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News and views

Clarifying the context, dating and age range of the Gondolin hominins and *Paranthropus* in South Africa

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Introduction

In a recent article, Grine et al. (2012) provided a thorough analysis of the GD A-2 *Paranthropus robustus* M_2, one of the two hominin specimens recovered from the Gondolin palaeocave in the northeastern corner of the UNESCO Cradle of Humankind World Heritage Site ('Cradle'), South Africa (Menter et al., 1999). Although we appreciate the detailed approach of their research on the hominin specimen, we wish to clarify several incorrect citations of our work at the Gondolin site, including the probable origin of the hominin specimens and age of the deposits. Moreover, Grine et al. (2012) suggest that *Paranthropus* occurs in South Africa between 1.9 and 1.5 million years ago (Ma), an age range that does not reflect the ages produced by a number of dating studies on *Paranthropus*-bearing sites and continues to argue for the reliability of biochronology based on correlations with East Africa over existing chronometric ages that exist for the sites. With recent advances in a number of dating methods that are applicable to the South African caves and studies that show their accurate cross correlation (Lacruz et al., 2002; Herries et al., 2010, 2013), it is no longer necessary to rely on faunal estimations for the age of these deposits based on correlations with the other end of the African continent, and with little data existing in between. Moreover, recent geochronological studies on the South African caves have shown that many dates based on biochronological analysis with sites in East Africa are up to half a million years too old (Herries et al., 2010; Herries and Shaw, 2011). This discordance may relate to South Africa functioning as both a continuous population refuge and geographic origin for several Pleistocene and extant lineages (see summary in Lorenzen et al., 2012; also Pickford, 2004). This expanding dataset on the complex, dynamic biogeography of African mammals precludes the assumption that the South and East African sites, separated by 3000–4000 km, had homologous first/last appearance dates of species/lineages. It also highlights the importance of using the current chronometric dating framework of South African localities to establish revised, 'local' biochronological data, particularly given the recycling in the literature of early biochronological dates that, themselves, were based in part on South African site dates that have been revised in recent years. Here we review the dated record of *Paranthropus* in South Africa (2.0–<1.0 Ma; Table 1), including that of Gondolin (1.95–~1.78 Ma; Table 1) and review chronometric ages that Grine et al. (2012) dismiss as unreliable, so that such errors are not left to propagate their way through the published literature.

Recovery and depositional context of the Gondolin hominins

As is the case at most South African palaeocaves, the Gondolin site was mined for lime deposits during the early twentieth century. The mining activity at Gondolin was particularly extensive and obliterated the central portions of the cave system, leaving only extensive ex situ dumpsites and partial in situ remnants of the original karstic deposits along the margins of the open cast mine (Menter et al., 1999; Herries et al., 2006a,b; Adams et al., 2007). One of these in situ remnant deposits, designated GD 2, preserves a dense accumulation of fossils in a red siltstone matrix (Watson,

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Table 1
Age range for *Paranthropus* sites in South Africa.

Site	Unit	Age	Method	Reference
Swartkrans	Member 1 Hanging Remnant	2.0–1.8 Ma	U–Pb, ESR	Pickering et al. (2011), Curnoe et al. (2001): this paper.
Swartkrans	Member 1 Lower Bank	Sometime between 2.3 and 1.6 Ma (likely contemporary with Hanging Remnant)	U–Pb	Pickering et al. (2011),
Gondolin	GD 1	~1.78 Ma	Palaeomag. Fauna	Herries et al. (2006a,b), Adams et al. (2007)
Gondolin	GD 2	1.95–1.78 Ma (~1.8 Ma)	Palaeomag. Fauna	Herries et al. (2006a,b), Adams et al. (2007)
Gondolin	GD A	1.95–~1.78 Ma	Correlation/fauna	Herries et al. (2006a,b), Adams et al. (2007)
Kromdraai B	Member 3	1.8–1.6 Ma	Palaeomag. Fauna	Thackeray et al. (2002), Herries et al. (2009)
Sterkfontein	Member 5b	1.4–1.1 Ma	Palaeomag. U–Pb, ESR	Curnoe (1999), Pickering and Kramers (2010), Herries and Shaw (2011)
Swartkrans	Member 2	1.7–1.1 Ma	U–Pb	Balter et al. (2008)
Cooper's D	Upper Facies A and C	<1.4 Ma	U–Pb	de Ruiter et al. (2009)
Cooper's D	Lower Facies A and C	1.6–1.4 Ma	U–Pb	de Ruiter et al. (2009)
Drimolen	All	2.0–<1.4 Ma	Faunal estimate	Keyser et al., 2000. This paper.
Swartkrans	Member 3	1.3–0.6 Ma	U–Pb, ESR	Blackwell (1994), Balter et al. (2008)

1993; Menter et al., 1999). The GD 2 deposits were excavated in the late 1970s and yielded a rich faunal assemblage that was later only partially described (Watson, 1993). Subsequent analysis of the entire GD 2 assemblage (Adams and Conroy, 2005; Adams, 2006, 2010) failed to identify any primate remains among the 95,549 specimens recovered from the GD 2 sample. The only other in situ fossil-bearing deposits thus far identified at Gondolin, designated GD 1, occur along the western rim of the excavated cave system and consist of a complex mix of grey breccia, conglomerates and other finer-grained clastic sediments that have become partially decalcified through erosional dissolution (Adams et al., 2007). Excavation of these deposits and analysis of the 4843 specimens recovered fossil assemblage also failed to identify any primate specimens and the hominin remains are an oddity in this respect (Adams, 2006).

At present, the only primate (including hominin) bearing deposit at Gondolin is 'Dumpsite A', a massive ex situ pile of calcified sediments near the southwestern edge of the mined cave system (Menter et al., 1999; Adams, 2006). Excavation in 1997 into the top of the dumpsite through two adjacent 1 m^2 units to a depth of approximately 2 m (Trench A) yielded both the GD A-2 *P. robustus* M_2, as well as a partial, indeterminate hominin lower molar (GD A-1) (Menter et al., 1999). In their description of the recovery of the two hominin specimens, Menter et al. (1999) noted the occurrence of at least two types of calcified sediment blocks within Dump A: a grey, clastic 'breccia' (Conglomerate Unit sensu Menter et al., 1999) and a fine, red siltstone with sporadic clasts (Finer Clastic Unit sensu Menter et al., 1999). Both hominin teeth were recovered from small blocks attributed to this Finer Clastic Unit and no attempt was made to specifically associate the ex situ blocks with the limited GD 1 or GD 2 in situ remnants (Menter et al., 1999). Given the disturbance of the original palaeocave system through mining and limited sampling of the GD 1 and GD 2 deposits, both Adams (2006) and Adams et al. (2007) also advocated a cautious treatment of the GD A ex situ hominins and 'associated' fossils processed from Trench A blocks. At no point does Adams et al. (2007) argue that the GD 1 in situ deposits "is the likely source for the 'breccia' blocks in Dump GD A that yielded two hominin teeth (Menter et al., 1999)", contra Grine et al. (2012: 598). Instead, Adams et al. (2007) reinforced that the GD A dump is a heterogeneous mix of fossil-bearing deposits and noted that the exposed GD 1 calcified sediments appeared analogous to the grey 'Conglomerate Unit' sediment blocks recovered from Trench A, and not the hominin-bearing 'Finer Clastic Unit' blocks recovered by Menter et al. (1999) that more closely resemble the red siltstone matrix currently adhering to the northern and southern remnant cave walls (GD 2 and GD 3 datum points; Adams, 2006; Herries et al., 2006a,b). By directly equating the in situ GD 1 deposits with the ex situ GD A dumpsite, Grine et al. (2012) establishes GD 1 as the sole in situ source deposits for the ex situ Gondolin hominins, GD A blocks and processed fossils; a position that has not been advocated in any prior publications on the Gondolin hominins or fossil deposits (e.g., Menter et al., 1999; Adams and Conroy, 2005; Herries et al., 2006a,b; Adams, 2006, 2010; Adams et al., 2007). In sum, we wish to reinforce that: 1) the Dumpsite A ex situ calcified sediments have never been described as being either largely or exclusively derived from deposits near the GD 1 datum point; 2) only the grey 'Conglomerate Unit' ex situ blocks from Trench A are similar to those in the GD 1 in situ deposits; 3) both of the ex situ Gondolin hominin teeth were processed from 'Finer Clastic Unit' blocks that have a red siltstone matrix dissimilar to that of the GD 1 deposits (but resembling that near the northern [GD 2] and southern [GD 3] datum points); and 4) neither of the Gondolin hominin specimens have been definitively associated with excavated in situ deposits at the site (GD 1, GD 2).

Dating of the Gondolin site deposits

It has seemingly become the opinion that the South African palaeocave sites are too complex to understand and thus date accurately. This is a view perpetuated by studies of, and arguments over, the dating and geology of complex multi-generational sites where multiple phases of karstification, infilling and erosion occur, such as Sterkfontein (Partridge, 2000; Clarke, 2007; Pickering and Kramers, 2010). Moreover, mis-citation and continued misrepresentation of dating methods in papers that are not fundamentally about dating, as is the case in Grine et al. (2012), exacerbate this issue. Sterkfontein, in having a currently active cave system associated with it, is the oddity amongst South African palaeocave sites, not the rule. Other 'sites' such as Cooper's, Bolt's Farm and even Kromdraai (site A and B) contain multiple small caves that are best viewed as separate sites and such distinctions need to be made in the literature with clear identification of what locality (Kromdraai), cave site (A or B) and Member/Unit (1–3, etc.) is being studied or from which a fossil comes. Simply comparing fossil material from 'Taung', 'Kromdraai' and 'Sterkfontein' means that you are not taking account of major temporal and/or taphonomic variations that may exist between different deposits/sites at these localities. In contrast, Gondolin, like many other smaller Cradle sites (e.g., Haasgat, Hoogland; Adams et al., 2010) has a much less complicated depositional history and appears to be temporally confined to a short period of deposition. A series of later infill does occur at

Gondolin (Adams et al., 2007) but these are confined and have not been shown to contain fossils.

In their discussion of the age of the Gondolin deposits, Grine et al. (2012: 598) cite Adams et al. (2007) when stating that the GD 1 in situ deposits contain only reversed polarities and then write that the Gondolin fossils "might be ca. 2.0 Ma (or older), or perhaps 1.7–1.5 Ma". In fact, neither Herries et al. (2006a,b) nor Adams et al. (2007) state that the GD 1 deposits contain only reversed polarities or suggest these date ranges for either the GD 1 or GD 2 in situ deposits. Instead, these papers suggest that the sampled normal polarity GD 2 deposits date to the Olduvai SubChron between 1.95 and 1.78 Ma and that the GD 1 deposits, which record a reversal from normal to reversed polarity, date to the reversal at the end of the Olduvai SubChron at 1.78 Ma. This same reversal is noted in the flowstone capping GD 2. The mis-citation by Grine et al. (2012) on both the occurrence of both normal and reversed polarities in the deposits, and the interpreted depositional ages, yields the suggestion that the site may date to a much longer period of time than has been previously argued to be the case. While there is some complexity in the formation of the basal deposits at GD 1, as outlined by Adams et al. (2007), these deposits consist of different flowstone layers and fossil sterile breccias that do not contain fossil material and are therefore not likely to be the source of the ex situ fossil collections. The GD 2 normal polarity fossil-bearing siltstones exhibit a sharp contact with the reversed polarity basal flowstone (the only deposit argued to be older than 2 Ma), while there is continuous transition from the fossil bearing sediments into the flowstone capping the GD 2 deposit. As such, the fossil deposits were argued to be closer to this reversal at the end of the Olduvai at 1.78 Ma and the same as that found in the GD 1 deposits. Given that the same aged reversal was seen in both the capping flowstone of GD 2 and GD 1 sediments meant that an age of ~1.8 Ma was thus argued for the hominins as there was little evidence at the site for fossil bearing deposits of any other age. Critically, neither of these prior studies suggested fossil deposition at Gondolin in excess of the Olduvai SubChron (>1.95 Ma) or within the 1.7–1.5 Ma range offered by Grine et al. (2012).

While it is possible that the flowstone capping GD 2 may have formed significantly after the fossil deposits, even if this were the case, the normal polarity of these deposits limits their upper age to 1.95 Ma as no other major normal polarity period exists in even the broadest time range of the fauna with which these deposits can be correlated. Thus, while the palaeomagnetic data was interpreted via the faunal data, the suid biochronology is only influencing the final age assessment in a very broad way. The dating of Swartkrans Member 1 (Pickering et al., 2011) to between 2.0 and 1.8 Ma (also see below) only strengthens the earlier age assessments made by Herries et al. (2006a,b) and Adams et al. (2007) as GD 1 contains numerous *Metridiochoerus andrewsi* (Artiodactyla: Suidae) specimens analogous to those of Swartkrans Member 1. Pickering et al. (2011) have noted that flowstones form synchronously in a number of different caves in the region and the flowstone capping the GD 2 deposits is likely the same as that capping the Hanging Remnant of Swartkrans at ~1.8 Ma. In this light, the current chronological framework of the Gondolin fossil-bearing deposits suggests that the GD A-2 *Paranthropus* tooth dates to after 1.95 till around ~1.78 Ma (Table 1), although perhaps closer to the younger age.

ESR dating of *Paranthropus* in South Africa

Grine et al. (2012: 597) state that Electron Spin Resonance (ESR) ages for the *Paranthropus* bearing sites have a "spectacularly bizarre range" between 4.38 and 0.36 Ma, citing Blackwell (1994) and Curnoe et al. (2001, 2002). This is a fundamental misrepresentation of the dates and issues related to the ESR studies conducted on the South African sites. It uses ages from multiple uranium uptake models and ignores more recent studies where linear uptake (LU) ESR ages have been shown to correlate well with dates derived from other methods (Lacruz et al., 2002; Grün, 2006; de Ruiter et al., 2008; Porat et al., 2010; Herries and Shaw, 2011). Although admittedly in need of new studies and reanalysis using the most recent techniques (Joannes-Boyau and Grün, 2011), ESR remains broadly reliable and consistent with dates derived from palaeomagnetism and uranium-lead (U–Pb) dating. Work at Sterkfontein Member 4 (Herries et al., 2010; Herries and Shaw, 2011) indicates that the linear uptake model ESR ages correlate very well with U–Pb ages and palaeomagnetism age estimates for that deposit between 2.6 and 2.0 Ma (Herries et al., 2010). Given this good correlation, there seems little reason to simply discount the younger than expected ESR ages for Member 5B (1.4–1.2 Ma; Herries and Shaw, 2011; Table 1) without good evidence, especially when the ages for Member 4 are also younger than previously expected. That being said, Joannes-Boyau and Grün (2011) have suggested up to a 30% underestimate in the age of previously produced ESR ages when dating much younger deposits. If this were the case for Member 5, then the Oldowan and *Paranthropus* fossils would perhaps date to between ~1.8 and ~1.6 Ma, which would still be consistent with other data. However, if the same thing was done for ESR dates from Member 4 they would produce a significant overestimate (up to 600 ka [thousands of years ago]) in the ages of that deposit based on other methods. As such, while there are admittedly many issues with the early ESR data as outlined by Herries et al. (2009) and Curnoe et al. (2001), and as shown by recent methodological work (Grün, 2006; Joannes-Boyau and Grün, 2011), direct correlations with other methods suggest that on this timescale the ages are broadly correct using a linear uptake model.

What is now needed is a reinvestigation of the use of ESR on the South African sites that are now well dated by other methods. The significant recent advances in ESR dating methods offer the possibility of reliable virtually non-destructive direct dating of human fossil remains rather than the sediments and or flowstone associated with them. This is particularly important at some sites given arguments over the stratigraphic contexts of some of the fossils and their relationship to flowstones. Moreover, not every flowstone is suitable for U–Pb dating (high uranium concentrations are needed over this time range) and not every site has flowstones in close association with the hominin bearing sediments. Overall, a multiple method dating strategy is needed at every site so the entire developmental history of a site can be accessed and dated. ESR provides an additional method for accessing the potential mixing of material at the sites due to multiple phases of karstification and remains one of the few methods available to date many of the archaeological and fossil sites outside of the caves formed in the Malmani dolomite (Grün, 2006; Porat et al., 2010). As such, studies that further test the reliability of ESR within the 'Cradle' caves through cross-correlating ESR-derived dates with those from other methods is key for building a complete chronological framework for southern African archaeological and fossil sites independent of faunal correlation with East Africa. Part of the misunderstanding over the published ESR dates is threefold: 1) the complexity of the uranium uptake modelling and the fact that more than one age range is often published; 2) a lack of understanding of or not taking account of the context, which has a knock on effect with regards the dosimetry; especially if the teeth are from museum collections or ex situ deposits, which has sometimes been the case; and 3) the method of publication and creating mean results from multiple teeth without a critical assessment of their context.

The above studies and others (see Herries, 2011) indicate that the LU model is most consistent with other dating methods and it is these ages that are given throughout. The apparent upper age limit of 4.38 Ma for the ESR ages as cited by Grine et al. (2012) are from Blackwell (1994) for Swartkrans Member 3 based on the recent uptake (RU) models that is extremely unlikely for teeth of this age (Curnoe et al., 2001), rather than the LU age. In contrast, the LU ESR age for this Swartkans Member 3 sample is 800 ± 150 ka, entirely consistent with U–Pb ages on teeth by Balter et al. (2008; 1.04–0.62 Ma) and some faunal age estimates (Herries et al., 2009). The reason that LU-ESR are consistent with other methods at South African cave sites is likely related to the often consistent, relatively low dose environment at the sites (Curnoe, 1999; Grün, 2006).

The context of the tooth will have a major effect on the dose rate and uptake, or even leaching history of uranium from the tooth itself. Herries and Shaw (2011) note that in the StW53 deposit at Sterkfontein a tooth from decalcified parts of this deposit gave ESR ages that were a bit younger (1.35 ± 0.34 and 1.20 ± 0.13 Ma) than a number of very consistent dates (five) from two teeth from calcified portions (1.65 ± 0.32, 1.69 ± 0.20, 1.63 ± 0.16, 1.69 ± 0.26, 1.71 ± 0.35 Ma; Herries and Shaw, 2011). Thus, it may be the case that teeth from calcified deposits may give more reliable ages than those from decalcified deposits and the context of many of the teeth in previous ESR studies on the South African sites is not known. Given the almost universal strategy of collecting dumpsite material or excavating decalcified deposits at these sites, this may explain the younger ages for teeth recovered from museum collections compared with material recovered from in situ calcified breccia. Moreover, there is much greater uncertainty in the background dosimetry of teeth whose exact context is not known and cannot be measured. The practice of sampling these teeth has thus complicated the published record of ESR at the sites. An example is an 814 ± 32 ka year old tooth from Kromdraai that was excavated in 1959.

Alternatively, reworking may be a more extensive issue in the multi-generational caves than expected as the ages for this younger tooth are consistent with teeth from Member 5B (1.40–1.24 Ma; Herries and Shaw, 2011). Moreover, as Herries and Shaw (2011) pointed out many of the so called 'younger' teeth from Sterkfontein Member 4 came from the interface zone with Member 5 and have consistent ages with those taken from that unit. Reynolds et al. (2007) in particular have noted that older stone tools and even hominin remains have been reworked from Member 5 at Sterkfontein into the much younger (288–108 ka) Lincoln Cave deposits. de Ruiter (2003) has also suggested the potential presence of significant mixing in Swartkrans, suggesting that the presence of such extinct taxa as *Paranthropus robustus*, *Papio ingens*, *Chasmaporthetes nitidula* and *Sivatherium maurusium* indicates that Member 2 is an older deposit that has been contaminated by younger material; represented by *Hippotragus niger*, *Ourebia ourebi*, *Taurotragus oryx* and perhaps other taxa. Of course geologically it is more likely that a younger deposit has been contaminated with older, reworked material than vice versa, unless pockets of younger material were not noted during excavation. Brain (1976) did seemingly note mixing during excavation. It should be noted that this is much less likely to be as big an issue at many of the smaller, temporally constrained South African sites that have undergone only one major phase of karstification. At other sites, it may be a significant problem and ESR is one way of assessing this. For example, ESR ages for samples purportedly from Swartkrans Member 2 give very young ages more consistent with Middle Stone Age (MSA) deposits from Member 4 (~110 ka; Curnoe et al., 2001; Sutton et al., 2009). Unfortunately, as Member 2 has been entirely excavated away it is now impossible to re-evaluate the stratigraphy and age of this deposit. This further highlights one of the major issues with defining the last appearance of *Paranthropus* at Swartkrans in the post-Member 1 deposits as the occurrence of *Paranthropus*, or even other taxa in the deposit, does not suggest that was it was necessarily in primary context. It also shows the danger of defining the age of deposits based on a few taxa, especially if they are older than other taxa in the assemblage.

The way the ESR dates have been published (i.e., the averaging of ages from samples that may have actually come from different deposits due to mixing) has also not helped their perceived usefulness. Some LU ESR dates from the Swartkrans Member 1 Hanging Remnant, while broad (2.02 ± 0.36 Ma, 2.07 ± 0.37 and 1.68 ± 0.28 Ma; [1.96–1.70 Ma weight mean] Curnoe et al., 2001) are consistent with recent U–Pb ages on flowstone from the Hanging Remnant of 2.3–1.8 Ma (Pickering et al., 2011). However, when they were published by Curnoe et al. (2001) these ages were averaged together with dates that were younger (1.53–1.03 Ma LU weighted mean) to give a mean age that is perhaps not representative of the Member 1 Hanging Remnant as a whole, rather than looking into potential contextual issues that may be responsible for this discrepancy. The younger ESR ages are consistent with U–Pb ages for teeth from Swartkrans Member 2 (1.65–1.07 Ma; Balter et al., 2008), but of course not the ESR ages. As such there is a question of whether these younger ages are related to issues with the teeth dated, the method used at the time or their association. If the ESR ages of the older group of teeth is taken together with the U–Pb ages on capping and underlying flowstone (Pickering et al., 2011) the Swartkrans Hanging Remnant would date to between 1.96 and 1.80 Ma (Table 1). This demonstrates the potential utility of ESR ages as it directly dates the fossils, rather than underlying and capping flowstones. Palaeomagnetism could also be used to refine the age range for the deposits and confirm the ESR ages as a normal polarity would indicate a date of 1.95–1.78 Ma within the Olduvai Chron.

The age range of *Paranthropus* in South Africa

Ignoring the ESR and other recent chronometric dates, Grine et al. (2012) suggest that *Paranthropus* occurs in South Africa between 1.9 and 1.5 Ma based on faunal data and states that recent chronological studies do not contradict this age range. However, several published ages for South African sites based on a range of dating techniques do contradict this statement. Currently, the oldest confirmed *Paranthropus*, early *Homo* (SK 847) and stone tool-bearing deposit in South Africa is the Hanging Remnant of Member 1 at Swartkrans, recently dated using U–Pb to sometime between 2.3 and 1.8 Ma by Pickering et al. (2011). Grine (2013:91) has also tried to cast doubt on the use of U–Pb dating of the South African sites stating that "the dates published by Pickering et al. (2011) for speleothems that supposedly bracket the fossiliferous Member 1 deposit at Swartkrans would see *A. africanus* at Sterkfontein and *P. robustus* at Swartkrans as contemporaneous. This is patently ridiculous". What Grine (2013) seemingly fails to realize here is that while the dates for Sterkfontein Member 4 are between 2.6 and 2.0 Ma, and the ESR suggests that deposition may have taken place throughout this period, the dates for the Hanging Remnant of Swartkrans suggest that the *Paranthropus* fossils could have been deposited anytime between 2.3 and 1.8 Ma. There is no suggestion by Pickering et al. (2011) that the Swartkrans deposits are as old as 2.3 Ma and contemporary with Sterkfontein Member 4. In fact, Pickering et al. (2011) argue for the fossils as being deposited closer to the time of the capping flowstone at 1.9 to 1.8 Ma. This is confirmed in part by the ESR age estimates that combined give an age of 1.96–1.80 Ma (Table 1). It is not uncommon for there to be a large time gap between the end of a basal flowstone forming and the subsequent deposition of fossil bearing sediments. At Buffalo Cave, the basal flowstone is estimated to be older than ~1.5 Ma and yet the fossil bearing sediments are not deposited until after 1.1 Ma (Herries et al., 2006a,b; Hopley et al., 2007). The Lower Bank deposit of Swartkrans Member 1 was also dated by Pickering et al. (2011) to sometime between 2.33 and 1.64 Ma. However, the greater age range for the Lower Bank is due mainly to a greater uncertainty in the dates for the upper flowstone (1.71 ± 0.07 Ma in the Lower Bank compared with 1.80 ± 0.01 Ma in the Hanging Remnant). It seems likely that both flowstones date close to 1.79–1.78 Ma and the end of the Olduvai SubChron. This would make this flowstone the same age as that capping GD 2 at Gondolin, further showing evidence for Pickering et al.'s (2011) suggestion that flowstones are forming contemporaneously in several caves at the same time. A ∼1.8 Ma flowstone has also been dated at Sterkfontein between deposition of Member 4 and 5 (Pickering and Kramers, 2010). Palaeomagnetic analysis of the Hanging Remnant flowstone would confirm this. Equally, if a reversal also occurred in the flowstone capping the Lower Bank deposits, this could be used to confirm the contemporaneity of both of the Swartkrans flowstones and refine the U–Pb age ranges for the Lower Bank (dated to between 2.33 and 1.64 Ma: Pickering et al., 2011; Table 1). Eventually, such flowstones that often form above and below fossil bearing 'flowstone bound units' (FBUs; Pickering et al., 2007; Adams et al., 2010), could be used in a similar way to the volcanic tuffs of East Africa in establishing correlations between sites.

The next oldest, or potentially contemporary, *Paranthropus* deposits are those at Gondolin dated to just before and after 1.78 Ma, although they could date to as old as 1.95 Ma (Table 1). This is followed by Kromdraai site B Member 3, with a date between ∼1.8 and ∼1.6 Ma (Herries et al., 2009; Table 1). The nearby Cooper's site D dates to between 1.6 and <1.4 Ma based on U–Pb (de Ruiter et al., 2009) with *Paranthropus* fossils stratigraphically occurring both between 1.6 and 1.4 Ma and younger than 1.4 Ma (Table 1). The Sterkfontein Member 5-Oldowan Infill deposits also contain *Paranthropus* and have been dated using ESR, U–Pb and palaeomagnetism to between ∼1.4 and ∼1.2 Ma (Herries and Shaw, 2011; Table 1). Further evidence for *Paranthropus* younger than 1.4 Ma comes from faunal data and U–Pb analysis of teeth from Swartkrans Member 3 with dates of between 1.04 and 0.62 Ma (Balter et al., 2008; Herries et al., 2009). Moreover, again using LU-ESR ages, teeth from Swartkrans Member 3 date to between 1250 ± 90 ka and 650 ± 150 ka, entirely consistent with these other age estimates. Thus, we argue that the duration of *Paranthropus* is not as suggested by Grine et al. (2012) and is in actual fact much broader, at 1 Ma or more, between 2.0/1.8 Ma and 1.0/0.6 Ma. This contrasts with the age range of *Paranthropus* in East Africa at <2.7 to >1.4 Ma (Herries et al., 2009). The age of Drimolen remains difficult to assess and was originally dated to between 2.0 and 1.5 Ma (Keyser et al., 2000) based on faunal correlation. The fauna from this site has been suggested to have faunal affinities to Cooper's D and Swartkrans, meaning that it could date to anytime between ∼2.0 Ma and <1.4 Ma. However, O'Regan and Menter (2009) in particular note that the felids have their closest affinities to Cooper's D (1.6–<1.4 Ma).

Refining the age range and particularly the extinction of *Paranthropus* in South Africa is of prime interest given that Herries et al. (2009) have previously pointed out that this genus appears to have gone extinct much earlier in East Africa and this is not reflected by Grine et al.'s (2012) age range given for *Paranthropus*. Based on all age estimates, *Paranthropus* can currently be seen to have first occurred in South Africa around 2.0 Ma and become extinct between 1.0 and 0.6 Ma. This makes the Gondolin *Paranthropus* likely one of the older specimens of the genus in South Africa at ∼1.78 to 1.95 Ma. If *Paranthropus* existed as late as 1.0–0.6 Ma then it may not only have been contemporary with *Homo ergaster*, but also later forms of *Homo* as represented at Elandsfontein (1.0–0.6 Ma; Klein et al., 2007). The late occurrence of archaic human species in South Africa is not without precedence given that Brink et al. (2012) have recently argued for the occurrence of a species of early *Homo* as late as 1.07–0.99 Ma at Cornelia-Uitzoek. However, part of the problem in answering these questions is that few sites have been found or dated in the Cradle to the period after 1.4 Ma and many of the sites outside the Cradle will remain difficult to date without further work into the application of ESR or other dating methods to open air earlier Pleistocene deposits.

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