Hominin Postcranial Remains from Sterkfontein, South Africa, 1936–1995

Edited by Bernhard Zipfel, Brian G. Richmond, and Carol V. Ward

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This volume is dedicated to the memory of
Dr. Charles Abram Lockwood III
1970–2008

For his inspiration in initiating this volume and the workshop that led to it, his thoughtful scholarship of South African fossil hominins, and his leadership in the field of hominin paleontology.

Photo credit: Photo by Kaye Reed. Courtesy of Institute of Human Origins

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Preface

Carol V. Ward, Brian G. Richmond, and Bernhard Zipfel

The discovery in 1924 in southern Africa of an early hominin child's skull, referred to *Australopithecus africanus* by Raymond Dart in 1925, was a major event in the history of paleoanthropology, providing the first evidence of early hominins in Africa and overturning conventional ideas about human evolution. Subsequent discoveries over the next several decades, notably from cave deposits at Sterkfontein, yielded the first evidence of postcranial anatomy in *Australopithecus*, and the first evidence that early hominins were habitual bipeds. Nearly 50 years after Dart's report, the discoveries in eastern Africa of a wealth of fossil evidence of the slightly older and craniodentally more primitive taxon, *A. afarensis*, catalyzed debates that continue today about the origin and evolution of human gait and the phylogenetic relationships among early hominins. Since then, *A. afarensis* has formed the main basis of our understanding of early hominin bipedality and paleobiology. However, little attention has been paid to examining variation among species in postcranial anatomy and/or locomotion, although intriguing hints are beginning to appear in the literature. Did multiple varieties of bipedality evolve? Did australopith species differ in positional or manipulative abilities, body proportions, or patterns of sexual dimorphism? These are critical questions for understanding the evolution of australopiths and hominin locomotion, yet research has been limited because only the postcrania of *A. afarensis* have been extensively studied, despite the existence of a large fossil collection from Sterkfontein as well.

The Sterkfontein hominin fossils generally are attributed to the species *Australopithecus africanus*, because most craniodental remains from the site are attributable to that taxon (reviews in Grine, 2013, 2019). However, there may be more than one hominin represented within the sample, even within the most productive member, Member 4, and, given the complex stratigraphy of the site and challenges in dating the deposits, this may or not may be the case. In general, several studies have suggested the presence of two or more australopith taxa within the sample, each citing more morphological variation among the craniodental remains from Sterkfontein than can be attributed to a single species, at least compared to extant hominoid taxa (Clarke, 1988, 1994; Kimbel and White, 1988; Lockwood, 1997, Lockwood and Tobias, 2002). However, it is notable that none of these studies agree on which specimens comprise the different possible taxa or groups, largely due to emphasis on different aspects of morphology varying among the fossils. The likely time depth of the Sterkfontein sample, even within Member 4 (see Pickering and Herries, Chapter 3, this volume), may also complicate assessment of potential taxonomic heterogeneity at the site.

None of the Sterkfontein postcranial fossils can be definitively associated with any craniodental specimens (but see Thackeray et al., 2002) and so cannot be related directly to any of the proposed taxonomic divisions within the sample. However, some studies have cited variation within the postcranial fossils that may also reflect taxonomic variation, although many analyses to date have not tackled this question rigorously. Even though these suggestions have been made occasionally in the literature, no clear or consistent suggestion of two or more taxa has been apparent within the postcranial samples (reviewed in Grine, 2019). Taxonomic variation is one of the key questions that each chapter in this volume addresses (summarized in Ward and Zipfel, Chapter 18, this volume).

Excavations at Sterkfontein cave continued throughout the late 20th century and have yielded one of the largest collections (>150) of postcranial fossils of any hominin taxon. These fossils remain relatively unstudied, and few are published, despite the enormous potential of these fossils for answering questions about *Australopithecus africanus* paleobiology, early hominin variation, and early human evolution. The goal of this volume is to provide descriptions and figures of all of the Sterkfontein fossils and inspire more research on this important collection of hominin fossils.

In 2009, the University of the Witwatersrand held a workshop funded by the Wenner Gren Foundation for Anthropological Research, The Ford Foundation, Palaeontological Scientific Trust (PAST) of South Africa, and the university that brought together experts on early hominin postcranial anatomy to describe and analyze the Sterkfontein fossils, exchange ideas, and foster innovative and internationally collaborative research. South African students attended the workshop as well, interacting with their more senior colleagues and engaging in stimulating and productive discussions about the Sterkfontein hominins. The participants had a chance to interact with the fossils over several days, describing and comparing the fossils and discussing interpretations and what the fossils tell us about *Australopithecus africanus* and how they inform us about human evolution. Ultimately, these participants contributed chapters to this volume, bringing in other experts as authors as well as their work progressed.

The timing of the workshop helped promote Africa-based paleoanthropology at a crucial time. From a scientific perspective, it is becoming ever more apparent in recent literature and in conferences that variation among hominins is key to understanding the early evolution of bipedality and interpreting how patterns of locomotion relate to the origin of *Homo*, but without more formal work on the Sterkfontein fossils, we are ill-equipped to address differences among *Australopithecus* species.

This volume presents all Sterkfontein hominin postcranial fossils that were available for study when the workshop was convened. Appendix I lists these fossils and what is known about their provenience.

Back row, left to right: Shahed Nalla, Alan Morris, Adam Gordon, J. Michael Plavcan, Matthew Tocheri, William Jungers, Colin Menter, Kristian Carlson, Bernhard Zipfel. Middle row, left to right: Michelle Drapeau, Job Kibii, Roshna Wunderlich, Dipuo Mokokwe, Dominic Stratford, Danielle Vernon, Christine Steininger, David Green, Ronald Clarke. Front row, left to right: Carol Ward, Burt Rosenman, Christopher Ruff, Brian Richmond, Tea Jashashvili, Andrew Gallagher, Brendon Billings, Martin Haeusler.

Since this workshop was held, additional fossils from the Sterkfontein Cave have been recovered and are beginning to be published. The descriptions and analysis presented in this volume should stand as a foundation from which to interpret these and other fossils from Sterkfontein, and from all over Africa, that will be recovered in years to come.

This volume is organized in three parts. The volume opens with a transcript of the opening address for the workshop delivered by the late Professor Dr. Phillip V. Tobias, whose long-standing and indelible contributions to our understanding of the Sterkfontein fossils and to human evolution cannot be overstated. We were all honored to have him open the workshop and this volume. Chapters 1–3 present background and context of the Sterkfontein site and its fossils. J. Francis Thackeray reviews the remarkable history of this important site. Dominic Stratford reviews site formation, and Robyn Pickering and Andrew Herries review the geochronology of the site and temporal context of the fossils. Chapters 4–15 present descriptions and photographs of every postcranial fossil recovered from the site through 1995, along with basic comparative analysis and interpretation of each anatomical region. Chapters 16–17 present more synthetic analyses of anatomy, with consideration of long bone cross-sectional morphology and body proportions. Finally, Chapter 18 synthesizes some of the major conclusions from each chapter to summarize how these analyses have advanced our understanding of the taxonomy, functional anatomy, and paleobiology of the hominins from Sterkfontein.

Many people at the University of the Witwatersrand and beyond supported our efforts in carrying out the workshop. Notable are Belinda Bozzoli, former Deputy Vice Chancellor—Research, Trefor Jenkins, former Acting Director, Institute for Human Evolution (IHE), Bruce Rubidge, Director of the former Bernard Price Institute (BPI) for Palaeontological Research, and Marlize Lombard, former IHE Management Committee. They approved and supported this project without hesitation and allowed us to make use of university resources. Logistical support was kindly given by Rhod McRae-Samuel (Wits Palaeosciences) and Andrea Leenen and Ann Smilkstein from the PAST. Their time and resources in assisting with transport, communication, and catering is very much appreciated. We thank Joe Daley, former Head of the School for Anatomical Sciences at Wits, for graciously hosting us at the school. For access to fossils and comparative skeletal material, we thank the Wits Fossil Access Advisory Committee, Brendon Billings (School of Anatomical Sciences), and Stephanie Potze, Lazerus Kgasi, and Miriam Tawane (Ditsong Museum of Natural History). Roshna Wunderlich spent many hours painstakingly taking photographs of each specimen and made an additional trip to South Africa after the workshop to complete this important task. We are very grateful for her significant contribution. We also thank Mark W. Grabowski for assisting in the editing and checking of fossil descriptions. Our deepest gratitude also extends the Charlie Lockwood family for their support and for providing a grant to the then IHE to support palaeoanthropological activities, including this volume. Finally, we thank all the contributing authors, assistants, and reviewers for their time, enthusiasm, expertise, and patience in completing their respective tasks.

Most importantly, plans for the Workshop on Sterkfontein Postcranial Fossils and for this monograph were initiated by our esteemed colleague Dr. Charlie Lockwood, now deceased. Dr. Lockwood had energized the organization of this meeting and had already made major contributions to our understanding of the paleobiology of *Australopithecus africanus*. As of September 2008, Charles Lockwood was to become the inaugural director of the Institute for Human Evolution at Wits, and he energized this workshop initiative and made it possible. In recognition of his indelible contributions, we are honored to dedicate the Sterkfontein Hominin Postcranial Fossils Workshop and this volume to the memory of Dr. Charles Lockwood.

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Introductory remarks to the Workshop on Sterkfontein Hominin Postcranial Fossils

Phillip V. Tobias

Opening Remarks to Sterkfontein Hominin Post-cranial Remains Workshop in honor of Charles Lockwood, University of the Witwatersrand, Johannesburg, January 5–9, 2010.

Originally presented to Professor Francis Thackeray, Director of the Institute for Human Evolution, Professor Joe Daly, Head of the School of Anatomical Sciences, The Co-organizers of the Workshop, Colleagues, and Friends from at least three continents.

It is a great pleasure for me to welcome all of you to the School of Anatomical Sciences which you have chosen as the venue for the Workshop. It is of course an obvious choice since the School of Anatomical Sciences houses one of the largest collections of original hominin fossils in the world. The lion's share of these have been recovered from Sterkfontein between 1966 and the present. I shall return to this theme in a moment.

It would be unthinkable for me to continue without dwelling on the man who first proposed that such a workshop be held, Charles Abram Lockwood III. He was due to leave for South Africa to take up, on September 1, 2008, his position as the first director of the new University of the Witwatersrand formation, the Institute for Human Evolution. Six weeks before that, while riding his motor bicycle to work at University College London, he was apparently crushed by a lorry near King's Cross Station—and died on the spot. It was Monday July 14, 2008 ("Bastille Day").

He came to South Africa in 1994 to carry out his doctoral research, with myself as his supervisor. Of 50 or more doctoral and postdoctoral students whom I supervised, Charles stands out as one of the most brilliant, dedicated, and hard-working of all, completing his thesis in close to the minimum time, and obtained the Wits Ph.D. in 1997. He received high plaudits from his examiners, one of whom was Francis Clark Howell. This must have been one of the last such reports that Clark Howell tendered before his own death. Howell wrote of Charles's thesis, "I consider that this fine research accomplishment may well stand at the forefront of a series of contributions focused on ancient Transvaal hominins that will reestablish and reaffirm their extraordinary interest and relevance for a [full] appreciation of humankind's evolutionary diversity, adaptations and history." Lockwood's other examiners were Professor Leslie Aiello and myself.

Charles was one of my most outstanding protégés. He was a fine scholar, a serious and dedicated student. On September 1, 2008, the very date on which he was to take up his new post at Wits, he would have celebrated his 38th birthday—so he was only 37 at the time of his tragic and untimely death.

After completing his Ph.D. here he spent a period as a postdoctoral fellow at the Institute of Human Origins at Arizona State University, working with Bill Kimbel and John Lynch under Don Johanson. There followed a spell at Stony Brook University. Then, when Leslie Aiello left

Phillip V. Tobias, *Introductory remarks to the Workshop on Sterkfontein Postcranial Fossils* In: *Hominin Postcranial Remains from Sterkfontein, South Africa*, 1936–1995. Edited by: Bernhard Zipfel, Brian G. Richmond, and Carol V. Ward, Oxford University Press (2020).
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University College London to become president of the Wenner-Gren Foundation in New York City, Charles was appointed to a position in the Anthropology Department she had left. He was doing so remarkably well that only a short time before his lamentable death, he was promoted to the status of Reader at University College London.

In his last letter to me, less than three weeks before he died, he told me with enthusiasm about a workshop on Sterkfontein hominin post-cranial remains, which he was organizing for May or June 2009 as the first such activity of the Institute for Human Evolution. He added, "the final term in UCL recently ended, and I'm starting to prepare for the move." He added, "I'm very much looking forward to getting to Johannesburg in a couple of months."

My last letter to him was on July 9, 2008, five days before his fatal accident. I welcomed his plan for that workshop, suggested seven of my former Ph.D. graduates who might be considered as possible participants in the workshop, and accepted his invitation to open the workshop. He had told me that he had asked two of his American associates, Carol Ward of the University of Missouri and Brian Richmond of George Washington University, to help organize the workshop.

When the IHE and Wits University held a memorial meeting on Charlie's death on August 13, 2008, as part of my address, I stated, "It would be a most fitting tribute to Lockwood's memory if Wits University were to proceed with the holding of the proposed workshop, helped by Ward and Richmond of the USA and by one or two palaeoanthropologists of Wits and neighboring institutions. I foresee a *Charles Lockwood Memorial Meeting* carrying on with his plans for the workshop." Happily this has come to pass, through the conscientious endeavors and time-consuming hard work of Carol Ward and Brian Richmond, joined as a third co-organizer by Bernhard Zipfel.

After the news of Charles's death became known, a shockwave of horror and grief traveled around the world. Letters of sympathy arrived from Professor Nanneke Redclift of University College, London; Fred Grine of Stony Brook; Alan Bilsborough of the University of Durham ("His death is a tragic loss … particularly to Wits and to early hominid studies and especially the I.H.E. He had done and was doing some outstanding work, was an exemplary teacher and such a pleasant, informal personality, with a good sense of humour and without any pomposity or 'side' to him"); Don Johanson of Arizona State University where Charles had been a star, first as a postdoc. and then as an assistant professor ("This is an especially sad day for Wits. I know that everyone there, especially you, were very pleased that Charlie would be joining the faculty and carrying on the great tradition of paleoanthropology in South Africa. From my last conversation with Charlie he was thrilled and excited about his move to Wits"); Bernard Wood of George Washington University ("My thoughts are with you. It must be like losing a child. … At the Nairobi meeting last summer [I] realised just what a very special person [and] scientist he was."). Dr Qian Wang, now of Mercer University, Georgia, who had spent three years with me as a postdoc in Anatomical Sciences, wrote to the American Association of Physical Anthropologists, and proposed that a session of the annual meeting of the AAPA be dedicated to "celebrate Charles's truncated yet very productive and influential life." The vice president of AAPA, Lorena Madrigal, replied to Qian Wang that the Executive Board knew of Charles's passing and was already considering how best to honor him.

Charles had devoted his Ph.D. thesis to the morphology of australopithecine faces, following in the footsteps of Yoel Rak of Tel Aviv.

It is interesting that Charles selected the postcranial remains as the subject for this workshop. Forty years ago, the 1970 Burg Wartenstein Symposium was devoted to the Functional and Evolutionary Biology of Primates. Organized by Russell Tuttle of the University of Chicago, the proceedings appeared as a book of the same name and edited by Tuttle. My chapter in that book included a census of the numbers and anatomical parts of the hominin fossils from each of 14 African sites, 5 in South Africa and 9 in East Africa. Looking over this analysis the other evening, I was interested to note that 138 of the total number of specimens surveyed (1,410) were of postcranial remains. From the South African hominin sites, there were 78 and from the East African sites 60. In a further breakdown of the data I found that 44 postcranial specimens were from Sterkfontein. In preparation for this workshop, Dr. Bernhard Zipfel has recorded over 150 postcranial specimens from Sterkfontein alone. Thus, from 1970 to 2010, the total stockpile of Sterkfontein hominin post-cranial fossils has gone from 44 to 200+. This more than threefold increase is the consequence of a sustained program of systematic excavation of the Sterkfontein Cave deposit that I started in 1966, with Alun R. Hughes, and which continued relentlessly up to the present. In the early 1990s, when Hughes's health failed, the dig at Sterkfontein was continued by Professor Ronald J. Clarke.

These numbers alone justify the need for this workshop. Of course, the minimum numbers of individuals represented by the 200+ postcranial remains are far fewer, as they embrace clusters of carpals, metacarpals, and phalanges, as well as tarsals, metatarsals, and phalanges and partial and virtually complete vertebral columns. Indeed, Sterkfontein is noteworthy and perhaps unique in having yielded at least three partial skeletons of hominins, one of these virtually complete. The taphonomic implications of so high a number of skeletons from this one site, Sterkfontein, are well worthy of exploration.

It is not surprising that with these fair-sized samples of various regional anatomical subsets of postcranial remains, a number of our graduate students have devoted their dissertations and theses to the postcranial bones of australopithecines. These include Daleen Benade on the vertebral column; Lee Berger on the shoulder complex; Colin Menter on the elbow joint; David Ricklan on wrist, hand, and fingers; Ivan Suzman on the hip joint (sadly, not completed); and Peter Christie on the ankle joint.

Nine other postgraduate students devoted their theses to the postcranial elements of proto-historic and recent human populations of South Africa.

All of these postgraduate students and "postdocs" supplemented their fossil and other research materials by studying comparable bones of recent human cadaver-derived skeletons. These are mainly of modern African populations, of which the school has a very large collection. I called it the Raymond Dart Collection of Modern Human Skeletons after Professor Dart, my illustrious predecessor as head of the Department of Anatomy, who started the collection. During your stay here over the next five days, I hope that you will find the time to dip into that collection, which is housed down the corridor in the school.

I shall not be worrying you further during the coming days. I wish you all a most successful workshop and I feel confident that Carol, Brian, and Bernhard will produce a superb volume from the fruits of your collective labors.

Thank you and good luck.
Phillip V. Tobias
January 5, 2010

Section 1

Temporal, geologic, and historical context of the Sterkfontein hominins

1

A summary of the history of exploration at the Sterkfontein Caves in the Cradle of Humankind World Heritage Site

J. Francis Thackeray

The Sterkfontein Caves, situated approximately 70 kilometers southwest of Pretoria, are part of an area declared by UNESCO in 1999 as the Cradle of Humankind World Heritage Site. The caves are important in terms of their relative abundance of Plio-Pleistocene fossils attributed to *Australopithecus*, in addition to rare specimens representing *Paranthropus* and early *Homo*, associated with non-hominin fossils that reflect paleo-environmental changes within the last three million years.

Three historical periods of exploration can be recognized. First (1895–1935), the caves were explored by prospectors interested in the mining of limestone, coinciding with the unsystematic recovery of non-hominin fossils; second (1936–1966), the caves were the subject of scientific research and fieldwork by Robert Broom, his assistant John Robinson, and C. K. (Bob) Brain, all based at the Transvaal Museum within a period when Plio-Pleistocene hominin fossils and artifacts were discovered; and third, a period since 1966 when Professor Phillip Tobias and others from the University of the Witwatersrand (including Alun Hughes, Tim Partridge, Ron Clarke, Kathy Kuman and Dominic Stratford) undertook systematic fieldwork and research and made additional remarkable discoveries of fossils and artifacts under the aegis of the Department of Anatomy, later the School of Anatomical Sciences, and more recently through the Institute for Human Evolution (IHE) which was established in 2007 at the university. In 2013 the IHE was merged with the Bernard Price Institute to form the Evolutionary Studies Institute (ESI).

The early years (1895–1935)

The exploration at Sterkfontein was initially associated with the exploration of caves for limestone which was mined for agricultural purposes as well as for the purification of gold. One of the prospectors was G. Martignalia who used dynamite to open up a “wondergat” in the dolomite at Sterkfontein, *circa* 1895. His son noted, “There are only a few people alive today who saw these caves in the days of their original splendor before they were destroyed by commercial exploitation,” as quoted by van Riet Lowe (1947, p. 85). The mining attracted the attention of geologists who noted the presence of fossils in breccia deposits (Draper, 1896).

In 1895 David Draper was appointed as the first secretary of the Geological Society of South Africa, and in the same year he sent samples to the British Museum with a note referring to stalagmites and fossiliferous rock (breccia), including a primate skull and a lion claw (Brain, 1981). Draper’s fossiliferous breccia samples were prepared in acetic acid at the British Museum. Oakley (1960) reported the presence of a baboon, a carnivore, an equid, a porcupine, rodents, a lizard and some birds.

J. Francis Thackeray, *A summary of the history of exploration at the Sterkfontein Caves in the Cradle of Humankind World Heritage Site*. In: *Hominin Postcranial Remains from Sterkfontein, South Africa, 1936–1995*. Edited by: Bernhard Zipfel, Brian G. Richmond, and Carol V. Ward, Oxford University Press (2020). © Oxford University Press.
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In August 1897, an article appeared in a journal, *English Mechanic and World of Science*, with reference to "some wonderful caves" which had been "discovered recently at a place called Sterkfontein … Limestone had been quarried for some months in a small kopje, and after an explosion after some blasting operations, a cavity of great depth was left." The report referred to the exposure of "magnificent caves. The spectacle was one of great beauty, the light carried by the explorers being reflected from thousands of stalactites," as quoted by Malan (1959, p. 322).

This account, republished in a French journal called *Cosmos*, attracted the attention of a group of Marist brothers who explored the caves and subsequently wrote an article entitled "*Les grottes de Sterkfontein*," also published in *Cosmos*, in 1898. They referred to a fossilized mandible of an antelope, and speculated that it may have been killed by a carnivore.

Draper recognized the need to protect the Sterkfontein Caves from the activities of miners. Through his appeal, the owners of the farm instructed the manager to prevent "wanton destruction" (Malan, 1959, p. 321).

In February 1898, H. Exton (president of the Geological Society) presented an address in which he reported the presence of aragonite in the Sterkfontein cave formations, and suggested that the solution cavities must have been filled with warm water at some time in prehistory. In response to a suggestion by August Prister (1898) that glaciations had occurred in the Gauteng Highveld regions, M. E. Frames expressed interest in the possible relationship between paleoclimatic change and fauna. Frames referred to fossilized remains of horses, antelopes, monkeys, porcupines and bats at Sterkfontein. Without attempting to estimate their geological age, he commented that the geology pointed to some degree of antiquity.

Similar breccia deposits were discovered at Taung in 1924. Following the announcement of the "Taung Child," the type specimen of *Australopithecus africanus* (Dart, 1925), some fossiliferous breccia from Sterkfontein was sent to the University of the Witwatersrand, at a time when mining at Sterkfontein was being managed by George W. Barlow, associated with the Glencairn Lime Company. However, this material did not attract interest since it was considered to be relatively recent (Dart and Craig, 1959).

J. H. S. Gear collected samples of fossils from Sterkfontein, but unfortunately these have not been relocated in the collections at the South Institute for Medical Research, where Gear became Director (Tobias, 1973; Brain, 1981). In 1935, Trevor R. Jones, at that time a student of Professor Raymond Dart at the University of the Witwatersrand, collected a specimen of an extinct baboon (*Parapapio*). Additional fossil primates were collected in 1936 by two other of Dart's students, G. W. H. Schepers and H. le Riche. These fossils were shown to Robert Broom who had been appointed as a paleontologist at the Transvaal Museum in 1934.

The Transvaal Museum years (1936–1966)

The discovery of *Parapapio* at Sterkfontein stimulated Broom to visit the caves in 1936 when he met George Barlow, the mine manager who had previously worked at Taung where fossil baboons had also been discovered. Broom encouraged Barlow to look for anything which resembled the Taung Child. Within a short period, on August 17, 1936, Barlow showed Broom an australopithecine endocranial cast (Sts 60). After more exploration, Broom (1936) found associated parts of the cranium (TM 1511) of the same individual.

Additional fossils were found at Sterkfontein within the next three years, during which time H. B. S. Cooke (1938) prepared a map of the breccia deposits in relation to the dolomite. Broom worked closely with the miners. However, by 1939 the mining was no longer commercially viable, coinciding with the onset of World War II, and no more fossils were discovered until 1947 when the Prime Minister of the Union of South Africa, Jan Smuts, encouraged Broom to continue work at the site. On April 18, 1947, an almost complete cranium of *Australopithecus africanus* (Sts 5, nicknamed "Mrs Ples") was discovered, broken in two pieces as a result of a dynamite explosion (Broom, 1947). Four months later, a partial skeleton (Sts 14) was found close to the locality of "Mrs Ples." Broom continued work at Sterkfontein until his death in 1951. Until his departure for Madison, Wisconsin, John Robinson maintained fieldwork and preparation of fossils. Robinson (1972) published an important book on australopithecine postcrania, with special reference to Sts 14.

In 1956, C. K. (Bob) Brain discovered stone artifacts in the so-called West Pit. Focusing on sedimentology in an attempt to quantify changes in past rainfall, Brain (1958) published a study titled "The Transvaal ape-man-bearing cave deposits."

In 1958, the owners of Sterkfontein (Mr. and Mrs. E. Stegmann) donated an area of 20 morgen to the University of the Witwatersrand, for purposes of conservation and paleontological fieldwork.

The years associated with the University of the Witwatersrand (1966 until present)

In 1966, Professor Phillip Tobias embarked on a long-term systematic excavation of the Sterkfontein deposits (Tobias and Hughes, 1969). He subsequently established the Sterkfontein Research Unit with many collaborators. Alun Hughes supervised fieldwork, and Ian Watt undertook a detailed survey. On the basis of an extensive geological study, Tim Partridge (1978) recognized a sequence of six Members from Sterkfontein. Kathy Kuman recognized stone artifacts from Member 5. She recognized both Oldowan and Acheulian industries. Louis Scott explored the breccia deposits and flowstones for pollen; Marion Bamford studied fossilized wood, including liana (vine) samples; Alan Turner studied carnivores; Vera Eisenmann worked on equids; and Elizabeth Vrba analyzed bovids to asses both chronology and paleoenvironments. It was recognized that Member 4 was associated with periods when tragelaphines (associated with woodland savanna) were more abundant by comparison with fauna from Member 5 associated with relatively high abundances of grassland (alcelaphine) fauna such as wildebeest and hartebeest.

In August 1976, cranial remains of a hominin (StW 53) were discovered from deposits thought to be associated with stone artifacts from Member 5. The hominin fossil was attributed to *Homo habilis* (Hughes and Tobias, 1977). Recently, Ron Clarke has suggested that StW 53 is more likely to be associated with Member 4, and recognizes it as an australopithecine.

Other important discoveries during excavations at Sterkfontein under the direction of Phillip Tobias included an australopithecine cranium (StW 505) and a partial skeleton (StW 431), both from Member 4. Even more remarkable was a complete australopithecine skull and skeleton (StW 573) nicknamed "Little Foot" (Clarke and Tobias, 1995; Clarke, 1998) discovered by Ron Clarke, Stephen Motsumi, and Nkwane Molefe (Figure 1.1) from Member 2 in the Silberberg Grotto. Clarke (2008) believes this specimen to represent a "second species" of *Australopithecus*, distinct from *A. africanus*, but resembling the 3-million-year-old australopithecine fossils from Makapansgat, initially described by Dart as *A. prometheus*.

Provisional attempts to estimate the chronology of cave deposits at Sterkfontein were undertaken using biostratigraphy, based partly on non-hominin primates (Delson, 1988), suids (White and Harris, 1977), bovids (Vrba 1975), and carnivores (Turner, 1997), compared to fauna from radio-metric deposits in East Africa. Cosmogenic, uranium-lead (U-Pb) (Walker et al., 2006), and paleomagnetic dates (Herries and Shaw, 2011), together with faunal data, have been used in efforts to obtain absolute dates of the Sterkfontein cave deposits, ranging from 3.7 million years for Member 2, to about 2 million years for the top of Member 4, with Member 5 at about 1.8 million years.

The age of "Little Foot" from Member 2 is especially challenging, having been dated initially at 3.3 million years on the basis of paleomagnetic and faunal data (Partridge et al., 1999). Cosmogenic dates of about 4 million years (Partridge et al., 2003) were considered to be overestimates. More recently, using the same technique but with a careful study of more than ten samples, Granger et al. (2015) secured a date of 3.67 million years. This was challenged by Kramers and Dirks (2016, 2017) who contended that a younger date should be considered. A rebuttal was published by Stratford et al. (2017). U-Pb dates obtained from flowstones (Walker et al., 2006; Pickering

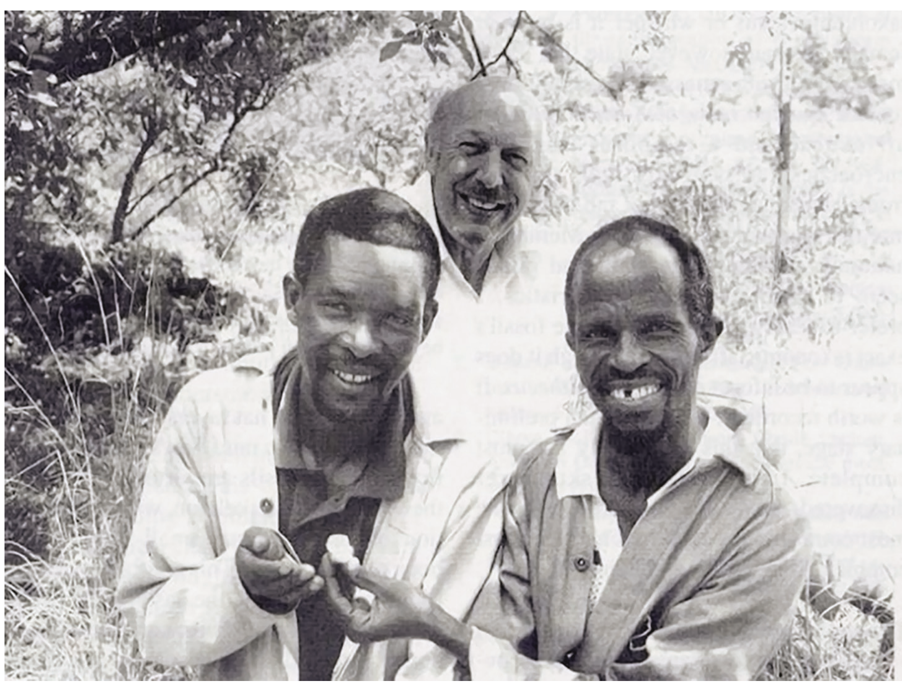

Figure 1.1 Professor Ronald J. Clarke, Stephen Motsumi, and Nkwane Molefe after the initial discovery of "Little Foot," attributed to *Australopithecus prometheus*. Credit: University of the Witwatersrand.

and Kramers, 2010), at *circa* 2 million years before present, are considered to be too young for the "Little Foot" skeleton itself. They may well be correct for the flowstones adjacent the skeleton, but these flowstones (as infillings) clearly postdate the fossil.

Ron Clarke and his assistants worked meticulously on the StW 573 skeleton which first saw light of day in 2014 when the blocks in which it had been preserved were lifted out of the Silberberg Grotto. Cleaning of the fossil using airscribes continued until 2017 when the skeleton was proudly announced to the world by Clarke in the Phillip Tobias Vault at the ESI. "Little Foot" continues to be the subject of detailed study, including the use of CT scanning. Clarke (2019) published a summary of the historical events relating to the discovery, excavation, and recent research of his extraordinary discovery.

Fieldwork at Sterkfontein is currently directed by Dominic Stratford and his team. One of their projects relates to the spatial and temporal distribution of artifacts and fossils, including hominins. New discoveries can be expected in the decades to come, with greater precision regarding chronology and context, in contrast to the circumstances under which Robert Broom worked almost a century ago.

Conclusion

Having been explored for more than a century, Sterkfontein is one of the most important cave sites in the Cradle of Humankind, recognized by UNESCO as a World Heritage Site. It has yielded more than 700 hominin specimens and a large quantity of non-hominin fossils, including primates, bovids, suids, carnivores, rodents, and insectivores as well as pollen and wood. For historical reasons, part of the collections is curated by the Transvaal Museum (now called the Ditsong National Museum of Natural History in Pretoria), and another part is curated by the University of the Witwatersrand in Johannesburg. Through the efforts of Robert Broom, John Robinson, Bob Brain, Elizabeth Vrba, Phillip Tobias, Alun Hughes, Tim Partridge, Ron Clarke, Dominic Stratford, and many others, the Sterkfontein cave deposits have provided a wealth of paleoanthropological and paleoenvironmental data which continue to be explored in an effort to understand human evolution in the context of Plio-Pleistocene changes in climate, habitats, and faunal species diversity.

Acknowledgments

I thank Brian Richmond, Carol Ward, and Bernhard Zipfel for the opportunity to contribute this historical summary for the Sterkfontein workshop held in honor of the late Charlie Lockwood whom I greatly admired. I wish to express my appreciation to John Robinson for taking me to Sterkfontein in the early 1960s, when as a young schoolboy I was allowed to collect fossils for the Transvaal Museum from breccia dumps, thereby stimulating my interest in paleontology; to Bob Brain and Elizabeth Vrba for the opportunity to prepare Sterkfontein fossils at the Transvaal Museum when I was employed as a laboratory assistant at the Transvaal Museum in 1971; and to Professor Phillip Tobias for his enthusiastic encouragement when I was embarking on a paleontological career. I wish to thank the Lockwood family, the National Research Foundation, the Wenner Gren Foundation, the Ford Foundation, the Andrew Mellon Foundation, and the French Embassy in South Africa for supporting the Institute for Human Evolution of which I was Director from 2009 to 2013, prior to its merger with the Bernard Price Institute to establish the Evolutionary Studies Institute at the University of the Witwatersrand.

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2

The geological setting, cave formation, and stratigraphy of the fossil-bearing deposits at Sterkfontein Caves

Dominic Stratford

The importance of understanding the spatial and stratigraphic context of the caves and their interred huge faunal assemblages has not gone un-noticed, as is evident at Sterkfontein from stratigraphic interpretations spanning over 76 years (e.g., Cooke, 1938; Wilkinson, 1983; Partridge & Watt, 1991; Pickering & Kramers, 2010; Herries & Shaw, 2011; Stratford et al., 2014; Bruxelles et al., 2019). Indeed, stratigraphic research was one of the research priorities when Phillip Tobias started directing excavations in 1966 (Tobias & Hughes, 1969). In recent years, under the direction of Professor Clarke, and since the discovery of the StW 573 "Little Foot" skeleton, the need for more focused stratigraphic work has intensified, leading to several new stratigraphically focused works (Pickering & Kramers, 2010; Herries & Shaw 2011; Bruxelles et al., 2014; Stratford et al., 2014; Bruxelles et al., 2019). The impetus for a renewed dedication to stratigraphic research has grown from continuing controversy over a basic chronological framework for the deposits and specific hominin specimens, like StW 573 (e.g. Granger et al., 2015; Kramers & Dirks, 2017a,b; Stratford et al., 2017; Bruxelles et al., 2019). The lack of contextual and chronological control has been a major challenge regarding palaeoanthropological work at Sterkfontein. As the richest repository of *Australopithecus* fossils in the world, improvements in our understanding of context and chronology are essential if South African hominin evolutionary histories are going to be understood. This chapter summarizes the geological and geomorphological context of the Sterkfontein karst system, and gives a brief description of the current stratigraphic interpretation of the Sterkfontein deposits.

Sterkfontein geological and geomorphological context

The Sterkfontein cave system has formed within a stromatolitic dolomitic limestone (the Malmani Subgroup) deposited during the Late Archaean (2.5–2.6 billion years ago) (Eriksson et al., 2001). At this time, an inland sea occupied the Transvaal Basin, depositing the limestone and chert beds into five formations (Eriksson et al., 1993). Uplift of the Johannesburg Dome to the southeast and intracratonic sag to the north (Eriksson et al., 2001) of the Cradle of Humankind area resulted in the dipping of the dolomites to the north to northwest and the development of abundant vertical faulting. The planation of the landscape resulted in the subaerial exposure of all five dolomitic members in the cradle. The Sterkfontein Caves occupy the boundary between the two basal formations, the Oaktree and Monte Christo (Figure 2.1), which are differentiated based on relative chert bed abundance and thickness (Eriksson et al., 2006). The Oaktree Formation is poor in chert beds whereas the overlying Monte Christo Formation is relatively rich in chert beds. Dominant faults are orientated roughly east-west (a result of uplift to the south) and subordinate faults are orientated roughly north-south. The activity of the faults and compound fractures has led to a complex history of speleogenesis, allogenic infilling, and rekarstification.

There have been a number of different speleogenetic models proposed for the Sterkfontein Caves (e.g., Partridge, 1973; Wilkinson, 1973, 1983; Partridge and Watt, 1991; Martini et al., 2003; Klimchouk, 2007; Bruxelles

Dominic Stratford, *The geological setting, cave formation, and stratigraphy of the fossil-bearing deposits at Sterkfontein Caves*. In: *Hominin Postcranial Remains from Sterkfontein, South Africa, 1936–1995*. Edited by: Bernhard Zipfel, Brian G. Richmond, and Carol V. Ward, Oxford University Press (2020).
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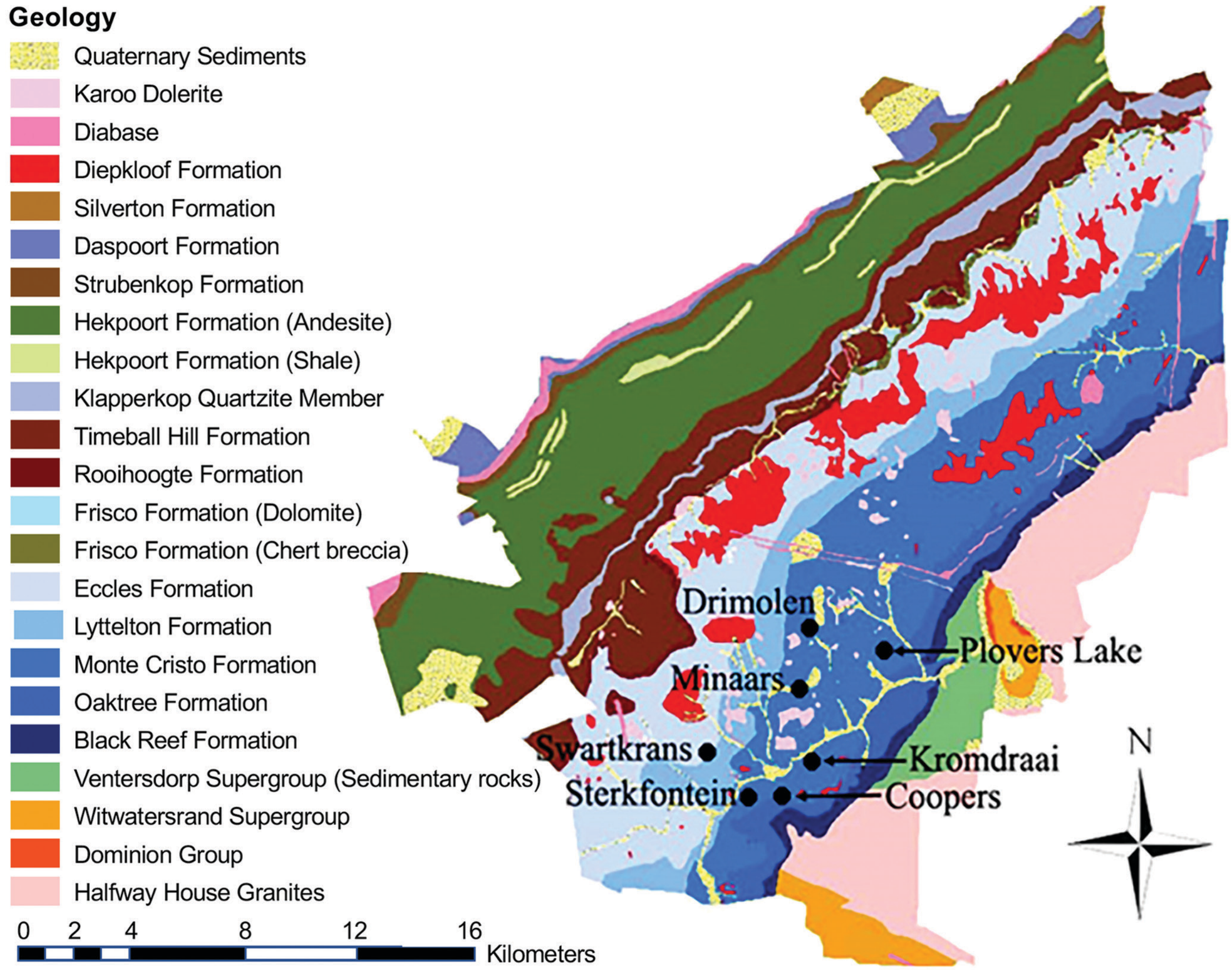

Figure 2.1 Geological map of the Cradle of Humankind (adjusted from Obbes, 2000).

et al., 2009; Dirks and Berger, 2013). Each model has specific implications on the timing of the opening of the caves to the landscape surface (i.e., the maximum age of the deposits) and the order in which deposition occurred underground (i.e., where the oldest sediment in the caves will be found). While the specific model is still to be determined with certainty, in the most basic terms, primary formation of the chambers and passages occurred under phreatic conditions (below the groundwater level) where dissolution was focused along vertical faults and unconformities in the dolomite. The influence of a near-static groundwater, low meteoric recharge (Martini et al., 2003), and fault distribution led to the formation of a complex network of tall, narrow, subparallel, and perpendicular passages. Major passages bear a general east-west trend relating to the dominant fault regime but show no hierarchical passage development relating to water flow direction. Larger passages and chambers formed through a combination of phreatic dissolution in areas where faults are particularly dense or intersect (Wilkinson, 1983), as well as vadose (above the groundwater level) collapse (Osborne, 2002) (e.g., Elephant Chamber; Figures 2.2, 2.3). A good example of this is the Name Chamber, Silberberg Grotto, and Milner Hall chamber complex near the center of the system where a particularly complex system of laterally and vertically articulated chambers and passages formed as a result of the close proximity of six faults (Figure 2.2; Wilkinson, 1983; Stratford et al., 2014).

The vadose cave network can be described as a two-level system comprising a lower, intact subterranean network of chambers and passages and an upper level, represented by a large, deroofed chamber exposed on the landscape surface, named the Fossil Cavern (Robinson, 1962). The same combination of passage and chamber forming factors resulted in the development of the 60m long, 25m wide east-west oriented Fossil Cavern whose north-south extent has been controlled by the major east-west trending faults. The exposed cave infills in the

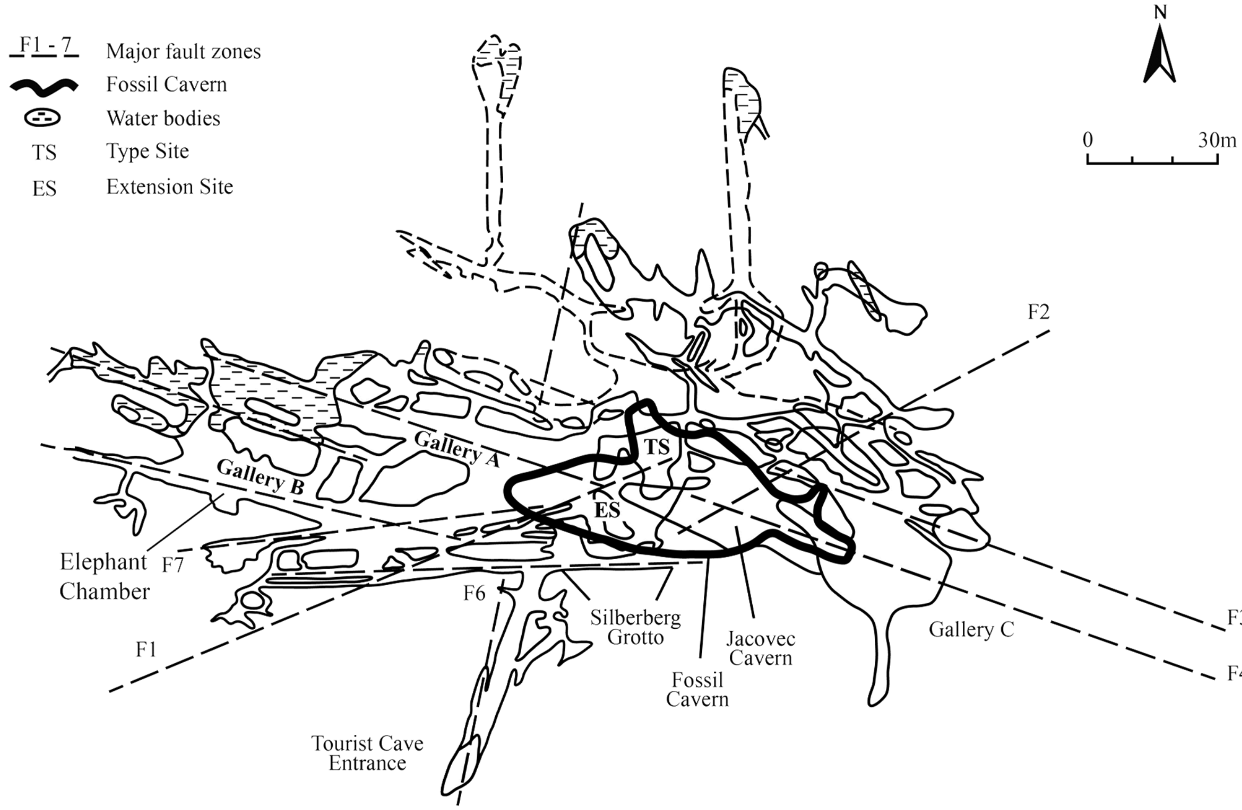

Figure 2.2 Geomorphological plan of the Sterkfontein Cave system. Major controlling faults are shown in relation to the upper level (Fossil Cavern; bold line) and the lower level (subterranean area; thin lines). Adjusted from Wilkinson (1983), with permission from Elsevier.

Fossil Cavern were the focus of extensive excavations carried out by Alun Hughes (Tobias and Hughes, 1969).

The opening of the caves to the landscape

The change of the cave to a vadose system and the associated removal of the buoyant support caused internal collapse throughout the network (e.g., Figure 2.3). This too was controlled by existing vertical faults in the dolomite, facilitating both an increase in passage height and an enlargement of chambers where fault systems and passage density are high. In some cases, this breakdown led to the development of openings to the surface, thereby allowing externally derived (allogenic) sediment to enter the caves. The timing of the opening of the caves in relation to the groundwater level has been debated (Partridge, 1978; Wilkinson, 1983, 1985; Partridge & Watt, 1991; Pickering & Kramers, 2010; Stratford et al., 2014; Bruxelles et al., 2019) and has significant implications for the maximum age of the Sterkfontein deposits (Wilkinson, 1973).

Most openings at Sterkfontein are represented by apertures high in the roof of passages or chambers. Where landscape erosion has intersected with the uppermost passages, or the roof has collapsed due to surface erosion, long deep gullies are opened. Many openings are very steep sided and represent a serious natural trap danger to animals, and thus “death trap” assemblages represent a common bone accumulation agent (Pickering, 1999; Kibii, 2004; Pickering et al., 2004a).

At Sterkfontein, vertical shafts have developed between upper and lower galleries (e.g., the Name Chamber), where a 12m vertical shaft articulates the western end of the overlying Fossil Cavern with the deeper Name Chamber (Clarke, 1994; Stratford et al., 2012). Connections also exist between the landscape surface and lower gallery—depositing sediments directly into the deepest areas of the caves (e.g., the Milner Hall). There are also examples of single chambers articulated to other chambers and the landscape through multiple conduits—creating coeval infilling processes from multiple sources (e.g., Milner Hall and the Jacovec Cavern). The chambers located on the southern boundary of the cave network (Silberberg Grotto, Fossil Cavern, Milner Hall, and Jacovec Cavern) (Figure 2.2), have particularly complex infilling histories directed by dynamic activity of openings near areas of high fault density (Wilkinson, 1973).

Figure 2.3 Sterkfontein Elephant Chamber. Note the sloping dolomite and interbedded chert (A) and evidence of the vadose collapse on the cave floor (B). View looking west along "Gallery B" in Figure 2.2. Railing in background is 1 m high and roof is 13 m high (Photo: D. Stratford).

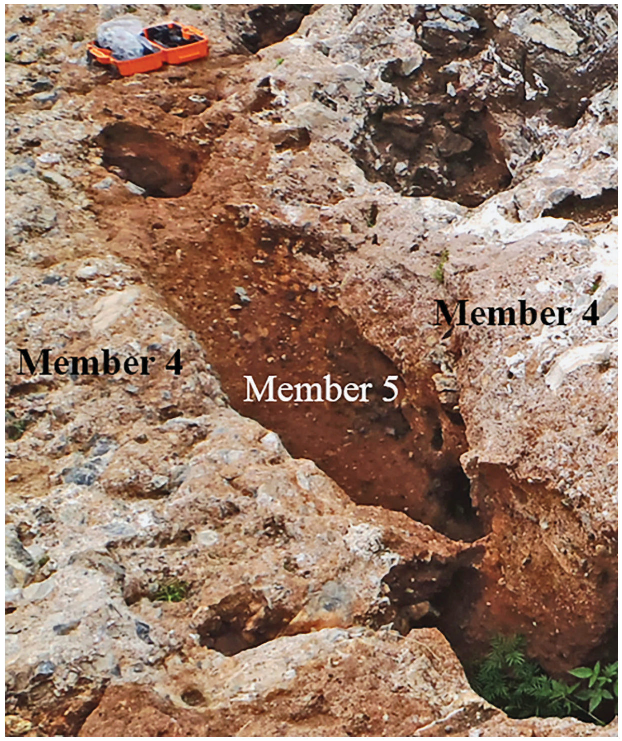

Figure 2.4 An image showing localized erosion of Member 4 stony gray breccia (upper right and lower left) that formed deep, vertical pockets subsequently filled with artefact-bearing red, matrix-supported sediments of Member 5 (center). When the pockets were excavated by Alun Hughes in the early 1970s, were filled with a mixture of decalcified Member 5 (Oldowan-bearing) and modern sediments. Total station box for scale (Photograph by L. Bruxelles with permission).

More recent openings, or reactivation of previous openings and faults, have caused localized erosion and rekarstification of more ancient breccias and led to collapses of undercut deposits, inverted stratigraphic sequences where new sediments are washed into cavities, and vertical deposit contacts. An excellent example of this is the western end of the surface exposed deposits of the Fossil Cavern where artefact-bearing Member 5 has filled into deep, vertical (east-west oriented) cavities in *Australopithecus*-bearing Member 4 (Figure 2.4). Opening shape (White, 2007), receptacle topography (Kidwell et al., 1986), and infilling sediment properties (Bertran et al., 1997; Bertran & Texier, 1999) all play dynamic but identifiable roles in the morphological development of the deposit and the accumulation, distribution, and preservation of archaeological and palaeontological material. These patterns are, however, greatly complicated by multigenerational diagenetic processes acting over long periods of time.

Most of the allogenic deposits in Sterkfontein have developed through colluvial sediment accumulation, forming characteristic talus cones (Martini et al., 2003) with varying contributions of flowing water. The formation of talus slope deposits (referred to as sediment gravity flows) involve intricate processes (e.g., Lowe, 1982; Postma, 1986; Major, 2000). These are complicated more so in karst environments where chemical and physical diagenesis is temporally and spatially highly variable (Karkanas et al., 2000; Goldberg and Sherwood, 2006).

Current stratigraphic interpretations

The complexities of Sterkfontein stratigraphy are aptly demonstrated by the number of interpretations and refinements (e.g., Cooke, 1938; Brain, 1958; Wilkinson, 1973; Partridge, 1978; Clarke, 1994; Pickering and Kramers, 2010; Herries & Shaw, 2011; Bruxelles et al., 2014; Stratford et al., 2014; Bruxelles et al., 2019; Table 2.1). Most works have focused on providing a macro-scale stratigraphic interpretation in an attempt to describe the entire site in the simplest chronological sequence possible (e.g., Partridge, 1978; Wilkinson, 1983; Partridge and Watt, 1991; Clarke, 2006; Pickering and Kramers, 2010) and some (e.g., Clarke, 1994a; Kuman and Clarke, 2000; Stratford et al., 2014; Bruxelles et al., 2014, 2019) have focused on specific deposits and areas. Generally, interpretations have proposed progressively more complex scenarios as researchers have tried to account for the dynamic nature of karst cave depositional processes. Macro-scale interpretations of the stratigraphy have tended to simplify the complex depositional processes acting within the caves.

The exception to this trend in increasingly intricate interpretations is the site-scale stratigraphic interpretation by Pickering and Kramers (2010), who attempt to simplify the member system through the re-examination of the Partridge and Watt (1991) sediment cores, combined with uranium-series dating of speleothems identified as bounding sedimentary units.

All recent works adopt the member system to classify bodies of sediments, a system applied to Sterkfontein by Partridge (1978). The established system of Partridge and Watt (1991) is described here for two reasons. First, because this book is focused on the hominin fossils, most readers will be familiar with the established member system nomenclature. Departure from that system here is likely to confuse more than clarify interpretations of hominin provenience. Second, debate is ongoing over many aspects of the deposits including extent and geometry, sediment flow direction, opening position, and deposit contact presence and morphology. This brief overview is not the stage for a detailed discussion of these debates but recently proposed adjustments are presented where pertinent. As dedicated stratigraphic investigations continue to challenge the Partridge and Watt (1991) model, however, it will need to be refined, adjusted, and reassessed.

The Sterkfontein deposits (incorporated within the "Sterkfontein Formation; SACS (1980)") are separated into six members, Member 1 to Member 6 (M1–M6) (Figure 2.5). The members are numbered in proposed chronological order of infilling. Members 2 and 3 were described from their exposures underground in the Silberberg Grotto, while Members 4, 5, and 6 are exposed on the landscape surface and are contained in the deroofed Fossil Cavern (Partridge, 1978). It should be noted that several fossiliferous deposits found at Sterkfontein are not incorporated into the member system. The sediments in the Jacovec Cavern are a good example of these more remote infillings of potentially significant age with as yet unknown stratigraphic correlations to the centrally located members (Partridge et al., 2003). Other remote fossiliferous deposits can be found in the extreme west and east of the site and in the adjacent Lincoln Cave.

Member 1 (M1) represents a mass of sediments accumulated prior to the opening of the caves to the surface, during early breakdown of the caves in the vadose period. These autogenic sediments are comprised of "occasionally voluminous blocks set in a dark brown manganiferous matrix" (Martini et al., 2003, p. 57).

Member 2 (M2) represents one of the earliest known fossil-bearing deposits to have accumulated in the caves. M2 sediments were originally described from exposures in the Silberberg Grotto (Partridge, 1978) and then further identified in sediment cores examined by Partridge and Watt (1991). The M2 sediments within the Silberberg Grotto contain two facies (Clarke, 2006; Bruxelles et al., 2014) and represent the proximal portion of a gradually accumulated extensive talus deposit that spread into the Milner Hall through multiple entrances (Stratford et al., 2014; Bruxelles et al., 2019). Famously, M2 has yielded the most complete single *Australopithecus* skeleton yet found (StW 573) (Clarke, 1998; Clarke, 2019). This discovery has

Table 2.1 Major stratigraphic works conducted at Sterkfontein.

Author	Year	Interpretations
Cooke	1938	Recognized the deposits as a single breccia body exposed at the surface and "lower cave."
Brain	1958	Recognized the deposits as a single breccia exposed in two underground areas.
Robinson	1962	Divided the breccias into "lower," "middle," and "upper." Underground sediments were a single breccia except for a collapse of "middle" breccia into the Name Chamber.
Wilkinson	1973	Proposed a "deep phreatic" karstification model from the continuous exposures of breccias through all depths of the caves.
Partridge	1978	Described the 6 Members of the "Sterkfontein Formation" from breccia exposures in the Silberberg Grotto and surface excavations. Silberberg Grotto is considered the base of the sequence.
Wilkinson	1983, 1985	Reinterpretation of the full depth of deposits in relation to the formation of the caves. Proposes the deepest deposits may be the oldest.
Partridge and Watt	1991	Supports Partridge's initial interpretation that the Silberberg Grotto contains the oldest sediments from descriptions of sediment cores.
Clarke	1994	Proposed three phases of formation in the M5 deposit and clarifies Robinson's (1962) hypothesis of collapsed M5 sediments in the Name Chamber.
Kuman and Clarke	2000	Refined M4 and M5 stratigraphy and proposed distribution of hominin specimens in relation to the M4/M5 boundary.
Clarke	2006	Proposed the erosion and collapse of the StW 573 torso and subsequent intrusion of speleothem in the resultant void.
Reynolds et al.	2007	Proposed the erosion and movement of fossils and artifacts from the western Member 5 areas through an articulating tunnel into the Lincoln Cave.

continued

Table 2.1 Continued

Author	Year	Interpretations
Ogola	2009	Proposed the continuation of M4 below the Member 5 west.
Pickering and Kramers	2010	Proposed a re-assignment of Member 3 as distal Member 4; suggests deepest deposits in the Milner Hall and Jacovec are younger than M2 in the Silberberg.
Herries and Shaw	2011	Generally proposed younger dates for the deposits and an intermediate age for the StW 53 infill between M4 and M5.
Stratford et al.	2012	Suggested a rapid and gradual re-working of the Oldowan-bearing M5 sediments into the Name Chamber and Milner Hall.
Stratford et al.	2014	Suggested M2 originally accumulated down to close to the current base level suggesting the current depth of the caves were formed when the caves opened to the surface.
Bruxelles et al.	2014	Proposed a refined sequence of depositional and erosional processes active in the taphonomy of StW 573 and identified instrusive flowstone characters in speleothems around the skeleton.

Author	Year	Major data resources
Cooke	1938	Faunal representation; sediment description
Brain	1958	Faunal representation; sediment description
Robinson	1962	Faunal and stone tool representation; sediment description
Wilkinson	1973	Cave geomorphology; deposit distribution
Partridge	1978	Sedimentological analysis of exposed breccias
Wilkinson	1983, 1985	Cave geomorphology; deposit distribution
Partridge and Watt	1991	Sedimentological analysis of sediment core samples
Clarke	1994	Sediment description and stone tool, hominin representation
Kuman and Clarke	2000	Hominin and stone tool representation and spatial distribution, sediment description
Clarke	2006	Faunal representation; taphonomy; deposit and sediment feature description
Reynolds et al.	2007	Artifact, hominin, faunal representation; U-Pb speleothem dates
Ogola	2009	Artifact, hominin and faunal representation; taphonomy
Pickering and Kramers	2010	U-Pb seriation of speleothem, longitudinal facies identification from exposed breccias and Partidge's 1989 sediment cores
Herries and Shaw	2011	Palaeomagnetic seriation of siltstones and associated speleothems; faunal and artifact representation and ESR dates
Stratford et al.	2012	Deposit and sediment description, macro- and micro-fauna and artifact a representation
Stratford et al.	2014	Sedimentological and geochemical analysis; artifact and fauna representation; taphonomy; spatial analysis of deposits
Bruxelles et al.	2014	Micromorphology, geochemistry, sedimentology

prompted a great deal of research into the stratigraphy and age of this deposit, the latest accounts of which can be found in Bruxelles et al., 2019. The StW 573 specimen represents the only hominin found within the M2 deposit and Clarke suggests the extraordinary preservation of the entire skeleton is due to the hominin's entrance into the cave close to the end of the M2 deposition (Clarke, 2006; Bruxelles et al., 2019; Clarke, 2019). Widespread post-depositional erosion of the calcified deposit caused the formation of extensive voids around and through the body of the skeleton, which were later filled with flowstones and associated siltstones (Bruxelles et al., 2014, 2019; Granger et al., 2015) making dating the specimen problematic (e.g., Partridge et al., 1999, 2003; Berger et al., 2002; Clarke, 2002; Walker et al., 2006, Pickering and Kramers, 2010; Pickering et al., 2011; Herries and Shaw, 2011; Granger et al., 2015; Kramers & Dirks, 2017a,b; Stratford et al., 2017; Bruxelles et al., 2019).

A covering flowstone (unit 3A in Partridge, 1978) subsequently formed on top of the M2 deposit, before M3 was deposited directly on top of the stalagmite body (Clarke, 2002; Martini et al., 2003). Mining of the

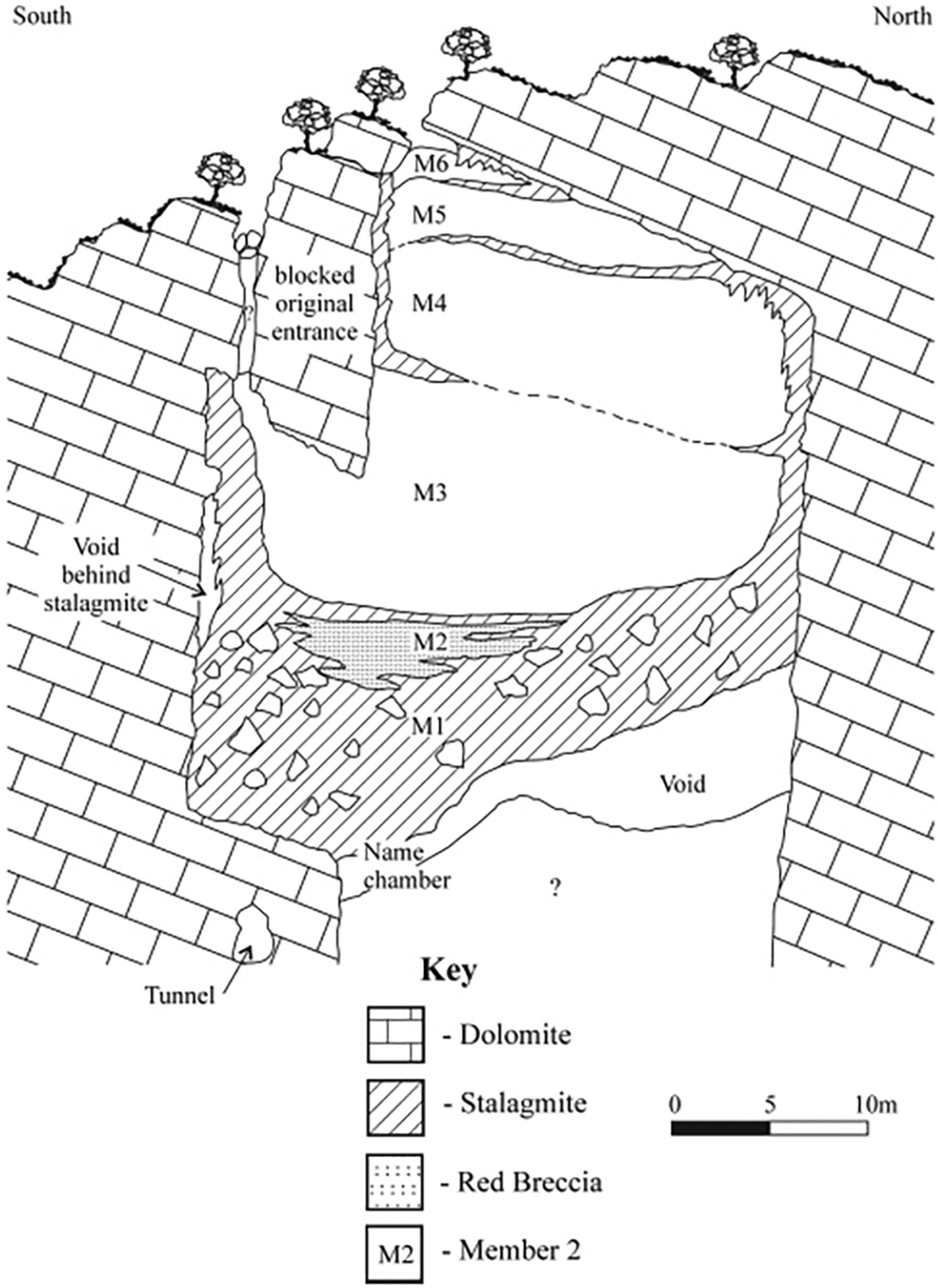

Figure 2.5 Composite stratigraphic column of the main sedimentary members described initially by Partridge (1978). Various adjustments have been made since the Partridge work but the major sediment body nomenclature remains the same (Clarke, 2006).

large 'boss' stalagmite that formed on top of Member 1 in the central eastern area of the Silberberg Grotto produced a large amount of fossiliferous rubble on the floor of the Silberberg Grotto. This rubble provided the first faunal evidence from the Silberberg Grotto M2 sediments (Broom, 1945; Tobias, 1979) and may also have included a component of M3 sediments (Pickering et al., 2004a).

Member 3 (M3) has been described as a colluvial talus deposit with potential inclusion of an aeolian component (Partridge, 1978). Partridge describes the deposit as approximately eight metres thick and underlying the eastern area of Member 4 (Partridge, 1978; Martini et al., 2003). The association of M3 and M4 (the oldest of the surface exposed deposits) is subject to some debate (Berger et al., 2002; Clarke, 2002, 2006; Pickering and Kramers, 2010; Bruxelles et al., 2019). Pickering and Kramers (2010) used deposit separating flowstones and longitudinal sediment facies identification in their reanalysis of Partridge's 1989 sediment core samples to propose that Member 3 represents a distal portion of the Member 4 deposit and not a distinct deposit as proposed by Partridge (1978) and then Partridge and Watt (1991). As yet, Member 3 has not been systematically sampled, and its associations with the other members and its sedimentological properties will remain unclear until a representative sampling of the sediments and fauna is carried out.

Member 4 (M4) is the largest of the currently sampled Sterkfontein members and is exposed across the majority of the surface excavation. The northern, western, and lateral boundaries of M4 are still unclear, and work by Ogola (2009) suggests that M4 may stretch west, across and underneath Member 5 (M5) (Figure 2.6). Given the size of the M4 deposit, it is not surprising that the deposit may have accumulated over 600,000 years (Pickering and Kramers, 2010; Herries and Shaw, 2011) and that a variety of taphonomic accumulation agents is present (Kibii, 2004; Pickering et al., 2004b). It is also not surprising that a great deal of variation is seen in the faunal assemblages and hominin morphology within the M4 deposit if it does indeed represent landscape, ecological, and hominin evolution over a period exceeding half a million years.

M4 represents the main repository of *Australopithecus*, and has yielded hundreds of hominin bones (MNI of 87; Pickering et al., 2004b) and a possible second species of *Australopithecus* (Clarke, 2008; Clarke, 2013; Clarke & Kuman, 2019). The deposit also contains the only fossil wood yet discovered in the Cradle of Humankind, providing a rare palaeoenvironmental perspective (Bamford, 1999). Although four 'beds' (3 clastic and 1 speleothemic) were identified within M4 (Partridge, 1978), the central, decalcified area of the was excavated as a single unit and so the extent and associations of Partridge's beds

Figure 2.6 The Sterkfontein type site and the spatial distribution of the M4, M5, and M6 breccias. From Kuman and Clarke (2000).

are unclear, making inferences of assemblage associations based on faunal and hominin evidence problematic. This poor stratigraphic resolution also means the infilling dynamics and internal morphology of the deposit are also unclear (Partridge and Watt, 1991; Wilkinson, 1983; Pickering and Kramers, 2010). A number of collapse events may have also evidently affected parts of the M4 deposit (Robinson, 1962; Partridge and Watt, 1991).

In the southern area of the extension site close to the preserved boundary between M4 and M5 is the breccia known as the StW 53 infill (Figure 2.6). This small area of the site has been heavily affected by solution cavities but yielded the StW 53 cranium (Hughes and Tobias, 1977). Originally, this area was associated with M5 and the stone tool assemblages nearby (Partridge, 1978), but Kuman and Clarke's (2000) refined stratigraphic work in the area of Member 5 demonstrates that the specimen was yielded from an irregular remnant of M4 cemented to the southern wall of the cave with M5 forming around it. Herries and Shaw (2011), who date the area to an intermediate period between M4 and M5, also support its distinction from M5.

Partial collapses and localized erosion of deposits are common, and the spaces created are often filled with sediments from distinct sources, as can be seen in the case of M5. At the western end of the surface excavation, M5 has formed unconformably against the side, and in pockets of, the eroded M4 deposit (Figure 2.4). Mixing of the two deposits (M4 and M5) was first recognized by Robinson (1962), who found blocks of M4 breccia within the M5 deposit. Unfortunately, the location of these blocks was not recorded. Due to the heavy-duty excavation methods used to extract the heavily calcified sediments, provenience data from past excavations is limited in resolution. Also, during the excavation of the western M4 and eastern M5 area, no records were kept of pertinent stratigraphic features. Given the irregularity of residual deposit contacts in this area, it is extremely difficult to predict the pre-excavation morphology of the deposits and their contacts. The M4 and M5 boundary is a good example of ongoing stratigraphic interpretative issues exacerbated by previous research and excavation methodologies. The problem of the M4/M5 boundary, from a paleoanthropological perspective, arises when attempting to provenience hominin fossils that have been excavated from the area and associate them to a specific deposit. In order to understand intra- or inter-species variation, solid stratigraphic associations are necessary and deserve dedicated studies (Karkanas, et al., 2000; Farrand, 2001).

Kuman and Clarke (2000) proposed a spatial distribution for the M4 and M5 deposits (Figure 2.6) based on faunal and artifactual contents. This does, however, assume that the samples are representative of the respective squares and that certain taxa are exclusive to certain deposits and have experienced minimal localized mixing. Kuman and Clarke (2000) have determined the hominin taxa based on morphology, not provenience (Clarke, pers. comm., 2010). Appendix 1 (this volume) presents the most recent member allocation for the hominin material (also see Kuman and Clarke, 2000). The reconstruction of previous deposit contacts from poorly provenienced fauna, without stratigraphic support, is problematic and as Harris (1979) points out, classification of deposit based on contents alone is risky, and deposit differentiation should be supported by a host of stratigraphic data. Unfortunately, much of this supportive data (bulk sediment samples, for instance) has been lost and so deposit classification through contents is one of the only options available. Dedicated studies utilizing micromorphology and geochemistry of deposit contact remnants and detailed 3D modeling with fabric analysis of exposed deposit profiles are currently underway to improve the stratigraphic resolution of this area.

Member 6 is the smallest of the Sterkfontein deposits and formed on top of the flowstone that capped M5 West filling the remainder of the cavern to the roof only at the western end of the site (Kuman and Clarke, 2000; Ogola, 2009). The underside of this breccia and a portion of the uppermost M5 East Acheulean deposit were eroded and filled with both Middle Stone-Age-bearing sediments and older reworked Acheulean artifacts and is classified as post-Member 6 (Kuman and Clarke, 2000; Ogola, 2009).

Summary

It has been over 70 years since the first stratigraphic interpretation of the deposits exposed in the Sterkfontein Caves by Basil Cooke (1938). Since this first attempt to describe the physical and chronological extent of the fossiliferous sediments exposed on the Sterkfontein hill and "lower cave," each work (Table 2.1) has proposed a more detailed account of the formation and physical and temporal extent of the interred deposits. It is not surprising that many of these studies have challenged previous hypotheses. The complex nature of the karst, coupled with the long deposit accumulation times and pervasive diagenetic processes, has obscured those proxies usually used to delineate depositional entities. In this manner, these processes have complicated attempts to understand the cultural, taxonomic, morphological, landscape, and environmental evolution at Sterkfontein. This complexity starts with the formation of the dolomites 2.6 billion years ago and its burial, early karstification, uplift, and fracturing over huge time scales. These processes have affected the size and shape of the cave system, as well as the position, nature, and timing of the opening to the landscape surface. Many of these processes, such as the process of cave formation, are still debated and have important implications for the age and distribution of the fossils. As the caves have gradually accumulated sediments, bones, and stone tools over hundreds of thousands of years, the dynamic processes of erosion, collapse, and redistribution have modified many aspects of the original assemblages. The six members making up the Sterkfontein Formation represent a macro-level chronostratigraphic reconstruction of the filling of the cave and are commonly differentiated by the presence or absence of certain fauna, stone tool types, and taphonomic agents; the identification of interbedding flowstones; or the description of basic sedimentological characters. The sequence starts with Member 1, formed before the cave was open, followed by the first allogenic sediment accumulation (Member 2) *c.* 3.76 million years ago (Granger et al., 2015). On top of Member 2, Member 3 and the *Australopithecus*-rich Member 4 accumulated within the relative confines of the Fossil Cavern. The Oldowan- and early Acheulean-bearing Member 5 formed around the heavily eroded M4 surface, followed by Member 6, filling the last space near the western roof and finally by Post-Member 6, a mix of younger and older reworked sediments filling an eroded pocket. With the exception of the flowstone that separates M2 and M3, deposit boundaries and their morphology are difficult to identify and correlate across 3D space from the available sediment cores and exposed profiles. Both sources of evidence are problematic from a theoretical and methodological perspective. Most of the deposit contacts are erosional and irregular, leading to difficulty in differentiating deposit and assemblage contact areas. Even more difficult is retrospectively modeling deposit contact morphology in areas that have been excavated. Characterizing taxonomic, morphological, or cultural variability from excavated deposits where no stratigraphy was recognized is difficult but is the subject of ongoing work. This is exactly the case within the important *Australopithecus*-bearing M4 and at its contact with the Oldowan-bearing M5.

As more recent dedicated stratigraphic research has identified complications inherent to cave sites, increasingly intricate site formation histories have been proposed. As Goldberg and Sherwood (2006) point out, the processes influencing the formation of fauna or artifact-bearing deposits do not often receive the attention they deserve, with the role of sediment accumulation being simplified, and perhaps overly simplified, in an effort to facilitate interpretations. Current research at Sterkfontein aims to apply new mutlidisciplinary stratigraphic analyses to new stratigraphically sensitive excavations, thereby providing high-resolution contextual support to recovered assemblages and attempts to increase our understanding of excavated deposit morphology through identification and study of sedimentary and stratigraphic features preserved in the remnants of previous excavations.

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