

Expanded Explorations of the Dinaledi Subsystem, Rising Star Cave System, South Africa

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ABSTRACT

The Dinaledi Chamber of the Rising Star cave system has yielded a large assemblage of fossil hominin material, attributed to *Homo naledi*. The unusual taphonomic and geological situation of the assemblage suggested that the remains may have been deliberately deposited in the chamber. However, the route and mechanism of deposition of the remains within the Dinaledi Chamber are still uncertain. During the 2017–2018 field seasons, we expanded explorations of the passages surrounding the Dinaledi Chamber. These explorations improved our understanding of the cave's spatial complexity, necessitating a revision of the way the spaces are named and described. The work supported the hypothesis that there is no alternate entrance into the system other than the Chute. The work also identified new fossil deposits in several remote passages, three of which contain material attributable to *H. naledi*. Here, we clarify the definition of the Dinaledi Subsystem and provide terminology for new fossil localities found in this portion of the Rising Star cave system. These results emphasize the complex depositional environment of the Dinaledi Subsystem and raise new questions about the process and timing of the fossil accumulations.

INTRODUCTION

The Rising Star cave is located in the Bloubaank River valley, 2.2km west of Sterkfontein Cave in the Cradle of Humankind UNESCO World Heritage Site. The currently mapped system (Figure 1) consists of more than 4000 linear meters of passageways and other complex spaces. The cave system is stratigraphically bound to a 15–20m thick dolomite horizon, which dips to the west at an angle of 17° and is capped by a 1–1.3m thick chert horizon (Dirks et al. 2015). This chert unit forms the ceiling of several large cave chambers, including the fossil-bearing Dinaledi Chamber. Fossil-bearing sediments are present in many areas of the cave system, most notably the hominin fossil deposits within the Dinaledi Chamber (Berger et al. 2015; Dirks et al. 2015) and the Lesedi Chamber (Hawks et al. 2017). Both chambers preserve remains of multiple individuals of *Homo naledi* in unlithified clastic deposits (Berger et al. 2015; Dirks et al. 2015; Hawks et al. 2017).

When it was discovered, several aspects of the Dinaledi Chamber assemblage and its context stood out in comparison to other sites in the Cradle of Humankind (Dirks et al. 2015). The location of the chamber is deep within the cave system, its sedimentology is distinct from nearby chambers, and the fossil assemblage is, in places, densely packed and nearly monospecific, with almost no non-hominin macrofauna. The fossil assemblage includes

multiple hominin individuals, representing all life stages and parts of the skeleton, and some articulated remains. However, the fossils lack evidence of carnivore or scavenger activity, size-sorting, or fluvial transport, as is common in other sites. This unusual combination of factors led to the hypothesis that the accumulation was purposeful, and the result of deliberate deposition by the hominins (Berger et al. 2017; Dirks et al. 2015). Subsequent commentaries on this hypothesis proposed that alternate entry routes to the Dinaledi Chamber may have existed in the past to allow the entry of the fossil material (Thackeray 2016; Val 2016; but see Dirks et al. 2016; Randolph-Quinney et al. 2016), or that the accumulation was the result of natural processes (Egeland et al. 2018; Nel et al. 2021).

Today, the only route into the Dinaledi Chamber is via a 12m high fracture in the dolostone, known as the Chute (Dirks et al. 2015). This fissure is extremely restricted and punctuated by multiple pinch-points, some as narrow as 18cm. Despite its confines, geological and speleological investigations both on the surface and underground have failed to find another entry into the area and several lines of evidence suggest that the Chute was the only viable access point during the time that the hominin material accumulated, and thereafter. This evidence includes the 1–1.3m-thick capping chert layer above the system and the absence of breaches in the dolomite above the Dinaledi chamber itself

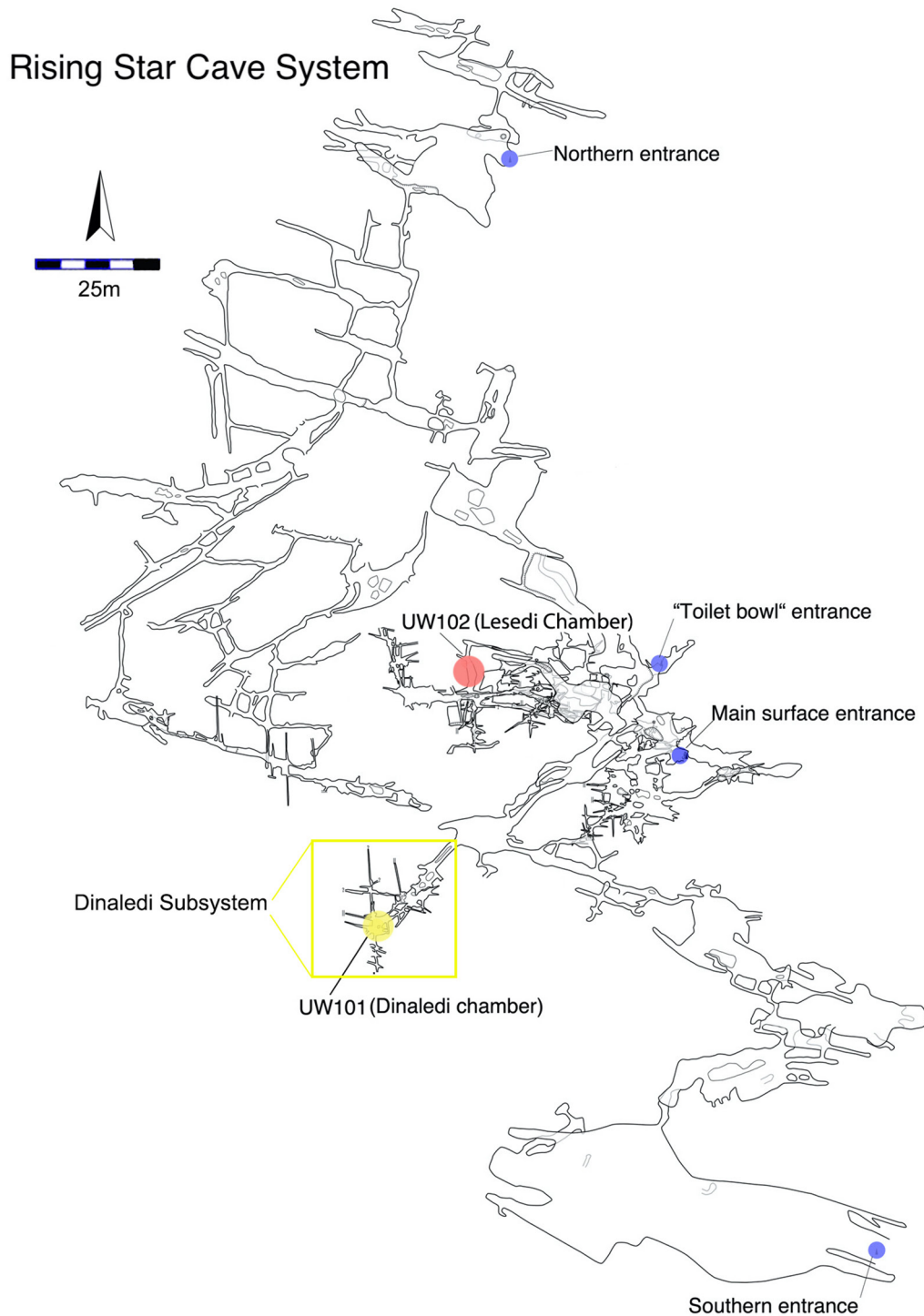


Figure 1. Plan view of the full Rising Star Cave System as currently mapped.

(Dirks et al. 2015). Surface investigations did identify a single, flowstone-filled crack ~10m SW of the Dinaledi Chamber. However, U-Th dating of the flowstone (sample RS9) indicated that it filled the fracture sometime before ~600 ka (Dirks et al. 2017). In the Dinaledi Chamber itself, U-Th dating of an overlying flowstone established a minimum

geological age of 236 ka for the deposition of the hominin material, while direct ESR sampling of three hominin teeth produced a maximum age of 335 ka (Dirks et al. 2015; 2017). As a result, the fissure could not have been an access point for the *H. naledi* remains, and the Chute remains the only known entrance.

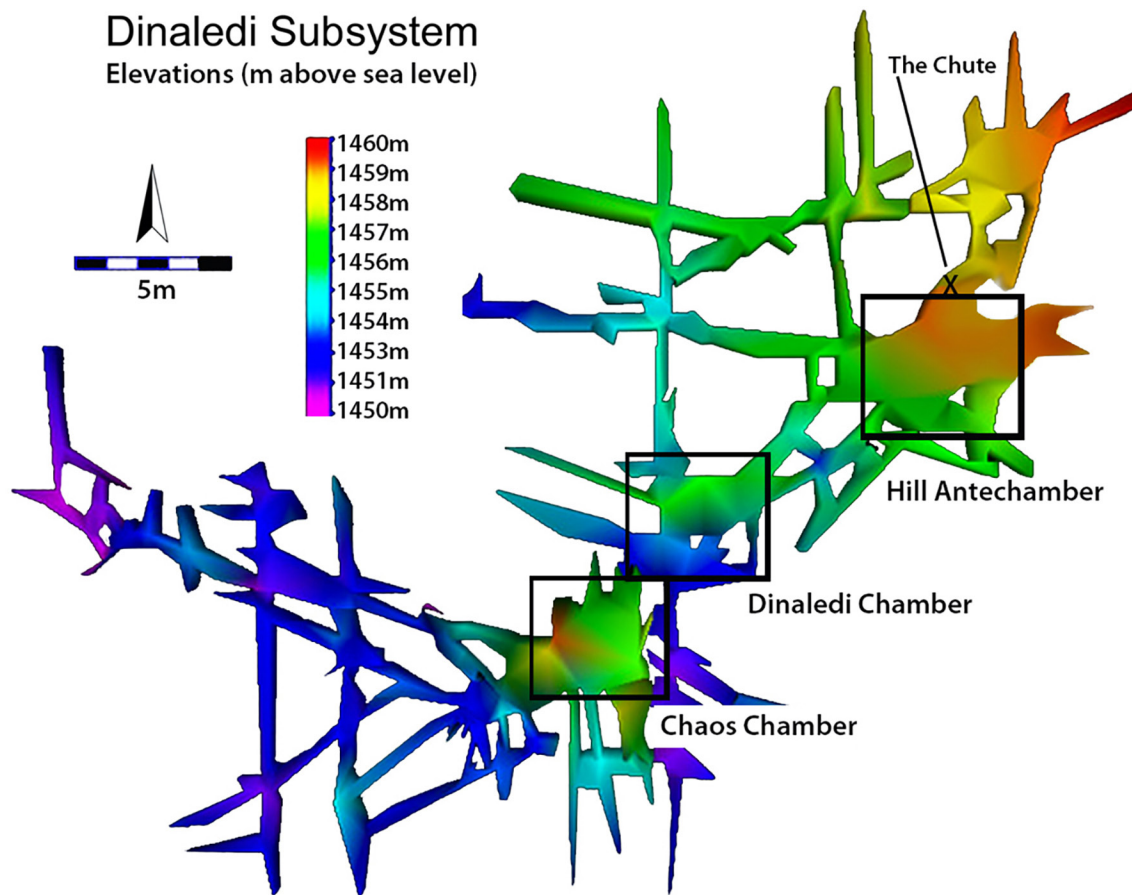


Figure 2. Three-dimensional model of the Dinaledi Subsystem, showing 'heat-map' elevations.

The recovery of fossil hominin material in the Lesedi Chamber, distant from the Dinaledi Chamber, in very similar context and similarly inaccessible, reinforced the hypothesis that the *H. naledi* hominins were active deep in the cave system (Hawks et al. 2017). To better understand this behavior, as well as the complexity of the cave system itself, we expanded explorations around the Dinaledi Chamber. Our motivation was to provide data to test hypotheses for where, and how, the *H. naledi* remains entered this part of the cave system. Explorations of the numerous chambers and passages around the original fossil deposit were conducted to determine if we could identify other possible routes into the area and to look for additional evidence of hominin activity (Tucker et al. 2018). Here, we present the results of explorations undertaken in the 2017–2018 field seasons that contribute to our understanding of the cave's spatial complexity, as well as the context and content of the fossil deposits.

MATERIALS AND METHODS

All chambers and passages around the original Dinaledi Chamber excavation area were physically explored to the limit of human ability (Tucker et al. 2018). A FARO Focus^{3D} X330 laser scanner (<http://www.faro.com>) had been used previously to obtain an accurate pointcloud model of the route from the cave entrance to the Dinaledi Chamber (Kru-

ger et al. 2016). However, the Chute, and many of the passages branching off from the original excavation area, are too confined for this equipment. An alternate 3D mapping system was needed before these areas could be incorporated into existing maps. This resulted in the application of a DistoX2 integrated electronic cave survey tool, consisting of a Leica DistoTM X310 distance meter (Leica Geosystems[®]) combined with a 3-axis compass, clinometer and BluetoothTM connection. Measurement data were collected and then transferred to the TopoDroid cave surveying application (<https://sites.google.com/site/speleoapps/home/topodroid>) on a smartphone. Scale sketches were also drawn on site with TopoDroid. Therion (<https://therion.speleo.sk/>) open-source cave surveying software was used to produce final plan views and link the data to previous maps of the system. Chamber and passage roof heights were added to create a simplified three-dimensional model of the subsystem and assist with visualizing the horizontal and vertical relationships between different areas (Figure 2). Finally, ParaView (www.paraview.org) was used to convert the 3D data into an STL file to allow virtual manipulation and physical models to be printed out.

RESULTS

The current explorations added 316 linear meters of mapped passages around the Dinaledi Chamber to the

Dinaledi Subsystem

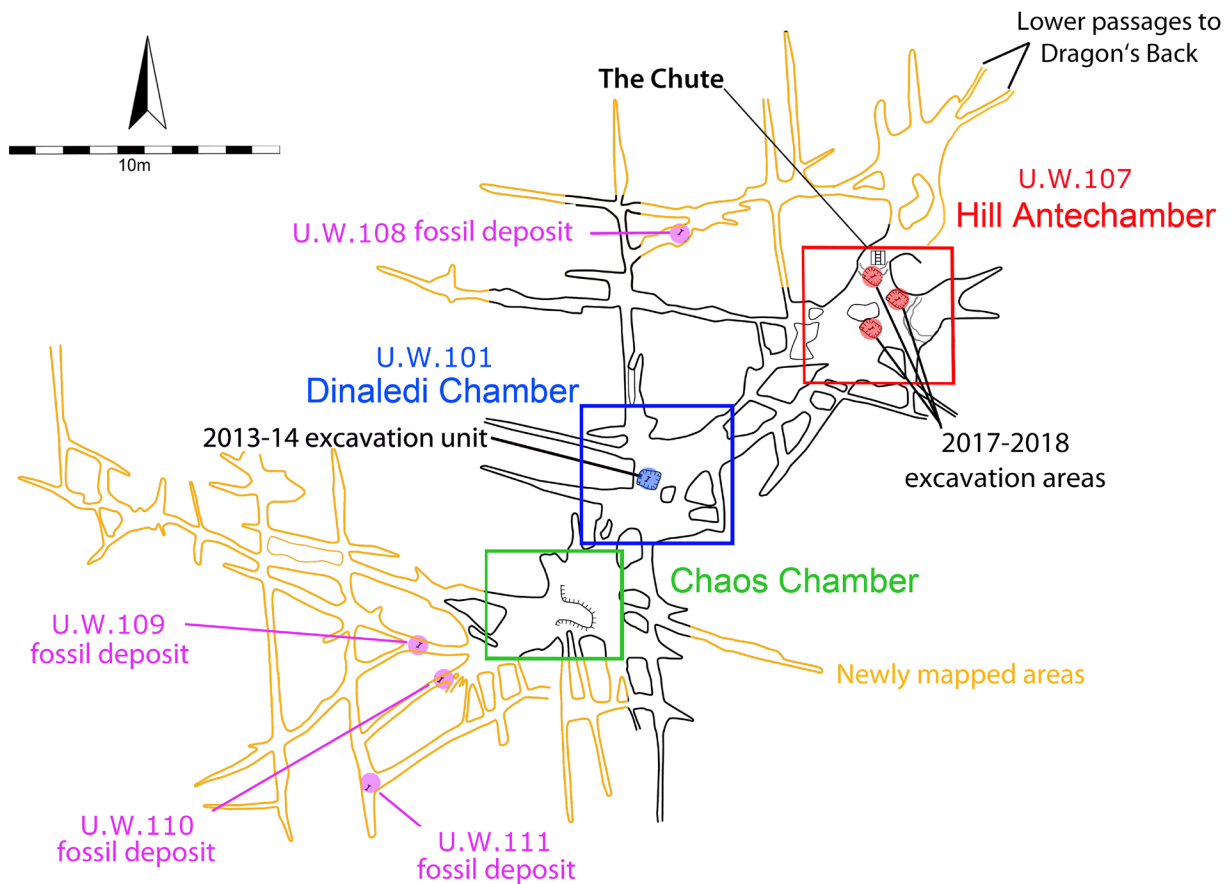


Figure 3. The Dinaledi Subsystem, showing the newly mapped areas (in yellow), named chambers (colored boxes) and new fossil deposits (in pink).

4010m that had been mapped previously (Figure 3). During this process, it became apparent that each chamber, antechamber, and passage, surrounding the original *H. naledi* fossil deposit is sufficiently distinct that they may have had substantially different sedimentary and formation histories. As a result, we developed a formal system to identify and name different sections of the cave to help clarify the relative stratigraphic and spatial relationships between each of the areas (Berger et al. 2018). To this end, the contiguous network of chambers and passages between the base of the Chute and the furthest-explored passages to the south of the primary *H. naledi* deposit was re-named the ‘Dinaledi Subsystem’ (see Figure 3). Within this subsystem, there are two other chambers that are internally connected by passages to the Dinaledi Chamber, but collectively, only linked to the larger Rising Star cave system via the Chute. These chambers have been given separate names to recognize their spatial distinctiveness from the Dinaledi Chamber. Newly identified fossil deposits within the subsystem were also given unique fossil locality numbers, following the Wits fossil locality numbering system (Zipfel and Berger 2009).

Within the Dinaledi Subsystem we now limit the term

‘Dinaledi Chamber’ to the ~3m x 5m chamber where the first fossil material was discovered in 2013 (Dirks et al. 2015). Fossils from this area are accessioned under U.W. 101 (Berger et al. 2015). The open area below the base of the Chute, previously referred to as ‘the landing zone’ (Dirks et al. 2015), has been renamed the Hill Antechamber (Berger et al. 2018) and given the Wits fossil locality designator U.W. 107. This area is approximately 4m wide and 4m long, with a 5m high ceiling. In its northeast corner, near the base of the Chute, a partially flowstone-covered debris cone preserves the topographically highest deposits of hominin-bearing sediments within the subsystem (Sub-Unit 3b) (Dirks et al. 2017). This debris cone is comprised dominantly of cave-derived sediment, and slopes steeply down towards the Dinaledi Chamber, with an elevation drop of ~2m (Figure 2). At the base of the slope however, the antechamber narrows down tightly and access to the Dinaledi Chamber is via two narrow fissures in the dolostone, the most accessible of which is 25–35cm wide and approximately 4m long. Therefore, although the Hill Antechamber is connected to the Dinaledi Chamber, the two are spatially separated by passages that impede the movement of people, fossils, and sediments between them. During the

2017–2018 seasons, formal excavations were undertaken in the sediments at the top and bottom of the debris cone within the Hill Antechamber to determine if skeletal material had entered the subsystem via the Chute (Elliott et al. 2018). Further descriptions of these excavations and the recovered material are forthcoming.

Another chamber lies 5.5m southwest of the Dinaledi Chamber excavation unit (see Figure 3). It is ~3m wide, 3.5m long, 8.5m high, and separated from the Dinaledi Chamber by two short (1–2m) crawls. It has been named ‘Chaos Chamber’ (Berger et al. 2018). The floor of this chamber is almost flat and lies 52cm below the level of the Dinaledi Chamber excavation unit. A number of large dolostone blocks have fallen from the roof to the chamber floor, partially impeding access to the passages to the south of the chamber. The floor sediments here have also been interpreted as being composed of Sub-Unit 3b mud clast breccia (Dirks et al. 2017). However, a thin, horizontal flowstone sheet, part of Flowstone Group 2 (FS2) (ibid) covers most of the floor, precluding confirmation of the sediment composition below. Five small fragments of bone were recovered from the surface of this chamber. These fragments were isolated and scattered on the surface of the chamber floor and given the connecting passages and close proximity, may have originated in the Dinaledi Chamber. As a result, fossils from this area were accessioned under U.W. 101, rather than under a separate locality number. Descriptions of this material are underway, but formal excavations have not been conducted in this area.

We also investigated the numerous narrow passages surrounding the Hill Antechamber, and Dinaledi and Chaos Chambers to their physical limits, some for the first time. A total of 316m of passages were mapped and incorporated into a grid system imposed for excavation purposes (Elliott et al. 2018). The explored passages have formed predominantly along interconnected north, west-northwest, and southwest trending vertical fractures and joints that penetrate through the stratigraphy and cut through five thin (10cm thick) chert marker horizons. However, they do not cut through the 1.0–1.3m capping chert unit that forms the roof of the subsystem (Dirks et al. 2015; 2016; 2017). The passages are variably filled with sediments, flowstones, and columns of stalactites and stalagmites, and some include collapsed dolomite blocks, making it difficult to determine how deep the fissures penetrate. In the chert-poor dolomite, the passages develop into more open chambers, as with the Hill Antechamber, Dinaledi Chamber, and Chaos Chamber.

Of the 316m of outlying passages that were explored, four of them contained fossil material (see Figure 3). These fossil deposits are in very isolated locations and are extremely difficult to access. Because they are spatially separate from the larger chambers, and each other, and because they potentially represent different depositional events, we gave each fossil deposit its own Wits locality number (see Figure 3). Thus, the first deposit of skeletal material, located north of the Dinaledi Chamber, was designated U.W. 108. Three fossil deposits located to the southwest of Chaos

Chamber were designated (from north to south) U.W. 109, U.W. 110 and U.W. 111.

Fossil locality U.W. 108 lies ~9m to the north of the 2013–2014 Dinaledi Chamber excavation unit (see Figure 3). It sits in a narrow (20–35cm wide), NE-SW trending fracture, 2.2m in from a N-S trending passage known as the ‘Rodent Passage’ (Dirks et al. 2015) and can be reached with difficulty from either the Hill Antechamber or the Dinaledi Chamber. A single long bone was recovered as two pieces (previously U.W. 101-1975 and U.W. 101-1976, now U.W. 108-1 and U.W. 108-2), and subsequently repaired in the lab. It was recovered from the surface in a pocket of typical Sub-Unit 3b mud clast breccia (Dirks et al. 2017), partially overlain by a thin (< 0.5cm) layer of flowstone. U.W. 108-1/ U.W. 108-2 has been tentatively identified as a *Homo naledi* humeral diaphysis, but a full analysis and description are in progress. Additional geological and stratigraphic studies, and dating of the flowstone are also pending, but formal excavations have not been undertaken.

Fossil locality U.W. 109 lies 8.2m SW of the Dinaledi Chamber excavation unit, in a very small (0.3m x 0.4m) E-W tunnel that branches off of Chaos Chamber (see Figure 3). The elevation of the grid square is -0.47m below that of the Dinaledi Chamber excavation area. The floor of the tunnel slopes down ~10 degrees towards the N and is partially filled with Sub-Unit 3b mud clast breccia (Dirks et al. 2017). The locality is accessed by climbing up and over the fallen dolomite blocks in Chaos Chamber and dropping into a narrow (<1m), 2m high shaft. Six fragments of what has been preliminarily identified as a juvenile baboon (*Papio* sp.) were collected from the surface in this locality, including femoral fragments, a partial os coxae, and a left-side portion of mandible with dentition. Detailed skeletal descriptions, taxonomic identifications and geological analyses are also in progress, but only this surface material has been collected to date.

Fossil locality U.W. 110 is located in a low passage 12.8m SW of the Dinaledi excavation unit (see Figure 3). It lies at the intersection of several fracture passages, the main one being in an E-W direction. This passage can also be accessed by climbing over the Chaos Chamber dolomite blocks and lies almost parallel to the U.W. 109 passage. The two areas are connected by a short, but difficult crawl. Here, thirty-four fragments, including six teeth and twenty-eight cranial fragments of a juvenile *H. naledi* individual, were recovered (Brophy et al. 2021). The fossil material was collected from the surface of a short sloping fissure ~15cm wide by 80cm long, containing ferromanganese-rich and hardened mudstone clast sediments. Again, fossil recovery in this locality involved surface collection only and formal excavations have not been conducted.

The fourth fossil locality, U.W. 111, is located 15.8m SW of the Dinaledi Chamber excavation area (see Figure 3). It is also accessed via Chaos Chamber but is entered through a squeeze on the right side of the chamber that leads to a N-S fracture passage 16–30cm wide. The fossil locality is at the southern end of this passage, at the intersection with another, non-navigable, NE-SW trending fracture that leads back

to the Dinaledi Chamber. The sediments in this area are composed of orange mud clast breccia similar to the fossil-bearing sediments in the Dinaledi and Hill Antechambers (Dirks et al. 2015; 2017). The floor is covered by a flowstone that has been eroded at several places, exposing the sediments beneath. Thirty-three bone fragments were collected from the surface in this locality, including several long bone shaft fragments, all consistent with *H. naledi*. Again, detailed analyses and descriptions are being undertaken and will follow this publication. Geological analyses are also being conducted to confirm sedimentary sub-unit/s, flowstone group/s, and to date the associated flowstone in this passage, but excavations have not been undertaken.

We also investigated several passages connecting the Hill Antechamber to the Dragon's Back Chamber in an effort to identify an alternate entrance to the subsystem (see Figure 3). These fractures are parallel, and in close proximity to the Chute, but average less than 25cm wide. Only one passage is navigable, but access into the antechamber is substantially more difficult than the Chute. We then investigated two areas outside the subsystem to determine if they might lead into the area. The first of these is a 60cm wide fissure, 12m north of the subsystem and 30m north of the original fossil deposit. The second area consists of a large chamber at the southern limit of the system, 42m south-east of the Dinaledi Subsystem (51m from the original deposit). No physical connections or navigable passages between these areas and the Dinaledi Subsystem were identified.

DISCUSSION AND CONCLUSION

Speleological explorations, geological investigations, and augmented cave mapping during the 2017–2018 field season have expanded the mapped passages of the Dinaledi Subsystem and improved our understanding of the area's spatial complexity. This research led to the recognition that although they are interconnected, the various passages and chambers are separate spaces, with their own formation histories. As a result, we have renamed several areas with unique identifiers, to emphasize their distinctiveness (Berger et al. 2018).

Exploration of the narrow passages within the Dinaledi Subsystem involves considerable effort, navigating areas with irregular floors and walls, numerous obstructions and fissures less than 30cm wide. These surveys were directed towards identifying whether other routes into the subsystem may have existed in the past. However, we failed to identify any viable alternate entrance, other than the current route through the Chute. The only other navigable passage leading into the subsystem (from the Dragon's Back to Hill Antechamber), is even more restricted than the Chute and thus, cannot be considered a practical alternative. The narrow passages to the south and west of the Dinaledi and Chaos chambers do not provide navigable connection to other parts of the system. We consider further human exploration of these fissures beyond what has been mapped to be impossible due to the constricted nature of the spaces.

Explorations also identified four new fossil deposits within the Dinaledi Subsystem, expanding the known spa-

tial distribution of fossils and adding new *H. naledi* fossil material to the current collection. The presence of fossil material in these extremely difficult and remote localities suggests potentially different depositional events and processes from the material recovered in the larger chambers. The recovery of *Papio* material in one of these localities is interesting. Until this material was discovered, the only other macrofauna recovered from the Dinaledi Chamber was a single juvenile baboon tooth, recovered from sediments 55–60cm below the hominin material and dated by combined US-ESR to 723–635 ka (Dirks et al. 2017). Given this date, the tooth likely entered the subsystem long before the Dinaledi Chamber hominin material, possibly via the previously mentioned fissure, before it filled with flowstone around 600 ka. Alternatively, it is possible that the current *Papio* specimen may represent an accidental incursion into the cave system. Baboons are known to enter the karstic cave systems of southern Africa (Barrett et al. 2004 and references therein, Nel et al. 2021). Therefore, the presence of their fossils in the deep recesses of the Rising Star System, in the absence of obvious taphonomic agents of accumulation such as carnivores, is not wholly unexpected. Further study may provide evidence for the manner and timing of both the hominin and cercopithecine fossil accumulations. A few fragments of owl bone (*Tyto* sp.) (Kruger and Badenhorst 2018) were also recovered in the Dinaledi Chamber and a number of small mammal remains have been recovered from the Lesedi Chamber (Hawks et al. 2017). However, these faunal remains do not have secure stratigraphic association with the *H. naledi* material in either locality. Additional geological, sedimentological and taphonomic analyses, as well as dating of the material from each locality, are underway to address such questions.

Overall, the Dinaledi Subsystem of the Rising Star Cave continues to be an anomaly among hominin fossil sites. However challenging, an alternate entrance into the subsystem has not been found and the Chute remains the only demonstrable access point. The newly discovered fossil localities also add complexity to the overall depositional situation. The presence of fossil material within extremely constricted passages as far as 40m from the Chute appears inconsistent with gravity-driven accumulation of bodies or skeletal elements from beneath this entrance into the subsystem. Additional targeted excavations, geological analyses and detailed taphonomic studies will be needed to resolve the numerous questions relating to how, when, and where the fossil material was deposited.

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COMPETING INTERESTS

The authors declare no competing interests

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