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Brief Communication: Revised Age Estimates of *Australopithecus*-Bearing Deposits at Sterkfontein, South Africa

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KEY WORDS *Australopithecus africanus*; Sterkfontein; magnetostratigraphy; faunal dating

ABSTRACT The Sterkfontein fossil site in South Africa has produced the largest concentration of early hominin fossils from a single locality. Recent reports suggest that *Australopithecus* from this site is found within a broad paleontological age of between 2.5–3.5 Ma (Partridge [2000] The Cenozoic of Southern Africa, Oxford: Oxford Monographs, p. 100–125; Partridge et al. [2000a], The Cenozoic of Southern Africa, Oxford: Oxford Monographs, p. 129–130; Kuman and Clarke [2000] J Hum Evol *38:*827–847). Specifically, the hominin fossil commonly referred to as the "Little Foot" skeleton from Member 2, which is arguably the most complete early hominin skeleton yet discovered, has been magnetostratigraphically dated to 3.30–3.33 Ma (Partridge [2000] The Cenozoic of Southern Africa, Oxford: Oxford Monographs, p. 100–125; Partridge et al. [2000a], The Cenozoic of Southern Africa, Oxford: Oxford Monographs, p. 129–130). More recent claims suggest that hominin fossils from the Jacovec Cavern are even older, being dated to approximately 3.5 Ma. Our interpretation of the fauna, the archeometric results, and the magnetostratigraphy of Sterkfontein indicate that it is unlikely that any Members yet described from Sterkfontein are in excess of 3.04 Ma in age. We estimate that Member 2, including the Little Foot skeleton, is younger than 3.0 Ma, and that Member 4, previously dated to between 2.4–2.8 Ma, is more likely to fall between 1.5–2.5 Ma. Our results suggest that *Australopithecus africanus* should not be considered as a temporal contemporary of *Australopithecus afarensis*, *Australopithecus bahrelghazali*, and *Kenyanthropus platyops*. Am J Phys Anthropol 119:192–197, 2002.

Determining an absolute age for the South African hominin-bearing cave infills, from which over 1,100 early hominin fossils have been recovered to date, is crucial to the understanding of evolutionary relationships among the early African hominins. The cave systems and associated infills of South Africa are complex (Brain, 1993; Kuman and Clarke, 2000), a situation made more difficult by a relatively poor understanding of taphonomic and geochemical processes relating to dolomitic caves and their fossil assemblages (Brain, 1981; Backwell, 2000; de Ruiter, 2001; de Ruiter and Berger, 2000). Damage from mining activities and from excavations that have emphasized recovery of fossils over recording of context has created further confusion. The accurate dating of fossils in these caves has also been frustrated by the lack of volcanic tuffs within the systems, so that the argon/argon technique or other radiometric methods cannot be applied, and most of the deposits are older than the range of other established archeometric techniques. Paleomagnetism has been attempted at a variety of sites, and the results will be discussed below. Some progress was recently made in utilizing electron spin resonance (ESR) to date Plio/Pleistocene aged assemblages in South Africa (Schwarcz et al., 1994; Curnoe et al., 2001). The use of cosmogenic isotopes has also been discussed, but results are extremely preliminary and unpublished, and the complexities of this method are largely unexplored in the South African context. Biochronological dating has been by far the most common method applied to South African sites. It is therefore clear that no absolute dating method has come forward, and we are reliant on the use of multiple methods to establish relative and absolute ages of the South African fossils. Nevertheless, the dating of these sites is clearly critical to our understanding of hominin and mammalian evolution in Africa, and in this paper, the results of our exami-

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nation of the dating of the older Members of Sterkfontein are discussed.

DATING OF STERKFONTEIN

Biochronology and paleomagnetism

The dating of the Sterkfontein Member 2 "Little Foot" skeleton has been the focus of much discussion (Clarke and Tobias, 1995; McKee, 1996; Tobias and Clarke, 1996; Clarke, 1998; Partridge, 2000; Partridge et al., 2000a). As reportedly the most complete skeleton of an australopithecine yet recovered, it will prove critical to our understanding of hominin evolution. An age estimate for the Sterkfontein Member 2 assemblage was recently set via magnetostratigraphy at a near-absolute date of 3.30–3.33 Ma, with an outside range of 3.22–3.58 Ma (Partridge et al., 2000a). This date, however, is dependant on bracketing the flowstones that were sampled within the "broad paleontological age" of Member 2 (Partridge et al., 2000a). This broad age bracket was set at between 2.7–4.0 Ma, based on its stratigraphic position 6.5 m below Member 4 (Clarke and Tobias, 1995; Clarke, 1998; Partridge et al., 2000a) and the presence of a carnivore specimen attributed to *Chasmaporthetes nitidula* (Turner, 1997; Partridge, 2000). The paleontological age range of Sterkfontein Member 4 was in turn established by faunal time ranges set by previous researchers at between 2.4–2.8 million years (Vrba, 1985; Delson, 1988; McKee et al., 1995), with the majority of researchers suggesting an age greater than 2.5 Ma.

The principle of superposition, whereby underlying sediments are considered older than overlying strata, does not necessarily apply in a cave system, and the error in the use of simplistic models of deposition in South African caves has been pointed out by others (White et al., 1981; Brain, 1993; McKee, 1996). Member 4 has been shown to be a complex geological situation, presenting areas of collapse and reworking where mixing of older and younger fossils is evident (Schwarcz et al., 1994; Kuman and Clarke, 2000). The presence of *Chasmaporthetes nitidula* at both Swartkrans (Brain, 1981; Turner, 1997; de Ruiter, 2001) and Members 2 and 4 of Sterkfontein (Turner, 1997) suggests that this taxon may not be a sensitive chronological indicator, thus lessening its value in age-bracketing the Sterkfontein Member 2 deposit (Partridge, 2000). Sterkfontein Member 4 also yielded the remains of *Equus* (Brain, 1981; Vrba, 1995; Kuman and Clarke, 2000), which in Africa is unlikely to be older than 2.36 Ma (Behrensmeyer et al., 1997; Bernor and Armour-Chelu, 1999).

The updated faunal list for Sterkfontein Member 4 (Table 1) illustrates both the potential for mixing in the assemblage as well as the predominance of mammalian taxa typically assigned to a "Plio-Pleistocene" temporal range (<2.5 Ma) in this deposit. Of the taxa listed in Table 1 as belonging to Sterkfontein Member 4, only four are not also found in deposits of late Pliocene or early Pleistocene age (e.g., Swartkrans and/or Kromdraai, or radiometrically dated East African sites). All five of these taxa are endemic to South Africa: *Australopithecus africanus* is found at Sterkfontein, Makapansgat, and Taung; *Parapapio broomi* is known from Sterkfontein, Makapansgat, and Bolt's Farm; *Parapapio whitei* is known from Sterkfontein and Makapansgat; *Papio izodi* has been recovered from Sterkfontein and Taung. The restricted distribution of these taxa indicates that they are not useful as chronological indicators, since they cannot be correlated to well-dated deposits elsewhere in Africa. Comparison of the Sterkfontein Member 4 faunal list with those of Swartkrans and Kromdraai shows that beyond these endemic South African forms, the faunae of these presumably "younger" sites almost completely overlap those of Sterkfontein Member 4.

Recent work across southern Africa has shown that some mammalian forms once thought to be confined temporally to the Pliocene, and thus of value in establishing paleontological ages, are now known from the Pleistocene. The genus *Makapania* is one such form. Considered as critical to the dating of Sterkfontein Member 4 (Vrba, 1985) *Makapania* and *Makapania*-like forms are now known from South African sites of Early, Middle, and even Late Pleistocene age (Brain, 1981; Brink, 1999; de Ruiter, 2001; Lacruz, 2002; Pickering, 1999). Based solely on the presently available faunal evidence, there clearly exists the possibility that Sterkfontein Member 4 samples wholly, or in part, almost any temporal period between approximately 1.5–2.5 Ma. This is emphasized by the presence of at least 10 taxa in the Sterkfontein Member 4 faunal list that do not have secure temporal ranges exceeding 2.5 Ma at radiometrically dated sites elsewhere in Africa.

At least two studies, independently examining discrete taxa, have considered a minimum age for Sterkfontein Member 4 of between 2.4–2.5 Ma (Vrba, 1985; Delson, 1988). We, however, suggest 2.5 Ma as a *maximum* age estimate for this Member. While we tentatively support the generally accepted hypothesis that most of the Sterkfontein Member 4 assemblage is older than the Kromdraai/Swartkrans/Sterkfontein Member 5 sequences, we do not know how much older. Given the probability that the Hanging Remnant of Swartkrans represents a temporal period not younger than ca. 1.5 Ma (Turner, 1997; Marean, 1989; Brain, 1993; Curnoe et al., 2001), we suggest that the broad temporal range estimate for Sterkfontein Member 4 should be between ca. 1.5– ca. 2.5 Ma. One ESR study suggested conflicting dates for fossils within Sterkfontein Member 4, giving a range of between 1.26–2.87 Ma (Schwarcz et al., 1994). This same study suggested that there may be mixing within the sample. The reported average ESR estimated age of 2.1 ± 0.5 Ma (Schwarcz et al., 1994) is, however, in agreement with the present study.

TABLE 1. Large mammal faunae reported from Sterkfontein Member 4 and Member 2, compared to faunae from Swartkrans and Kromdraai[1,3]

Member 4
- Class Mammalia
  - Order Primates
    - Family Hominidae
      - ***Australopithecus africanus*** (1)
    - Family Cercopithecidae
      - ***Parapapio jonesi*** (1, 3)
      - ***Parapapio broomi*** (1)
      - *Parapapio whitei* (1, 2)
      - *Papio hamadryas robinsoni* (3)
      - ***Papio izodi*** (1, ?3)
      - *Cercopithecoides williamsi* (2, 3)
  - Order Rodentia
    - Family Hystricidae
      - *Hystrix africaeaustralis* (3)
  - Order Carnivora
    - Family Hyaenidae
      - *Chasmaporthetes silberbergi* (1, 3)
      - *Chasmaporthetes nitidula* (1, 3)
      - *Crocuta crocuta* (3)
      - *Pachycrocuta brevirostris* (3)
      - *Parahyaena brunnea* (1, 3)
    - Family Felidae
      - *Panthera pardus* (3)
      - *Panthera leo* (3)
      - *Dinofelis barlowi* (1, 3)
      - *Megantereon cultridens* (3)
      - *Homotherium latidens* (1, 3)
    - Family Canidae
      - *Canis mesomelas* (3)
  - Order Proboscidea
    - Family Elephantidae
      - *Elephas recki* (3)
  - Order Hyracoidea
    - Family Procaviidae
      - *Procavia antiqua* (3)
      - *Procavia transvaalensis* (1–3)
  - Order Perissodactyla
    - Family Equidae[2]
      - *Equus capensis* (2, 3)
      - *Equus sp.* (2, 3)
  - Order Artiodactyla
    - Family Suidae
      - *Potamochoeroides shawi* (1)
    - Family Bovidae
      - *Damaliscus sp.* (2, 3)
      - *Parmularius sp.* (3)
      - *Connochaetes sp.* (2, 3)
      - Cf. *Megalotragus sp.* (3)
      - *Antidorcas cf. recki* (1–3)
      - *Antidorcas cf. bondi* (1–3)
      - *Gazella sp.* (3)
      - *Oreotragus oreotragus* (3)
      - *Makapania cf. broomi* (1, 3)
      - *Hippotragus cf. equinus* (3)
      - *Syncerus sp.* (2, 3)
      - *Tragelaphus cf. angasi* (1–3)
      - *Radunca cf. arundinum* (1, 3)

Member 2
- Class Mammalia
  - Order Primates
    - Family Hominidae
      - *Australopithecus sp.*
    - Family Cercopithecidae
      - ***Parapapio jonesi*** (1, 3)
      - ***Papio izodi*** (1, 3)
  - Order Carnivora
      - *Panthera pardus* (3)
      - *Dinofelis barlowi* (1, 3)
      - *Megantereon cultridens* (3)
      - *Acinonyx jubatus* (3)
    - Family Hyaenidae
      - *Chasmaporthetes silberbergi* (1, 3)
      - *Chasmaporthetes nitidula* (1, 3)

[1] Bold taxa are those species known from Sterkfontein, but not Swartkrans or Kromdraai. All other taxa are shared by Sterkfontein, Swartkrans, and/or Kromdraai (see text for details). Numbers in parentheses represent the following: 1) taxa endemic to southern Africa, 2) taxa not securely radiometrically dated to in excess of 2.5 Ma in Africa, and 3) taxa considered poor age estimators as they are known from broad temporal ranges. [2] Kuman and Clarke (2000) transferred all ***Equus*** material at Sterkfontein from Member 4 to Member 5, including an *in situ* Member 4 specimen, citing the rarity of ***Equus*** in the deposit as justification. The absence of ***Equus*** was then used to define Member 4. However, as several species in the Sterkfontein Members are represented by only a few specimens, many taxa could potentially be removed from the Member 4 faunal list if such an argument were to be accepted. At present we accept there are still many ***Equus*** specimens (n > 18) derived from breccia attributed to Member 4. [3] Faunal identifications are taken from published sources (Brain, 1981; Churcher, 1956, 1970, 1974; Delson, 1984; de Ruiter, 2001; Freedman, 1957; Freedman and Brain, 1977; Kibii, 2001; Kuman and Clarke, 2000; Maglio, 1971, 1972; McKee et al., 1995; Pocock, 1987; Turner, 1986, 1987, 1997; Vrba, 1976, Vrba, 1985, Vrba, 1995; Watson, 1993; Werdelin and Lewis, 2001).

DISCUSSION

Based on the above, we suggest that one must apply a younger and broader paleontological age estimate for Sterkfontein Member 4 of ca. 1.5–ca. 2.5 Ma, rather than the 2.6–2.8 Ma that was recently suggested (Kuman and Clarke, 2000; Partridge et al., 2000a,b). If *Equus*, however uncommon in the assemblage, is definitively in situ, this supports the suggestion that Sterkfontein Member 4 could not be older than ca. 2.36 Ma. A broader paleontological age estimate for Sterkfontein Member 4 will obviously have an effect on the estimate of the age of other Members in the system as well as the age estimates of other sites in South Africa. Based on a seriation of the fauna and the geological position of Sterkfontein Member 2, McKee (1996) already brought into question the original 3.0–3.5 Ma age estimate originally proposed (Clarke and Tobias, 1995). Based on our analysis, we support his caution in an acceptance of a date in excess of 3.0 Ma for this Member. Given our age estimates for Sterkfontein Member 4, the suggested minimum bracketing age of 2.7 Ma (Partridge et al., 2000a) for the Sterkfontein Member 2 hominin should be set at ca. 1.5 Ma. The potential magnetostratigraphic matches for the Sterkfontein Member 2 series consequently increase beyond the narrow 3.22–3.58 Ma (Partridge et al., 2000a), and younger dates may not be excluded.

Figure 1 provides one example of an alternative hypothesis of the magnetostratigraphic sequence of Partridge et al. (2000a). If the sequence (flowstones 3 and 2D) begins not with the Gauss Normal Epoch but with the Olduvai Event within the Matuyama Reversed Epoch, the age of the Sterkfontein Member 2 hominin would fall between 2.15–3.04 Ma. Since

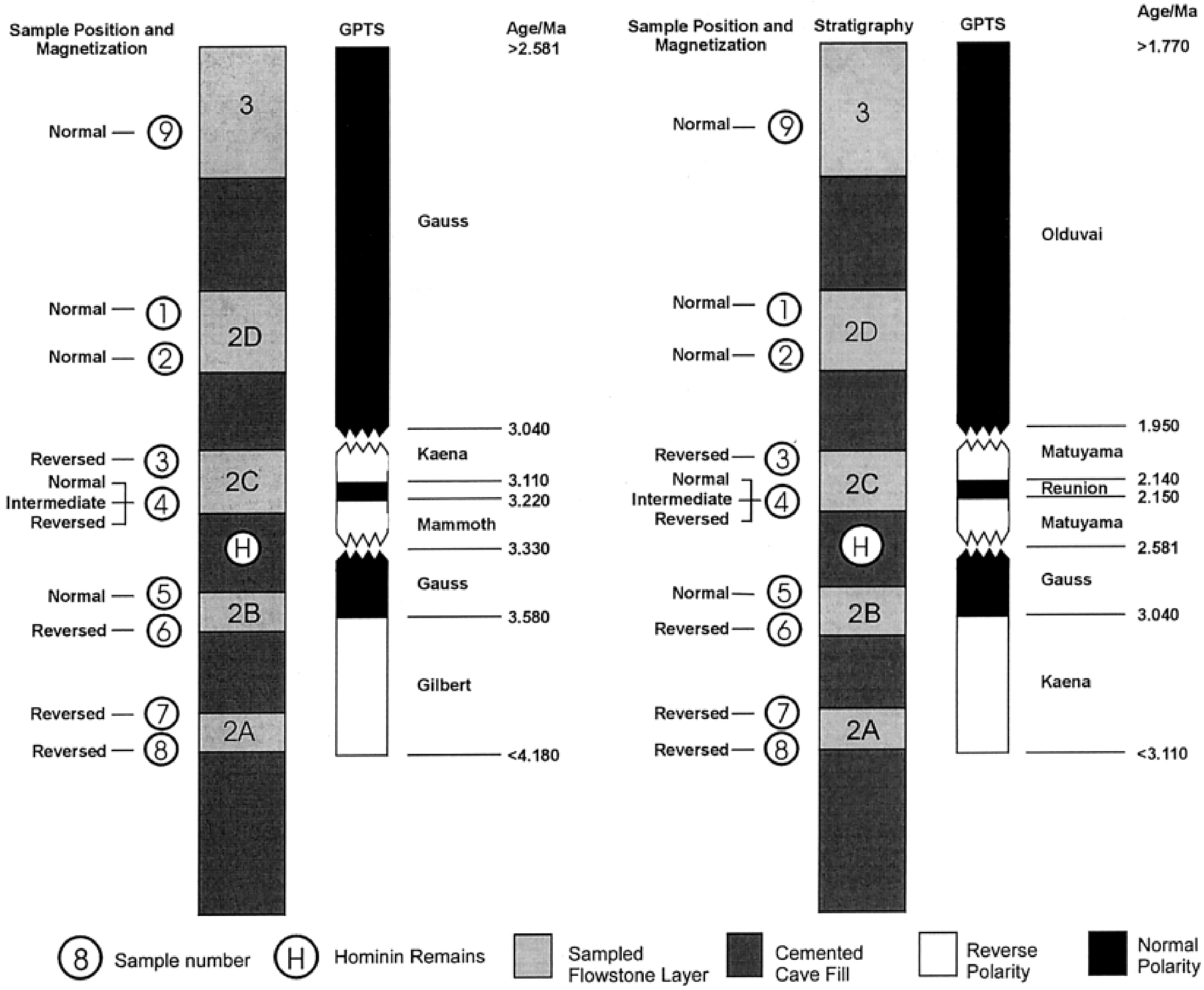

Fig. 1. Modified from Partridge et al. (2000a). A proposed alternative correlation of the determined Sterkfontein Member 2 magnetostratigraphy to the Geomagnetic Polarity Timescale, using the Olduvai Event as the top of the sequence instead of the Gauss Normal Epoch. Breaks in the Sterkfontein polarity scale indicate positions of reversals that lie between discrete samples, as discussed by Partridge *et al.* (2000a). Ages are based on the Geomagnetic Polarity Timescale (GPTS) of Cande and Kent (1995). The "Little Foot" skeleton falls within the time frame 2.15–3.04 Ma in this scheme, but see text for discussion of other possible dates for the skeleton based on this magnetostratigraphy.

the faunal evidence from this Member (Table 1) does not at present suggest that it should be considered any older than the broad temporal range of Sterkfontein Member 4 (1.5–2.5 Ma), several other equally plausible hypotheses may be generated. Flowstones 3 and 2D could correspond to the Jaramillo Event (990 Ka–1.07 Ma), placing the hominin within the range of the Matuyama Epoch/Reunion Event, producing an age estimate of 1.95–2.15 Ma (Cande and Kent, 1995). Conversely, flowstones 3 and 2D could represent the Brunhes Normal Epoch, positioning the hominin nearer to the Matuyama Epoch/Olduvai Event series, thus indicating a date of 1.07–1.95 Ma (Cande and Kent, 1995). Given these revisions, and utilizing the fauna as supporting evidence, we suggest that the Member 2 "Little Foot" skeleton is not older than 3.04 Ma, and may be as young as 1.07–1.95 Ma. These age estimates, however, are based on the assumption that this is a continuous, uninterrupted magnetostratigraphic sequence. Faunae from Member 2 and Member 4 of Sterkfontein do not at present suggest a date in excess of 2.5 Ma.

Recent announcements of even older fossil hominins in the Sterkfontein Jacovec Cavern, reportedly dating to 3.5 Ma, are also brought into question by our study, as they too are dependent on the broad paleontological age of Sterkfontein Member 4 (Clarke, 2002). A recent study of the fauna from the Jacovec Cavern deposit recorded a high degree of mixing in the assemblage (Kibii, 2001). It was also reported that the faunae from the Jacovec Cavern are notably similar to those of Sterkfontein Member 4, indicating the two deposits should be of a broadly similar age (Kibii, 2001). This makes a date of >3.5 Ma for the deposit unlikely.

Redating Sterkfontein Member 2 to below 3.0 Ma, and Sterkfontein Member 4 to 1.5–2.5 Ma, has broad implications for interpretations of the phylogenetic position of southern African early hominins, as well as for our general understanding of the evolution early hominins in Africa during the Middle and Late Pliocene. It also has a direct bearing on the age estimates produced for the other *Australopithecus africanus*-bearing sites of Makapansgat and Taung. If, as we propose, *Australopithecus africanus* from Sterkfontein dates to between 1.5 Ma–ca. 2.5 Ma, then the paleontological range of *A. africanus* probably does not overlap the temporal ranges of early East African hominins such as *Australopithecus afarensis*, *A. bahrelghazali*, and *Kenyanthropus platyops*. Rather, it is broadly contemporaneous with more derived species such as *Australopithecus garhi*, *A. aethiopicus*, *A. boisei*, and early members of the genus *Homo*. Our results may explain the well-recognized enigma posed by the derived cranial and dental morphology of *A. africanus* compared to the more primitive cranial and dental morphology of hominins dated to older than ca. 3.0 Ma.

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