A deeper understanding of the stratigraphy of Sterkfontein fossil hominid site

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In 1938, Basil Cooke published the first stratigraphic assessment of the Sterkfontein *Australopithecus* site. Since then, excavations have provided ever-broader and deeper insights into the complex stratigraphy of the site. A brief review of past stratigraphic assessments is here provided together with the latest stratigraphic information on the oldest deposits that are associated with a virtually complete *Australopithecus* skeleton (StW 573).

INTRODUCTION

The Sterkfontein caves near Krugersdorp, South Africa, have received much attention since 1936 because of the diversity of their Plio-Pleistocene fauna, including *Australopithecus* and *Homo*, as well as early stone tools that have been recovered from the ancient cave infills. Over time there have been several attempts to unravel the stratigraphic history of the caves and I will here briefly review the major studies and also present some of the most recent observations on the stratigraphy.

EARLIER STRATIGRAPHIC STUDIES

It was seventy years ago, 17 August 1936, that Robert Broom discovered the crushed skull of the first known adult *Australopithecus* at the Sterkfontein Caves (Broom, 1936). Two years later, Basil Cooke (1938) published the first assessment of the stratigraphy of that area of the cave system from which the cranium and other fossils had been blasted out by lime-miners. He published a plan and section of the site (Figure 1) in which he delineated an area of breccia exposed to the surface in a quarry about 2–3 m deep and in a lower cave at the eastern end of the quarry. We know this 'lower cave' to be at the exit steps of the tourist route through the caves. Cooke discussed the composition of the breccia and noted that the upper part was bone-rich, whilst the lower part was devoid of bone. Thus, at that stage Sterkfontein was known to consist of a single breccia mass of not very great depth.

Until 1942 all Sterkfontein fossils were known only from this quarry locality, but in that year Broom was given a significant fossil of a hyaena from old quarry workings in a much deeper part of the cave system. Broom (Broom & Schepers, 1946) identified the fossil, which had been collected by H.K. Silberberg, as *Lycyaena silberbergi* (now *Chasmaporthetes silberbergi*) and concluded that the Sterkfontein deposit was Pliocene rather than Pleistocene in age. Although the deposits were much lower, Broom said (Broom & Schepers, 1946: 83) that "the other specimens I found here did not seem to indicate any difference in age." From this statement it seems that Broom must have visited those lower workings, but it is most likely that the mining took place before Broom's first (1936) visit to the caves. Otherwise he would surely have collected and referred to the many fossil monkeys and carnivores that were being blasted out, whereas they had been left on the cave floor and were only removed to the surface by A.R. Hughes between 1978 and 1980. This lower cave was subsequently named the Silberberg Grotto by Tobias (1979) and was to prove of very great significance as will be discussed later.

Despite the much greater depth of the Silberberg Grotto deposits and the fact that they were rich in fossils, no attention was paid to them until 1978. Before that they were considered to be of one and the same infill as the *Australopithecus*-bearing deposit in the surface quarry. Neither Brain (1958) nor Robinson (1962), in their stratigraphic works, singled out the Silberberg Grotto deposits for any mention. Brain (1958) stated that the bone-bearing breccia of the quarry was exposed at two places in the underground passages. He thus concluded that the Sterkfontein deposit was one continuous infill. He envisaged a large block of dolomite having become detached from the roof and fallen into the lower part of the cave. The top of this block acted as the floor of the upper fossil cavern and breccia had filled gaps around the block down to the lower cavern (Figure 2). Like Cooke, 20 years earlier, he differentiated a bone-rich deposit at the top from a bone-poor deposit that formed the bulk of the lower infill.

One new development in 1956 had been the discovery by C.K. Brain of archaic stone tools in lime-miners dumps at the western end of the Sterkfontein breccias (Robinson, 1957). Subsequent excavations in that area by R.J. Mason and Brain, and then by J.T. Robinson, revealed *in situ* artefacts and it was concluded that, as there were no artefacts from the quarry site, the western breccia must be a separate infill. Robinson (1957) divided these deposits into the oldest, or Type Site, breccia (the quarry) at the eastern end where *Australopithecus* fossils but no tools and no *Equus* fossils were found, and the younger, or Extension Site, red-brown breccia to the west, which yielded stone tools and *Equus* fossils. He also recognised a third, or youngest breccia, on top of the red-brown and he designated it "brown breccia". It also contained *Equus* fossils but no stone tools. In 1962, Robinson published his stratigraphic analysis of the Sterkfontein deposits in which he redesignated the infills (Figure 3) as Lower breccia (type site), Middle breccia (red-brown) and Upper breccia (chocolate brown). Robinson, like Brain, considered that the lower part of the cavern was filled entirely with one breccia. Thus, he did not recognise anything as being older than the Lower breccia and he did not mention the breccia that had yielded the *Chasmaporthetes silberbergi* in the lower cavern.

In addition to recognising the Lower, Middle and Upper breccias, Robinson (1962) made another very important observation, i.e. that there had been ancient collapse of Middle breccia into the lower tourist cave in the area now known as the Name Chamber. He recovered three typical Middle breccia artefacts from the top of a collapsed talus slope in that chamber.

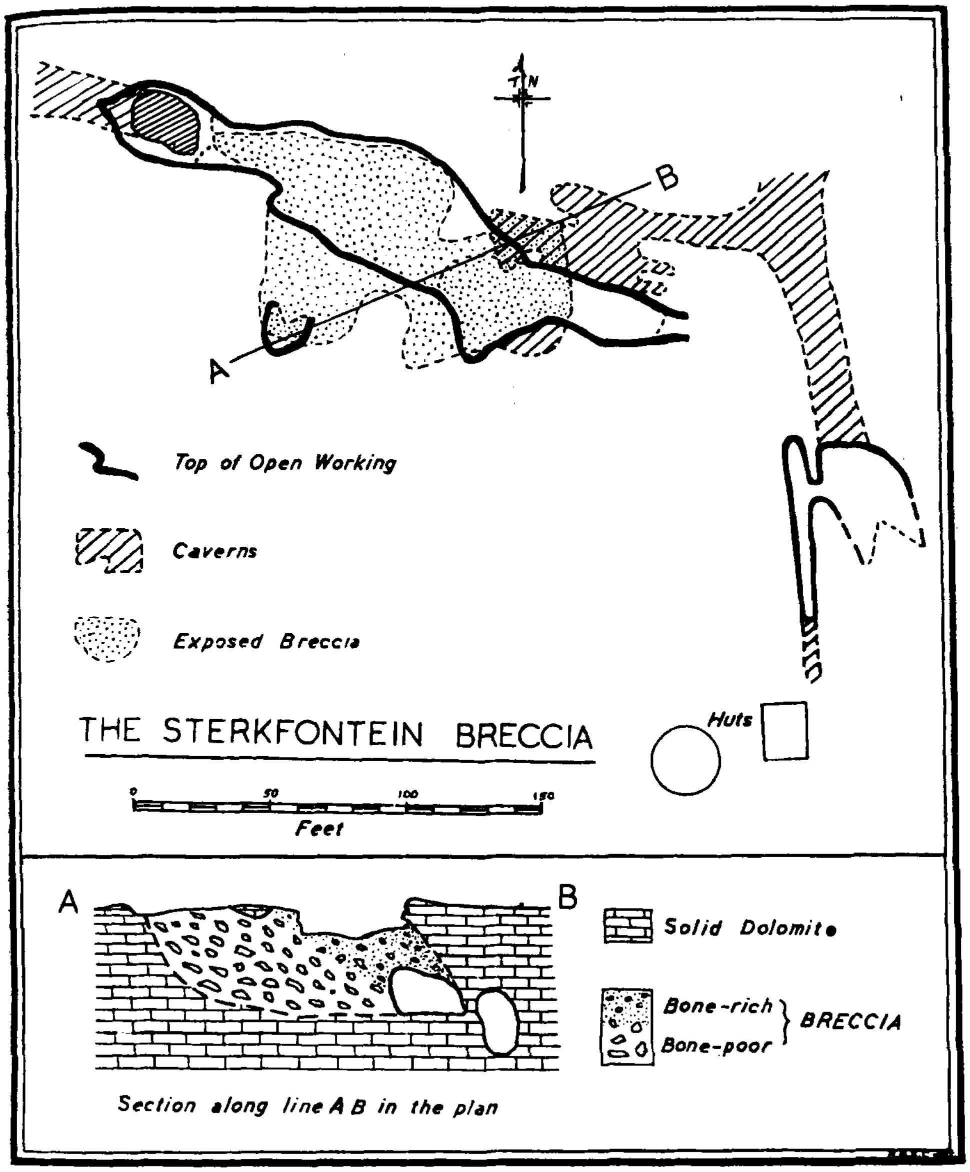

Figure 1. Cooke's (1938) stratigraphy.

Although a very thorough geomorphological study of the Sterkfontein cave system provided locations of, and discussion about, various breccia bodies within the system (Wilkinson, 1973), it was to be Partridge (1978) who provided the first analysis of the total depth of breccia in what he termed the Sterkfontein Formation. He divided them into Members 4, 5 and 6 (corresponding to Robinson's Lower, Middle and Upper Breccias) in the surface exposures and added Members 1, 2 and 3 in the Silberberg Grotto. This was forty years after Cooke's geological note on the caves.

Wilkinson (1983) was convinced that Member 1 was not the base of the Sterkfontein sequence and argued that there had to be much deeper deposits, some of which were represented in the Jacovec Cavern, formerly named the Terror Chamber by Wilkinson (1973) (Figure 4). This was disputed by Partridge & Watt (1991), who considered the Jacovec deposits to be separate from the Sterkfontein sequence (Figure 5). My excavations in the eastern area of the Jacovec deposits in 1994 produced 11 *Australopithecus* fossils belonging to several individuals as well as many faunal remains, including *Chasmaporthetes* limb bones (Partridge *et al.*, 2003). Although the Jacovec Cavern is situated at a lower level than the Silberberg Grotto there is, as yet, no proven stratigraphic connection between the deposits of the two caves and it seems most likely that the source of origin of at least some of the Jacovec deposits was an entrance well to the east of the entrance that provided the main Sterkfontein sequence. However, an *Australopithecus* clavicle from the Jacovec excavation was uniquely ape-like in morphology, suggesting it is older than the more human-like clavicles from Member 4 and that it is possibly broadly contemporary with Member 2 of the Sterkfontein Formation. There is also a possibility of a blocked connection between the eastern Silberberg deposits and the western end of the Jacovec cavern (Figure 6).

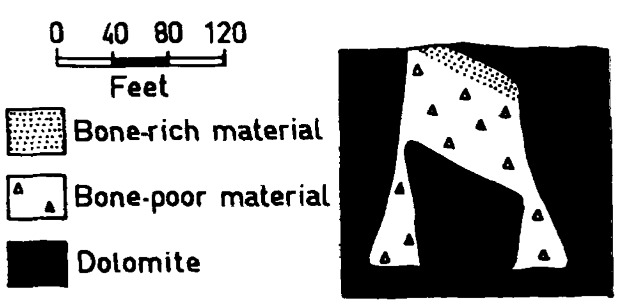

Figure 2. Brain's (1958) stratigraphy.

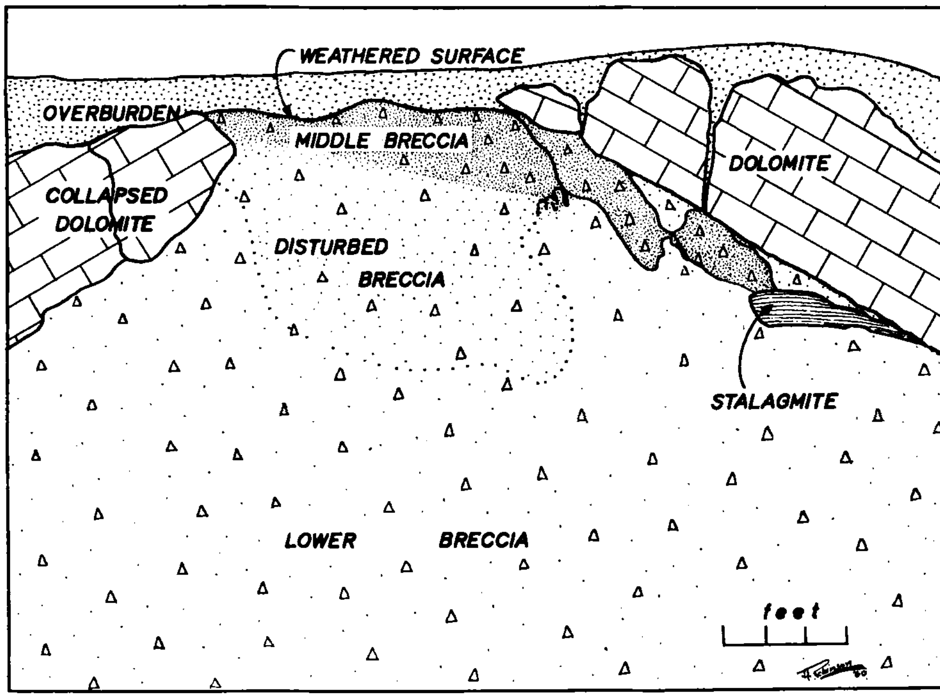

Figure 3. Robinson's (1962) stratigraphy.

THE IMPORTANCE OF THE SILBERBERG GROTTO

In 1978, P.V. Tobias decided to investigate the Silberberg Grotto (formally known as the Daylight Cave), which contained Members 1, 2 and 3 of the Sterkfontein formation (Figure 7) and from which Silberberg had obtained the interesting *Chasmaporthetes* skull portion in 1942 (Tobias, 1979). Accordingly, Hughes supervised the removal to the surface of the rubble from the lime-miners breccia dump that covered the floor of the grotto. From this dump (D.20) Hughes and his team of preparators recovered a large assemblage of fossils of mainly

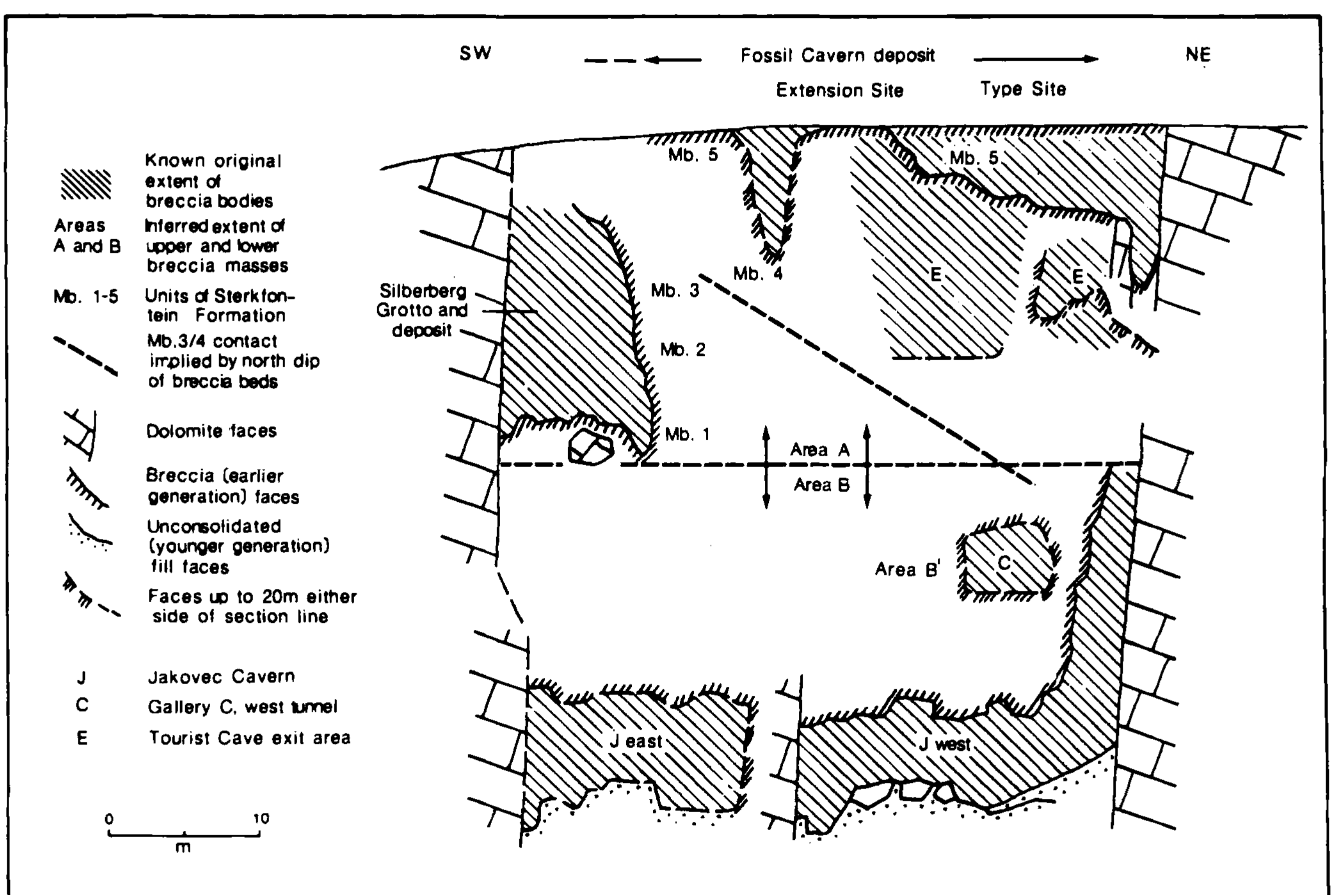

Figure 4. Wilkinson's (1983) stratigraphy.

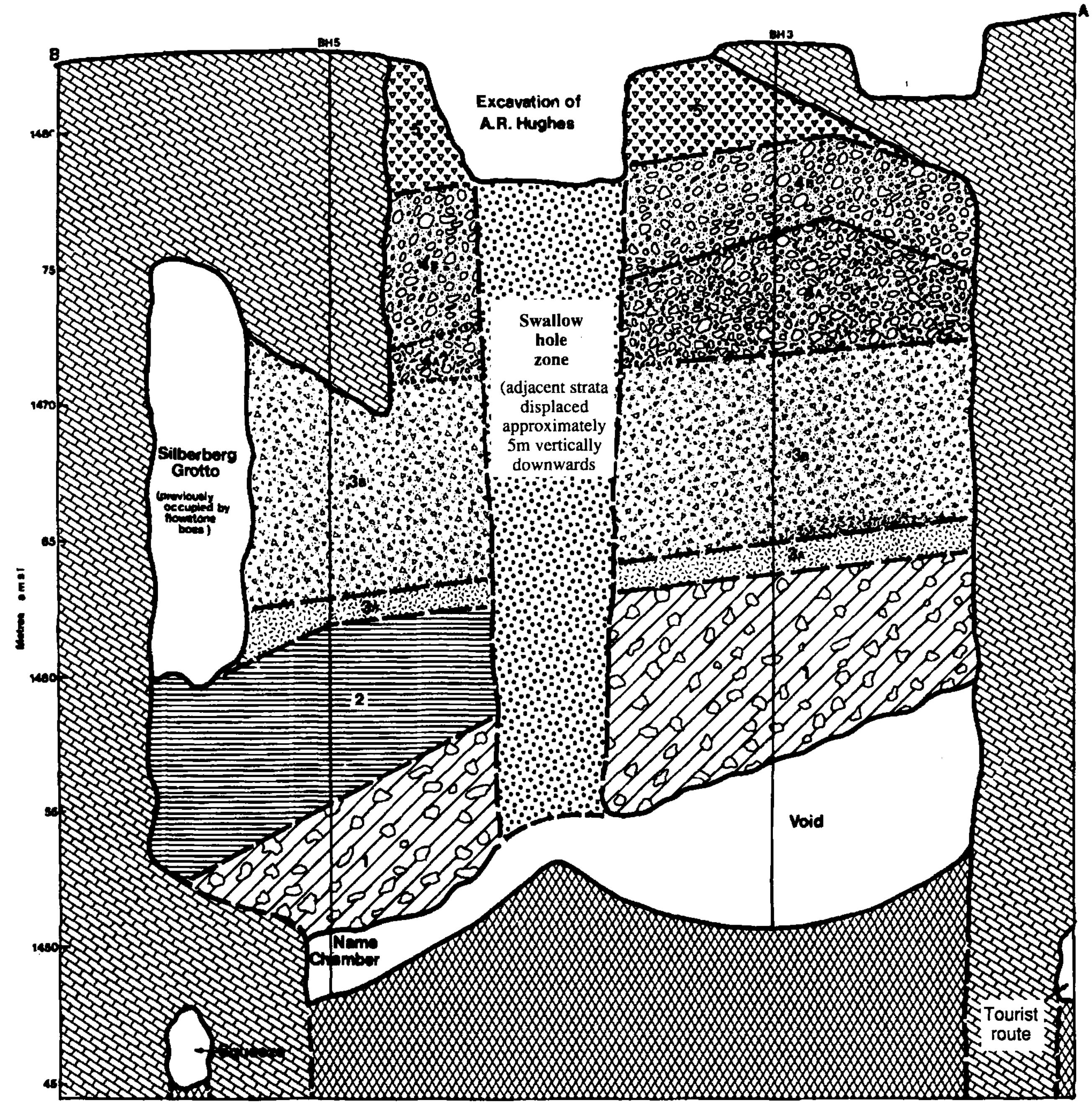

Figure 5. Partridge & Watt's (1991) stratigraphy.

monkeys and carnivores between 1978 and 1980. In 1992 Tobias and I arranged for blasting of the Member 2 *in situ* breccia at the eastern end of the grotto. This resulted in a further large sample of fossils, again mainly of monkeys and carnivores. Analysis of this sample by Pickering *et al* (2004) showed monkeys to be the best represented, followed by cats with a few antelopes and hyaenas. The fact that there were articulating limb bones, (sometimes with opposite limbs of the same individual), of monkeys, carnivores and antelopes with very little sign of carnivore damage in the total assemblage suggested that these animals fell into a steep shaft, which acted as a natural death trap. Significantly, not a single hominid fossil was identified from either the dumps or the *in situ* blasting.

In 1994, however, I identified, from the lime-miners' dump fossils, four conjoining foot bones of a hominid (Clarke & Tobias, 1995). My subsequent discovery of eight other foot and leg bones of the same individual prompted me to send S. Motsumi and N. Molefe to search the Silberberg Grotto for an *in situ* exposed section of tibia shaft that would fit to the distal tibia from the dump breccia. Remarkably, they found the contact at the western end of the grotto and subsequent excavation has uncovered a virtually complete skeleton of *Australopithecus* (Figure 8) in Member 2 breccia (Clarke, 1998). This excavation has revealed further insights into the stratigraphic history of the Sterkfontein deposits. I found that the middle part of the skeleton had collapsed into a shallow cavity that extended beneath the breccia and that subsequently a flowstone had formed over the upper and middle part of the body, but beneath the lower legs (Clarke, 2002). This cavity had been formed by water washing out softer, reddish deposit from beneath the harder, stony deposit that contained the skeleton. Subsequently, the cavity had been lined with small stalactites on its upper surface. The floor of the cavity consists of a surface of botryoidal (like bunches of grapes) stalagmite that extends over a large area adjacent to the cavity. This latter formation typically forms underwater in caves, which accords with the

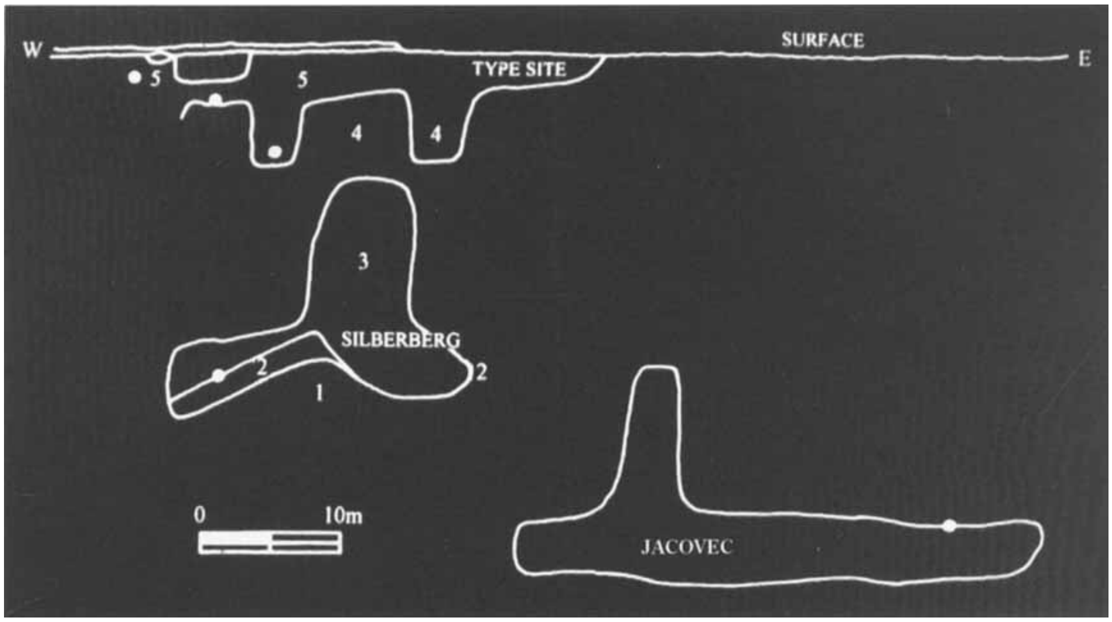

Figure 6. The vertical relationships of the Sterkfontein breccias labelled 1 to 5. Large dots in Silberberg and Jacovec caverns mark positions of *Australopithecus* fossils.

observation by Partridge (1978) that the sedimentological features of Member 2 suggest periodic ponding and episodic subaqueous deposition.

The excavation has also shown that the hominid skeleton and other animal bones in its vicinity are embedded in a very stony breccia consisting of a wide range of sizes of dolomite and chert blocks. This is situated on the lower northwest flank of a steep talus slope of mainly loosely-calcified reddish sediment with interbedded thin calcite layers and dark brown calcified mud flows. This extensive breccia slope rests on top of a collapsed debris pile of large roof blocks cemented with flowstone (Member 1). These roof blocks had probably fallen from a roof that originally covered part of the eastern end of the Silberberg Grotto at a much lower level than the roof that covered

Figure 7. The Silberberg Grotto, looking west, showing steep talus slope of Member 2 in centre beneath ladder. Member 3 is vertical face to the upper right of ladder. Dolomite cave wall is at left.

Figure 8. The skull and left humerus of the Silberberg Grotto *Australopithecus* skeleton.

Figure 9. The Silberberg Grotto, looking east. Lucas Sekowe points to *Australopithecus* skeleton in stony Member 2 breccia. To the right is a slope of reddish Member 2 breccia with stalagmite layers. Botryoidal stalagmite formation is at lower right. (See also Figure 11.)

Member 4. The upper part of this debris cone consists of flowstone, which extended vertically and conformably into a massive stalagmite boss that formed against the southern wall of the grotto. This boss was removed by the lime-miners in the late 1920s or early 1930s, but has left a negative impression, as well as occasional surface remnants of the stalagmite, against the breccias comprising Members 2 and 3. The reddish sediment currently appears to contain very few obvious fossils in any of its exposures. Although this stratified reddish deposit and the stony breccia that contains many obvious fossils both form parts of Partridge's Member 2 and are both sealed by one and the same thick flowstone, they appear to be two distinct deposits (Figure 9). The reddish deposit, mostly poorly calcified, formed over the very steep westward dipping slope of Member 1. Its relatively stone-free composition and the paucity of fossils suggest that it formed prior to a major opening to the surface. Once such an opening had occurred the stony debris and bones accumulated at the lower flank of the talus slope to the west and from the northern side of the low part of the roof, which is situated just above the hominid skeleton. At the same time, some of this stony bone-rich breccia accumulated in a pool of water at the eastern end of the Silberberg Grotto. That the grotto was for long periods partially filled with water is shown by two extensive shelf-stone formations that I recently found at different levels around short, stumpy stalactites on the roof above the lower western end of the talus slope (Figure 10), together with nearby botryoidal stalactites. The presence of water is further confirmed by the botryoidal stalagmite formation beneath the same area of talus slope (Figures 9 and 11).

At some time water caused the hollowing out of a shallow cavity beneath the stony breccia that contained the skeleton, resulting in collapse of the central part of the skeleton and its enclosing breccia into the cavity. Following a drop in the water level, the flowstone emanating from the immense stalagmite boss against the southern grotto wall, formed over the Member 2 breccias and this appears sectioned through at different levels above and beneath parts of the hominid skeleton.

MEMBER 3

The next event was the build up of fossiliferous breccia against the stalagmite boss and on top of the flowstone that covers Member 2 at the eastern end. This breccia, which Partridge & Watt (1991) calculated to be at least 8 m thick, constitutes Member 3. It has not been excavated due to the verticality of its exposed face in the Silberberg Grotto and the difficulty of access. It is exposed next to the wooden steps that lead down into the grotto and several fossils can be seen on the vertical face that bears the impression of the stalagmite boss as well as some adhering layers of the stalagmite itself.

MEMBER 4

Apart from in the core drilling samples (Partridge & Watt, 1991), no connection can be seen between Member 3 and Member 4, which is exposed in the surface excavation (Figure 5). This is because Member 3 reaches to the roof of the Silberberg Grotto and Member 4 is banked against its northern flank beneath a higher section of roof to the north. Member 4 has yielded a large number of *Australopithecus* fossils belonging to *A. africanus* and to a second, larger-toothed species of *Australopithecus* (Clarke, 1988, 1989, 1994a). It has also yielded fossil lianas (*Dichapetalum mombuttense*) and shrubs typical of

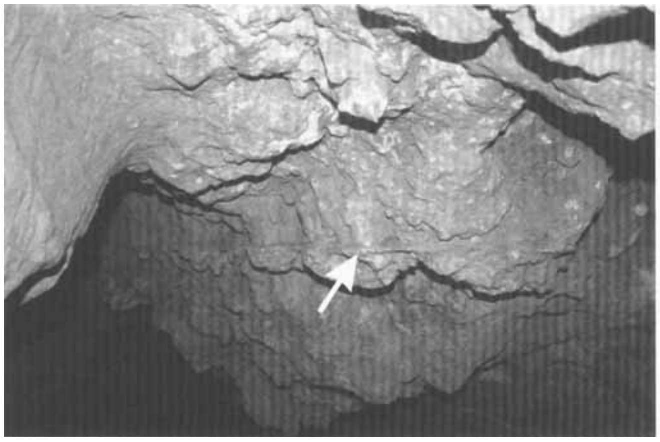

Figure 10. Shelfstone around stalactites on roof above Member 2.

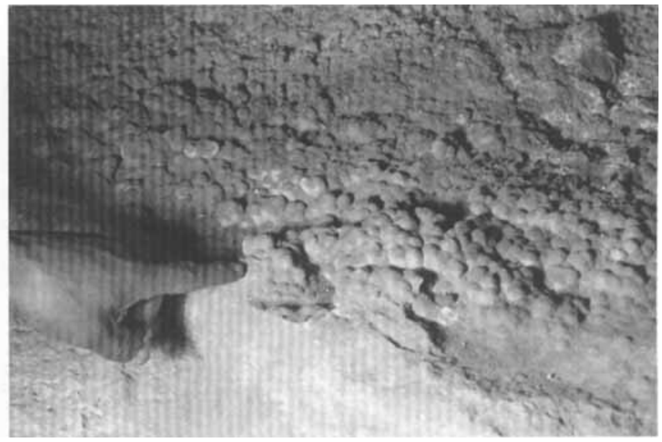

Figure 11. Botryoidal stalagmite formation in Member 2.

tropical forest (Bamford, 1999). This is consistent with the kind of fauna found there, which includes many large monkeys of the genus *Parapapio* as well as some large colobus monkeys (*Cercopithecoides*) and forest or woodland antelopes (Vrba, 1976). There are also several types of carnivore but no *Homo* remains, no stone tools and no representatives of the typical grassland fauna such as are found in Member 5. Excavations have revealed that Member 4 formed a talus cone with slopes apparent to the north and west (Clarke, 1988). At its western end parts of the talus slope eventually collapsed into the lower tourist cave in what is known as the Name Chamber, leaving a hanging remnant of Member 4 against the southern cave wall. The spaces between the remaining western projections of Member 4 were later filled with Member 5 breccia that also banked up against the sloping talus of Member 4 (Clarke 1994b, Kuman & Clarke 2000).

MEMBER 5

This deposit, which is exposed largely in the western end of the excavation but also occurs as a thin deposit beneath the dolomite roof in the Type Site quarry, contains stone tools of Oldowan and Early Acheulean type as well as *Homo* and *Paranthropus* fossils and a fauna indicative of grassland (horse *Equus* spp., ostrich *Struthio*, springhare *Pedetes* sp.). A stratigraphic section and discussion of this deposit and its contained artefacts and hominids are provided by Kuman & Clarke (2000). It was during excavation of Member 5 in 1992 to 1993 that we broke through into a vertically descending hole in the breccia that emerged above a steep and massive talus slope in the Name Chamber of the tourist cave (Clarke, 1994b). This demonstrated that there had been collapse of breccia into the lower cavern prior to infilling with Member 5 Oldowan breccia. It thus confirmed Robinson's (1962) model of a history of collapse and then infilling with later breccia. It also supported Partridge & Watt's (1991) observation that there was a swallow hole in the centre of the cave infill. This area of instability corresponds with decalcified breccia that includes parts of Members 4 and 5.

MEMBER 6 AND POST-MEMBER 6

These infills at the western end of the current surface excavations represent the final events in the filling of the cave (Kuman & Clarke, 2000). Member 6 remains only as a very small layer on top of the capping flowstone of Member 5 West. The faunal sample obtained by Robinson from here is small and includes grassland antelopes, zebra *Equus* sp., porcupine *Hystrix* sp., hyraxes Hyracoidea, a small carnivore and a bird. There are no hominids or other primates and no stone tools.

Post-Member 6 is an infilling of an eroded tunnel through the breccia of Member 5 West that extends into the Lincoln cave to the north. Excavations in the Lincoln cave by Reynolds (Reynolds *et al.*, 2003) produced a mixture of *in situ* Middle Stone Age artefacts and reworked Early Acheulean artefacts and hominid teeth from Member 5.

SUMMARY

Because of the complex nature of dolomite caves and disruptions to infills occasioned by floor collapse and erosion, as well lime-mining, core-drilled samples and exposed sections can give only partial indications of the stratigraphic history of the Sterkfontein hominid-bearing infills. Many questions remain and much research into these ancient deposits still needs to be done. Nevertheless, due to the extensive excavations and the investigations of the Silberberg Grotto and Jacovec cavern, as well as the core drilling, we now have a much deeper understanding of the Sterkfontein stratigraphy (Figures 12 and 13), which can be summarised as follows:

1) Stalactites and stalagmites, including a boss on the southern wall were forming in the Silberberg Grotto.
2) Possibly around 4 Ma, part of a dolomite gallery floor above the Silberberg Grotto collapsed, forming a massive talus cone on the floor of the Grotto.
3) The talus was cemented by stalagmitic dripstone, which eventually formed a huge stalagmite boss on the south wall above the talus and sealed it with a capping flowstone. This talus and the associated stalagmite formations comprise Member 1.
4) A small surface entrance above the vicinity of the stalagmite boss permitted ingress of reddish sediment, which formed a covering over the westward dipping slope of the rocky talus. At the same time dripstone continued to form thin layers interbedded with the sediment. The western end of the talus was under water and botryoidal stalagmite formed on the floor of the pool. Stalagmitic shelfstone formed at the water's surface around stalagmites beneath the roof.
5) About 3.3 Ma, a larger opening to the surface formed somewhere to the north of the Silberberg stalagmite boss and permitted entrance of large and small rocks and sediments as well as animals, mostly monkeys and carnivores, that fell to their deaths. The rocks, bones and sometimes carcasses, tumbled in two directions: a) some, including the *Australopithecus* body, fell to the south-west around a low part of the roof, where they rested against the lower western flank of the red sediments; b) others fell to the south-east where they were loosely stratified in

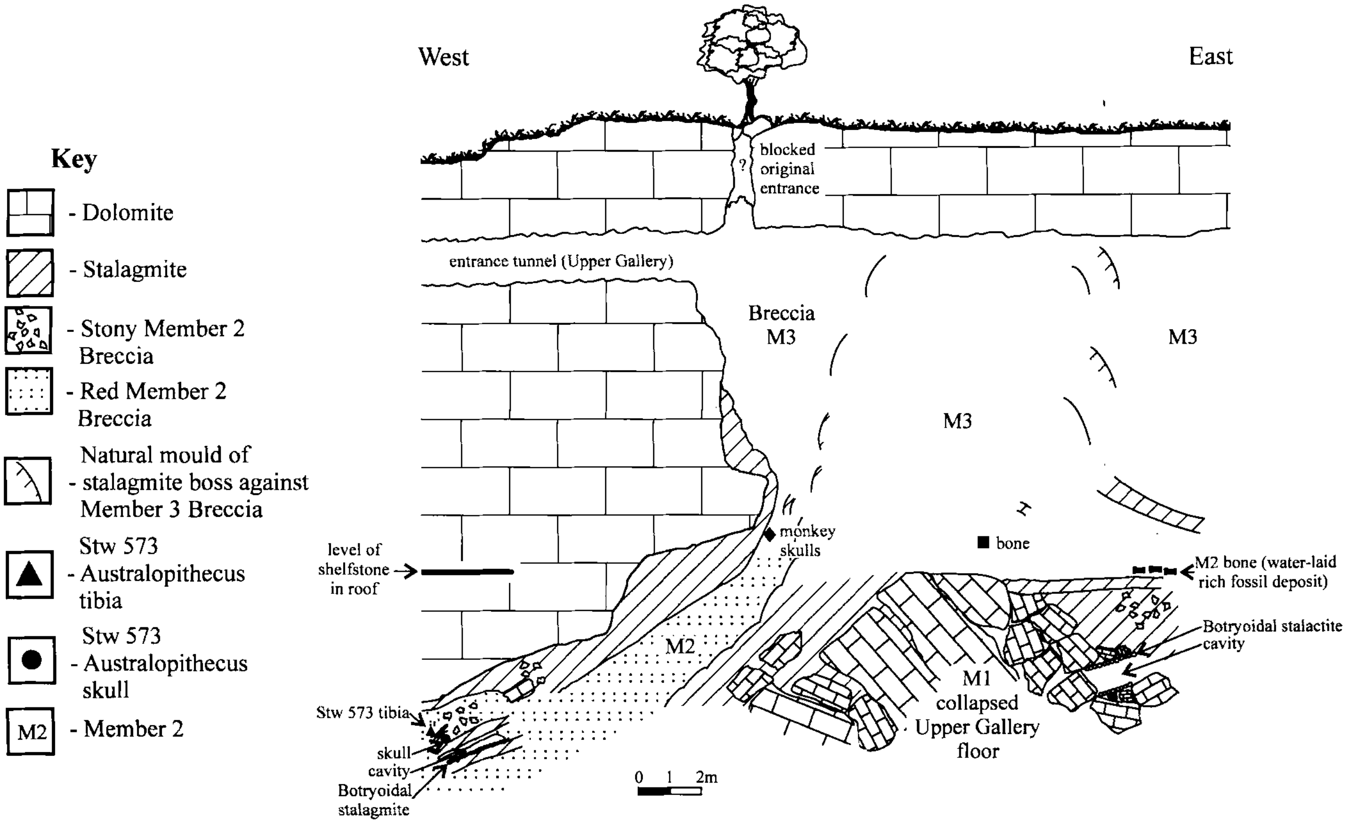

Figure 12. New interpretation of Silberberg Grotto stratigraphy by R.J. Clarke.

a pool of water. These deposits, together with the reddish sediment and the hominid-containing stony breccia, comprise Member 2.

6) A high water level washed out reddish sediment from beneath the rocky talus containing the *Australopithecus* skeleton, forming a shallow cavity on top of the botryoidal stalagmite within Member 2. This resulted in the collapse of the central part of the skeleton into the cavity and the crushing and disintegration of part of the pelvis as well as breakage and scattering of the right forearm bones and hand.
7) The water level dropped and flowstone emanating from the stalagmite boss formed over the sloping red sediments and the rock-filled, bone-containing east and west talus slopes of Member 2. The flowstone sealed the upper part of the *Australopithecus* body and filled a cavity beneath its lower legs.
8) Further ingress of rocks, sediment and bone to the north of the stalagmitic boss built up against the boss and on top of its flanking flowstone to form the massive Member 3 infill.
9) During the period from just under 3 Ma to just over 2 Ma, continuing infill of rocks, sediment and bones formed Member 4 as a talus cone sloping steeply to the north, reaching the cave roof, and to the west.
10) A change in climate to drier grassland conditions at around 2 Ma heralded the ingress of Member 5 deposits that banked against the steeply westward sloping talus of Member 4 and filled spaces left from the partial collapse of the western end of Member 4 into the lower cave.
11) Following the capping of Member 5 by a flowstone, the Member 6 deposit accumulated just under the roof at the western end.
12) Water eroded away part of the northern area of Member 5, forming a tunnel into the Lincoln cave and redepositing artefacts and bones there. The tunnel was then filled with a bone-containing deposit constituting post-Member 6.

This is the general sequence of events as I currently see them. The relative timing of certain events, such as the high water levels in the Silberberg Grotto, must be the subject of further investigation. However, the sequence of events follows the expected pattern for caves of this type.

The temporal order of events as outlined for the Sterkfontein stratigraphic sequence is also supported by the content of the breccias. Thus, Member 1 formed before any openings to the surface and has no faunal content. Member 2 has apparently not much faunal content in the reddish sediments but the stony debris contains fossils of animals that fell down steep vertical shafts, perhaps in some cases into standing water. The hominid skeleton in Member 2 has a skull with strong resemblances to the 3.2 Ma *Australopithecus afarensis* rather than to the younger *Australopithecus africanus* of Member 4. The next deposit, Member 3, which rests on top of and against the thick stalagmite flowstone that sealed off Member 2, has never been sampled. Member 4 differs from Member 2 in that it contains a very large number of *Australopithecus* specimens as well as a greater variety of other animals, with a higher percentage of antelopes, and it reaches to the cave roof at the surface of the Sterkfontein site. Member 5 is seen to be banked against the talus slope of Member 4 and contains stone tools for the first time in the Sterkfontein sequence. The earliest are Oldowan which, compared to dated East African sites, could date to around 2 Ma. Next are the Early Acheulean handaxes, cleavers and cores associated with *Homo ergaster* fossils, which date to around 1.7 Ma in East Africa. Finally, Member 6 is separated from Member 5 by a flowstone, has no Acheulean stone tools and occupies only a small area beneath the roof of the cave.

Thus, in the 68 years that have passed since Basil Cooke's first

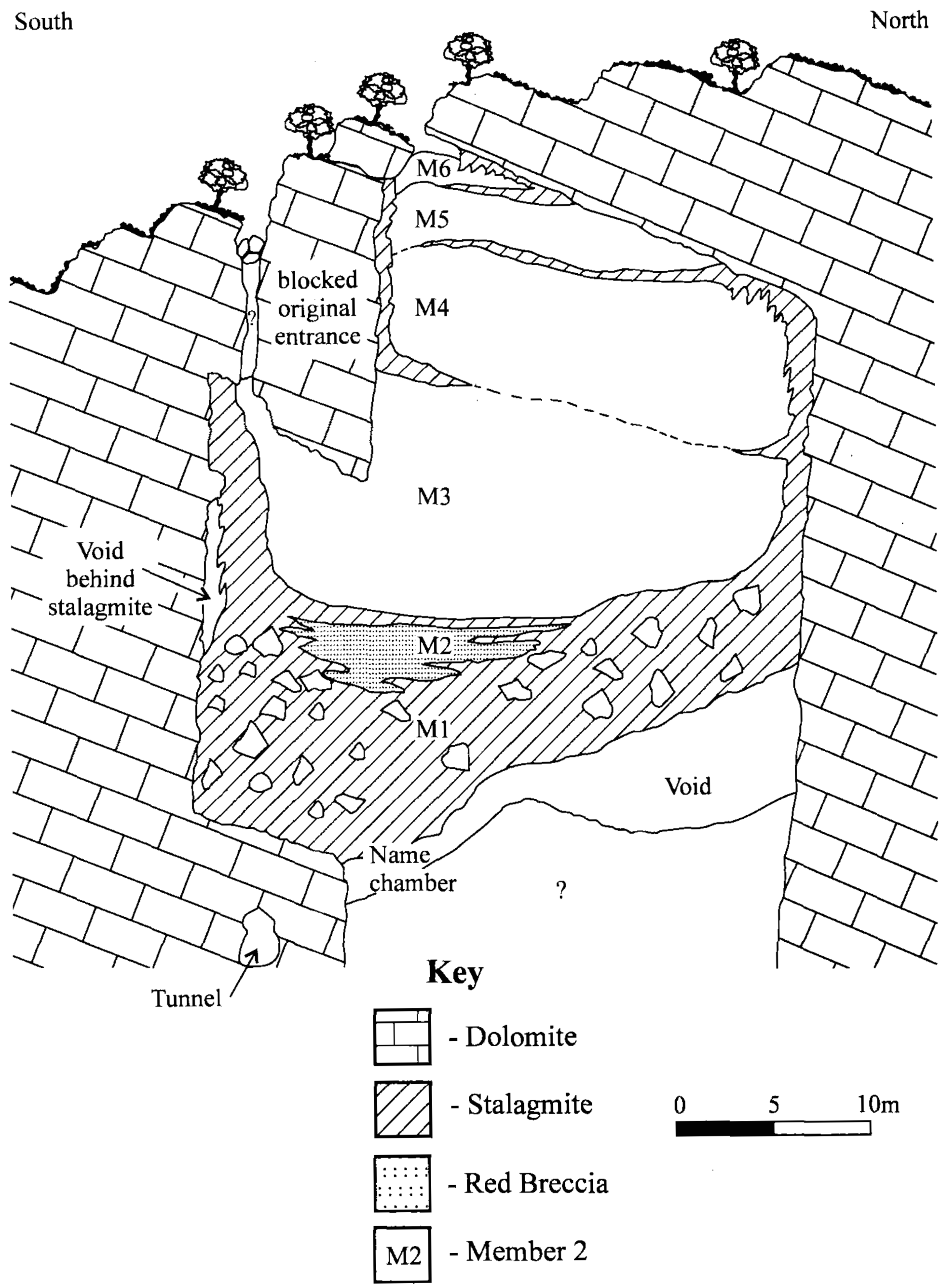

Figure 13. Schematic north-south section of Sterkfontein to show general relationship of breccias with suggested original openings and possible surface topography. Modified from Partridge & Watt (1991).

stratigraphic study of Sterkfontein breccia we have formed a much deeper understanding (about 30 m deeper!) of what has proved to be a very productive fossil hominid site.

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I am particularly grateful to the editors of this Festschrift for inviting me to contribute and thus enabling me to show my appreciation to Basil Cooke for more than forty years of friendship, collegiality and inspiration. I first met Basil and Dorette Cooke following my employment in 1963 by Louis Leakey at his Centre for Prehistory and Palaeontology in Nairobi, Kenya. They were regular visitors and always showed great kindness to me, a young man just setting out on his career in African palaeoanthropology. Little did I know then that, one day, I would be making significant discoveries at the site of Sterkfontein where Basil, as a young man himself in 1938, made his early contribution to African palaeoanthropology. I wish to thank also the many donors who have made my Sterkfontein research possible, these include the Leakey Foundation, the Wenner Gren Foundation, the Ford Foundation, the Mott Foundation, the National Geographic Society, the South African National Research Foundation, the South African Department of Science and Technology, the Palaeontological Scientific Trust, and the Embassy of France in South Africa. I am indebted to Mike Buchanan for informative discussion about underwater formations in caves, to Meraewin Clarke for assistance in preparation of this manuscript, and to Wendy Voorvelt for drafting Figures 12 and 13.

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