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Comments on 'The age of fossil StW573 ('Little Foot'): An alternative interpretation of $^{26}Al/^{10}Be$ burial data'

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StW573, or 'Little Foot', is a nearly complete *Australopithecus* skeleton discovered in 1997[1], in Member 2 of the Sterkfontein Formation – the oldest fossil-bearing member of the cave[2]. The importance of StW573 lies not only in its completeness, which provides comprehensive anatomical and locomotor information on one individual, but also in its age and phylogenetic relationships with other hominid species. The age of StW573 was first suggested to be about 3.5 Ma based on its deep stratigraphic position and the absence of any other hominid fossils which are so abundant in the higher Member 4 deposits.[3] McKee[4] argued on faunal grounds that it should be younger, but Tobias and Clarke[5] countered his arguments. Berger et al.[6] even suggested that StW573 'may be as young as 1.07–1.95 Ma'. Their arguments were comprehensively countered by Clarke[7]. A date of 4.17±0.35 Ma was based on cosmogenic burial dating of the breccia in which the skeleton was found.[8] Dating has also been applied to calcite speleothems found in close proximity to the skeleton[9-12], but careful stratigraphic mapping[13] refined and expanded in Bruxelles et al.[14] shows that the speleothems postdate the skeleton and thus cannot be used to determine more than a minimum age for the specimen.

Granger et al.[15] then used the cosmogenic isochron burial dating method with ^{26}Al and ^{10}Be to determine a depositional age for the breccia containing the skeleton of 3.67±0.16 Ma. The isochron date is based on a suite of 11 different samples taken from a narrow stratigraphic interval encompassing the accessible thickness of M2 above, below and adjacent to the StW573 specimen. Nine of the samples are consistent with a single depositional age and are well-fit by the curve (MSWD=2.12); one sample is older and must have been reworked from an older deposit within the cave, and one sample was an outlier.[15]

The age of StW573

Kramers and Dirks[16] have produced an alternative interpretation of the cosmogenic nuclide data in Granger et al.[15] that they argue is consistent with a younger age for the skeleton. Their re-interpretation, however, hinges on a series of assumptions that are unjustified and based on demonstrably incorrect interpretations of the cave structure and stratigraphy:

1. On Page 1 (paragraph 2), they make an incorrect statement about the dating of Member 4 when they give reference to an article by Clarke as declaring that 'the lower age limit for Member 4 was firmly placed at ca 2 Ma'. In fact, Clarke[7] wrote exactly the opposite, i.e. that the top of Member 4 was slightly older than 2 Ma. Clarke[7] gave references to several researchers who had published even older dates for Member 4.

2. Kramers and Dirks[16] deconstruct the isochron burial date, which is based on the regression of a curve through multiple samples, and instead consider each sample separately. In any statistical regression there will be some samples above the curve (i.e. statistically younger) and some below (i.e. statistically older). They chose the youngest sample, still within the expected statistical uncertainty of the isochron regression, and recalculated its burial age using an assumption that deserves careful explanation. The regression of Granger et al.[15] showed that Member 2 continued to accumulate cosmogenic nuclides after deposition, and that the total amount of ^{26}Al and ^{10}Be produced was 85±13 and 21±3 thousand atoms per gram, respectively. The exact amount of postburial production depends on the age, the burial depth, the density of the overlying rock, and the erosional history of the rock. Postburial production cannot be calculated a priori with high confidence because these multiple parameters are difficult or impossible to determine independently. However, the isochron method solves for postburial production implicitly, without requiring any assumptions regarding the burial history. Kramers and Dirks[16] calculated the postburial component directly, assuming a specific burial depth, overlying rock density, a constant erosion rate at Sterkfontein, and a $^{26}Al/^{10}Be$ production rate ratio of 8.1. They determined a postburial component slightly less than the one that was independently determined by the isochron regression, and then neglected to assign any uncertainty to it. Using this new value, the youngest sample in the regression (and the one that is most sensitive to postburial production) becomes artificially younger, and appears to be younger than 2.8 Ma. Their recalculation assumes that the depth, density, and erosional history of the site are known with certainty (which they are not), and that the production rates of ^{26}Al and ^{10}Be by processes of muon capture and fast muon reactions can be calculated exactly (Balco[17] estimates a 25% uncertainty in calculating muon production rates using a scaling model). They then use this single sample to represent the true age of the deposit and explain that the other samples from the isochron must have all been reworked from a hypothetical upper cave deposit that no longer exists, which leads to additional problems with their interpretation.

   Kramers and Dirks' assumptions are based on several erroneous stratigraphic conclusions which illustrate that they are not familiar with the depositional context of StW573[14]. They also made inaccurate interpretations of our previous work, including points which are not in the papers they cited.

3. Despite our detailed macro- and micro-stratigraphic work, there is no evidence of the collapse they propose anywhere in the exposed Member 2 breccia. If StW573 was deposited with a collapse of older cave fillings, it should represent a discrete and discernible event within the stratigraphy, demonstrated by a facies dominated by poorly organised dolomite clasts and reworked breccia and speleothem pieces. None of these features

is found in the Member 2 deposit. This collapse also cannot be represented by the whole depth of Member 2, which is stratified consistently and conformably – indicative of a long and progressive accumulation.

4. On Page 4, Kramers and Dirks[16] use the Name Chamber as an example of 'such a secondary deposit'. The movement of material into the Name Chamber has been studied in detail[18,19], and the various facies associated with different modes of deposition have been documented. No similar facies are found in the Silberberg Grotto and at no time during the filling of the Name Chamber through collapse or gradual sedimentation would it have been possible for an entire, fully articulated skeleton to be redeposited.

5. As evidence for the collapse of a former cave, Kramers and Dirks[16] focus on a massive collapsed dolomite block visible adjacent to the Type Site (Page 4). The position of this block is incorrect in their Figure 2a. This block is located 5–10 m northeast of their documented position (Figure 1), is not above any part of the Silberberg Grotto, and it collapsed onto Member 4 sediments during the accumulation of that deposit. Many other collapsed roof blocks have been found during the excavations of Members 4 and 5[18], but no dolomite blocks can be seen in Member 2 associated with such collapse. Furthermore, this block does not represent a dolomite feature that separated two chambers. It is simply a collapsed dolomite block – a common feature in Sterkfontein Cave (e.g. Milner Hall) and a karstic feature associated with the geomorphological development of the system, as Clarke[18] recognised in Members 4 and 5. Its collapse is not necessarily related to the collapse of the roof as we can see in the present day underground section of the caves.

6. Contrary to Kramers and Dirks[16] (Page 6), we have never proposed that StW573 was deposited in a muddy debris flow. The specimen was embedded in talus cone breccia[14] in dry conditions, as evidenced by the mummification of the body[20] which lies conformably within the talus slope.

7. The cosmogenic analyses showed no evidence of the mixing of two kinds of breccia, as the collapse of a former upper cave should imply. Contrary to what Kramers and Dirks said (Page 4), previous work has not proposed that the layer STM2-light contained chert debris from a higher level in the cave system. Granger et al.[15] state that the angular, unweathered chert clasts 'were probably eroded from the walls of the cave within a few meters of the surface', rather than from the surface where weathering would result in rounding and pedogenic iron-staining. We can only say that that particular sample derives from higher in the same chamber and as such has a different cosmogenic production history. This does not imply that the chert comes from the landscape surface, or from a previous cave filling.

8. Other mistakes were made concerning the use of speleothems as stratigraphic evidence. For example on Page 6, Kramers and Dirks use shelf stones to say that the cave was flooded after deposition of Member 2. But, as one can see today around the lake in Sterkfontein Cave, there are no shelf stones because the phreatic water is not saturated with calcite. These kinds of shelf stones are linked with localised pools, formed in the isolated voids of the talus.[14]

9. On Page 7, Kramers and Dirks suggest that StW573 entered the hypothetical upper cave and 'wandered or fell' from there into the Silberberg Grotto through a 'passageway' that opened suddenly between the two, disturbing and re-depositing 'unconsolidated sediment material that had been lying in the upper cave for hundreds of thousands of years'. The only upper cavern is that containing Member 4 and 5 deposits, which is situated to the north and east of Silberberg Grotto and not directly above it. If such deposits had been re-worked into the Silberberg Grotto, then there would be other fossils of *Australopithecus* in addition to StW573, which there are not.

10. On Page 7, Kramers and Dirks admit that the flowstones formed post-depositionally in voids within the breccia, accepting our previous work (Bruxelles et al.[14]), but then they use those flowstone-derived dates[10-12] as a relevant comparison for their reinterpreted age for the same breccia. We must reiterate that all the flowstones around StW573, including F1, are filling flowstones and formed a long time after its deposition.[14]

11. On Page 7 – just before their conclusion – Kramers and Dirks[16] state that *Cercopithecoides williamsi*, which occurs in the Silberberg Grotto deposits, has not been reported from reliably dated sites older than 2.5 Ma. This statement is misleading, because one can argue about reliability of certain dates, whether from South or East Africa or Chad, but the fact remains that *Cercopithecoides williamsi* occurs in Makapansgat Member 3, which has been dated to about 3 Ma. For discussion see Klein[21] (p.155).

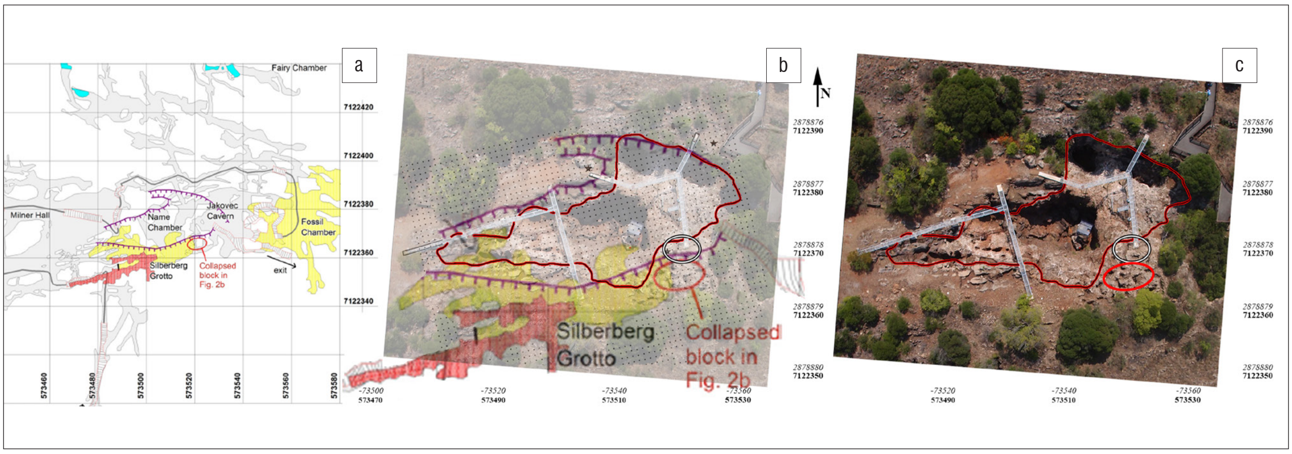

Figure 1: Composite figure illustrating the position of the 'collapsed block' discussed in Kramer and Dirks[16]. (a) Figure 2a from Kramers and Dirks[16] illustrating the position of the 'collapsed block' (red circle) in relation to the chambers mentioned in the text. (b) The same Figure 2a[16] scaled, aligned and superimposed on a georeferenced aerial photograph of the Sterkfontein site. Figure 2a[16] is made transparent to illustrate the position of the 'collapsed block' (red circle from Kramers and Dirks[16]) and position of the Silberberg Grotto in relation to the outline of the excavation (solid red line) and the position of the discussed block (white circle) identified from the photograph. Notice that the block described[16] is north and further from the Silberberg Grotto and Name Chamber than proposed. (c) Georeferenced aerial photograph (photo: D. Stratford) with excavation outline (red line), the suggested position of the 'collapsed block'[16] (red circle), and actual position of the 'collapsed block' discussed in Kramers and Dirks[16]. See supplementary material for enlarged version of Figure 1.

Conclusion

Kramers and Dirks[16] propose a complicated two-stage burial scenario for Sterkfontein Member 2 based primarily on the re-analysis of a single statistically younger sample isolated from the well-fit isochron calculated by Granger et al.[15] Their re-analysis is purely hypothetical and is based on unjustifiable assumptions rather than observations or measurements of the cave or its stratigraphy. After dedicated work on Member 2 over the last 20 years by Clarke[1,13,18,22] and by Bruxelles et al.[14], we find no sedimentological, stratigraphic or geomorphological evidence that supports the two-stage burial scenario. The cosmogenic nuclide data, the cave morphology, and the sediment stratigraphy are all consistent with a single episode of deposition contemporaneous with StW573 at 3.67$\pm$0.17 Ma.

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