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The first uses of colour: what do we know?

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Summary - *Colour strongly shapes our perception of the world and plays a main role in the emergence of language and in the transmission of information. It has been shown that systematic use of ochre, along with other cultural traits that reflect cognitive complexity, disappear and reappear from the archaeological record, suggesting that cultural transmission follows discontinuous trajectories that to this day are unknown to us. Understanding when humans started using colour and how this feature evolved may therefore be instrumental to understand the evolutionary paths followed by members of our lineage towards cultural complexity. The earliest secure evidence for ochre use is found at 300.000-year-old archaeological sites from Africa and Europe. It usually consists of iron-rich rocks characterised by a red, orange, yellow or brown colour and/or streak, modified by grinding, scraping and knapping to produce red or yellow powder, ochre residues adhering to different types of artefacts or sediment stained with ochre or rich in ochre microfragments. Around 160 ka, ochre use becomes a recurrent feature. Although analyses of ochre collections have become increasingly frequent, there is still very little information on the first instances of ochre use and on how this cultural feature evolved through time. Most cases of early evidence for colour use by different human fossil species were recovered during excavations conducted several decades ago, when ochre was not documented systematically. Excluding a few recently studied cases, there is often a lack of evidence to support the anthropogenic nature of these findings. The aim of this paper is to summarise what we know on ochre use during the Lower Palaeolithic / Early Stone Age (ESA) and Middle Palaeolithic / Middle Stone Age (MSA), review techniques currently used for the analysis of this material and highlight analytical and theoretical issues surrounding this complex cultural feature.*

Keywords - *Palaeolithic, Ochre, Pigment, Complex cognition, Symbolic behaviour.*

Introduction

The question of when and how our ancestors developed a complex cognition is fundamental to our understanding of the origin and development of human cultures and currently represents one of the most debated questions in Prehistory (d'Errico and Stringer 2011). Complex behaviour has been defined as a breakthrough corresponding to an increased cognitive sophistication (McBrearty and Brooks 2000), with actions shaped by minds equivalent to those of *Homo sapiens* today (Henshilwood and d'Errico 2011). Symbolically-mediated behaviour –intended as the ability to attribute specific meaning to signs and to manipulate symbols to mediate hominins behaviour (d'Errico and Stringer 2011; Watts 2010; Zilhão et al. 2010)– is an essential feature of such a new cognitive setting. Different models were proposed to explain the emergence of complex behaviour (d'Errico and Stringer 2011). Some researchers suggest that complex cognition is the direct consequence of a genetic mutation that took place 50 ka ago in Africa (Klein 2009). Others associate it with the appearance of anatomically modern humans (McBrearty and Brooks 2000) and favour a gradual evolution starting in the African Middle Stone Age (MSA). A third model argues that the origin of behavioural complexity is the result of a discontinuous evolutionary path taking place in Africa and Eurasia among modern and archaic human populations, between 200 and 40 ka (d'Errico and Colagè 2018; Scerri et al. 2018; Zilhão et al. 2010). The latter scenario seems to be more consistent with recent discoveries that show that the emergence and dispersal of anatomically modern humans are the result of much more complex processes than previously thought. From 350 ka, human remains found throughout the African continent show 'modern' anatomical features, but these are associated with 'archaic' features (Scerri et al. 2018). The morphological and chronological variability, as well as the geographical dispersion of the earliest fossils currently attributed to *Homo sapiens* seem to show that the evolution of our species took place among subdivided populations in different regions of Africa and that these populations were connected by sporadic gene flow (Scerri et al. 2018; Stringer 2016). Furthermore, it seems now clear that genetic exchanges took place between *Homo sapiens*, Denisovians and Neanderthals (Alves et al. 2012; Green et al. 2010; Meyer et al. 2012; Reich et al. 2010; Sánchez-Quinto et al. 2012; Yang et al. 2012). These findings show that the emergence of complex cultures is the result of intricate and non-linear evolutionary trajectories that are not fully understood and still need to be detected at a regional scale (Scerri et al. 2018). It is therefore necessary to revisit the question of the emergence and development of what characterises us as human beings, such as complex cognition, language, beliefs, and art.

To this end, researchers try to find proof for complex behaviour in the archaeological record (McBrearty and Brooks 2000). It is often argued that systematic exploitation of pigments, such as ochre, is a marker of cognitive complexity (Wadley 2010a). Colour in fact plays a main role not only in our perception of the world but also in the emergence of language and in the transmission of information (Roberson et al. 2000). The colour red in particular carries strong symbolic connotations, often related to blood and fertility (Hodgskiss 2020) and is fundamental to colour classifications in all human societies (Berlin and Kay 1969; McBrearty and Stringer 2007). Recent studies suggest that many cultural features that were thought specific to humans are also observed among other species (Whiten 2021). The use of colour is not an exception. For instance, deliberate staining with iron oxide-rich soil for its chemical proprieties, but also for purposes such as camouflaging or status-signalling was observed among different bird species (Delhey et al. 2007; Montgomerie 2006). Although the comparison of colour use among humans with that of other species is a question that still needs to be explored, assessing the cognitive significance of this cultural feature may be key to understanding the evolutionary foundations of ochre use among humans (Whiten 2021). However, many consider that systematic use of ochre reflects symbolically mediated behaviour among human cultures (Watts 2010). The presence of ochre from distant sources, the selection of certain hues or the deliberate thermally induced transformation of goethite into hematite to produce red pigment were some of the arguments used to support this interpretation (Bordes 1952; Hovers et al. 2003; Knight et al. 1995; Watts 1999, 2009). Nevertheless, some researchers consider that, while ochre may be used for symbolic purposes in some cases, it is difficult to prove it in an archaeological context. In addition, it has been shown that ochre can be used for functional purposes such as hide tanning (Rifkin 2011) or adhesive production (Kozowyk et al. 2016; Wadley 2010a; Zipkin et al. 2014b). Its use as an insect repellent (Rifkin 2015a), as sunscreen (Havenga et al. 2022; Rifkin et al. 2015) or for antiseptic treatments (Velo 1984) has also been highlighted. Today, researchers argue that the polarisation between symbolic and utilitarian activities does not reflect the complex interaction that exists between functional and symbolic activities among most traditional societies (d'Errico and Stringer 2011; Rosso 2017).

In the past few years, analyses of ochre collections have become increasingly frequent. However, there is still very little information on the first instances of ochre use and how this cultural feature evolved through time. The aim here is to review what we know on ochre use during the Lower Palaeolithic / Early Stone Age (ESA) and Middle Palaeolithic / Middle Stone Age (MSA), revise techniques currently used for the analysis of this material and highlight analytical and theoretical issues surrounding this complex cultural feature.

Definitions

By "ochre" (Cornell and Schwertmann 2003; Jercher et al. 1998; Popelka-Filcoff and Zipkin 2022; Salomon et al. 2021; Siddall 2018; Triat 2010) I mean an association of minerals in the form of soil lumps to iron ores, characterised by a red, orange, yellow or brown colour and/or streak. Red and yellow colours come respectively from a high content in iron oxides (generally hematite) or iron hydroxides (generally goethite or limonite). Ochre is also composed of variable proportions of other minerals such as quartz, calcite, gypsum, feldspars and clay minerals and therefore include a wide range of raw materials, such as shales, ferricretes, mudstones, siltstones, sandstones or specularite (Hodgskiss 2020).

In Palaeolithic contexts, ochre can be found in different forms. It is usually recovered in the form of modified or unmodified rocks (Figs. 1A-G, K). However, sediment stained with ochre or rich in ochre microfragments (Cavallo et al. 2017; Wadley 2010b; Wadley et al. 2020) is also found. Other common occurrences are ochre residues on different types of artefacts, including lithic or bone artefacts, macrolithic tools (Figs. 1H,I), rocks or pebbles (Fig. 1J), shells (Figs. 1L,M), personal ornaments (Cârciumaru et al. 2014; Henshilwood et al. 2011; Rosso et al. 2016; Wadley 2010a; Zilhão et al. 2010) or cave walls and portable art (Pomiès et al. 2000; Roldán García et al. 2016; Vignaud et al. 2006). Ochre residues can be intentionally applied to colour surfaces or draw motives. They can also be found on instruments that were used to process (Figs. 1H,I), contain or apply ochre, or on tools hafted with ochre-based adhesives. However, ochre residues may also have been deposited unintentionally, from direct contact with surfaces covered in ochre (skin, hide, sediment or other objects) or from post-depositional contact with iron oxides naturally present in the sediment (Rifkin 2015b).

Analytical methods for the study of ochre assemblages

The first chemical characterisation of prehistoric ochre dates back to 1902 (Moissan 1902, 1903). Over time, new methodologies were used to characterise the chemical composition of this material (Couraud 1988; Menu and Walter 1992; Pomiès et al. 1999). Studies were usually aimed at characterising pigment in the context of the Upper Palaeolithic parietal art (Cabrera Garrido 1978; Couraud and Laming-Emperaire 1979). Ochre pieces, ochre residues on different types of artefacts and ochre accumulations or sediment impregnations from Upper or Middle Palaeolithic sites were sometimes mentioned in the literature (Bordes 1952; Capitan and Peyrony 1912; Cartailhac and Breuil 1906) but rarely analysed (Couraud 1983, 1988). In the past two decades, the debate on the origin of complex behaviour has increased the interest in early instances of ochre use (Barham 2002; Hovers et al. 2003; Watts 1998, 2002) and a number of ochre assemblages in Europe, Africa and the Near East were studied systematically. Chemical, technological, and experimental data were explored and combined in order to reconstruct different phases of the ochre *chaîne opératoire*, from the acquisition of the raw material to its processing and use.

Over the past few years, a combination of different methods have been used to characterise ochre, including petrographic, elemental and mineralogical analyses (Dayet 2021; Domingo and Chieli 2021; Popelka-Filcoff and Zipkin 2022). Some of those methods are non-invasive or require small samples of ochre (Dayet 2021). A few examples of analytical techniques that are used to analyse ochre are: Scanning electron microscopy coupled with Energy Dispersive X-ray Spectrometry (SEM-EDS), Electron probe microanalysis (EPMA), X-ray fluorescence (XRF), X-ray diffraction (XRD), Raman spectroscopy, Colorimetry, Infrared spectroscopy, Inductively coupled plasma-mass spectrometry (ICP-MS), Inductively coupled plasma-optical emission spectroscopy (ICP-OES), Particle-Induced X-ray Photon Emission (PIXE), Neutron activation analysis (NAA), or Transmission electron microscopy (TEM) (Beck et al. 2011; Cavallo et al. 2015; Dayet 2021; Dayet et al. 2014; Huntley et al. 2015; Lebon et al. 2018; MacDonald et al. 2011; Mauran et al. 2021; Moyo et al. 2016; Pitarch Martí and d'Errico 2018; Pomiès et al.

***Fig. 1** – Evidence for ochre use from African Early and Middle Stone Age sites (A-J) and European Middle Palaeolithic sites (K-M). (A) Modified ochre piece from Olorgesailie, Kenya. Photo: courtesy F. d'Errico; (B) Engraved ochre piece from Blombos Cave, South Africa. Photo: courtesy F. d'Errico, C. Henshilwood; (C, D) Ochre pieces with striations produced by scraping and grinding from Klasies River Mouth, South Africa. Photo: courtesy F. d'Errico; (E) Ochre piece with striations produced by scraping from Panga ya Saidi, Kenya. Photo: courtesy F. d'Errico; (F, G) Ochre pieces with striations produced by scraping and grinding respectively from Porc-Epic Cave, Ethiopia. Photo: D. E. Rosso (Rosso et al. 2017); (H, I) Ochre processing tools from Porc-Epic Cave, Ethiopia. Photo: D. E. Rosso (Rosso et al. 2016); (J) Painted pebble from Porc-Epic Cave, Ethiopia. Photo: D. E. Rosso (Rosso et al. 2016); (K) Ochre piece from Combe-Grenal, France. Photo: courtesy L. Dayet and F. d'Errico (Dayet and d'Errico 2016); (L) Perforated upper half-valve of* Pecten maximus *bearing ochre residues from Cueva Antón, Spain. Photo: courtesy J. Zilhão (Zilhão et al. 2010); (M)* Aspa marginata *shell bearing ochre residues from Fumane Cave, Italy. Photo: courtesy M. Peresani, F. d'Errico (Peresani et al. 2013). Scales: 1 cm.*

1999; Popelka-Filcoff et al. 2008; Popelka-Filcoff and Zipkin 2022; Roldán et al. 2013; Rosso et al. 2016; Velliky et al. 2019; Zilhão et al. 2010). Chemical analysis of ochre allows to determine the provenance of the raw material (Popelka-Filcoff et al. 2008; Zipkin et al. 2017) and to verify whether ochre is naturally occurring at a site or if it has been imported by humans. This is of particular importance in contexts where no clear anthropogenic modifications can be identified on ochre pieces. Additionally, it can bring important data on raw material selection criteria and it can allow the identification of complex transformation techniques, such as thermally-induced transformation of goethite into hematite (Cavallo et al. 2018; Pomiès et al. 1999; Salomon et al. 2012).

Despite a certain lack of consensus on terminology for specific types of ochre modifications (Haaland et al. 2020), technological analyses are fundamental and new technologies allow precise quantification of modifications. By recording morphometric variables and identifying striations produced by grinding (Fig. 2A), scoring or scraping (Fig. 2B), smoothed (Fig. 2C) and lustred areas, and flaking or pitting marks (Hodgskiss 2013), researchers reconstruct ochre processing techniques in order to determine how ochre was handled, what type of ochre powder would be produced and for what purposes. Surface texture analysis and three-dimensional modelling techniques (Figs. 2E,F) are often used in wear studies on teeth (Scott et al. 2006; Souron et al. 2015), lithics (Evans and Donahue 2008), and bone tools (Martisius et al. 2018). They were recently used to study anthropogenic modifications on ochre, with techniques such as confocal microscopy or X-ray microcomputed tomography (micro-CT) (Haaland et al. 2020; Rosso et al. 2017). Descriptions of modifications are usually conducted qualitatively and are based on subjective criteria, resulting in non-replicable results. By quantifying surface textures, intra-observer error is significantly reduced (Martisius et al. 2018). In addition, surface texture analysis can provide important data on how and with which tools ochre was processed (Rosso et al. 2017). Micro-CT scanning is also used to inspect the internal structure of ochre pieces (Haaland et al. 2020).

Experimental replication of ochre processing (Fig. 2D) is also used to provide a comparative framework for the interpretation of modification marks (Rifkin 2012; Wadley 2010a). It has also shown the physical proprieties and effectiveness of ochre as sunscreen, hide-tanning agent, and hafting mastic ingredient.

Although rare, ethnoarchaeological studies on ochre use, colour perception and categorization (Huntley 2021; Lydall 1978; Rifkin 2015b; Rosso 2017; Rudner 1982; Sagona 1994) provide important insights into traditional uses of ochre consistently transmitted though time as part of a behavioural system that experimental data cannot provide. Recent accounts of ochre extraction, processing and use among the Ovahimba of North-western Namibia (Rifkin 2015b; d'Errico and Quentin 2014) and the Hamar of Southern Ethiopia (Rosso 2017) allow us to evaluate the complexity of the ochre processing *chaîne opératoire* (Fig. 3). Even though ethnographic analogues are not directly applicable to Palaeolithic cultures (Rifkin 2015b), they create a link between material culture and human behaviour (David and Kramer 2001; O'Connell 1995; Skibo 2009) and are therefore instrumental to bring forward new research questions and possible interpretations of ochre use among past societies.

Significant progress was made in combining different analytical methods for the analysis of ochre assemblages in the past two decades. However, integrated and pluridisciplinary analyses are still relatively rare, particularly in Lower Palaeolithic and ESA contexts, and often focused on specific regions of the world.

Early instances of ochre use

Information on early uses of colouring materials is still scant. The lack of modifications in most early ochre assemblages often makes it difficult to differentiate iron oxides naturally present at a site from ochre pieces brought by humans. In early contexts, it is therefore essential to verify whether iron oxides are part of the sedimentary environment of the studied sites or whether they are exogenous.

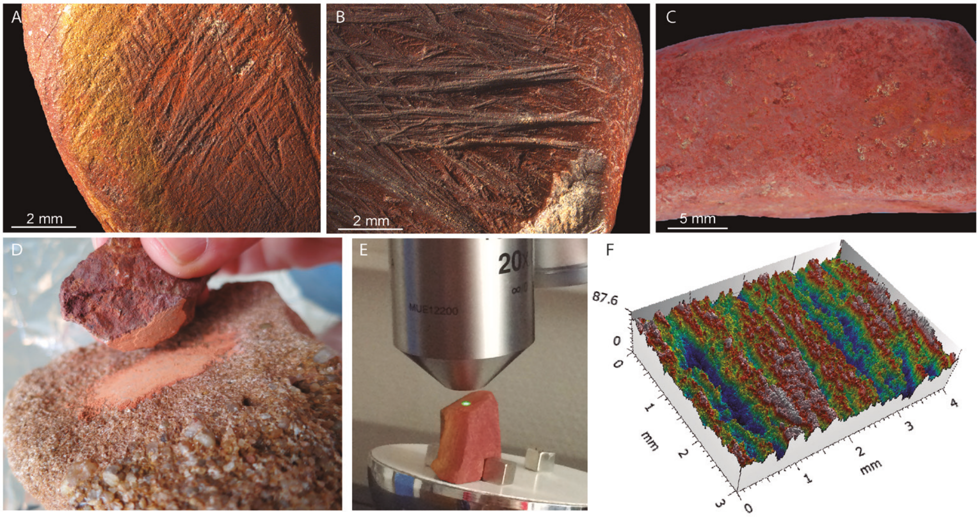

***Fig. 2** – Anthropogenic modifications on ochre pieces from Porc-Epic Cave, Ethiopia (A-C, F) and experimental pieces (D, E). (A, B) Striations produced by grinding and scraping respectively. Photo: D. E. Rosso; (C) Smoothed areas. Photo: D. E. Rosso; (D) Experimental grinding. Photo: F. d'Errico and D. E. Rosso; (E) Confocal microscopy conduced on experimental piece. Photo: D. E. Rosso; (F) 3D image produced by confocal microscopy of ground facet from an ochre piece found at Porc-Epic Cave (Rosso et al. 2017).*

This can be done by using different analytical techniques to characterise the chemical composition of the potential pigment. Contextual information can also be fundamental to determine whether ochre was used by humans, for instance by identifying anthropogenic ochre accumulations in specific areas or archaeological layers.

The earliest evidence of ochre (Appendix 1) would come from archaeological levels dated between 1.5 and 1 million years in two East African sites: fragments of weathered basalt characterised by a red streak were found at Gadeb, Ethiopia (Clark and Kurashina 1979) and two lumps of red ochre were recovered at Olduvai Gorge, Tanzania (Leakey 1958). At Isernia la Pineta, Italy, pebbles with possible traces of ochre were found in levels dated to 610 ka (Coltorti et al. 2005; Cremaschi and Peretto 1988) and at Garba I, Melka Kunture, Ethiopia, a red stain in the sediment, associated with small elongated and rounded ochre lumps were found in levels dated to ca. 500 ka BP (Chavaillon and Berthelet 2004). At Kathu Pan 1, South Africa, modified ochre pieces were found in layers dated to ca. 500 ka (Beaumont and Bednarik 2013; Watts et al. 2016). In Acheulean levels of Kathu Townlands 1, South Africa, possible evidence for retrieval of both specularite and red ochre is reported (Beaumont and Vogel 2006). In the Kapthurin formation, GnJh-15 site, Kenya, possible grindstones stained with ochre and >70 pieces of red ochre are reported in layers dated to 500–284 ka (Deino and McBrearty 2002; McBrearty 2001; McBrearty and Brooks 2000; Tryon and Faith 2013). The site of Terra Amata, France, yielded 77 possible ochre pieces from levels dated to 380–400 ka. Lustred areas were identified on a few pieces and XRD analyses indicate that some of them may have been heated (De Lumley et al. 2016). Evidence for ochre use was also recovered in levels dated to >350 ka at Ambrona, Spain, in the form of a slab of ochre, possibly shaped by trimming (Howell 1966; Pérez-González et al. 1999). At Olorgeisailie, Kenya, 86 lumps of potential black pigment and two red ochre pieces (Fig. 1A) are reported in levels dated from ≥295 to ~320 ka, (Brooks et al. 2018). Geochemical

***Fig. 3** – An ethnographic example of ochre use: the Hamar of Southern Ethiopia. Photos: D. E. Rosso (Rosso 2017). (A) Raw material acquisition; (B) Unmodified ochre pieces; (C, D) Ochre processing; (E) Ochre powder application for traditional hairstyle; (F) Hamar traditional hairstyle.*

analyses show that these rocks are exogenous. Both ochre pieces show striations produced by grinding. One also bears a possible attempted perforation and the other anthropogenic notches. At Kabwe (Broken Hill), Zambia, one piece of weathered hematite with no visible modifications and one rounded stone featuring a reddish brown residue and interpreted as a possible grindstone were found in levels that are probably 300 ka old (Clark et al. 1947). 497 pieces of yellow, brown, red, purple, pink, and blue-black rocks, interpreted as potential pigments were found at Twin Rivers, Zambia, associated with pigment processing tools in levels dated to 300–140 ka (Barham 1998, 2000, 2002; Clark and Brown 2001; Zipkin et al. 2014a). Geochemical analyses suggest a preferential exploitation of exogenous minerals (Zipkin et al. 2014a). At Canteen Kopje, South Africa, two ochre pieces, one of which bears anthropogenic modifications, were recovered in levels dated to ca. 300 ka (Watts et al. 2016) and a ground piece of hematite is reported at Nooitgedacht, South Africa from an apparently pre-MSA context (Beaumont 1990a; Watts et al. 2016). Evidence for ochre use was also found at Hungsi, India, in levels dated to 200–300 ka (Paddayya 1976). A lump of red ochre identified as hematite is reported at Duinefontein 2, South Africa, in levels dated to 270–290 ka (Cruz-Uribe et al. 2003). At Pniel 6, South Africa, half a dozen hematite fragments, some of which were slightly smoothed, were found in Early Middle Stone Age levels (Beaumont 1990b; Beaumont and Bednarik 2013).

Around 250–170 ka, ochre use seems more frequent. In Europe, one rubbed ochre piece was found in layers dated to ca. 250 ka ago at Achenheim, France (Bednarik 2014; Thévenin 1976). Possible ochre pieces and grindstones, apparently used to process pigments, were found in early Mousterian levels (250–200 ka) at Beçov I, Czech Republic (Marshack 1981; Šajnerová-Dušková et al. 2009; Trabska et al. 2010). Small concentrates of red material identified as non-local hematite were detected in archaeological levels dated to >200–250 ka at Maastricht-Belvédère, Netherlands (Roebroeks et al. 2012).

In Africa, ochre fragments and tools bearing ochre residues were recovered in Tuff K4, Kapthurin Formation, Kenya, in levels dated to more than 250 ka (McBrearty and Brooks 2000). Small (~220–2970 μm) red and orange grains detected in grass beddings in layers dated to 200 ka at Border Cave, South Africa, were tentatively identified as ochre resulting from processing activities, or from contact with painted human skin or objects. However, chemical analyses could not exclude a possible natural origin of these iron oxides (Wadley et al. 2020). At the same site, one ochre piece is reported in levels dated to >227 ka, and a systematic use of ochre was observed between ca. 170 and 150 ka (Watts 2009). At Kalambo Falls, Zambia (Barham et al. 2015; Clark et al. 2001; Duller et al. 2015), red, yellow and white potential pigments sometimes showing anthropogenic modifications, and grindstones with no ochre residues were found in levels probably dated around 200 ka. At Wonderwerk Cave, South Africa (Watts et al. 2016), secure evidence for ochre use found in levels dated to >187 ka consists of four specularite pieces, of which two are utilised, a ground piece of weathered iron hydroxide and two pieces of hematite, of which one is possibly modified. Other possible evidence of ochre use at this site includes one scraped piece of weathered dolomite and an incised ironstone slab. Yellow and red ochre pieces associated with ochre processing tools (sandstone mortars shaped by knapping and small chert pebbles bearing yellow and red residues) were recovered in MSA levels of site Sai 8-B-11, at Sai Island, Sudan (Van Peer et al. 2003, 2004), dated to ca. 180 ka. Gouged, rubbed, and flaked limonite and specularite pieces and colour-bearing sandstones possibly used as pigments were found in Mumbwa, Zambia (Barham 2000), in levels dated around 172–30 ka.

Systematic use of ochre from 160 ka to the end of the Middle Palaeolithic and MSA

Ochre pieces with clear anthropogenic modifications and coloured residues on different types of artefacts become recurrent features around 160 ka, in Europe, in the Middle East and in Africa. Evidence for ochre use during this period usually consists of modified lumps or residues on processing tools or other artefacts.

In Europe, Neanderthals systematically used mostly black (Bonjean et al. 2015; Pitarch Martí et al. 2019) but also red colouring materials well before the arrival of *Homo sapiens*. A large number of Mousterian sites yielded evidence for a systematic use of ochre, such as: Cueva de los Aviones, Cueva Antón (Fig. 1L) (Zilhão et al.

2010), Cueva Ardales (Ramos-Muñoz et al. 2022), Cueva del Castillo and Cueva Morín (Kraybill 1977) in Spain, Combe-Grenal (Fig. 1K) (Dayet et al. 2019), Ormesson (Bodu et al. 2014), Pech de l'Azé (Pitarch Martí and d'Errico 2018; Soressi and d'Errico 2007; Soressi et al. 2008), Le Moustier (Peyrony 1930; Pitarch Martí and d'Errico 2018), La Micoque, La Chapelle-aux-Sains, La Grotte de l'Ermitage, la Quina, la Ferrassie (Demars 1992) in France; Fumane Cave (Fig 1M) in Italy (Peresani et al. 2013), among many others. Research has shown that the last Neanderthals used large quantities of red and black pigments. Cases in point are the Chatelperronian sites of Grotte du Renne or Roc-de-Combe in France (Caron et al. 2011; Dayet et al. 2014). Although this view has been contested (Aubert et al. 2018; Slimak et al. 2018; White et al. 2020), it has been proposed that Neanderthals may also have used pigments to produce cave art (Hoffmann et al. 2018; Pitarch Martí et al. 2021; Ramos-Muñoz et al. 2022).

In the Near East, convincing evidence for the use of colouring materials has been found in levels dated around 100 ka at Qafzeh and Es-Skhul (Israel). Some pieces appear to have been heated to modify their colour (d'Errico et al. 2010; Godfrey-Smith et Ilani 2004; Hovers et al. 2003; Salomon et al. 2012).

During the MSA in Africa, examples of an intensive and recurrent use of ochre by early *Homo sapiens* are numerous. Ochre pieces with striations produced by grinding, scoring or scraping, and ochre-stained grindstones are frequent. Engraved ochre pieces are also found (Fig. 1B), but are not a common feature (Henshilwood et al. 2009; Hodgskiss 2010; Watts 1999, 2002).

Studies on ochre use have been conducted mostly in South Africa. Blombos Cave's MSA levels, dated to ca. 100–72 ka, yielded a collection of more than 8000 ochre pieces weighing approximately 5.8 kg (Henshilwood et al. 2001, 2002, 2009; Moyo et al. 2016; Watts 2009). Modifications, including striations, grooves, scraping marks, percussion pits, possible traces of handling and abstract engravings (Fig. 1B), were identified on a large number of pieces (Henshilwood et al. 2001, 2002, 2009; Rifkin 2012; Watts 2009). Henshilwood et al. report two toolkits used for the production and storage of ochre-rich compounds, found in layers dated to 100 ka (Henshilwood et al. 2011). They included two large abalone shells containing an ochre-rich compound found in close proximity to modified ochre lumps, bones, as well as upper and lower grindstones. A silcrete flake displaying a cross-hatched pattern drawn on with an ochre crayon from 73,000-year-old levels was also found (Henshilwood et al. 2018). At Pinnacle Point Cave 13B (McGrath et al. 2022; Watts 2010), 380 ochre pieces (1.08 kg) from layers dated to ca. 164–91 ka were analysed. Possible evidence for the heating of ochre, and a preference for dark red shades have been identified. In MSA levels of Diepkloof Rockshelter dated to 110–55 ka, several thousand ochre pieces were recovered (Dayet et al. 2016). Some of them show modifications including striations, smoothed areas, and flaking. One piece is engraved. The analysis of 558 pieces (1.9 kg) identified different types of rocks, with the presence of exogenous raw materials suggesting complex mobility patterns. Quartzite slabs and silcrete flakes bearing ochre residues may have been used as processing tools. At Sibudu, South Africa, levels dated between 77.2 ± 2.6 ka – 37.6 ± 2.6 ka (Jacobs et al. 2008a,b; Wadley 2007; Wadley and Jacobs 2006), yielded 5449 pieces of ochre (>8mm, 15,4 kg) and 3837 small pieces. Modifications produced by grinding, rubbing and scoring were identified, mostly on bright red ochre fragments (Hodgskiss 2010, 2012, 2013). A few pieces are described as engraved (Hodgskiss 2014). Cemented hearths with significant ochre deposits in layers dated to ca. 58 ka have been interpreted as receptacles for ochre powder or work surfaces (Wadley 2010b). Sandstone slabs and other lithic artefacts with ochre residues were also recovered (Soriano et al. 2009; Wadley 2005; Wadley et al. 2004; Williamson 2004; Wojcieszak and Wadley 2018, 2019). The analysis of residue adhering to a dolerite flake allowed the identification of a compound including ochre and milk casein in layers dated to 49 ka BP (Villa et al. 2015). At Klasies River Cave 1, 314 ochre pieces (Figs. 1C,D) were recovered from MSA levels dated between 115 and 55 ka (d'Errico et al. 2012; Dayet Bouillot et al. 2017). Some show grinding and scraping marks, and one is engraved. Results indicate that some pieces may have been intentionally heated. Other sites that yielded important ochre assemblages in South Africa include Hollow rock shelter (Högberg and Larsson 2011), Die Kelders (Thackeray 2000), Rose Cottage Cave (Hodgskiss and Wadley 2017), Hoedjiespunt (Will et al. 2013), Klipdrift Shelter (Henshilwood et al. 2014), Klein Kliphuis (Mackay and Welz 2008), Apollo 11 (Rifkin et al. 2016), Mwulu Cave (de la Peña et al. 2019), Olieboompoort (Watts 1998) and Wonderkrater (Backwell et al. 2014).

The presence of ochre is also reported in East Africa, but systematic studies of these collections are rare. At Panga ya Saidi, Kenya, 17 ochre fragments (Fig. 1E) were found in layers dated to ca. 14.5–48 ka (d'Errico et al. 2020; Shipton et al. 2018). Two of those, recovered in layers dated to ca. 25–48 ka, bear modification marks. Evidence for ochre use was also found at Enkapune Ya Muto in Kenya (Ambrose 1998); Mumba (Conard 2012; Diez-Martín et al. 2009; Gliganic et al. 2012; Mehlman 1989; Prendergast et al. 2007; Tryon and Faith 2013), Nasera (Mehlman 1989; Tryon and Faith 2013; Tryon and Ranhorn 2018) and Kisese II (Inskeep 1962; Leakey 1983; Tryon et al. 2018) rockshelters in Tanzania; Mochena Borago Rock Shelter (Brandt et al. 2012), Gorgora Rock Shelter (Clark 1988; Leakey 1943; Moysey 1943), Aduma (Yellen et al. 2005) and Goda Buticha (Leplongeon 2014; Pleurdeau et al. 2014; Tribolo et al. 2017) in Ethiopia. A significant example of the intensification of ochre use after 100 ka is Porc-Epic Cave, Ethiopia, that yielded a substantial MSA ochre assemblage, comprised of 40 kg of ochre (n = 4213 pieces, Figs. 1F,G), 21 ochre processing tools (Figs. 1H,I) and two ochre-stained artefacts (Fig. 1J) from levels dated to ca. 40 ka cal BP (Rosso et al. 2014, 2016, 2017). The analysis of the spatial distribution of this assemblage allowed the identification of possible areas devoted to ochre processing. The variety of raw materials and processing techniques, including flaking, grinding, scraping and pounding, showed that ochre powders of different coarseness and shades were used for a variety of functions. Chemical analyses of the residues identified on the grindstones demonstrate that these tools were used to process different types of ochre. Microscopic analyses show that some ochre pieces were curated and ground at different times to produce small quantities of red powder, which seems to be more consistent with symbolic activities. In addition, a round pebble with half its surface covered with ochre and no use-wear related to ochre processing was found (Fig. 1J). Possibly used as a stamp to create patterns or apply pigment to soft materials, this object also supports the hypothesis that ochre was utilised in symbolic practices at Porc-Epic Cave.

In other regions of the African continent, research on ochre use is even scarcer, although ochre use is reported in MSA layers of a number of sites, such as Sehonghong, Lesotho (Carter et al. 1988), ≠Gi, Botswana (McBrearty and Brooks 2000), Nswatugi, Pomongwe, Bambata and Zombepata, Zimbabwe (Cooke 1971; Cooke et al. 1966; Larsson 1996; McBrearty and Brooks 2000; Walker 1995; Watts 2009) and Songona I, Mali (Huysecom et al. 2008, 2009). In North Africa, evidence for ochre use is reported at Grotte des Pigeons, Taforalt, in Morocco (Bouzouggar et al. 2007; d'Errico et al. 2009), in levels dated to 82 ka.

Sahul and Asia have often been neglected in global narratives on the emergence of complex behaviour (Langley et al. 2019, 2020) but recent studies have shown that ochre was also used in these regions during the Palaeolithic. In Asia, one piece of ground ochre was found at Jwalapuram, India (Petraglia et al. 2007), in 74,000-year-old layers. Red, yellow and "silver" mica-rich ochre pieces were found in the Sri-Lankan site of Fa-Hien Lena, in levels dated to 48 ka (Langley et al. 2020). Ochre pieces displaying anthropogenic modifications were collected from levels dating to around 40,000 cal BP at Jerimalai, Timor-Leste (Langley and O'Connor 2019). In China, the earliest known evidence for ochre processing was found at Xiamabei in levels dated to ca. 40 ka (Wang et al. 2022) and consists of two ochre pieces, one of which bears clear traces of having been repeatedly abraded, and one limestone slab preserving residues of hematite-rich ochre. These three artefacts were lying on a spot of red-stained sediment. At Zoukoudian Upper Cave and Shuidonggou Locality 2, evidence for ochre use was also found, dating back to 34–29 ka cal BP and 31.3–29.9 ka cal BP respectively (Pitarch Martí et al. 2017). In Sahul, the first evidence for ochre use was found at Madjedbebe, Australia. Ground ochre was recovered in levels dated between 65.0 ± 5.7 and 52.7 ± 4.3 ka and possibly in levels dated to 80.2 ± 9.0 to 71.0 ± 7.3 ka (Clarkson et al. 2015, 2017), although this chronology was contested by some (O'Connell et al. 2018).

Discussion and conclusion

Although there is a growing interest in Palaeolithic ochre use, there are still many gaps in our knowledge on how this cultural feature emerged and spread in different areas of the world.

Among Lower Palaeolithic and ESA ochre collections, a few cases have been studied systematically (Brooks et al. 2018; De Lumley et al. 2016; Roebroeks et al. 2012; Watts et al. 2016; Zipkin et al. 2014a). However, most cases of early evidence for colour use by different members of our lineage were recovered during excavations conducted several decades ago, when ochre was not documented systematically. Gadeb, Ethiopia (Clark and Kurashina 1979), Olduvai Gorge, Tanzania (Leakey 1958), Isernia la Pineta, Italy, (Coltorti et al. 2005; Cremaschi and Peretto 1988), Kabwe, Zambia (Clark et al. 1947), Ambrona, Spain (Howell 1966), Hungsi, India (Paddayya 1976) and Achenheim, France (Bednarik 2014; Thévenin 1976) are some of the sites where ochre remains were briefly mentioned in the literature, but for which there is no detailed evidence to support the anthropogenic nature of these findings. Excluding a few exceptional cases (Brooks et al. 2018; De Lumley et al. 2016), ochre remains in Lower Palaeolithic and ESA contexts rarely feature clear modification marks. It is therefore essential to determine whether the ochre is natural or whether it was brought by humans to the sites. This can be evaluated by using different analytical techniques and by studying the context in which ochre remains were found (Roebroeks et al. 2012). However, this cannot be done when reassessing ochre collections that were not recovered in recent excavations. The same problem affects the analysis of raw material transformations, for example thermally induced transformation of goethite into hematite. While TEM and XRD analyses can determine whether an ochre piece has been heated (Pomiès et al. 1999), it is very difficult to demonstrate the intentionality of this transformation without detailed contextual data (Salomon et al. 2015). Finally, some early cases of ochre use are questioned for dating issues (Roebroeks et al. 2012; Wreschner et al. 1980) and often cannot be reassessed as their current location is in many cases unknown.

In MSA and Middle Palaeolithic contexts, systematic analyses of ochre assemblages are more frequent, but they tend to focus on specific regions, resulting in a biased view on how ochre use appeared and spread throughout the world. In South Africa, discoveries in key MSA sites such as Blombos (Henshilwood et al. 2001) or Sibudu Cave (Wadley and Jacobs 2006) among many others have led to significant advances in research on the emergence of complex cultures (Conard 2008). Although evidence for ochre use was found in other areas of the African continent, their analysis is rarely systematic. The question of whether Neanderthals shared our capacity to create and manipulate symbols has also favoured studies in ochre use, mostly focused in Southwestern Europe. Other regions of the world, including Asia and Sahul, are rarely mentioned in reviews on ochre use in Palaeolithic contexts. Cultural adaptations associated with human fossil species and the incoming populations of *Homo sapiens* into these regions remain unclear (Bae 2017).

Another important issue in ochre studies is that there are few cases in which the spatial and stratigraphic distribution of ochre fragments is used to identify changes in ochre processing through time and detect specialised activity areas (Caron et al. 2011; Dayet et al. 2014; Roebroeks et al. 2012; Rosso et al. 2014; Salomon et al. 2015; Zilhão et al. 2010). This is either due to a bias in the methodology used to study ochre assemblages in multistratified sites, or to the lack of ochre collections large enough to explore diachronic shifts in ochre processing technology and function (Rosso et al. 2014).

Despite these issues, research in the past few years has brought new essential data to our understanding of Palaeolithic ochre use. First of all, it has been shown that the use of colouring materials began well before the emergence of anatomically modern humans, among different human fossil species. Between 1.5 million years and 300 ka, evidence for ochre use is still punctual and sparse in Europe and Africa. At this stage, ochre rarely features clear anthropogenic modifications and issues related to their dating and context make it often difficult to confirm that they were used by humans. Around 300-250 ka, secure evidence proves that ochre was collected from far away sources and processed by humans. It is only from 160 ka onwards that ochre use becomes ubiquitous, among the first anatomically modern humans and Neanderthals. Complex technical behaviours are observed: intentional heating to modify the colour of pigments, selection of specific colour shades, use of diverse processing tools and techniques including grinding, scraping, scoring and pounding to produce different types of ochre powders, and production of complex ochre-rich compounds. The presence of crayon-shaped ochre pieces featuring micro-faceting on the tip and polished surfaces may indicate respectively a use of ochre to produce drawn coloured lines and a direct application on soft materials (Hodgskiss 2020). Archaeological evidence shows that ochre was probably used for both functional and symbolic activities (see above).

Looking at evidence around the world, it has been highlighted that there is a substantial time lag is between the anatomical evolution of our species and the appearance of cultural innovations (Wadley 2021) and that between 160 ka and 20 ka, systematic use of ochre, along with other cultural traits such as engravings, personal ornaments, bone tools and other complex technologies appear, disappear and reappear from the archaeological record, suggesting that cultural transmission and complex behaviour follow discontinuous and non-linear trajectories, probably triggered by social, demographic and environmental factors, that to this day are still unknown to us (d'Errico and Stringer 2011; Scerri et al. 2018). Retracing cultural paths followed by different human fossil species, investigating when these populations started using colour and how this feature evolved through time may therefore be instrumental to understand this crucial stage in the evolution of our lineage.

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***Appendix 1** - Potential early evidence for ochre use (before 160 ka).*

SITE	LOCATION	OCHRE PIECES	GRINDSTONES/ OCHRE-STAINED ARTEFACTS	OCHRE STAINS IN SEDIMENT/ OCHRE MICROFRAGMENTS	CHRONOLOGY	REFERENCES
Gadeb	Ethiopia	Weathered basalt with red streak	-	-	1–1.5 Ma	Clark and Kurashina 1979
Olduvai Gorge	Tanzania	Two lumps of red ochre	-	-	1–1.5 Ma	Leakey 1958
Isernia la Pineta	Italy	-	Pebbles with possible ochre residues	-	ca. 610 ka	Cremaschi and Peretto 1988
Garba I, Melka Kunture	Ethiopia	Ochre pieces	-	Red stains in sediment	ca. 500 ka	Chavaillon and Berthelet 2004
Kathu Pan 1	South Africa	Modified ochre pieces	-	-	ca. 500 ka	Beaumont and Bednarik 2013; Watts et al. 2016
Kathu Townlands 1	South Africa	Specularite and red ochre	-	-	Acheulean	Beaumont and Vogel 2006
Kapthurin formation, GnJh-15	Kenya	>70 pieces of red ochre	Possible grindstones with ochre residues	-	284–500 ka	Deino and McBrearty 2002; McBrearty 2001; McBrearty and Brooks 2000
Terra Amata	France	77 ochre pieces (some possibly modified)	-	-	380–400 ka	de Lumley et al. 2016
Ambrona	Spain	Slab of ocre, possibly shaped by trimming	-	-	>350 ka	Howell 1966
Olorgeisailie	Kenya	86 lumps of potential black pigment and two modified red ochre pieces	-	-	~320 to ≥295 ka	Brooks et al. 2018
Kabwe, Broken Hill	Zambia	One piece of weathered hematite	One rounded stone with reddish brown residue	-	300 ka	Clark et al. 1947
Twin Rivers	Zambia	497 pieces of yellow, brown, red, purple, pink, and blue-black pigments	-	-	300–140 ka	Barham 2002; Clark and Brown 2001; Zipkin et al. 2014a
Canteen Kopje	South Africa	Two ochre pieces (one modified)	-	-	ca. 300 ka	Watts et al. 2016
Nooitgedacht	South Africa	Ground piece of hematite	-	-	Pre-MSA	Beaumont 1990a; Watts et al. 2016
Hungsi	India	Evidence for ochre use	-	-	200–300 ka	Paddayya 1976
Duinefontein 2	South Africa	One lump of red ochreous pigment	-	-	270–290 ka	Cruz-Uribe et al. 2003

***Appendix 1* - Continued.**

SITE	LOCATION	OCHRE PIECES	GRINDSTONES/ OCHRE-STAINED ARTEFACTS	OCHRE STAINS IN SEDIMENT/ OCHRE MICROFRAGMENTS	CHRONOLOGY	REFERENCES
Pniel 6	South Africa	6 hematite fragments (some slightly smoothed)	-	-	Early MSA	Beaumont 1990b; Beaumont and Bednarik 2013
Achenheim	France	One rubbed ochre piece	-	-	ca. 250 ka	Bednarik 2014; Thévenin 1976
Beçov I	Czech Republic	Possible ochre pieces	Grindstones	-	250–200 ka	Šajnerová-Dušková et al. 2009; Trabska et al. 2010
Tuff K4, Kapthurin Formation	Kenya	Ochre pieces	Tools with ochre residues	-	>250 ka	McBrearty and Brooks 2000
Maastricht-Belvédère	Netherlands	-	-	Small concentrates of hematite	>200–250 ka	Roebroeks et al. 2012
Border Cave	South Africa	One ochre piece	-	Small red and orange grains in grass beddings	>227 ka / 200 ka	Watts 2009; Wadley et al. 2020
Kalambo Falls	Zambia	Red, yellow and white pigments (some are modified)	Grindstones with no ochre residues	-	ca. 200 ka	Barham et al. 2015; Clark et al. 2001; Duller et al. 2015
Wonderwerk Cave	South Africa	Secure evidence: four specularite pieces (two modified), a ground piece of weathered iron hydroxide and two pieces of hematite (one modified). Possible evidence: one scraped piece of weathered dolomite and an incised ironstone slab	-	-	>187 ka	Watts et al. 2016
Sai 8-B-11, Sai Island	Sudan	Yellow and red ochre pieces	Sandstone mortars shaped by knapping and small chert pebbles with yellow and red residues	-	ca. 180 ka	Van Peer et al. 2003, 2004
Mumbwa	Zambia	Gouged, rubbed, and flaked limonite and specularite pieces and colour-bearing sandstones possibly used as pigments	-	-	ca. 172–30 ka	Barham 2000