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Abstract

Bone tool-use by Early Pleistocene hominins is at the center of debates in human evolution. It is especially the case in South Africa, where 102 bone tools have been described from four Early Stone Age (ESA) archaeological sites, which have yielded Oldowan and possibly Acheulean artefacts, as well as *Paranthropus robustus* and early *Homo* remains. Here we describe a bone tool from Cooper's D. The deposit, dated between 1.4 and 1.0 Ma, has yielded seven *P*. *robustus* remains and 50 stone artefacts. Our results highlight similarities in morphology and use-wear patterns between the Cooper's D bone tool and those previously identified at nearby Sterkfontein, Swartkrans, Kromdraai and Drimolen. Our findings increase the number of Early Stone Age bone tools and provide further evidence of their association with *P*. *robustus*. They suggest *P*. *robustus* had the cognitive capacities to develop this cultural adaptation and the manipulative abilities to implement it.

1. Introduction

Although formal bone tools, i.e. tools entirely or almost entirely shaped with techniques specifically conceived for bone material such as scraping, grinding and grooving, are well known in the Eurasian Upper Palaeolithic and the African Later Stone Age, it is only in the last twenty years that we have begun to have information on the origin of this cultural innovation (Backwell and d'Errico, 2001; d'Errico et al., 2012, 2020). Early instances are found at Middle Stone Age sites from southern, northern, and central Africa (Brooks et al., 1995, 2006; Yellen et al., 1995; Henshilwood et al., 2001; Backwell et al., 2008, 2018; d'Errico et al., 2012, 2020; El Hajraoui and Debénath, 2012; Backwell and d'Errico, 2015). More debated issues concern the first use of bone modified with techniques generally applied to stone such as knapping (Backwell and d'Errico, 2004; Zutovski and Barkai, 2016; Doyon et al., 2020; Pante et al., 2020; Porraz et al., 2020), and the use of minimally modified bone fragments. Ever since the discovery of the species *Australopithecus africanus*, referred to then as *A. prometheus*, Dart (1949, 1957, 1959a, b, 1960, 1961a, b, 1962) proposed that this hominin was able to use bone as a tool. He referred to the bone collection from Makapansgat as the "osteodontokeratic culture". Dart's 'bone tool' hypothesis was challenged by the work of Brain (1967a, 1967b, 1976, 1981), Mills (1973), Mills & Mills (1977), Skinner (1976) and Klein (1975), who emphasized the role of natural agents, particularly hyaena, in the production of pseudo-tools. While maintaining his opinion on the highly questionable nature of the Makapansgat "bone tools", it was the same Brain who published the discovery of 68 bone tools from the hominin site of Swartkrans (Brain & Shipman 1993). Since then, evidence for the existence of an early bone tool technology at Early Stone Age (ESA) sites in South Africa has grown (Brain, 1967; Brain et al., 1988; Brain and Shipman, 1993; Backwell, 2000; Backwell and d'Errico, 2001, 2001, 2003, 2005, 2008; d'Errico et al., 2001; d'Errico and Backwell, 2003, 2009; Stammers et al., 2018). A growing body of data indicate that these tools mostly consist of weathered limb bone shaft fragments of medium to large size animals with a worn and polished area at the tip (Brain and Shipman, 1993; Backwell and d'Errico, 2001, 2008). According to d'Errico et al. (2001) and Backwell and d'Errico, (2001), Swartkrans bone tools are characterized by a single rounded end with a smoothed/polished area ranging from 5 to 50 mm from the tip. At microscopic scale, 5-40 μm wide sub-parallel, overlapping striations oriented along the main axis of the tool cover the smoothed area. Broader striations are visible, transverse to the main axis of the bone, with a width ranging from 100 to 400 μm. These bones mainly derived from medial portions of long bone shafts from medium (size-class II-III) to large-size (size-class III-IV) class mammals (Brain and Shipman, 1993; Backwell and d'Errico, 2003). They have been interpreted as digging sticks used to forage for termites and plant roots, and possibly to process fruit (d'Errico and Backwell, 2009). To date, four South African sites have yielded definitive evidence of early hominin bone tool technology, namely Sterkfontein, Swartkrans, Drimolen and Kromdraai, all situated in the Cradle of Humankind UNESCO World Heritage Site, located northwest of Johannesburg (Figure 1).

Here, we provide a description of the first bone tool from the *P. robustus*-bearing deposit of Cooper's D. This site is dated between 1.4 and 1.0 Ma (see below), a timespan that fills the chronological gap between Swartkrans Members 2 and 3. This paper also provides descriptions of associated pseudo-tools from Cooper's D, some of which feature a similar rounded tip morphology, but lacking diagnostic traces of utilisation, and a discussion of South African ESA bone tools.

1.1. Bone tools from Early Stone Age deposits in South Africa

Robinson (1959) was a pioneer as he was the first to identify a bone tool from the Cradle of Humankind, from Sterkfontein Member 5 West, Acheulean Infill. In his original paper in 1959, this author proposed that *Telanthropus* (attributed today to *Homo*) was the most probable stone and bone toolmaker. The deposit has been dated by paleomagnetism to between 1.3 and 1.1 Ma, and has yielded *Homo* remains associated with Acheulean stone tool technology (Kuman and Clarke, 2000; Herries and Shaw, 2011). Subsequent studies provided descriptions of additional bone tools from the site of Swartkrans Members 1 to 3 (Brain et al., 1988; Brain, 1993; Brain & Shipman 1993; Backwell and d'Errico, 2001, 2003; d'Errico and Backwell, 2003), and then from Drimolen (Backwell and d'Errico 2008), Krombraai B (Stammers et al., 2018) and possibly the Sterkfontein Name Chamber (Val and Stratford, 2015). Based on these studies, 102 bone tools have been identified at four South African early hominin sites.

The bone tool-bearing deposits cover a time span of almost one and a half million years (2.4-0.96 Ma). Drimolen Main Quarry (MNQ) has been recently dated *c*. 2.04 – 1.95 Ma (Herries et al., 2020). In the MNQ, the bone tools are associated with both *Homo* and *Paranthropus robustus* remains, as well as Oldowan stone artefacts (Keyser et al., 2000; Moggi-Cecchi et al., 2010; Stammers et al., 2018). A similar situation occurs for Swartkrans Member 1 (Brain, 1993; d'Errico and Backwell, 2003; Caruana, 2017), which is dated between 2.4 and 1.8 Ma (Pickering et al., 2019). In Member 2 of Swartkrans, dated *c*. 1.4 Ma, an Acheulean stone tool industry is found associated with bone tools and both *Homo* and *P*. *robustus* remains (Brain, 1993; d'Errico and Backwell, 2003; Kuman, 2007; Balter et al., 2008). The largest collection of bone tools was found in Swartkrans Member 3, which is dated *c*. 0.96 Ma, associated with an Acheulean Industry and only *P*. *robustus* remains (Brain, 1993; d'Errico and Backwell, 2003; Kuman, 2007; Gibbon et al., 2014). Two bone tools have been described from the

Kromdraai B site, which has yielded only two stone tools and *P. robustus* remains (Kuman, 2007; Braga et al., 2017; Stammers et al., 2018). The age of this deposit is unresolved, but it is thought to be >2.2 Ma (Bruxelles et al., 2017). Finally, one bone tool is reported from the newly excavated area of the Sterkfontein Name Chamber (Val and Stratford, 2015), but we still lack photographic evidence supporting its identification, and the age of the deposit is unclear; a mixture of Members 4 (2.95-1.95 Ma; Pickering and Kramers, 2010) and 5 East Oldowan (2.18±0.21 Ma; Granger et al., 2015).

1.2. Cooper's D site

Cooper's Cave is located in the UNESCO Sterkfontein, Swartkrans, Kromdraai and Environs World Heritage Site in South Africa, at 1.5 km northeast of Sterkfontein, 1 km southwest of Kromdraai, and 45 km northwest of Johannesburg (Figure 1) (Berger et al., 2003; de Ruiter et al., 2009). These cave deposits occur on dolomite of the Monte Cristo Formation (Malmani Subgroup, Transvaal Supergroup) and yield abundant fossil assemblages in both calcified and decalcified breccias (Berger et al., 2003; Steininger et al., 2008; de Ruiter et al., 2009).

Excavations at Cooper's between 2001 and 2009, were conducted in decalcified sediments, which has preserved an abundant fossil assemblage of large and small vertebrates (n >50,000), stone tools (n = 49), and seven hominin remains, six of them attributed to *Paranthropus robustus* (Berger et al., 2003; Steininger et al., 2008; de Ruiter et al., 2009; Sutton et al., 2017). The first radiometric uranium-lead (U-Pb) dates estimated the age of the basal speleothem to be 1.526±0.088 Ma (de Ruiter et al., 2009). A flowstone layer situated in the middle of the deposit was dated to *c*. 1.4 Ma. A more recent study based on the resampling of the basal speleothem for U-Pb dating gives an age of the basal speleothem to be 1.375±0.113 Ma (Pickering et al., 2019). A minimum age of 1.0 Ma for the deposit is proposed by Hanon (2019), based on biochronological data from the large mammal assemblage. Thus, we assume that the Cooper's D material from decalcified sediments accumulated between *c*. 1.4 and 1.0 Ma.

Two previous taphonomic studies were conducted on large mammal sub-assemblages at Cooper's D (de Ruiter et al., 2009; Val et al., 2014). The first one focused on a sub-sample of the large mammal assemblage, and suggested that a hyaenid – particularly the brown hyaena (*Parahyaena brunnea*) – was the main accumulating agent of the faunal deposit (de Ruiter et al., 2009). The second study relied on the large-bodied primate assemblage to suggest that both leopards and hyaenas were the most probable accumulating agents (Val et al., 2014). These two studies did not report any bone surface modifications consistent with damage produced by hominins through carcass exploitation or the use of bone tools.

The first extensive taphonomic study of the Cooper's D large mammal assemblage, conducted by one of us (Hanon, 2019), led to the identification of butchery marks and potential bone tools that are the subject of the present study.

2. Materials and methods

Between 2017 and 2018, we undertook a taphonomic study of the entire large mammal faunal assemblage, composed of 21,193 specimens housed at the Evolutionary Studies Institute, University of Witwatersrand, Johannesburg. For our anatomical and taxonomic identifications, we used the modern osteological collection housed in the same institution. We also compared Cooper's material to the modern collections and fossil assemblages from Sterkfontein, Swartkrans and Kromdraai, housed at the Ditsong National Museum of Natural History, Tswane (formerly Pretoria). Potential bone tools identified during the taphonomic study of the Cooper's D assemblage were macro- and microscopically compared with previously identified bone tools from Swartkrans housed at the Ditsong National Museum of Natural History, and those published from Sterkfontein, Drimolen and Kromdraai.

All specimens from the large Cooper's D faunal collection were observed using an Olympus SZ51 binocular microscope (10-40x magnification). We recorded the following bone modifications: fracture pattern, weathering stage, cortical preservation state, abrasion and polish, manganese coating, decalcification, concretion, compaction, carnivore and rodent tooth marks, trampling and butchery marks, microbial damage and insect modification. These identifications were made based on criteria developed by several authors (e.g. Behrensmeyer, 1978; Binford, 1978; Brain, 1980, 1981; Maguire et al., 1980; Potts and Shipman, 1981; Shipman and Rose, 1983, 1983; Behrensmeyer et al., 1986; Hill, 1987; Blumenschine, 1988; Blumenschine and Selvaggio, 1988; Olsen and Shipman, 1988; Fiorillo, 1989; Cruz-Uribe, 1991; Villa and Mahieu, 1991; Lyman, 1994; Blumenschine et al., 1996; Patou-Mathis, 1997; Kaiser, 2000; Pickering, 2002; Domínguez-Rodrigo et al., 2009, 2010; Kuhn et al., 2010; Backwell et al., 2012; Fourvel, 2012; Bountalis and Kuhn, 2014; Huchet, 2014; Parkinson, 2016). The results of this comprehensive taphonomic analysis will be published elsewhere (Hanon et al., in prep.). This led us to identify 12 possible bone tools featuring morphological characters matching, to some extent, those published by Backwell and d'Errico (2001, 2004) and Pante et al. (2020). These pieces were photographed with a Dino-Lite AD7013MTL digital microscope (20-100x magnification) and an Olympus SZX 16 multifocal microscope coupled to a digital camera (7-115x magnification).

Selected areas of these specimens were moulded with a silicone dental elastomer (Coltène President light body) and analysed with the Tescan Vega 2 LSU scanning electron microscope (SEM) housed at the *Muséum national d'Histoire naturelle* electron microscopy and microanalysis technical platform, Paris. The resin replicas were not metal coated, and all the images were taken using 15.00 kV, 25 Pa and a view field ranging from 15 to 1 mm with a LVSTD detector. Transparent replicas were made with the MA2+ resin (PRESI, France). These casts were examined in reflected and transmitted light using a motorized Leica Z6 APOA microscope equipped with a DFC420 digital camera and the Leica Application Suite (LAS) software, including the multifocal module (4-40x magnification). This microscope used digital images acquired at variable heights and combined them to obtain a single composite image with an extensive depth of field. As a reference we used descriptions and images of early hominin bone tools from South Africa provided by the literature, and experimental counterparts used in tasks such as digging in different sedimentary environments, digging for termites, plant roots, and fruit processing (Backwell and d'Errico, 2001, 2004, 2008; d'Errico and Backwell, 2003, 2009).

3. Results

Examination of the 21,193 large mammal bone specimens resulted in the selection of 12 potential bone tools (Table 1). Two bones were identified as fragments of bovid metapodials. The rest of the specimens are unidentifiable to taxonomic level and skeletal element. Most of the bones belong to size class I and II mammals (n = 9/12, Table 2). This small assemblage is composed of well-preserved specimens with no sign of abrasion (n=8/12), as well as very abraded bone fragments (n=4/12, Table 3). No modification by biological agents was identified. Morphometric data on each specimen are provided in Table 1.

The two limb shaft fragments CD.9977 and CD.3046C (Figure 2) have bevelled edges that appear to be the result of fresh bone fracture. These specimens are characterized by the presence of contiguous micro flake scars along their sides. The sharpness of the edges, however, indicates the flake scars may result from post-depositional processes such as trampling or sediment compression. Six other specimens (CD.343, CD.3528, CD.7900, CD.3529, CD.1649, CD.15631) mimic the general morphology of bone tools found at early Pleistocene hominin sites (Figure 3). However, at microscopic scale, we were not able to identify the diagnostic use-wear pattern associated with the fossil tools, and the smoothing present on them generally extends to the entire bone surface, which is consistent with the action of a natural agent such as water abrasion.

CD.3538 (Figure 3d) is a limb bone shaft fragment with a morphology similar to that of early Pleistocene hominin bone tools. However, no typical use-wear pattern is visible at a microscopic scale, and the preservation of the periosteal surface is more consistent with that resulting from a digestion process. For these reasons we identified this specimen as modified by a carnivore.

CD.6978A (Figure 4a) is a fragment of a small bovid metapodial (size class II). One end is bevelled, while the other shows a transverse fracture on dry bone. A crack parallel to the main axis of the bone structure is visible on its periosteal surface. We attribute this crack to a potential post-depositional process rather than to weathering, since no other evidence of exposure is observable on the bone. The specimen has a manganese coating. The general morphology is very similar to that of bone tools identified at Swartkrans, Drimolen and Kromdraai, but we did not observe the use-wear pattern found on the bone tools from these sites (Figure 4b).

CD.1293 (Figure 4c) is an indeterminate long bone shaft fragment attributed to a size class II mammal. The piece is bevelled with a slightly smoothed end. Dry breakage is observed at the opposite end as well as stage 1 weathering. However, the absence of microstriations and polish restricted to the area of the tip does not permit us to identify this specimen as a bone tool (Figure 4d).

Only one specimen can be confidently identified as a bone tool. CD.7895 (Figures 5-7) is a fragment of an indeterminate long bone characterized by a rounded end. The other end has a dry bone fracture. The general morphology of the fragment may correspond to a bovid metapodial. The piece belongs to an animal of size class 2. The use-wear pattern is visible from the tip for 28.9 mm along the edge, medullary and periosteal surfaces of the bone (Figures 5-7). The microstriae are clearly visible on both multifocal and SEM photographs (Figures 5-7). They are mostly longitudinal or oblique to the main axis of the long bone and appear, as on well-preserved specimens from Swartkrans and Drimolen, to result from abrasion by individual particles, each following a slightly different trajectory and marking successively the bone surface. Microstriation widths are highly variable, ranging from 25 to 300 μm. However, very few striations with a width >45 μm can be observed. Most of them are curved and subparallel to the main axis of the bone. Longitudinal thin cracks indicate the bone was at a weathering stage 1 when it was used as a tool.

4. Discussion

During our taphonomic investigation of the large mammal collection from Cooper's D, we were able to identify 12 specimens as bone tools or pseudo-tools. However, after close microscopic examination, only one specimen can be securely identified as a bone tool. The remaining 11 pieces are interpreted as pseudo-tools produced by non-human post-depositional processes, or tools so heavily affected by natural processes that their identification as implements is impossible.

The CD.7895 bone tool from Cooper's D bears features (i.e. rounded and strongly polished end associated with longitudinal or oblique microstriae between 25 to 300 µm wide) identical to those identified on bone tools from the Sterkfontein, Swartkrans, Drimolen and Kromdraai sites (Backwell and d'Errico, 2008; d'Errico and Backwell, 2009; Stammers et al., 2018). At Cooper's D, the faunal material is dominated by small to medium size class mammals (Hanon, 2019) and the only bone tool specimen is attributed to a size-class II mammal. At Sterkfontein and Swartkrans, mammal size class II-III and III-IV dominate the bone tool assemblage, while at Drimolen, the size class II-III is dominant and the mammals over or under this size class are underrepresented. The bone tool from Cooper's D has been made on a bovid metapodial, which is consistent with the trend observed at Swartkrans and Drimolen, where the majority of the bone tools were obtained from long bone shaft fragments (Backwell and d'Errico, 2003, 2008). Unlike these assemblages, we found no bone tools made from horncores, mandibles or ribs. This is not surprising, however, if one considers that they occur at the two sites in very low proportions.

The wear-pattern observed on the tip of the CD.7895 specimen from Cooper's D is very similar to that recorded on bone tools from Sterkfontein, Swartkrans and Drimolen (Backwell and d'Errico, 2008). Originally, these bone tools were interpreted as digging implements to dig up tubers (Brain and Shipman, 1993). Subsequent quantitative study and comparison between archaeological and experimental specimens lead some authors to suggest that these bone tools were used for termite foraging (Backwell and d'Errico, 2001, 2008; d'Errico et al., 2001). Subsequently, more detailed analysis of the bone surface texture indicated that even though termite foraging is the most likely task for the Drimolen bone tools, other foraging activities such as fruit processing and extraction of tubers could also be possible (d'Errico and Backwell, 2009). It is difficult, at this stage, to assess the function of the bone tool from

Cooper's D, but given the orientation and fine width of the striations we propose termite foraging as most likely.

Bone tools from Swartkrans Member 1 (n = 32), which is dated between 2.249±0.077 – 1.706±0.069 Ma, is associated with the Oldowan stone tool industry, *P. robustus* and *H.* cf. *erectus* (Backwell and d'Errico, 2001, 2003; d'Errico and Backwell, 2003; Caruana, 2017; Pickering et al., 2019). According to Herries et al. (2020) the depositional age of Swartkrans Member 1 remains uncertain, and based on ESR dates and faunal evidence could have occurred somewhere between 2.4 and 1.8 Ma, most likely 1.8 Ma. Based on this assertion, Drimolen MNQ, recently dated between 2.04 – 1.95 Ma, could represent the oldest occurrence in southern Africa of bone tools (n = 14), stone tools, *Homo* and *Paranthropus* (Herries et al., 2020). The bone tools apparently disappear around 0.96 Ma, with the last occurrence in Swartkrans Member 3 (n = 41; Brain, 1993; Backwell and d'Errico, 2003). This implies that bone tools are known in South Africa from at least 2.4 to 0.96 Ma. During this time, five sites have yielded definitive evidence of bone tool technology (Table 4). The Cooper's D assemblage fills the chronological gap between Swartkrans Members 2 and 3. At Cooper's D, *P. robustus* is the only hominin identified (Steininger et al., 2008; de Ruiter et al., 2009). According to Sutton et al. (2017), there are 49 stone artefacts from Cooper's D, but this small assemblage does not permit allocating them to a specific industry. Although two bone tools are reported from the Kromdraai B deposit (Stammers et al., 2018), there is an absence of clear radiometric dates. A second bone tool has been reported from Sterkfontein, from the Name Chamber (Val and Stratford, 2015), and while a detailed study of this specimen is lacking, it confirms a bone tool technology at this site.

We agree with Stammers et al. (2018) that an overall study of these sites shows no clear pattern of associations with bone tools, not with hominins or stone tool industry. Bone tools are associated with Oldowan as well as Acheulian stone tool industries in deposits containing *P*. *robustus* and early *Homo* remains (Table 4). Some authors have suggested a link between the presence of *P*. *robustus* and the early bone tools (Brain, 1993; Backwell and d'Errico, 2003, 2008). Indeed, the largest collection of ESA bone tools has been discovered in Swartkrans Member 3, which is rich in *Paranthropus* remains (Brain, 1993). Drimolen MNQ has also yielded a large number of *P. robustus* remains associated with a collection of bone tools (Backwell and d'Errico, 2008). Finally, South African bone tools disappear after 0.96 Ma in Swartkrans Member 3, as is the case for both *P. robustus* and early *Homo*. We can assume that the most parsimonious hypothesis is that *Paranthropus* may have been the user of the bone tools, but the presence of *Homo* complicates the picture (Backwell and d'Errico, 2008; Stammers et al., 2018; Herries et al., 2020).

5. Conclusion

In this study we identify and describe the first bone tool from the Cooper's D faunal assemblage. The general morphology and use-wear pattern observed at the tip of the Cooper's D bone tool are very similar to that observed on bone tools from Sterkfontein, Swartkrans and Drimolen. It has been shown that these tools were probably used to forage for termites and plant roots and to process fruits. Based on the longitudinal orientation of the fine striations at the tip of the specimen we tentatively propose that it was used in termite foraging, but wish to investigate further this issue in the future. The fact that *P. robustus* is the only hominin identified at Cooper's D supports the hypothesis that *P. robustus* probably used the bone tool (Brain, 1993; Backwell and d'Errico, 2001, 2003).

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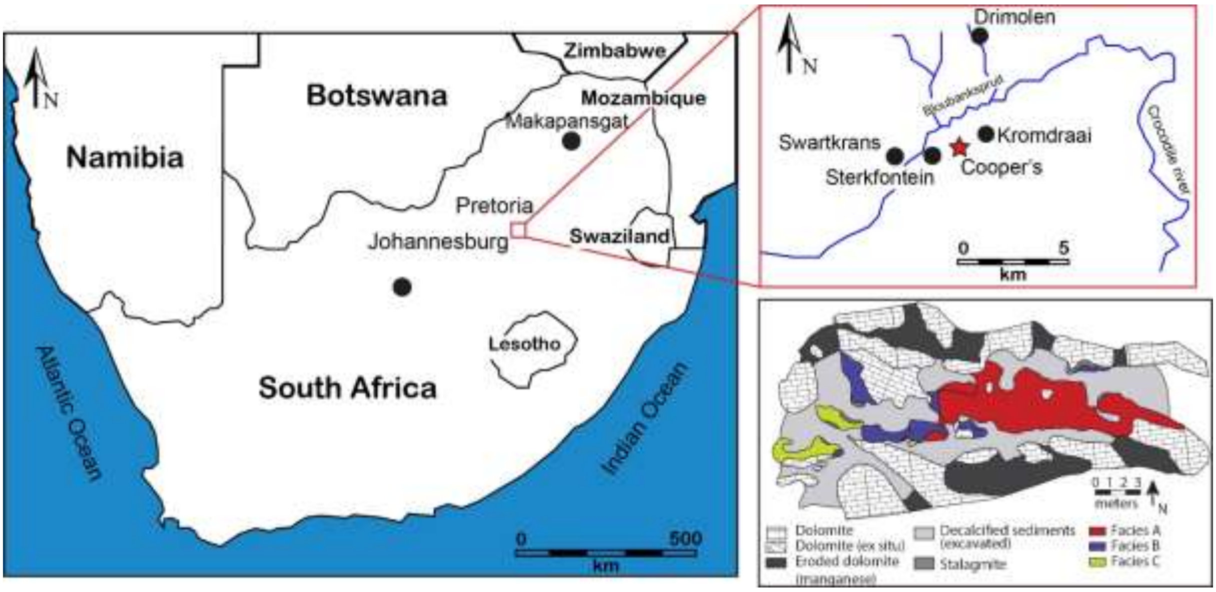

Figure 1: Locality of Cooper's Cave and other Early Stone Age-bearing bone tool sites in South Africa with a geological plan of the Cooper's D site (modified after de Ruiter et al., 2009).

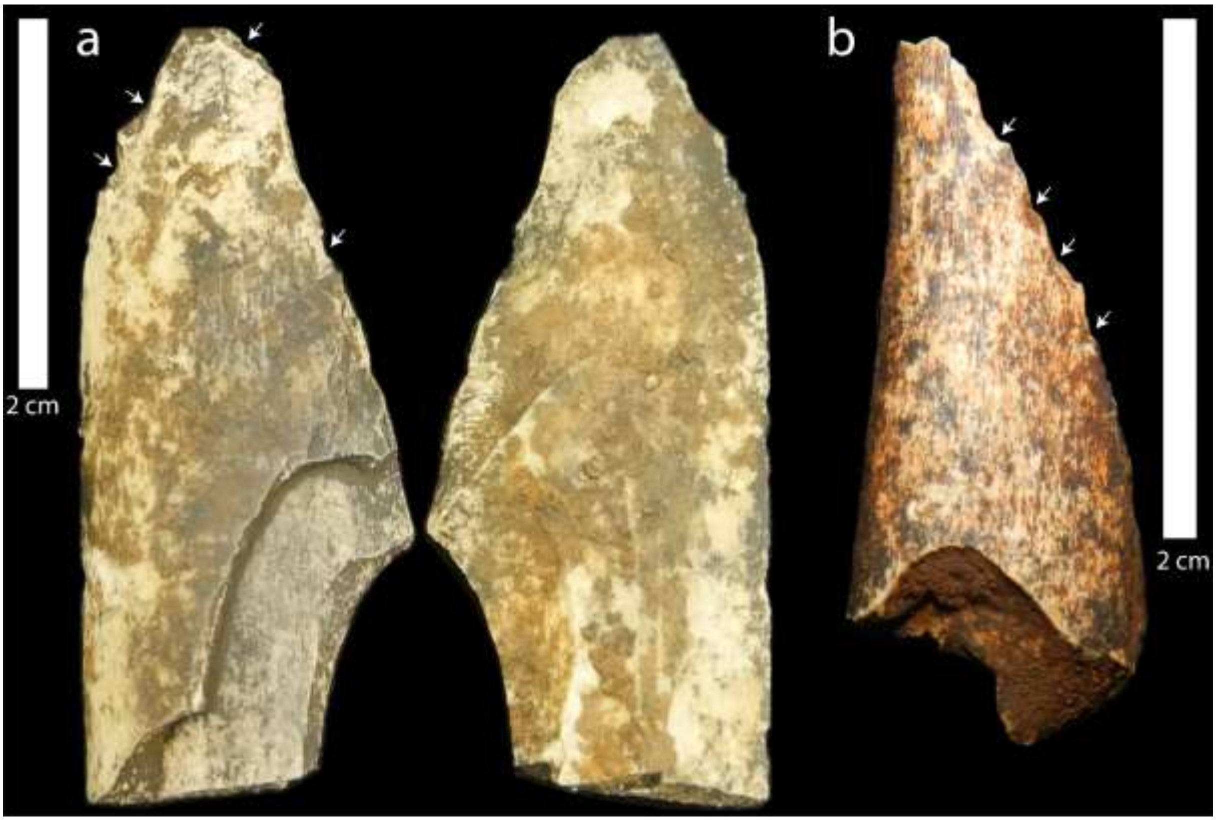

Figure 2: Photographs of specimens CD.9977 (a) and CD.3046C (b) displaying denticulated micro flake scars along their edges (arrows). Scales = 2 cm.

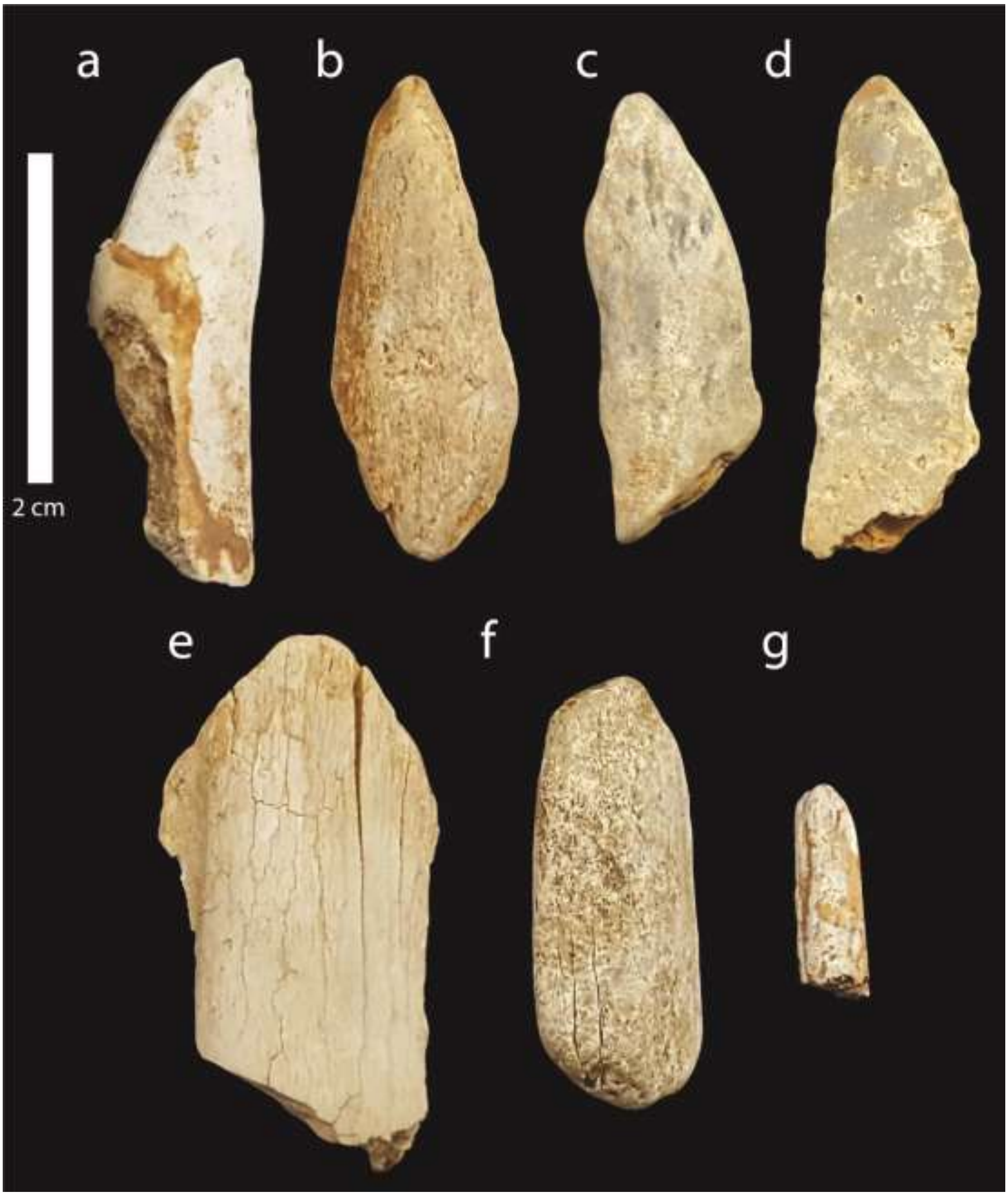

Figure 3: Rounded bone fragments from Cooper's D interpreted as pseudo-tools; CD.1649 (a), CD.7900 (b), CD.15631 (c), CD.3538 (d), CD.3529 (e), CD.3528 (f), CD.343 (g). Scale = 2 cm.

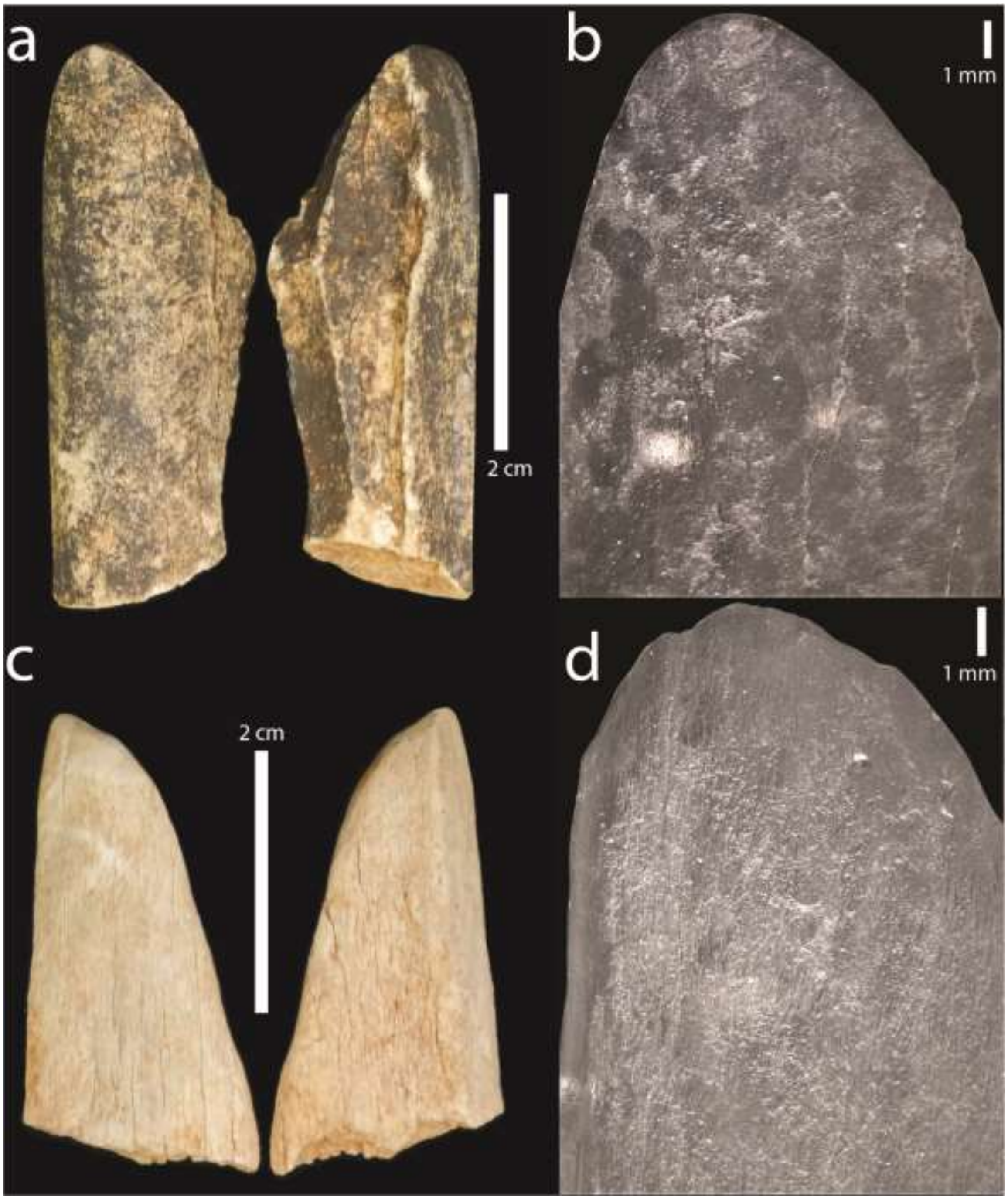

Figure 4: Photographs of bone fragments from Cooper's D interpreted as pseudo-tools, CD.6978A (a) and CD.1293 (c) and photographs of their rounded tips taken in transmitted light on resin replicas CD.6978A (b) and CD.1293 (d). Scales = 2 cm (a, c) and 1 mm (b, d).

Figure 5: Photographs of the bone tool from Cooper's D (CD.7895) showing the cortical (left) and medullary (right) surfaces. Scale = 2cm.

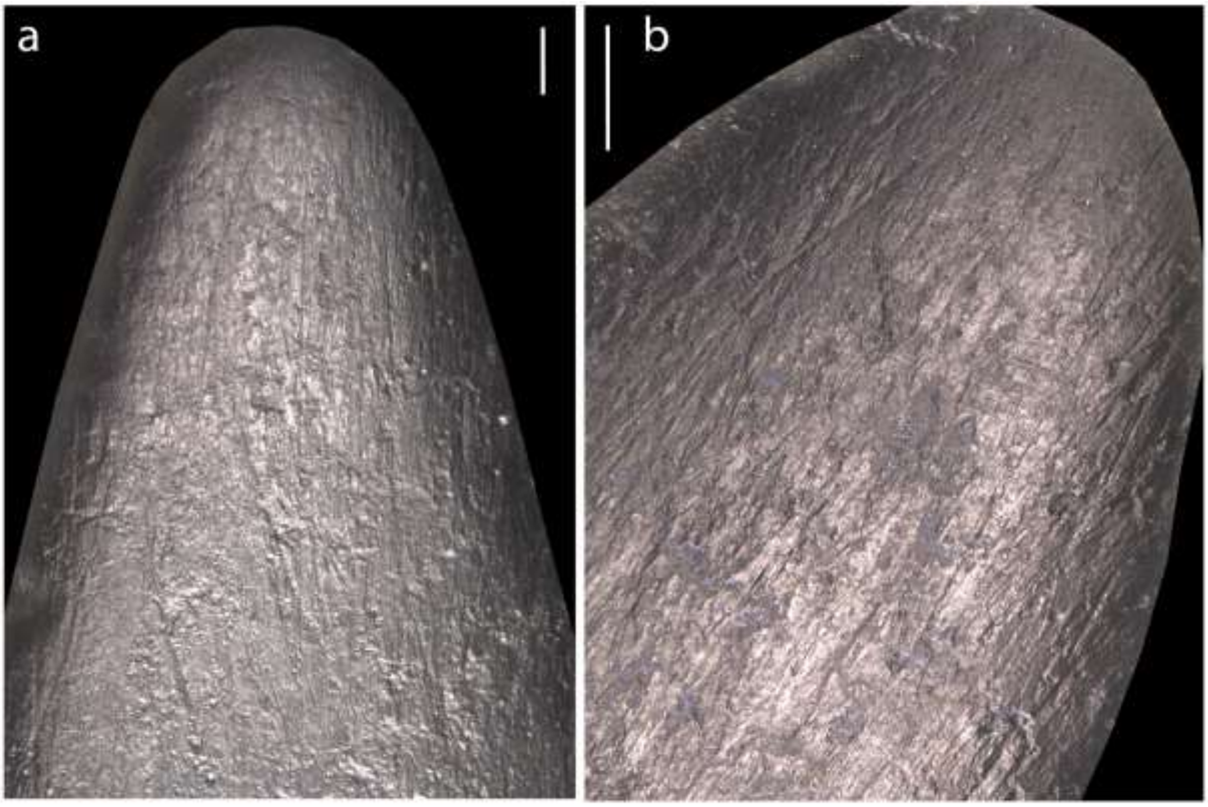

Figure 6: Periosteal surface of the bone tool tip from Cooper’s D (CD.7895) showing characteristic longitudinal subparallel, intersecting striations. Photographs taken in transmitted light on resin replicas. Scales = 1 mm.

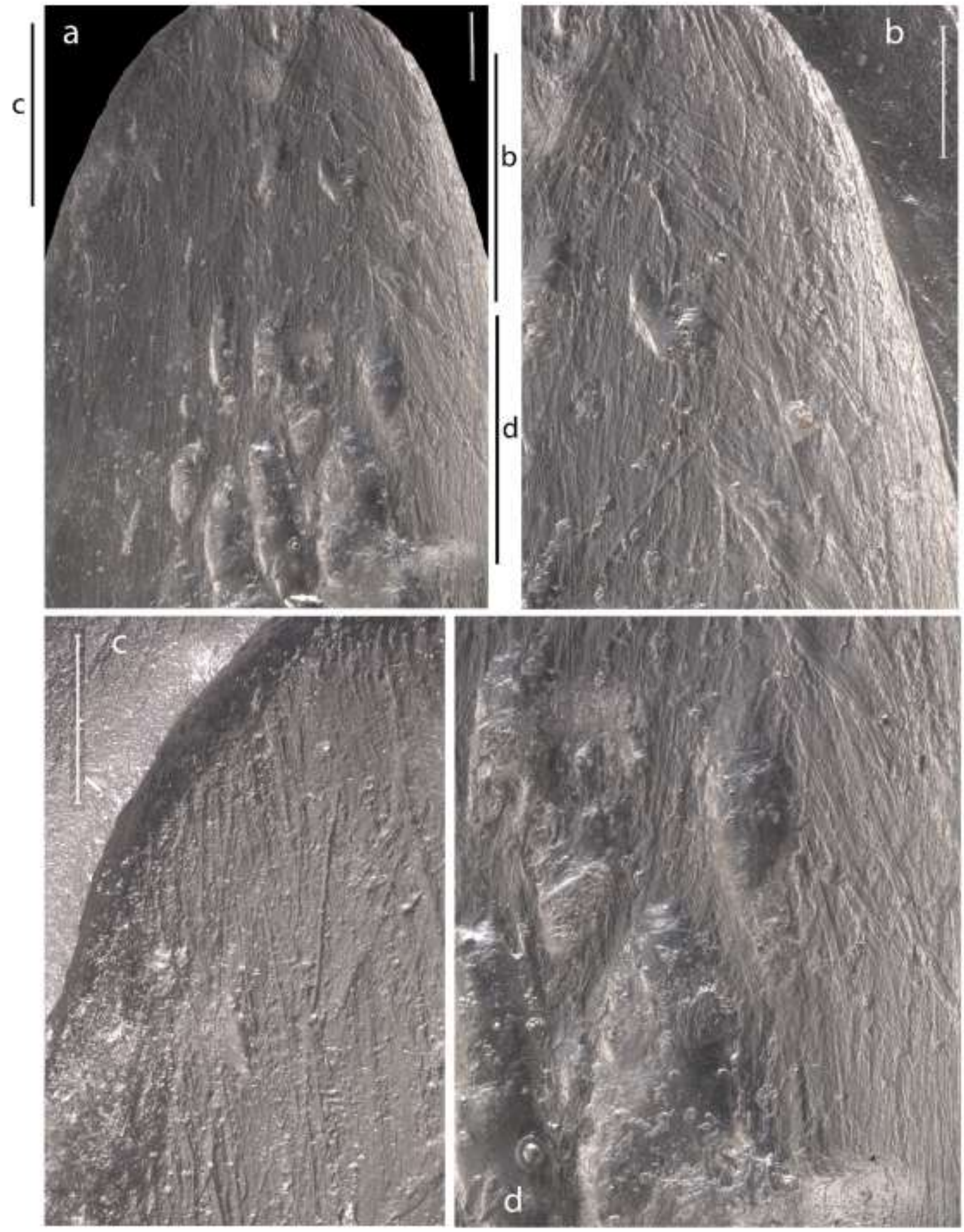

Figure 7: Medullary surface (a) of the bone tool from Cooper's D (CD.7895) and close-up views of the tip (b-c) and right side of the object. Notice the myriad number of individual intersecting lines flattening the bone surface and only sparing concave areas of trabecular bone. Scales = 1 mm.

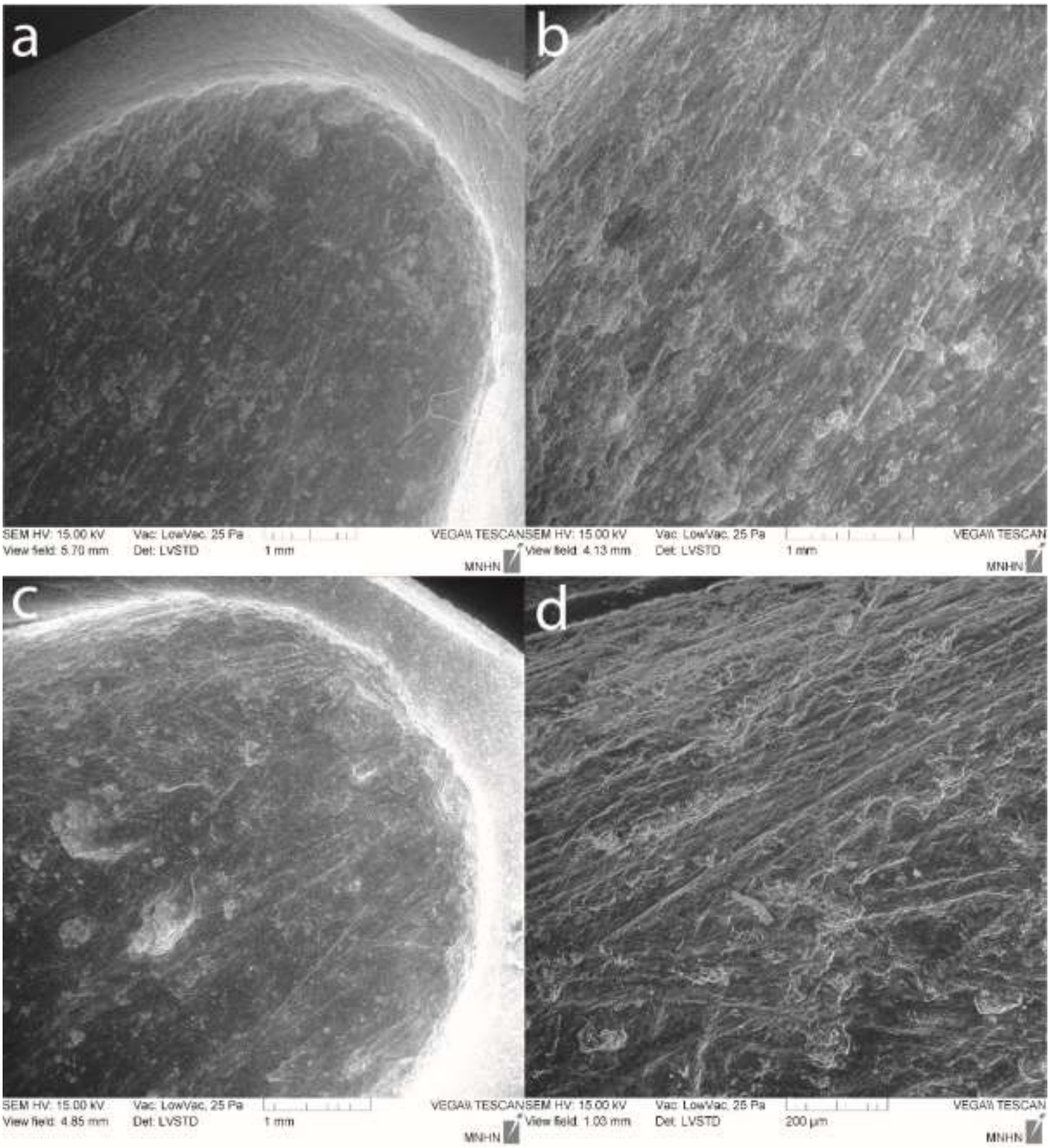

Figure 8: Scanning electron micrographs of the Cooper's D bone tool tip (CD.7895) (top and bottom left) and close-up views (right) showing microstriations produced by the use of the tool. Scales = 1 mm (a-c) and 200 µm (d).