

Chronology of the Hominin Sites of Southern Africa

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Summary

The identification of the Taung Child *Australopithecus africanus* type specimen as an early human fossil (hominin) by Raymond Dart in 1924, followed by key discoveries at sites like Sterkfontein, Swartkrans, and Makapansgat in the 1930s and '40s, was key to understanding that humans first arose in Africa, not Europe or Asia. Later discoveries in eastern Africa have shown that the earliest potential hominins (e.g., *Orrorin tugenensis*) date back to at least 6 million years ago. In contrast, the oldest fossils hominins in South Africa are those of *Australopithecus* from the sites of Taung and Makapansgat and are dated to between about 3.0 and about 2.6 million years ago (Ma); only one specimen, from Sterkfontein, potentially dates to earlier than this sometime between 3.7 and 2.2 Ma. However, the majority of early hominin fossils in southern Africa come from 2.8- to 1.8-million-year-old palaeocave remnants in the Malmani dolomite of the Gauteng province. These sites have a rich record of hominin species, including *Australopithecus africanus*, *Australopithecus sediba*, *Paranthropus robustus*, and *Homo erectus*. Most of these species, except for *Homo erectus*, are endemic to South Africa. However, the DNH 134 specimen from Drimolen Main Quarry does represent the oldest fossil of *Homo erectus* anywhere in the world. This specimen occurs at a time around 2 Ma when there is a turnover in hominin species with the extinction of *Australopithecus* and the first occurrence of *Homo*, *Paranthropus*, and an archaeological record of Oldowan and bone tools. Acheulian technology occurs from at least 1.4 Ma and is associated with specimens simply attributed to early *Homo*. The oldest hominin fossil outside the northern Malmani dolomite karst is dated to between 1.1 and 1.0 Ma, at Cornelia-Uitzoek in the Free State, and also represents the last specimen defined as early *Homo*. *Paranthropus* is also last seen around 1 million years ago, when the first specimen attributed to *Homo rhodesiensis* may also have occurred at Elandsfontein in the Western Cape. There is a dearth of hominin fossils from the terminal Early Pleistocene until the late Middle Pleistocene when a high diversity of hominin species occurs between about 340,000 and about 240,000 years ago (c. 340 and c. 240 ka). This includes a late occurring specimen of *Homo rhodesiensis* from Broken Hill in Zambia, *Homo helmei* or early modern humans from Florisbad, and *Homo naledi* from Rising Star. This is also a period (post 435 ka) containing both late occurring Acheulian and early Middle Stone Age (MSA) technology, but none of these fossils is directly associated with archaeology. Definitively early modern human fossils are not found until after 180 ka in direct association with MSA technology, and the majority, if not all, of the record occurs during the last 120 ka.

Keywords: *Australopithecus africanus*, *Paranthropus robustus*, *Homo erectus*, *Homo rhodesiensis*, *Homo naledi*, *Homo sapiens*, electron spin resonance, palaeomagnetism, uranium series, luminescence, hominin

Subjects: Archaeology, Biological Anthropology

Introduction

The record of human evolution in southern Africa covers between 3 and 4 million years; however, there is a significant geological bias to the southern African record that means the earliest records of humans in the region are restricted to three very confined areas of Malmani dolomite karst in Gauteng, North West, and Limpopo provinces (Figure 1). Moreover, whether these fossils represent the first time that hominins occurred in southern Africa or whether it is related to the lack of survival of older fossil-bearing deposits due to the nature of karst erosion is an open question (Herries et al. 2019). Together these palaeokarst infills make up the Fossil Hominid Caves of the South Africa World Heritage Area, known locally as the “Cradle of Humankind” or “Cradle” (Figure 1, Table 1). The fossil sites in Limpopo (Makapansgat) and North West province (Taung) have equally yielded fewer than 50 hominin fossils compared with the thousands that have been recovered from the dense number of caves (Sterkfontein, Swartkrans, Kromdraai, Drimolen, Malapa, etc.) that occur in the 25-by-10-km area of karst in Gauteng (Herries et al. 2009, 2013, 2020; Martin et al. 2021). These fossil sites have yielded fossils of *Australopithecus africanus* and perhaps fossils from two other australopithecine species (*A. sediba* and *A. prometheus*) as well as *Paranthropus robustus*, early *Homo*, *Homo erectus*, *Homo naledi*, and *Homo rhodesiensis* (Berger et al. 2015; Clarke 2013; Dirks et al. 2010, 2017; Herries 2011; Herries et al. 2009, 2013, 2020; Martin et al. 2021).

Outside the Malmani dolomite, there are only a few early to middle Pleistocene hominin fossil sites dating to after 1.1 Ma (million years ago), such as the Elandsfontein and Hoedjiespunt dune fields and calcretes (Braun et al. 2013), the Florisbad spring (Curnoe and Brink 2010; Grün et al. 1996), and the Cornelia-Uitzoek alluvial sequence (Brink et al. 2012). Later Pleistocene Early modern human fossils have been recovered primarily from coastal cave sites such as Klasies River Mouth, Blombos, Pinnacle Point 13B, and Die Kelders Cave as well as the more inland cave sites of Sibudu and Border Cave (Grine and Henshilwood 2002; Grine et al., 2017a, 2017b; Grün 2006; Herries 2011; Marean et al. 2004; Will et al. 2019). A couple of other specimens have been recovered from alluvial and estuarine settings at Hofmeyr and Blind River (Grine et al. 2007; Wang et al. 2008). Outside South Africa, southern Africa is rather devoid of hominin fossils with specimens having been recovered only from Broken Hill in Zambia, the about 300,000-year-old type site of *H. rhodesiensis* (Grün et al. 2020; Woodward 1921) as well as the undated Berg Aukas *Homo* femur from the dumps of a vanadium mine in Namibia (Grine et al. 1995; Partridge 2000).

Many of these fossils were recovered from the 1920s through to the 1950s when excavation techniques and documentation of excavations were limited, and a number were recovered from mines where the original site has been destroyed. Moreover, many were found at a time when there were no radiometric methods available at all or for dating the specific time or deposits from which the fossils were recovered. Owing to a lack of Plio-Pleistocene volcanics in South Africa, the accurate dating of the South African hominin fossil record has lagged behind that in the eastern African Rift Valley where the Argon-Argon technique can often produce precise ages for volcanic tuffs sandwiching fossil deposits.

Since the 1980s, methods such as electron spin resonance (ESR; dating teeth), optically stimulated luminescence (OSL; dates burial of quartz), thermo-luminescence (TL; dates heating of quartz), and infrared stimulated luminescence (IRSL; dates burial of feldspar) have been increasingly used to date fossils in South Africa (Blackwell 1994; Grün 2006; Marean et al. 2007; Schwarcz et al. 1994). Since the 2000s, the accuracy of these methods has increased as methods such as single-grain OSL (Jacobs and Roberts 2017; Marean et al. 2007) and dual uranium-thorium (U-Th) ESR dating (US-ESR) have been developed (Herries et al. 2020), and new methods such as uranium-lead (U-Pb; Pickering et al. 2019; dates speleothem) and cosmogenic burial (Al/Be; Granger et al. 2015; dates burial of quartz) dating have begun to be widely used. This has been augmented by palaeomagnetic analysis (dating reversals of the magnetic field), which was first used in the 1970s (McFadden et al. 1979) but has been used more extensively since 2000 (Herries et al. 2006, 2020). Thermally transferred optically stimulated luminescence (TT-OSL) has also begun to expand the time range (back to about 1.1 Ma) over which luminescence methods can date deposits (Pickering et al. 2013).

In some cases, U-Pb and Al/Be age estimates have given very different age estimates for certain deposits, creating a lot of debate over the reliability of these methods (Granger et al. 2015; Kramers and Dirks 2017; Pickering 2015; Pickering and Kramers 2010; Shaar et al. 2021). However, other studies have shown that U-Pb is extremely accurate when it is compared with modern US-ESR methods and palaeomagnetism (Dirks et al. 2010, 2017; Herries et al. 2013, 2018, 2020; Pickering and Herries 2020). This shows the need to always date deposits with multiple methods and multiple dating samples if possible as well as redoing the dating of sites with modern methodologies.

The First Hominins (*Australopithecus*)

Whereas the earliest potential hominins occur in central and eastern Africa from about 6 million years with fossils such as *Sahelanthropus* and *Orrorin*, the South African record does not begin until sometime between 4 and 3 Ma with *Australopithecus* (Herries et al. 2013). Whether this reflects the fact that hominins were simply not in South Africa prior to this or that few fossil deposits survive prior to this remains a question. Few Pliocene fossil deposits exist in South Africa, and all the early hominins have been recovered from palaeocaves and tufa within the Malmani dolomite. Owing to the nature of karst landscape evolution, older palaeokarst is eventually eroded from the landscape and so older hominin-bearing deposits may have been removed, creating a geological bias to the record (Herries et al. 2019).

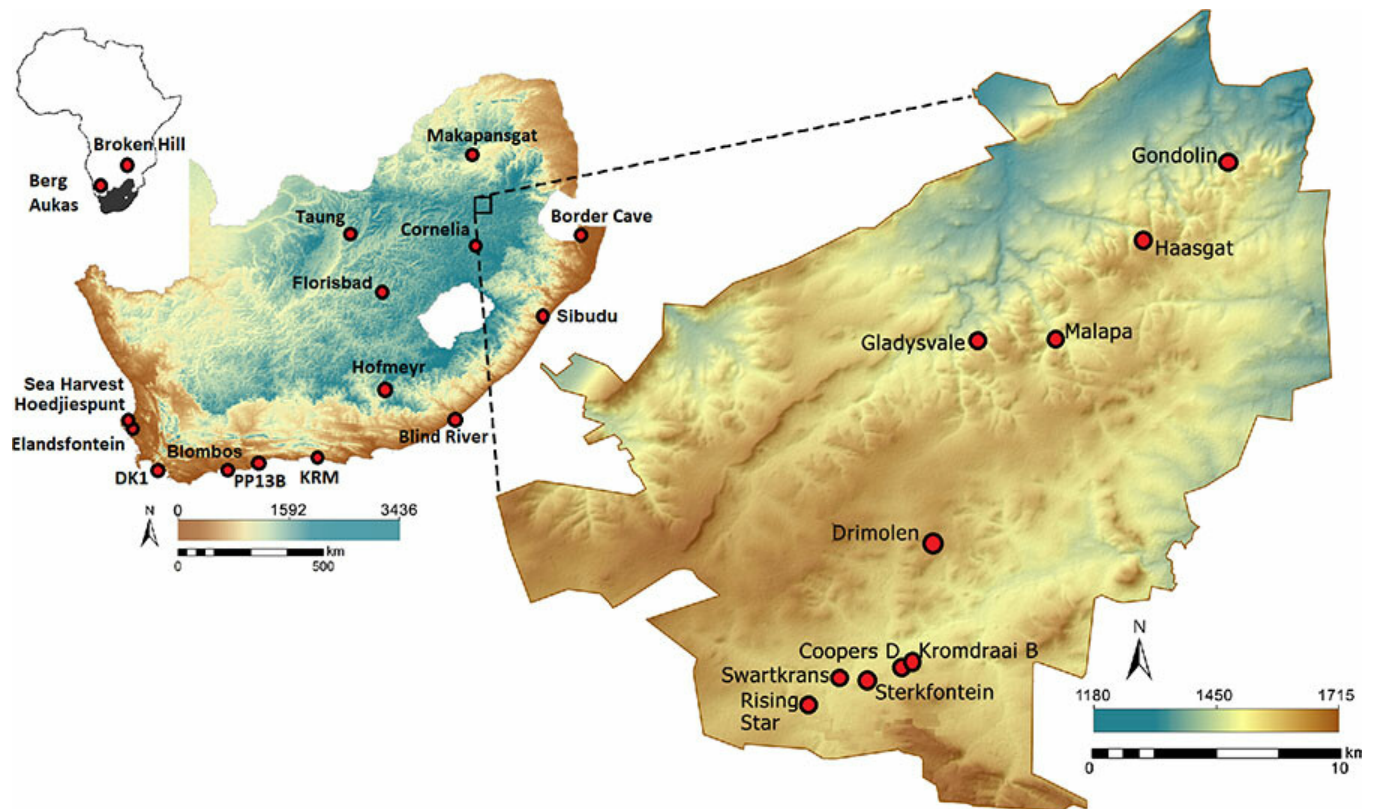


Figure 1. The hominin sites of southern Africa

Credit: Author-created image, made using open-source elevation data from Jarvis et al. 2008.

Sterkfontein Underground Deposits (Silberberg Grotto, Jacovec Cavern, and Milner Hall)

The oldest potential hominin fossil in South Africa is the StW 573 *Australopithecus* skeleton from Member 2 in the Silberberg Grotto at Sterkfontein, Gauteng. It is the most complete early hominin skeleton ever discovered and has been suggested by Clarke (2013) (Clarke and Kuman 2019) to represent a species (*A. prometheus*) that he also argues occurs in Sterkfontein Member 4 and the Makapansgat Limeworks between 3.0 and 2.1 Ma. The naming of this species employing an old name used for the Makapansgat Limeworks fossils is problematic (Berger and Hawks 2018), but it follows a long-running debate of whether more than one species of *Australopithecus* occurs at Sterkfontein (Moggi-Cecchi 2003). Silberberg Grotto represents part of the underground exposures of palaeokarst at Sterkfontein, which is part of an extensive, complex, and still active multigenerational cave system (Martini et al. 2003). The dating of StW 573 has been controversial (Herries et al. 2013). U-Pb dating indicates that a flowstone (2C; F3–F4) capping the Stony Breccia containing StW 573 is dated to about 2.2 Ma (2.17 ± 0.07 , 2.11 ± 0.06 , 2.25 ± 0.08 Ma; Pickering et al. 2019), while another flowstone (2B) beneath StW 573 is dated to 2.24 ± 0.08 Ma (Pickering et al. 2019). A short normal magnetic polarity period within the reversed polarity 2C flowstone is associated with either the Réunion Event (~ 2.2 Ma) or Feni SubChron (2.16–2.12 Ma) (Herries and Shaw 2011; Singer 2014). This correlation of the U-Pb and palaeomagnetism suggests that the age estimate for these flowstones is accurate. However, the

U–Pb ages on the speleothem are at odds with cosmogenic nuclide isochron burial dating (Al/Be) on the sediments themselves, which suggest an age of 3.67 ± 0.32 Ma (2 sigma error; i.e., 95% confidence that the true age is within this error range Granger et al. 2015; Partridge et al. 2003). Kramers and Dirks (2017) have challenged the cosmogenic age and suggest a maximum possible age of 2.8 Ma (the upper age limit for Member 3/4 on the surface exposures) based on samples potentially having been previously buried and reworked, something that can cause the overestimation of cosmogenic burial ages and is well documented at Sterkfontein (Stratford et al. 2016). Studies on other sites, such as Wonderwerk Cave, have also shown the overestimation of cosmogenic ages for Malamani dolomite cave deposits (Pickering 2015; Shaar et al. 2021). Bruxelles et al. (2019) argue that the U–Pb dated flowstones fill voids formed within the stratigraphic sequence and as such are much younger than StW 573. Based on the palaeomagnetic analysis, the flowstones did not all form at the same time. Flowstone 2D and 3 above StW 573 record normal polarity, and Bruxelles et al. (2019) argue that these are flowstones that seal the Member 2 sequence in Silberberg Grotto (Herries and Shaw 2011). In contrast, flowstone 2A at the bottom of the sequence records reversed polarity like flowstones 2B and 2C. These lower flowstones are thus not related to the same phase of speleothem formation as the sealing flowstones.

Jacovec Cavern is another lower *Australopithecus*-bearing cave unit at Sterkfontein which has been argued to date to about 3.76 ± 0.26 (Dark Brown Sediments) and 4.02 ± 0.27 Ma (Orange breccia) based on Al/Be dating (Partridge et al. 2003). The StW 578 fossil (from the Orange Breccia) is suggested to resemble *A. africanus* fossils Sts 505 and Sts 71 from Sterkfontein Member 4 and has been used to suggest that, if this age were correct, the cranial vault thickness pattern seen in *A. africanus* must have evolved early on (Beaudet et al. 2018). However, the apparent occurrence of *Equus* in these deposits does create some cause for concern regarding the context of the fossils or reliability of the Al/Be age as *Equus* is known to occur only in Africa after 2.3 Ma (Geraads et al. 2004; Reynolds and Kibii 2011).

Milner Hall is the third underground deposit that has yielded hominins at Sterkfontein (Stratford et al. 2016). A single tooth and phalanx (toe/finger bone) were recovered from the T1 mining rubble that caps the Milner Hall sequence and so are *ex situ* to their original site of deposition. In fact, the fossils may have been reworked a number of times in that it is suggested by Stratford et al. (2016) that the underlying T2 deposits are reworked from the surface palaeocave deposits at Sterkfontein, specifically the Oldowan Infill of Member 5 (~1.3 Ma). This shows the complexity of Sterkfontein and the processes of sediment reworking from the surface to active underground caverns that happens at the site and that could influence cosmogenic age estimates as suggested by Kramers and Dirks (2017). The tooth has been attributed to *Homo*, and Stratford et al. (2016) suggest that the material recovered from T1 also derives from Member 5 (see age below). Currently, the age of the StW 573 *Australopithecus* skeleton can only be said to be somewhere between 3.7 or 2.8 Ma and 2.2 Ma. However, the complexity of the Sterkfontein deposits and evidence for reworking of deposits from higher in the cave sequence to lower chambers may suggest that they are contemporary with Member 4 between 2.8 and 2.1 Ma.

Makapansgat and Taung

If the StW 573 fossil is younger than 2.8 Ma, then the oldest hominin fossils may instead come from either the Makapansgat Limeworks, around 240 km north of the Gauteng sites, or the Taung Pinnacles Type Site at the Buxton–Norlim Limeworks about 300 km west of the Gauteng sites (Herries et al. 2013). Makapansgat and Taung have yielded fossils assigned to *A. africanus*, and the single specimen from Taung represents the type specimen for this species (Dart 1925). Both have been dated only by combining palaeomagnetism with biostratigraphy.

Taung Pinnacles Type Site

The Buxton–Norlim Limeworks, near the town of Taung in North West province, consists of a series of tufa deposits that have formed over at least the last 3 million years and contains fossils sites that span this entire period (Kuhn et al. 2016). The Taung Child *A. africanus* type specimen was found as part of the mining of the tufa prior to 1924 and came from what was originally considered to be a cave deposit that had formed through the Thabaseek Tufa (Dart 1925). The original find site has been destroyed, but two pinnacles (The Dart [aka *Australopithecus*] and Hrdlicka Pinnacles) were left in place as remnants of the deposits from which it was recovered close to the find site. These pinnacles are artificial remnants of both the tufa and at least two associated sediment deposits. The older PCS deposit is thought to have formed at the same time as the Thabaseek tufa was forming, as an open-air deposit (Herries et al. 2013; Hopley et al. 2013; Kuhn et al., 2016), whereas the YRSS deposit infilled caves that formed through both the tufa and indurated PCS at a later stage. Matrix adhering to the Taung Child fossil aligns it with the older PCS unit (Herries et al., 2013; Hopley et al. 2013; Kuhn et al., 2016). PCS and the tufa have a normal magnetic polarity. Based on this polarity and associated fauna (e.g., *Parapapio broomi* as found at the Makapansgat Limeworks), the fossil has been attributed to the Gauss Chron between 3.60 and 2.61 Ma and most likely to between 3.03 and 2.61 Ma (Herries et al. 2013). At a later period, caves formed through the PCS and Tufa deposits and record a reversed magnetic polarity. Based on the occurrence of species such as *Papio izodi* (found at Sterkfontein Member 4), these deposits have been suggested to date to between 2.61 and 1.95 Ma in the early part of the Matuyama Chron of the Geomagnetic Polarity Timescale (GPTS) (Herries et al. 2013; Singer 2014).

Makapansgat Limeworks

The Makapansgat Limeworks, often referred to only as Makapansgat, despite there being several sites in the valley (e.g., Cave of Hearths and Buffalo Cave), occurs in South Africa's Limpopo province and has yielded over 40 specimens, all of which are assigned to *A. africanus* (Herries et al. 2013). They have been recovered mostly from a grey bone and speleothem breccia (GBB or Member 3), and some others (MLD 46, MLD 37/38) come from fine-grained pink deposits of the Partridge Block (Member 4) (Reed et al. 1993). The complexity of the stratigraphy at the site and changes to naming conventions are outlined in Herries et al. (2013). The GBB and underlying laminated, red sandstone, and siltstone deposits (Member 2 west) record a normal magnetic polarity that, based on biostratigraphic age estimates of less than 2.85 Ma, has been assigned to the end of the Gauss Chron between 3.03 and 2.61 Ma, potentially contemporary with PCS at

Taung (Herries et al. 2013). A key biochronological species at the site, Stage 1 *Metridiochoerus andrewsi*, has been dated at other South African sites to about 2.61 Ma (Drimolen Makondo; Herries et al. 2018; Rovinsky et al. 2015) and 3.03 to 2.61 Ma (Aves Cave, Bolt's Farm; Edwards et al. 2020). The Gauss–Matuyama Boundary itself at 2.61 Ma is recorded in a speleothem that caps GBB. The beginning of this same reversal is also identified in deposits just below the Member 4 deposits that yielded MLD 46 and MLD 37/38 and suggests that these fossils date to about 2.61 Ma. Deposits underlying the sandstone and siltstone deposits, known as the Original Ancient Entrance (OAE), have yielded a series of alternating polarities that have been interpreted as representing the Kaena and Mammoth events, within the Gauss Chron between 3.60 and 3.03 Ma (Herries et al. 2013). However, some of the palaeomagnetic results from this part of the site are problematic and so the exact nature of the reversal sequence is hard to determine. This is exacerbated by the sedimentary sequence that alternates between flowstone speleothem and clastic sediments several times (Latham et al. 2003). The OAE deposits are then underlain by a mostly reversed polarity speleothem that is thought to date to more than 3.60 Ma (Herries et al. 2013).

Member 4, Sterkfontein

The Sterkfontein Member 4 deposits consist of fossil-bearing breccia that represent the partly eroded infill of a palaeocavern whose roof and upper units have been eroded away. Member 4 has yielded the vast majority of *Australopithecus* fossils recovered from Sterkfontein as well as South Africa (Clarke 2013). Traditionally, they have all been defined as belonging to *A. africanus*; however, there has been ongoing debate about whether more than one species exists in this assemblage of fossils, including the occurrence of specimens that are more *Paranthropus*-like, more *Homo*-like or representing the same species as StW 573 (*A. prometheus*) (Clarke 2013; Moggi-Cecchi 2003). The deposit has been dated by a combination of U–Pb, ESR, and palaeomagnetism to between 2.61 and 2.07 Ma (Herries and Shaw 2011; Pickering and Herries 2020; Pickering and Kramers 2010). ESR ages were initially undertaken on the Member 4 deposit by Schwarcz et al. (1994) but were generally dismissed as being too young; the average age was 2.1 ± 0.5 Ma, and peaks in the data were at 2.37 ± 0.29 Ma and 1.72 ± 0.31 Ma (Schwarcz et al. 1994). A further series of ESR dates showed a similar variation in ages for Member 4; ages were as old as 3.09 ± 0.29 Ma and as young as 1.23 ± 0.59 Ma (Herries and Shaw 2011). However, Herries et al. (2009) and Herries and Shaw (2011) noted that when these ESR ages were plotted out in three dimensions, the young ages came from areas that were very close to the boundary of, or within, the area of the younger archaeology-bearing Member 5. Moreover, these young ESR ages were the same age as ESR ages from within Member 5 (Herries and Shaw 2011). Given that the contact between these two units was hard to identify exactly, they were likely excavated from the Member 5 deposits. Once this replotting was finalized, the ages for samples definitively within Member 4 ranged between 3.09 ± 0.29 Ma and 2.06 ± 0.18 Ma (Herries and Shaw 2011). Similarly, the larger study by Schwarcz et al. (1994) obtained dates ranging between 2.87 ± 0.42 Ma and 2.03 ± 0.51 Ma.

Palaeomagnetic analysis on the speleothem portion of Member 4 as well as some adhering sediment recorded reversed magnetic polarity, suggesting deposition after the Gauss Matuyama Boundary at 2.61 Ma, consistent with the old ESR ages (Herries and Shaw 2011). A capping

speleothem (Mrs Ples Flowstone: so named because it formed over the Sts 5 cranium) recorded normal and intermediate polarity that was interpreted as representing either one or two short magnetic polarity events (Herries and Shaw 2011). U-Pb dating indicates that this flowstone dates to 2.03 ± 0.06 Ma (Pickering and Kramers 2010; Pickering et al. 2019). This age came from the very base of this flowstone and, as such, the magnetic reversal can be confidently linked to the Huckleberry Ridge event at about 2.07 Ma, providing a lower age limit for the Member 4 *Australopithecus* fossils and particularly the Sts 5 fossil which the flowstone covered (Pickering and Herries 2020; Singer 2014). U-Pb dating of a flowstone underlying Member 4 dates to 2.65 ± 0.18 Ma and 2.80 ± 0.14 Ma (Pickering and Kramers 2010; Pickering et al. 2019), again consistent with the palaeomagnetic and ESR ages. An age of between 2.61 and 2.07 Ma has thus been suggested for the age of Member 4 (Pickering and Herries 2020).

The occurrence of fossils of *Equus* in some of the Member 4 deposits suggests that at least some of this unit is less than 2.3 Ma (Geraads et al. 2004; Herries and Shaw 2011), as do younger ESR ages of 2.06 ± 0.18 Ma and 2.03 ± 0.51 Ma (Herries and Shaw 2011). While the reversed polarity of the Member 4 flowstone suggests an upper age limit of 2.61 Ma, ESR ages of 3.09 ± 0.29 Ma and 2.87 ± 0.42 Ma do also occur, suggesting that some of the deposits, perhaps not sampled for palaeomagnetism, are older than this and that the deposit as a whole may have formed over at least 700,000 years (2.80–2.07 Ma). In certain areas of the surface, deposits at Sterkfontein Partridge (1978, 2000) also defined the occurrence of a Member 3 unit beneath Member 4 (Pickering and Kramers 2010 and Pickering et al. 2019 call this unit Member 2). Based on U-Pb ages, this unit dates to about 2.8 Ma; a capping flowstone dates to 2.80 ± 0.14 Ma and an underlying flowstone dates to 2.75 ± 0.17 Ma (Pickering et al. 2019). Based on this age and the ESR ages, it suggests that the fossil material attributed to Member 4 may actually span both of these units, dating to between 2.80 and 2.07 Ma.

Gladysvale and Malapa

Gladysvale Cave is located in the northeastern part of the Gauteng exposures of the Malmani dolomite and was first excavated in the 1940s by the University of California Museum of Palaeontology Expedition to South Africa. A couple of hominin teeth were later recovered from lime miners' dumps at Gladysvale and have been attributed to *A. africanus* (Berger et al. 1993). Because the teeth are *ex situ*, it is hard to assess their age but ESR dates as old as 2.4 Ma occur for the internal cave deposits at Gladysvale (Herries et al. 2013).

Malapa was discovered in 2008 and is located close to Gladysvale. The site has yielded two partial skeletons of a suggested new species, *A. sediba* (Berger et al. 2010). The site has been dated by a combination of U-Pb dating and palaeomagnetism. A massive speleothem underlying the hominin deposits has been U-Pb dated to 2.06 ± 0.02 Ma and records normal to reversed polarity that is interpreted as recording the Huckleberry Ridge event at 2.07 Ma (Dirks et al. 2010). The sediments overlying the flowstone recorded normal and intermediate polarities and this was originally interpreted as representing the beginning of the Olduvai SubChron at 1.95 Ma (Dirks et al. 2010). In a subsequent study, another flowstone that was suggested to cap the *Australopithecus*-bearing deposits was dated to 2.05 ± 0.14 Ma and had reversed magnetic polarity. Based on this, the reversed polarity could occur only prior to the Olduvai SubChron at 1.95 Ma, not

after it post 1.78 Ma, yet it seemingly capped the normal polarity originally measured for the fossil-bearing sediments between these two similar aged flowstones. Pickering et al. (2011) therefore argued that the normal polarity signal was not that of the Olduvai SubChron but instead represented the pre-Olduvai event at about 1.98 Ma. There are a number of potential issues with this interpretation. First, the capping flowstone published by Pickering et al. (2011) came from a second pit (Pit 2), not Pit 1 containing the hominin material, and there is no stratigraphic connection between the two pits, which are separated by a large block of dolomite (Pickering et al. 2011). The upper flowstone occurs under what is interpreted as Facies F, the upper unit in Pit 1 and forms over Facies C, which underlies the massive dated basal flowstone beneath the hominin fossils in Pit 1. Based on this, there is no real evidence that this second flowstone is capping the fossils and is not just a lateral equivalent of speleothem phases formed before the hominins were deposited at about 2.07 Ma, especially given that the U-Pb ages for the flowstones are overlapping. As such, the best age estimate for *Australopithecus* from Malapa maybe the age published by Dirks et al. (2010) at close to, but younger than, 1.95 Ma. Either way, *A. sediba* from Malapa are the youngest known *Australopithecus* fossils from South Africa dating to around either 1.95 or 1.98 Ma.

Early Pleistocene *Homo* and *Paranthropus*

Sometime between about 2.3 and 1.95 Ma, the first *Paranthropus* and early *Homo* (including *Homo* aff. *erectus*) as well as Oldowan stone artefacts and bone tool technology occur in South Africa, and *Australopithecus* became extinct soon after this (Herries et al. 2020; Stammers et al. 2018).

Drimolen Main Quarry

Drimolen Main Quarry (DMQ) is located 6 km to the north-northeast of Sterkfontein (9 km southwest of Malapa), just north of the Blaauwbank stream valley. Drimolen has yielded the most complete skull of an adult female (DNH 7) and adult male crania (DNH 155) of *Paranthropus robustus* as well as isolated teeth and a partial cranium (DNH 134) of early *Homo* (Herries et al. 2020; Moggi-Cecchi et al. 2010). DNH 7 and DNH 155 have been argued to represent an early part of the *P. robustus* lineage based on differences between these fossils and the younger Swartkrans Member 1 Hanging Remnant (Martin et al. 2021). To date, DMQ has yielded over 155 hominin specimens as well as the second largest number of bone tools and a small selection of stone tools (d'Errico and Backwell 2008; Stammers et al. 2018). The DNH 134 juvenile represents the oldest example of a cranium with clear affinities to *Homo erectus* (Herries et al. 2020). The layer in which the cranium was recovered has been dated to 2.04 ± 0.24 Ma by US-ESR of a bovid tooth, setting an upper age limit of 2.28 Ma for the cranium (Herries et al. 2020). The lower age limit is 1.95 Ma based on its occurrence below the magnetic reversal at the base of the Olduvai SubChron. This magnetic reversal was identified in layers 3.6 to 4.8 m above DNH 134 (Herries et al. 2020). A flowstone that formed during the magnetic reversal that records an intermediate polarity was U-Pb dated to 1.96 ± 0.11 Ma (Herries et al. 2020). In addition, another US-ESR date on a tooth from just below this flowstone gave an age of 1.97 ± 0.15 Ma (Herries et al. 2020). Based on the similarity of the US-ESR and U-Pb age mean value and the magnetic reversal itself, it would seem reasonable to consider the 2.04 Ma median age estimate for DNH 134 based on US-ESR to also be

accurate. Moreover, the sequence does not show evidence for the earlier Huckleberry Ridge event at 2.07 Ma, as noted at Sterkfontein and Malapa. Other *in situ* hominins such as the DNH 155 and DNH 153 *P. robustus* crania can also confidently be dated to between 2.04 and 1.95 Ma, but closer to the latter given that they occur nearer the magnetic reversal (~2 m above DNH 134 and ~1.7 m below the reversal) (Herries et al. 2020; Martin et al. 2021). The hominin material published by Keyser et al. (2000), Keyser et al. (2000) and Moggi-Cecchi et al. (2010) comes mostly from decalcified and collapsed *ex situ* material or miners' rubble that was excavated in the 1990 and early 2000s by Andre Keyser and Colin Menter rather than the *in situ* stratigraphy. However, about 2.04 to 1.95 Ma is still a good age estimate for this material given that no younger or older deposits have yet been identified in DMQ.

Swartkrans Member 1

Swartkrans is located on the opposite side of the Blaauwbank stream valley and 1 km west from Sterkfontein. The stratigraphy of the cave has been divided into five Members, and Members 1 to 3 contain early stone age archaeology (bone and stone tools) as well as *Paranthropus robustus* fossils (Brain 1981, 1993; Grine 1993). Early *Homo* fossils have also been recovered from Members 1 and 2 (Grine 1993). Member 1 is considered to be the oldest unit and has been divided into two parts: the older Lower Bank (LB) and the younger Hanging Remnant (HR). The HR was the first of these two deposits to be sampled, and the majority of the well-known hominin fossils (e.g., SK 46, 48, 54, 847) come from the HR, although a lot of the SK fossils came from *ex situ* lime miners' dumps during the early days of sampling from 1949 to 1953 (Brain 1993). The LB was not discovered until excavations were undertaken at the site by Bob Brain in the late 1970s and early 1980s as it was buried under lots of lime miners' rubble (Brain 1993). As such, the earlier collected fossils could not have come from LB. Moreover, they were associated with HR based on the pink color of their indurated breccia matrix. Most of LB remains uncalcified.

Some fossils, such as the SK 15 early *Homo* jaw, also came from the earliest period of collection at the site but were recovered from a distinctly different brown colored infill that is considered to be what Butzer (1976) later termed Member 2 (Brain 1993). Much of Member 2 occurred in the inner cave and was a stratified siltstone and sandstone. Member 3 was not identified and added until later work by Brain (1981). Another distinction between the Member 1 deposits is that LB has significant amounts of Oldowan stone and bone tools (Caruana 2017), whereas HR does not, and Members 2 and 3 are thought to represent Acheulian technology, again with bone tools (Kuman 2007). Brain (1993) considered LB to represent an earlier infill compared with HR, and upon its discovery (after the establishment of Butzer's Member system), it was added into Member 1. However, given the fact that the majority of hominins come from HR and all of the archaeology from LB, they are probably best considered different units with their own distinct taphonomy.

Member 1 Lower Bank has been dated by both Al/Be and U-Pb dating. It should be noted that R. Pickering et al. (2011) and T. Pickering et al. (2012) disagree about the relationship of the speleothem flowstones used for U-Pb dating and their relationship to the different Member 1 units. R. Pickering et al. (2011, 2019) indicate that two flowstones were dated that bound the Lower Bank and 2 were dated that bound the Hanging Remnant. T. Pickering et al. (2012) state that the same flowstones were dated twice, but in different locations, and that one of these

underlies both LB and HR and the other caps both LB and HR as a sequence. The U–Pb ages of the flowstones underlying LB and HR are similar at 2.25 ± 0.08 Ma and 2.25 ± 0.05 Ma, respectively. The flowstones capping LB and HR deposits are also similar at 1.71 ± 0.07 Ma and 1.80 ± 0.01 Ma, respectively. As such, Member 1 as a whole dates to sometime between about 2.3 and about 1.8 Ma. Al/Be ages of 2.19 ± 0.08 Ma and 1.80 ± 0.09 Ma suggest that LB itself might date to the entire period encompassed by the flowstone ages (Gibbon et al. 2014). Further Al/Be ages from the base of LB yielded an age of 2.22 ± 0.09 Ma. These lowest layers contain a small number of *P. robustus* fossils and Oldowan stone tools, representing the oldest potential evidence for *P. robustus* in South Africa (Kuman et al. 2021). The age of the upper part of LB, which contains a single specimen of early *Homo*, can still only be defined as occurring between 2.22 ± 0.09 Ma and 1.80 ± 0.09 Ma. Based on the fact that HR must have formed after LB, the HR can thus be dated to between 1.80 ± 0.09 Ma and 1.80 ± 0.01 Ma. This means that the HR must have formed over a short period between 1.89 to 1.79 Ma. Herries and Adams (2013) have noted that the 2.25 ± 0.05 Ma SKW 7 U–Pb sample comes from a heavily truncated flowstone underlying the HR and this would equally suggest a large time gap between the age of this basal flowstone and HR, which would thus be closer to the capping 1.8 Ma age, as suggested by the Al/Be dating. Old US–ESR ages also suggest that this deposit is at the younger end of this age range (Curnoe et al. 2001).

Kromdraai B

Kromdraai is located 1.7 km east of Sterkfontein in the Blaauwbank stream valley. Kromdraai is important as the type site for *P. robustus*, identified in 1938 by Robert Broom. The Kromdraai palaeocave deposits have generally been separated into multiple sites, with the presumed younger Kromdraai A containing Acheulian stone tools, and important type specimens such as *Dinofelis piveteaui* but no hominins, and Kromdraai B the hominin material and a couple of bone tools (Braga and Thackeray 2016; Broom 1938; Stammers et al. 2018). The type specimen of *P. robustus*, TM 1517 is from an *ex situ* block and, owing to the complexity of the stratigraphy, it is difficult to be certain about its provenience and age. The hominin and other fossil material excavated from Kromdraai B by Brain (1981) in the 1950s come from decalcified material that could have come from several different indurated units, and again its provenance is not certain.

Partridge (1982) defined five members at Kromdraai B and stated that the majority of fossils come from the base of Member 3 (Partridge 2000). Based on palaeomagnetism, Member 2 was suggested to cover the Olduvai SubChron at 1.95 to 1.78 Ma, and one sample KRM2 recorded the reversal at the end of the Olduvai at 1.78 Ma (Thackeray et al. 2002). By inference, Herries et al. (2009) suggested that Member 3 was thus younger than 1.78 Ma, the Members defined by Partridge theoretically being sequential. But as Latham et al. (2003) and Herries et al. (2020) point out, such sedimentologically based units are often not sequential. Bruxelles et al. 2016) now show that the stratigraphy identified by Partridge is an oversimplification, and older and more extensive units (Members 1 to 7 with Member 4 having 3 submembers), which also include older hominin-bearing units (Member 2; Bruxelles et al. 2016; Braga et al. 2017; renamed Unit P in Ngoloyi et al. 2020), have now been identified. Their suggestion is that the previously recovered hominin sample, including type specimen TM 1517, may come from younger units (Members 5–6) and that the site may contain multiple aged units over a long period of time stretching back to

around 2 Ma (Braga et al. 2017). Braga et al. (2013) have addressed how some of these palaeomagnetic samples relate to the new stratigraphy. They suggest that a hominin specimen, KB 5522, may relate to the TM 1517 type specimen and comes from Member 5 above a reversed polarity flowstone that Thackeray et al. (2002) attributed to the period prior to 1.95 Ma. Deposits overlying this flowstone had normal polarity and would thus be dated to the Olduvai SubChron between 1.95 and 1.78 Ma. In Bruxelles et al. (2016), this flowstone is shown overlying a remnant of Member 1 Grey Breccia and is surrounded by Member 5 and 6 deposits. This would suggest that Members 5–6 which contain many of the historically collected hominins, including TM 1517 (Member 5), are between 1.95 and 1.78 Ma or younger. As yet, no radiometric dates other than a very young, ESR age of 814 ± 32 ka (Curnoe et al. 2002) have been published, but if correct, this would confirm a potentially long history for the site of over a million years, like Swartkrans.

Sterkfontein Member 5

Member 5 at Sterkfontein has yielded hominin specimens attributed to both *Paranthropus*, early *Homo* and perhaps *Australopithecus*. Partridge (1978) split Member 5 into three distinct units (A–C), often also referred to as the StW 53 Infill, the Oldowan Infill, and the Acheulian Infill (Herries and Shaw 2011), which is yet again split into Member 5 West and East portions (Kuman and Clarke 2000). Kuman and Clarke (2000) consider the StW 53 Infill to represent a younger portion of Member 4, and the StW 53 cranium itself as *Australopithecus* (Clarke 2013), in contrast to other researchers who have defined it as *Homo habilis* or early *Homo* (Curnoe and Tobias 2006). A reversed magnetic polarity and ESR dates suggest that this unit dates to soon after the Olduvai SubChron at about 1.7 Ma (Herries and Shaw 2011). This would make StW 53 by far the youngest occurrence of *Australopithecus*, if it were confirmed to be of that genus, rather than *Homo*. ESR ages for the Oldowan and *Paranthropus* bearing Oldowan Infill suggest an age of about 1.3 Ma (Herries and Shaw 2011), and the younger Acheulian and early *Homo* infill date to about 1.1 Ma (Herries and Shaw 2011). However, Al/Be dating of a quartz cobble from the Oldowan Infill has also produced an age of 2.18 ± 0.21 Ma, suggesting a minimum age of about 2 Ma (Granger et al. 2015). Confirming evidence for a <1.8 Ma post-Olduvai SubChron age for the entirety of Member 5, as suggested by ESR and palaeomagnetism, comes from U–Pb dates for a speleothem underlying Member 5 at 1.78 ± 0.09 Ma, and the speleothem that caps Member 4 at 2.07 Ma. As such, U–Pb, ESR, and palaeomagnetism are all consistent with an age of 1.8 to 1.1 Ma for the entirety of Member 5 and are at odds with the Al/Be age.

Gondolin Cave

Gondolin has yielded a single tooth of *Paranthropus* and a single tooth of early *Homo* (Menter et al. 1999). The *Paranthropus* tooth has received attention as it is the largest tooth of *Paranthropus* recovered from South Africa. Both were recovered from lime miners' dumps and so their provenience is problematic other than coming from the site, which has not yielded any other hominins or primates from the *in situ* excavations into the GD1 and GD2 deposits (Adams 2006). Palaeomagnetic analysis indicates that the GD2 deposits record a normal magnetic polarity with a normal to reversed polarity reversal occurring in a capping flowstone (Herries et al. 2006). Based on the fauna at the site this reversal is best correlated to the end of the Olduvai SubChron at 1.78

Ma (Herries et al. 2006). Similar-aged flowstones are found capping the Member 1 deposits at Swartkrans, underlying Member 5 at Sterkfontein, at Drimolen and Bolt's Farm (Pickering et al. 2019). The GD1 sequence also records a reversal from normal to magnetic polarity in a flowstone and overlying reversed polarity fossil-bearing sediments (Adams et al. 2007). Together this suggests that the hominin teeth date to either slightly before or after 1.78 Ma, but not older than 1.95 Ma (Herries and Adams 2013).

Haasgat

The site of Haasgat is located in the higher-altitude northeastern area of the Cradle of Humankind halfway between Malapa and Gondolin (Figure 1) and was first described by Keyser and Martini (1991). To date, only a single partial tooth has been recovered from *ex situ* lime miners' blocks at the site (Leece et al. 2016). The tooth represents either *Australopithecus* or early *Homo*, sharing similarities with a tooth attributed to *Homo* at Swartkrans (Leece et al. 2016). A single U-Pb date from the site suggests that the internal deposits formed around 1.69 ± 0.24 Ma (1.93–1.45 Ma; Pickering et al. 2019). These deposits record reversed polarity directions underlain by intermediate and normal polarity that may relate to the end of the Olduvai SubChron at 1.78 Ma, that is within the U-Pb range. However, this age is somewhat at odds with some of the fauna. In particular, the *Oreotragus* sp. is dissimilar to populations of this genus found at Makapansgat Limeworks Member 3 (3.03–2.61 Ma) and Gondolin at 1.8 Ma (Adams 2012). Given that Gondolin is very close to Haasgat, it would seem unlikely that there were such different populations of *Oreotragus* on the landscape at about 1.8 Ma (Adams 2012). The exterior deposits record reversed to normal polarity that was originally interpreted as the base of the Olduvai SubChron at 1.95 Ma (Herries et al. 2014). However, with the recent U-Pb date, this appears less likely, although the large error range on the U-Pb does come close to overlapping with the age of the lower Olduvai Reversal at about 1.95 Ma. Other fauna at Haasgat, such as *Damaliscus dorcas* and *Connochaetes gnou* suggest an age less than about 1.1 Ma. This reversal could therefore be a much younger reversal such as the Jaramillo SubChron (1.07–1.00 Ma) or the Gilsa event at 1.567–1.575 Ma (Singer 2014). This would suggest, as is also implied from some of the fauna (Adams 2012), that the Haasgat deposits formed over a long period of time. If so, given the *ex situ* nature of the hominin tooth, it is hard to be sure of its age until there is better resolution on the dating of the site.

Swartkrans Members 2 and 3

Swartkrans Member 2 has yielded fossils of *P. robustus* as well as important fossils of early *Homo*, including the SK 15 mandible. The current age estimates for Swartkrans Member 2 are problematic. U-Pb dating of teeth from Member 2 gave an age estimate of 1.36 ± 0.29 Ma (Balter et al. 2008); however, there are questions over the accuracy of this method given the open system nature of teeth. US-ESR dates of teeth from Member 2 gave very young ages of between about 224 and 98 ka (Curnoe et al. 2001). In the early days of work at Swartkrans, only the Member 1 Hanging Remnant and Member 2 were defined as deposits based on the distinct difference between the pink breccia of the HR and red to chocolate brown breccia and laminated sediments

of Member 2 (Brain 1958, 1981). Brain (1981) noted that it was becoming apparent through his excavations that Member 2 actually consisted of a number of different breccias and channel fills of very different ages and this likely explains the discrepancy of the very young ESR ages. Some fossil deposits originally considered to represent Member 2, such as the “bondi channel,” have since been radiocarbon dated to about 11 ka (Brain 1993).

The sequence at Swartkrans, like Sterkfontein, represents the initial infill of a larger cavern, represented by Member 1 at Swartkrans, that is then altered by erosion and collapse. Spaces between the indurated Member 1 were then infilled by Member 2 and a range of other subsequent infills covering 2 million years. This creates a great deal of complexity but also means that fossils and archaeology from older deposits maybe eroded and redeposited into younger units. Member 3 is another such unit that is important for containing the last potential occurrence of *P. robustus*. However, given that all the hominin fossils from Member 3 are isolated teeth, the possibility that these may have been reworked from older units has to be considered. Member 3 has been dated by a combination of ESR (0.80 ± 0.15 Ma to 0.65 ± 0.15 Ma; Blackwell 1994), U-Pb on teeth (0.83 ± 0.21 Ma; Balter et al. 2008), and Al/Be (0.96 ± 0.09 Ma; Gibbon et al. 2014) with a consistency of age estimates that suggests an age range between about 1.0 and 0.8 Ma.

Cooper's D

A number of *P. robustus* fossils have been recovered from the site of Cooper's D, located between Sterkfontein and Kromdraai in the Cradle of Humankind (de Ruiter et al. 2009). The basal flowstone at Cooper's D was redated to 1.38 ± 0.11 Ma, showing further support for *P. robustus* occurring in the region after 1.4 Ma, as also suggested by Swartkrans Member 3 (Pickering et al. 2019).

Cornelia-Uitzoek

A single tooth attributed to early *Homo* has been recovered from a hyena den within fluvial deposits at Cornelia-Uitzoek in the Free State of South Africa. The tooth is associated with Acheulian technology and has been dated to between 1.07 and 1.00 Ma based on palaeomagnetism and biostratigraphy (Brink et al. 2012). The tooth and associated Acheulian technology come from normal polarity deposits both overlain and underlain by reversed polarity deposits. Based on the fauna, which is similar to that seen in Olduvai Gorge Beds III and IV, this normal polarity period has been associated with the Jaramillo Subchron currently dated to between 1.07 and 1.00 Ma (Brink et al. 2012; Singer 2014). Although the tooth cannot be assigned to a specific species, it is important because it represents the oldest hominin remains outside of the Malmani dolomite of Gauteng, Makapansgat, and Taung in northern South Africa and the last specimen attributed to early, rather than Middle Pleistocene *Homo*.

Middle Pleistocene *Homo*

There is a dearth of Middle Pleistocene hominin fossils from southern Africa. The record is dominated by three crania found between 1920 and 1953, which include the type specimens of *Homo rhodesiensis* and *Homo helmei* (Dreyer 1935, 1947; Woodward 1921). More recently, a large collection of cranial and post-cranial fossils of *Homo naledi* (Berger et al., 2010) have increased the number of Middle Pleistocene hominin fossils.

Elandsfontein (Also Known as Saldanha, Hopefield)

Elandsfontein is located on the western coast of Western Cape province, around 100 km north of Cape Town. The hominin cranium is either late Early or early Middle Pleistocene in age, but age estimates for this specimen are problematic because of both the difficulty of dating the sequence and the provenience of the cranium itself, which was found in 1953 (Drennan 1953). Ages for the specimen are based on biochronology, and some limited palaeomagnetic analysis indicates both normal and reversed polarity occurs. Based on biostratigraphy of original collections, Klein et al. (2007) suggested an age of 1.0 to 0.6 Ma. Biochronology based on newly recovered fossils from Elandsfontein suggested perhaps a slightly older age range with specimens such as *Kolpochoerus heseloni* similar to that found in Olduvai Bed III–IV at slightly older than 1.07 Ma and at Cornelia-Uitzoek between 1.07 and 1.00 Ma (Braun et al. 2013). *Syncerus antiquus* is also found and occurs at sites such as Cornelia-Uitzoek (1.07–1.00 Ma), Cooper's D (<~1.4 Ma), and Swartkrans Member 3 (~1.0–0.8 Ma) (Braun et al. 2013). *Rabaticeras* was also recovered and is last seen at Gladysvale External deposits between 0.78 and 0.58 Ma (Braun et al. 2013; Lacruz et al. 2002). Combined with the palaeomagnetic data, this suggests an age of sometime from just prior to the Jaramillo SubChron between 1.07 and 1.00 Ma and perhaps as late as the early Brunhes Chron soon after 0.78 Ma. Given the large extent of Elandsfontein deposits, it is also possible that several time periods are represented, and Braun et al. (2013) have identified at least two well-defined fossil layers. The cranium is generally assigned to *H. rhodesiensis* (*H. heidelbergensis*), although it has also been assigned to *Homo erectus* by some researchers (Tappen 1987). The specimen is associated with Acheulian technology. Based on the reversed polarity of deposits in Homo Bay, where the fossil was discovered, the cranium is perhaps between 1.00 and 780 ka (Braun et al. 2013).

Cave of Hearths

The Cave of Hearths is located in the Makapansgat Valley in Limpopo province and has yielded a partial hominin mandible from the Acheulian-bearing Bed III deposit along with a hominin radius from a swallow-hole (collapsed and mixed sediments due to subsidence) context (Dart 1948; Herries 2011; Tobias 1971). The mandible has been attributed to *Homo rhodesiensis* (Tobias 1971). The Bed I–III Acheulian sequence from which the mandible was recovered has a normal magnetic polarity that suggests it is younger than 780 ka (Herries and Latham 2009). A direct ESR date on the mandible from Bed 3 suggests an age of 600 to 400 ka; however, there are issues with the dosimetry for this sample (Herries 2011). An apparent short magnetic reversal in the Hyena

Mandible Cave deposits that are older than Beds I–III likely relates to the period between 780 and 530 ka when several such reversals occur (Singer 2014). The radius is indistinguishable from those of modern humans and may thus date to the younger undated MSA levels (Pearson and Grine 1997).

Broken Hill (Also Known as Kabwe) Zambia

The Broken Hill cranium from Zambia is the type specimen of *Homo rhodesiensis* and was the first non-*Homo sapiens* fossil to be discovered in Africa in (1921) (Woodward, 1921). The cranium was found *in situ* in a metal ore mine, but, as with many early discoveries (especially from mines), the original context has since been mined away. Direct dating of the cranium and associated fossils found inside and outside the cranium using U-Th dating suggests an age estimate of 299 ± 25 ka (Grün et al. 2020). U-Th dating on bone often produces only a minimum age estimate because of the open system nature of the bone. However, US-ESR on tooth fragments suggests an upper age estimate of 322 ka and indicates that the cranium is likely around 322–274 ka (Grün et al. 2020). Owing to the unknown dosimetry of the sediments in which the cranium was deposited, a full US-ESR age could not be calculated.

Berg Aukas

The proximal half of a hominin right femur was recovered during vanadium mining operations at Berg Aukas in the karst of the Otavi Hills of northern Namibia in 1965 (Grine et al. 1995). The femur was recovered from L5, 177.4 m below the collar of shaft number 1, from partly indurated mid and ore breccia (Grine et al. 1995). The location from which the femur is alleged to have come was subsequently destroyed by mining, and level 5 of shaft 1 is now around 100 m under water (Grine et al. 1995). It is therefore impossible to date the context of the fossil, and direct dating is complicated by the highly mineralized nature of the fossil. Comparisons with other hominin femurs align it with Middle Pleistocene *Homo* (Grine et al. 1995).

Hoedjiespunt

Hoedjiespunt is located on Saldanha Bay to the northwest of Elandsfontein in the Western Cape province of South Africa and has yielded isolated teeth and a tibia of *Homo* from a hyena den deposit (Berger and Parkington 1995). The site remains undated other than through biostratigraphy and is associated with the Florisian Land Mammal Age (780/600–10 ka). The MSA site that is higher in the sequence has been TL dated to about 117 ka giving a minimum age, although the data for this TL age is not published (Stynder et al. 2001). The hominin material itself is comparable with other Middle Pleistocene hominin specimens (i.e., *H. rhodesiensis*) (Stynder et al. 2001).

Florisbad

Florisbad in the Free State of South Africa is the type site for the Middle Pleistocene species *Homo helmei*, which shows a mixture of traits seen in early *Homo sapiens* and *Homo rhodesiensis* (Bruner and Lombard 2020; Clarke 1985; Curnoe and Brink 2010; Dreyer 1947). It was found in a complex spring eye deposit at Florisbad in 1932 (Dreyer 1935), which makes it a complex setting for dating, and the record for its provenience is very limited. The cranium was “directly dated” by means of an isolated tooth that is assumed to associate with the cranium, although the cranium itself does not preserve any teeth. The ESR age of to 259 ± 35 ka ($294\text{--}225$ ka) (Grün et al. 1996) overlaps with OSL ages for the oldest stratified MSA bearing units at Florisbad at 279 ± 47 ka and 281 ± 73 ka. Both OSL and ESR methodologies have improved dramatically since the 1980s, as have methodologies for measuring dosimetry that is crucial for the reliability of ages using these methods. Given the similarity between the OSL and ESR ages, the best current age estimate for the cranium is between about 300 and 230 ka, although redating the site with modern methods, including direct U–Th dates on the cranium, would make this age assessment more secure.

Rising Star

Rising Star Cave, near Swartkrans Cave in the Cradle of Humankind, has yielded extensive remains of a new species *Homo naledi* since 2013 (Berger et al. 2015). The fossils have come primarily from two areas of the cave: the still-undated Lesedi Chamber (de Ruiter et al. 2019) and the originally described Dinaledi Chamber (UW-101) (Berger et al. 2015). The context of the *Homo naledi* fossils is unusual in that the hominin fossils occur in unlithified sediments within the subterranean part of an active cave system rather than in surface-exposed palaeokarst (Dirks et al. 2017). The oldest deposits and fossils in the Dinaledi Chamber date to a period prior to 780 ka based on a reversed to normal polarity flowstone (FS1a) and a US–ESR age on a baboon tooth of 723 ± 181 ka. This 1a flowstone continued to form until shortly after 500 ka based on U–Th dating (Dirks et al. 2017). During this period, the majority of the chamber may have been filled with sediment. Subsequent to this, these sediments were removed from the chamber and filled with the *Homo naledi*–bearing SubUnit 3b. This SubUnit has been capped near the walls of the chamber by a flowstone speleothem (FS1c) dated by U–Th to $244 \text{ ka} \pm 3 \text{ ka}$ (Robbins et al. 2021). Direct US–ESR dating of the hominin teeth gave ages of 284 ± 51 ka and 247 ± 42 ka, suggesting an age estimate of deposition between 335 and 241 ka (Dirks et al. 2017). However, because the flowstones do not seal and cap the entire deposit, it is possible that some of the fossils are younger than this with a minimum age model. While it has been suggested that the *Homo naledi* fossils were deposited through a confined chute in the ceiling of the Dinaledi Chamber (Brophy et al., 2021) work by Robbins et al. (2021) indicates that *H. naledi* could have entered the Dinaledi Chamber more directly prior to the collapse of a large block, the Dragon’s Back sometime prior to 241 ka.

Upper Pleistocene *Homo sapiens* of the Middle Stone Age

There is a significant gap in the hominin record between the potentially early *Homo sapiens* cranium at Florisbad about 260 ka and a series of definitively modern human remains found in direct association with MSA technology after about 125 ka.

Border Cave

A series of *Homo sapiens* fossils were recovered during guano mining (in the 1940s) and excavations (1940s and 1970s) of Border Cave on the border between KwaZulu-Natal in South Africa and Eswatini (previously called Swaziland), not far from the Mozambique border (Beaumont 1979). All the *H. sapiens* fossil remains from Border Cave (BC1–5) are older than the Howieson's Poort layers and are likely older than about 67 ka based on the dating of the Howieson's Poort at numerous sites across South Africa (Jacobs and Roberts 2017). This is supported by the direct dating of the youngest BC5 fossil to between 79 and 69 ka using ESR (Grün 2006). The ESR dates further suggest that the BC3 infant burial is around 84 to 72 ka (Grün 2006). The BC1–2 remains appear to be the oldest dating to somewhere between 179 and 80 ka, but this does depend on their provenience (Grün 2006), which is uncertain because BC1 and BC2 were recovered from guano mining dumps in the early 1940s (Cooke et al. 1945). If from the older units, it would be the oldest definitive modern human remains in South Africa dating to the late Middle Pleistocene and filling in the gap between Florisbad and the post-125 ka remains.

Blind River

A modern human femur was found in Estuarine Calcarenites at Blind River in the Eastern Cape in the 1930s (Wang et al. 2008; Wells 1935). The deposits from which the femur is thought to have been recovered are restricted to a short section of the river and have been dated by OSL to 118 ± 6 ka (Wang et al. 2008).

Klasies River Mouth

A series of 54 modern human fossils have been recovered from multiple members (LBS, SAS, and Upper) across Klasies River Mouth 1, 1A, and 1B in the Eastern Cape of South Africa (Grine et al. 2017a). The oldest fossils from LBS date to between about 110 and 100 ka based on ESR, AAR, U-Th, TL, and OSL (Grine et al. 2017a). The youngest from the post-Howieson's Poort Upper Layer 6 date to around about 60 to 57 ka based on TL and OSL dating (Grine et al. 2017a). The majority of the human fossils (39) come from the SAS member, and many are clustered in a small area of Cave 1, Layer 14. These date to sometime between 85 and 100 ka (Grine et al. 2017a).

Sea Harvest

The Sea Harvest fossil site is located close to Hoedjiespunt on Saldanha Bay in the Western Cape province of South Africa and has yielded a distal hominin phalanx and maxillary premolar (P₄) attributed to modern humans (Grine and Klein 1993). The fossils come from a fossil-bearing pocket within a 12- to 15-m sandstone cliff of aeolines and colluvial sand that was excavated in 1977 (Grine and Klein 1993). The deposits did not contain stone tools and are thought to have been accumulated by carnivores, as at Hoedjiespunt. Above these deposits is a Middle Stone Age bearing shell midden that is beyond the limit of radiocarbon dating (>40 ka; Grine and Klein 1993). This represents a minimum age for the fossil material. The whole sequence overlies a wave cut platform at +6–7 m amsl, and Butzer (1984) suggested that the material was thus all younger than the last interglacial maximum (~125 ka). This height is consistent with MIS 5e highstands dated on the southern Cape coast (Carr et al. 2010; Cawthra et al. 2018).

Pinnacle Point 13B

A hominin cranial fragment and incisor have been recovered from Pinnacle Point Cave 13B near Mossel Bay in South Africa's Western Cape province (Marean et al. 2004). Unfortunately, both were recovered from disturbed deposits (Marean et al. 2004). Marean et al. (2004) state that there is little question, however, that it came from the Brown Sands MSA Facies. Later excavation of this Western Area of PP13B split the MSA units into a number of distinct facies which were dated to between 91 and 102 ka (Marean et al. 2010). This is currently the best age estimate for these hominin remains, although they could be a little older as they fall between Middle Pleistocene hominins and modern humans in terms of the incisors' metric attributes (Marean et al. 2004). The dates come from a combination of OSL dating of the sediments themselves along with U-Th dating of a flowstone speleothem that formed on the back side of a large dune that sealed the cave from the outside, allowing the flowstone to form (Marean et al. 2010). The formation of flowstone is unusual in such a Table Mountain Sandstone (TMS) cave setting but occurs because of a calcrete which caps the TMS.

Die Kelders Cave 1

Twenty-six isolated teeth, a mandibular fragment, and three phalanges of children and sub-adults (Grine 2000; Grine et al. 2017b) have been recovered from DK1. ESR and luminescence dating suggest that the deposits were formed sometime between about 75 and about 50 ka (layers 4 to 13), although human fossils have also been recovered from layers (14 and 15) older than these dates (Feathers and Bush 2000; Schwarcz and Rink 2000).

Blombos Cave

Nine modern human teeth were recovered from Blombos Cave on the southern Cape coast of South Africa between 1997 and 2000 (Grine and Henshilwood 2002). The teeth come from a variety of different layers (CK being the oldest and CB/CC the youngest) that have been dated by OSL to between 98 ± 5 ka and 71 ± 4 ka (Jacobs et al. 2020). The oldest five teeth (SAM-AP 6292,

6295, 6303, 8972, and 8973) from the M3 Phase (Layers CJ, CK, and CI) are dated to between 98 ± 5 ka and 82 ± 4 ka during MIS 5c to 5b (Jacobs et al. 2020). Tooth SAM-AP 6293 from Phase M2 upper (Layer CF) is dated to between 76 ± 3 ka and 74 ± 3 ka and is associated with the Still Bay industry during MIS 5a (Jacobs et al. 2020). Teeth SAM-AP 6264, 8971, and 8928 from Phase M1 (Layers CB, CC, CD) are dated to between 74 ± 3 ka and 71 ± 4 ka and are also associated with the Still Bay industry during late MIS5a and early MIS 4 (Jacobs et al. 2020).

Sibudu Cave

Three modern human teeth (SIB 1 to 3) have been recovered from MSA contexts at Sibudu Cave in the Kwa-Zulu Natal province in South Africa (Will et al. 2019). SIB 3 is associated with the Howieson's Poort industry at about 64.7 ± 1.9 ka from PGS3. SIB1 and SIB 2 are associated with a pre-Still Bay Industry in layers Casper and Danny prior to 77.2 ± 2.1 ka (Will et al. 2019).

Hofmeyr

A nearly complete modern human cranium was found in a dry channel of the Vlekpoot River northeast of the town of Hofmeyr in the Eastern Cape province of South Africa (Grine et al. 2007). Luminescence dating of sediments from the interior of the cranium was dated to 36.2 ± 6.6 ka (2 sigma weighed mean; Grine et al. 2007). U-Th dating of carbonate on the cranium gave an age of 24.0 ± 5.2 ka, supporting this MIS 3 age (Grine et al. 2007).

Equus Cave (Buxton-Norlim Limeworks)

Twelve isolated teeth and a mandible fragment have been recovered from Equus Cave at the Buxton-Norlim Limeworks in the Northwest province of South Africa (Grine and Klein 1985). Equus Cave is located several hundred meters from the area that the Taung Child *A. africanus* skull was discovered but is located within a different, younger tufa flow (Oxland Tufa; Kuhn et al. 2016). Dating of Equus Cave has been problematic with a number of studies using radiocarbon dating on OES, charcoal, teeth, and bone as well as amino acid racemization. There are a lot of age inversions in the sequence that likely relate to a number of issues: (1) underestimates related to the dating of bulk carbon in bone rather than using modern collagen extraction; (2) OES overestimates due to a dead carbon fraction occurring in OES because the cave is on a karst landscape and the ostriches potentially ingested limestone rocks to aid digestion, and (3) mixing during the excavations itself (Kuhn et al. 2016). The oldest teeth (EQ-H9 to H12) come from Unit 2B and are probably Later Pleistocene in age, dating between 32,002 and 19,200 cal yrs BP (all ages are recalculated using Oxcal 4.4 and ShCal20; see Table 1 of Kuhn et al. 2016) during terminal MIS3 and the early part of the Last Glacial Maximum. No dates exist for Unit 2A, which has yielded another three teeth (EQ-H6 to H8), but based on dates in the underlying Unit 2B and overlying 1B, these likely date to the terminal Pleistocene prior to 13,486 cal yrs BP. A single tooth (EQ45) from Unit 1B may also be terminal Pleistocene between 14,016 and 10,765 cal yrs BP. The mandible fragment's (EQ-H 71/33) context is uncertain but is thought to come from Unit 1B or lower, so is also likely Pleistocene in age. The remaining teeth (EQ-H1- H3) from Unit 1A are

Holocene in age (8,392 to 2,147 cal yrs BP). This chronology is supported by environmental data that suggests cold glacial conditions during Unit 2B and lower 2A and gradually warming conditions occurring in upper 2A and 1B, representing the period between the LGM and the Holocene (Kuhn et al. 2016).

Table 1. The age of hominin sites in South Africa

Site	Location	Deposit	Species	Age range, Ma/ka	Methods
Sterkfontein	Silberberg Grotto	Member 2	<i>Australopithecus</i>	3.7/2.8–2.2	Al/Be, U-Pb, Pmag
Sterkfontein	Jacovec Cavern	Orange Breccia	<i>Australopithecus</i>	4.0–3.5 or <2.3	Al/Be, fauna
Makapansgat	Limeworks	Member 3/4	<i>A. africanus</i>	3.03–2.61	Pmag. fauna
Taung (Buxton-Norlim Limeworks)	Dart Pinnacle	PCS	<i>A. africanus</i>	3.03–2.61	Pmag. fauna
Gladysvale		Ex situ dump	<i>A. africanus?</i>	<2.4 Ma	ESR
Sterkfontein	Surface	Member 4/3	<i>A. africanus</i>	2.80–2.07	U-Pb, ESR, Pmag
Swartkrans	Member 1	Lower Bank	Early <i>Homo</i> , <i>P. robustus</i>	2.2–1.8	Al/Be, U-Pb
Swartkrans	Member 1	Hanging Remnant	Early <i>Homo</i> , <i>P. robustus</i>	~1.8 Ma	U-Pb, ESR
Drimolen	DMQ	ALL	<i>Homo erectus</i> , <i>P. robustus</i> , <i>Homo sp.</i>	2.04–1.95	U-Pb, ESR, Pmag
Malapa	Pit 1	Facies D, E	<i>A. sediba</i>	~1.95 Ma	U-Pb, Pmag.
Haasgat		<i>Ex situ</i> dump	Early <i>Homo?</i>	1.95 to <1.78 Ma	Pmag, fauna
Gondolin		<i>Ex situ</i> dump	<i>P. robustus</i>	~1.8	Pmag, fauna

Site	Location	Deposit	Species	Age range, Ma/ka	Methods
Swartkrans		Member 2	Early <i>Homo</i> , <i>P. robustus</i>	1.7–1.1 (~1.4)	U-Pb (bone)
Swartkrans		Member 3	<i>P. robustus</i>	1.0–0.8	U-Pb (bone), ESR, Al/Be
Kromdraai	B	Member 2-6	<i>P. robustus</i>	2.0–0.8	ESR, fauna
Sterkfontein	Member 5	StW Infill	Early <i>Homo</i>	1.8–1.6	ESR, U-Pb, Pmag
Sterkfontein	Member 5	Oldowan Infill	<i>P. robustus</i>	1.4–1.2	ESR
Sterkfontein	Member 5	Acheulian Infill	Early <i>Homo</i>	1.3–1.0	ESR Pmag
Sterkfontein	Milner Hall	T1	Early <i>Homo</i>	~1.3 Ma?	correlation
Coopers	D	ALL	<i>P. robustus</i>	<1.4	U-Pb
Cornelia	Uitzoek	MYC	Early <i>Homo</i>	1.07–1.00	Pmag, fauna
Elandsfontein	Homo Bay	Calcrete	<i>H. erectus</i>	1.0–0.8	Pmag, fauna
Makapansgat	Cave of Hearths	Bed III	<i>H. rhodesiensis</i>	0.8–0.4	Pmag, ESR
Broken Hill			<i>H. rhodesiensis</i>	322–274	ESR, U-Th
Berg Aukas			<i>Homo</i>	unknown	

Site	Location	Deposit	Species	Age range, Ma/ka	Methods
Rising Star	Dinaledi Chamber	SubUnit 3a	<i>H. naledi</i>	335–241	ESR, U-Th
Rising Star	Lesedi Chamber		<i>H. naledi</i>	unknown	
Florisbad	SPRING EYE		<i>H. helmei</i> (<i>H. sapiens?</i>)	294–225 ka	ESR
Hoedjiespunt	HDP1		<i>Homo</i> sp.	780–117 ka	TL, fauna
Border Cave			Modern human	179–67	ESR
Blind River		Estuarine Calcarenites	Modern Human	224–112	OSL
Sea Harvest			Modern Human	>40 ka to <125 ka	C14, sea level
Klasies River Mouth	1, 1A, 1B	LBS, SAS, Upper	Modern Humans	110–57 (SAS; 100–85)	OSL, TL, ESR
Pinnacle Point	13B	<i>Ex situ</i> (brown MSA sands)	Modern Humans	102–91 ka	OSL, U-Th
Blombos Cave	M1 to M3	CJ, CK, CI, CF, CD, CC, CB	Modern human	<103 ka to >67 ka	OSL
Die Kelders cave 1		Layers 4–15	Modern Human	75–50	OSL, TL, ESR

Site	Location	Deposit	Species	Age range, Ma/ka	Methods
Sibudu Cave		PGS3/Casper& Danny	Modern Human	62.8 to >75.1 ka	OSL
Hofmeyr	Vlekpoort River	Cranium interior	Modern human	42.8–29.6	OSL, U-Th
Buxton-Norlim Limeworks	Equus Cave	2B to 1B	Modern human	32 to 11 ka	C14

Peers Cave and Plovers Lake

Modern human remains associated with the MSA time period have been described from Peers Cave (Fishhoek, Western Cape) and Plover's Lake (Gauteng) (de Ruiter et al. 2008; Stynder et al. 2009). The Peers Cave skeleton, found in the 1920s, was thought to be associated with the MSA levels and was long considered to be the most complete Pleistocene South African human skeleton (Stynder et al. 2009). This was also important as one of the few potential MSA burials from Africa. Radiocarbon dating of this specimen now shows that this skeleton is dated to the Holocene (7685 ± 50 cal yr BP using Oxcal and SHCal20).

Modern human remains associated with the MSA at Plovers Lake were dated to between 88.7 ± 1.6 ka and 62.9 ± 1.3 ka using U-Th dating of "capping" and "underlying" flowstones in the cave. This was corroborated by an ESR age of 75.6 ± 5.6 ka (de Ruiter et al. 2008), although the data behind these age estimates has never actually been published. The assemblage contained seven modern human fossils that were considered to come from a single individual (de Ruiter et al. 2008), making them a rare example of MSA modern human remains from the caves of Gauteng. However, Lombard et al. (2019) subsequently undertook radiocarbon and ancient DNA analysis on (5 of the 11) the human remains and faunal remains. Ancient DNA analysis from three specimens indicated that they were likely related to Iron Age farming communities and dated to less than 532 cal yr BP. Not everything in these deposits is this young, but it does suggest that the human remains are and indicates that the deposits contain a mixed assemblage and illustrates the danger of assuming that everything that is recovered from below what is assumed to be a capping flowstone, when it does not completely cap all the deposits, is actually stratigraphically older. It is critical where false flowstone floors may occur in cave sites that the dating of the flowstones is complemented with micromorphology to confirm the relationship of sediments to flowstones.

Discussion and Conclusions

The Malmani karst outcropping in the Gauteng region of South Africa appears to preserve a relatively confined age range of fossil-bearing deposits and this perhaps in part due to the erosion of older caves (Herries et al. 2019; Pickering et al. 2019). Although there appear to be fossil deposits that stretch as far back as 3.2 Ma (Pickering et al. 2019) or maybe even 3.7 Ma (Granger et al. 2015; but see Kramers and Dirks 2017), the vast majority of hominin fossil deposits that remain on the landscape appear to date to between about 3.0 and about 1.0 Ma, and there is a particular concentration of sites between 2.0 and 1.4 Ma. U-Pb ages, confirmed in many cases by the presence of magnetic reversals and events, show that flowstones of the same age occur across multiple caves in the Cradle (Pickering et al. 2019). As such, the flowstones can now be used in a similar way that argon-argon dated tuffs are used to correlate and date hominin fossils across the eastern African rift. The various deposits and hominin fossils can be sandwiched between these dated flowstones to create chronologically constrained flowstone-bound units (Pickering et al. 2019). Work at Drimolen has further shown how the addition of US-ESR and palaeomagnetism can then be used to refine the age of the fossils in these flowstone-bound units even further,

dating all the different contemporary units within the caves (flowstone, sandstone and siltstone, and the fossils themselves) (Herries et al. 2020). However, to achieve reliable ages from the sites, sample selection is a key factor, particularly for the US-ESR dating of teeth. Analysis has shown that if teeth are recovered from unaltered indurated cave deposits, then they produce ages that are consistent with other methods, but if the teeth are taken from decalcified cave deposits or from excavated collections, then the ages are generally underestimated (Herries and Shaw 2011; Herries et al. 2020). A number of early ESR analyses used teeth from collections where the dosimetry could not be accurately calculated and this will significantly affect the age estimate. Modern methods combining uranium series dating of the teeth can provide ages comparable to other methods that have pushed the limit of US-ESR dating back to at least 2.61 Ma (Herries et al. 2018, 2020).

Cosmogenic nuclide burial ages have the potential to add to this methodology by dating quartz clasts from breccias that cannot be dated by some of the other methods, as well as the direct dating of stone tools (Kuman et al. 2021). However, cosmogenic nuclide burial ages have often not correlated well with other dating methods (Pickering 2015) and there are complexities to using this method in dating such cave deposits, including knowing whether the samples have been buried more than once (Kramers and Dirks 2017; Shaar et al. 2021). However, in some cases, such as Swartkrans Member 3, it does correlate with other methods despite the potential for some of the material dated to have been previously buried and reworked in older Members first. Cosmogenics also correlates with U-Pb in Lower Bank, although the addition of other methods (US-ESR and palaeomagnetism) would strengthen the chronological certainty of these deposits, as would redating of Hanging Remanent by all these methods. The same is true of most of the other sites. Other factors, such as the influence of magnetic reversals on cosmogenic dates, due to a decreasing magnetic field intensity, need to be better understood now that it is known that such reversals often occur in the sequences.

Owing to the sites primarily dating to the period between 3.0 and 1.0 Ma, several have yielded fossils of *Paranthropus robustus* (nine deposits) and early *Homo* (eight deposits) but far fewer fossils of *Australopithecus africanus* (maybe two sites in Gauteng and two others at Taung and Makapansgat). However, while there are sites containing *A. africanus* that stretch over several 100 km in South Africa (from Taung to Sterkfontein to Makapansgat), all we know about *P. robustus* is known from the 25-by-10-km area of karst in Gauteng. This early karst record shows that *A. africanus* and perhaps a second species of *Australopithecus* occur in South Africa between 3.0 and 2.1 Ma. Around 2.2 to 2.0 Ma, *Australopithecus* became extinct in South Africa but was contemporary for a short period of time until about 2 Ma with *P. robustus*, *H. erectus*, and perhaps other species of early *Homo* (Herries et al. 2020). *P. robustus* and early *Homo* continue to be found in northern south Africa, along with Oldowan and then Acheulian technology, until around 1.0 to 0.8 Ma (Caruana 2017; Herries 2011; Kuman et al. 2021). Both of these technologies are also accompanied by a uniquely South African modified bone tool technology, primarily associated with rich *P. robustus*-bearing deposits, mostly at Drimolen and Swartkrans (Stammers et al. 2018).

Outside these restricted areas of karst in northern South Africa, the next oldest hominin fossil is a single “early *Homo*” tooth recovered from the 1.07- to 1.00-Ma alluvial deposits at Cornelia-Uitzoek in the Free State, about 200 km to the southeast of the Gauteng sites (Brink et al. 2012). This is followed by the about 1.0- to 0.8-Ma *Homo erectus* (or *H. rhodesiensis/heidelbergensis*) cranium from Elandsfontein in the Western Cape that is associated with Early Acheulian technology, like *Homo* specimens from Sterkfontein, Swartkrans Member 2, and Cornelia-Uitzoek. It is likely that this sudden change in the biogeography of hominins across South Africa after 1.1 Ma is a geological bias, with few Pliocene and Early Pleistocene fossil deposits occurring outside the karst..

H. rhodesiensis occurs in southern Africa represented by the 0.8- to 0.4-Ma Cave of Hearths mandible and the late-occurring about 322 to 274 ka Broken Hill Cranium from Zambia. There are so few fossils in this time period, with little certainty over which species they represent, that it is hard to know what is happening in this critical time period in the Middle Pleistocene, where Acheulian technology transitions to MSA technology and where the common ancestor of Neanderthals and modern humans may have occurred in Africa. However, the period around 300 ka seems to have been a period of high hominin diversity in southern Africa with specimens of *H. rhodesiensis*, *H. naledi*, and perhaps another distinct species (*H. helmei*) or early *Homo sapiens* occurring (Florisbad). This is the same period when early modern humans are suggested to occur in northern Africa (Hublin et al. 2017) and slightly before they occur in eastern Africa at Omo, redated to older than about 233 ± 22 ka (Vidal et al. 2022). In South Africa, the oldest potential evidence for modern humans comes from Border Cave after 179 ka, at Blind River about 118 ± 6 ka, and then from the various coastal cave sites after 110 ka. From about 500 to 300 ka, there is a transition from Acheulian to MSA technology in the interior of South Africa, but none of these fossils is directly associated with MSA technology (Herries 2011). The Florisbad cranium does occur at a site with early MSA technology, although the skull and archaeology are not from the same deposits, although perhaps of similar age (Herries 2011).

As such, South Africa has a rich early hominin record that can be well dated, between 3.0 and 1.0 Ma, but after this the record is very fragmentary with the majority of fossils having been found during the early 20th century, which makes certainty over their provenance and dating problematic. Moreover, dating many of these sites outside of the Malmani dolomite is problematic, until the last couple of 100,000 years, where OSL has revolutionized the dating of the MSA and modern human record. This is particularly an issue at open sites, although new methods such as TT-OSL and post IR-IRSL hold a lot of promise (Richard et al. 2022). Key sites, such as Florisbad, that were dated by older ESR and OSL methods probably need redating with modern methods, and there needs to be less of a reliance on single methods and ages to define the chronology of the South African record.

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