The Sterkfontein Caves after Eighty Years of Paleoanthropological Research: The Journey Continues

Dominic Justin Stratford

ABSTRACT The Sterkfontein Caves, the richest *Australopithecus*-bearing site in the world, occupies a crucial position in the history of South African scientific inquiry and has been pivotal to the development of the field of paleoanthropology. The site is physically and culturally embedded in the foundations of Johannesburg and is recognized as being one of the world's most important cultural heritage resources. The year 2016 was the eightieth anniversary of the discovery of the first adult *Australopithecus* by Robert Broom at Sterkfontein in 1936, a find that inspired three generations of paleoanthropological research throughout South Africa's Cradle of Humankind. Since this discovery, through fortune or dedicated research efforts, Sterkfontein has provided some of the most crucial clues to the complexities of our evolutionary past. In an auspicious year, 150 years since Robert Broom's birth, eighty years since Broom's discovery, and fifty years since Tobias's inauguration of a new Sterkfontein research program, this article presents a brief review of the history of research at Sterkfontein and its role in the development of the field of paleoanthropology. In light of this juncture, this article contributes two consolidated resources: a literature archive and a consolidated record of excavation-diary entries since 1967. [*Sterkfontein, Australopithecus, Cradle of Humankind, paleoanthropology, Robert Broom*]

RESUMEN Las cuevas de Sterkfontein, el sitio de mayor interés sobre los australopitecos en el mundo, ocupa una posición crucial en la historia de la investigación científica sudafricana y ha sido decisivo en el desarrollo del campo de la paleoantropología. El sitio está física y culturalmente empotrado en los cimientos de Johannesburgo y es reconocido por ser uno de los recursos del patrimonio cultural más importantes del mundo. El año 2016 fue el octavo aniversario del descubrimiento del primer adulto australopiteco por Robert Broom en Sterkfontein en 1936, un descubrimiento que inspiró tres generaciones de investigación paleoantropológica a través de la cuna de la humanidad de Sudáfrica. Desde este descubrimiento, por medio de la fortuna o esfuerzos investigativos dedicados, Sterkfontein ha proveído algunas de las claves más cruciales hacia las complejidades de nuestro pasado evolucionario. En un año propicio, 150 años desde el nacimiento de Robert Broom, 80 años desde el descubrimiento de Broom y 50 años desde la inauguración de Tobías de un nuevo programa de investigación de Sterkfontein, este artículo presenta una breve evaluación crítica de la historia de la investigación en Sterkfontein y su papel en el desarrollo de la paleoantropología. A la luz de esta coyuntura, este artículo contribuye con dos recursos consolidados: un archivo de literatura y un registro integrado de entradas del diario de excavación desde 1967. [*Sterkfontein, australopitecos, cuna de la humanidad, paleoantropología, Robert Broom*]

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This article presents a brief review of the history of the work, the discoveries, and the people involved in the research at the Sterkfontein Caves, and the implications of this work for the science of human origins. I have investigated the deep literature archives and excavation diaries for the historical insight that sets the stage for the research being conducted now. I started writing this article eighty years and a week after Robert Broom's discovery of the first adult *Australopithecus** fossil,[1] TM1511*, at the Sterkfontein Caves, just northwest of Johannesburg, South Africa (Figure 1). The find, made twelve years after the discovery of the Taung Child* by Raymond Dart, gave impetus to the speculation of Charles Darwin that Africa was likely the cradle of humankind. But this impetus would not gain international traction for almost another two decades. Two significant events helped turn the international academy's attention away from Europe and Asia. The first was the reclassification of Eugene Dubois's *Pithecanthropus erectus** and *Sinanthropus pekinensis** into *Homo erectus** by Ernst Mayr in 1950 (Mayr 1950), aptly demonstrating that despite Eugene Dubois's greatest efforts to place "Java Man" at the junction of ape and human, it was likely to be closer to human than ape. The second significant event was the exposure of the Piltdown Man as a hoax in 1953 (Stringer 2012).

The then-called "ape-man" fossils discovered by Broom in the early years of research at the Sterkfontein Caves lie firmly at the foundations of the science of paleoanthropology and are tightly ingrained within South African cultural heritage and intellectual identity. Over the last eighty years, Sterkfontein has continued to produce remarkable fossils of both hominids* and the diverse range of fauna that lived on the landscape over the last 3.67 million years (Ma).[2] The Sterkfontein evolutionary record is not limited to fossils but also documents the rich development of stone tool technology (Kuman 1994a, 1994b, 1996, 1998, 2007) from the Oldowan to Middle Stone Age over a period of two million years (Granger et al. 2015). It is one of the only sites in the world that documents such a long sequence of overlapping biological and technological evolution.

Reviews of Sterkfontein research have focused on very specific aspects—like stratigraphy (Clarke 2006), excavation (Clarke 2012), *Australopithecus* at Sterkfontein (Clarke 2013), and geomorphology (Stratford 2017)—or presented a dedicated distillation of paleoanthropological data (e.g., Reynolds and Kibii 2011). This article takes the opportunity afforded by the 150-year anniversary of Robert Broom's birth, the eightieth year since his discovery of TM1511, and the fiftieth year since Tobias's inauguration of a new Sterkfontein research program to consider the contribution of Sterkfontein with reference to the prevailing political and paleoanthropological environment. My specific interests are in how previous research processes affect how we work at the site today and how we understand, reconcile, and carry forward the rich Sterkfontein record in all its forms. To this end, I contribute two consolidated resources that are increasingly important as we press forward with research at Sterkfontein: (1) a searchable literature archive of over 350 key references spanning 120 years (presented in several formats) and (2) a searchable archive of excavation-diary entries since 1967. Neither has been previously compiled into an easily accessible resource.

1936: "IS THIS WHAT YOU ARE AFTER?"

Every major fossil discovery in the UNESCO World Heritage Site called the Cradle of Humankind (hereafter Cradle) is integrally linked to the birth and industrialization of Johannesburg. The calcium carbonate deposits that form within the karst caves of the area as stalagmites, stalactites, and flowstones (speleothems*) (referred to by Broom as "dripstones") were essential to the physical and economic development of Johannesburg and were used in industrial and commercial enterprises ranging from the smelting of gold to the making of cement. Within the Cradle, mining of large quantities of calcium carbonate began as early as the 1890s and continued as late as 1950 at Swartkrans (Figure 1) (Robinson 1952).

The gold-mining industry, on which Johannesburg was primarily built, played a central role in the development not only of formalized scientific inquiry in South Africa but also of territorial, cultural, economic, and political segregation in Johannesburg and the Cradle area (Bonner 2007). The mining industry provided financial support for the establishment of a formal university in Johannesburg in 1922, the University of the Witwatersrand—curators of the majority of Sterkfontein's fossil material. Leading up to the beginning of the university, the dramatic increase in geologists and geology students also inspired the founding of the Geological Society of South Africa (GSSA) in 1895, whose members would be some of the first to explore the caves of Cradle and document the first fossils at the site of Kromdraai (Figure 1) (Tobias 1973, 2007).

As Robinson pointed out, "according to South African law, commercial interests take precedence over scientific ones in matters of this sort" (Robinson 1952, 4), and so Raymond Dart's students T. Jones, H. le Riche, and G. W. H. Schepers, together with Broom, Robinson, and local curio hunters, were left to scavenge fossils from the mining dumps. It is in these dumps, which are found all over the Cradle, that many significant fossil discoveries have been made over the years, including TM1511 (Broom 1936a), TM1517 (Broom 1938), GDA-1* and GDA-2 (Menter et al. 1999), MH1* (Berger et al. 2010), and StW* 573 ("Little Foot") (Clarke 1998)—the most complete *Australopithecus* skeleton yet found.

The removal of the calcium deposits, usually through blasting with dynamite, exacted benefits and drawbacks that are still being felt today. Benefits include exposure of fossiliferous deposits, opening entrances to underground chambers, and dumping large quantities of fossiliferous sediment on the landscape surface as spoil heaps (dumps) (e.g., fossils found recently within mining spoil underground [Stratford et al. 2016a]). The drawbacks include the destruction of

TABLE 1. *Definitions of Customary Paleoanthropological Terms and Hominid Species Names*

Term	Definition
Australopithecus	Genus named by Raymond Dart in 1925 and based the juvenile skull recovered from Taung, South Africa
Australopithecus africanus	Named by Raymond Dart based on the juvenile skull recovered from Taung, South Africa, in 1924
Australopithecus prometheus	Species named by Raymond Dart based on specimens discovered at the site of Makapansgat, South Africa, in 1947. Later absorbed into *Australopithecus africanus* but recognized as a distinct taxon by Clarke at Sterkfontein
Breccia	General term used to describe a calcified or decalcified cave infill. Note: This term does not follow the geological definition of a breccia
GD	Specimen number prefix given to hominid fossils found at the site of Gondolin
Hominid	In this article, "hominid" refers to "all species on the human side of the human/chimpanzee phylogenetic split" (White et al. 2015, 4877) (i.e., A*rdipithecus, Australopithecus, Paranthropus,* and *Homo*)
Homo erectus	Named by Ernst Meyr in 1950; a species of fossil hominid appearing at about 1.9 Ma and found across Eurasia and Africa
Member 4	Major stratigraphic unit of the "Sterkfontein Formation" and the richest *Australopithecus*-bearing deposit at Sterkfontein
MH	Specimen number prefix given to hominid fossils found at the site of Malapa
Paranthropus	Genus of a robust hominid named by Robert Broom after the discovery of TM1517 at Kromdraai in 1938
Pithecanthropus erectus	Originally named *Anthropithecus erectus* by Eugene Dubois in the 1894 publication of his discoveries in Java, later absorbed into *Homo erectus*
Plesianthropus	Genus named by Robert Broom from early finds at Sterkfontein, later absorbed into *Australopithecus* by Robinson
Pliocene	Geological epoch extending from 5.333 to 2.58 Ma
Plio-Pleistocene	Geological time period at the boundary of the Pliocene and Pleistocene epochs
Sinanthropus pekinensis	Named by Davidson Black based on fossils discovered at the site of Zhoukoudian, China
Speleothem	General term for different forms of precipitated calcium carbonate developed in a cave environment
StS 5	Popularly known as "Mrs Ples," a specimen discovered by Robert Broom in 1947 at Sterkfontein and named *Plesianthropus transvaalensis*, later absorbed into *Australopithecus africanus*
StW	Specimen number prefix given to hominid fossils found at Sterkfontein after 1966
Taphonomy	Field of study conceived by Efremov in 1940 that examines postmortem processes of bone and plant modification
Taung Child	Juvenile skull and brain endocast discovered by Raymond Dart in 1947 and the type specimen of *Australopithecus africanus*

fossils through multiple aspects of the mining process, creation of extensive and widespread dumps of mixed sediments, general disregard for fossil remains, and selling and gifting of fossils to tourists and curio collectors (Broom 1949).

The story of the discovery of TM1511 at Sterkfontein involves several important figures in South African history. It was Raymond Dart, discoverer of the famous Taung Child and type specimen of *Australopithecus africanus** (Dart 1925), who petitioned General J. C. Smuts and President J. H. Hofmeyr to support Broom's return to South Africa in 1934. Smuts's consistent personal and financial support of Broom, Dart, and South Africa's early archaeologists is particularly interesting in light of South Africa's increasingly segregationist political ideals at the time and an educational environment in which teaching evolution was banned. Bonner (2007, 204–5) explores this interesting relationship and writes:

> In 1936, in another paradoxical synchronicity, Smuts celebrated Robert Broom's hominid find at Sterkfontein, which confirmed Dart's earlier claims for the Taung Skull, while supporting the Hertzog Bills, which finally elaborated the policy of segregation. On the one hand Smuts was a prime architect of the white supremacist system of segregation which asserted the inferiority of blacks.[3] On the other hand, he supported the view that the human race had evolved in South Africa and not in "civilised" Europe or Asia.

Through Smuts's drive to establish "Western" science in South Africa, which he considered a pillar of a civilized

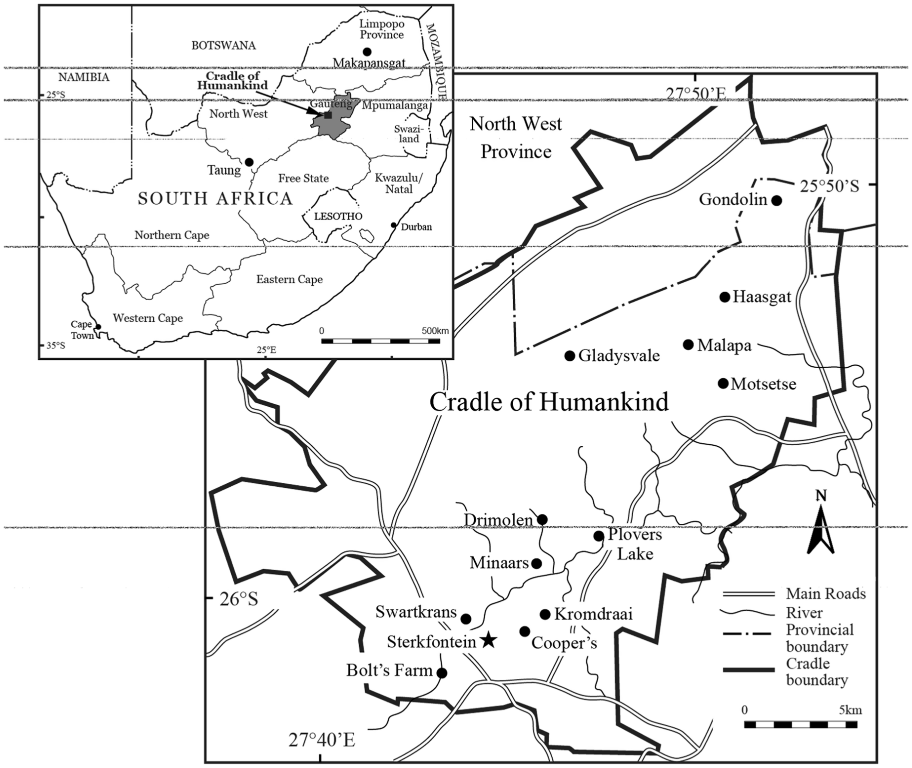

FIGURE 1. *The location of the Sterkfontein Caves, the Cradle of Humankind, and key sites mentioned in the text. (Adjusted after Stratford et al. 2016a)*

nation (Bonner 2007), influential support was given to Dart and Broom and their early projects. Later, the apartheid government (from 1948) would endorse the doctrines of the Dutch Reform Church and withdraw support for archaeology and paleoanthropology. This was aptly demonstrated by the withdrawal of South Africa's offer to host the 2nd Pan-African Archaeological Association (PAA) in 1948, an organization established by Louis Leakey with Broom acting as vice president, and South Africa's withdrawal from UNESCO, despite being a founding member, in 1946. Public and financial support for paleosciences consequently deteriorated.

It was also Dart, and his discovery, that inspired students at the Anatomy Department of the University of the Witwatersrand to explore similar geological settings to that of the Lime Works at Taung for fossils (Figure 1). In 1935, Trevor Jones collected some of the first fossils for academic study from Sterkfontein. Jones's visit to the caves came forty years after bone-bearing cave sediments at Kromdraai had been reported in newspapers and at the early GSSA meetings by Draper (Malan 1959; Tobias 2007), and thirty-seven years after perhaps the first report of bones in the Sterkfontein Caves, which was recorded by an unknown member of a visiting group from the Marist Brothers School in Johannesburg in 1898 (Un Frère Marist 1898).

A year after Jones's visit, le Riche and Schepers also made the trip to Sterkfontein and encouraged Broom to visit the site with them. In 1936, Broom, who was seventy, had recently been employed at the Transvaal Museum in Pretoria with the endorsement of Smuts. On August 8, Broom, le Riche, and Schepers visited the Sterkfontein site, which was being quarried under the supervision of G. W. Barlow, who, coincidentally, had been working at the Lime Works at Taung when the famous skull was discovered. Broom asked Barlow if he'd look out for anything similar to the Taung skull. On a visit eight days later, Broom was handed "two-thirds of a beautiful fossil brain cast" (Broom 1949, 21) and famously was asked "Is this what you are after?" A search of the nearby exposed sediments revealed the *in situ* impression of the top of the skull from an area to be named the "Type Site" (Figure 2). Initially, Broom named this specimen *Australopithecus transvaalensis*.

The discovery, published in *Nature* and the *Illustrated London News* in the same year (Broom 1936a, 1936b), initiated eighty years of scientific exploitation of Sterkfontein and started a long, complex, and often contentious relationship among the Cradle caves, landowners, local communities, excavators, fossil preparators, research assistants, local and international scientists, and the regulatory departments in various guises. Broom himself held a robust and published contempt for the Historical Monuments Commission, an organization established by Smuts (e.g., Broom 1949). The shift from commercial to intellectual exploitation was not always clear in terms of the methods of "excavation" or the role of the local community in the work.

Over the next three years, Broom and his assistant, Robinson, collected many craniodental specimens from Sterkfontein, even as mining continued (Broom 1939).

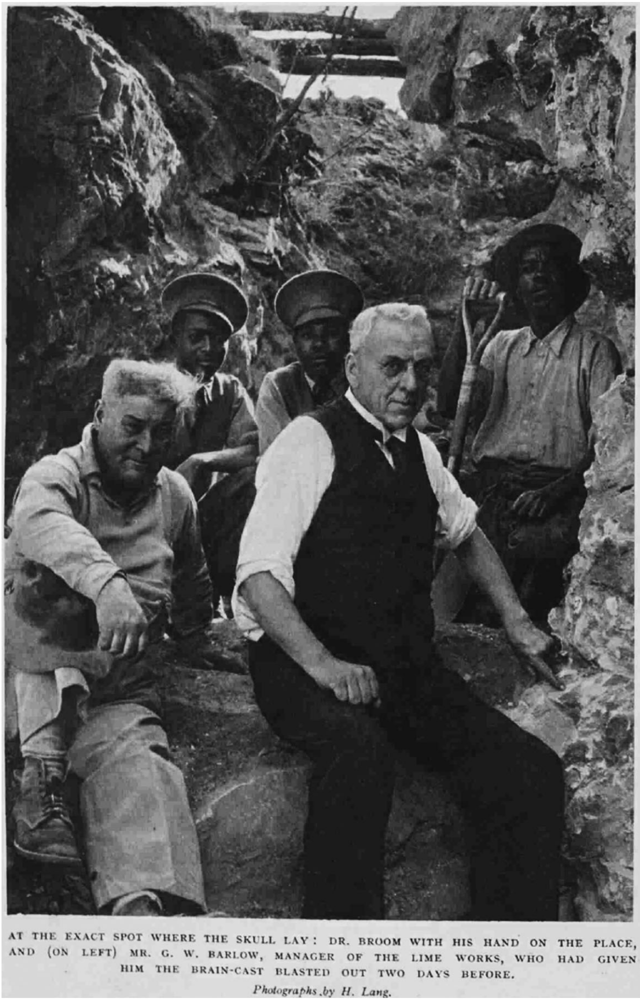

FIGURE 2. *Robert Broom at the site of the discovery of TM1511 next to quarry supervisor Barlow (Broom 1936b). (Photograph courtesy of the British Newspaper Archive; brightness and contrast adjusted from digital scan of original)*

Within this assemblage, Broom recognized smaller female and larger male hominids with a brain different enough from Dart's Taung specimen to place them into a new genus, *Plesianthropus**. Though criticism continued from the international academe, Broom's discoveries began to draw support from scholars who would visit South African to study the fossil assemblages (e.g., Gregory and Hellman 1939, 1940).

Soon after WWII, Broom and Schepers (1946) published a compilation of data on the Australopithicinae, the first of numerous major works over the next twenty years that would see many adjustments and reassessments of the taxonomy, phylogeny, and chronology of the South African and Eurasian assemblages (e.g., Broom 1949, 1950; Clark 1950; Mayr 1950; Robinson 1954a, 1966). Much of this explosion of taxonomic attention was due to the particularly productive year of 1947. Between May and August 1947, Sterkfontein produced an almost complete cranium (StS 5*) (Broom 1947), a large and nearly complete lower jaw (Broom and Robinson 1947a), and the first partial skeleton (StS 14) of *Plesianthropus* (Broom and Robinson 1947b). At the site of Makapansgat, Dart identified another species, *Australopithecus prometheus** (Dart 1948a, 1948b, 1948c).

Adding further confusion, Shaw (1939) published in *Nature* an isolated tooth from a cave "midway between the sites where Broom discovered the remains of *Plesianthropus* and *Paranthropus*" (Shaw 1940, 145), and suggested it may represent a different but "contemporary of *Plesianthropus* and *Paranthropus**" (155). To the broader scientific community, this seemed like a daringly rapid proliferation of hominid species from South Africa, as evidenced by a letter sent to Broom by Julian Huxley advising caution (Broom 1949). Importantly, the period of broader scientific consideration inspired by these finds resulted in the sinking of Broom's *Plesianthropus* into *Australopithecus* by Robinson (Robinson 1954a, 1954b, 1956, 1961),[4] who would then go on to absorb *Australopithecus* into *Homo*, naming the South African *africanus* species *Homo africanus* (Robinson 1965, 1966, 1967).[5]

It is the size and diversity of the Sterkfontein hominid assemblage that played a major role in the evolution of our perspectives and sensitivities to hominid variation and diversity. The rapidly increasing fossil sample size required scientists to think about the nature of variation (e.g., Brace 1969; Broom and Robinson 1948; Tobias 1974), how variation is interpreted in taxonomy and phylogeny, and the role of other forms of evidence, like biostratigraphy (e.g., Broom 1950).

The discovery of the partial skeleton StS 14 in 1947 further complicated the picture by providing the first evidence of *Plesianthropus* stature and locomotive behavior, supporting the broader ideas of the sequence of bipedalism and encephalization proposed by Lamarck (1809), Haeckel (1868), and Darwin (1871) (for a review, see McHenry 1982). Broom describes the ilium of StS 14 (Broom and Robinson 1947b, 1950; Broom, Robinson, and Schepers 1950) as "essentially human, and very unlike the ilia of any known anthropoid or Old World monkey" (Broom and Robinson 1950, 490). As recognized by Broom (1950), different parts of the pelvis looked more or less human and, in some cases, displayed distinctive morphologies. This pertinently acknowledged intra-elemental morphological variation (referred to as mosaics) and recognition of complex evolutionary, functional, and developmental relationships between different parts of the body continues to be the subject of debate (e.g., DeSilva and Devlin 2012; Green and Gordon 2008; McHenry 1975; Susman and Creel 1979). Variability continues to cause difficulty when interpreting hominid functional repertoires, hominid taxonomic attribution, and phylogenetic relationships (e.g., Clarke and Tobias 1995; and reanalysis by Haeusler and McHenry 2007; Kidd and Oxnard 2005; Kibii et al. 2011; Kivell et al. 2011; Lockwood and Tobias 2002; Tobias 2000).

Work with Leakey's collections in East Africa in 1947 (Findlay 1972) led Broom to propose that the "human line

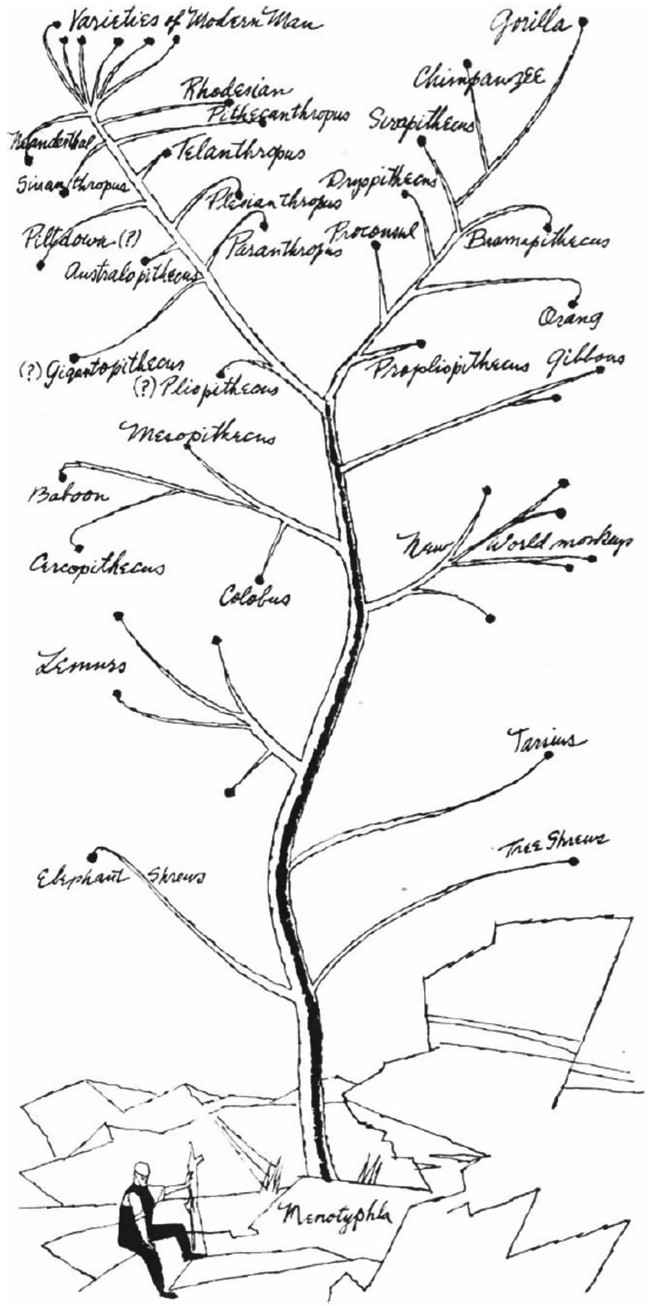

FIGURE 3. *Broom's primate family tree as imagined in 1949. Australopithecus, Plesianthropus, and Paranthropus lie halfway up the left-hand fork just below "Piltdown (?)" (Broom 1949).*

split off from the anthropoids at least as early as the Lower Oligocene, perhaps 25 million years ago, and that the nearest known type to man's remote ancestor is not a chimpanzee-like ape but the little fossil ape *Propliopithecus* of Egypt" (Broom 1949, 24; Figure 3). Although this isn't generally accepted today, Broom's South African hominid anatomical observations, taxonomic assessment, and phylogeny were astute but fundamentally hindered by a relatively small sample of fragmented fossils sourced from poorly provenanced and dated fossils.

1966: DUMPS, DIARIES, AND DIGGING

After an eight-year hiatus, during which the Swartkrans cave deposits were explored, Phillip Tobias initiated a new phase of research at Sterkfontein. His objectives were clear (Hughes and Tobias 1967): to focus on clarifying the extent of the breccias* by excavating the overburden (mixed surface rubble), to expand upon Robinson's early stratigraphic sequence, to "explore the possibilities of absolute dating on the site" (Tobias and Hughes 1969, 158), and not to prioritize the search for more hominids. The project included a survey of the geology, vegetation, topography, mine dumps, and surface exposures of the *in situ* cave infills (generally referred to as breccias) (Tobias and Hughes 1969). Several of these early reports were never published (e.g., geology and topography), including those that document the early planning phases of the excavations (Mason 1966) and the establishment of the main excavation grid (Watt 1969).

First, however, the new team would need to deal with the extensive mining dumps littering the Sterkfontein hill that had yielded fossil curios for many visitors (Figure 4). Along with abundant nonhominid fossils, remarkable finds still appear in these dumps, like missing teeth from the TM1511 cranium discovered from D18 (Clarke 2006). For Tobias and Hughes, it would be almost two years before the first hominid would be found on June 10, 1968, from Dump 13 (D13). StW 1 to 73 represent specimens that were recovered by Hughes and his team from dumps, with the exception of StW 13, 14, 53, and 71, which were discovered *in situ*. As useful as the isolated elements were for morphological analyses (e.g., Moggi-Cecchi, Grine, and Tobias 2006), the loss of provenance severely limited correlating these finds spatially and temporally.

The impact of this loss of context cannot be underestimated. In our efforts to glean all possible information from the fossil record, we tend to create comparative populations that represent potentially substantial differences in age (e.g., Lockwood and Tobias 2002). Interpreting intraspecies variability, functional repertoires, and sexual dimorphism across specimens representing a possible temporal range of over half a million years is highly problematic. The exception to this pattern was Dump 20, which was cleared from the Daylight Cave (Silberberg Grotto) in June 1978 and contained the foot and lower-limb fragments of Little Foot (Clarke and Tobias 1995), the provenance of which could be constrained to at least the same chamber.

Hughes started removing overburden and exposing underlying breccias to help identify the extent of the undisturbed sediments and clarify the stratigraphic associations of the stone tools recognized by Brain in 1956 and excavated from the "extension site" by Mason in 1957 (Robinson and Mason 1957)—an area later named Member 5 (Partridge 1978). Hughes progressed gradually east, removing the soft sediments that occupied cavities in the dolomite and hard breccia, and in 1976 discovered the highly fragmented partial cranium StW 53 (Hughes and

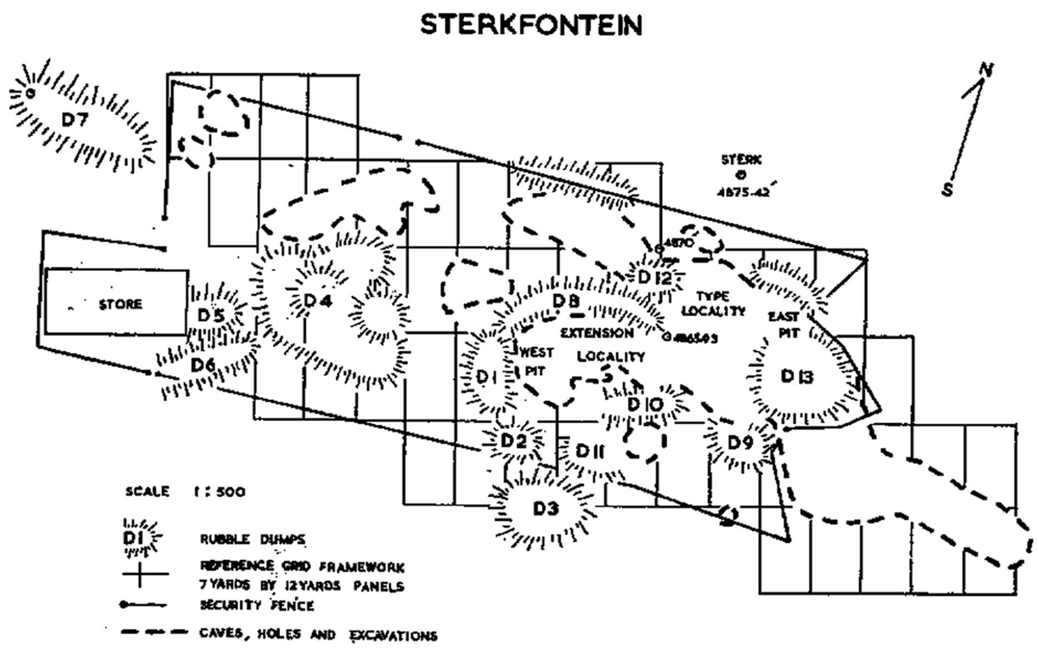

FIGURE 4. *Map of the mine dumps in 1966. The "Type Site" mentioned in the text is labeled here "TYPE LOCALITY." Dump 18 (D18), which has yielded an abundance of Australopithecus fossils, is located just northwest of Dump 13 (D13) and the "EAST PIT" (Tobias and Hughes 1969).*

FIGURE 5. *Excavations of the Sterkfontein Member 4* deposits circa 1987. Notice the large horizontal squares being excavated into the northern wall. Also notice in the background the commemorative plaque identifying the location of the Mrs Ples skull, discovered in 1947. Simon Sekowe, site foreman, sits on the deposit in the foreground; Nkwane Molefe stands at the base of the excavation; and Mishaka Maghotokha stands in the background. (Photograph by Alun Hughes and courtesy of Ron Clarke; image brightness, contrast, and color adjusted from scan of original photograph) [This figure appears in color in the online issue]*

Tobias 1977). Two reconstructions (Clarke 1985; Curnoe and Tobias 2006) and two proposed stratigraphic associations (Clarke 1994b; Hughes and Tobias 1977; Kuman and Clarke 2000) have led to debate concerning the taxonomy of this specimen (e.g., Clarke 2013, 2017; Curnoe 2002; Curnoe and Tobias 2006; Ferguson 1989; Williams, Schroeder, and Ackerman 2012). By 1982, Hughes reached the central part of the site and encountered a large volume of sediments that had decalcified (Figure 5). Hughes's excavations here yielded over six hundred hominid specimens, including the partial skeleton StW 431 (Toussaint et al. 2003; Figure 6).

1997: PIECING "LITTLE FOOT" TOGETHER

The remarkable story of the discovery of Little Foot involves three independent narratives, taking millions of years to reach their culmination on July 3, 1997. The first story begins with the death of a small *Australopithecus* on the Sterkfontein landscape 3.67 Ma (Granger et al. 2015).[6] Its fate would be to fall thirty meters onto a slope of rocks and bones of other primates in the depths of the Silberberg Grotto. The details of Little Foot's death are important because they led to its incredible preservation in a context where generally only isolated, broken bones survive (Bruxelles et al. 2014).[7] Based on reconstructions of the paleoenvironment and context of Little Foot (Bruxelles et al. 2014; Pickering, Clarke, and Heaton 2004a), it has been proposed that Little Foot fell into the Silberberg Grotto through a small opening in the roof of the chamber. Over time, this opening began to close and the deposition of sediments into that area of the cave began gradually ceasing. As Little Foot was slowly buried, the corpse mummified, creating a wrap of dried skin holding the bones together (Clarke 2007).

The next event in Little Foot's chronicle began when the activity of the lime miners unknowingly disturbed the skeleton. Extensive blasting took place within the Silberberg, but, incredibly, the blasting stopped after having just removed the feet and distal tibiae from the skeleton. These bones were removed from the Silberberg Grotto and labeled Dump 20 (D20).

The last piece of Little Foot's narrative is the story of discovery and excavation by Clarke. Excavation of a sample

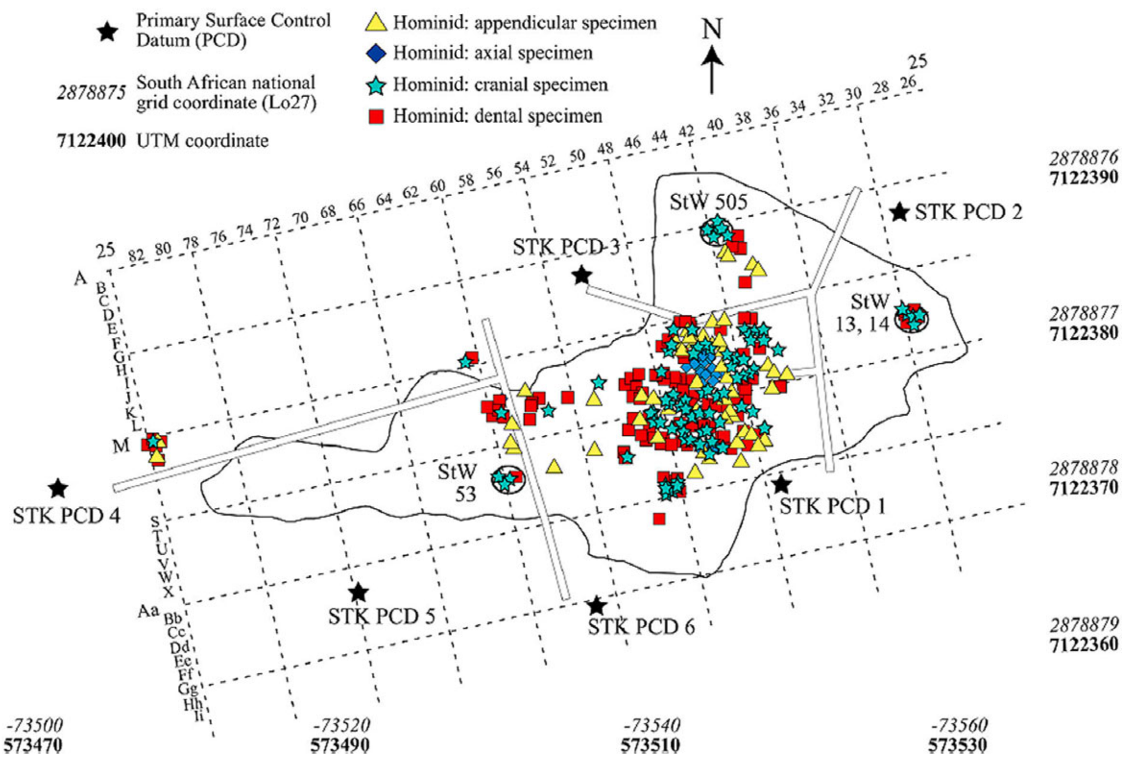

FIGURE 6. *Distribution of Sterkfontein hominid fossils excavated from in situ deposits between 1971 and 1993 under the supervision of Hughes. Specimens are classified by significant body part (appendicular, axial, cranial, and dental) (Stratford, Merlo, and Brown 2016b). Three spatial control systems are presented. The grid superimposed over the excavation site is the grid system of squares and numbers established by Watt in 1969. The provenance of all fossils recovered by Hughes and Clarke has been documented using this system. A new framework encompassing the whole cave system and landscape was established by Stratford, Merlo, and Brown (2016b) and uses both the UTM (Universal Transverse Mercator) global reference and the South African Lo27 system. PCDs (Primary Control Datums) are securely spatially established datums used to anchor all other reference datums (Stratford, Merlo, and Brown 2016b). [This figure appears in color in the online issue]*

of fossils from the eastern end of the Silberberg Grotto in 1992 initiated by Tobias yielded a large number of carnivore and cercopithecoid fossils. Clarke, interested by the scarcity of bovid fossils represented in this sample, started to explore part of the collection stored at Sterkfontein in 1994. It was in these boxes that Clarke found the first pieces of the displaced but articulating StW 573 foot bones (Clarke 1998; Clarke and Tobias 1995; Dugard 1995). Upon further investigation, more articulating foot bones were found in 1997 by Clarke at Wits University. The presence of several bones of the same foot and leg suggested to Clarke that more of the skeleton must be present, as these elements are a rarity in the hominid fossil record. Further examination of boxes labeled “D20 bovid tibiae and bovid humeri” yielded even more articulating bones. By mid-1997, Clarke had twelve bones from both feet and legs of what he proposed must be a complete skeleton still to be discovered in the cave.

The discovery of the skeleton would come on July 3, 1997, by Nkwane Molefe and Stephen Motsumi. The pair was tasked with finding the cleanly broken shaft of the right distal tibia. Using handheld lamps, the two searched the walls, floor, and ceiling of the Silberberg Grotto. Two days later, they found where the bones had been blasted off over a half-century before (Clarke 1998). Since then, Clarke has devoted his attention to the excavation and reconstruction of the skeleton.

By 2008, Clarke had exposed enough of the cranium of Little Foot to tentatively propose that StW 573, along with other specimens from Member 4, belonged to what he had previously recognized as a second species of hominid (Clarke 2013). Clarke argued that the second species coexisted with *Australopithecus africanus* during Member 4 times (Clarke 1988, 1989, 1990, 1994a, 1998) and that these specimens should be attributed to *Australopithecus prometheus* (Clarke 2008, 2013), a species first identified at Makapansgat (Dart 1948a; Tobias 1974). The implications of this proposal are that two *Australopithecus* species may have occupied broad areas of the South African landscape at the same time (Herries et al. 2013). Although these species appear together in Sterkfontein Member 4, the nature of their coexistence is not accessible without much greater chronological and stratigraphic control.

Variation within *Australopithecus* had been acknowledged since its initial discovery. Broom (1938) attributed some of this variation to sexual dimorphism but still distinguished enough differences between the Sterkfontein specimens and the Taung Child to classify these hominids as a distinct species of the same genus—*Australopithecus transvaalensis* and *Australopithecus africanus,* respectively. Then, after discovering at Sterkfontein a child's mandibular symphysis that he considered different from the Taung Child's, Broom placed the Sterkfontein specimens into their own distinct genus, *Plesianthropus* (hence the nickname Mrs Ples). Since then, scientists have sought to investigate hominid variation and taxonomic diversity across the large hominid assemblage using a variety of qualitative and quantitative techniques (e.g., Ahern 1998; Fornai, Bookstein, and Weber 2015; Fornai et al. 2010; Harmon 2009; Kimble and Rak 1993; Kimble and White 1988; Lockwood and Tobias 2002; Moggi-Cecchi, Grine, and Tobias 2006; Thackeray 2007; Williams, Schroeder, and Ackerman 2012; Wolpoff 1974).

This evidence has been interpreted differently across the field. Some support a second species (e.g., Fornai et al. 2010) or allude to a possible second species (e.g., Calcagno et al. 1997; Kimble and Rak 1993; Lockwood and Moggi-Cecchi 1998; Lockwood and Tobias 2002; Schwartz and Tattersall 2005). Some attribute variation to sexual dimorphism (e.g., Lockwood and Tobias 1999) or conclude that the differences fall within expected ranges of species variation and multiple species are not identifiable (e.g., Fornai, Bookstein, and Weber 2015; Grine 2013; Harmon 2009; Moggi-Cecchi, Grine, and Tobias 2006; Wood and Richmond 2000). Others interpret the variation as reflecting evolution within *Australopithecus* (e.g., Moggi-Cecchi, Tobias, and Beynon 1998). Debate on this subject will continue as new methods of analysis and new fossils are discovered, but it is interesting to note that those who have alluded to two possible species at Sterkfontein often haven't agreed about which specimens should belong to which group (Grine 2013).

The age of Little Foot has been the subject of extensive and continued debate over the last twenty years, and efforts to date the specimen have drawn on a range of absolute and relative dating techniques, stratigraphy, and taphonomy*. The result has been proposals ranging from 1.07–4.17 Ma (Berger, Lecruz, and De Ruiter 2002; Clarke 2002; Clarke and Tobias 1995; Granger et al. 2015; Herries and Shaw 2011; Kramers and Dirks 2017a, 2017b; McKee 1996; Partridge et al. 1999, 2003; Pickering and Kramers 2010; Stratford et al. 2017; Tobias and Clarke 1996; Walker, Cliff, and Latham 2006). This debate clearly demonstrates the difficulties inherent in dating cave deposits. Although I do not elaborate on the arguments here, the issues are discussed in Partridge et al. (2005), and some of the complexity is demonstrated in Bruxelles et al. (2014). With detailed stratigraphic support and a well-fit cosmogenic burial isochron, Granger et al. (2015) recently proposed 3.67 Ma as the age of the skeleton (see Kramers and Dirks [2017a, 2017b] and Stratford et al. [2017] for discussions of this date).

LEARNING FROM THE PAST

The new phase of work implemented by Tobias in 1966 established new standards of documentation at Sterkfontein. These included field diaries recording work activities and fossil and artifact provenance, Tobias's excavation reports, and reports to the National Monuments Council (to be succeeded by the South African Heritage Resource Agency, or SAHRA). We still rely heavily on these as we reprocess and reexamine the collections of 1966–1991. In addition to the excavation reports, National Monuments Council reports, and personal diaries of Tobias that require archiving, the daily excavation diaries that have been kept since 1967 provide an interesting additional resource that can be integrated into our GIS framework. I present the 1967–2013 diaries as a searchable digital resource in the supplementary information to this article (see supplementary information online).[8] It should be noted that between these documents, there are some conflicting accounts of the activities on site.

As an example of how the daily diaries can be used in our ongoing work, we can model at a daily resolution the placement and progress of excavations and reconstruct the division of work across the site, as dump processing and *in situ* digging were sometimes concurrent. As an observation, in the early years of Tobias's project, there are interesting trends when excavation and dump processing were conducted that may hint to some of the pressure to find hominid fossils despite the explicit goals set out at the beginning of the project (see above, Tobias and Hughes 1969). The dumps were the most productive aspect of the work at Sterkfontein for Tobias's new project, and the early, shallow excavations that started in 1972 were generally not productive as they worked through decalcified, mixed deposits in the western end of the site. Dumps continued to yield fossil hominid material and were processed concurrently with excavations in the mid-1970s and between 1976 and 1978. Dump 18, one of the most productive dumps for hominid fossils since processing began in 1969, received the most attention over these two years.

Another example, from an excavation perspective, is how remarkably consistent the depths of Hughes's excavated squares were. Hughes excavated in one-square-yard grids and twelve-inch "spit" levels, and started his excavations on the west side of the site and worked toward the east. In the western area, he encountered many dolomite pinnacles, which were buried by deposits. These are very irregular in shape and sometimes separated by less than six inches. In each of Hughes's squares across the site, he documented the removal of a full square and depth regardless of any hindrances. It is highly improbable that the same volume of sediment was removed from across these areas, so when we start to model potential relative densities of fossils in different areas for taphonomic and site-formation investigations, we must take this into account and approximate the "real" volume of removed sediment from each square. This can be done by modeling previous excavation-square grids onto 3-D laser scans of the exposed cave morphology.

There is a clear but gradual change in the information recorded in these diaries from 1973. In the beginning, additional notes were taken on what was found and from where. This practice gradually disappears through 1975, until the record becomes just about what was being excavated, developed, broken (processing the cemented sediments is called "breaking"), or sieved.

As paleoanthropology continues to move toward hyperspecialized fields and greater utilization of sophisticated quantitative techniques, it is increasingly important for paleoanthropologists to reflect on the work of earlier scientists who provide a long, diverse legacy of inquiry. At Sterkfontein, we have a large body of archival material relevant to both paleoanthropology and anthropology, documenting the lives of Broom, Robinson, Tobias, Hughes, and Clarke. We are only starting to manage this material, and it is very clear that dedicated conservation of the science's past (including accounts and histories of the fossil technicians, excavators, and developers) is an area that can be significantly improved. This includes the substantial body of scientific literature published since the earliest references to the caves in the 1890s and refers to the site and its diverse archaeological, paleontological, geological, environmental, and depositional history. Therefore, I present an introductory bibliography for Sterkfontein in various formats (see supplementary information to this article). This bibliography does not attempt to reference every article, book chapter, or textbook mentioning Sterkfontein but rather focuses on presenting the major primary research conducted on the site and its assemblages. This is not a definitive work but serves as a foundational resource to be expanded.

THE JOURNEY CONTINUES

There are two questions that I am asked more frequently than any others by tourists and researchers alike: "Is there anything left to find at Sterkfontein?" followed by "What are you looking for?"

Is there anything left to find? There are many areas of the Sterkfontein Cave system that remain either unexplored or only superficially sampled. One of the most intriguing unsampled deposits is the eight-meter-thick Member 3 (Partridge and Watt 1991), which stratigraphically occupies an interesting time between Little Foot, found in Member 2, and the wealth of *Australopithecus* fossils found in Member 4, dated to around 2.6 Ma (Herries and Shaw 2011; Herries et al. 2013; Pickering and Kramers 2010). During this intervening period, we may witness the evolution of more gracile forms of *Australopithecus* exemplified by Mrs Ples (female). The Sterkfontein system also includes the Lincoln Cave, which stretches almost one kilometer from the western end of Sterkfontein to the northeast. Although sampled (Reynolds, Clarke, and Kuman 2007; Reynolds et al. 2003), this cave contains large and unexplored fossiliferous deposits.

An additional valuable resource to be utilized for a wide range of studies is the large assemblages previously excavated by Broom and Hughes, which are curated at the Ditsong Museum of Natural History, Pretoria, and the University of the Witwatersrand, Johannesburg. Only a fraction of the nonhominid fossils from excavations has been studied (e.g., Elton 2001; Heaton 2006; Kibii 2004; O'Regan and Reynolds 2009; Monson et al. 2017; Pickering, Clarke, and Moggi-Cecchi 2004b; Vrba 1976, 1982, 1995;), and all are available for study through the repository curators. As a long-term project, we aim to integrate each fossil into a unified database, incorporating a range of spatial, metric, taxonomic, and taphonomic data.

What are you looking for? Anyone who has conducted fieldwork knows there is rarely a simple answer to this question. When I reply that we're looking for hominid fossils, stone tools, and associated fauna, the response is usually, "So, more of the same." Well, not exactly. Superficially, we're looking for more of the same, but our continued search intends to address two of the principle questions in paleosciences with greater control. The first focuses on the study of context and the clarification of the environmental and ecological pressures that played a crucial role in shaping the evolution of locomotive, dietary, and cultural behavior. The second focuses on morphological variation and its origins as well as their timing and phylogenetic implications. Both require control of space and time, and are improved with increased sample sizes. Sterkfontein provides a valuable resource to study evolution and hominid variation in a well-constrained geographical area over a two-million-year period, with an abundance of associated fossil fauna. The record we have, however, remains fragmentary. It is only through detailed multifaceted studies of unique specimens like Little Foot, instead of composite representatives, that we can start to investigate the development and implications of mosaic hominid morphologies through time.

So yes, we are looking for more of the same, but in the same way that astronomers are still looking up at the sky. Currently, the tools being utilized in the field and the laboratory on a growing and controlled fossil assemblage provide datasets that are incredibly detailed and nuanced so that every fossil adds color and depth to our picture of the past. To better control these datasets, we have developed a new, high-resolution geospatial framework at Sterkfontein (Stratford, Merlo, and Brown 2016b). As we find and explore fossiliferous and hominid-bearing deposits in deeper caverns (e.g., the Milner Hall, Jacovec Cavern, Lincoln Cave, Name Chamber), we aim to link these units stratigraphically and chronologically to the main surface-exposed deposits, like Member 4.

CONCLUSION

Over the last eighty years, Sterkfontein has consistently provided some of the most crucial clues to the complexities of our evolutionary past. Through fortune or dedicated research efforts, Sterkfontein has yielded fossils that have contributed significantly to the field of paleoanthropology

(Broom 1943). For example, a major criticism of Dart's Taung Child, and a source of the academy's skepticism, was the juvenile age of the individual (e.g., Hrdlička 1925). It was argued that the specimen's morphology would change significantly before adulthood and, as a result, its human-like facial morphology was simply a reflection of its juvenile state (for recent research, see McNulty, Frost, and Straight 2006). Broom recognized the necessity of an adult fossil *Australopithecus* discovery, and his discovery of TM1511 at Sterkfontein in 1936 vindicated Dart's earlier conclusions. Consideration of the evolution of bipedalism, locomotive behavior, and the order in which the early hominid body evolved would be assisted by the discovery of the partial skeleton StS 14 in 1947. Our current and far-from-complete understanding of *Australopithecus* variation and sexual dimorphism would be even more limited if the specimens excavated at Sterkfontein over the last eighty years were removed from the fossil record.

What is still needed at Sterkfontein, and to what I am dedicating my time, is placing the rich fossil hominid record into a more accurate environmental, ecological, depositional, taphonomic, and chronological framework. This is a challenge that is aptly demonstrated by the number of stratigraphic articles generated from the site and the range of dates proposed for the whole site and individual specimens.[9] With undoubted challenges ahead, we are tackling the site, chamber by chamber, deciphering linkages and associations as we go. For the first time, we have a high-resolution 3-D map of the caves, providing us with a dynamic GIS-compatible geomorphological framework into which we can begin populating virtual spaces with new and legacy multidisciplinary data—allowing us to integrate every specimen of Sterkfontein's large assemblages into a GIS database for future spatial, taphonomic, stratigraphic, and paleoenvironmental study.

Simplistically speaking, we are finding "more of the same" at Sterkfontein eighty years after it first came into the human evolutionary lexicon. But, today, by combining the wealth of information embedded in old excavation diaries, reports, researchers' diaries, and the fossil assemblages with technological innovations in site modeling, geology, and biology, Sterkfontein will continue to play an important role in the future of paleoanthropology.

Dominic Justin Stratford *Department of Archaeology, School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, Johanneburg, South Africa; Dominic.Stratford@wits.ac.za*

NOTES

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1. Customary paleoanthropological terms and hominid species names are defined in Table 1 and denoted by an asterisk.
2. The issues of dating the caves and specimens is not the focus of this article, but I have made reference to major works and discussions later in the text.
3. See Smuts (1952) for an alternative assessment of Jan Smuts's involvement with Hertzog.
4. Generally accepted across the paleoanthropological community.
5. Generally not accepted across the paleoanthropological community.
6. The various contributions to this debate are briefly discussed in the text below.
7. The scenario in which the skeleton was deposited and buried has been the subject of debate (e.g., Kramers and Dirks 2017a, 2017b; Pickering and Kramers 2010; Stratford et al. 2017). Here I present the scenario proposed by Bruxelles et al. (2014) based on detailed stratigraphic research in the Silberberg Grotto.
8. It should be noted that although the diaries have been reformatted for consistency during digitization, each entry is presented as it was originally recorded in the diary. Mistakes are present (in some recordings of depths of excavations), but these were not changed through the archiving process. Where names of visitors were illegible or unclear, I have made a suggestion of who they may be.
9. For discussion of stratigraphic works see Clarke (2006), Pickering and Kramers (2010), Bruxelles et al. (2014), and Stratford, Grab, and Pickering (2014). See Partridge (2005), Pickering and Kramers (2010), Herries et al. (2013), Bruxelles et al. (2014), Granger et al. (2015), Kramers and Dirks (2017a, 2017b), and Stratford et al. (2017) for discussions of dates.

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