Interpreting access to the Dinaledi Subsystem by *Homo naledi*: redefining the "Chute" as a labyrinth

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Competing interests

The authors declare that no competing interests exist.

Abstract

A large assemblage of fossils attributed to the hominin species *Homo naledi* was originally discovered in the remote and difficult-to-access Dinaledi Subsystem of the Rising Star cave system, South Africa. Entry into this section by scientists and explorers has always been through a narrow and complex fissure network that includes a substantial vertical descent. This area was named the "Chute" and was described and illustrated in simplified form as a ~12 m vertical passage that gives direct access from the entry point into the chamber itself. However, due to the very constrained nature of the fissure network, previous descriptions of this space have not been based on detailed survey. In this paper, we provide the first detailed survey data and accurate spatial descriptions of the area between the Dragon's Back and the Dinaledi Subsystem, showing the full complexity of the horizontal and vertical fractures and

fissures that comprise the network connecting these spaces. To reduce misconceptions, we have renamed this space the "Chute Labyrinth" to highlight its true form. While some changes have occurred in the last 335 ka, these did not change the access from the rest of the cave into the Dinaledi Subsystem. The new spatial data and re-description of the space contextualize how *Homo naledi* individuals physically entered the Dinaledi Chamber via the Chute Labyrinth into the chambers below to dispose of their dead.

Keywords

Palaeoanthropology; Archaeology; Geology; Human Evolution; Speleology

Please note: All cave surveys are shown in plan view unless otherwise specified.

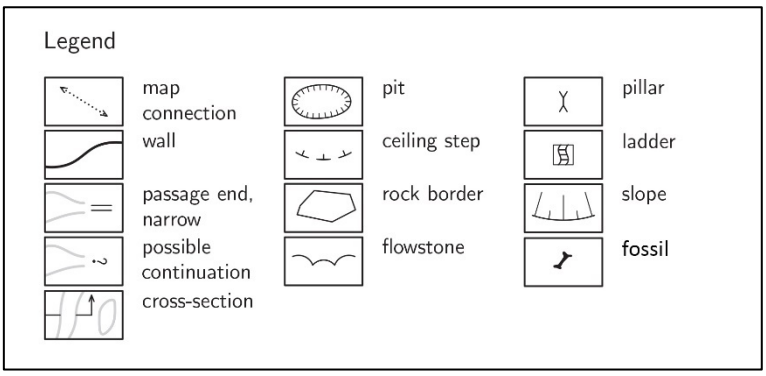


Figure 1. Legend to be used for all cave surveys.

Introduction

Fossils attributed to *H. naledi* were discovered in a remote part of the Rising Star cave system in 2013 and first described by Berger et al. (2015) and Dirks et al. (2015). The sedimentary deposits in this part of the cave system, known as the Dinaledi Subsystem (Elliott et al., 2021), contain abundant fossil material of *H. naledi,* including articulated body parts, but only a small number of fossils attributed to other macrofaunal taxa (Dirks et al., 2015; Berger et al., 2025a). This situation is unique in comparison to other fossil hominin assemblages worldwide (Dirks et al., 2015; Dirks et al., 2016), including hominin fossil rich cave sites such as Atapuerca, Drimolen, Krapina, Kromdraai, Malapa, Sterkfontein and Swartkrans (Brain, 1981; Russell, 1987; Arsuaga, 1997; Keyser et al., 2000;). The modes of deposition hypothesized for the formation of other fossil-bearing sites in the region (e.g. Brain, 1981; Berger & Clarke, 1995; Pickering et al., 2004) include waterborne transport of bones, carnivore accumulations, and natural falls into a cave system (Dirks et al., 2015; Dirks et al., 2016; Berger et al., 2025a). By contrast, within the Dinaledi Subsystem evidence shows

hominin entry into the subsystem (Dirks et al., 2015; 2016), hominin manipulation of remains, and burial of some bodies prior to decomposition of soft tissue (Berger et al., 2025a). Unlike other cave sites in the region, the Dinaledi Subsystem has almost no non-hominin macrofauna and lacks course-grained sediment input from outside the cave system (Dirks et al., 2015). The sedimentological observations mean that physical constraints to entry of sediment would have existed throughout the time *H. naledi* was present in the system and afterward (Dirks et al., 2015; Berger et al., 2025a). Exactly where such physical constraints were located and how they may have changed over time are central questions for understanding the behavioural evidence in the Dinaledi Subsystem, including the burial of *H. naledi* remains (Berger et al., 2025a) and other cultural uses of this space (Dirks et al., 2015, 2016; Berger et al., 2025b).

For today's teams working in the Dinaledi Subsystem, the difficult point of access into this subsystem from the adjacent Dragon's Back Chamber has previously been described as a ~12 m vertical and narrow passage. This area became colloquially known as the "Chute", which was the name given by the first scientific explorers in 2013 and first published in 2015 (Berger et al., 2015; Dirks et al., 2015). Due to the narrow confines of the Chute area, only a small number of scientists, including a few geologists, have entered this space, limiting the extent of first-hand observations. Instruments used by the original teams for mapping larger parts of the cave system were not capable of recording spatial data accurately within this space, which contains constrictions of less than 20 cm along the route and maximum widths of 50 cm.

Despite a lack of direct data from the Chute, many illustrations were published in the scientific and popular media that became critical to discussions of how *H. naledi* might have accessed the areas in and around the Dinaledi Chamber. This area was first illustrated in Dirks et al. (2015) as a vertical tube with a talus cone at the base (Dirks et al., 2015; Figure 3 and Figure 4), and then re-interpreted in multiple popular and scientific outlets (Figure 5 and see as examples Shreeve, 2015; Wong, 2015; Kruger et al., 2016; Durand, 2017), popularizing the idea that this space is a single narrow, vertical tube. While data from the Chute area have until now been extremely limited, teams have extensively investigated surrounding areas for other possible access points into the subsystem without result (Elliott et al. 2021; Berger et al., 2025a; Berger & Hawks, 2023). Thus, the images and superficial description of the Chute became prominent parts of the subsequent scientific discourse about the entry pathway by *H. naledi* into the subsystem.

Many authors have suggested either that there may once have existed a much easier alternative route into the underground spaces, or that the "Chute" was once much easier to traverse than it is today (e.g. Thackeray, 2016; Val, 2016; Durand, 2017; Pettit, 2022; Petraglia et al., 2023; Price, 2024; Foecke et al., 2025; Martinón-Torres et al., 2024; Pettit & Wood, 2024). Implicit or explicit within these comments is the idea that the ease of the route matters greatly to the credibility of the hypothesis of cultural use of the space. Some authors have considered it unlikely that a hominin with brain size as small as *H. naledi* might have accessed such a space via its present narrow constraints for cultural purposes (e.g. Val, 2016; Thackeray, 2016; Durand, 2017). In recent work describing the cultural burial of *H. naledi* remains within the Dinaledi Subsystem, this question of an easier route of access has been an important issue to those reviewing the evidence, so that this remains an outstanding issue related to the cultural phenomena under study (Berger et al., 2025a). Until now the evidence about the entry pathway comes from extensive observation of the contours and geological makeup of this pathway, the sedimentology of the Dinaledi Subsystem deposits, and the lack of faunal representation and other taphonomic aspects of the skeletal assemblage. Over the course of the 12 years since the discovery of the chamber have found no other viable entrance (Dirks et al., 2015; Randolph-Quinney, 2015; Dirks et al., 2016; Randolph-Quinney et al., 2016; Berger and Hawks, 2017, 2023; Robbins et al., 2021; Elliott et al., 2021). The sediment characteristics of the Dinaledi Subsystem are not consistent with any direct access from outside the cave system; this contrasts with the nearby Dragon's Back Chamber, for example, which experienced significant external sediment input during its history (Dirks et al., 2015; Robbins et al., 2021).

In this study, we build on this record with an intensive study of the access and egress spaces that comprise the only routes between the Dragon's Back Chamber and the Dinaledi Subsystem. The new survey has brought to light several ways that previous descriptions of the space have oversimplified the structure of these spaces, including illustrations of the main access route as a narrow vertical tube or chimney (e.g. Dirks et al., 2015; Berger and Hawks, 2017, 2023; Wiersma et al., 2020; Robbins et al., 2021). This intensive mapping exercise of the Chute area gives rise to a new understanding of the form of this space. With this new data, and imaging of the area, we explore the likelihood of various hypothesized uses of this space by *H. naledi*. We re-examine and reinterpret the shape and form of the space to address specific aspects of the hypotheses presented by Dirks et al. (2015) and others regarding the likely routes taken by ancient hominins into the Dinaledi Subsystem and the means by which

bodies of *H. naledi* reached the Dinaledi Subsystem. Finally, we introduce some new terminology related to these spaces to help to address misconceptions about their structure.

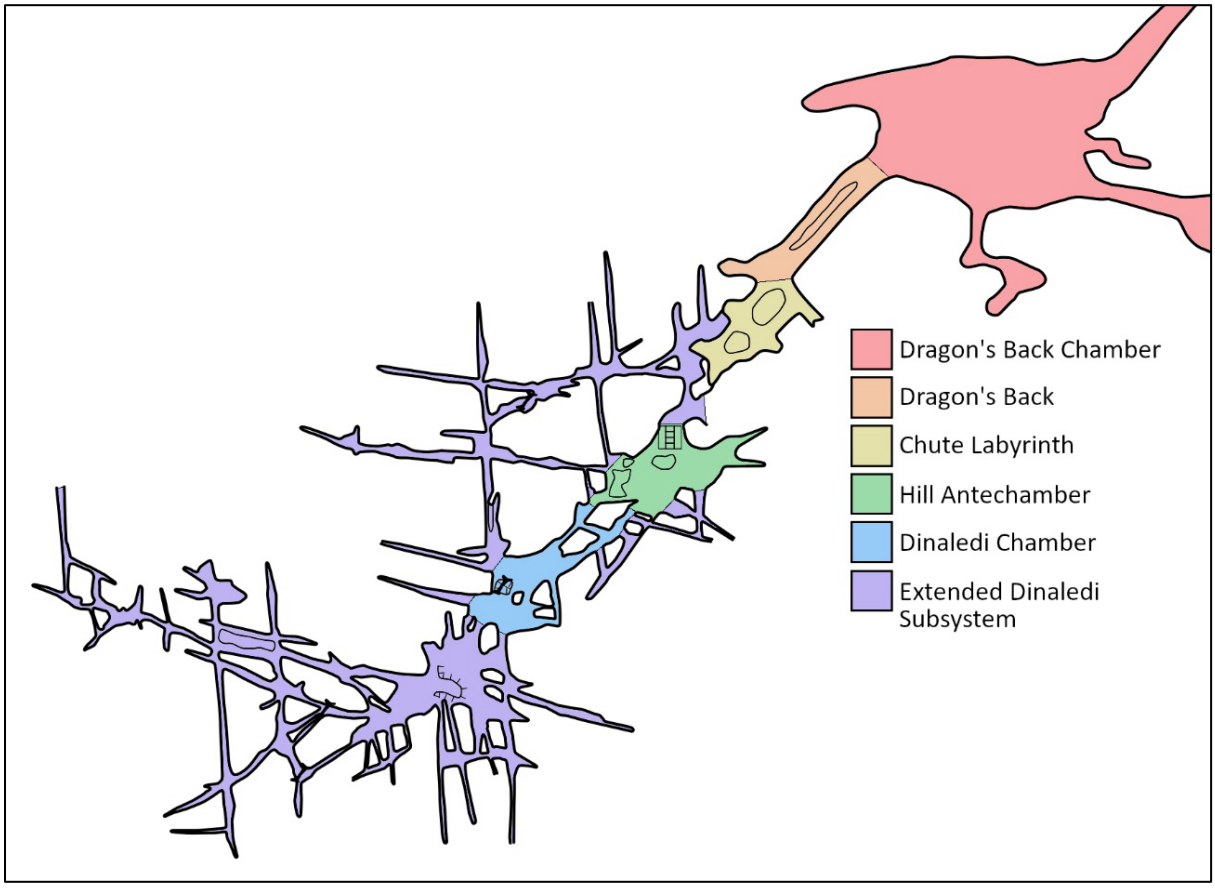
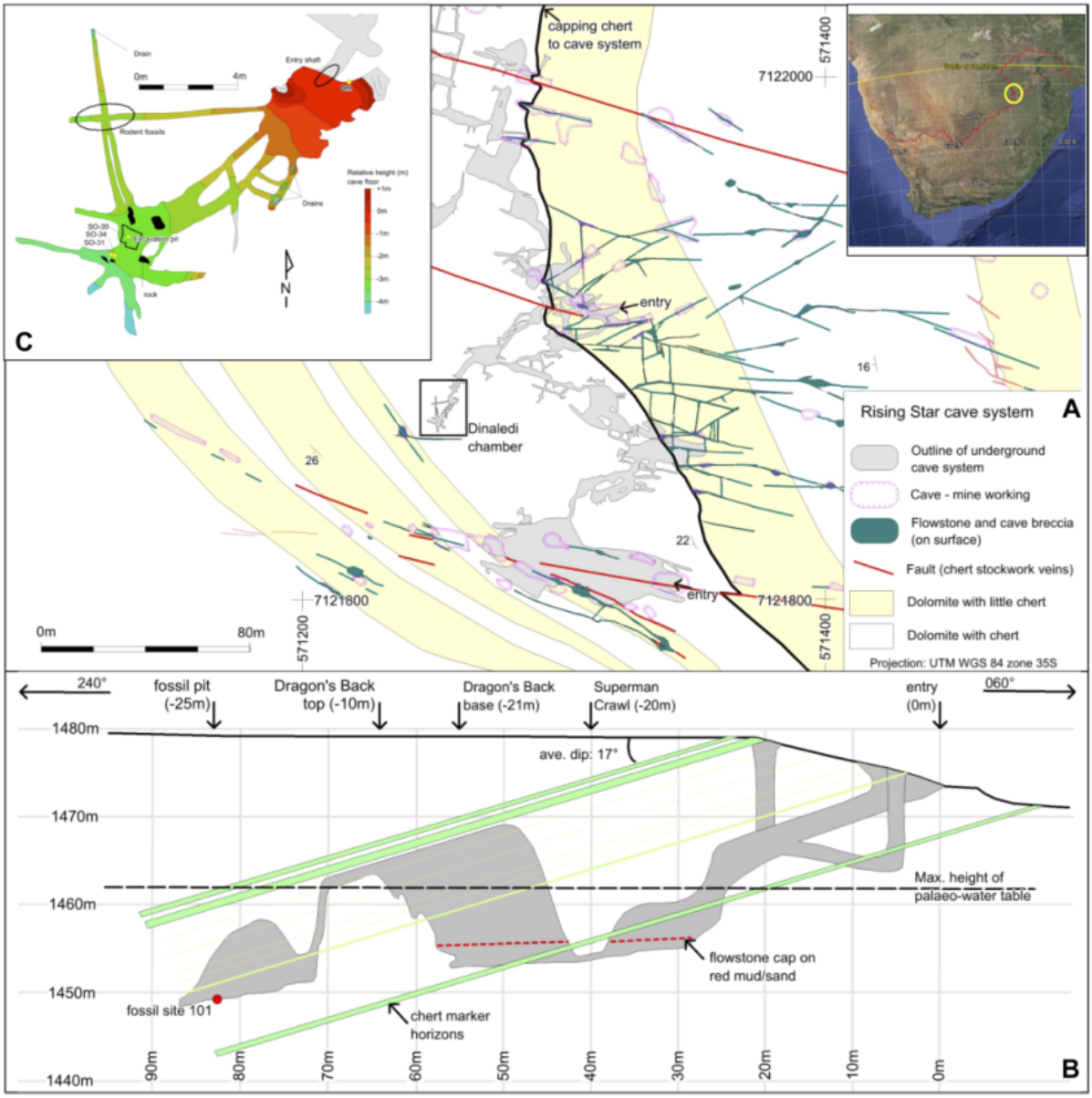


Figure 2. Survey showing the study area within the Rising Star cave system.



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126 **Figure 3. The first map published in Dirks et al. (2015) showing the simplified map of the cave from the closest**
127 **entrance to the Dinaledi Subsystem. Original image from *eLife* reused under CC-BY license.**

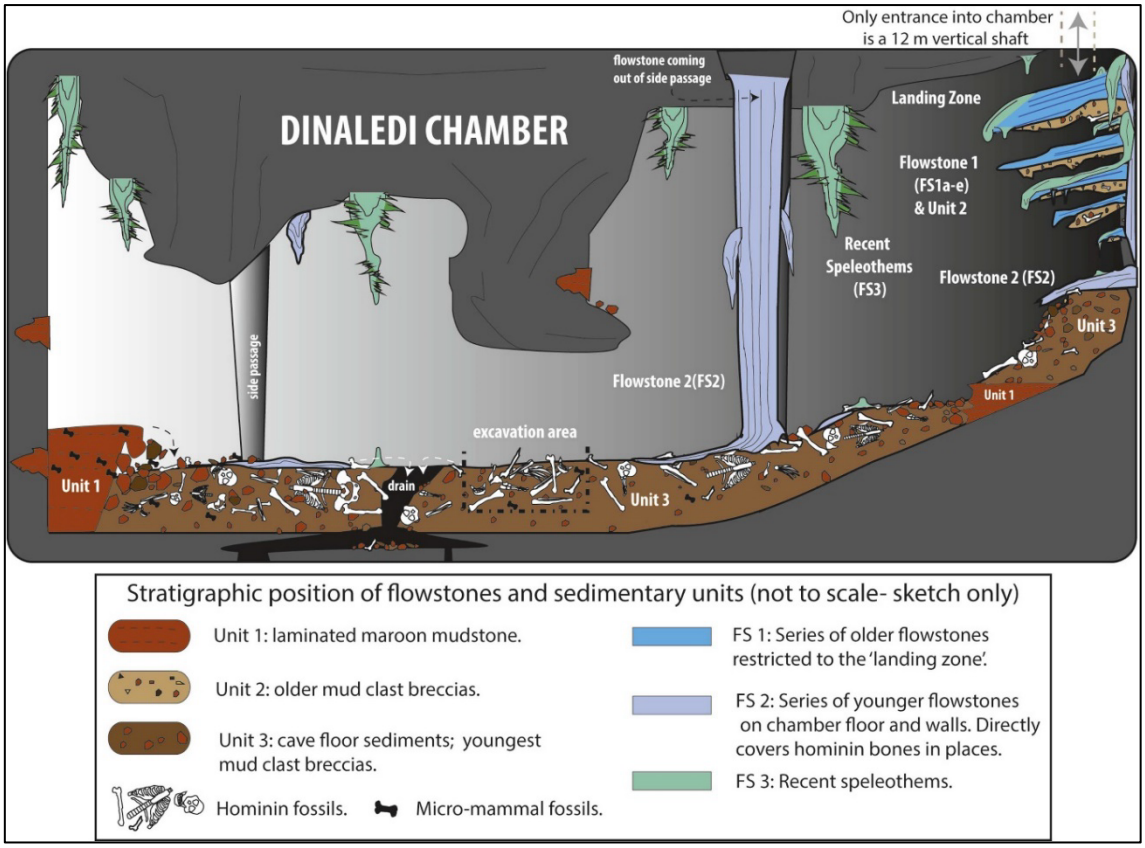


Figure 4. Profile view illustration published in Dirks et al. (2015) portraying the Chute as a ~12 m vertical shaft dropping directly into the Dinaledi Chamber. Original image from *eLife* reused under CC-BY license.

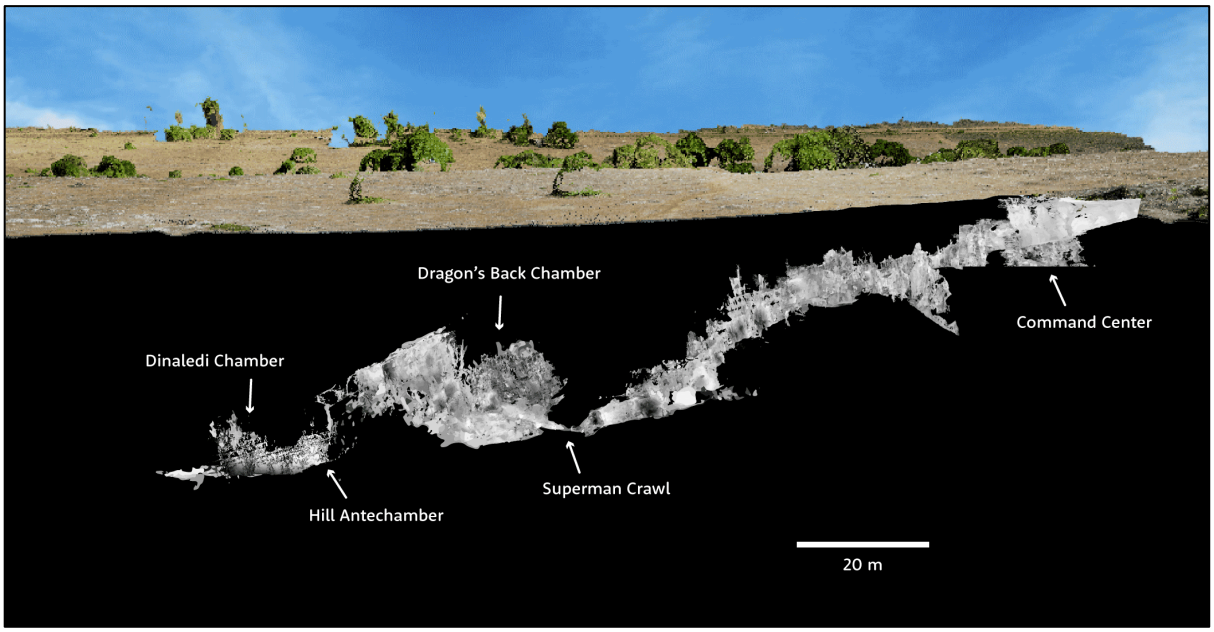


Figure 5. A simplified cross-section of the pathway through the Rising Star cave system from the surface toward the Dinaledi Chamber. This image was created based on scan data by JH and later used as a basis for illustrations in several press outlets. Nearly all the press and popular interpretations of the route into the Dinaledi Subsystem rely

upon this basic illustration, which shows the connection between the Dragon's Back Chamber and the Hill Antechamber as a single vertical chimney.

Rising Star cave system

Background

The Rising Star cave system is situated between 1450 m and 1480 m above sea level in the Blaubank River valley, in the Cradle of Humankind UNESCO World Heritage Site. Most of the accessible cave system surveyed to date sits within -40 m of the surface. The cave and its fossil assemblage attributed to *H. naledi* "represents one of the richest and most unusual taphonomic assemblages yet discovered in the hominin fossil record" (Dirks et al., 2017). The cave consists of over 4 km of total mapped passages covering an area of 250 x 150 m that is stratigraphically bound to a relatively chert-poor stromatolite-rich dolomite strata of between 15 and 20 m thick in the lower parts of the Monte Christo Formation with a gently west-dipping open fold of between 15 and 20 ° (Dirks et al., 2015; Dirks et al., 2017; Robbins et al., 2021; Wiersma et al., 2020). An intact capping chert horizon between 1 m and 1.3 m thick forms the upper contact of the cave and makes up the roof of several of the large chambers, including Dragon's Back Chamber and the Dinaledi Subsystem. This capping chert acts as a physical barrier preventing coarse-grained sediments and other larger objects from penetrating the chambers from the surface (Dirks et al., 2015; Robbins et al., 2021; Wiersma et al., 2020). The cave is typically observed as a network maze system of interconnected passages and cavities that developed along west-northwest, north, and northwest-trending faults and joints (Dirks et al., 2015; Robbins et al., 2021; Wiersma et al., 2020).

Dragon's Back Chamber

The Dinaledi Subsystem is a physically and geochemically isolated section of the Rising Star cave system ~30 m to ~35 m below the surface and ~80 m in a straight line from the closest present entrance. The subsystem can today only be reached via the Dragon's Back Chamber (Figure 6), which itself is currently accessible by only two principal routes (Robbins et al., 2021). The first route (and most frequently used for access today) is taken by; (1) entering the Skylight Chamber and going through Superman Crawl (Figure 5); (2) or by entering the Main Entrance, climbing down into the Postbox Chamber, and squeezing through the narrow constraint known as the Postbox (Figure 6). The Dragon's Back Chamber is large and open, with a high roof in some areas and flowstone ceilings in others. It is of significance to any

study related to *H. naledi* because of its location as the staging point into the Dinaledi Subsystem as well as the junction where two routes from different entrances intersect (Superman's Crawl and Postbox). As a structural catchment, the Dragon's Back Chamber acts as a form of trap preventing any coarse-grained sediments and high-energy water flow coming from present entrances from travelling past and entering the Dinaledi Subsystem. This is due to a 5 m high sill behind the Dragon's Back climb (Robbins et al., 2021) (Figure 7). The capping chert above a large part of the cave also covers this chamber, along with covering the Dinaledi Subsystem. This means that any material, apart from low-energy water, airborne dust, and only the finest-grained sediments, cannot penetrate the ceiling and must travel through the Dragon's Back Chamber to get to the Dinaledi Subsystem (Dirks et al., 2015; Robbins et al., 2021).

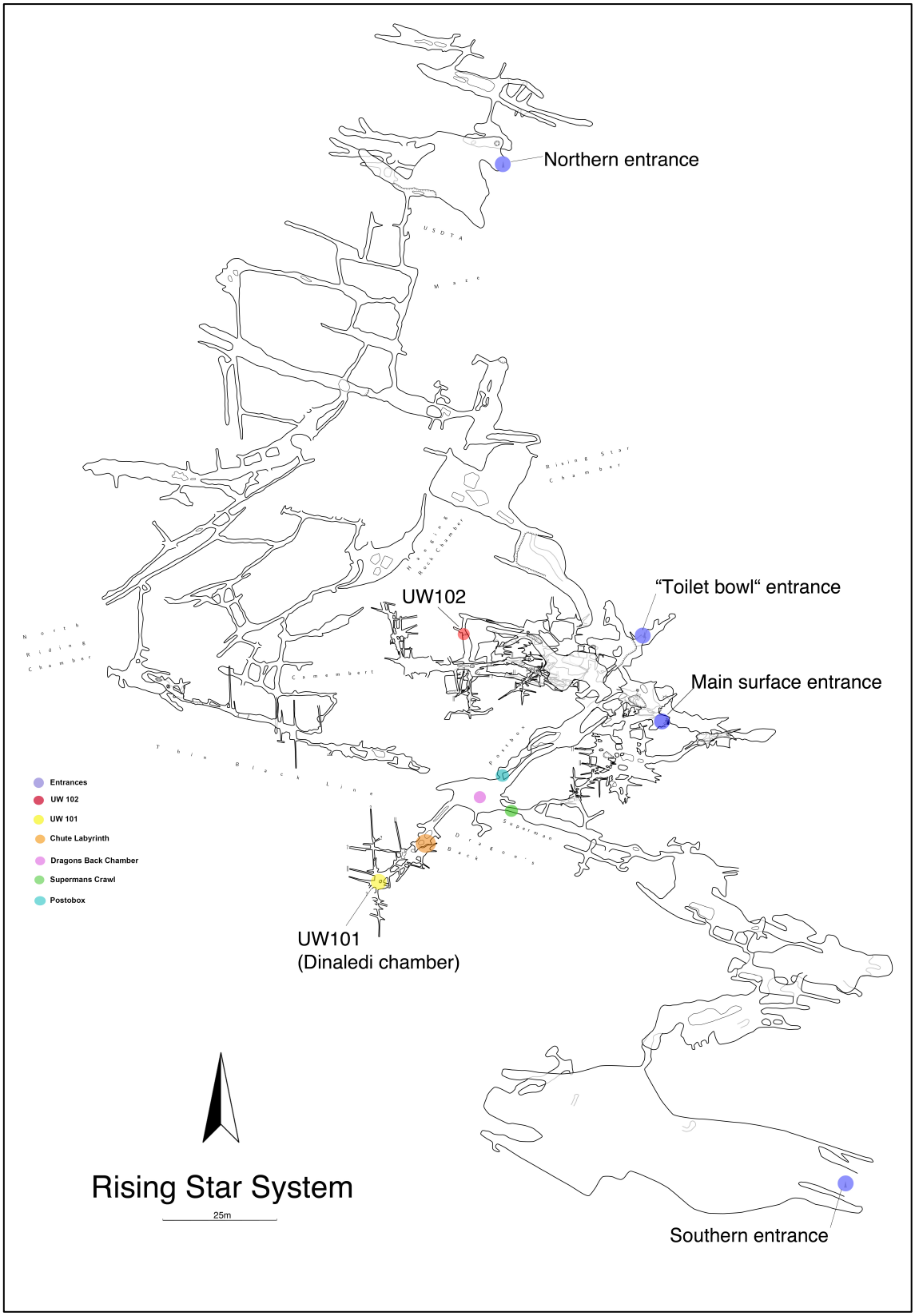


Figure 6. Localities referred to in the text.

The structure known as the Dragon's Back is a narrow ridge of rock that rises as a continuous septum within the centre of a tall, narrow extension of the Dragon's Back Chamber. Cavers

today can ascend the Dragon's Back beginning near its northeastern end, where it is ~3 m high from the floor of the Dragon's Back Chamber, and continue southwest along the narrow ridge, surmounting three pinnacles, to a height of ~12 m above the chamber floor. Upon reaching the highest point, cavers must cross a gap where a wooden bridge has been erected, upon which they reach an elevated platform that has multiple entries into a complex fissure network. The passage known as the Chute is the entry into the fissure network that is furthest from the Dragon's Back (Figure 19).

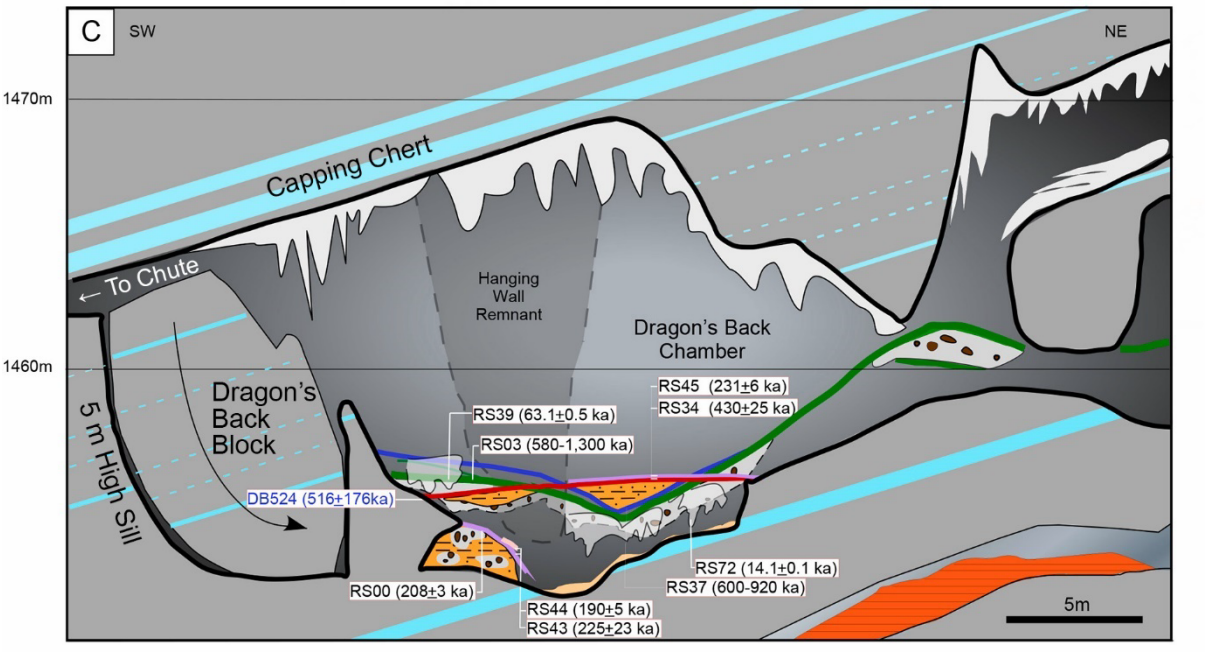


Figure 7. Schematic profile view of the Dragon's Back Chamber showing the collapse and rotation of the Dragon's Back block, as well as the flowstones and sedimentary units in the chamber (Robbins et al., 2021, used with authors' permission).

Chute Labyrinth

We are naming and describing here for the first time the *Chute Labyrinth*. The name *Chute Labyrinth* was chosen because it better describes the space as a complicated, multileveled network of fractures and fissures. This network is both small in terms of the size of the passages, crawls, and climbs, as well as in terms of the spatial area of the cave that it covers, which is only ~13 x 13 x 8 m. As Robbins et al. (2021) put it: "Currently, entry to the Dinaledi Chamber is complex." Even though there are several routes to get to the Dragon's Back Chamber, there is no other observable entry point to get into the Dinaledi Subsystem other than via the Dragon's Back route, nor is there visible evidence there ever were any other entrances. There is also no evidence to suggest that other entry points existed in the past which have since been blocked off due to sediment accumulation, collapse, or flowstone

development (Dirks et al., 2015; Dirks et al., 2017; Robbins et al., 2021). Again, this is supported by the lack of course-grained sediments and macro-fauna fossils apart from *H. naledi* in the Dinaledi Subsystem.

A note is necessary here regarding the relationship of the Dragon's Back structure with the *Chute Labyrinth*. Previous work by Robbins et al. (2021) and by Elliott et al. (2018), did not make clear the relationship of the Chute to the Dragon's Back block, and to avoid further confusion we describe this relationship here. The Dragon's Back structure largely consists of a single large dolomite block formed the host bedrock, which includes chert horizons. These chert horizons can be correlated to the same chert bands in the walls of the surrounding chamber, which show that the block that comprises the Dragon's Back was once attached to the chamber ceiling and at some point fell by approximately 60 cm, with 10° of rotation (Robbins et al., 2021) (Figure 7). The estimated date for this event is sometime between 225 ka and 290 ka, based on an argument that an underlying flowstone is a maximum age and sediments at the start of the Dragon's Back climb are a minimum age (Robbins et al., 2021). The vertical displacement of this block was limited by large boulders that underlie it today, and at its southwestern end the block lodged itself against a pinnacle which forms a 5 m high sill that acts as a physical barrier between the Dragon's Back Chamber and Dinaledi Subsystem (Robbins et al., 2021) (Figure 7). The Dragon's Back block does not impinge upon the Dinaledi Subsystem, and as such, if the Dragon's Back block were not in its current position, a climb of the 5 m sill would still be necessary to access the *Chute Labyrinth* as described below (Robbins et al., 2021). We know this because (1) the Dragon's Back structure does not have a solid base but rather the major block is supported upon a series of boulders, and these boulders must be squeezed around to get to the area below the block; and (2) as previously mentioned, the sill has always been a barrier stopping water from transporting course-grained sediment into the Dinaledi Subsystem. This evidence indicates that there are no alternative routes beneath or behind the Dragon's Back block apart from going up the sill and through the *Chute Labyrinth.* If an alternate, easier or more direct route existed between the rest of the cave and the Dinaledi Subsystem, it would be demonstrated geologically in the form of courser grained sediments, evidence of high-energy water flow and the presence of other macro-faunal remains. Thus, the geological change represented by the vertical displacement of the Dragon's Back block is irrelevant to the constraints of the various spaces within the *Chute Labyrinth*, which are themselves the key limitation on access into the Dinaledi Subsystem both now and in the past.

Methodology

Surveying

The surveying technique we employed is called the Paperless System (Heeb, 2008; Redovniković et al., 2014; Trimmis, 2018; Tucker, 2015; Tucker et al., 2018) in which a handheld device with a built-in laser rangefinder, compass, and inclinometer called the Leica Disto X2 (similar technology to LiDar) is used to take digital measurements of the spaces being surveyed and sends them to a smartphone or tablet where an app called Topodroid is used to store and manage the data in real-time. It is then transferred to a computer for further processing in a program called Therion which is used to generate the survey data into several 2D and 3D exports. This system is more accurate, and faster to use than traditional cave surveying methods such as measuring tape, compass and inclinometer, while being significantly more compact and lightweight than a total station (Almeida-Warren et al., 2020; Redovniković et al., 2014; Tremmis, 2018; Tucker, 2015). Accuracy within a mean error of ~5.00 cm for horizontal readings and ~2.00 cm for vertical readings can be achieved when using the hand-held device (Almeida-Warren et al., 2020). This technique has been the standard surveying method used by caving clubs internationally for the last 20 years and there are several variations of the devices, apps and software (Trimmis, 2018; Tucker, 2015). It is the fastest and most efficient way to create accurate maps of complex cave systems in challenging and technical environments where harsh conditions limit the use of sometimes bulky and often sensitive equipment such as LiDar or photogrammetry. A higher frequency of splay data can be generated in a shorter time frame compared to a total station which translates to a more detailed map. The calibration required for a DistoX2 is faster than the setup and reference required each time a total station is used (Almeida-Warren et al., 2020; Redovniković et al., 2014; Tucker, 2015). Difficult obstacles to overcome with a total station such as surveying in confined spaces and irregular or uneven terrain such as that experienced in the *Chute Labyrinth* are made easier due to the size and portability of the device. For the purposes of this study attempting to demonstrate the complexity of the Chute Labyrinth, the accuracy and error of this method are adequate.

Complex subterranean spaces like the Rising Star system are challenging to portray within the constraints of publications using two-dimensional maps. Attempts to portray these spaces come with a danger of creating misconceptions through oversimplification. Researchers working in the Rising Star system have, to mitigate this, released substantial video and 3D material to help enable researchers and the public to better understand the spaces in Rising

Star. Still, due to its extremely narrow spaces, the *Chute Labyrinth* has never before been fully mapped or published due to the constraints previously described. Even with the major technological advances that have been made in recent years in the fields of mapping and 3D imaging such as photogrammetry and LiDar, complex, small, 3-dimensional spaces such as the *Chute Labyrinth* are still very hard to accurately portray, whether it is within the constraints of publications or not. We make use of mostly two-dimensional maps in this study supplemented with photos to illustrate the different spaces by simplifying them and making them understandable while retaining dimensional accuracy. 3D imaging technologies using LiDar and photogrammetry can be used to supplement 2D maps, but they are difficult to decipher on their own due to the complexity of the mapping area. Because of this, the spatial data must be processed in the field in real-time to filter out the 'noise' created by irregularities in the cave and the only technology currently capable of this is the Paperless System. We have created LiDar models of caves before which results in massive datasets that need to be cleaned up and rendered before a useful model or map can be created. This only works if the surveyor is very familiar with the scanned spaces and knows which features are important and which can be excluded to simplify the model into something useful and understandable.

Results

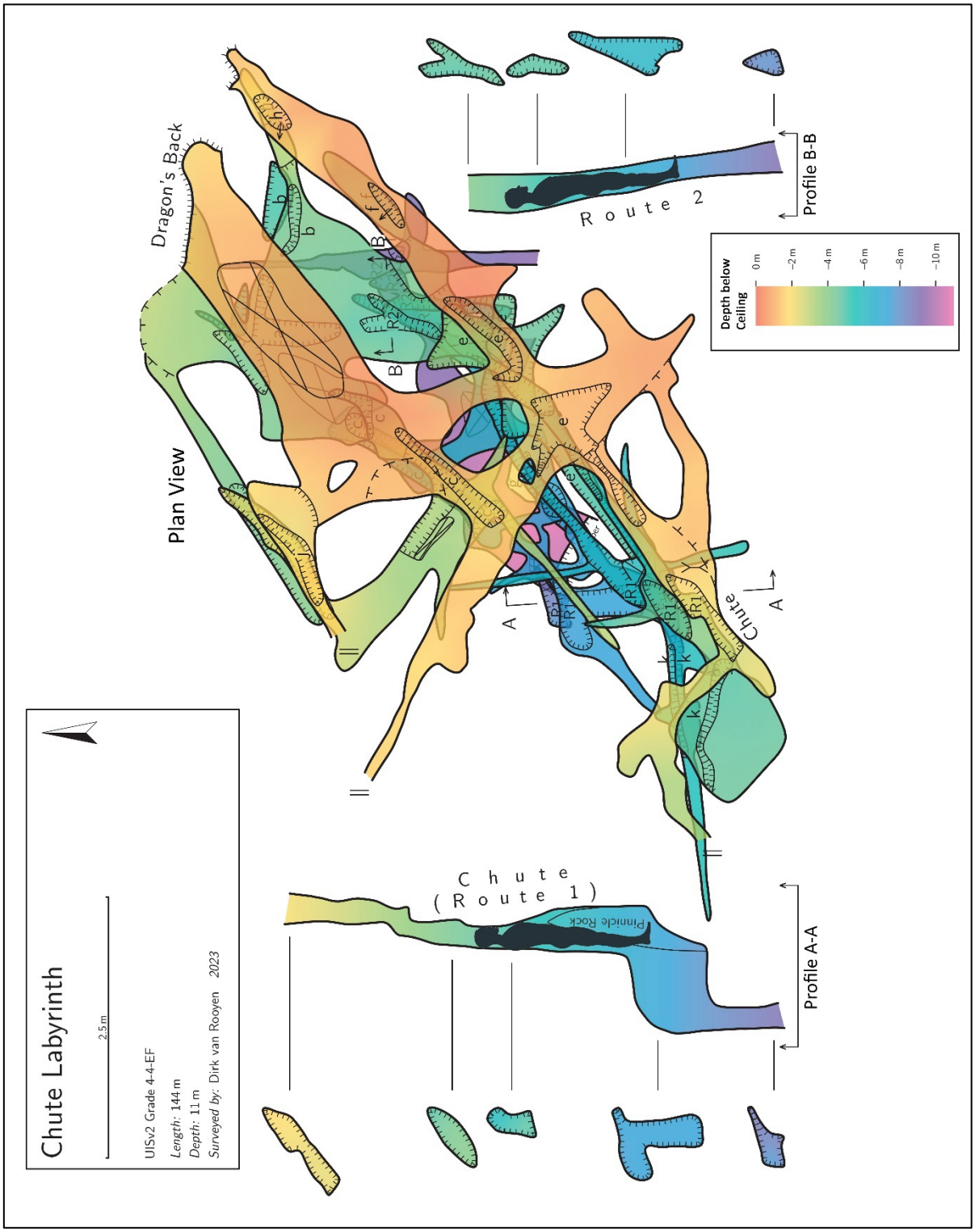
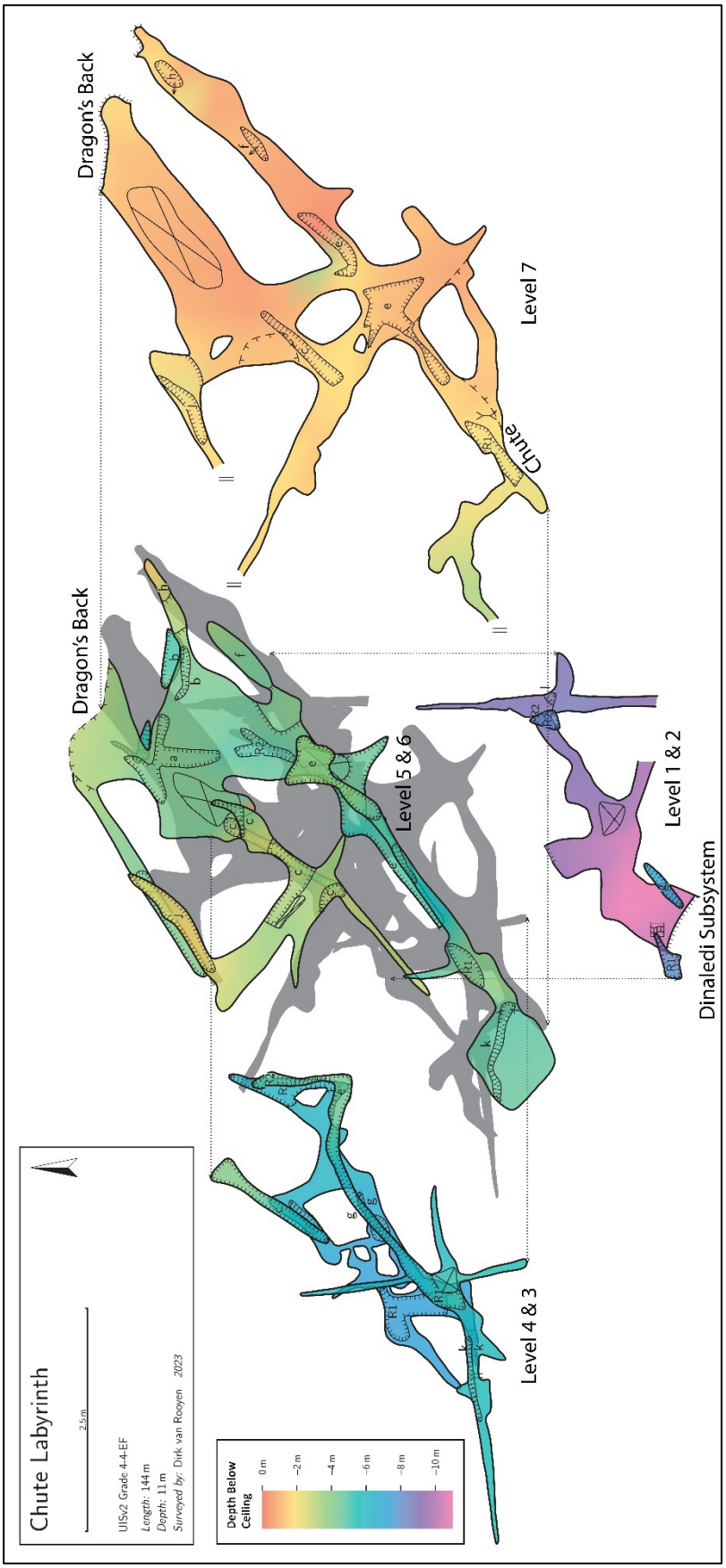


Figure 8. Survey of the *Chute Labyrinth* consisting of all seven overlapping levels at varying heights. Two profile views show Routes 1 & 2 to get to the Dinaledi Subsystem.



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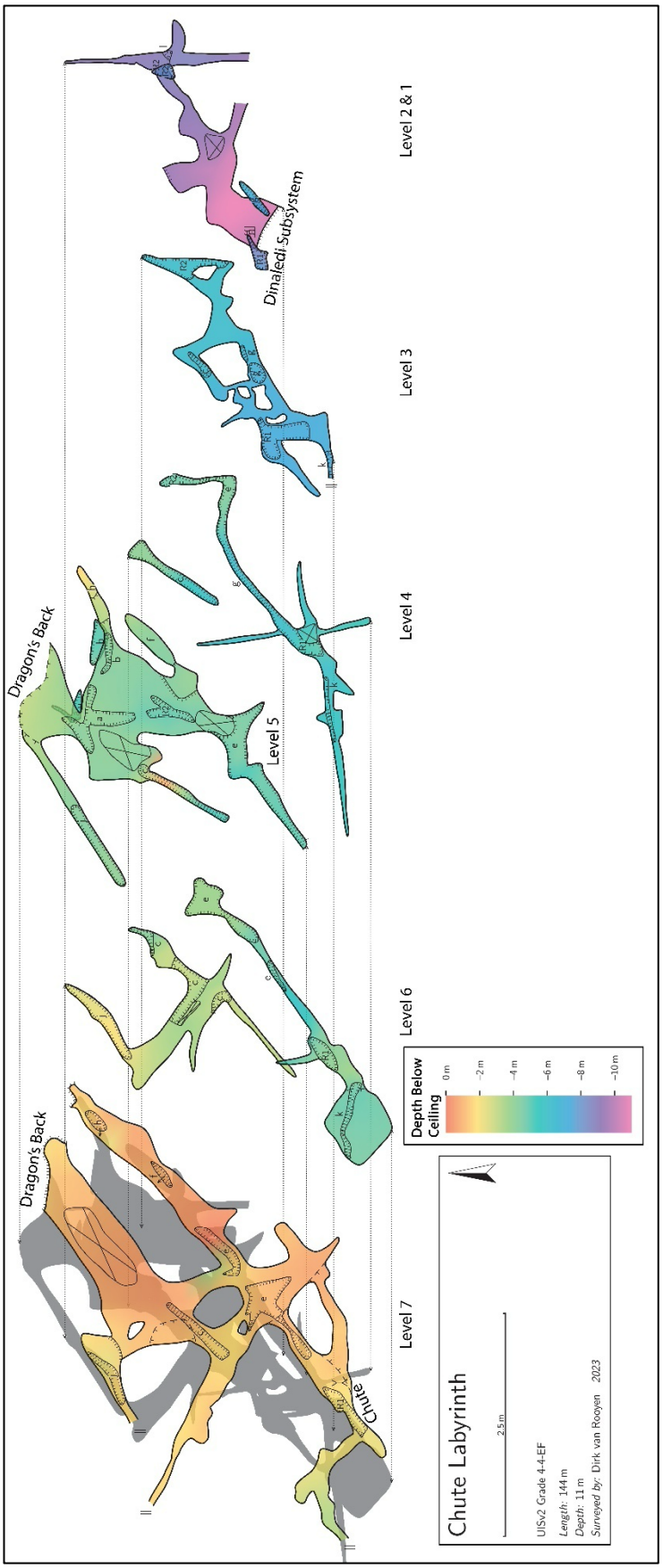
292 **Figure 9. Survey of the *Chute Labyrinth* with offset views of the different levels.**



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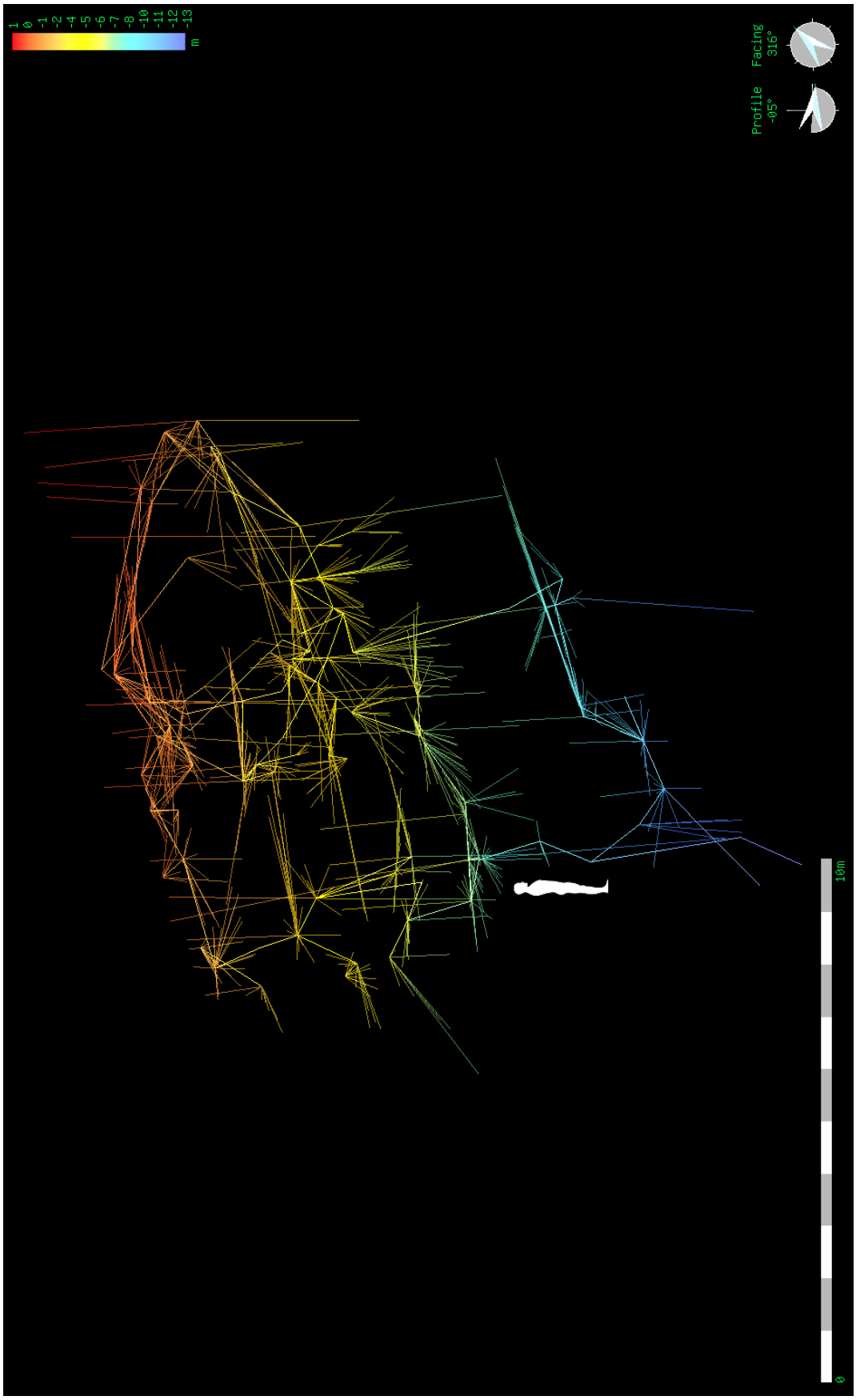
294 **Figure 10. Survey of the *Chute Labyrinth* with offset views of each level individually.**



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296 **Figure 11. 3D view of the shot data to illustrate the *Chute Labyrinth*'s complexity. Note the slight incline of all the**
297 **subhorizontal levels (top is left, bottom is right).**

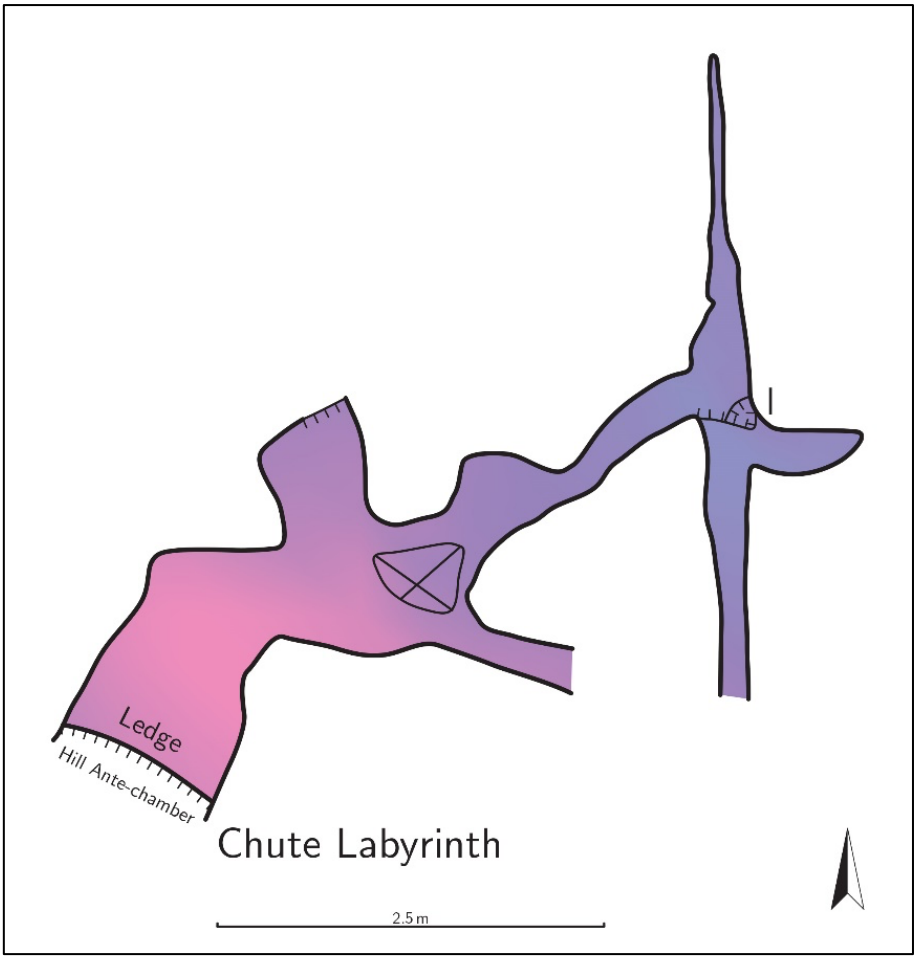
Layout

While surveying, it became apparent that we would need to divide the *Chute Labyrinth* into different levels due to its complexity and the presence of overlapping sections which are difficult to display on two-dimensional maps. A total of seven levels were created with *Level 1* being the lowest in the Hill Antechamber and *Level 7* being the highest at the top of the Dragon's Back. The five levels in between are a combination of crawls, squeezes, small chambers, and chimneys that connect the levels in multiple areas. The levels consist of chimneys and passages that intercept each other at various points, some of which can be navigated by small-bodied and experienced cavers and some that are too small to access. To better illustrate the relationship between the vertical spaces and show where each level connects with its upper and lower levels, we have given the corresponding chimneys unique letters. The chimney labelled with the letter "*e"* for instance as illustrated on the map at different levels indicates that they connect at each level where the letter is shown. The chimneys are essentially vertical passages between the different levels, with some running across all the levels and others only across two or three.

The seven different levels and access between them consist of the following:

Level 1

This level is ~11.1 m below the ceiling of *Level 7* and is the lowest level in the *Chute Labyrinth*. It is essentially part of the Hill Antechamber, although in this study it relates to the area slightly above this chamber starting on a ledge right below the *Chute Labyrinth*'s lowest entrance (*Route 1* or *R1*) as well as the small section further to the northeast where *Route 2 (R2)* offers access into (see *Routes*) (Figure 12) the Hill Antechamber. This whole back section is called colloquially the *Ledge* and the three open passages continue to small extensions that are not on this survey.



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323 **Figure 12. *Level 1* or the *Ledge* which is towards the northeast and above the Hill Antechamber.**

324 ## Level 2

325 This level is ~7.2 m below the ceiling of *Level 7* and consists of three chimneys connecting
326 the *Chute Labyrinth* with the area below it which is the Hill Antechamber and the *Ledge*
327 section to the northeast (Figure 13). The westernmost chimney, or the chimney closest to the
328 Hill Antechamber, is *R1*, while *Chimney g* to the east is another hole connecting the same two
329 spaces as *R1* but is inaccessible by humans as it is very small. The third chimney to the
330 northeast is where *R2* enters the Dinaledi Subsystem at the back of the *Ledge* section.

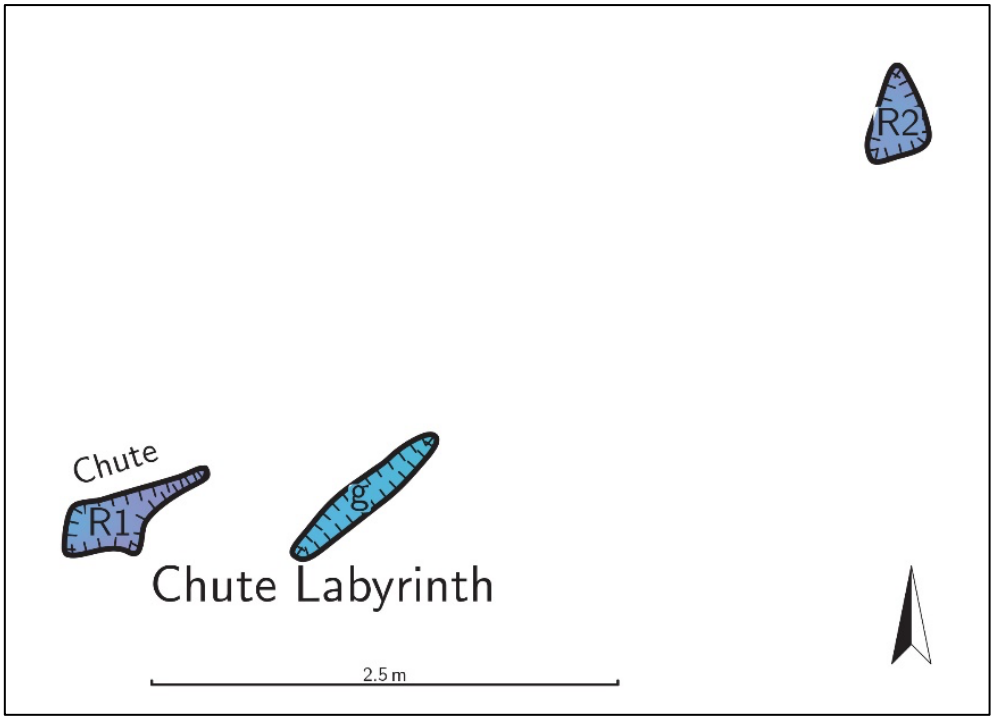


Figure 13. ***Level 2*** **where the chimneys of** ***R1*** **and** ***R2*** **drop down into** ***Level 1*****.**

Level 3

Level 3 is right above *Level 2* and consists of a narrow maze-like passage connecting *R1* and *R2* vertically (Figure 14). This is the only passage connecting the two routes that are accessible, although it is very small. *Chimney g* connects to *Levels 2* and *4* while *Chimney c* only connects to *Level 4*. This level is ~6 m below the ceiling of *Level 7* and even though the area is confined, it is the most spacious part of *R1*.

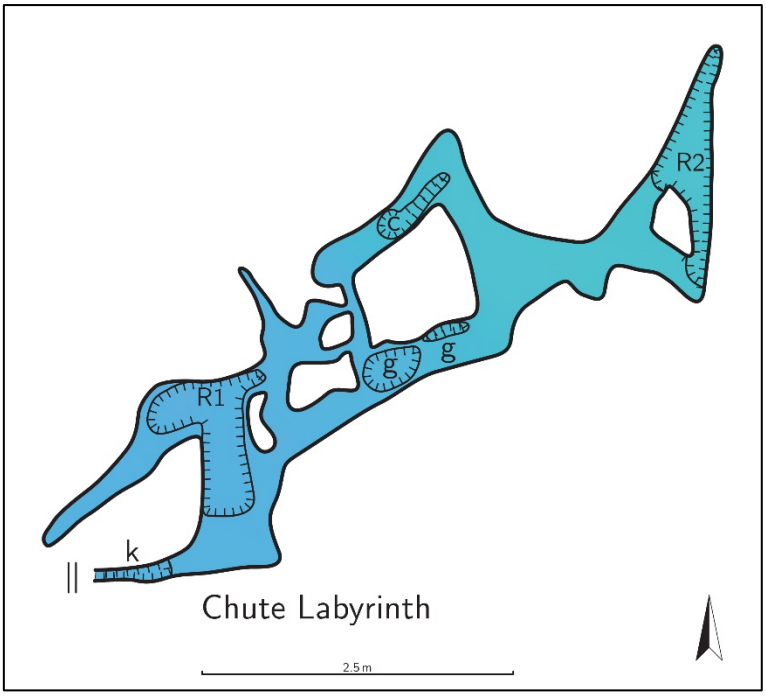


Figure 14. ***Level 3*** **which is the most spacious part of** ***R1*** **and the only connection between** ***R1*** **and** ***R2*****.**

Level 4

The smallest part of *R1* is on this level because of a block named the "Pinnacle Rock" that is partly obstructing the passage (Figure 15). A caver is required to climb over this rock and squeeze past a pinch point less than ~20 cm in width between it and the surrounding walls. A few small fissure passages shoot off in different directions including to the west where *Chimney k* connects with *Levels 3* and *5*. To the northeast, *Chimney g* forms a long and narrow crack connecting *Levels 3* and *5* at an incline curving down towards the northwest. This crack connects *R1*, *Chimney g*, Chimney *e* and *R1* vertically, although the areas cannot be accessed on this level. The lower extensions of chimneys *a, b* and *c* are also on this level while their access points are on *Level 5*. *Level 4* is ~4.5 m below the ceiling of *Level 7*.

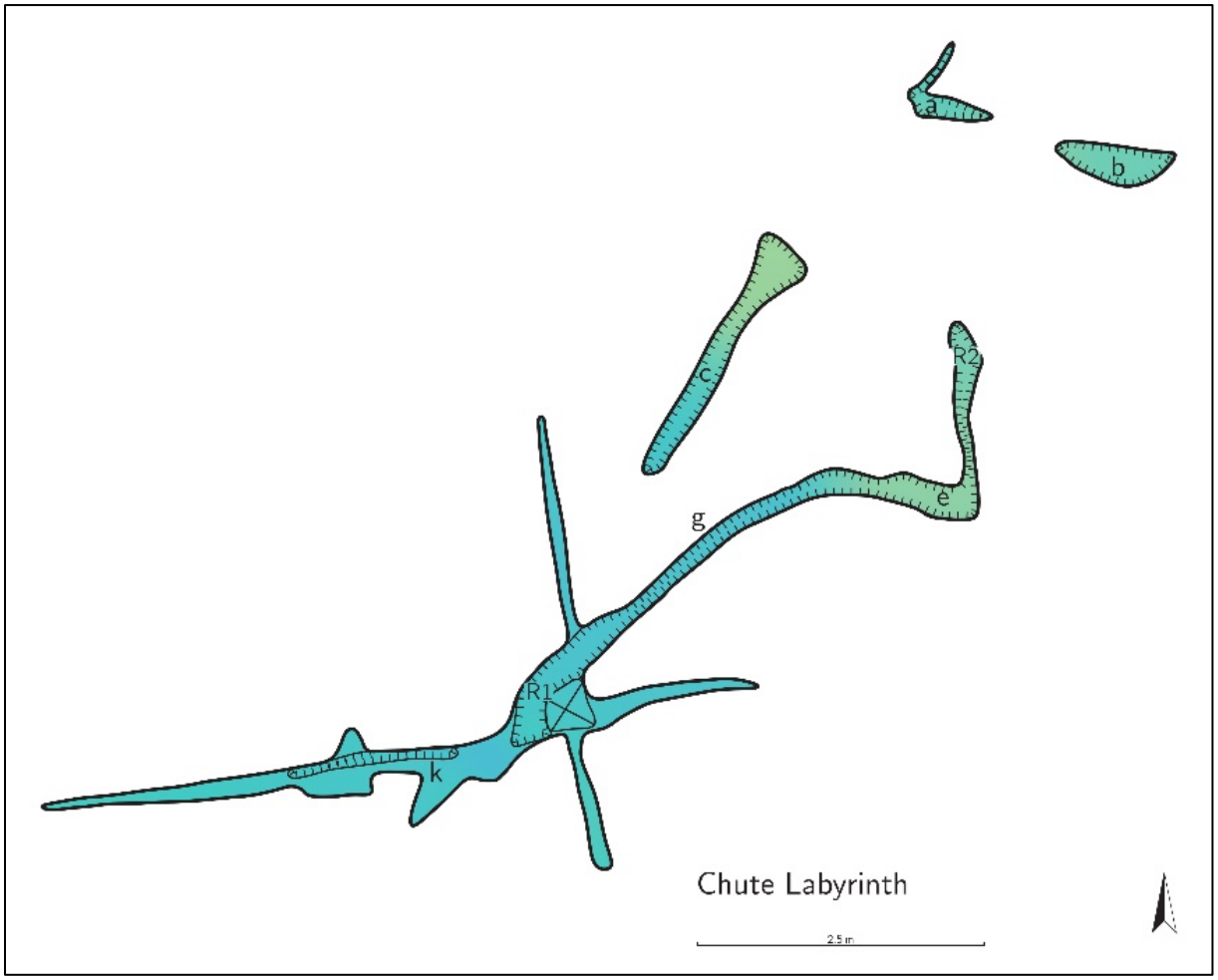
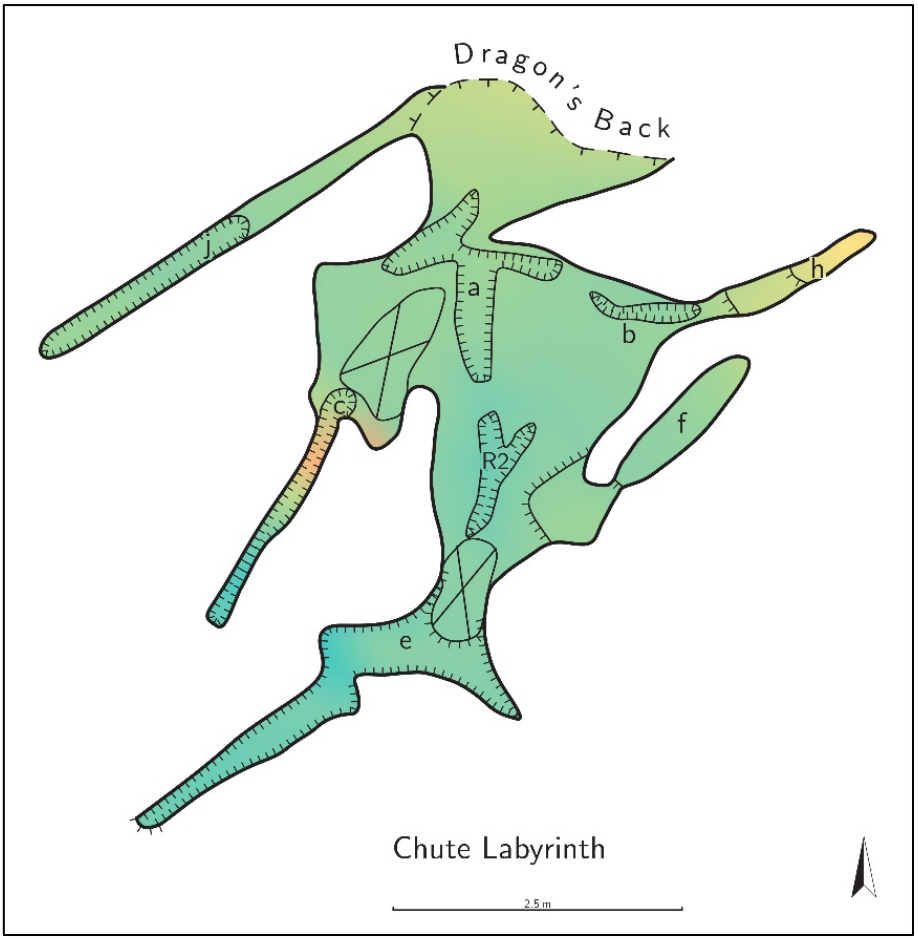


Figure 15. ***Level 4*** **where the pinnacle rock in** ***R1*** **is located.**

Level 5

This level is ~5 m below the ceiling of *Level 7* and consists of a small chamber which is accessed by climbing down and to the right from the top of the Dragon's Back instead of crossing the bridge towards *Level 7* and the top of *R1* (Figure 16 & Figure 17). Before entering this chamber, a small tunnel can be seen leading southwest to *Chimney j* which is not accessible. Once in the chamber, several chimneys are visible in the floor which lead down to lower areas. Chimneys *a* and *b* pinch out lower down in *Level 4* while the chimney to the south is the start of *R2*. *Chimneys h* and *f* drop down into this small chamber from *Level 7*. Two additional routes can be accessed by squeezing over rocks, one to the southwest which leads to Chimney *c* but is inaccessible from this level, and one towards the south past the entrance to *R2* which leads to *Chimney e*. This squeeze opens slightly into a crack that gives access to both *Chimneys e* and *g* and can be used to squeeze further down to *Level 3* where *R1* can be accessed. This route seems possible to navigate but is very small and has not been successfully attempted.



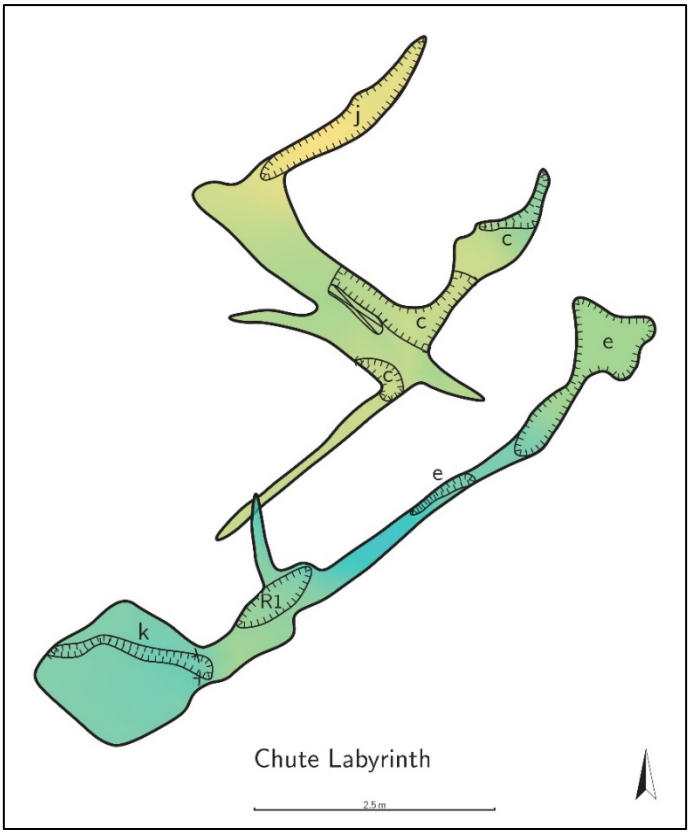
367

368 **Figure 16. The small chamber of *Level 5* where the start of *R2* is located.**

Figure 17. Photo of *Level 5* showing chimneys *a, b* and *R2* viewed from above. Markings on scale bar are 10 cm.

Level 6

This level is ~3 m below the ceiling of *Level 7* and consists of a narrow crack connecting *Levels 5* and *7* vertically and *R1* with *Chimney e* and *k* horizontally, although *R1* and *Chimney e* are not accessible on this level (Figure 18). *R1* is fully in the southeasternmost fracture on this level and travels vertically straight up to *Level 7* from here. *Chimney k* is located in a small and flat area adjacent to *R1*. Another separate area on this level can only be reached by climbing down *Chimney c* in *Level 7* after which it opens up slightly and separates the upper chimney into three, all of which continue further down but pinches out. The south westernmost of these chimneys does have a connection to *Level 3*, but it is completely inaccessible. This area also has a small connection to *Chimney j,* but it is also inaccessible.



381

382 **Figure 18. *Level 6* which consists of two separate areas, the most northern of which can only be reached through**
383 ***Chimney c* in *Level 7*.**

384 ## Level 7

385 The uppermost level is also the largest and connects the top of the Dragon's Back with *R1*
386 (Figure 19). It is the only level stretching across the parallel fractures I, II and III (Figure 20).
387 The top entrance to *R1* can be reached at the furthest point away from the Dragon's Back in
388 the southeastern fracture. Several chimneys lead from this level to lower levels, including *c*,
389 *e*, *f*, *h* and *j*. This level has a low ceiling consisting of the capping chert that covers a large
390 part of the cave.

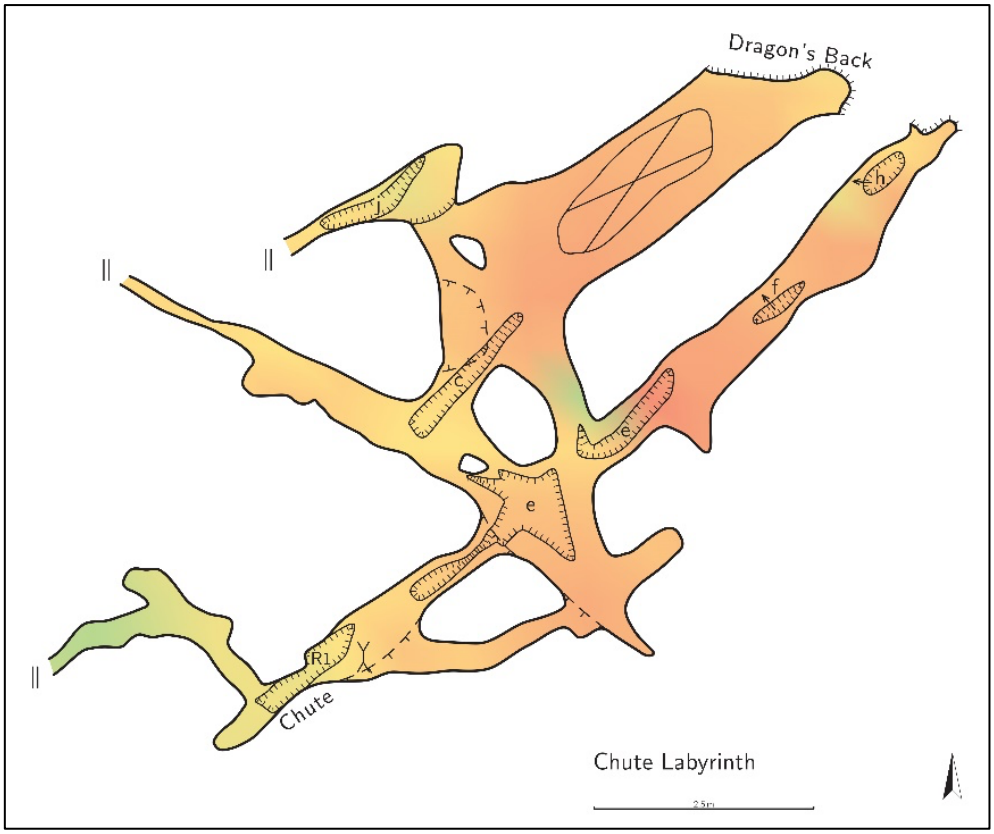


Figure 19. ***Level 7*** **which is the uppermost and largest level of the** ***Chute Labyrinth*** **where the start of** ***R1*** **is located.**

Fractures

The *Chute Labyrinth* developed across three subparallel fractures (*I, II* and *III*) with a southwest-northeast orientation (Figure 20). One major intercepting fracture (*IV*) can be identified with a northwest-southeast orientation which runs perpendicular to the three parallel fractures. Several additional passages developed along small fractures and fissures at different angles, but they are mostly inaccessible to us. It is important to note that *R1* starts in *Fracture III* in the upper level but as it travels down, it moves over laterally to the northwest and ends up in *Fracture II* before it drops into the Hill Antechamber. Not only is *R1* not vertical, but it travels across two parallel fractures ~2.5 m laterally.

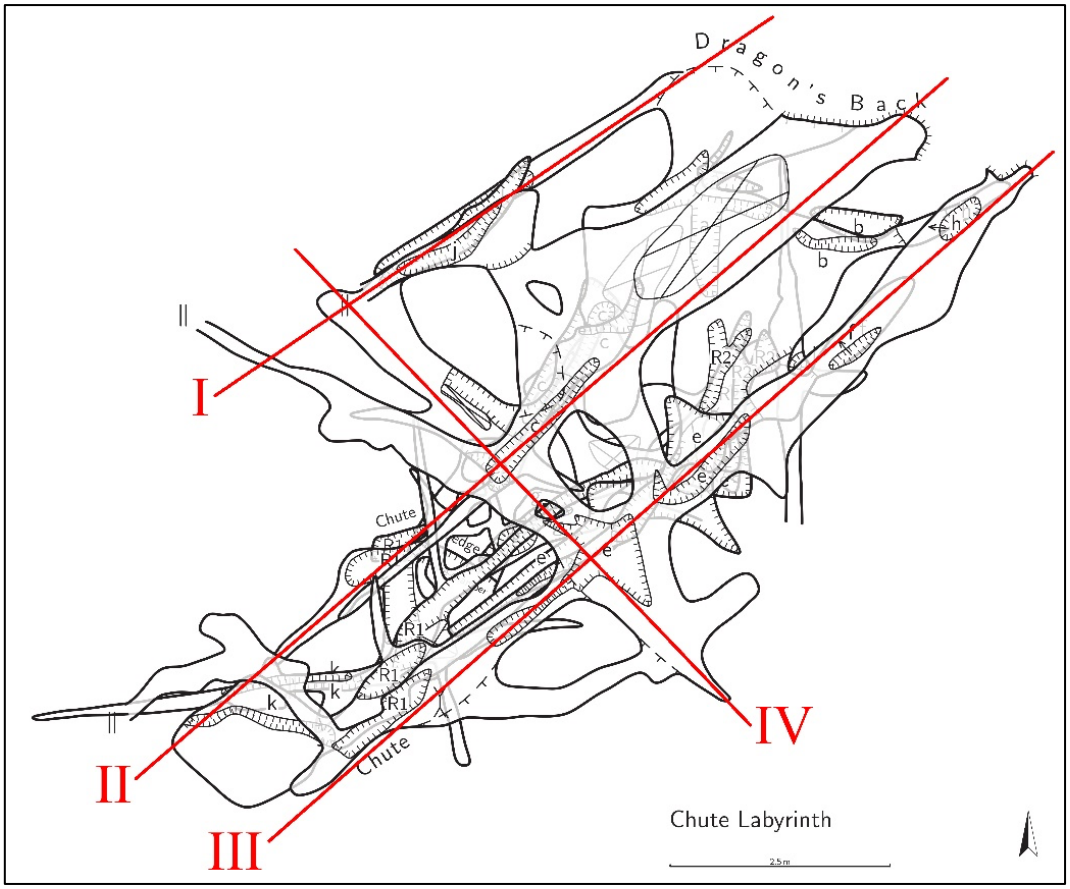


Figure 20. Survey of the *Chute Labyrinth* with the major fractures shown in red. The fractures are numbered for easy reference. All levels are shown.

Flowstones

During exploration work in the *Chute Labyrinth*, we observed at least two passages that are partially restricted by the formation of three flowstones. The first (*CL1)* is located at the start of a small passage in *Fracture I* when facing southwest from the Dragon's Back in *Level 5* which leads to *Chimney j* (Figure 21). The flowstone is growing on the right-hand wall when looking into the passage as well as below it. Even though the flowstone partially restricts the entrance into the passage, the walls of the passage just after the flowstone are very narrow and would not allow access even if the flowstone was not present.

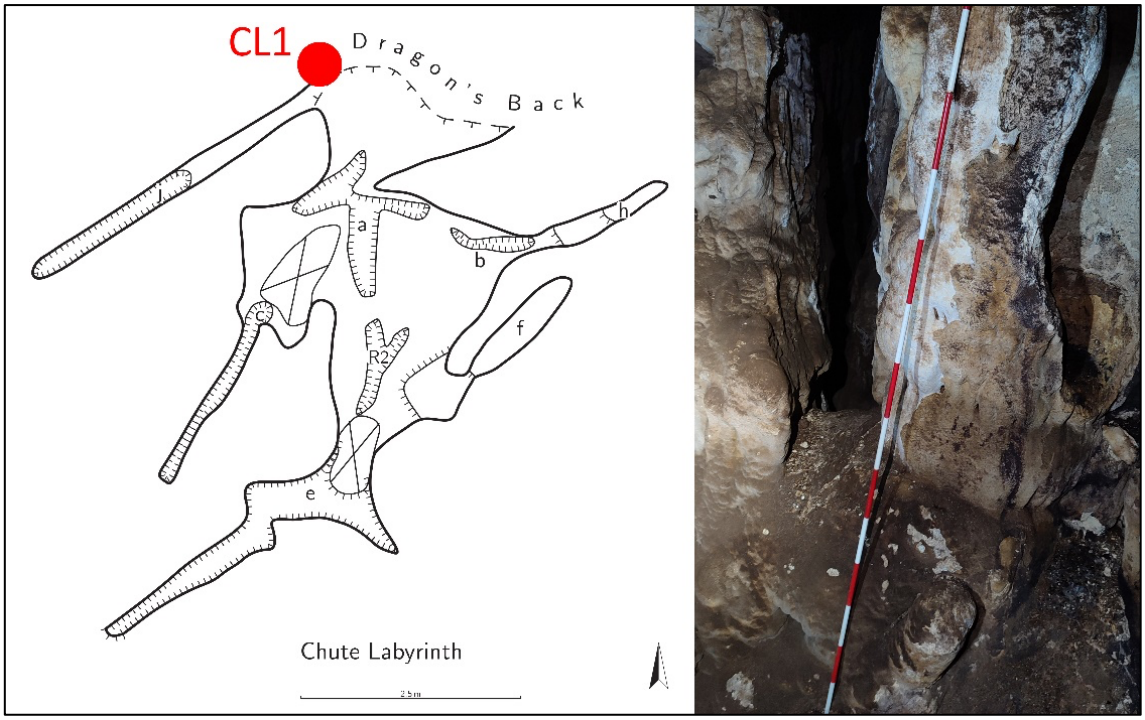


Figure 21. Survey of the *Chute Labyrinth* showing the location of flowstone *CL1*. The narrow passage at the start of *Fracture I* in *Level 5* is partially restricted by flowstone on both sides of the passage and below. Only *Level 5* is shown.

The second (*CL2)* flowstone is also located in *Fracture I,* at the furthest point of *Chimney j* away from the Dragon's Back (Figure 22). The flowstone is partially visible through *Fracture I* in *Level 5,* and by climbing down into *Fracture II* from *Level* 7. This fairly large flowstone does not restrict access to any passages as the narrow crawl leading to *Chimney j* has dolomite walls and is too small to access despite the flowstone. It is important to note that we do not know what lies beneath or behind this flowstone and it will have to be dated to determine how much, if any deposition took place since *H. naledi* used the cave.

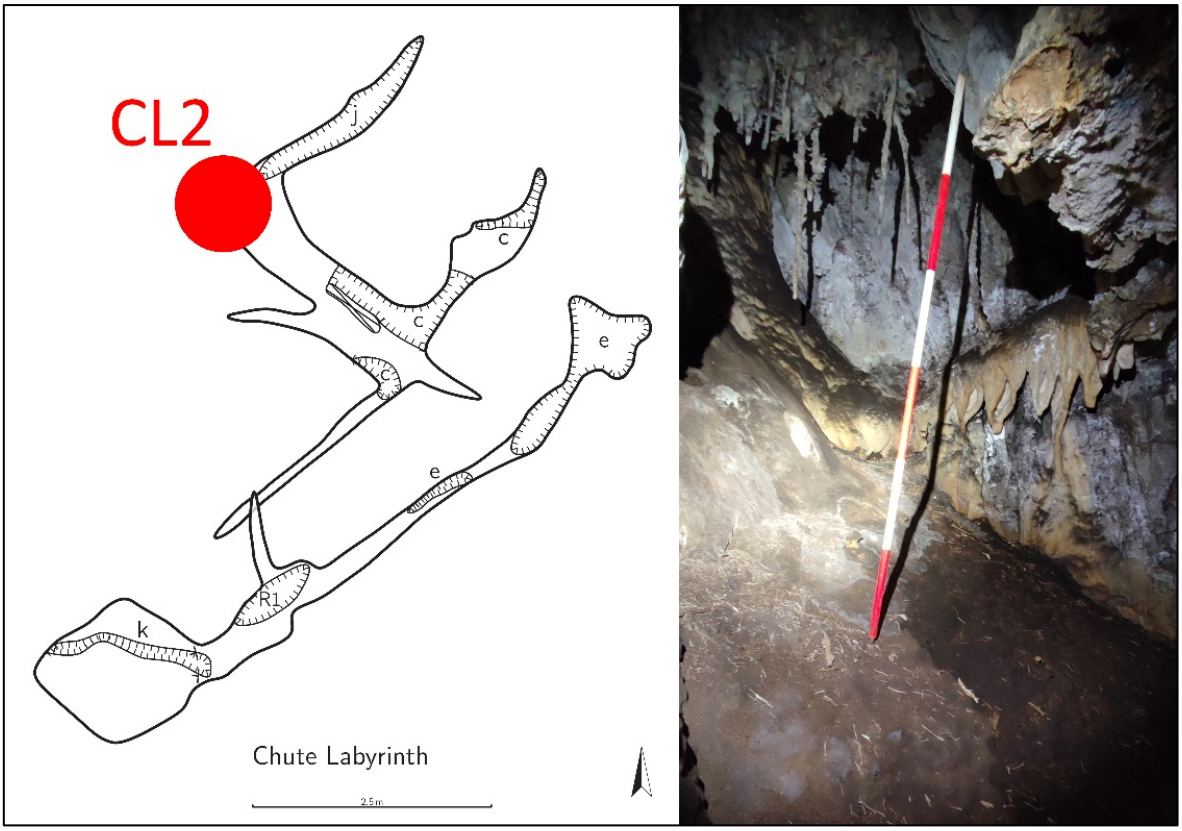


Figure 22. Survey of the *Chute Labyrinth* showing the location of flowstone *CL2* from the perspective of Fracture *II* in *Level 6.* Only *Level 6* is shown.

The third flowstone (*CL3)* is located at the lowest point of *Chimney c* in *Fracture II* where it can only be seen in *Level 3* by climbing down to this level through *Chimney e* in *Level 5*, or from *R1* (Figure 23). This flowstone is small and access into the area where it is located is not possible. The flowstone does not restrict access to otherwise accessible passages.

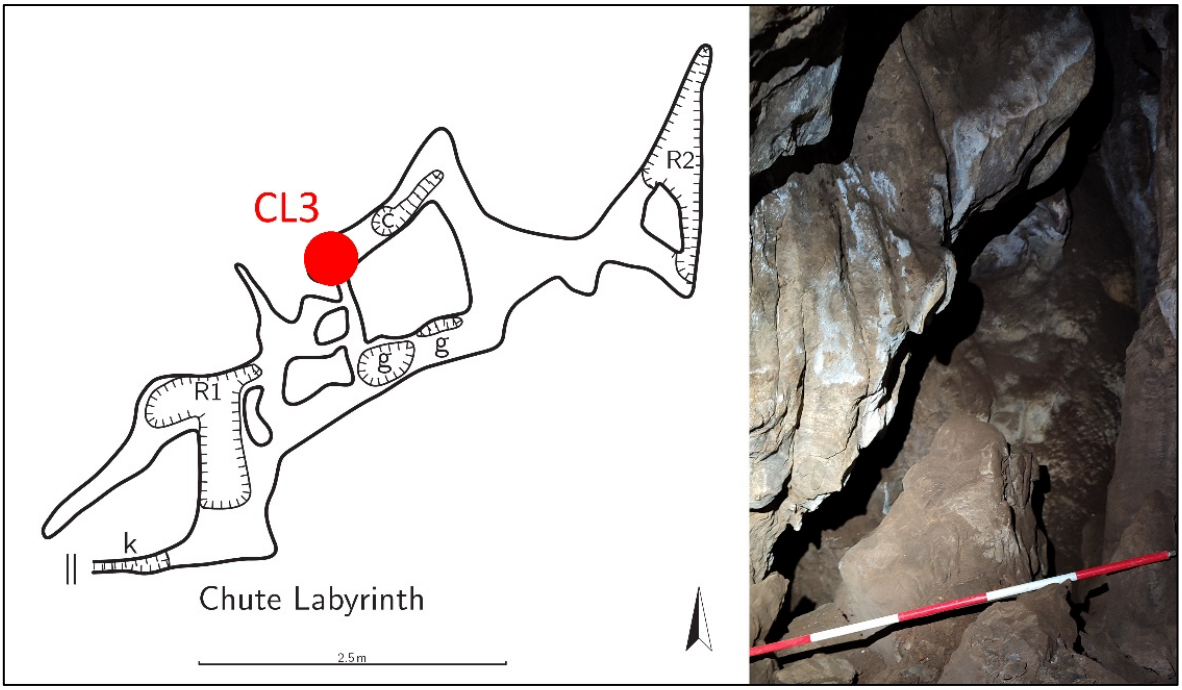


Figure 23. Survey of the *Chute Labyrinth* showing the small hole through which flowstone *CL3* can be seen by looking through it, but access into this very small section is not possible. Only *Level 3* is shown.

There are more speleothems located in the *Chute Labyrinth* but they are much smaller and do not obstruct any passages so they will not be mentioned here.

Routes

There are currently two different routes available to humans to get from the Dragon's Back to the Dinaledi Subsystem. Both routes are confined and technically difficult and can only be navigated by small-bodied, physically strong, and experienced cavers.

Route 1

Route 1 (*R1*) is what was traditionally known as the "Chute", which is the most direct route that links the top of the Dragon's Back to the Hill Antechamber. R1 was the route used by Rick Hunter and Steven Tucker when they initially discovered the *H. naledi* fossils in 2013 and thus subsequent trips by scientists into the cave rarely ventured from this tried path due to the perceived danger and difficulty of access. As described previously, *R1* is accessed by climbing to the top of the Dragon's Back, crossing the wooden bridge, and heading ~6 m southwest in *Level 7* where a small passage leads another ~2.7 m to the start of the Chute (Figure 24). The initial ~3 m down is vertical with numerous small handholds, and then drops onto a small platform in *Level 6*. From here, a caver climbs a further ~1.2 m down through a small hole which moves ~0.9 m towards the northeast. The passage opens up slightly and the

caver can now reach and stand on the top of the pinnacle rock in *Level 4* with their feet, after which they climb a further ~1.8 m down by squeezing through between the pinnacle rock and surrounding walls (~18 cm) until it opens up into *Level 3*. A small chimney can be seen ~1.1 m to the north which leads down all the way through *Level 2* and then drops ~3.9 m down onto *Level 1* (Figure 28).

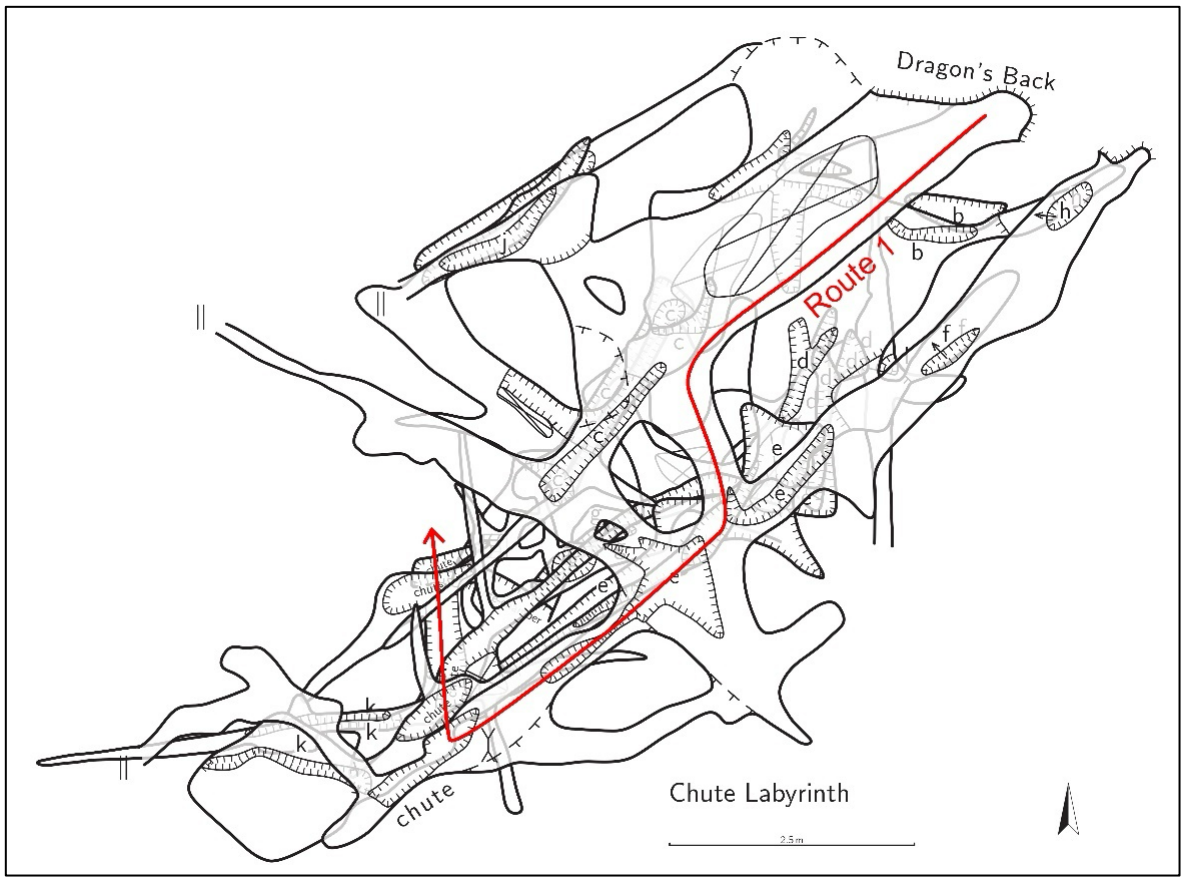


Figure 24. Survey of the *Chute Labyrinth* showing *R1* from the Dragon's Back Chamber to the Dinaledi Subsystem. All levels are shown.

458

459 **Figure 25. The R1 chimney looking down from above (left) and looking up from below (right).**

460

461 **Figure 26. R1 from Level 4 looking up with the pinnacle rock visible (left) and looking down to the lower levels**
462 **(right). Boot is for scale.**

Route 2

Route 2 (*R2*) is a shorter climb which was discovered during subsequent exploration of the Chute area. *R2* is accessed by climbing to the top of the Dragon's Back and instead of crossing the wooden bridge, climbing down ~2.5 m to the southwest. A small triangular chamber of ~1.6 x 2.2 m can be entered by climbing through a ~0.5 m gap between the rocks where a chimney (*R2* on the maps) can be seen in the floor that drops down ~4 m (Figure 27). When climbing down, the vertical passage becomes smaller with the tightest point being at ~2 m, and a person is required to manoeuvre themself slowly downward by feeling for hand and foot holds as the space is too small to turn one's head. Once the person has climbed past the ~2 m pinch point, it opens up slightly allowing them to drop down ~6 m to the northeast of the Hill Antechamber in the *Ledge* area (Figure 28). Although *R2* is a shorter climb down, it is smaller and more technical than *R1*, especially when climbing back up. Our team uses *R2* to run the power and network cables for two reasons: (1) because it is the shortest distance from the Dragon's Back to the Dinaledi Subsystem and (2) to keep the more frequented *R1* clear of cables which might get in the way or become damaged by cavers.

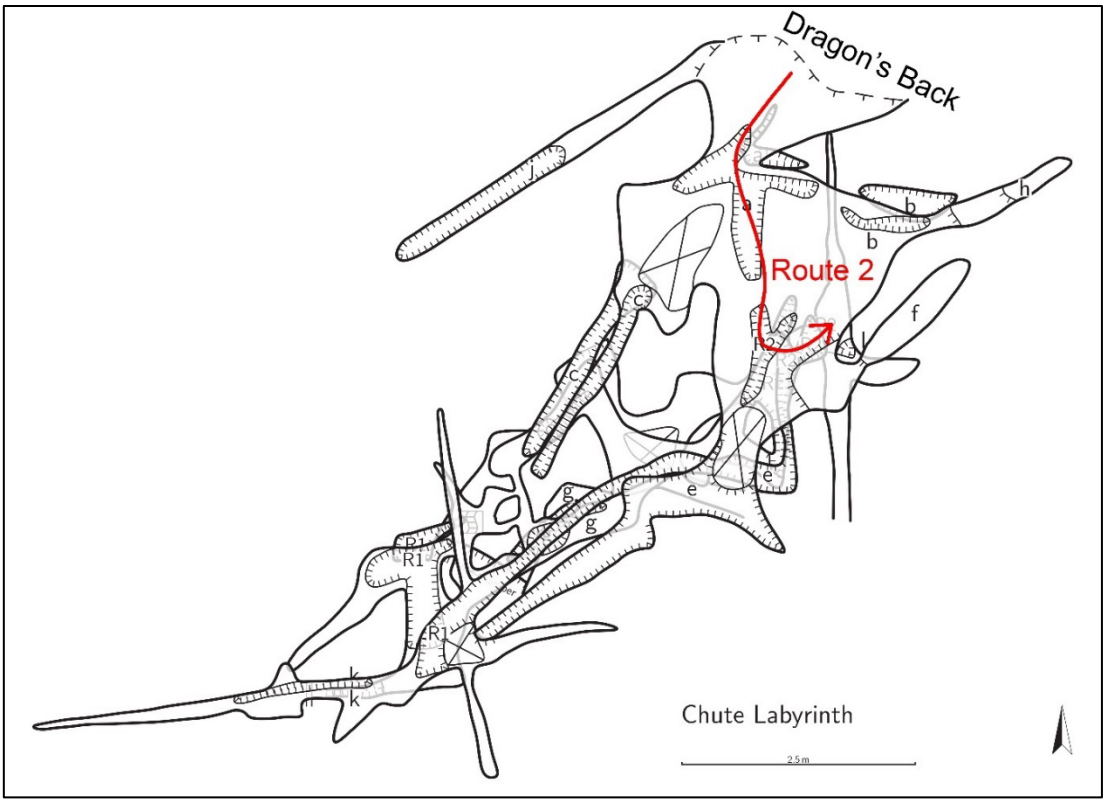
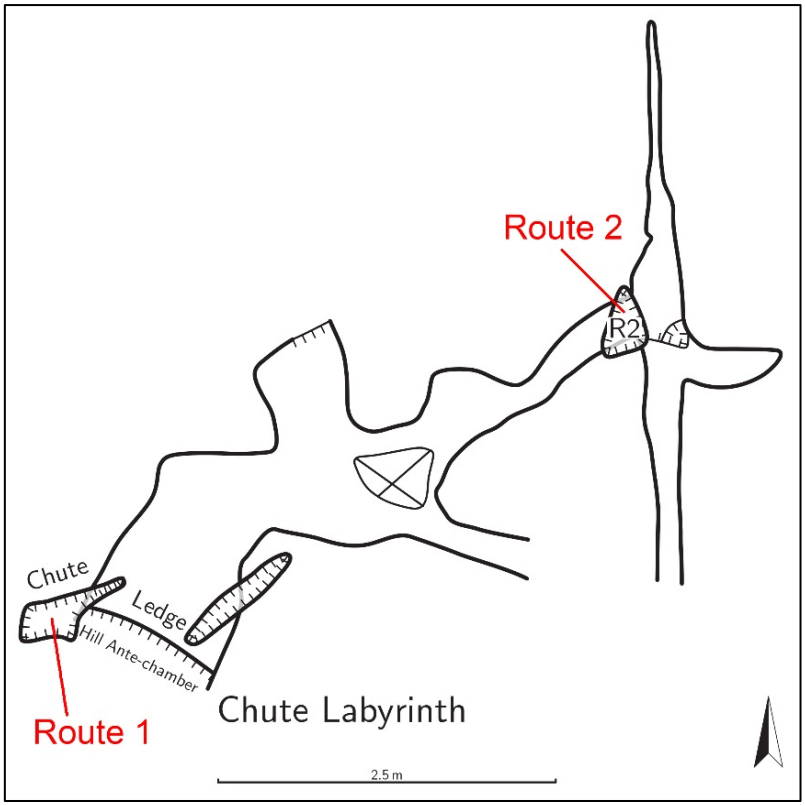


Figure 27. Survey of the *Chute Labyrinth* showing *R2* from the Dragon's Back Chamber to the Dinaledi Subsystem. Levels *1* to *5* are shown in black while *6* and *7* are shown in light grey.



481

482 **Figure 28. Survey of the lower two levels of the *Chute Labyrinth* showing where the two routes drop into the Dinaledi**
483 **Subsystem. Only *Levels 1* and *2* are shown.**

Figure 29. The R2 chimney from above looking down (left) and from below looking up (right).

Figure 30. Image showing the width of R2 from the top looking down. Boot is for scale.

Figure 31. The Ledge area leading away from the Hill Antechamber to where R2 drops into the Dinaledi Subsystem.

A third route exists which is not a separate route but a connection of ~4.5 m between *Chimney e* in the small chamber in *Level 5* and a small crawl that enters *R1* about midway (~6 m below the ceiling of *Level* 7) down (Figure 32), although this connection has not been successfully attempted (see *Level 3*). There are additional routes in the *Chute Labyrinth* network, but they are not navigable today as they are all too small for typical adult humans to pass through (see *Flowstones*).

Figure 32. Narrow horizontal passage in Level 3 which connects R1 and R2 looking towards R1 (left) and out of R1 (right) with *Chimney g* visible in the floor of the passage.

Discussion

The Chute

During research conducted in 2022, LRB entered the Dinaledi Subsystem for the first time via *R1*, and together with other members of the team investigated this fissure network. This initiated the current study with the goal of evaluating whether *H. naledi* could have accessed the Dinaledi Subsystem in multiple ways through this network. We have now observed that several potential entry points at the top of Dragon's Back would have allowed *H. naledi* individuals to pass into the fissure network. Lateral passage through the network is possible at a few places, and at least one additional entry point from this network would have provided access into the Dinaledi Subsystem. The *Ledge*, at the northeast corner of the Hill Antechamber, is ~4 m from the entry point of *R1* (Figure 28).

This survey made clear that the illustrations published by Dirks et al. (2015; 2017) (Figure 4) which have been modified and repeated in numerous scientific and popular publications are a significant oversimplification of the study area. *R1* is described by Dirks et al. (2015) as a ~12 m vertical shaft connecting the top of *R1* directly to the Dinaledi Chamber, which is illustrated as a single open chamber separated by a flowstone pillar. These illustrations

implied that objects dropped down *R1* would land in the Hill Antechamber and from there might roll or slide down as far as the Dinaledi Chamber. These descriptions and illustrations (Figure 4) do not correspond with the survey results for the layout of *R1* and the area immediately below it, and therefore are not accurate with respect to access into the chamber by materials from the area of the Dragon's Back Chamber, and have led to the many misconceptions about access to the Dinaledi Subsystem mentioned previously.

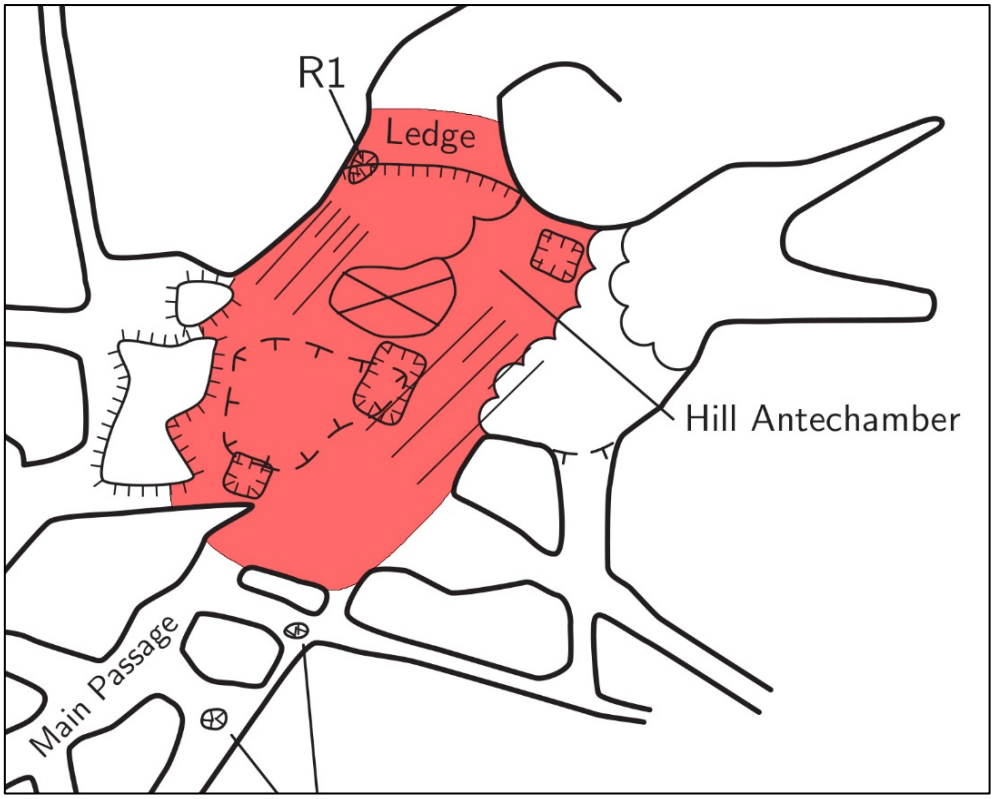


Figure 33. Survey of the Hill Antechamber showing the area below R1 where a higher concentration of accumulated fossils would be expected if bodies were dropped down the Chute. Apart from the juvenile individual in unit N50W100, only a few fragmented remains were found scattered on the surface (Elliott et al., 2018).

Figure 34. Two views of the area directly below where the R1 chimney drops down into the Hill Antechamber. The rope hangs directly out of the R1 chimney.

Through reanalysis of this area, our studies indicate that *R1* is not a simple vertical shaft, but a complicated three-dimensional labyrinth consisting of multiple connecting levels along three parallel fractures running northeast to southwest which also connect at multiple points. This labyrinth is the sole entryway for humans into the Dinaledi Subsystem. The survey data make clear that no objects can fall vertically from the top of the *Chute Labyrinth* down into the Dinaledi Subsystem. Apart from the main vertical Chute (*R1*), there are numerous other smaller fractures, fissures, and chimneys adjacent to and running along *R1* through which slumping or falling material would get caught in or fall into. The bottom of *R1* opens partly onto the *Ledge* which requires a further ~1 m climb down to the floor of the Hill Antechamber. Anything dropped down *R1* would (1) get caught in one of the many side fractures and ledges; (2) end up on the elevated *Ledge* to the northeast of the Hill Antechamber which is in the opposite direction from the Dinaledi Chamber, (3) fall down the

slope right below the *R1* chimney (Figure 33). Very few fossils were found in any of these areas and neither the *Ledge* nor the climb down from the *Ledge* to the Hill Antechamber was illustrated in Dirks et al. (2015; 2017), even though these features would greatly impact the journey of any fossils falling through *R1*. This was a critical oversimplification and has led to many misinterpretations about how bodies of dead *H. naledi* individuals might have entered this space. The results of the present work indicated that however remains entered, they were not tossed or dropped in from the top of the "Chute".

Chute Labyrinth evolution

An important question concerning access into the Dinaledi Subsystem by *H. naledi* is whether the *Chute Labyrinth* may have changed in its dimensions or configuration since the time *H. naledi* was active in the cave system. The *H. naledi* fossils from the Dinaledi Chamber have been dated to between 236 ka and 335 ka (Dirks et al., 2017), but our geochronological data do not tell us the earliest or latest times that *H. naledi* may have been in this cave system.

Because of the present work, we now recognize that the *Chute Labyrinth* itself is formed by fissures and fractures in the dolomite host rock. No part of the *Chute Labyrinth* is comprised of rubble, breccia, or infill that block fissure passages such as would result from the collapse of higher cave areas or ceilings. In our surveys of Rising Star and other caves in the regions, we encounter this situation where the collapse of chert layers opens entrances to the surface, which then the introduction of rubble and other types of infill into a cave. The thick chert-capped ceiling in the area above the Chute Labyrinth, however, prevents entrances from forming and all current entrances into the Rising Star system are lower down on the hill to the northeast and below the chert-capped ceiling, or in areas where the chert band is thinner. All of these are distant from the Dinaledi Subsystem.

Factors such as flowstone growth and rock dissolution, sediment deposition caused by infill and water flow, as well as collapses and rockfalls, can cause significant alteration in the size of passages like the *Chute Labyrinth*. According to Dirks et al. (2015), "Flowstone formation continues today, changing the morphology of cave passages, which makes it possible that a more direct access way or easier passage may have existed when hominins entered". We, however, now posit that the *Chute Labyrinth* has changed very little in the last 335 ka according to the geochronological evidence, and the survey evidence presented here. We thus hypothesize that to *H. naledi,* the *Chute Labyrinth* had a similar configuration and

dimensions as it does today. We also note that rather than being easier in the past, it is likely that the passages were more constraining and difficult. The walls of the passages in the Chute Labyrinth could have widened marginally in the last 335 ka due to the dissolution of the dolomite, but this process is extremely slow, and we suggest would likely not have made any significant change to what is presently encountered. We also acknowledge that flowstones can potentially grow enough in this time frame to block off entrances or passages and thereby restrict access. Three flowstones were identified in the *Chute Labyrinth* during surveying, but only one of them (*CL1)* partially restricts access into *Fracture I* from the Dragon's Back, and this passage does not form part of either *R1* or *R2*. Even without this flowstone, the walls of the *Fracture 1* passage itself are too narrow to access (see *Flowstones*). With or without flowstone, these especially narrow routes through the *Chute Labyrinth* might never have been used since other much easier options were available. The existence of easier and more accessible routes makes the importance of these smaller and much more technically difficult routes essentially redundant to the hypotheses presented here.

One additional aspect of the *Chute Labyrinth* that is important to consider is the present access to the *Chute Labyrinth* from the top of the Dragon's Back block. Based on the sedimentation history within the Dragon's Back Chamber, Robbins et al. (2021) hypothesized that Dragon's Back block may have settled approximately 60 cm to its current position between 225 ka and 290 ka. If this hypothesis is correct, it does not tell us whether *H. naledi* accessed the Dinaledi Subsystem either before, during, or after the formation of the Dragon's Back as it currently exists. However, irrespective of the relative timing, the Dragon's Back would not have been a barrier to *H. naledi*. Before the collapse of the Dragon's Back block, *H. naledi* would potentially have walked or crawled beneath the block to reach the sill behind it. Reaching the *Chute Labyrinth* section would still require climbing the sill instead of climbing the Dragon's Back block. After the collapse, access would have been like it is today, by either climbing up the ridge of the block or next to it. The climb up the ridge of the Dragon's Back is quite easy with abundant handholds on both sides and multiple routes for human climbers with moderate skills and experience. If humans experienced in caving and climbing find the Dragon's Back climb relatively easy, it would be more than possible for a *H. naledi* individual or multiple individuals to move through this section.

Access

Robbins et al. (2021) hypothesized that an entrance into the cave system may once have existed above the Postbox Chamber based upon the presence of externally derived sediments within this chamber, and further into the Dragon's Back Chamber. This entrance may have been accessible to *H. naledi* in the period before 241 ka and if so, it would have provided the shortest avenue to the *Chute Labyrinth*, at an approximately 80 m distance. If *H. naledi* individuals entered the cave system above the Postbox Chamber, they would have descended via a sloping southwest-trending fracture into the Dragon's Back Chamber. This would involve a ~30 m descent and ~30 m horizontal distance, parts of which are today partially obstructed by flowstones.

A key point in the discussion by Robbins et al. (2021) is the hypothesis that access into the Dinaledi Subsystem could have been more direct before the fall of the Dragon's Back block. The logic behind this hypothesis is the assumption that it would have been possible to walk within a ~60 cm space beneath the block to gain access to the fracture system behind it. This can however be easily misinterpreted to mean that access into the Dinaledi Subsystem was also easier or more direct before the fall of the Dragon's Back block, which is not the case. As previously discussed (see *Chute Labyrinth evolution*), our observations have shown that the fall of the block would not have affected the current entry points to the *Chute Labyrinth* to any great extent. This is because passing the Dragon's Back block itself still leaves the 5 m sill to climb to gain access to the *Chute Labyrinth*. The displacement of the Dragon's Back block did not affect either *R1*, *R2*, or other aspects of the *Chute Labyrinth* itself. These are important points of clarification and we would like to make it clear that (1) access into the Rising Star cave and access into the Dinaledi Subsystem are two separate and independent matters and; (2) neither the closer entrance in the roof of the Postbox Chamber, nor the collapse of the Dragon's Back block would have circumvented the Chute Labyrinth or made navigating it any easier.

It is also important to note that these other potential routes through the fissure network of the *Chute Labyrinth* do not constitute a different and as-yet unmapped entrance into the subsystem. The different routes described in *Routes* are not separate entrances into the Dinaledi Subsystem but merely different pathways connecting this area to the rest of the cave. Getting from the closest entrance to the *Chute Labyrinth* was slightly different, albeit easier and more accessible, than what it is today, yet it still required the navigating of difficult

climbs, squeezes, and crawls in complete darkness. There are two main routes through the *Chute Labyrinth* which surpass all other possible routes in their probability of utilisation by *H. naledi* because they are by far the least difficult. The evidence shows that (1) no other macro-fauna fossils were discovered in the Dinaledi Subsystem in certain temporal association with *H. naledi* fossils, other than *H. naledi* themselves, and; (2) no course-grained sediments are present in this section. It is therefore evident that the Dinaledi Subsystem has always been isolated from the rest of the cave, both physically and geologically, and that access was always complicated and difficult even before the collapse of the Dragon's Back block.

Physical and cognitive ability

After careful examination of the whole *Chute Labyrinth* area, we have determined that no simple or easy route into the Dinaledi Subsystem exists and all of them are technical and require of contemporary humans advanced caving and climbing skills to navigate. However, it is important to remember that *H. naledi* individuals were not contemporary *H. sapiens* in either stature, physical form or physiology. *H. naledi* was smaller than modern humans in body size (Berger & Hawks, 2017; Garvin et al., 2017), more adept at climbing (Feuerriegel et al., 2016; Feuerriegel et al., 2019; Kivell et al., 2015; Voisin et al., 2020) and has a small skull diameter (Holloway et al., 2018; Garvin et al., 2017). Their estimated thorax diameters (Williams et al., 2016) and pelvic breadths (VanSickle et al., 2018), which are the most relevant physical dimensions for passing through small spaces, are in particular smaller than humans. Narrower trunks in both anteroposterior and mediolateral dimensions would have enabled them to pass many rock projections that make climbing difficult for people today. It is fair to posit that *H. naledi* had calloused hands and feet able to feel and grip climbing holds similar to modern active rock climbers. Their likely ability to access a wider number of spaces in the fissure network than contemporary humans meant that several individuals could likely climb down and through the confines of the *Chute Labyrinth* together.

One of the insights that we have learned while working with a diverse team of skilled caving specialists is that one person's experience in a space is not necessarily a guide to how other people will experience it. An inexperienced or less fit caver might find the Dragon's Back climb and *Chute Labyrinth* some of the hardest obstacles they have attempted, while someone who has the physical skills and who is familiar with these spaces can navigate them without excessive physical exertion. These two experiences are at extremes to one another, and they

666 are from two individuals of the same species. Some researchers have taken up to 40 minutes
667 to climb up *R1* of the *Chute Labyrinth*. At the other extreme, one of the excavators who is
668 small in stature (Becca Peixotto), during the original Rising Star expedition in 2013, could do
669 this climb in under 2 minutes (the authors were present when this was attempted).

670 In the same way, human experience is not an accurate guide to how *H. naledi* probably used
671 or experienced these spaces. They spent their life outdoors, surviving in a harsh landscape
672 while climbing trees, hunting, and foraging for food. These daily struggles would likely have
673 made them fitter and stronger for their small body mass than most humans today, comparable
674 to the most physically fit cavers and climbers. This combined with *H. naledi's* body mass,
675 stature, and anatomy suggests to us that they would have been extremely adept at climbing,
676 crawling, and squeezing in the cave environment.

677 If, as we hypothesize, their only other obstacle was the complete darkness of the cave, they
678 would have had to overcome this to navigate any part of it. Archaeological evidence for the
679 use of fire by early hominids has been discovered at over 30 Lower and Middle Pleistocene
680 sites in Africa, Asia, and Europe (James, 1989). Although no direct evidence has been
681 published linking *H. naledi* to the controlled use of fire, it is reasonable to assume that they
682 had developed the technology if it was already in use by other hominin species 1.5 ma ago at
683 Swartkrans, which is a mere 1.2 km away (Brain & Sillen, 1988; James, 1989), and one of the
684 authors (LRB), reported in 2022 of the presence of abundant evidence of charcoal, soot and
685 ash as well as hearth structures of an archaic nature within the system (Berger, 2022). Thus,
686 we feel the likelihood that *H. naledi* controlled and had fire is high and future work is likely
687 to associate chronologically the reported fire residue with the species.

688 ## Conclusion

689 This study provides the first detailed mapping of the *Chute Labyrinth* within the Rising Star
690 cave system, the critical space which provides the connection between the Dinaledi
691 Subsystem and the adjacent Dragon's Back Chamber and ultimately allows access and egress
692 to the present surface outside the cave system. We have demonstrated that the *Chute*
693 *Labyrinth* is a complex network of fissures and fractures that can be navigated by present-day
694 cave explorers along at least two routes. Neither of these routes is a straight vertical drop as
695 previously hypothesized, and based on our survey, no straight-line vertical route exists
696 between the spaces within the Dragon's Back Chamber and the Dinaledi Subsystem. This

provides further evidence against the hypothesis that sediments, bodies, or other materials could have dropped from the Dragon's Back into the Dinaledi Subsystem.

The narrow dimensions of the available routes through the *Chute Labyrinth* are the key physical constraint operating on humans who enter the Dinaledi Subsystem and no other constraint within this part of the cave system is as extreme. Human body size and physiological capabilities are not necessarily indicative of the potential for *H. naledi* to traverse the *Chute Labyrinth*. The anatomy of *H. naledi* would have facilitated movement through smaller and narrower spaces than many living people, and their potential behavioural range was certainly different from today's humans. Previous exploration of deep caves for ancient hominin remains has been minimal compared to surface sites and rock shelters. We hope that the increasing number of both fossil and rock art sites being discovered in deep cave settings will encourage the exploration of such environments and lead to many new discoveries and increase our knowledge of ancient hominin evolution and behaviour.

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Authorship statement

LRB conceptualised the idea for the study and led the project. DVR, LRB, JH and ZJ worked on the methodology. DVR collected the data, mapped the area of study, documented, took photographs, processed the mapping data, conducted research and wrote the initial draft. LRB, JH and ZJ revised subsequent drafts and DVR edited the final version for submission.

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