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Abstract

The Sterkfontein Caves, located in the south-west of the Cradle of Humankind in Gauteng is the world's richest *Australopithecus*-bearing locality. The fossil-bearing cave deposits represent a more recent instalment of a history spanning 2.6 Ga, from the deposition of the karst-hosting dolomites, to the commercial exploitation of the caves by lime miners in the early twentieth century. The location and morphology of the caves is a result of lithological variation within the two host dolomite formations, multiple and complex phases of karstification and infilling of the resultant solution cavities over the two billion years since the dolomite deposition, and consistently active local tensional joint and fault systems. Where vadose collapse has opened the caves to the landscape, a broad range of geomorphological processes has created dynamic sedimentary environments with complex stratigraphic histories.

Keywords

Karstic caves • Malmani dolomites • Cave deposits • *Australopithecus*

17.1 Introduction

The Cradle of Humankind World Heritage Site covers an area of approximately 800 km² in the north-west of Gauteng Province (Fig. 17.1). The boundaries of the Cradle of Humankind (hereafter Cradle) partially enclose the exposed and karstified dolomitic limestone, which hosts the famous hominin-bearing caves. The densest collection of excavated fossil-bearing sites, including Sterkfontein, is located in the south-western area of the Cradle near the Blaauwbank river valley (Fig. 17.1). The site occupies the top of a low hill about 300 m south of, and rising 50 m above (1,491 m a.s.l.), the Blaauwbank River. Palaeoanthropological attention was brought to Sterkfontein after lime mining activities had de-roofed the uppermost chamber, exposing the fossil-rich cave infill. As a by-product of the blasting of the calcite deposits, large fossil-bearing dumps were created. It was in one of these dumps that the first hominin fossil was found in 1936.

The site remains one of the most prolific and long-studied fossil hominin localities in the world, yielding over 750 hominin specimens. Key finds include the first adult cranium of an *Australopithecus* found in 1936, the first complete adult *Australopithecus* cranium, affectionately known as Ms. Ples, and the most complete skeleton of an *Australopithecus* yet discovered (Clarke 2013). This chapter reflects on: (1) the hypothesized geomorphic evolution and formation of the Sterkfontein Caves, (2) the cave geomorphology and interned fossil-bearing sediments, and (3) the significance of the caves to palaeoanthropology and geotourism.

17.2 Geological Context

The Sterkfontein karst caves formed within the Neoproterozoic dolomites of the Malmani Subgroup which were deposited under epeiric (inland) marine conditions (Eriksson et al. 1995) between 2,550 and 2,423 Ma and reach a thickness of 1,450 m close to Sterkfontein (Truswell and Eriksson 1975). A range of tidal, deep-water and chemical depositional environments accumulated the dolomite and interstratifying

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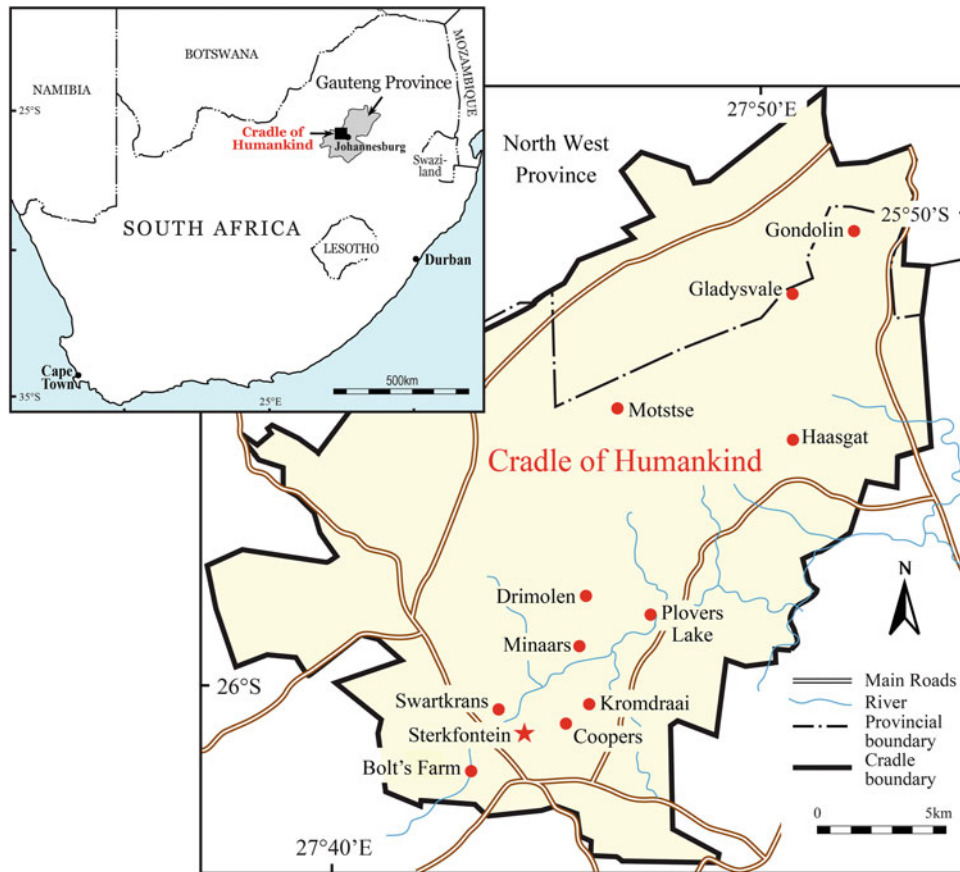


Fig. 17.1 Sterkfontein and other key fossil sites within the Cradle of Humankind, UNESCO World Heritage property, Gauteng, South Africa

chert beds within a general carbonate ramp model framework (Sumner and Grotzinger 2004). The Sterkfontein caves have formed within and across the boundaries of the two lower formations of the Malmani Subgroup (Fig. 17.2). The Oaktree Formation (basal member) is poor in chert beds and is overlain by the Monte Christo Formation, comparatively rich in chert beds (Martini et al. 2003). The difference in chert bed density between these two formations has strongly influenced the formation and geomorphology of the current cave system.

In the Sterkfontein area, early karst caves, formed during the early subaerial exposure of the dolomites, and open faults developed in the Monte Christo Formation were filled by chert breccias of the Rooihooft Formation (Dirks and Berger 2013). This formation represents the proximal and medial portions of alluvial fans formed from transported weathered products of the uplifted dolomite landscape (Catuneanu and Eriksson 2002). Remnants of this chert breccia palaeokarst fill are found in close association with the cave sites of Sterkfontein, Swartkrans, Kromdraai, Coopers Cave and Gladysvale. Where this association is found, the unconformities formed by the chert breccia-filled

palaeokarst provided the focus for the next generation of karstification, as the dolomites were again exposed and weathered.

Martini et al. (2003) suggest that the start of the Sterkfontein cave formation took place between 18 and 5 Ma, inferred from Miocene uplift of the area, erosion and exposure, and the age of oldest deposits yet found in the caves. Alternatively, Dirks and Berger (2013) propose that exposure of the dolomites took place after a much more recent erosion of overlying Karoo sediments (~2 Ma).

17.3 Karstification

The hyperphreatic model of cave formation has received great support over the history of geological research at Sterkfontein. The classic hyperphreatic model proposes that lowering of base level will result in the development of successively deeper parts of the cave network as dissolution is greatest within the upper 10 m of the local groundwater level (Martini et al. 2003). This model supports ideas of a lowering water table level related to uplift and erosion

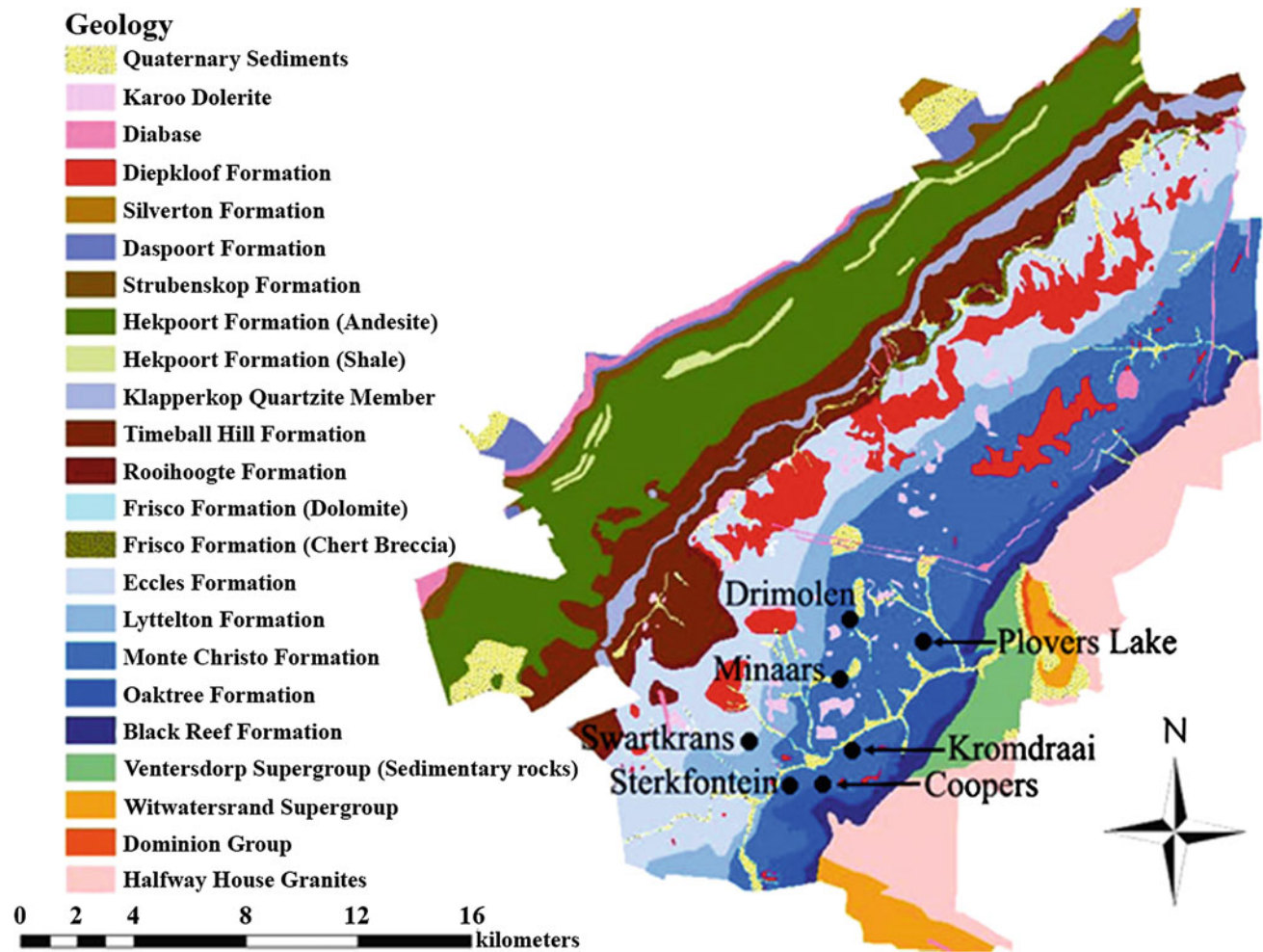


Fig. 17.2 Geological map of the Cradle of Humankind (adjusted from Obbes 2000)

cycles. However, Wilkinson (1973, 1983) proposed a ‘deep phreatic’ karstification process, suggesting that the entire vertical extent of the cave system had developed prior to the caves opening to the surface. This is based on geomorphological mapping of the cave network and tracking vadose autogenic and allogenic (internally and externally derived) colluvial deposits to the base of the cave system. Another alternative could be the hypogenic origin of the cave—i.e. its formation through rising deep water flow (likely thermal) (Martini et al. 2003; Klimchouk 2007). A more recent suggestion has been the in situ chemical alteration of the dolomite into ‘ghost rock’ (Bruxelles et al. 2009; Dubois et al. 2014). This process creates pseudophreatic karst morphologies, differing in the process of dissolution and final removal of the dolomite. Residual dolomite is removed as the groundwater level drops, leaving a vertically fully developed karst network as the caves open to the surface through vadose collapse. Low penetration of meteoric recharge and near-static groundwater also fits this formation model.

Identification of the specific development model for the Sterkfontein Caves has important implications for the age of the interred fossil and artefact-bearing deposits, a subject that remains a source of significant and continued debate (e.g. Herries and Shaw 2011; Stratford et al. 2014). The hyperphreatic model proposes that fossiliferous deposits found in the deepest areas must be younger than, or reworked from, older chambers above. Recent renewed geomorphological and stratigraphic work at Sterkfontein supports previous observations of early allogenic sediments being deposited at the base of the system (Wilkinson 1973), but has not yet succeeded in providing new absolute dates for these early sediments (Stratford et al. 2014).

17.4 Cave Geomorphology

The vertical depth of the karst network is difficult to estimate as passages descend below the groundwater table, but has been proposed to reach a depth of 79 m (Moen and Martini

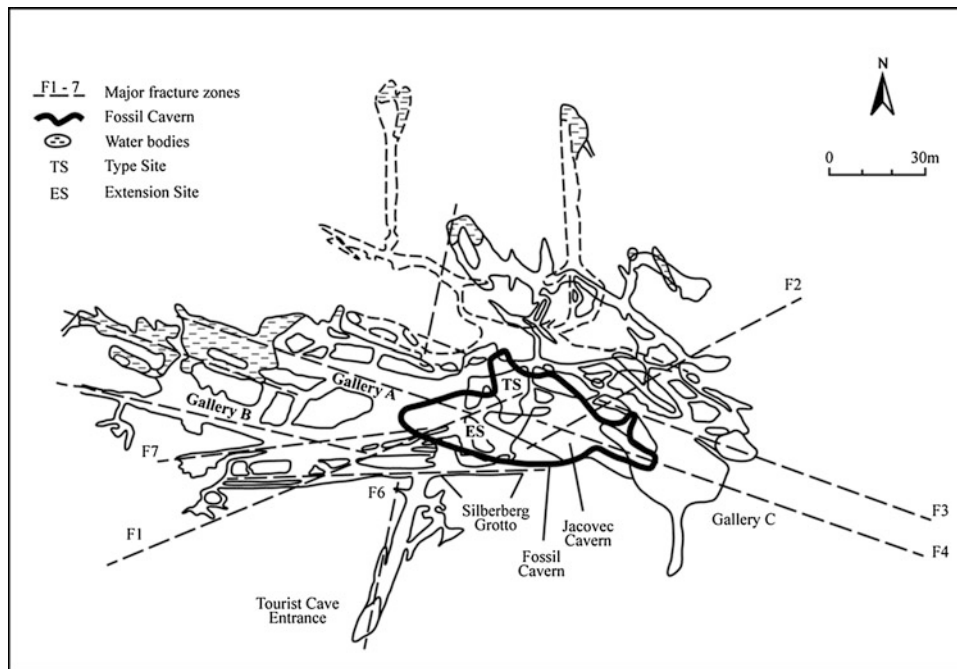


Fig. 17.3 Geomorphological plan of the Sterkfontein cave system. Major controlling joints and faults are shown in relation to the upper level (Fossil Cavern; *bold line*) and the lower level (subterranean area; *thin lines*)

1996). Lateral karst developmental controls are guided by dominant and subordinate fracture systems within the heavily fractured dolomites (Fig. 17.3). A dominant fracture system runs roughly east–west, and a subordinate system runs north–south. The influence of these fractures and joints can be seen in the perpendicular intersections of the major passages and galleries. The cave network is limited to an area 350 m east–west and 250 m north–south. In the phreatic system (under the water table), faults enable water penetration within the vertical fault planes, forming tall, narrow passages in chert-poor areas, or superimposed passages in chert-rich areas. In a vadose system (above the water table), the faults have several influences. First, they are the focus of collapse, increasing passage height, and in some cases facilitating the opening of the caves to the landscape. Second, they provide conduits for meteoric water recharge and localized dissolution. Allogenic sediment accumulation, erosion and speleothem growth are generally focused around these fault structures. The continued influence of these fracture systems is demonstrated by faulted calcified sediments and multiple generations of intrusive speleothem growth found in the vicinity of the joints and faults throughout the system.

The combination of tensional joint and fault systems and different chert densities has formed two main karst morphologies at Sterkfontein. An upper level is represented by a single, large, deep chamber named the Fossil Cavern. The infilling deposits are now exposed on the surface by a combination of landscape erosion and then lime mining activities removing the roof of the chamber (Fig. 17.4). The lateral

dimensions of the cavern are controlled by the convergence of five faults (Fig. 17.3). Enormous collapsed blocks ($>5 \times 5 \times 5$ m) at the base of the Fossil Cavern excavation suggest that the chamber has expanded through vadose collapse through its evolution, possibly activating different openings and depositing sediments in different areas.

The lower level of the cave system is more extensive than the upper, with passage lengths in excess of 4.5 km. Here, passage development is influenced by fault direction, fault density and chert-poor dolomite, creating very tall, narrow passages. Passages are generally labyrinthine to the east and parallel to the west, developing closely along active compound tensional fracture systems that are slightly more distant from one another (Gallery A and B in Fig. 17.3). The density of fracture systems exerts an important control on the lateral dimensions of these chambers and passages, with vadose collapses joining spaces between tall, narrow, closely parallel passages, forming galleries (e.g. ‘Gallery B’ in the Milner Hall; Fig. 17.5). Inter-gallery passages are generally smaller and perpendicularly orientated, developing along the subordinate north–south trending faults.

17.5 Cave Deposits

Opening of the caves to the surface occurs through a combination of vadose collapse and localized meteoric dissolution along faults. Openings are often very deep and, in some cases, connect the landscape directly to the base of the



Fig. 17.4 The Sterkfontein excavation site. The red allogenic sediments are visible against the grey dolomite. On the hill slope facing in the distance is the site of Swartkrans. (Photograph D. Stratford)

vadose system about 30 m below (Fig. 17.6). Where surface erosion has intersected with the uppermost passages, long deep gullies are opened. Typically, openings are very steep sided and represent a serious danger to people and wild animals. Consequently, ‘death trap’ assemblages represent a common bone accumulation agent. Concentration of vegetation around the cave openings, particularly the wild olive (*Olea oleaster*), is thought to have provided shelter for primates, carnivores and sometimes hominins.

Once open, the caves start to accumulate allogenic sediments, animal bones, stone tools and occasionally the bones of our hominin ancestors. Sediments generally accumulate through colluvial processes with varying degrees of water interaction, developing a range of sedimentary facies related to talus cone formation. Within the cave, sediments can calcify, decalcify, collapse, and be eroded and reworked by meteoric and percolating water. These processes spread sediments, and their interned bones and artefacts, vertically and laterally en masse or as separate components through the



Fig. 17.5 Sterkfontein Milner Hall passage wall remnants. Note evidence of the vadoso collapse on the cave floor, with the dolomite and interbedded chert dipping to the north (right). (Photograph D. Stratford)

system, sometimes stratigraphically isolating assemblages from their sources. Many of the deposits found at Sterkfontein are heavily calcified which, although providing a means of preserving fossils in situ for millions of years, require specialist excavation methods that are either small scale and very time-consuming, or heavy duty and problematic for stratigraphic control.

As the surface is eroded, new openings to the deepest chambers have been formed, and old openings have been opened again, depositing new sediments across the system and at all levels. Where erosive water is introduced, old deposits have been undercut and voids filled with new material. In some cases, re-karstification within autogenic and allogenic cave deposits has created irregular and vertical unconformities between sediment bodies. Such a situation can be seen in newly exposed deposit surfaces in the western area of the Fossil Cavern. The combination of these processes creates a highly dynamic depositional environment with complex stratigraphic histories.

Currently, the deposits found within the Fossil Cavern and its lower reaches (Silberberg Grotto) are organized into a macro-scale chronostratigraphic sequence (consecutively



Fig. 17.6 A typical cave opening surrounded by established vegetation at Sterkfontein. This particular opening articulates directly to the base of the system some 25 m below. (Photograph D. Stratford)

formed deposits classified by relative age) of six members (M1-6), referred to as the ‘Sterkfontein Formation’ (Partridge and Watt 1991). Of these, the most noteworthy are Member 2, the oldest allogenic deposit identified (between 4 and 2.8 Ma; Pickering and Kramers 2010) which contained the world’s most complete single *Australopithecus* skeleton—‘Little Foot’, and Member 4, the richest *Australopithecus*-bearing deposit in the world, which has yielded over 750 specimens.

17.6 Summary

The geomorphology of the Cradle of Humankind documents a long and complex history of landscape and environmental processes spanning over two billion years since the deposition of dolomitic limestone, which hosts the abundant caves. This is highlighted with a flash of hominin evolutionary history documented over the last three million years and which is preserved within fossiliferous deposits of the

Sterkfontein Caves. The cumulative influence of those processes has developed a unique sedimentary context in which we find the fossils of our hominin ancestors, their early technology and coexisting fauna. The preservation of these assemblages is largely owing to the fortuitous opening of the caves about three million years ago, facilitating the documentation of landscape and hominin evolution over the last several million years—a period of our evolution that is so intriguing due to the high levels of morphological variation found within the many different species of Plio-Pleistocene hominins inhabiting the southern African landscape. The varying lithologies and faulting of the dolomite have influenced the morphology of the cave network, the distribution of flora on the landscape, when and how the cave opened, and how sediments, bones and artefacts were deposited and distributed around the cave. The result is a dynamic karst network with a long and complicated depositional history. The Sterkfontein Caves and the Cradle of Humankind was awarded UNESCO World Heritage status in 1999 and is recognized as an invaluable cultural asset to South Africa. The Sterkfontein Caves are currently the only publicly accessible cave in the Cradle area and are visited daily by schools, tourists and students.

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