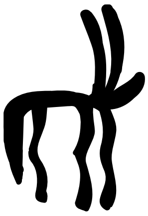
Interpretation

Microscopic observations, elemental and mineralogical analysis identify iron oxides in the residue. However, the tool is made of a volcanic rock (andesite) that naturally contains iron oxides, generated by oxidation during cooling or subsequent meteorization of the lava. It is therefore difficult to determine whether the detected hematite and goethite originate from the processed ochre or from surface alteration. The detected montmorillonite may derive from the alteration of feldspars originally present in the andesite. Quartz may also come from the tool.

CAPÍTULO 5

El uso de colorantes en la cultura Hamar, Etiopía

Rosso D.E., in press. Aproximación etnoarqueológica al uso de las materias colorantes de origen mineral: los Hamar (Etiopía) y el tratamiento del cabello. *Pyrenae*.



Aproximación etnoarqueológica al uso de las materias colorantes de origen mineral: los Hamar (Etiopía) y el tratamiento del cabello

Ochre use and hair treatment among the Hamar (Ethiopia): an ethnoarchaeological approach

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El uso de colorantes está actualmente en el centro del debate sobre el origen de la complejidad cultural. Diversos yacimientos paleolíticos han demostrado un uso sistemático de este material, que se relaciona con funciones prácticas o simbólicas. El estudio de los colorantes en sociedades tradicionales actuales es una etapa necesaria para aportar respuestas al debate. Nuestro objetivo es realizar un análisis preliminar de la cadena operativa de los colorantes para el tratamiento del cabello en la sociedad Hamar, Etiopía, y avanzar en el conocimiento sobre el papel de este tipo de materia prima en este grupo humano.

PALABRAS CLAVE: Pigmento, color, simbolismo, Hamar, Etiopía, *Middle Stone Age*.

Ochre use is currently at the centre of the debate on the origin of cultural complexity. Numerous Palaeolithic sites yielded proof of a systematic use of this material, which has been interpreted as functional or symbolic. The analysis of ochre use among traditional societies is essential in this context. Our aim is to conduct a preliminary analysis of the ochre *chaîne opératoire* for hair treatment among the Hamar women, and more specifically to understand the role of this material in the Hamar culture.

KEYWORDS: Pigment, colour, symbolism, Hamar, Ethiopia, Middle Stone Age.

1. Introducción

La etnoarqueología, estudio etnográfico de sociedades actuales desde una perspectiva arqueológica (David y Kramer, 2001), nos permite entender la relación entre cultura material y conducta humana (O'Connell, 1995; Skibo, 2009). Esta disciplina es esencial para determinar cuáles son las características específicas de un sistema cultural, y de qué manera éstas se reflejan en la primera (McCall, 2012; O'Connell, 1995). Sin embargo, la falta de una metodología clara para el establecimiento de analogías entre casos etnográficos y culturas del pasado ha provocado un debate sobre los objetivos de la etnoarqueología y su impacto en el estudio de la Prehistoria (Arnold, 2000; Arthur, 2014; David y Kramer, 2001; González-Ruibal, 2016, 2008, 2006, 2003; Huysecom, 1994; Politis, 2015; Rice, 1996; Schiffer y Skibo, 1997; Skibo, 1992; Stark, 2003; Sullivan, 2008). Actualmente, la etnoarqueología no consiste simplemente en comparar sociedades tradicionales actuales con sociedades del pasado, sino que sirve también para desarrollar una arqueología más crítica y una "arqueología del presente" (González-Ruibal, 2008; Politis, 2015).

El término "etno-arqueólogo" fue acuñado por Jesse Walter Fewkes (Fewkes, 1900), quien define la etnoarqueología como la adquisición de un conocimiento profundo de las sociedades actuales como medio para desarrollar la investigación arqueológica (David y Kramer, 2001). A finales del siglo XIX y en la primera mitad del siglo XX (Cushing, 1886; Mindeleff, 1900; Thomson, 1939), hubo algunos intentos tímidos de aplicación de este método, pero, de hecho, hasta los decenios del 50 y 60 no se produce un incremento importante de estos estudios (Ascher, 1962; Brain, 1967; Gould, 1968; Heider, 1967; Kleindienst y Watson, 1956; O'Connell, 1995). Progresivamente, la etnoarqueología se aplica a una gran variedad de temas (para una reseña bibliográfica completa, véase David y Kramer, 2001; González-Ruibal, 2003; Politis, 2015), entre los cuales encontramos los relacionados con la cerámica (Arnold, 2000; Arthur, 2014; David y Kramer, 2001; García Roselló, 2008; Huysecom, 1994; Rice, 1996; Schiffer y Skibo, 1997; Skibo, 1992; Stark, 2003; Sullivan, 2008; Vázquez Varela, 2003), la fauna y las estrategias de subsistencia (Binford, 1978a; Fisher, 1993; O'Connell *et al.*, 1988; Yellen, 1977a) o los patrones de distribución espacial (Binford, 1978b; O'Connell *et al.*, 1991; Yellen, 1977b).

La cuestión de la percepción y la categorización del color se estudió inicialmente desde perspectivas antropológicas, incidiendo en aspectos lingüísticos, rituales o medicinales (Balikci, 1970; Barley, 1983; Basedow, 1925; Berndt y Berndt, 1964; Fayers-Kerr, 2012; Heider, 1972; Lydall, 1978; Peile, 1979; Spencer y Gillen, 1968; Tornay, 1973; Turner, 1970, 1966). Son escasos los estudios que abordan aspectos técnicos que reconstruyan de manera precisa la cadena operativa del tratamiento de pigmentos (Paterson y Lampert, 1985; Rudner, 1982; Sagona, 1994; Simpson, 1951). En este panorama, fue una excepción el que se centra en los Ovahimba, en Namibia (d'Errico y Quentin, 2014; Rifkin, 2015; Rifkin et al., 2015b, 2015a).

El uso de colorantes en la sociedad Hamar ha sido descrito en diversos estudios etnográficos (Lydall y Strecker, 1979a, 1979b; Verswijver, 2008), pero nunca se ha explorado desde un punto de vista etnoarqueológico. Nuestro objetivo es analizar el tratamiento y uso de los colorantes bajo esta perspectiva: el presente estudio ofrece un análisis preliminar de las diferentes fases de la cadena operativa de los colorantes en la población Hamar, del sur de Etiopía, con el fin de entender el papel de esta materia prima en esta sociedad tradicional, y aportar nuevos datos al debate sobre el uso del colorante mineral en la Prehistoria. Dadas las múltiples funcionalidades de la materia colorante entre los Hamar, en esta primera fase de nuestro estudio nos centramos en analizar los diversos pasos de la cadena operativa de procesado del colorante para la realización del peinado femenino, relegando a futuros trabajos el estudio de la cadena operativa vinculada a otras posibles aplicaciones.

2. El uso de colorantes minerales en la Prehistoria: interpretación y contexto

El uso sistemático de colorantes minerales se interpreta en arqueología como la prueba de una cultura compleja (d'Errico, 2008; Henshilwood y Marean, 2003; Langley et al., 2008; McBrearty y Brooks, 2000; San Juan, 1991). Los colorantes a los que nos referimos son rocas de color rojo o amarillo formadas fundamentalmente por óxidos de hierro, a veces asociados a otros compuestos (cuarzo, arcillas, yeso o micas) (Hodgskiss, 2010; Jercher et al., 1998; Rifkin, 2012). El color amarillo deriva de la goethita (α -FeOOH), y el rojo de la hematites (α-Fe_2O_3). Actualmente se discute su función, que quizás se deba a una intención simbólica. La adquisición de materiales en áreas de aprovisionamiento alejadas de las zonas de hábitat, la selección de tonalidades más intensas, su calentamiento para modificar el color, o la presencia de residuos de colorantes sobre elementos de ornamentación personal, son algunos de los argumentos utilizados a favor de esta interpretación (Hovers *et al.*, 2003; Watts, 2010). En la vertiente opuesta y dada la dificultad para demostrar conductas simbólicas en un contexto prehistórico, se intenta explicar su uso para fines utilitarios. A través de comparaciones con casos etnográficos, se ha demostrado que los colorantes pueden usarse para curtir pieles (Rifkin, 2011), conservar alimentos, proteger la piel contra el sol o los insectos (Rifkin *et al.*, 2015a, 2015b), para fines médicos (Velo, 1984), o para producir adhesivos para el enmangue de herramientas (Lombard, 2007; Wadley *et al.*, 2004; Wadley, 2005; Wadley *et al.*, 2009;

Wadley, 2010a). Sin embargo, esta visión polarizada de la función de los colorantes, que opone lo funcional a lo simbólico, no refleja la realidad. Actividades que en la cultura occidental se definirían cómo puramente funcionales, están a menudo estrechamente ligadas a conductas simbólicas en las culturas tradicionales (d'Errico y Stringer, 2011). Es el caso de las mujeres Ovahimba (Namibia), que consideran el hecho de cubrirse el cuerpo con colorantes rojos cómo un símbolo de pertenencia a su cultura y a la vez usan este material para funciones utilitarias (protección contra el sol y los insectos, etc) (Rifkin, 2015).

A día de hoy, no sabemos aún en qué momento se integra el uso del color en la cultura humana. Se hallaron posibles pigmentos en Gadeb (Etiopía) y Olduvai Gorge (Tanzania) en niveles fechados alrededor de 1,5-1 Ma, en Isernia la Pineta (Italia) en niveles fechados hacia 610.000 años BP, y en Garba I, Melka Kunture (Etiopía) en niveles de ca. 500.000 años BP (Chavaillon y Berthelet, 2004; Coltorti *et al.*, 2005; Cremaschi y Peretto, 1988; Desmond Clark y Kurashina, 1979; Leakey, 1958). Alrededor de 250-300.000 años, en África y Europa aparecen pruebas menos ambiguas del uso de pigmentos como en los yacimientos de Terra Amata (Francia), Hunsgi (India), Ambrona (España), Achenheim (Francia) y en Tuff K4, Kapthurin Formation (Kenya) (Bednarik, 1990; de Lumley, 1969; Deino y McBrearty, 2002; Howell, 1966; McBrearty y Brooks, 2000; Paddayya, 1976; Thévenin, 1976).

En Europa se ha demostrado que los Neandertales usaban pigmentos rojos y amarillos antes de la llegada del *Homo sapiens* (Bar-Yosef, 1997; Beyries y Walter, 1996; Cârciumaru y Ţuţuianu-Cârciumaru, 2009; Soressi y d'Errico, 2007; Zilhão et al., 2010). En el yacimiento de Maastricht-Belvedere (Holanda), por ejemplo, se encontraron fragmentos de colorantes rojos en niveles fechados a >200-250.000 años BP (Roebroeks *et al.*, 2012). Los últimos Neandertales usaban intensivamente pigmentos rojos y negros, como lo demuestran los estudios sobre la Grotte du Renne (Caron *et al.*, 2011; Salomon *et al.*, 2014) o Roc-de-Combe (Dayet *et al.*, 2014) en Francia.

En el continente africano, se hallaron pruebas del uso de colorantes en numerosos yacimientos *Middle Stone Age* (MSA), como por ejemplo: Twin Rivers, Zambia (>200.000 años BP), Sai Island, Sudán (180.000 años BP), Nooitgedacht y Pinnacle Point en Sudáfrica, Charama en Zimbabwe, así como Kabwe y Mumbwa en Zambia (Barham, 2002, 1998; Marean et al., 2007; Van Peer et al., 2003; Watts, 2010). A partir de 100.000 años BP, la presencia de colorantes con marcas de uso producidas por abrasión o raspado es recurrente. Además, aparecen en forma de residuos en útiles líticos, molinos, machacadores, contenedores o elementos de ornamentación personal (McBrearty y Brooks, 2000). Algunos casos conocidos son los de Klasies River Mouth (d'Errico *et al.*, 2012), Hollow Rock Shelter (Högberg y

Larsson, 2011), Border cave (Watts, 2002), Diepkloof Rockshelter (Dayet *et al.*, 2016) y Sibudu Cave (Hodgskiss, 2014, 2013, 2012; Lombard, 2008; Soriano et al., 2009; Villa et al., 2015; Wadley, 2010b) en Sudáfrica, así como Apollo 11 cave en Namibia (Vogelsang *et al.*, 2010; Wendt, 1974). Una de las colecciones de colorantes más importantes se encontró en Blombos Cave (Sudáfrica). En niveles fechados alrededor de 100-72.000 años BP, se hallaron aproximadamente 5,8 kg de colorantes (Henshilwood *et al.*, 2009; Moyo *et al.*, 2016). Un gran número de fragmentos presentaba estrías de abrasión y de raspado, marcas de percusión y grabados (Henshilwood *et al.*, 2009; Rifkin, 2012). Fueron hallados, asimismo, dos equipos de útiles para producir y contener una mezcla rica en colorantes en niveles de 100.000 años (Henshilwood *et al.*, 2011). Aunque se hayan encontrado fragmentos de colorantes modificados en yacimientos cómo Gorgora Rockshelter (Desmond Clark, 1988; Leakey, 1943; Moysey, 1943) y Mochena Borago Rockshelter (Brandt *et al.*, 2012) en Etiopía, GvJm-11 (Lukenya Hill) en Kenya (Tryon *et al.*, 2015) o Mumba rockshelter en Tanzania (Mehlman, 1989), en el este de África, la investigación sobre este asunto está mucho menos desarrollada que en Sudáfrica. Porc-Epic Cave (Desmond Clark y Williamson, 1984) es uno de los pocos yacimientos en esta área geográfica cuya colección de colorantes se ha estudiado sistemáticamente. En sus niveles MSA, se han encontrado 40 kg de colorantes, así como veintiún útiles para su procesado y dos cantos con residuos de ese mismo material. De éstos, uno ha sido interpretado o bien como "tampón" para realizar motivos, o bien como canto pintado, poniendo así de relieve una posible relación del colorante con actividades simbólicas (Rosso et al., 2016, 2014).

Durante el Paleolítico Superior, o *Later Stone Age*, el uso de pigmentos se extiende a nuevos contextos, como el arte parietal (Clottes *et al.*, 1990; Garate *et al.*, 2004; Iriarte *et al.*, 2009; Lorblanchet *et al.*, 1990; Martí, 1977; Vignaud *et al.*, 2006). Incluso en algunos casos, se asocia a prácticas mortuorias (por ejemplo, Pettitt, 2013).

El hábito del uso de colorantes continúa vivo durante el Epipaleolítico (por ejemplo, Thévenin, 1992) y el Mesolítico (por ejemplo, Courtaud y Duday, 1995). Entre las sociedades productoras también hay constancia de un uso recurrente de este material en diferentes áreas geográficas, para una variedad de funciones: durante en Neolítico existen diversos ejemplos en Europa (Domingo et al., 2014, 2012, García Borja et al., 2006, 2004) o en el Próximo Oriente (por ejemplo, Hodder y Meskell, 2011; Özbek, 2009). Lo encontramos de forma continuada hasta la actualidad en sociedades tradicionales.

3. Aproximación al área de estudio: los Hamar

Numerosas sociedades tradicionales emplean colorantes de forma intensiva, en contextos geográficos extremadamente variables. Un caso que ejemplifica lo anteriormente dicho es el que se produce en el suroeste de Etiopía, en la frontera con Kenia, en la región de las *Naciones, Nacionalidades y Pueblos del Sur*, en la zona Debub Omo, dónde diversos grupos étnicos usan esta materia prima de forma cotidiana. Entre ellos encontramos a los Mursi (Fayers-Kerr, 2014, 2012; Turton, 1980), los Kara (Petros, 2000), los Nyangatom (Tornay, 1973) o los Hamar, también denominados Hamer (Lydall y Strecker, 1979a, 1979b; Strecker, 1979).

Los Hamar, objeto de este trabajo, habitan al norte del lago Turkana, al este del rio Omo, y al oeste del lago Chew Bahir y del valle del Rift (Lydall, 1978), en el Hamer woreda (distrito Hamer) (fig. 1a). Según el censo de 2007 (Central Statistical Agency, 2007), 46.129 individuos pertenecen a este grupo étnico. Su lengua es el Hamar (o Hamar-Banna), que pertenece al grupo de lenguas omóticas meridionales (Bender, 2000; Cupi *et al.*, 2013; Petrollino, 2016). Su economía se basa en el ganado cabrío, ovino y vacuno. Practican la agricultura de tala y quema, para el cultivo de sorgo, maíz, moringa y diversas legumbres, así como la recolección, la caza y la apicultura (Strecker y Lydall, 2006). Las mujeres se ocupan de los cultivos, situados cerca de sus poblados. Los hombres, que se encargan de la apicultura, la caza y el ganado, se desplazan con frecuencia a campamentos temporales cerca de las zonas de pastoreo (Dubosson, 2014; Lydall, 1978). Los asentamientos Hamar están relativamente dispersos y su localización depende de la proximidad a las zonas aptas para el cultivo y el pastoreo, y el acceso al agua. Los poblados suelen tener desde menos de diez, hasta unas treinta fincas (fig. 1b). Cada finca incluye un *kraal* para el ganado vacuno, un corral para el cabrío y ovino, y una o más casas (Strecker y Lydall, 2006). La sociedad Hamar se organiza en un sistema de descendencia patrilineal y se divide en diversos clanes, descritos detalladamente por Lydall y Strecker (1979b).

Hasta finales del siglo XIX, los grupos del suroeste de Etiopía estaban relativamente apartados de la política y economía etíope (Dubosson, 2014). La ocupación de la zona por Menelik II y posteriormente por los italianos afectó a la situación económica y social de estos grupos y provocó de forma paulatina una pérdida de ritos e instituciones. Sin embargo, numerosas costumbres profundamente arraigadas se mantuvieron en la sociedad Hamar (Lydall, 1978; Strecker, 2013a). Hasta finales de los años 60 no se realizó una verdadera investigación sobre las sociedades tradicionales del área, exceptuando alguna exploración puntual a finales del siglo XIX y mediados del siglo XX. Ivo Strecker y Jean Lydall llevaron a cabo una impresionante labor etnográfica sobre los Hamar, abarcando aspectos sociales, políticos, culturales o lingüísticos (Lydall y Strecker, 1979a, 1979b, Strecker, 1979, 2013b, 2013a; Strecker y Lydall, 2006; Strecker, 1988). Además, dejaron constancia de la cultura Hamar a través de numerosos documentales (Gardner y Strecker, 1973; Head y Lydall, 1996a, 1996b, 1996c; Lydall y Strecker, 2001; Strecker, 1996, 1976; Strecker et al., 1994). Los últimos estudios han incidido en temas lingüísticos (Bender, 2000; Cupi *et al.*, 2013; Petrollino, 2016) o en la relación entre los humanos y animales (Dubosson, 2014).

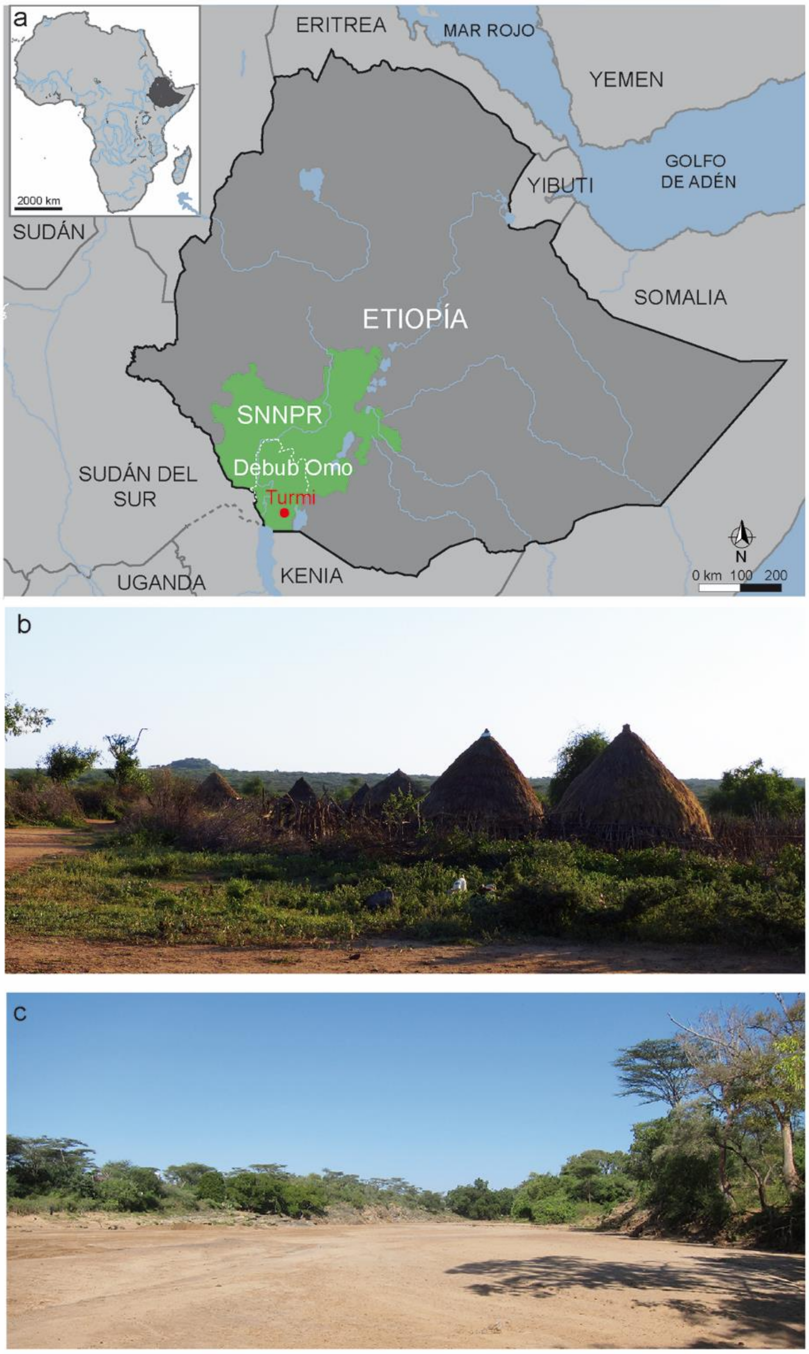

Fig. 1. Situación geográfica de los Hamar. a) Mapa de la zona. b) Poblado Hamar (Dombo). c) Uadi Kaeske.

4. Antecedentes: Usos y significados de la materia colorante entre los Hamar

En esta sección del trabajo haremos una revisión bibliográfica, en la que sintetizaremos, en primer lugar, las aportaciones de Lydall y Strecker en cuanto a los usos de las materias colorantes en la población Hamar y, en segundo lugar, el estudio llevado a cabo por Lydall en cuanto al significado del color en los rituales Hamar, y específicamente el rojo.

4.1. Usos del colorante rojo entre los Hamar según Lydall y Strecker

Hasta ahora no se ha realizado ningún estudio etnoarqueológico específicamente centrado en los diversos pasos del procesado (o cadena operativa) de las materias colorantes en la cultura Hamar. Sin embargo, los trabajos de Lydall y Strecker hacen a menudo referencia a su tratamiento y uso, y nos permiten vislumbrar la variedad de funciones para las que es empleado. Aunque no pretendamos aportar una lista exhaustiva, vamos a reseñar los usos mencionados por estos dos autores, conscientes de que sus trabajos datan del decenio de los 70 y que, evidentemente, esos hábitos pueden haberse modificado, e incluso desaparecido, desde entonces.

La finalidad más común de los colorantes rojos en la cultura Hamar es estética. Las mujeres se enrollan el cabello en finos mechones o rizos cortos, que cubren con una mezcla de mantequilla, resina de acacia y colorante (Lydall y Strecker, 1979b: 130, 201). En uno de los documentales de Strecker, vemos cómo una mujer transforma el colorante en polvo con un molino de mano para hacerse el peinado. Ésta explica que la resina sirve para fijar el colorante (Strecker, 1983). Para ocasiones especiales (bailes o rituales), las mujeres Hamar se retocan el peinado. Lydall y Strecker (1979a: 30, 32) mencionan por ejemplo que algunas mujeres se vuelven a aplicar la mezcla de colorante antes de los ritos de iniciación durante los cuales los *ukuli* (jóvenes que se preparan para la iniciación) saltan por encima del ganado para transformarse en *maz* (jóvenes iniciados todavía solteros). El uso del colorante para el pelo también se observa entre los hombres que llevan un “moño” cubierto de arcilla, a veces adornado con plumas. En los documentales, vemos cómo aplican colorante mezclado con un aglutinante alrededor del moño para decorarlo (Lydall y Strecker, 2001). El tipo de peinado de los hombres, además, tiene una intención significativa precisa. Lydall y Strecker explican que, en el pasado, cuando un hombre mataba determinados animales, como elefantes, leones, leopardos o rinocerontes, se afeitaba la parte de delante de la cabeza, y la cubría de colorante rojo (Lydall y Strecker, 1979b: 74, 193). Estas son probablemente prácticas en desuso porque, actualmente, muchas de estas especies están amenazadas o extinguidas. Costumbres similares se observaban también en los grupos vecinos de los Hamar. Por ejemplo, Strecker describe unos jóvenes Kara que, habiendo matado miembros del grupo de los Bume, llevaban un atuendo específico que denomina “el distintivo del asesino”: tiras de piel de cabra sobre los hombros, los brazos, las piernas y la cabeza, y la parte frontal de la cabeza afeitada y cubierta de colorante rojo (Lydall y Strecker, 1979a: 127).

Los Hamar también usan el colorante para aplicarlo sobre la piel o como pintura corporal. El aspecto higiénico del colorante aparece mencionado en las reflexiones de Lydall y Strecker, que describen las manos de los Hamar, siempre cubiertas de colorante y mantequilla: “*No, these hands are not dirty, they are clean in the Hamar way*” (“No, estas manos no están sucias, están limpias en el modo Hamar”) (Lydall y Strecker, 1979a: 88). Los dos etnólogos describen como unas mujeres cubren de colorante y mantequilla el cuerpo de un recién nacido, después de haberlo lavado con agua. La importancia del colorante como elemento característico de esta cultura se ve reflejada en la frase: “*The baby now becomes the proper color of a Hamar, red and brown”* (“el niño ahora muestra los verdaderos colores de un Hamar, rojo y marrón”) (Lydall y Strecker, 1979a: 42). El uso del colorante como pintura corporal es común sobre todo durante los bailes o rituales (Lydall y Strecker, 1979a: 158). Por ejemplo, durante los ritos de iniciación, los *maz* se pintan la cara con colorante y arcilla blanca para imitar la piel de leopardo (Lydall y Strecker, 1979b: 82, 197). Los hombres usan colorante para pintar su cara también durante los bailes dedicados al “animal favorito” (*errawak*), para parecerse a él (Strecker, 1983). El *errawak* (Dubosson, 2014) es un toro o un buey que eligen a veces los hombres Hamar, con el que establecen una relación especial. Se distingue del resto del rebaño por las modificaciones permanentes que presenta (cortes en las orejas, motivos realizados quemando la piel o deformación de los cuernos). Además, los *errawak* llevan collares decorativos que al final de su preparación se cubren de mantequilla y colorante (Lydall y Strecker, 1979b: 106). El colorante tiene un papel esencial también durante los ritos matrimoniales (Head y Lydall, 1996a, 1996b, 1996c; Lydall y Strecker, 1979b). Cuando la futura familia política va a buscar a la novia a casa de sus padres, la madre de la futura esposa aplica colorante y mantequilla a la cabeza del casamentero y del futuro suegro, en la zona clavicular de la futura suegra y en todo el cuerpo de la futura esposa (Lydall y Strecker, 1979b: 139). Al llegar a la finca de la familia del esposo, la suegra afeita la cabeza de la esposa y le aplica colorante y mantequilla de nuevo en todo el cuerpo y en la cabeza (Lydall y Strecker, 1979b: 140–141). Cada tres o cuatro días, se vuelve a aplicar la mezcla en todo el cuerpo, durante aproximadamente dos meses. Si la esposa es joven, se puede llegar a aplicar colorante sobre su cuerpo durante cuatro o cinco meses. Pero por lo general, al tercer mes, cuando terminan los ritos de preparación a la concepción, se entrega la esposa a su marido, y a partir de ese momento deja de cubrirse el cuerpo de colorante, y deja crecer su pelo para hacerse el tradicional peinado con colorante y mantequilla (Lydall, 1978). A veces, el colorante se usa también para cubrir la vestimenta. Antes de que las mujeres llevasen el característico delantal hecho de piel de cabra, llevaban faldas de cuero cubiertas de colorante (Lydall y Strecker, 1979b: 130).

El colorante se utiliza en numerosos casos para cubrir objetos. Por ejemplo, existe la costumbre de cubrir de colorante y mantequilla los bastones rituales (*koli*) usados en los ritos matrimoniales (Lydall y Strecker, 1979a: 155, 1979b: 139, 145). Otro ejemplo sería el del *gore* (*gorr* o *goro*) (Lydall y Strecker, 1979a: 162–163). Los *gore* son tiras fabricadas masticando y trenzando la parte interna de la corteza de determinadas plantas (*Ficus thonningii*, *Cordia ovalis* o *Lannea triphylla*). Estas tiras se atan al cuello, a las muñecas, a los codos y a los tobillos de los niños de dos o tres años, en el período en el que se destetan. Su fabricación es parte de un complejo ritual en el que participan los familiares del niño. Al final del ritual, se aplica colorante y mantequilla a las tiras antes de dejarlas secar, para luego atarlas al niño. El colorante se usa también para tratar los trofeos genitales (Lydall y Strecker, 1979b: 204). Si un Hamar mata a un enemigo de otro grupo, se conserva la piel del pene y del escroto del vencido como trofeo, que a veces se cubre de colorante y mantequilla (Lydall y Strecker, 1979b: 114, 204).

Los Hamar usan preferentemente colorantes minerales de color rojo (sólo ocasionalmente, usan arcillas blancas o amarillas para la pintura corporal), hecho particularmente importante porque denota un simbolismo del color, como se explica en el siguiente punto.

4.2. Los Hamar y el significado del color según Lydall

La denominación de los colores y el significado de éstos en los rituales Hamar han sido descritos por Lydall (1978). Según Lydall, para que un color tenga una carga simbólica en el ritual Hamar, éste tiene que ser característico de algún elemento usado durante los rituales. El color obtiene su valor simbólico por metonimia, reemplazando los elementos rituales a los que se asocia. El rojo es característico de la sangre, que se utiliza con frecuencia en diversos rituales, y es, por tanto, uno de los colores con significado ritual junto con el blanco, el negro y el verde. Cada color corresponde a un principio fundamental del pensamiento Hamar. El rojo se asocia a un principio de acción y substanciación, el blanco a un principio de determinación o de causa, el negro a un principio de definición, y el verde a un principio de expansión. Estos principios explican cualquier fenómeno. Lydall detalla que durante algunos ritos, se pintan ciertos elementos de determinados colores para relacionarnos con estos principios. Para el color rojo, Lydall usa el ejemplo de los ritos matrimoniales, durante los cuales la esposa se cubre de colorante rojo. La recién casada entra a formar parte del hogar de su marido, donde su función será la de producir alimentos y procrear. Estas funciones son, según Lydall, las mismas que las del principio de substanciación y realización, representado por el color rojo, y se ve materializado en el colorante.

5. Métodología: aproximación etnoarqueológica a la cadena operativa del colorante

Para la documentación etnoarqueológica de la cadena operativa del colorante nos trasladamos a Turmi (región de las *Naciones, Nacionalidades y Pueblos del Sur*, en la zona Debub Omo, Etiopía). Los datos presentados en este artículo fueron recopilados durante una estancia de corta duración en diciembre de 2013.

En el presente artículo, nos interesamos únicamente por el uso de colorantes rojos (hematites), en primer lugar porque es el colorante que se usa con más frecuencia en la sociedad Hamar y en segundo lugar porque es uno de los colorantes más comunes en los yacimientos paleolíticos y MSA. De entre la variedad de usos que tiene este colorante en la cultura Hamar, decidimos centrarnos en uno de estos: la producción de una mezcla de colorante, resina y mantequilla para la realización del peinado tradicional.

El proceso que vamos a describir fue planificado para este trabajo y documentado en una vez. Hemos adoptado una estrategia de observación (Baker, 2006), pero también hemos realizado entrevistas a dos informantes especializadas. Se registraron los datos con notas, fotografías y videos realizados con el consentimiento de ambas. Nuestro contacto en la zona pertenecía al Konso Cultural Centre y fue la persona que nos guió en la búsqueda de informantes y nos hizo de intérprete. En la ciudad de Turmi, un guía oficial de la zona nos puso en contacto con dos mujeres Hamar, Buno Goffa y Ballo Aysire, del poblado de Dombo (situado aproximadamente a 2 km de Turmi), que usan colorantes de forma cotidiana. Ambas mujeres aceptaron ser nuestras informantes durante nuestra investigación preliminar. Ellas nos enseñaron las etapas de preparación del colorante, desde la búsqueda de la materia prima hasta la aplicación sobre el pelo.

6. Primeros resultados: la cadena operativa del colorante vinculada al peinado tradicional de las mujeres Hamar

En este apartado, describiremos las diversas etapas del procesado (o cadena operativa) del colorante rojo utilizado por las mujeres Hamar para la realización de su peinado tradicional, a partir de las observaciones etnográficas llevadas a cabo en 2013. Los pasos registrados en el procesado son: la adquisición de la materia prima, su tratamiento térmico para modificar el color, la preparación del aglutinante, la molturación del colorante para su transformación en polvo. En cada uno de estos pasos describiremos de forma detallada las herramientas, las técnicas y los gestos utilizados, así como los resultados obtenidos.

6.1 Adquisición de la materia prima

La adquisición de la materia prima tuvo lugar en la cercanía de la zona de hábitat. Buno Goffa y Ballo Aysire se desplazaron a pie hasta un afloramiento calcáreo en el lecho del uadi Kaeske (fig. 1c), situado aproximadamente a dos kilómetros de distancia de su poblado. Ambas participaron en esta fase de la cadena operativa.

Los útiles usados para la extracción de la materia prima fueron un pico sin mango, una broca helicoidal (pieza metálica para taladradoras) y un canto de unos 15 cm de largo y ancho que recogieron directamente en el afloramiento (fig. 2a, b). Les sirvió para transportar la materia prima extraída un recipiente hecho de calabaza (*Lagenaria siceraria*) que presentaba una rotura. Este tipo de contenedores se usan generalmente para conservar líquidos (Strecker *et al.*, 1994), así que suponemos que este objeto, ya inservible para su función original, asume aquí un uso diferente.

Tras una inspección del afloramiento, las dos mujeres identificaron unas venas de óxidos de hierro, ricas en hematites, de color entre el rojo claro y el violeta oscuro. Durante los trabajos de extracción ambas mujeres se repartieron las tareas: mientras una de ellas se encargaba de la extracción de la materia prima, la otra examinaba los fragmentos extraídos antes de meterlos en el recipiente. Pudimos observar cómo las técnicas usadas para fracturar la roca fueron variando en función de la morfología de la zona de extracción elegida. Cuando los óxidos de hierro se encontraban en zonas con una morfología convexa, recurrían a la percusión directa, golpeando repetidamente la roca con el canto. Durante el proceso, alternaban impactos desde direcciones opuestas. Cuando la zona rica en colorante era plana o cóncava, se recurría a la percusión indirecta (fig. 2c). Se situaba la broca o el pico en la zona que se deseaba fracturar y se golpeaba su extremidad con el canto. Una vez que el pico penetraba la roca, se presionaba para hacer palanca. Tras haber extraído unos diez fragmentos en una zona, las mujeres volvían a examinar el afloramiento y se desplazaban para seguir extrayendo material. En total, se extrajeron unos 40 fragmentos (aproximadamente 5 kg) de tamaño variable (3-20 cm de largo). La mitad de estos fragmentos tenían un color rojo oscuro, mientras que el resto eran fragmentos de caliza con una proporción mínima de partículas rojas (fig. 2d). Terminada la extracción del material, las mujeres recogieron sus herramientas y abandonaron el canto en el afloramiento.

Fig. 2. Extracción y preparación de la materia prima. a) Afloramiento calcáreo dónde se extrae la materia. b) Herramientas para la extracción. c) Extracción de colorante. d) Colorante antes del tratamiento térmico. e) Hoguera dónde se calienta el colorante. f) Colorante después del tratamiento térmico.

6. 2 Tratamiento térmico

La segunda fase de la cadena operativa consistió en someter la materia prima extraída a un tratamiento térmico para modificar el color. Esta es una etapa esencial: si el colorante no se calienta, no adquiere el color intenso que requieren los Hamar. Además, el hecho de documentar este proceso es significativo para los estudios de materias colorantes prehistóricas, ya que este tipo de tratamiento se ha documentado desde el Paleolítico Medio (Pomiès y Vignaud, 1999; Salomon et al., 2012). El hecho de calentar colorantes para obtener determinados colores se ha interpretado en muchos casos como el reflejo de una conducta simbólica. En el caso que hemos observado, esta acción se realizó inmediatamente después de la extracción de la materia prima, en una hoguera que nuestras informantes construyeron en el matorral situado a 20 metros del afloramiento. Para ello, las dos mujeres recogieron ramas de diversos tamaños de diferentes tipos de arbustos y trozos de corteza de árbol (en total aproximadamente 1 kg) y las acumularon sobre dos bloques de piedra de unos treinta centímetros de largo. A continuación procedieron a vaciar el recipiente de calabaza que contenía el colorante extraído junto a la acumulación de ramas, seleccionaron los fragmentos de materia prima de mayor tamaño, y los colocaron sobre las ramas. Encima de éstos colocaron los fragmentos más pequeños. Una vez acumulado todo el colorante, lo cubrieron con más ramas, y con los trozos de corteza. Con una cerilla, encendieron la hoguera. Una de las mujeres cogió diversas ramas con hojas para ventear la hoguera. Esto permitió que el fuego prendiese rápidamente y evitó que los fragmentos de colorante se oscureciesen y adquirieran un color negro. Después de haber venteado el fuego durante unos 15 minutos (fig. 2e), las mujeres lo dejaron y volvieron al poblado. A la mañana siguiente, las mujeres volvieron a recoger todos los fragmentos de colorantes que habían dejado en la hoguera. Después del tratamiento térmico, presentaban un color rojo intenso (fig. 2f) y algunos incluían todavía partículas blancas.

6.3 Preparación del aglutinante

Uno de los elementos esenciales en la cadena operativa de preparación de pigmento es el aglutinante, necesario para fijar el colorante al pelo. Hemos estudiado esta fase en el poblado de Dombo, enfrente del hogar de Buno Goffa. Nuestra segunda informante, Ballo Aysire, no estaba presente en esta fase. Se produjo una mezcla constituida por resina de acacia, mantequilla y de café líquido, preparado previamente haciendo una infusión en un recipiente de calabaza. Los procesos de obtención de la resina y de la mantequilla no se han documentado en el marco de este análisis. Los objetos utilizados en esta fase fueron un recipiente hecho de calabaza, un machacador (canto de 9,5 cm de largo, 9 cm de ancho y 9 cm de espesor) y un molino de mano (bloque de 40 cm de largo, 30 de ancho y 20 de espesor, 1 kg de peso) hechos de rocas metamórficas (fig. 3a,b). Las dos herramientas ponían de manifiesto un uso prolongado porque ambos mostraban zonas desgastadas y el machacador evidenciaba facetas (zonas planas) cubiertas de estrías producidas por fricción contra una superficie dura, así como cúpulas de impacto en los laterales. En el molino, completamente cubierto de colorante, se advertían en la zona de trabajo, dos concavidades cubiertas de estrías longitudinales.

Fig. 3. Preparación del aglutinante, producción del polvo y aplicación sobre el cabello. a) Preparación de la resina con mantequilla. b) Preparación de la resina con café. c) Fracturación del colorante. d) Producción de polvo de colorante grosero. e) Producción de polvo de colorante fino. f) Aplicación de la resina. f) Aplicación del colorante. f) Resultado final.

La resina fue sometida a un tratamiento previo que, como ya hemos señalado, no hemos documentado en el marco de este estudio, y se presenta en forma de masa de color negro. La postura de la mujer en este momento era o en cuclillas, o sentada en el suelo con el molino posicionado longitudinalmente entre las piernas extendidas. Extendió mantequilla sobre el molino y el machacador, y colocó la masa de resina sobre el molino (fig. 3a), la golpeó repetidamente con el machacador agarrado con una mano, mientras que, con la otra mano, sujetaba la masa de resina. Paulatinamente vertía pequeñas cantidades de café a la mezcla para ablandarla y la amasaba (fig. 3b). Las dos técnicas (golpeado y amasado) se alternaban. Cuando la masa estuvo suficientemente blanda, la metió en el recipiente y la mezcló con mantequilla y se transformó en una crema densa. Terminado el tratamiento, la mujer recogió sus herramientas y recipientes, y los guardó en su hogar.

6.4 Molturación del colorante para su transformación en polvo

Otra fase de la cadena operativa consiste en la pulverización de los fragmentos de colorante sometidos a tratamiento térmico. En el caso observado durante nuestro trabajo de campo, las herramientas utilizadas fueron un machacador (canto de 13 cm de largo, 9 cm de ancho y 9 cm de espesor, 1 kg de peso) y un molino de roca granitoide (bloque de unos 50 cm de largo, 35 cm de ancho y 15 cm de espesor). La acción se llevó a cabo cerca del lugar dónde se había sometido la materia prima al tratamiento térmico por razones logísticas, aunque por lo general esta tarea se lleva a cabo en el campamento.

Para la transformación del colorante en polvo, nuestra informante se sentó en el suelo, colocó un fragmento de colorante sobre el molino colocado longitudinalmente entre sus piernas extendidas y, sujetándolo con una mano, lo golpeó despacio con el machacador. Lo fracturó progresivamente y lo redujo a fragmentos de menos de 1 cm de largo (fig. 3c). Cuando obtuvo 50 gramos de colorante en pequeños fragmentos, apartó el fragmento del que los extrajo. Con la mano, juntó los pequeños fragmentos y, empuñando el canto con una sola mano, machacó el colorante con impactos más fuertes, levantando ligeramente el canto, mientras que con la otra contenía las partículas para que no se dispersaran (fig. 3d). Cuando obtuvo un polvo grosero, el gesto cambió para transformar esos fragmentos en un polvo más fino. Para ello, puso las dos manos sobre el machacador e hizo un movimiento regular de vaivén, sin despegar el canto del molino (fig. 3e). El gesto era rápido, y el canto “recorría” únicamente unos 20 cm del molino en el movimiento de vaivén. De cuando en cuando, examinaba el polvo y retiraba alguna partícula de cuarzo. En cuanto el colorante se transformó en un polvo fino, volvió a coger el fragmento que había dejado de lado, lo fracturó, y volvió a empezar el proceso.

Progresivamente se crearon acumulaciones de polvo de colorante fino alrededor de la zona de trabajo, sobre el molino. Una vez obtenida la cantidad de polvo necesaria, la guardó en pequeños recipientes de calabaza o en bolsas de plástico.

Cuando se requiere menos cantidad de colorante, por ejemplo para decorar el peinado de los hombres, el tratamiento es diferente. Se frota el fragmento de colorante directamente sobre un bloque (produciendo de esta manera facetas cubiertas de estrías de abrasión sobre el fragmento) y se mezcla el polvo producido con un aglutinante (Lydall y Strecker, 2001). Actualmente, el colorante ya procesado se puede adquirir en el mercado de Turmi, pero es ligeramente más grosero que aquel producido por nuestras informantes.

6.5 Aplicación del colorante

La fase final de esta cadena operativa del colorante consiste en la aplicación del aglutinante y del colorante sobre el pelo. Este proceso requiere la actividad de dos personas: una que realiza la coloración y la otra que se somete a ella.

Tras haber extendido una piel de cabra en el suelo, ambas mujeres se quitaron sus dos mandiles de piel de cabra y los dejaron a su lado. Una de ellas (la que llevó a cabo la aplicación) se sentó en un asiento de madera para estar ligeramente más alta que la otra, que se había sentado en el suelo. Tenían el polvo de colorante en una bolsa de plástico, pero también disponían de un pequeño recipiente de calabaza que contenía un colorante de color más claro, mezclado con hierbas perfumadas, que vaciaron en los mandiles de piel para hacerlo más accesible. Ambas mujeres manifestaban su preferencia por el color más intenso, el que había sido calentado durante más tiempo. Tenían, además, junto a ellas, la mantequilla en un recipiente de metal y el recipiente de calabaza con la mezcla a base de resina preparada el día anterior. Se comenzó la elaboración del peinado por la parte de delante de la cabeza. En primer lugar retiró el colorante seco del pelo, frotando los mechones enérgicamente. A continuación, le echó mantequilla a la mezcla de resina y removió con la mano, verificando entre los dedos la consistencia. Cuando la resina y la mantequilla formaron una crema líquida, la aplicó sobre el pelo (fig. 3f). Una vez extendida, espolvoreó el polvo de colorante con una mano sobre el pelo cubierto de resina (fig. 3g) y comenzando por la parte delantera de la cabeza, frotó cada mechón entre las dos manos con la mezcla de colorante y aglutinante para obtener rizos definidos. Una vez terminada la parte de delante, procedió de la misma manera con el pelo de la parte de atrás, hasta que la cabeza estuvo totalmente cubierta de colorante y resina. El resultado fue un pelo de color rojo intenso y reluciente, con mechones perfectamente definidos (fig. 3h). Durante la aplicación, los hombros, la ornamentación personal, la piel del mandil y las conchas que lo decoraban, así como las pieles usadas como alfombra se cubrieron de colorante por accidente. Sin embargo, las mujeres dejaron el colorante encima de estos objetos. Además, la mujer se aplicó la mezcla de colorante y mantequilla al pecho: sus collares, incluido su *binyere* (collar de mujer casada) (Lydall y Strecker, 1979b) estaban totalmente recubiertos de colorante. El colorante que sobró fue almacenado en bolsas de plástico.

7. Discusión, conclusión y perspectivas

El objetivo de este trabajo es documentar en una sociedad actual todas las fases de la cadena operativa del colorante. Dada la multiplicidad de usos del colorante en este grupo humano, hemos decidido en este artículo centrarnos en un solo uso en particular: la preparación del peinado característico de las mujeres Hamar. Este análisis nos ha permitido demostrar que detrás del uso del colorante en la cultura Hamar existe en efecto una cadena operativa compleja. Ésta implica un conocimiento profundo de la materia y del proceso de transformación térmica, la elaboración de recetas específicas para la preparación del aglutinante y una combinación de distintos gestos para la producción de colorante en polvo. En cuanto a la gestualidad y las herramientas usadas para transformar el colorante en polvo, vemos similitudes con el tratamiento del colorante de las mujeres Ovahimba, en Namibia. Sin embargo, éstas últimas tienen acceso a colorantes arcillosos de mejor calidad, y no necesitan recurrir al calentamiento para obtener un color rojo intenso. En cuanto al aglutinante, las Ovahimba sólo usan mantequilla, quizás porque la resina se adapta menos a la pintura corporal (d'Errico y Quentin, 2014; Rifkin, 2015). Arqueológicamente, podemos encontrar paralelos con la cadena operativa Hamar, como el tratamiento térmico para modificar el color (Couraud, 1987; d'Errico et al., 2010; Domingo et al., 2014; Onoratini, 1985; Périnet y Onoratini, 1987; Salomon et al., 2012; San Juan, 1991), la elaboración de mezclas complejas (Domingo et al., 2012; Henshilwood et al., 2011; Villa et al., 2015), o el empleo de molinos de mano para machacar y pulverizar el colorante (Cristiani et al., 2012; Domingo et al., 2012; Dubreuil, 2004; Rosso et al., 2016). Existen diversos ejemplos arqueológicos, especialmente a partir del Neolítico, que sugieren que en algunos casos el colorante había sido machacado y después molturado para la obtención de un polvo más fino (Domingo et al., 2012). Sin embargo, es más complicado determinar si la gestualidad de los Hamar es similar a la de poblaciones paleolíticas. En algunos yacimientos paleolíticos europeos (de Beaune, 2000), o del MSA africano (Rosso *et al.*, 2016) se encontraron molinos y machacadores con residuos de colorante que presentan zonas desgastadas, estrías y cúpulas de percusión. Estos molinos paleolíticos, sin embargo, suelen tener tamaños reducidos (o por la presencia de fracturas post-deposicionales, o por diferencias en el tratamiento) y su grado de modificación suele ser menos importante. Cabe destacar que una de las marcas de uso más comunes en los yacimientos paleolíticos, las facetas de abrasión sobre los fragmentos de colorante, se producen también en la cultura Hamar, únicamente cuando necesitan una pequeña cantidad de polvo.

Más allá del aspecto técnico, analizar el papel de las materias colorantes en las sociedades tradicionales puede ofrecer hipótesis de interpretación y permite plantearnos métodos de análisis concretos para los casos arqueológicos. Dado que nuestro estudio se centra en un sólo uso del colorante, nuestras informantes destacaron únicamente su función higiénica y estética. Pero, como demuestran los estudios de Lydall y Strecker, no se limita solo a eso: los pigmentos se usan para materializar conceptos básicos del pensamiento Hamar (Lydall, 1978). El uso del colorante durante rituales es por lo tanto significativo y demuestra una relación estrecha entre este material y las actividades simbólicas (Lydall, 1978; Lydall y Strecker, 1979b, 1979a). Sin embargo, en la sociedad Hamar, como en muchas culturas tradicionales, no suele haber una separación clara entre lo funcional y lo simbólico (d’Errico y Stringer, 2011). Strecker indica que “no existe una línea divisoria entre lo sagrado y lo profano” (Strecker, 1988). Para los Hamar, la función del colorante está sin duda a caballo entre lo utilitario y lo simbólico y esto refuerza los argumentos de los investigadores que rechazan esa dicotomía en contexto arqueológico.

La observación de casos etnográficos es el único medio del que disponemos para documentar gestos y técnicas de procesado que reflejan una tradición cultural transmitida a través de varias generaciones. Por ello, en el futuro ampliaremos nuestro análisis al resto de usos (peinado de los hombres, pintura corporal, recubrimiento de objetos rituales) y evaluaremos la variabilidad de la cadena operativa de este material investigando en otros poblados. Además de esto, el análisis elemental y mineralógico de muestras de colorantes antes y después del tratamiento térmico nos permitirá aportar datos que puedan servir a la interpretación de materiales arqueológicos. Documentando de forma exhaustiva el tratamiento de los colorantes en la sociedad Hamar podremos enriquecer el debate sobre el uso de este material en la Prehistoria. Nuestro análisis representa el primer paso hacia una documentación sistemática del uso de los colorantes en la cultura Hamar y demuestra que el estudio de poblaciones actuales es una etapa importante para la comprensión de materiales arqueológicos.

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Short text

Ochre use and hair treatment among the Hamar (Ethiopia): an ethnoarchaeological approach

Ethnoarchaeology is the study of traditional societies from an archaeological perspective. It allows understanding the link between material culture and human behaviour (David and Kramer, 2001; O'Connell, 1995; Skibo, 2009). However, the lack of a clear methodology for the application of analogies generated from ethnoarchaeological studies to the archaeological record has been pointed out by many researchers. The objectives of ethnoarchaeology and its impact in archaeology are therefore widely debated questions (Arnold, 2000; David and Kramer, 2001; McCall, 2012; Skibo, 2009; Stark, 2003). Ethnoarchaeological research increased considerably since the 50's and 60's (Ascher, 1962; Brain, 1967; Gould, 1968; Heider, 1967; Kleindienst y Watson, 1956), focusing on a variety of subjects such as ceramics (Arnold, 2000; Arthur, 2014; David and Kramer, 2001; Huysecom, 1994; Rice, 1996; Schiffer and Skibo, 1997; Skibo, 1992; Stark, 2003; Sullivan, 2008), fauna and subsistence strategies (Binford, 1978a; Fisher, 1993; O'Connell et al., 1988; Yellen, 1977a), or spatial distribution patterns (Binford, 1978b; O'Connell et al., 1991; Yellen, 1977b). However, other questions, such as colour perception and categorization have not often been explored in ethnoarchaeological studies (Rifkin, 2015; Rudner, 1982; Sagona, 1994), despite the fact that systematic use of pigments is a largely debated question in archaeology.

In an archaeological context, systematic use of ochre is often considered as proof for complex behaviour (d'Errico, 2008; Henshilwood and Marean, 2003; McBrearty and Brooks, 2000). Some interpret it as evidence of colour symbolism (Hovers et al., 2003; Watts, 2010), but others disagree, pointing out possible uses for functional activities (Rifkin et al., 2015a; Velo, 1984; Wadley, 2010). Some researchers, however, argue that in many cultures, symbolic and utilitarian functions are difficult to separate. The analysis of ochre use among traditional cultures is therefore an essential step to our understanding of the function of this material among past societies.

The aim of this paper is to analyse ochre processing and use among the Hamar of Southern Ethiopia from an ethnoarchaeological perspective. More specifically, we describe the ochre *chaîne* opératoire related to the Hamar women's hair treatment. Ochre use among the Hamar was described in numerous ethnographic studies (Lydall, 1978; Lydall and Strecker, 1979a, 1979b; Strecker, 1979), but there has not been any study focusing specifically on the different phases of ochre processing. We present here our first results on the ochre *chaîne opératoire* among the Hamar, with the aim of understanding the role of said material, and providing new data for the debate on ochre use in Prehistory.

The agro-pastoral Hamar (Lydall and Strecker, 1979a, 1979b; Strecker, 1979) live in the Ethiopian Southern Nations, Nationalities and Peoples' Region (fig. 1), in the Debub Omo zone (South Omo). An impressive ethnological study of the Hamar has been conducted by Ivo Strecker and Jean Lydall focusing on social, political, cultural and linguistic aspects (Lydall and Strecker, 1979a, 1979b, Strecker, 1979, 2013a, 2013b; Strecker and Lydall, 2006; Strecker, 1988). Along with other ethnic groups from this area, such as the Mursi (Fayers-Kerr, 2012; Turton, 1980) or the Kara (Petros, 2000), the Hamar use ochre on a daily basis. Lydall and Strecker's work demonstrates that ochre is used for a variety of functions. The most common is for covering their hair in ochre, butter and acacia resin. However, they also use it to paint their bodies during different rituals or dances. For example, brides are entirely covered in ochre for at least two months (Head and Lydall, 1996a, 1996b, 1996c; Lydall and Strecker, 1979b). Objects used during rituals, such as ritual sticks, are also sometimes covered in ochre. The use of red ochre during rituals is noteworthy, as this colour clearly carries a symbolic meaning, associated to blood, according to Lydall (1978).

In this study, two Hamar women from a village next to Turmi (Dombo) showed us how they process and use ochre, from the acquisition of the raw material, to the application to their hair. With their consent, we were able to photograph and film the entire ochre *chaîne opératoire*.

The first phase of the operative sequence is the raw material acquisition (fig. 2a-d), which takes place in a calcareous outcrop next to the wadi Kaeske, two kilometers away from Dombo. Tools used for the extraction are a drill bit, a pickaxe head and a pebble. Approximately 5 kg of rock fragments rich in iron oxides are extracted and carried in a gourd. The second phase consists in heating the rock fragments (to approximately 600ºC), in order to modify their colour. A fire, where ochre fragments are placed, is built in the bush next to the wadi (fig. 2e). After a few hours, ochre fragments acquire an intense red colour (fig. 2f). The third phase of the *chaîne opératoire* involves the production of a resin compound, which is prepared by pounding a resin paste between an upper and a lower grindstone, and mixing it with butter and coffee until it becomes almost liquid (fig. 3a,b). The fourth phase is the ochre processing (fig. 3c-e). Ochre fragments are fractured, then crushed and ground between an upper and lower grindstone for the production of a fine red powder. The final step of the operative sequence is the application of the resin paste (fig. 3f) and the ochre powder (fig. 3g) while twisting hair into ringlets. The result is shiny and intense red coloured hair (fig. 3h). The shoulders and attire of the woman are also covered in ochre after the application.

This analysis shows that behind ochre use among the Hamar lies a complex *chaîne opératoire*. It requires a deep knowledge of the transformation of physicochemical properties of the material through heating, an elaboration of a complex binder, and a combination of a variety of techniques for the production of ochre powder. Tools and techniques used by Hamar women show similarities with those used by Ovahimba women, in Namibia (d'Errico and Quentin, 2014; Rifkin, 2015). The main difference lies in the binder, which among Ovahimba only contains butter. This can probably be explained by the fact that resin is used to fix ochre to the hair ringlets. Similarities can also be found with archaeological materials. Proof of ochre heating (d'Errico et al., 2010; Salomon et al., 2012), of a production of complex ochre compounds (Henshilwood et al., 2011; Villa et al., 2015), or of a use of upper and lower grindstones (de Beaune, 2000; Rosso et al., 2016) was found at different Palaeolithic sites in Europe, Africa or the Middle East. Neolithic sites have provided proof of a production of ochre powder by crushing and then grinding ochre fragments (Domingo et al., 2012). However, it is difficult to determine whether techniques used by the Hamar are similar to those that were used among Palaeolithic populations. Palaeolithic grindstones are not worn to the same degree as those observed among the Hamar, and are generally smaller (for taphonomic reasons or for differences linked to the type of processing).

Beyond technical aspects, the role of ochre in traditional societies in essential for the interpretation of archaeological materials. Given that our analysis focuses on one of the different uses of ochre among the Hamar, only the hygienic and esthetic functions were pointed out. However, studies carried out by Lydall and Strecker show that, even though ochre is employed for utilitarian purposes, it also has a symbolic function. Proof of it is the fact that ochre is often used during rituals (Lydall, 1978; Lydall and Strecker, 1979b, 1979a). Additionnally, Strecker argues that among the Hamar "there is no dividing line between the sacred and the profane […]" (Strecker, 1988). Ochre use among the Hamar is therefore an example that strengthens the idea that the opposition between symbolic and utilitarian activities represents a false dichotomy. In the future, by extending our analysis to other uses of ochre among the Hamar and including other villages to our study, we will be able to evaluate the variability of techniques and functions of this material.

CAPÍTULO 6

Discusión y conclusión

6.1 Discusión

6.1.1 Distribución espacial de los colorantes

La reevaluación del material excavado en los niveles MSA de la cueva de Porc-Epic (Desmond Clark y Williamson, 1984) por Kenneth D. Williamson en 1975 y 1976 nos ha permitido demostrar que la colección de materias colorantes (40 kg, 4213 fragmentos) de este yacimiento es la más amplia jamás hallada en un contexto paleolítico.

La importancia de este material en los debates actuales sobre la emergencia y el desarrollo de culturas complejas, especialmente en un área tan relevante como África Oriental, puso de relieve la necesidad de precisar la proveniencia espacial y la atribución cronológica de esta colección y de utilizar datos sobre la distribución espacial para evaluar la integridad de los depósitos arqueológicos. La finalidad del artículo titulado "*Stratigraphic and spatial distribution of ochre and ochre processing tools from Porc-Epic Cave, Dire Dawa, Ethiopia*" (Rosso et al., 2014), presentado en el capítulo 2 de la presente tesis, fue, por lo tanto, la de aportar nuevos datos sobre la estratigrafía del yacimiento a través del análisis vertical y horizontal de la distribución de los colorantes y de los útiles para el procesado de colorantes, estableciendo una correlación con la de otras categorías de objetos (industria lítica y opérculos de gasterópodos terrestres).

El material analizado incluye todas las materias colorantes halladas en la excavación de 1975-1976 con información estratigráfica (n=3792), 21 útiles de procesado de colorantes y dos cantos con residuos rojos. Este material fue registrado en una base de datos con toda su información contextual y sometido a un análisis estadístico para verificar si las variaciones observadas en la distribución espacial son significativas. Para la comparación de la distribución espacial de los colorantes con la industria lítica y los opérculos de gasterópodos terrestres se utilizaron respectivamente datos proporcionados por D. Pleurdeau y Z. Assefa (Pleurdeau, 2004; Assefa et al., 2008).

Los resultados de nuestros análisis nos han permitido demostrar que los niveles MSA no fueron perturbados significativamente por fenómenos post-deposicionales. La presencia de colorantes en los niveles superiores (-0-60 cm), atribuidos al LSA y al Neolítico es escasa. Se han identificado dos zonas de acumulación de colorantes y de útiles de procesado de colorantes en distintos niveles arqueológicos, cuya localización cambia significativamente, lo que hemos interpretado como posibles cambios en la localización de las zonas dedicadas al tratamiento de colorantes. Por otra parte, la distribución vertical de los colorantes y de la industria lítica, así como la de los opérculos de gasterópodos terrestres tienden a seguir la misma tendencia. Sin embargo, las acumulaciones de colorantes y útiles de procesado de colorantes no coinciden espacialmente con las acumulaciones de opérculos.

Las fechas de los opérculos obtenidas por ^{14}C indican una cronología relativamente corta para la acumulación de los principales depósitos MSA (cómo mínimo 4500 años); hacia 40 ka cal BP se sitúan los niveles con la más alta frecuencia de colorantes. Nuestros resultados concuerdan con el hecho de que no se hayan identificado variaciones en la industria lítica a través de la secuencia y parecen indicar una fase de transición desde el MSA al LSA en esta área geográfica.

6.1.2 Los fragmentos de colorantes

A pesar de que el uso de colorantes se haya demostrado en numerosos yacimientos MSA (Watts, 1999, 2002, 2009, 2010, 2014; McBrearty y Brooks, 2000; Barham, 2002; Henshilwood et al., 2009, 2011; d'Errico et al., 2012c; Hodgskiss, 2012; Dayet et al., 2013), existen muy pocos estudios que permitan detectar cambios diacrónicos en la cadena operativa de este material de forma fiable y precisa. Esto se debe en primer lugar a la falta de análisis sistemáticos de colecciones de colorantes, especialmente en África Oriental y a la escasez de yacimientos con secuencias estratigráficas en las que se haya registrado un uso de colorantes de forma continua (Watts, 2010; Henshilwood et al., 2011; Hodgskiss, 2013; Dayet et al., 2016; Moyo et al., 2016). Sin embargo, para comprender las trayectorias culturales de las poblaciones MSA es necesario documentar el ritmo de estos cambios de conducta y deducir cuáles fueron los mecanismos de transmisión específicos de estas sociedades. La cueva de Porc-Epic es uno de los pocos yacimientos MSA que permiten identificar estos cambios diacrónicos, debido a la densidad excepcionalmente alta de colorantes por nivel arqueológico.

En el artículo titulado "*Patterns of change and continuity in ochre use during the late Middle Stone Age of the Horn of Africa: the Porc-Epic Cave record*" (Rosso et al., in press) presentado en el capítulo 3 de la presente tesis, hemos realizado un análisis tecnológico de los fragmentos de colorantes hallados en 1975-1976. El objetivo fue reconstruir la cadena operativa de los colorantes e identificar posibles cambios en el tratamiento y uso de este material en la secuencia, con el fin de explorar la función y el significado de este material en las poblaciones MSA del Cuerno de África.

Para llevar a cabo este estudio, hemos empleado diferentes métodos de análisis, comparando el material arqueológico (n=3792 fragmentos de colorantes) con material experimental y muestras de colorantes producidas por mujeres Ovahimba (Namibia) y Hamar (Etiopía). Hemos combinado una caracterización visual de los colorantes, una identificación microscópica de las marcas de uso, un análisis morfológico y morfométrico de las piezas, con un análisis de granulometría de polvos de colorantes experimentales y etnográficos y un estudio rugosimétrico de las facetas arqueológicas y experimentales producidas por abrasión.

Aunque la cronología de Porc-Epic no se haya determinado todavía de forma precisa, las dataciones por radiocarbono indican que sus niveles arqueológicos se acumularon al menos durante un período de 4500 años. En este estudio hemos detectado que durante este lapso hubo o bien una continuidad o bien cambios progresivos en el tratamiento y uso de colorantes, pero ninguna transformación repentina. Las proporciones de cada tipo de materia prima son relativamente estables en toda la secuencia. En cuanto a las marcas de uso, se ha identificado una disminución gradual de las marcas de abrasión, un aumento progresivo de las marcas de talla y raspado así como de los impactos de percusión y una presencia estable de las zonas de desgaste (zonas con superficies aplanadas por el uso). Si tenemos en cuenta la cantidad de colorantes modificados que se encuentran en este yacimiento (casi la mitad de los fragmentos), esta continuidad puede ser interpretada como la expresión de una adaptación cultural compartida por todos los miembros de una comunidad y transmitida de forma constante. Los cambios progresivos observados en las técnicas empleadas para tratar los colorantes han sido interpretados como el reflejo de una deriva cultural dentro del marco de esta práctica.

Los análisis rugosimétricos que hemos realizado sobre los colorantes intensamente modificados mostraron que algunos fragmentos presentan facetas de abrasión producidas con útiles de materias primas diferentes. Asimismo, hemos observado que el tamaño de los fragmentos de colorantes con más de una faceta de abrasión es significativamente más grande que aquellos con una sola faceta. Todo esto parece indicar que la abrasión se empleaba para producir cantidades reducidas de polvo de colorante, lo que es más compatible con actividades de orden simbólico, como la pintura corporal o la realización de diseños abstractos (Watts, 2009, 2010; Rifkin, 2012).

Evidentemente, esto no significa que el polvo de colorante producido en la cueva de Porc-Epic se usara únicamente para actividades simbólicas. Los polvos de colorante producidos experimentalmente con útiles de materias primas diversas muestran diferencias del punto de vista de la granulometría. Esto nos permite deducir que los fragmentos arqueológicos que presentan variables rugosimétricas diferentes en sus distintas facetas probablemente sirvieron para producir polvo de granulometrías diversas, adaptadas a una variedad de funciones.

6.1.3 Los útiles para el tratamiento de colorantes

La presencia de colorantes es una característica recurrente en los yacimientos MSA y Paleolíticos. Sin embargo, disponemos de pocos datos sobre cómo se seleccionaban, procesaban, almacenaban y utilizaban los colorantes durante el MSA. Algunos estudios presentan análisis de residuos de colorantes identificados en útiles de tratamiento (Henshilwood et al., 2011), en industria lítica (Gibson et al., 2004; Wadley et al., 2004, 2009; Williamson, 2004), en conchas usadas como contenedores (Zilhão et al., 2010; Henshilwood et al., 2011) o en ornamentos personales (Vanhaeren et al., 2006; d'Errico et al., 2009; Zilhão et al., 2010; Peresani et al., 2013; d'Errico y Backwell, 2016) hallados en yacimientos musterienses o MSA (especialmente en África Austral o en África del Norte), pero éstos son escasos.

En el artículo titulado "*Middle Stone Age Ochre Processing and Behavioural Complexity in the Horn of Africa: Evidence from Porc-Epic Cave, Dire Dawa, Ethiopia*" (Rosso et al., 2016), presentado en el capítulo 4, hemos llevado a cabo un análisis detallado de veintiún útiles de tratamiento de colorantes (14 molinos, 6 machacadores y 1 útil posiblemente usado como molino y machacador) y dos cantos con residuos de colorante hallados en 1975-1976 en los niveles MSA de la cueva de Porc-Epic. El objetivo de este trabajo ha sido obtener nuevos datos sobre el tratamiento y uso de colorantes en África Oriental y evaluar el grado de complejidad cultural que reflejan estas actividades. El interés de estos objetos reside en su cantidad y variedad, así como en el excelente estado de conservación de las marcas de uso y la presencia sistemática de residuos de colorantes. Además, tal y como hemos presentado en el capítulo 2, la mayor parte de estos útiles estaban asociados a las acumulaciones de fragmentos de colorantes. Así, este material permite una reconstrucción completa de los procedimientos técnicos implicados en el tratamiento y uso de colorantes, en un área del continente africano nunca estudiada desde esta perspectiva.

Hemos recopilado datos contextuales y morfométricos y hemos identificado la materia prima y las marcas de uso presentes en cada uno de estos útiles. También hemos caracterizado los residuos de colorantes a través de análisis por difracción de rayos X, espectrometría μ-

Raman y microscopía electrónica de barrido con sistema de detección de energía acoplada (MEB-EDS).

Nuestros resultados demuestran que los habitantes de Porc-Epic usaron una gran variedad de rocas para procesar colorantes. Algunas de éstas (caliza, arenisca y conglomerado) eran locales, otras (basalto) se encontraban aproximadamente a 5-10 km del yacimiento, pero también se han identificado algunos casos de rocas exógenas (cuarcita, esquisto y granito). Las marcas de uso detectadas sobre estos objetos permiten señalar que el tratamiento de colorantes se ha llevado a cabo usando técnicas diversas, desde la abrasión directa de los colorantes sobre los molinos, hasta la fracturación con un machacador. Asimismo, el análisis de los residuos demuestra que diferentes tipos de colorantes, de composición, de colores (mayoritariamente rojos, pero también amarillos) y texturas diversas fueron procesados con estos útiles. La variedad de rocas empleadas como molinos y machacadores y la diversidad de colorantes y de técnicas empleadas para tratarlos indican que los habitantes de la cueva de Porc-Epic producían polvos de colorante de diferentes granulometrías y texturas, probablemente adaptados a una gran variedad de usos, funcionales o simbólicos.

En este estudio hemos identificado un canto que refleja un posible uso de colorante para actividades de orden simbólico. La mitad de su superficie está recubierta de residuo rojo repartido de forma homogénea como si hubiese sido sumergido parcialmente en una mezcla de colorante y un aglutinante líquido. Además, no presentaba ningún tipo de marcas de uso relacionadas con el tratamiento de colorantes. Este objeto ha sido interpretado o bien como un canto pintado, o bien como tampón utilizado para aplicar colorantes sobre materiales blandos.

6. 1.4 El uso de colorantes en la sociedad Hamar

A partir de finales de los años 50 y durante la década de los 60 se observa un importante desarrollo de la etnoarqueología. Esta disciplina abarca una gran variedad de temas (David y Kramer, 2001; González-Ruibal, 2003; Politis, 2015), entre los cuales encontramos los relacionados con la cerámica, la fauna o los patrones de distribución espacial. La cuestión de la percepción y la categorización del color se estudió inicialmente desde perspectivas antropológicas, incidiendo en aspectos lingüísticos, rituales o medicinales. A pesar de que este sea un tema ampliamente debatido en arqueología, son escasos los estudios etnoarqueológicos centrados en aspectos técnicos que reconstruyan de manera precisa la cadena operativa del tratamiento de colorantes (Simpson, 1951; Rudner, 1982; Paterson y Lampert, 1985; Sagona, 1994; d'Errico y Quentin, 2014; Rifkin, 2015a; Rifkin et al., 2015b).

El objetivo del artículo presentado en el capítulo 5 de la presente tesis, titulado "*Aproximación etnoarqueológica al uso de las materias colorantes de origen mineral: los Hamar (Etiopía) y el tratamiento del cabello"* (Rosso, in press) es analizar el tratamiento y uso de los colorantes bajo una perspectiva etnoarqueológica. Hemos llevado a cabo un análisis preliminar de las diferentes fases de la cadena operativa de los colorantes en la población Hamar, del sur de Etiopía, con el fin de entender el papel de esta materia prima en una sociedad tradicional y aportar nuevos datos al debate sobre el uso del colorante mineral en la Prehistoria. En la cultura Hamar, los colorantes se usan de forma recurrente: para cuestiones higiénicas, como pintura corporal durante diversos rituales, o para cubrir objetos rituales. En este estudio, nos hemos centrado en analizar el procesado del colorante para su uso más común, es decir para la realización del peinado femenino.

Para la documentación etnoarqueológica de la cadena operativa del colorante nos trasladamos a Turmi (región de las Naciones, Nacionalidades y Pueblos del Sur, en la zona Debub Omo, Etiopía). Dos mujeres Hamar, Buno Goffa y Ballo Aysire, del poblado de Dombo (situado aproximadamente a 2 km de Turmi) nos demostraron las etapas de preparación del colorante.

La adquisición de la materia prima se llevó a cabo en un afloramiento cerca del poblado, en la orilla del uadi Kaeske. Las dos mujeres usaron diferentes herramientas: un pico, una broca helicoidal y un canto. Aproximadamente 5 kg de colorantes fueron extraídos y posteriormente sometidos a un tratamiento térmico para modificar su color. Los colorantes calentados, caracterizados por un color rojo intenso, fueron pulverizados por molturación y aplicados al cabello con un aglutinante compuesto de resina de acacia, mantequilla y café, para realizar el peinado tradicional Hamar.

Este estudio nos ha permitido demostrar que detrás del uso del colorante en la cultura Hamar existe una compleja cadena operativa. Ésta implica un conocimiento profundo de la materia y del proceso de transformación térmica, la elaboración de recetas específicas para la preparación del aglutinante y una combinación de gestos diversos para la producción de colorante en polvo. En cuanto a la gestualidad y las herramientas usadas para transformar el colorante en polvo, vemos similitudes con el tratamiento del colorante de las mujeres Ovahimba, en Namibia. Arqueológicamente, podemos encontrar paralelos con la cadena operativa Hamar, como el tratamiento térmico para modificar el color, la elaboración de mezclas complejas o el empleo de molinos de mano para machacar y pulverizar el colorante.

En cuanto a la gestualidad, existen diversos ejemplos arqueológicos, especialmente a partir del Neolítico, que muestran similitudes con el tratamiento de los Hamar. La comparación es sin embargo más difícil de llevar a cabo en el caso de yacimientos paleolíticos. Más allá del aspecto técnico, analizar el papel de las materias colorantes en las sociedades tradicionales puede ser esencial para ofrecer hipótesis de interpretación y plantearnos métodos de análisis concretos para los casos arqueológicos. Los pigmentos en la sociedad Hamar se usan no sólo para funciones estéticas o higiénicas, sino que sirven también para materializar conceptos básicos del pensamiento Hamar (Lydall, 1978). El uso del colorante en esta cultura es por lo tanto uno de los numerosos ejemplos de un empleo a caballo entre lo funcional y lo simbólico.

6.2 Conclusión

6.2.1 Aportes sobre la secuencia de Porc-Epic

Para documentar las variaciones de rasgos culturales de forma precisa a nivel regional, es esencial tener un control estratigráfico y usar datos cronológicos precisos de la zona estudiada. Sin embargo, en África Oriental son escasos los yacimientos MSA en los que disponemos de dataciones fiables, lo que reduce la resolución de cualquier interpretación (Mirazón Lahr y Foley, 2016). A esto se añade la escasez de cuevas o yacimientos con secuencias potentes (Tryon y Faith, 2013). La cueva de Porc-Epic es uno de los pocos yacimientos con secuencias estratigráficas espesas y por ello representa un marco favorable para documentar variaciones diacrónicas en el uso de colorantes. Sin embargo, la falta de datos cronológicos fiables que caracteriza los yacimientos de África Oriental se ve reflejada en la cueva de Porc-Epic. Por ello, el estudio de las informaciones contextuales para intentar aportar datos sobre la secuencia de este yacimiento ha sido una etapa esencial de nuestro trabajo.

Nuestros resultados indican, como ya señalamos, que las variaciones en la distribución del material no se deben a procesos tafonómicos: las zonas de acumulación de colorantes no coinciden con las de los opérculos aunque verticalmente sigan un mismo patrón.

Las fechas ^{14}C de los opérculos de gasterópodos terrestres parecen indicar que la secuencia se acumuló en un período de aproximadamente 4500 años. Comparando estas fechas con la distribución vertical de los colorantes, hemos propuesto una fecha de ca. 40 ka cal BP para los niveles más ricos en colorantes. El aumento en el uso de este material en estos niveles no parece estar asociado a un cambio en las funciones del mismo, ya que se ha observado una continuidad en el tipo de colorantes usados y en las técnicas de procesado. Esto parece sugerir o bien un aumento de las frecuentaciones del yacimiento, o bien la ocupación de la cueva por un grupo de humanos más amplio alrededor de 40 ka cal BP. Con dataciones e informaciones medioambientales más precisas sería posible determinar si este aumento fue el resultado de una expansión demográfica favorecida por cambios climáticos.

Asimismo, el hecho de que Porc-Epic fuera un lugar visitado frecuentemente durante el MSA u ocupado por un grupo importante de individuos parece coincidir con su interpretación como campamento base propuesto en estudios previos (Assefa, 2006).

6.2.2 Tratamiento de los colorantes

En nuestro estudio, el análisis de los fragmentos de colorantes de la cueva de Porc-Epic (presentado en el capítulo 3) se complementó con el de los útiles de tratamiento de colorantes y cantos con residuos rojos del mismo yacimiento (presentado en el capítulo 4). Esto nos ha permitido abordar la cuestión del tratamiento de colorantes desde dos ángulos diferentes.

Los colorantes de Porc-Epic se caracterizan por una gran variabilidad del punto de vista del color, de la dureza, textura y densidad. Seis categorías de colorantes fueron identificadas visualmente y su proporción en la secuencia no varía considerablemente. Sin embargo, la morfología de estas materias primas evoluciona en la estratigrafía, lo que sugiere que los habitantes de la cueva buscaban determinados tipos de materias primas independientemente de su morfología. Aunque la mayoría de fragmentos puedan incluirse en la categoría de colores rojos, muchos fragmentos presentan otros colores. Podemos suponer que los humanos de Porc-Epic percibiesen estas distintas categorías de colores. Los útiles de procesado de colorantes también se caracterizan por la presencia de una gran variedad de materias primas. El hecho de que algunas de éstas sean exógenas y la presencia de zonas de acumulación de objetos de distintas materias primas en los mismos niveles arqueológicos indican que el tratamiento de colorantes requería un conjunto de útiles diversos. Los habitantes de la cueva adquirían estos objetos o bien desplazándose por el territorio o bien intercambiando material con grupos vecinos.

Se ha observado también una gran variabilidad de marcas de uso, tanto en los fragmentos de colorantes como en los útiles de procesado, que nos han permitido demostrar que los habitantes de la cueva producían polvo de colorante de diferentes tipos. Los análisis tecnológicos de estas dos categorías de útiles indican un uso importante de la talla y de la abrasión. Se han identificado lascas de colorante, fragmentos de colorante con negativos de percusión y con facetas de abrasión, así como machacadores con marcas de impacto y molinos con zonas desgastadas a veces cubiertas por estrías producidas por abrasión. También se observaron en los fragmentos de colorantes otras marcas de uso menos frecuentes: cúpulas de percusión, estrías producidas por raspado y zonas desgastadas. Uno de los molinos del yacimiento nos ha permitido sugerir que en algunos casos el polvo de colorante se mezclaba con aglutinante líquido.

A través del análisis espacial de los colorantes y de los útiles de tratamiento, hemos demostrado que los procesos de tratamiento de los colorantes probablemente se llevaban a cabo en zonas específicas de la cueva especializadas en el tratamiento de colorantes y que éstas cambiaron de localización a lo largo de la secuencia.

Teniendo en cuenta la gran cantidad de colorantes modificados hallados en cada nivel arqueológico, hemos podido comprobar la presencia de variaciones progresivas en la manera en la que se procesaba este material a lo largo del tiempo. Hemos identificado un aumento paulatino de la talla, el raspado y las marcas de percusión, una disminución de la abrasión y una presencia estable de las zonas de desgaste. También se han observado cambios en la gestualidad, con una progresiva variación en la orientación de las estrías de abrasión que pasan de ser oblicuas a longitudinales. Considerando que la secuencia de Porc-Epic se ha acumulado durante aproximadamente 4.500 años, la identificación de una continuidad o de cambios graduales en el tratamiento de colorantes se ha interpretado como el reflejo de una adaptación cultural transmitida a través de las generaciones.

6.2.3 Función de los colorantes

¿Cuál era la finalidad del tratamiento de los colorantes en la cueva de Porc-Epic? Hemos demostrado a través de la experimentación que dependiendo del tipo de colorante y del útil empleado para tratarlo, se obtienen polvos de características diferentes. La variedad de materias primas (tanto de colorantes como de útiles de procesado), la identificación de residuos de colorantes de diferentes tipos en los útiles de tratamiento y la variedad de técnicas empleadas parecen apuntar a una producción de polvo de colorante de diferentes colores y granulometrías, probablemente adaptados a una variedad de usos.

Los análisis rugosimétricos demostraron que algunos fragmentos presentan facetas de abrasión producidas con útiles de diferentes materias primas. Añadido al hecho de que los fragmentos con una sola faceta son más pequeños que aquellos con varias, esto nos permite sugerir que se procesaban en varias sesiones para producir pequeñas cantidades de polvo. Esta interpretación es coherente con el hecho de que los útiles de tratamiento tengan un tamaño reducido, poco adaptado a la producción de grandes cantidades de polvo. La comparación de estos objetos con los útiles empleados por las mujeres Hamar, caracterizados por un tamaño mucho mayor y cuya función es producir cantidades importantes de colorante apoya esta idea.

Tal y como hemos mencionado en el capítulo 3, la producción de cantidades reducidas de polvo de colorante suele asociarse más a menudo con actividades de orden simbólico, como la pintura corporal o la realización de motivos (Watts, 2009, 2010; Rifkin, 2012). Muchas actividades funcionales requieren cantidades importantes de polvo de colorantes: el curtido de piel o el uso como protección contra el sol y los insectos (Rifkin, 2015a; Rifkin et al., 2015b). Asimismo, la identificación de un canto posiblemente pintado o usado como tampón parece demostrar un uso de este material para actividades simbólicas en la cueva de Porc-Epic, sin descartar la posibilidad de un uso para actividades funcionales. Cantidades de polvo reducidas pueden usarse también para actividades funcionales: para usos medicinales (Velo, 1984) o para el enmangue (Wadley, 2010b). Además, el hecho de que probablemente se produjeran polvos de colorante de diferentes granulometrías podría ser indicativo de un uso para distintas funciones. Debemos también de tener en cuenta que un uso simbólico puede estar estrechamente relacionado con funciones utilitarias, como lo demuestra el caso de las mujeres Hamar presentado en el capítulo 5. En la sociedad Hamar, los colorantes se usan por razones higiénicas, pero también se emplean durante rituales, para materializar conceptos básicos del pensamiento Hamar.

6.2.4 Contribuciones generales

Estudios recientes en arqueología y genética indican que la difusión de nuestra especie fue un proceso complejo que no tuvo lugar de forma inmediata en todo el continente africano. Todo apunta hacia la presencia de un mosaico de poblaciones en África durante el MSA. Prueba de ello son las introgresiones de genes arcaicos en poblaciones africanas de *Homo sapiens* (Hammer et al., 2011; Sánchez-Quinto et al., 2012). En este contexto, cada región del continente africano constituye todavía una incógnita.

Es por lo tanto esencial documentar detalladamente los rasgos culturales de poblaciones MSA a nivel regional, con el fin de aportar piezas que permitan comprender las variaciones de las poblaciones del *Homo sapiens* en África y de qué manera los cambios climáticos influyeron en la estructura de éstas. El uso de colorantes, indicativo de una complejidad cognitiva (McBrearty y Brooks, 2000; Henshilwood y Marean, 2003; d'Errico, 2008) y en algunos casos de una conducta simbólica (Watts, 2002, 2009, 2010; Zilhão, 2007; d'Errico, 2008; Zilhão et al., 2010; d'Errico et al., 2012c) es sin duda uno de los rasgos que deberían ser analizados en el marco de esta problemática.

Así, el interés de nuestro estudio reside en el hecho de que aporta por primera vez datos precisos sobre un rasgo característico de una cultura compleja (el uso de colorantes) en una de las áreas geográficas más significativas en el estudio de la emergencia de los Humanos anatómicamente modernos.

En la cueva de Porc-Epic, la gran variedad de colorantes, de útiles para tratarlos y de métodos de procesado, así como la presencia de posibles áreas dedicadas al tratamiento de colorantes sugieren un alto grado de especialización en la explotación de este material en el Cuerno de África desde al menos 40-45 ka cal BP. Esto nos deja suponer que hubo antecedentes a esta utilización y que, posiblemente, el uso de colorantes en la cueva de Porc-Epic sea el resultado de una tradición preexistente en esta área geográfica. Prueba de ello es la presencia de colorantes (o posibles colorantes) en yacimientos con ocupaciones anteriores o contemporáneas a la de Porc-Epic. En niveles fechados hacia 1–1,5 Ma, en Gadeb, Etiopía (Desmond Clark y Kurashina, 1979) y Olduvai Gorge en Tanzania (Leakey, 1958) y en niveles de ca. 500 ka en Melka Kunture en Etiopía (Chavaillon y Berthelet, 2004) se hallaron posibles colorantes, aunque éstos no presentan marcas de uso. Asimismo, en Kapthurin Formation (McBrearty y Brooks, 2000; Tryon y Faith, 2013) y Enkapune Ya Muto (Ambrose, 1998) en Kenia, en Mumba y Nasera Rock Shelters (Mehlman, 1989) en Tanzania, así como en Etiopía, en Mochena Borago Rock Shelter (Brandt et al., 2012), Gorgora Rock Shelter (Leakey, 1943; Moysey, 1943; Desmond Clark, 1988) y Aduma (Yellen et al., 2005) se encontraron pruebas menos ambiguas de un uso de este material. En este panorama, el estudio de los colorantes de Porc-Epic representa el primer paso hacia la documentación sistemática de la explotación de este material en el Cuerno de África. Demuestra que ya desde el MSA el uso de colorantes era probablemente parte de una tradición arraigada. De hecho, la importancia del uso de este material en el Cuerno de África es también evidente en la actualidad: numerosas sociedades tradicionales siguen utilizando colorantes de forma cotidiana, lo que nos permite establecer paralelos etnoarqueológicos.

6.3 Perspectivas

Combinando metodologías diversas (análisis espacial, observación micro y macroscópica, estudios morfométricos y tecnológicos, análisis de residuos, análisis rugosimétricos y granulométricos) y comparando las piezas arqueológicas con materiales experimentales y etnográficos, hemos conseguido aportar datos sobre la estratigrafía del yacimiento, reconstruir un número de etapas de la cadena operativa de los colorantes, proponer hipótesis en cuanto a su función e identificar una posible transmisión cultural relacionada con la explotación de colorantes. Actualmente, se empiezan a estudiar los mecanismos que subyacen tras la transmisión de prácticas culturales relacionadas con el uso de colorantes y el estudio sistemático de colecciones significativas como la de Porc-Epic es esencial para proponer hipótesis válidas. Por ello, ciertos puntos que nuestro estudio ha dejado sin explorar serán desarrollados en el futuro.

Como hemos indicado anteriormente, hemos llevado a cabo análisis elementales y mineralógicos de los fragmentos de colorantes que no se han incluido en las publicaciones presentadas en esta tesis. Estamos actualmente tratando los resultados de estos análisis que serán el objeto de una futura publicación que completará nuestro estudio tecnológico. Una nueva estancia en Addis Abeba nos permitiría aumentar la muestra de fragmentos analizados por EDXRF. Además de concretar ciertos aspectos de nuestro estudio tecnológico, los resultados de los análisis elementales y mineralógicos serán utilizados para abordar ciertos aspectos de la cadena operativa que no hemos incluido en esta tesis, como por ejemplo la procedencia de la materia prima. Una prospección preliminar nos ha permitido recoger colorantes en el uadi Laga Dächatu. Estos han sido analizados por EDXRF y los resultados serán comparados a los de los materiales arqueológicos. Futuras prospecciones nos permitirán muestrear diferentes zonas alrededor del yacimiento para intentar identificar otras posibles áreas de aprovisionamiento. Desarrollando estos aspectos de nuestra investigación, la cueva de Porc-Epic será uno de los pocos yacimientos dónde tendremos datos sobre la proveniencia, composición elemental y mineralógica de la materia prima utilizada, las técnicas de tratamiento de éstas, el tipo de útiles empleados y la composición de sus residuos.

Un equipo del laboratorio IRAMAT-CRP2A de la Universidad de Bordeaux Montaigne, en colaboración con el *Muséum National d'Histoire Naturelle* de París, está actualmente llevando a cabo nuevas dataciones OSL que quizás aportarán elementos útiles para precisar el marco cronológico de este yacimiento. Así, será posible llevar a cabo comparaciones con colorantes de yacimientos de otras áreas geográficas (Sudáfrica o el norte del continente africano) y enmarcar nuestros resultados en un contexto más amplio del MSA.

La etnoarqueología es otro aspecto de nuestra investigación que será desarrollado en el futuro. Nuestro estudio preliminar del uso de colorantes para la aplicación al cabello en la sociedad Hamar será extendido a los demás usos de este material de forma sistemática. Actualmente estamos preparando un corto documental con las imágenes registradas durante el trabajo presentado en el capítulo 5. También vamos a efectuar un análisis de los fragmentos de colorantes recogidos durante nuestro trabajo de campo. Compararemos la composición de los colorantes antes y después del tratamiento térmico, lo que nos permitirá aportar datos para la interpretación de materiales arqueológicos.

En nuestros artículos hemos explorado nuevas metodologías para el estudio de los colorantes que podrían ser desarrolladas en el futuro, abriendo así nuevas líneas de investigación. El uso de la microscopía confocal es una de ellas. Ampliando nuestra experimentación y analizando más tipos de materias primas podremos intentar identificar de forma más precisa de qué manera influye el tipo de útil empleado para producir una faceta en las variables rugosimétricas.

Más allá de los aspectos metodológicos que serán aplicados en el futuro a la colección de Porc-Epic, existe una clara necesidad de extender este tipo de análisis a otros yacimientos del Cuerno de África. Como hemos mencionado anteriormente, es probable que el uso de colorantes en la cueva de Porc-Epic sea la punta del iceberg de un rasgo cultural profundamente arraigado en el MSA del Cuerno de África. Éste necesita ser explorado sistemáticamente para precisar el origen y desarrollo de las culturas complejas en África Oriental y para poder llevar a cabo comparaciones con otras áreas geográficas como Sudáfrica o el norte del continente. Esto será esencial para aportar datos que puedan ayudar a comprender la compleja difusión de *Homo sapiens* en el continente africano.

En este contexto, es necesario el estudio de los materiales de Gadeb, Olduvai Gorge o Melka Kunture (Leakey, 1958; Desmond Clark y Kurashina, 1979; Chavaillon y Berthelet, 2004) y la reconstrucción detallada de la cadena operativa del procesado de colorantes en otras colecciones de colorantes de yacimientos MSA de esta área geográfica. La cueva de Porc-Epic debe representar el inicio de una nueva línea de investigación en el Cuerno de África que sin duda alguna aportará valiosos datos para nuestro conocimiento del origen y desarrollo de la complejidad cultural.

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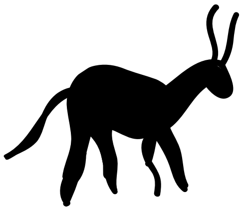
ÍNDICE DE FIGURAS Y TABLAS

FIGURAS

TABLAS

ANEXOS



ANEXO I

Origen del pensamiento simbólico y de la creatividad humana

d’Errico F., Rosso D. E. Origini del pensiero simbolico e della creatività umana. 2016. *Contributi del Centro Linceo Interdisciplinare "Beniamino Segre"* 133: 171–206.

A. RESUMEN

Investigaciones recientes en prehistoria y arqueología han revelado que el uso de ornamentos, la producción de simbolos abstractos, el uso de colorantes para actividades utilitarias y simbólicas y el desarrollo de tecnologías complejas surgieron en África alrededor de 300–70 ka.

Algunas de estas innovaciones parecen desaparecer del registro arqueológico y reaparecer bajo otras formas miles de años más tarde. Esto sugiere una evolución cultural discontinua. Un número importante de estos cambios culturales se encuentran también en Eurasia, en yacimientos ocupados por neandertales y otros homininos arcaicos.

Este panorama parece oponerse a la idea de que las conductas complejas surgieron como consecuencia de una causa única de origen biológica. La hipótesis de una “modernidad” cultural surgida como resultado de trayectorias culturales complejas y no lineares parece mucho más verosímil, debiendo ser éstas documentadas a nivel regional.

En este artículo sintentizamos la información conocida hoy en día sobre las prácticas mortuorias, el uso de colorantes, la ornamentación personal y las representaciones abstractas y figurativas.

ANEXO II

Las primeras pruebas del uso de colorantes en el Cuerno de África

Rosso, D. Les premières traces de l'utilisation de l'ocre dans la Corne de l'Afrique. 2016. *Annales de la Fondation Martine Aublet* 1: 56–61.

A. RESUMEN

El uso sistemático de colorantes es una de las características usadas para identificar una cultura compleja en contexto arqueológico y su análisis es esencial en el marco del estudio del origen de la modernidad.

A partir de 100 ka, el uso de colorantes es recurrente en el continente africano. Sin embargo, en África Oriental, las colecciones de colorantes hallados en yacimientos *Middle Stone Age* (MSA) nunca se habían estudiado sistematicamente, a pesar de la importancia de esta área geográfica para el estudio del origen de los Humanos anatómicamente modernos. Los estudios llevados a cabo en la cueva de Porc-Epic representan el primer paso hacia un conocimiento más amplio del uso de colorantes en el MSA del Cuerno de África.

En este artículo, resumimos nuestra investigación en la cueva de Porc-Epic, presentando brevemente los resultados obtenidos a través del análisis espacial de los colorantes de la cueva, y el estudio de la cadena operativa del tratamiento de este material.

La variedad de colorantes y de utiles para su procesado indican que en la cueva de Porc-Epic se producían diferentes tipos de polvos de colorante, para poder adaptarse a funciones diversas.

ANEXO III

Síntesis en francés

SYNTHÈSE

Notre vision du monde et notre langage sont étroitement liés à la perception et à la catégorisation des couleurs (Berlin et Kay, 1969; Davidoff et al., 1999; Roberson et al., 2000). C'est pour cela que l'utilisation de matières colorantes, telles que l'ocre, est souvent étudiée par les archéologues, préhistoriens et ethnologues. L'ocre, matière riche en oxydes de fer et autres composés (quartz, argiles, gypse, mica…), dont la couleur rouge ou jaune dérive généralement de l'hématite ou de la goethite, est un matériau qui a été utilisé par l'homme depuis la Préhistoire jusqu'à nos jours. Plusieurs indices d'une utilisation récurrente de l'ocre ont été trouvés dans des sites datant du Paléolithique moyen et du *Middle Stone Age* (MSA), mais la fonction de ce matériau reste l'objet d'un vif débat. Dans cette thèse, nous étudions l'utilisation de l'ocre dans la grotte du Porc-Epic, site clef du MSA de la Corne de l'Afrique. Il s'agit de la première étude systématique d'une collection d'ocre dans cette aire géographique, qui pourtant est essentielle dans l'étude de l'émergence de l'homme moderne.

1. Introduction

1.1 L'ocre dans la Préhistoire : interprétations et problématiques

L'une des questions les plus débattues en Préhistoire est l'origine de la complexité culturelle qui caractérise toutes les sociétés humaines présentes et connues historiquement. Quand et comment sont apparues les sociétés caractérisées par une pensée abstraite et une faculté d'innovation (McBrearty et Brooks, 2000; d'Errico et Stringer, 2011)? Quels sont les facteurs qui ont impulsé leur émergence ? Plusieurs modèles ont été proposés pour répondre à ces questions. Certains auteurs proposent une apparition soudaine autour de 50-40 ka, associée à *Homo sapiens*. D'autres soutiennent que la «modernité» est apparue graduellement en Afrique à partir de 300 ka pendant le MSA. Un troisième modèle consiste en une émergence asynchrone et discontinue en Afrique et en Europe, pendant le MSA et le Moustérien (d'Errico, 2003; Zilhão et al., 2010), en partie favorisée par des facteurs démographiques ou climatiques. C'est ce dernier modèle qui semble être le plus en accord avec la découverte des échanges génétiques qui ont eu lieu entre populations dénisoviennes, néandertaliennes et d'*Homo sapiens* d'origine africaine (Green et al., 2010; Reich et al., 2010; Alves et al., 2012; Meyer et al., 2012; Sánchez-Quinto et al., 2012; Yang et al., 2012), ainsi que des introgressions de gènes archaïques au sein de populations africaines d'*Homo sapiens* (Hammer et al., 2011; Sánchez-Quinto et al., 2012).

Afin de vérifier ces différents modèles, les archéologues cherchent dans les sites archéologiques des traces de comportements qui puissent être le reflet d'une culture complexe. Dans ce contexte, le fait de créer et de transmettre des systèmes symboliques et de les incorporer à une culture matérielle se considère comme un trait comportemental probant. Différent critères peuvent être considérés comme la preuve d'une cognition complexe et, dans certains cas, d'une pensée symbolique : la présence de parure, de représentations abstraites, et l'utilisation récurrente d'ocre en sont quelques exemples (d'Errico, 2003; Henshilwood et Marean, 2003). Ce dernier critère joue un rôle complexe, étant donné que l'ocre peut être utilisée dans des buts aussi bien utilitaires que symboliques. Pour soutenir l'idée d'une fonction symbolique, des arguments tels que l'utilisation en tant que peinture corporelle ou crayon pour réaliser des tracés sont proposés. Cependant, cette vision reste controversée. Sans nier la possibilité d'une fonction symbolique, certains chercheurs soulignent la difficulté de la démontrer, et s'en tiennent à l'aspect utilitaire, en proposant des exemples tels que l'utilisation de l'ocre pour la production d'adhésifs (Wadley et al., 2009), pour le tannage des peaux (Rifkin, 2011), ou pour la protection de la peau contre les rayons solaires (Rifkin et al., 2015a).

Plusieurs sites MSA ont livré des preuves d'une utilisation de l'ocre. Les premières preuves en Afrique viennent des sites de Kapthurin, au Kenya, dans des niveaux datant de plus de 250 ka (McBrearty et Brooks, 2000; Deino et McBrearty, 2002) et de Twin Rivers, en Zambie, dans des niveaux datés entre 260 et 400 ka (Barham, 2002). En Europe, des fragments d'ocre ont été trouvés dans le site de Maastricht-Belvédère, aux Pays-Bas, dans des niveaux datant de >200–250 ka (Roebroeks et al., 2012). À partir de 100 ka, cette utilisation devient récurrente. Parmi les collections d'ocre les plus étudiées jusqu'à présent, nous trouvons celles de Blombos, Diepkloof, Pinnacle Point ou Sibudu en Afrique du Sud (Watts, 2010; d'Errico et al., 2012b; Hodgskiss, 2012; Dayet et al., 2013). En Afrique de l'Est, plusieurs sites MSA ont livré des preuves d'une utilisation récurrente de l'ocre : ceci est le cas à Enkapune Ya Muto (Ambrose, 1998) au Kenya, Mumba et Nasera Rock Shelters (Mehlman, 1989) en Tanzanie, ainsi que Mochena Borago Rock Shelter (Brandt et al., 2012), Gorgora Rock Shelter (Leakey, 1943; Moysey, 1943; Desmond Clark, 1988) et Aduma (Yellen et al.,

2005) en Ethiopie. Cependant, l’ocre n’a jamais fait l’objet d’études approfondies dans cette aire géographique.

1.2 Objectifs

L'objectif de cette thèse est d’analyser pour la première fois l’utilisation de l’ocre dans un site du MSA de la Corne de l’Afrique, la grotte du Porc-Epic, en reconstruisant les différentes étapes de la chaîne opératoire du traitement de ce matériau, afin de comprendre sa fonction. Pour cela, nous avons analysé d’un côté les fragments d’ocre, et d’un autre côté, les outils utilisés pour traiter l’ocre (meules et broyeurs avec des résidus de colorants) et les galets ocrés. Nous avons également exploité l’information contextuelle de l’ocre pour apporter de nouvelles données quant à la stratigraphie du site. De plus, nous avons comparé le matériel de la grotte du Porc-Epic avec du matériel expérimental et ethnographique afin de mieux comprendre les implications de cette utilisation.

1.3 Contexte archéologique

La grotte du Porc-Epic, située 3 km au Sud de la ville de Dire Dawa, en Éthiopie, est un site clef du MSA de l’Afrique de l’Est. Découverte Henry de Monfreid et Pierre Teilhard de Chardin (Teilhard de Chardin, 1930; Teilhard de Chardin et al., 1940), elle a été fouillée et étudiée en 1933 par Henri Breuil et Paul Wernert (Breuil et al., 1951), en 1974 par John Desmond Clark (Desmond Clark et Williamson, 1984) et en 1975-1976 par Kenneth D. Williamson.

Le site s'ouvre dans des falaises calcaires jurassiques, et sa stratigraphie montre une succession de niveaux d'argile, de sable et de brèche. Ses niveaux archéologiques ont été attribués au MSA, ainsi qu’au *Later Stone Age* (LSA) et au Néolithique. Trois artéfacts ont été datés par hydratation de l'obsidienne, méthode actuellement considérée comme peu fiable (Anovitz et al., 1999), livrant des âges entre 61202 ± 958 et 77565 ± 1575 ans. La mandibule humaine (Vallois, 1951) a été datée de environ 50000 ans par spectrométrie gamma de haute résolution (Leplongeon, 2013), et des datations par radiocarbone AMS (spectrométrie de masse par accélérateur) réalisées sur trois échantillons d'opercules de gastéropodes (Assefa,

2006) ont livré des âges non calibrés entre 33700 ± 300 (Beta – 193517) et >43200 ans (Beta – 193518).

Ce site représente un témoin essentiel pour la compréhension du MSA dans cette aire géographique. D’importantes informations ont été produites en ce qui concerne le matériel lithique (Perlès, 1974; Pleurdeau, 2003, 2005a, 2005b; Leplongeon, 2013), la faune (Assefa, 2006), les restes humains (Vallois, 1951), les opercules de gastéropodes terrestres (Assefa et al., 2008), et l'art pariétal (Breuil, 1934). Cependant, les fragments d'ocre et les outils de traitement d'ocre ont été analysés pour la première fois dans le cadre de cette thèse.

1.4 Méthodes

La collection que nous étudions ici, issue de la fouille de Williamson, est conservée actuellement au Musée National d’Ethiopie, à Addis Abeba. Elle inclut 4213 fragments d’ocre, 21 outils de traitement d’ocre et deux galets avec des résidus d’ocre. Plusieurs missions en Ethiopie nous ont permis d’étudier ce matériel en détail, à travers une observation macro et microscopique de chaque pièce. Une partie importante de notre temps a dû être employée pour reconditionner le matériel, qui se trouvait dans les mêmes sachets que le matériel lithique depuis la fouille de 1975-1976. Nous avons créé une base de données incluant 3792 fragments d’ocre, avec des données contextuelles, quantitatives (mesures, poids, nombre de facettes, mesures des facettes) et qualitatives (couleur, morphologie, types de matières premières, types de modifications, orientation des stries, formes des facettes…). Lors de notre séjour en Éthiopie, une courte mission à Turmi (Ethiopie) nous a permis d’aborder la question de l’utilisation de l’ocre sous une perspective ethnoarchéologique. Nous avons documenté les différentes étapes de la chaîne opératoire du traitement de l’ocre auprès de deux femmes Hamar, et nous avons récupéré des échantillons de poudre d’ocre.

Nous avons obtenu les permis d’exporter 80 fragments d’ocre et 20 microfragments d’ocre, et pour échantillonner des résidus d’ocre des outils de traitement. Cela nous a permis de caractériser la matière première en combinant différent types d’analyses, permettant de déterminer la composition élémentaire et minéralogique de ce matériau. Les résidus d’ocre présents sur les outils de traitement et les fragments d'ocre ont été analysés à l’aide d’un microscope électronique à balayage couplé à un spectromètre de rayons X en dispersion d’énergie EDS (MEB-EDS), par diffraction de rayons X (DRX) et par spectrométrie μ-Raman. Nous présentons ces analyses dans le chapitre 4. Les fragments d’ocre ont été analysés par MEB-EDS, fluorescence de rayons X (XRF), µ-Raman et PIXE (Particule-Induced X-Ray Emission Spectrometry). Les microfragments d'ocre ont été caractérisés par DRX. Étant donné que nous avons choisi d'effectuer une analyse technologique exhaustive des fragments d'ocre, ces résultats n'ont pas été présentés dans les articles qui sont inclus dans cette thèse, mais feront l'objet d'une future publication. Afin de quantifier les traces de modification, nous avons analysé 19 fragments d'ocre à l'aide d'un microscope confocal. Cela nous a permis de mesurer la rugosimétrie des facettes d'abrasion. Nous avons effectué des séances d'expérimentation pendant lesquelles nous avons abrasé des fragments d'ocre trouvés à proximité de la grotte du Porc-Epic. Ces pièces expérimentales ont également fait l'objet d'analyses rugosimétriques. Par ailleurs, les poudres d'ocre produites expérimentalement, ainsi que celles produites par les femmes Hamar ont fait l'objet d'analyses granulométriques. Les résultats de ces analyses sont présentés en détail dans le chapitre 3 de cette thèse.

1.5 Structure de la thèse

Le corps de cette thèse inclut quatre articles qui abordent la question de l'utilisation de l'ocre dans la Préhistoire. Ces articles ont été publiés ou acceptés dans des revues scientifiques (*Quaternary International*, *PLOS ONE*, et *Pyrenae*). Le premier s'attache à étudier la répartition spatiale des fragments d'ocre afin d'apporter de nouvelles données quant à la stratigraphie du site. Le deuxième consiste en une analyse technologique des fragments d'ocre dans laquelle nous cherchons à identifier des changements diachroniques dans le traitement de ce matériau. Le troisième est une étude des outils de traitement de l'ocre, dans laquelle nous caractérisons également les résidus identifiés sur la surface de ces outils. Le dernier est une approche ethnoarchéologique de l'utilisation de l'ocre au sein d'une population traditionnelle. Plus concrètement, nous décrivons les différentes étapes de la chaîne opératoire du traitement de l'ocre chez les femmes Hamar pour la réalisation de leur coiffure traditionnelle. En annexe, nous présentons deux articles supplémentaires écrits lors de la réalisation de cette thèse, le premier étant un état de l'art sur la recherche concernant l'origine de la modernité, et le deuxième un résumé de nos recherches conduites à la grotte du Porc-Epic.

2. Analyse spatiale de l’ocre de la grotte du Porc-Epic

La réévaluation du matériel fouillé par Kenneth D. Williamson en 1975-1976 (Desmond Clark et Williamson, 1984) nous a permis de montrer que la collection d’ocre (40 kg, 4213 fragments) de ce site est la plus abondante pour un site paléolithique. L’importance de ce matériel pour les débats actuels sur l’émergence et le développement des cultures complexes, et d’autant plus dans une région comme l’Afrique de l’Est, a souligné la nécessité de préciser la provenance spatiale et l’attribution chronologique de cette collection, et d’étudier les données sur la distribution spatiale pour évaluer l’intégrité des dépôts archéologiques. La finalité de l’article intitulé “*Stratigraphic and spatial distribution of ochre and ochre processing tools from Porc-Epic Cave, Dire Dawa, Ethiopia* ” (Rosso et al., 2014) est d’apporter de nouvelles données sur la stratigraphie du site à travers l’analyse verticale et horizontale de la distribution de l’ocre et des outils de traitement de l’ocre, en établissant une corrélation avec d’autres catégories d’outils (l’industrie lithique et les opercules de gastéropodes terrestres).

Le matériel analysé comprend tous les fragments d’ocre recueillis lors de la fouille de 1975-1976 ayant des données stratigraphiques (n=3792), 21 outils de traitement de l’ocre et deux galets portant des résidus d’ocre. Ce matériel a été inclus dans une base de données avec toute son information contextuelle et a été soumis à une analyse statistique afin de vérifier la significativité des variations observées dans la distribution spatiale. La comparaison de la distribution des fragments d’ocre avec celle de l’industrie lithique et des opercules de gastéropodes terrestres a été effectuée en utilisant des données fournies par D. Pleurdeau et Z. Assefa respectivement (Pleurdeau, 2004; Assefa et al., 2008).

Les résultats de nos analyses nous ont permis de démontrer que les niveaux MSA n’ont pas été significativement perturbés par des phénomènes post-dépositionnels. Peu de fragments d’ocre ont été trouvés dans les niveaux supérieurs (-0-60 cm), attribués au LSA et au Néolithique. Deux zones d’accumulations d’ocre et d’outils de traitement de l’ocre ont été identifiées dans des niveaux différents, et leur localisation change au cours du temps. Nous avons interprété cela comme de possibles changements dans la localisation d’aires spécialisées pour le traitement de l’ocre. La distribution verticale des fragments d’ocre, de l’industrie lithique et des opercules suivent les mêmes tendances. Cependant, les accumulations d’ocre et d’outils de traitement ne se trouvent pas dans les mêmes aires que celles des opercules, ce qui montre qu’elles ne sont pas le résultat de processus taphonomiques.

Les dates ^{14}C des opercules indiquent une chronologie relativement courte pour l'accumulation des dépôts MSA (au moins 4500 ans) et permettent d'estimer une date d'autour de 40 ka cal BP pour les niveaux plus riches en ocre.

3. Analyse technologique des fragments d'ocre

Bien que l'utilisation de l'ocre ait été attestée dans plusieurs sites MSA (Watts, 1999; McBrearty et Brooks, 2000; Watts, 2002; Barham, 2002; Watts, 2009; Henshilwood et al., 2009; Watts, 2010; Henshilwood et al., 2011; d'Errico et al., 2012c; Hodgskiss, 2012; Dayet et al., 2013; Watts, 2014), les études qui permettent de détecter des changements diachroniques dans la chaîne opératoire du traitement de ce matériel de façon fiable et précise sont extrêmement rares. Cela est probablement lié à la rareté d'analyses systématiques de collections d'ocre, surtout en Afrique de l'Est, et au manque de sites ayant des séquences attestant une utilisation de l'ocre de façon continue (Watts, 2010; Henshilwood et al., 2011; Hodgskiss, 2013; Dayet et al., 2016; Moyo et al., 2016). Cependant, pour comprendre les trajectoires culturelles des populations MSA, il est nécessaire de documenter le rythme de ces changements de comportements, et de déduire quels ont été les mécanismes de transmission spécifiques de ces sociétés. La grotte du Porc-Epic est l'un des rares sites MSA qui permettent l'identification de ces changements diachroniques, grâce à la quantité exceptionnelle de fragments d'ocre par niveau archéologique.

Dans l'article intitulé "*Patterns of change and continuity in ochre use during the late Middle Stone Age of the Horn of Africa: the Porc-Epic Cave record*" (Rosso et al., in press), nous avons effectué une analyse technologique des fragments d'ocre trouvés en 1975-1976. L'objectif de cette étude est de reconstruire la chaîne opératoire du traitement l'ocre, d'identifier de possibles changements dans le traitement et l'utilisation de ce matériau dans la séquence, et d'explorer la question de la fonction de l'ocre parmi les populations MSA dans la Corne de l'Afrique.

Différents types d'analyses ont été combinées dans cette étude. Nous avons comparé le matériel archéologique (n=3792 fragments d'ocre) avec du matériel expérimental et des échantillons de poudre d'ocre produits par des femmes Ovahimba (Namibie) et Hamar (Ethiopie). Nous avons réalisé une caractérisation visuelle des colorants, une identification microscopique des traces d'utilisation, une analyse morphologique et morphométrique des pièces, une analyse granulométrique de la poudre d'ocre expérimentale et de celle produite par les femmes Hamar, et nous avons effectué une étude rugosimétrique des facettes d'abrasion archéologiques et expérimentales.

Bien que la chronologie de la grotte du Porc-Epic n'ait pas encore été déterminée de façon précise, les datations radiocarbone indiquent que ses niveaux archéologiques se sont accumulés pendant une période au moins de 4500 ans. Dans cette étude, nous avons observé que, pendant cette période, il a eu une continuité dans le traitement de l'ocre, ou des transformations graduelles, mais en aucun cas des changements soudains. Les proportions de chaque type de matière première restent relativement stables tout au long de la séquence. Quant aux traces de modification, nous avons identifié une diminution graduelle des traces d'abrasion, une augmentation progressive des traces de taille, de raclage, et d'écrasement, et une présence stable de pièce émoussées. Cette continuité peut s'interpréter comme l'expression d'une adaptation culturelle partagée par tous les membres d'une communauté, transmise de façon constante au cours du temps. Les changements progressifs observés dans les techniques de traitement de l'ocre ont été interprétés comme une dérive culturelle dans le cadre de cette activité.

Les analyses rugosimétriques que nous avons effectuées sur les fragments d'ocre intensément modifiés nous ont montré que certaines pièces présentent des facettes d'abrasion produites par des outils de matières premières différentes. De plus, nous avons observé que les fragments d'ocre avec plus d'une facette sont en général plus volumineux que ce qui n'en présentent qu'une. Tout cela semble indiquer que l'abrasion était utilisée pour produire des quantités d'ocre réduites, ce qui est plus compatible avec des activités d'ordre symbolique, comme la peinture corporelle ou la réalisation de motifs abstraits (Watts, 2009, 2010; Rifkin, 2012).

Évidemment, cela ne signifie pas que la poudre d'ocre produite à la grotte du Porc-Epic ait été utilisée uniquement pour des fonctions symboliques. Nos expérimentations nous ont montré que les poudres d'ocre produites avec des outils de matières premières différentes présentent des différences au niveau de la taille des grains. Nous en déduisons que les fragments d'ocre qui présentent des facettes avec des données rugosimétriques différentes ont probablement permis la production de poudres d'ocre de différentes granulométries, adaptées à une grande variété de fonctions.

4. Analyse des outils de traitement de l'ocre

La présence d'ocre est une caractéristique récurrente dans de nombreux sites MSA et paléolithiques. Cependant, il y a peu d'information sur la façon dont ce matériau était sélectionné, traité, stocké et utilisé pendant le MSA. Très peu d'études s'attachent à analyser les résidus d'ocre identifiés sur des outils de traitement (Henshilwood et al., 2011), sur l'industrie lithique (Gibson et al., 2004; Wadley et al., 2004; Williamson, 2004; Wadley et al., 2009), dans des coquillages utilisés comme récipients (Zilhão et al., 2010; Henshilwood et al., 2011) ou sur la parure (Vanhaeren et al., 2006; d'Errico et al., 2009; Zilhão et al., 2010; Peresani et al., 2013; d'Errico et Backwell, 2016).

Dans l'article intitulé "*Middle Stone Age Ochre Processing and Behavioural Complexity in the Horn of Africa: Evidence from Porc-Epic Cave, Dire Dawa, Ethiopia*" (Rosso et al., 2016), nous avons effectué l'analyse détaillée de 20 outils de traitement de l'ocre (14 meules, 6 broyeurs et un outil probablement utilisé à la fois comme meule et comme broyeur) et deux galets avec des résidus d'ocre trouvés en 1975-1976 dans les niveaux MSA de la grotte du Porc-Epic. Le but de cette étude a été d'acquérir de nouvelles données quant au traitement et l'utilisation de l'ocre en Afrique de l'Est, et d'évaluer le degré de complexité comportementale que ces activités reflètent. L'intérêt de ces objets réside dans leur quantité et variété, ainsi que l'excellent état de conservation des traces de modification, et la présence systématique de résidus d'ocre. Par ailleurs, la plupart de ces outils étaient associés à des accumulations de fragments d'ocre. Ce matériel permet donc une reconstruction des processus techniques impliqués dans le traitement et l'utilisation de l'ocre, dans une région jamais étudiée de ce point de vue.

Pour réaliser cette étude, nous avons recueilli des données contextuelles et morphométriques, nous avons identifié la matière première et les traces d'utilisation présentes sur chacun de ces objets, et caractérisé les résidus d'ocre à travers des analyses par DRX, µ-Raman et MEB-EDS.

Nos résultats montrent que les habitants de la grotte du Porc-Epic utilisaient des outils de différentes matières premières pour traiter l'ocre. Certaines étaient locales (calcaire, grès et conglomérat), d'autres se trouvaient à 5-10 km du site (basalte), et d'autres encore étaient allochtones (quartzite, schiste et granit). Les traces d'utilisation détectées sur ces objets ont permis de montrer que le traitement des colorants a impliqué différentes techniques, telles que l'abrasion directe des fragments d'ocre sur des meules ou la fracturation à l'aide de broyeurs. De plus, l'analyse des résidus montre que différents types d'ocre, de composition, couleur et textures différentes ont été traités avec ces outils. La variété de roches utilisées comme outils de traitement, la diversité de résidus d'ocre et des techniques utilisées pour les traiter indiquent que les habitants de la grotte du Porc-Epic produisaient des poudres d'ocre de différentes textures et granulométries, probablement adaptées à une diversité de fonctions, d'ordre utilitaire ou symbolique.

Dans cette étude nous avons identifié un galet qui pourrait montrer une utilisation de l'ocre pour des activités symboliques. La moitié de sa surface est couverte d'un résidu rouge homogène, qui semble indiquer que cet objet a été partiellement submergé dans un mélange d'ocre et de liant liquide. De plus, cet objet ne présente aucune trace d'utilisation attribuable à un traitement de l'ocre. Cet objet a donc été interprété comme un galet peint ou comme objet utilisé en tant que tampon pour créer des motifs sur des surfaces souples.

5. Étude d'un cas ethnoarchéologique : les Hamar, Ethiopie

L'ethnoarchéologie est une discipline qui s'est développée depuis la fin des années 50 et pendant les années 60. Elle traite une grande variété de sujets, parmi lesquels la céramique, la faune ou les modèles de distribution spatiale (David et Kramer, 2001; González-Ruibal, 2003; Politis, 2015). La question de la perception et de la catégorisation de la couleur a été étudiée principalement d'un point de vue d'anthropologie culturelle, se focalisant sur des aspects linguistiques, rituels ou médicaux. Bien que ce sujet soit largement débattu en archéologie, les études ethnoarchéologiques qui reconstruisent en détail les processus techniques de la chaîne opératoire du traitement de l'ocre sont rares (Simpson, 1951; Rudner, 1982; Paterson et Lampert, 1985; Sagona, 1994; d'Errico et Quentin, 2014; Rifkin, 2015b; Rifkin, et al., 2015b).

L'objectif de l'article intitulé "*Aproximación etnoarqueológica al uso de las materias colorantes de origen mineral: los Hamar (Etiopía) y el tratamiento del cabello*" (Rosso, in press) est d'analyser le traitement et l'utilisation des colorants sous une perspective ethnoarchéologique. Nous avons réalisé une étude préliminaire des différentes étapes de la chaîne opératoire du traitement de l'ocre dans la culture Hamar, du Sud de l'Ethiopie, afin de comprendre le rôle de ce matériau dans une société traditionnelle, et d'apporter de nouvelles données au débat sur l'utilisation de l'ocre dans la Préhistoire. Plus concrètement, nous avons focalisé notre étude sur l'utilisation de l'ocre pour la réalisation de la coiffure traditionnelle des femmes.

Afin de documenter la chaîne opératoire du traitement l'ocre chez les Hamar, nous sommes allé à Turmi (Ethiopie). Deux femmes Hamar, Buno Goffa et Ballo Aysire, du village de Dombo nous ont montré les différentes étapes de traitement de ce matériau.

L'acquisition de la matière première a eu lieu dans un affleurement près du village. Les deux femmes ont utilisé différents outils : une pioche, un foret hélicoïdal et un galet. Environ 5 kg d'ocre ont été extraits et soumis à un traitement thermique pour modifier leur couleur. Les fragments d'ocre chauffés, caractérisés par une couleur rouge intense, ont été fracturés et réduits en poudre par mouture à l'aide d'une meule et d'un broyeur. La poudre a été appliquée sur les cheveux, mélangée à un liant composé de résine d'acacia, beurre et café.

Cette étude nous a permis de montrer que l'utilisation de l'ocre dans la culture Hamar implique une chaîne opératoire complexe. Elle nécessite une connaissance profonde de la matière et du processus de transformation thermique, l'élaboration de recettes spécifiques pour la préparation du liant, et une combinaison de gestes divers pour la production de poudre d'ocre. Quant à la gestuelle et les outils utilisés pour transformer l'ocre en poudre, nous observons certains parallélismes avec le traitement de l'ocre par les femmes Ovahimba en Namibie (d'Errico et Quentin, 2014). Nous trouvons également des parallélismes avec des matériaux archéologiques : le traitement thermique pour modifier la couleur, l'élaboration de mélanges complexes ou l'utilisation de meules et broyeurs pour produire de la poudre d'ocre. Plusieurs exemples archéologiques, surtout à partir du Néolithique, semblent mettre en évidence une gestuelle semblable à celle des Hamar. Cependant, il est plus difficile d'établir des parallélismes avec des sites paléolithiques. Au-delà de l'aspect technique, l'analyse de l'utilisation de l'ocre parmi les sociétés traditionnelles est essentielle pour proposer des hypothèses d'interprétation et pour suggérer des méthodes d'analyses à appliquer au matériel archéologique. Par ailleurs, cette analyse nous montre que la vision bipolaire, opposant les activités utilitaires et symboliques, souvent employée pour expliquer la fonction de ce matériau, ne s'adapte pas forcément à la réalité. L'ocre, dans la société Hamar, ne s'utilise pas exclusivement pour des raisons esthétiques ou hygiéniques. En effet, ce matériau joue également un rôle essentiel lors de certains rituels, étant donné qu'il matérialise certains éléments fondamentaux de la pensée Hamar (Lydall, 1978).

6. Conclusions

Des études récentes en archéologie et en génétique montrent que la diffusion de notre espèce résulte d'un processus complexe qui n'a pas eu lieu de façon immédiate dans tout le continent africain. Tout semble indiquer que le continent africain était caractérisé par une mosaïque de populations pendant le MSA. Cela semble s'accorder à la découverte d'introgressions de gènes archaïques parmi des populations africaines d'*Homo sapiens* (Hammer et al., 2011; Sánchez-Quinto et al., 2012). Dans ce contexte, chaque région du continent représente une énigme.

C'est pour cette raison qu'il est essentiel de documenter en détail les traits culturels de populations MSA a échelle régionale, afin d'apporter des éléments qui puissent permettre de mieux comprendre les variations des populations d'*Homo sapiens* en Afrique, et comment les changements climatiques ont pu influencer leur structure. L'utilisation de l'ocre est sans aucun doute l'un des traits qui nécessitent d'être analysés dans le cadre de cette problématique.

L'un des intérêts de notre étude réside dans le fait que celle-ci apporte des données précises sur un trait culturel caractéristique d'une culture complexe dans l'une des régions les plus significatives pour l'étude de l'émergence de la modernité. Dans la grotte du Porc-Epic, la variété de types d'ocre, d'outils de traitement de l'ocre et de méthodes employées pour les traiter, ainsi que la présence de possibles zones consacrées au traitement de l'ocre, suggèrent un haut niveau de spécialisation dans l'exploitation ce matériau dans la Corne de l'Afrique depuis au moins 40-45 ka BP. Cela nous permet de supposer que cette utilisation ait eu des antécédents dans la région. La présence d'ocre dans des sites contemporains ou plus anciens que la grotte du Porc-Epic appuie cette idée. Dans ce contexte, l'étude de l'ocre de ce site représente le premier pas vers une documentation systématique de l'exploitation de ce matériel dans la Corne de l'Afrique.

En combinant différentes méthodologies, nous avons apporté de nouvelles données sur la stratigraphie du site, reconstruit plusieurs étapes de la chaîne opératoire du traitement de l'ocre, proposé des hypothèses quant à sa fonction et identifié une possible transmission culturelle au cours des différentes occupations du site. Actuellement, on ne fait que commencer à étudier les mécanismes qui régissent la transmission de pratiques culturelles liées à l'utilisation de l'ocre, et l'analyse de collections significatives comme celle de la grotte du Porc-Epic est essentielle pour proposer des hypothèses valides. C'est pour cela que, dans le futur, nous allons développer certains aspects qui n'ont pas pu être inclus dans cette thèse, tels que l’analyse élémentaire et minéralogique des fragments d’ocre ou les sources d’approvisionnement. De nouvelles datations actuellement en cours de réalisation par une équipe du laboratoire IRAMAT de l’Université Bordeaux Montaigne, en collaboration avec le Muséum National d’Histoire Naturelle de Paris nous permettront peut-être d’affiner le cadre chronologique de ce site. Grâce à cela, nous pourrons comparer la collection d’ocre de la grotte du Porc-Epic à des sites d’autres régions et ainsi replacer ce site dans un contexte plus large du MSA africain. Par ailleurs, actuellement, il est nécessaire d’élargir ce type d’analyses à d’autres sites dans la Corne de l’Afrique, afin de mieux préciser l’utilisation de ce matériau à l’échelle régionale. Cela nous permettra sans doute d’apporter des données au débat sur l’émergence des cultures complexes dans le continent africain.

ANEXO IV

Cartas de aceptación

ICArEHB
INTERDISCIPLINARY CENTER FOR ARCHAEOLOGY AND EVOLUTION OF HUMAN BEHAVIOUR

April 9th, 2017

To whom it may concern,

Hereby, I certify that the manuscript Patterns of change and continuity in ochre use during the late Middle Stone Age of the Horn of Africa: the Porc-Epic Cave record by Daniela Eugenia Rosso is been accepted for publication in PLOS ONE and it is now under production. The expected date of publication is 2017.

Nuno Ferreira Bicho
Associate Professor of Archaeology
Academic Editor
PLOS ONE

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Gisela RIPOLL, Editora de *PYRENAE. Revista de Prehistòria i Antiguitat a la Mediterrània Occidental / Journal of Western Mediterranean Prehistory and Antiquity*, revista científica publicada por la Sección de Prehistoria y Arqueología de la Universitat de Barcelona,

HACE CONSTAR que
Daniela Eugenia Rosso es autora del artículo que lleva por título *Aproximación etnoarqueológica al uso de las materias colorantes de origen mineral: los Hamar (Etiopía) y el tratamiento del cabello*, que tras evaluación por pares ciegos ha sido aceptado para su publicación en la revista *Pyrenae*.

Y para que sirva a los efectos oportunos, firmo la presente en Barcelona a diez de mayo de dos mil diecisiete,

Dra. G. Ripoll
Editora de PYRENAE
Universitat de Barcelona
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