



# South African Spelaeological Association



Homo Naledi  
Rising Star System

Disto X2

Aha Hills Botswana

Koanaka Hills Botswana

Gwihaba Hills Botswana

Armageddon Cave  
*World's Oldest Cave?*

Armageddon Survey

Hairy Stalagmites

New Troglobitic

Figure 9 R-S knot

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# **SEC**

# Speleological Exploration Club

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along with **CPSS**

SASA is the South African National Body for Caving

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**Cover Photo:** A reconstruction of Homo Naledi's head by paleoartist **John Gurche**, who spent some 700 hours recreating the head from bone scans. The find was announced by the **University of the Witwatersrand**, the **National Geographic Society** and the **South African National Research Foundation** and published in the journal **eLife**. Photo by **Mark Thiessen/National Geographic**.

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## Rising Star Expedition

*Steven Joseph Tucker*

The Rising Star Cave System is a linking of four small caves; Silt, Rising Star, Empire and Westminster. They are very well-known caves close to Sterkfontein in the Cradle of Humankind and often better known as Westminster Cave. Cavers have done a classic route through the cave almost on a weekly basis at times. Enter at Silt Cave entrance, through the Upside-Down-Turnaround, through the Rising Star Chamber, through Empire Cave and its Postboxes and Superman Crawl, through the narrow section that connects Empire Cave and Westminster Cave and finally exiting at a large entrance, in the Westminster Cave section. Others have gone for a more challenging route, skipping the Rising Star Chamber and heading to the Hanging Rock Chamber, via Torture Passage, then through Pinch-and-Punch and passed Wobbly Rock to get to the Empire Cave section. A few have stuck to the belief that the cave has more to offer and that a big discovery was waiting to happen to cavers who dared to go off the beaten path. As cavers, it was believed that this would be a massive extension to the cave, however Harris' words in 1985 would turn out to be prophetic: "We can be sure that farmers, prospectors, and before them, our savannah-roaming-ancestors have looked into Westminster-Empire."

For many years only a small portion of the cave was known to cavers, the Westminster-Empire Caves. Even this was a classic route that was well visited. Some of the earliest references to the cave indicate that the Tube or Superman Crawl was dug through in the late sixties (Harris 1985). However as the cave had a very large and obvious entrance it is hard to know when it was first explored. It had been mined in the past and farmers in the area referred to it as Die Nachtwoel (Harris 1985). What is known is that the first survey of the cave was done by CROSA in 1975 and 1976 and this was of the Westminster-Empire Caves (Harris 1976). At some point another small cave entrance was found to the North of the main cave, named Silt Cave.

For many years, no major discoveries were made, until 10 June 1984, when Nick Hearn, Colin Priddle and Jim Harris discovered the Rising Star Chamber which led to a massive extension (Harris 1985). On this trip only Colin managed to get through the vertical squeeze that connects the two systems, but the squeeze was widened on subsequent trips and others managed to enter the new discovery. A dig at the Northern part of the cave eventually connected this part of the cave to Silt Cave via the Upside-Down-Turnaround (Rees 1985). In 1982, Jacques Martini wrote an article on the standing of the caving clubs in South Africa at the time and in that article, he referred to The Free Cavers as the Rising Stars of caving in South Africa. Feeling very honored by this, the Free Cavers named their new discovery Rising Star (personal communication with Horst Müller, 13 September 2014). As the new discovery was the largest section of the total cave system the name Rising Star System was adopted for the whole system (Rees 1990). Later a second connection between Rising Star and Empire Caves was found via Pinch-and-Punch.

The 1985 survey as well as the Pinch-and-Punch extensions are what most cavers know of the cave and this was how I first got to know the cave in 2011. However I was one of those who believed that the cave promised more than we knew of. On the 3rd of November 2011 I thought we had found it. Gerrie Pretorius, Dirk van Rooyen and I found an extension at North Riding Chamber. However we found a chisel at a narrow squeeze that led to the Camembert Section. It turned out that it was not a massive extension and that it had been entered before by Alistair Koliassnikoff-Keath in 1990 (Koliassnikoff-Keath 1991). On 28 January 2012 Dirk van Rooyen, Cassien Smit, David van Wijk and I found some tunnels and chambers below the main chamber of the Silt Cave section quite close to the

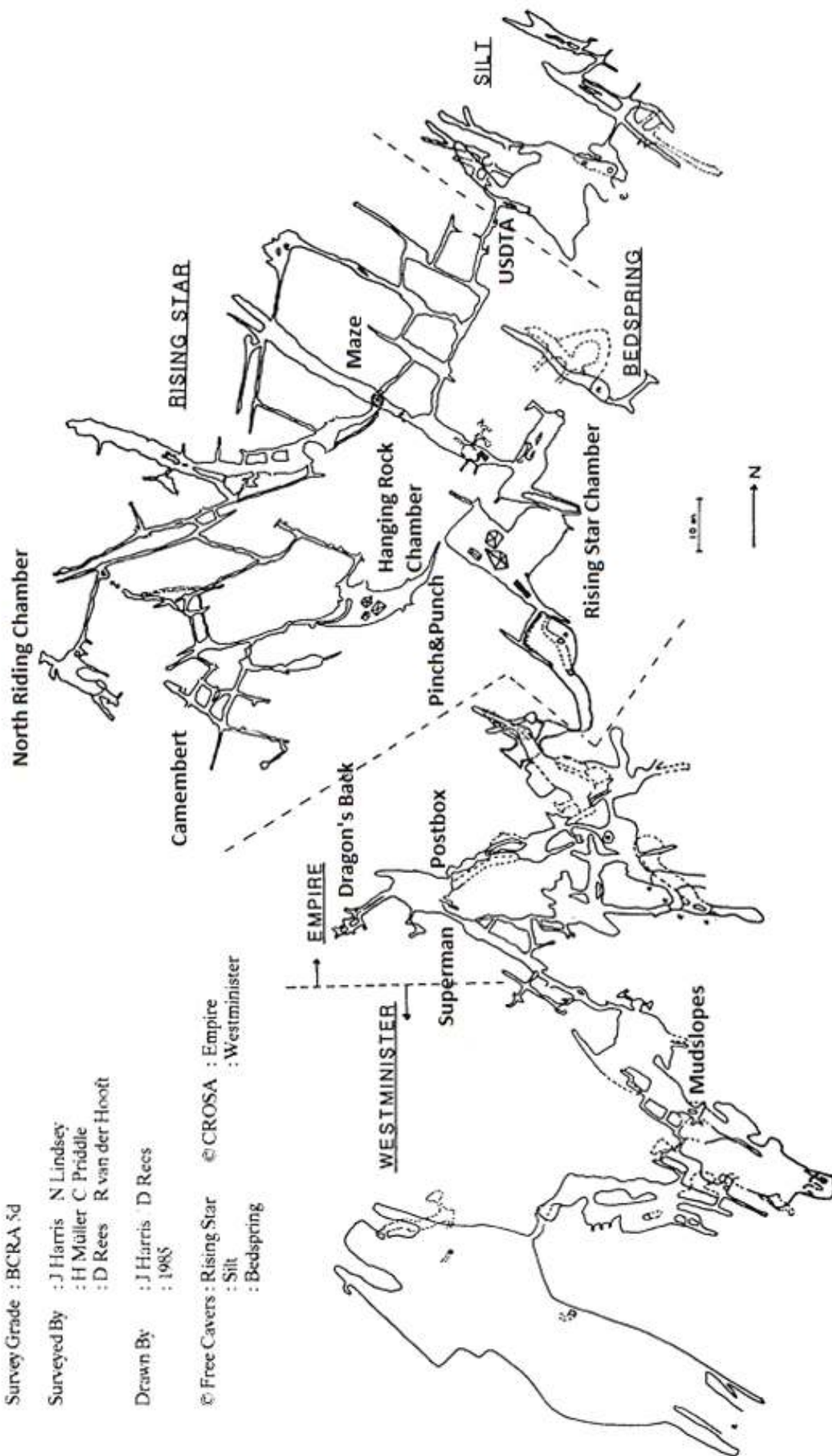
# RISING STAR SYSTEM

Survey Grade : BCRA 5d

Surveyed By : J Harris N Lindsey  
: H Müller C Priddle  
: D Rees R van der Hooft

Drawn By : J Harris D Rees  
: 1985

© Free Cavers : Rising Star : CROSA : Empire  
: Silt : Westminster  
: Bedspring





entrance on the way to the Upside-Down-Turnaround. However in this section we found a very large chisel and sledgehammer, therefore we were not the first in this section either! The next attempt at finding something new was on 21 April 2012, when Dirk van Rooyen, André Doussy, Irene Kruger and I explored the passages below the Wobbly Rock. Here I found a squeeze with some possible new passages through a tiny squeeze I could not negotiate at the time. The passage went in the direction of known parts of the cave, so it was only on 24 September 2013 that Rick Hunter and I returned there and managed to get through, only to find that it led to known sections of Empire Cave. Subsequently Dave Ingold informed us that the link was known as the Knee-Breaker. Another discovery that we made too late!

On 1 June 2012 I received an email from Neil Ringdahl, suggesting I try to find a section on the other side of the Dragon's Back, which he had found in the mid-nineties. He mentioned it being through a "shortish gnarly, crawly thing that will take you to another drop which will bring you back down to another complex little bit of cave at the end of which is a blowing hole." On 15 July 2012 André Doussy, Paul Gibbings, Charl Doussy, Johan Terblanche and I went to try and find this extension. We climbed up the Dragon's Back, but once up there we found nothing. The cracks in the floor looked impossible to climb down. We then proceeded to the Rising Star Chamber and there I climbed up into a hole in the ceiling that I had not entered before: another small section that had been done before we managed to get there. Those were the last areas I had in mind to try and find an extension to the cave and they had been unsuccessful. From that point onwards my focus moved to other caves and especially Armageddon Cave. The Rising Star Cave System became a nice place to take visitors and new cavers through.

On one of these casual trips on the 1st of September 2013, a trip organized for Irene Kruger's birthday, Rick Hunter led the trip through the cave. In the Westminster section, just before entering Empire Cave he found a small blowing hole that we could not enter at the time. Finally, a possible new extension to the cave! My interest in the cave quickly rekindled and we went back on Friday the 13th of September 2013. Before this trip Rick posted the following on Facebook: "I have a good feeling this Friday the 13th. Time for fun and adventure. And of course hopefully new discoveries. All cameras are charged and lights are ready. Hammers, chisels, gloves, boots and overalls. This is a deep underground rock session." We broke through the squeeze, but this only lead to a tiny chamber that could fit one person at a time and no indication of the origin of the airflow. Lots of cracks, but none that was even remotely large enough for a person to get through. At least it was a section that no one had entered before, even though it was tiny. From there I decided to show Rick the climb up the Dragon's Back. We wanted to do a nice climb and take some photos of the stalactites in the section. In a very narrow section Rick wanted to pass me. I had to climb down into a crack for Rick to move past me to take some photos. There I noticed that the crack I was in went even further down. I climbed down a bit more and the crack continued and continued. Eventually it opened up and I clambered down into a chamber I had never seen before. There were beautiful formations on the roof, but more importantly there were passages that continued. I called Rick down and he soon joined me, but the battery of his camera had died and he could not photograph the formations. We went through a narrow passage into a next chamber. Here we noticed some bones on the floor, but quickly carried on as there were more passages. There were also survey markers, so again we were not



The Chute – photo by Allen Herweg



The photo that started off the expedition – photo by Rick Hunter

the first to enter this chamber. By this time I had completely forgotten about the email that Neil had sent me 15 months before and it was only a few months later that I remembered the email. His email also indicated that the survey markers were not his, so someone had entered the area before he had. We carried on for some distance and finally found a very narrow squeeze that was blowing, which we could not enter. It was most likely the squeeze Neil had referred to.

On the way back we took another look at the bones we had seen on the way in. They were fairly large and we wondered how something of that size had gotten so deep into the cave, especially

through such a difficult entry route. The bones were numerous and included long bones, some flat bones and teeth. At first we had no idea what they could be until we found half a mandible (lower jaw). It looked human.

At the time Pedro Boshoff was working for paleoanthropologist Lee Berger with the goal of discovering new hominin bearing sites. In August he had asked Rick and I to keep our eyes open for any fossils we might come across during our regular caving trips. On the 15th of September, on the way back from a trip to Armageddon, I went to Pedro and told him what we had found. He was immediately interested and showed me a cast of a mandible of a hominin. I told him that it was very similar to what we had found. He asked us to return to the site and take photos with scale of the bones. On the day that we had gone to Pedro we had found a possible extension to Armageddon that was very promising. This possibility had our attention and we first went back there to explore Armageddon further. Once that option was eliminated, we went back to Rising Star on the 24th of September to take photos of the bones. We then proceeded on a long tour of the rest of the cave and soon found more bones, but did not photograph them. Two days later the discovery was discussed at an SEC committee meeting. It was another week before I took the photos to Pedro.

On the 1st of October I finally showed the photos to Pedro. His immediate reaction was massive excitement, almost shouting that we had found a hominin and had made a big discovery and that I didn't even realize the importance of what we had found. He tried to phone Lee Berger, but was unable to reach him and left him a message. We then drove through to Lee Berger's house at 8 o'clock in the evening arriving there at 9. When Lee answered the door Pedro's only words were: "Lee, you really want to talk to us." Lee let us in and seemed to be doubtful that we had anything interesting to show him. However as soon as he saw the photos there was at first a lot of cursing from him, followed by him being speechless, something that does not happen often. He quickly offered us some beers. Based on the couple of photos we showed Lee that night, he told us that the bones looked like a single reasonably complete skeleton of a *Paranthropus Robustus* and that this would make it one of the



Lee Berger and the six ladies who excavated the fossils

Photo by Dave Ingold

most important discoveries ever. He was quite anxious about the safety of the fossils. He said that he would phone National Geographic as soon as we left to start organizing an expedition to excavate the fossils and that this might be filmed for a documentary. On Facebook he posted: "Remember Oct 1 as a great day for fossil discoveries, promise!" Finally he said to me that this discovery would change my life forever. Now imagine just meeting a person and they tell you your life is going to change forever. I didn't believe him. Rick was unfortunately not with us that night, but received updates on everything via Facebook. I spent the following couple of days constantly on the internet reading up about other hominin fossil discoveries in South Africa and the rest of Africa and reading about Lee Berger and his discovery of *Australopithecus Sediba*. After seeing the list of other discoveries and how complete and significant Sediba was and Lee's reaction to the Rising Star fossils, it made me realize that this really was an important discovery.

On the second of October Lee Berger posted: "Creating a culture of exploration produces results... watch this space!" Three days later, on the 5th of October the SEC committee took Lee Berger and his son Matthew Berger to the cave. After pulling Lee through the Superman Crawl we climbed to the top of the Dragon's Back. Lee had no chance of getting down through the narrow crack, but Matthew got down and for the first few minutes his excitement was so high that he could not take any photographs. He finally managed to take the photos and when he climbed up his first words to Lee were: "Daddy, it's amazing!" The next morning Lee put out a notice on Facebook that read:

"Dear Colleagues - I need the help of the whole community and for you to reach out to as many related professional groups as possible. We need perhaps three or four individuals with excellent archaeological/paleontological and excavation skills for a short term project that may kick off as early as November 1st 2013 and last the month if all logistics go as planned. The catch is this – the person must be skinny and preferably small. They must not be claustrophobic, they must be fit, they should have some caving experience, climbing experience would be a bonus. They must be willing to work in cramped quarters, have a good attitude and be a team player. Given the highly specialized, and perhaps rare nature of what I am looking for, I would be willing to look at an experienced Ph.D. student or a very well trained Masters student, even though the more experience the better (Ph.D.'s and senior scientists most welcome). No age limit here either. I do not think we will have much money available for pay – but we will cover flights, accommodation (though much will be field accom., food and of course there will be guaranteed collaboration further up the road). Anyone interested please contact me directly on (Lee's email address) copied to my assistant (Wilma's email address). My deadlines on this are extremely tight so as far as anyone can spread the word, among professional groups. Many thanks Lee"

By 21:00 on the same day Lee informed me that National Geographic had given a final confirmation that they would be involved in the project and that he had already received 25 applications related to the above post.

On the 11th of October we spent a day at Wits where Lee discussed his initial plans for the excavations of the Rising Star Expedition. During October, Rick received an offer to work for Wits with Pedro, to assist during the November excavations and subsequently to look for more hominin sites. He of course accepted the offer. On the 6th of November the news of the discovery was made public. National Geographic were the first to share the news with the world just after the press conference with journalists from various newspapers which were published the following day. Present at this were Alia Gurtov, K Lindsay Eaves, Hannah Morris, Marina Elliot, Becca Peixotto and Elen Feuerriegel, the six cavers/scientists who would excavate the fossils.

From the 7th to the 10th of November many cavers of the SEC were involved. Together we setup safety ropes along the Dragon's Back, down the Chute and at climbs. Ladders were put up at certain climbs. A ladder was built inside the first chamber down the Chute. Two kilometres of ethernet cables were



installed which were connected to 8 infrared cameras situated at key points as well as the fossil area. Cables were installed to have telephone lines at the top of the Dragon's Back as well as a telephone at the bottom of the Chute and an intercom system in the fossil chamber. Power cables were installed to power all of the above as well as to power a 3D scanner and laptop that would be used inside the fossil chamber. On the surface 20 tents were put up as accommodation tents, as well as a cavers' tent (for equipment), kitchen tent, wi-fi/general area tent, two storage tents, tent to monitor the cameras and communications, a tent to clean, preserve and store fossils, 4 showers and 4 portable toilets. Security guards were present at all times, especially at night. At any point in time there were 40 to 50 people present on site, which



Photo of the tents setup at the Rising Star Expedition - photo by Google Earth

1. The tented village where everyone slept
2. Showers and toilet facilities
3. Storage tent, kitchen tent and wi-fi/general tent
4. Caver tent on the left and science tent on the right where the fossils were stored
5. Command center tent where cameras and communications were monitored with the cave entrance just below it



Command tent with cameras and communications – photo by Dave Ingold

From left to right are Marina Elliot and Becca Peixotto (standing), Lee Berger, John Hawks, Ashley Kruger and Natasha Barbolini (seated).

The screen shows the main fossil deposit with a long bone sticking out of the floor, which proved to be very difficult to excavate as numerous other fossils were densely packed around it. Thanks to the cameras monitoring the excavation as well as communications in the excavation area, it was possible to discuss excavation strategies with those on the surface.

further excavations. It turned out that it was a false alarm; however it did give a good practice run in case of a real emergency. When the mandible was uncovered on the surface the senior scientists went into private discussions with each other. It was not a mandible from a *P. Robustus*. They weren't sure what it was! In an interview Marina Elliot said that entering the fossil chamber for the first time was like Howard Carter entering King Tut's tomb for the first time and after being asked whether he could see anything he replied: "Yes, wonderful things."

included the 6 excavators, senior scientists, a paramedic and cavers. On site during the course of everything was National Geographic, filming away during setup, staying on site with us and filming inside the cave.

Soon after the preparations were completed on the 10th of November, the excavations started. The fossil area was scanned with a 3D scanner and each visible piece was photographed before anything was moved. The 3D scan had to be taken to the surface to be processed to ensure that the system worked. Once the call came through that the scans worked, the go ahead was given to start extracting fossils. The original mandible that had caught our attention was the first piece to be packaged and just after it was packaged, the CO<sub>2</sub> monitors in the cave gave a warning that halted



National Geographic filming during the expedition

Photo by Allen Herweg



Big smiles from some of the cavers and Lee Berger – photo by Allen Herweg. From left to right are André Doussy, Gerrie Pretorius, Lee Berger, Allen Herweg, Steven Tucker and Irene Kruger.

On the 11th of November excavations restarted at full speed. There were literally bags full of fossils that were retrieved on the day. Andrew Howley, the National Geographic blogger who covered the expedition soon had to report that there were now not only one, but two individual hominins. Very soon afterwards he had to report that a third individual was present. Soon after that he updated his report to simply state that multiple individuals were present in the fossil collection. When the discovery was simply a single skeleton, it was already considered to be a massive discovery. The discovery now became much more important.

Not everything went that smoothly. During the middle of the expedition Alia Gurtov slipped during a climb up the Chute and had a deep laceration on her shin. It was the first day that cavers were not present inside the fossil chamber during excavations and a first aid kit was not present. Rick was sent in very quickly with a first aid kit and Alia's leg was bandaged up and she was slowly assisted out of the cave.

Nights were spent around camp fires with everyone well fed and lots to drink. All cavers and excavators regularly received medical checkups to ensure that we were okay. As the expedition continued various cavers, scientists and others came and went, way too many to record here. In the evenings Skype calls were often made to schools overseas who were interested in the expedition. At one point the minister of tourism visited the site. Those involved with the expedition were taken to Malapa to view the work that had been done there. There were trips to Sterkfontein and Maropeng. Everyone had a lot of fun.

Underground excavations continued and more and more fossils surfaced. As opposed to most fossil sites in caves, these fossils were not in breccia, but rather in the soil of the cave floor. This made excavations much faster, but here was a very dense accumulation of bones which also slowed down the excavation. A long bone, for example a femur, would be present, but as they tried to excavate it, many other bones were found that overlaid the femur. The others needed to be excavated first, before the femur could be removed. Once the femur is removed more bones would be present below it. Many bones were very fragile, which slowed the work. Also, as excavations continued, bones were discovered in other areas of the fossil chamber. In these areas only surface deposits were taken, no excavation took place. Actual excavation was confined to a very small area of the chamber.

By the end of three weeks of excavations in this small area and surface fossils in side parts, a staggering 1200 specimens had been collected. All specimens had to be cleaned, preserved and stored safely. Up to this point, the richest hominin site in Southern Africa, was Sterkfontein, where approximately 700 specimens had been collected



Fossils being catalogued and photographed by Steve Churchill on the left and Peter Schmid on the right with John Hawks in the back

photo by Dave Ingold



over a period of 80 years. The 1200 specimens from Rising Star made up over 10 individuals. Many more fossils were present in this area of the cave and a femur and maxilla were visible which had to be left in the site as time ran out for excavations.

However, the 1200 specimens from the one chamber were not all that the cave would deliver. During the setup of the cables other fossils were seen. These were later identified as also probably being hominin, but these were in a very different section of the cave and were in solid breccia. Soon after a second breccia body with hominin fossils was found with numerous long bones present. On the last day of excavations Marina, Becca, Rick and I went to the other fossils Rick and I had seen on the 24th of September. They were identified as hominin and a femur and humerus were removed. Many other hominin fossils were seen here, including what looked to be a skull and some teeth. So another partial skeleton was present. Therefore a total of four completely separate hominin fossil localities were found within the Rising Star System, with the first locality alone being a richer locality than any other in Southern Africa.

After the expedition, the SEC was contracted to design, manufacture and install numerous gates protecting the fossil site. The club was also asked to install a security alarm system to warn of any intrusions in the fossil location as well as monitoring the cave on a regular basis to ensure that the gates were not damaged etc. These installations were done during December and January after the expedition. Despite the security measures, the majority of the cave remains open to cavers. On the 17th of December, I was asked to meet Lee at Wits, and I was offered a job to work with Pedro and Rick to continue searching for new hominin site, due to start in March 2014.



Mementos from the expedition – photo by Dave Ingold

In February 2014, Lee Berger and Alia Gurtov went to the second fossil site to start excavations there. Many fossils were excavated, as the fossils were again in soft sediment. This locality however seems to have only one individual. Its relationship with the main fossil site is not yet certain.

During March 2014, Marina Elliot and Becca Peixotto returned to excavate at the main fossil site. The plan was to extract the femur and maxilla which had been left in the site in November and then to move to the location that had been excavated in February to complete excavations there. However as the maxilla and femur were removed, many more fossils were uncovered below them, which turned out to be very complete and important specimens. Therefore the 10 days excavations were focused on the main site and no excavations were done in the second locality. After these 10 days the total number of specimens from this one locality numbered over 1750 specimens, more than all other early hominin sites in Southern Africa combined.

During May 2014, over 40 scientists from all over the world were invited to Wits to study the fossil assemblage. Within a period of a month the fossils were studied and compared to modern humans and other early hominin species and 13 papers were written which were submitted to Nature magazine soon after, with the intention of publication before the end of 2014. Other than the significance and volume of the fossils that came from this site, the expedition was also unique in that it has been shared with the world from the start. The work of excavating and studying the fossils has been divided up between a large amount of scientists, which increased the speed at which the fossils

were studied. Generally a large discovery would easily take a decade to be described. Sediba was described within two years of discovery, which made it a breakthrough in paleoanthropology at the time and now the largest single collection of hominin fossils has been described and papers submitted in less than a year.

Many more fossils are still present in the fossil chamber as only a small area of it has been excavated. Three other hominin fossil localities within the cave still need to be excavated and described. How much of our current knowledge of human evolution will be rewritten remains to be seen once the papers have been published.

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Steven Joseph Tucker

Professional Cavers  
*Steven & Rick*



Rick Hunter



## Disto X2

*Steven Joseph Tucker*

For most the only way to properly survey a cave is to take in a tape measure, compass, inclinometer, pencil and paper. One would start at a point, survey station one, choose the next survey point, station two, and measure the distance between the two points by unrolling the tape measure and reading the measurement to someone else who is recording the information. Furthermore a compass bearing had to be taken from station one to station two and recorded as well. Thirdly, the incline had to be measured and recorded. The tape measure would then be used to measure the distance from station one to the wall on its left and from the same station to the wall on the right, then the same for the roof as well as from the station to the floor. Lastly the person recording the measurements would have to sketch a plan and a profile view of the section of the cave just measured. When that is done, repeat the process between survey station two and three and then continue until the cave is completely surveyed.

The ten longest caves in Southern Africa; Apocalypse, Wonderfontein, Crystal, Chaos, West Driefontein, Congo, Sterkfontein, Arnhem, Thabazimbi Cave and Bat Cave have a combined length of over 65 kilometres.

Now try and imagine the effort this process took. Imagine that you are in the deepest part of Wonderfontein Cave; it's a flat out crawl, in which you are unable to turn your head, plus the crawl is half-filled with water with a very muddy floor. It's a struggle to keep your mouth above the water to breathe, never mind trying to survey this piece of horror. Now further imagine that you are at your survey station and your next one has already been selected. You only need a few pieces of information to get the survey done. The distance from your current station to the next station needs to be measured with a tape measure, which needs to be dragged through the mud to get the job done and soon you can barely read it and there is not a single clean spot to wipe it on. Next you need the inclination between the stations, so you try and maneuver your head in such a way and at a very awkward angle so that you can actually see the next station in order to use the inclinometer. The third measurement is the direction of the compass, even more difficult to get right as the result is affected by the light on your head, so you will have to get the light away from the compass, but still hold your face close enough to it in order to read the direction. Remember, this spot is so tight that you can barely turn your head. Next you require a height measurement (this is easy – as it is called way too low!), which you measure for the sake of accuracy. After all of this you still have the measurements to take for each of the walls in order to determine the width of the passage. It gets even tighter here, so you play rock-paper-scissors with your caving buddy in order to see

10-11	5320	+3	60		
11-12	3727	-5	220		
12-13	3402	+22	88°	0246	1173 5816
13-14	3405	-26°	248		
14-15	3520	-37	71°	8078-0546	6077 11500
15-16	5500	+37	251		
16-17	7895	-5°	102°	5044	2582-8525 -0000
17-18	7918	+3	282°	3313	3289 2765 1172
18-19	3242	-20°	26°	1630	4155 2765 1172
19-20	3274	+23	204		
20-21	5008	-25	302°	X	2159-10355
21-22	4976	+22	121°		
22-23	1624	+27	278°	0815	3787 3350 -0
23-24	1333	-27	105°		
24-25	5257	-14	278°	0188-2000	3724 1657
25-26	4190	+13	95°		
26-27	10453	-37	320°	0968	1871 12517 0580
27-28	11095	+35	110°		
28-29	6777	+6	314	6036	2238 3109 0762
29-30	4983	-5	134°	6515	2025 3311 0

Survey measurements taken inside a cave with the station numbers on the left, then the distance, incline, compass-bearing and left, right, up and down distances – Photo by Steven Tucker



Sketches and notes taken inside the cave with some more survey data  
photo by Steven Tucker

who is going to drag the tape measure to the edge of this wide and flat passage. You win and when he gives you these last measurements all of it needs to be written down and a sketch needs to be drawn. Now ask yourself how a piece of paper is able to survive this environment? It barely does, however as mud-caked and crumpled as it may be, you manage to keep it intact. Getting your pencil to write is another story, the only spot to wipe the point clean is your tongue and caving mud is not exactly tasty.

Fortunately not all passages surveyed are as difficult as this one, but to reduce errors the distance between survey stations could only be up to a maximum of ten meters (often much less). With the ten largest caves measuring in at a total of 65 km, this would result in 6500 measurements between stations at the very least as well as another 26,000 distance measurements in order to obtain the left, right, up and down passage dimensions. Every single one of these 6,500

measurements would be a three dimensional shot as it takes into account the actual distance between the two stations which has a vertical and horizontal element. The map that you would take into the cave would be two dimensional, either showing the horizontal or vertical profile of the cave.

The last step in the whole process would be to draw an accurate survey from the information collected. If one of the measurements is 10 meters at an inclination of -45 degrees in the direction 275 degrees magnetic, you would use trigonometry to calculate that the horizontal distance of the above shot is 7 meters. Trig would also show that the vertical distance of that shot is seven metres. Then your compass direction needs to be modified as you want to show true North on the survey, not magnetic North, for this you would simply deduct 17 or 18 degrees. You then need to draw this onto another piece of paper. You choose a scale of 1 metre equals 1 millimetre and using a protractor and ruler you draw a single seven millimeter line on the page that will be your horizontal survey paper, then you take the left and right measurements and indicate where the walls of this survey station are. You will also draw another seven millimeter line on another paper that will be your vertical survey. On this paper you will indicate how the roof and floor height relates to the survey station. Lastly imagine going through 65 km of cave passages that make up the ten longest caves in South Africa, you would go through this process another 6,499 times.

Once all the lines are drawn in on both the pages and the wall widths and roof heights are indicated, you can finally start to draw in the cave walls. Based on your sketches in the cave and the notes you made, you can now trace the outline of the cave passages and indicate any important features. Unfortunately mud would have covered portions of the sketches, however you would scrape the mud away and using memory, experience and some guessing you will be able to draw what the sections look like. Once all is complete, you put a blank piece of paper over the sketch and retrace all of the walls that you just spent hours drawing in. This is basically to remove the middle lines that you drew in on the initial sketch to make the final survey less confusing and less cluttered. Once completed you will add up all measurements as well as vertical measurements on the vertical sketch profile in order to indicate exactly how long and deep the cave really is. As a final gesture you proudly sign your name at

the bottom, because after all that hard work you deserve it.

All of the individuals, who helped to survey the 65 kilometres of the ten longest caves as well as those who surveyed approximately 100 kilometres of other caves in Southern Africa, really deserve a big thank you for all the hard work they performed during their many years of caving.

As time went on, technology improved and SEC recently acquired new survey equipment. The tape measure, compass and inclinometer have been replaced by a single electronic device. A Leica Disto X310 is the basic equipment which can measure distance and incline. An upgrade kit is then added which gives the device an electronic compass and Bluetooth capabilities and improves the functionality of the inclinometer. A special non-magnetic battery is also added to the device. According to Leica's website the device is dust proof, protected against water-jets and passes drop tests of up to two meters. The upgrade kit and battery do not affect the robust nature of the Disto. The upgrade kit however is not made by Leica, but by a caver in Europe, Beat Heeb, so by installing the upgrade kit into the Disto the warranty is unfortunately void.

The notebook and pencil is replaced by a tablet or smartphone which can connect to the DistoX2 via Bluetooth. The tablet or smartphone is loaded with survey software and in this case Topodroid is used. This combination was first tested in Villa Louisa III. At the entrance of the cave the tablet is switched on and in Topodroid a new file is created for Villa3. The tablet has GPS, so one immediately gets the exact coordinates of the cave entrance and makes the spot the first survey station. From this survey station, shots can be taken to the walls, roof and floor of the cave to get distance, incline and add compass-bearing for all of these. The final shot to be taken is between survey station one and two.

Now normally you would need to write down these measurements, but technology has simplified this. With a click of a button on the tablet, the information is downloaded from the DistoX2 to the tablet. There is no need to write anything down and no errors can occur due to information being shouted across a cave from one individual to another.

The upgrade kit allows multiple shots to be stored. Therefore at a survey station one could take left, right, up or down shots plus the shot to the next survey station, then with a click of a button transfer the shots to the tablet and have all five shots there in a matter of seconds. But why stop there? With the ability to take shots quickly and easily and download them easily many shots can be taken. In Villa Louisa III we averaged 50 shots per survey station! Probably too much, but we wanted to test the equipment fully. You can easily do a shot every 2 or 3 seconds and it takes about half a second per shot to download. So 50 shots will take you 3 minutes to take and transfer to the tablet. Now why would anyone want 50 shots at one survey station? Detail, especially in a chamber where the walls are very irregular, or where the roof is irregular and you want to get that exact detail of how its height changes between the survey stations. So ideally you could take a shot in a horizontal circle around the survey station, then a vertical circle to get the roof and floor dimensions.

Also, why would anyone want to go through the entire trigonometry exercise involved with 50 shots at each station and additionally draw all of these to scale on a piece of paper when TopoDroid does this for you? Once all 50 shots have been downloaded, the final shot is entered into TopoDroid and the program performs all trigonometry and magnetic declination calculations for you, plus it displays the horizontal and elevation profiles on the tablet. Within minutes, right there in the cave you have the line survey of the cave, calculated to scale. All that is left for you to do is to draw in the walls and features of the cave using the tablet.

In this way we went through almost a 100 survey stations and took close to 5,000 shots in about





Screenshots taken of the TopoDroid program that shows the survey data and the horizontal line survey of the cave.

7 hours of surveying. What emerged on the tablet is a sketch with lines everywhere, but so dense that you can exactly draw the walls in along the edges of the lines.

Once you get back from a long day of caving the information is exported to a computer. This is where another program called Therion is used. The information is transferred to Therion and with some minor modifications (taking about five minutes), a horizontal and vertical line survey is generated which can be used to draw in the walls of the cave.

Drawing walls and other features is the part that still takes the longest to complete. There are two options, the line surveys can either be printed out and the walls drawn manually, as done in the past, or Therion can be used. Using Therion can actually take longer in this instance than the manual method, but there is an advantage to using Therion. If something needs to be added, like an extension to the cave, the extension can be drawn separately and the two separate pieces can be joined within minutes. There is no need to redraw the entire survey when this is done. Subsequent changes or corrections to data can be added to the final survey within minutes.

In addition to having a line survey drawn, Therion also gives two other forms of data output. The first is a Google Earth file, which shows the line survey data on Google Earth. The second is a 3D viewer, in which the line survey data can be viewed in 3D with colours to indicate the changes of depth in the cave. One of the uses of this is that the data of two caves can be added to one 3D file and it can be seen which part of the caves may be close to each other and might lead to a connection between the caves. The exact distance between those two locations can also be calculated.

The above method of surveying the cave was not that much faster than the older method; however this is as a result of the extra detail included in the survey. At another stage we had to find the shortest route from the entrance to a specific point within a cave. In a matter of 25 minutes we surveyed a 135 metre loop from the entrance, to the point and back to the same entrance via a second route within a difficult part of the Rising Star System, so most of the time was actually spent on negotiating the difficult squeezes rather than the surveying. Within 5 minutes of using Therion we had closed the loop with only a two metre error, knew exactly which route was shorter, knew the depth of the specific



point in the cave and could determine exactly where this section of the cave was in relation to the surface. At no point did we do any back shots or use any other methods to determine or enhance the accuracy of the survey.

The above loop error was a 1.55% error, which falls into a Grade 5 survey class in the UIS and ASF standards. The largest portion of this error was a vertical error, so for a plan survey the accuracy is very high, however we have had very different results in different caves. Loop errors have generally varied from 1% up to 5%. These would fall from Grade 6 to Grade 4 within the UIS grading system. Generally the percentage of error tended to improve as the total loop length increased.

An interesting test for this survey system was Armageddon Cave. Initially a line survey was done with a laser distance meter, compass and inclinometer. More than a year later, this was resurveyed with the DistoX2 and a loop was created between the old and new survey data. This loop showed a 0.9% error over a loop of almost two kilometers. Therefore the DistoX2 is a very accurate method of surveying!

Playing around with the DistoX2 has shown some interesting results regarding its accuracy. A 35 meter loop was surveyed around a small house with a lot of steel, hence magnetic interferences, along the way. When only five shots were taken to measure the entire loop the error was 10 meters, a 30% error! This was mostly due to an error at a single station, where the DistoX2 was put onto a steel garden chair, which caused a 90 degree error on the compass bearing.

Decreasing the distances between stations and increasing the number of shots to 12 shots over the same distance, decreased the error to 3.2 meters and decreased the error to 10%.

Further decreasing the distance between stations and increasing the number of shots to 24 shots, decreased the error to 1.5 meters, which is a 4.3% error.

This shows that a high accuracy can be maintained if shorter shots are used between stations even when some magnetic errors are present. Of course, carefully checking the line survey as it is produced would have picked up the large error that was present from the steel garden chair and it could have been corrected whilst surveying.

Another factor that affects the accuracy of the device is its calibration. The device needs to be regularly calibrated. Many people suggest calibrating before each use, which is possible as it takes less than five minutes to calibrate the device. The calibration does not need any known references. The device can be calibrated anywhere at any time if no large magnetic anomalies are present.

So, regular calibrations, short survey shots and regularly comparing the line survey with the actual cave environment, whilst surveying, will almost certainly produce a very accurate survey.

The only down side is the price and getting all the parts together. The Leica Disto X310 can be purchased in South Africa for R 5,000. The upgrade kit is bought from Austria for 180 Euro, but can be a problem to get with the current postal service situation. The non-magnetic battery can be bought from the USA for approximately R200, but again, getting it delivered to South Africa may be an issue. These items would then need to be assembled and some parts even soldered, so one needs the skills to do this. Lastly a tablet should be bought and its price can vary greatly, anywhere from R1000 upwards.

Overall the DistoX2 is a very convenient surveying tool and makes surveying much easier and faster. It is certainly worth the price and effort to get all parts together and working.

For more info on the DistoX2 visit: <http://paperless.bheeb.ch/>

For more info on Therion visit: <http://therion.speleo.sk/>

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## Underground GPS: finally possible!

As GPS signals cannot penetrate into the ground it cannot be used in caves or mines. A Swiss company however found a smart solution to this problem and presents now the first Underground GPS.

Since 2004 researchers from the Swiss Institute of Speleology and Karstology (ISSKA) were working on a system for underground positioning (see paper about U-GPSv1).

In 2010 the company InfraSurvey was founded to commercialise the idea. A new prototype was developed (U-GPS v2) and tested in real world situations. It's now even possible to follow a caver in real time (see movie on the main page of Infrsurvey).

The system consists of:

- Underground - a mobile emitter (8 kg)

- At surface - four receivers at fixed positions determined by GPS, a radio link between the receivers and a computer with custom software to analyse and visualize the signals.

### How does it work?

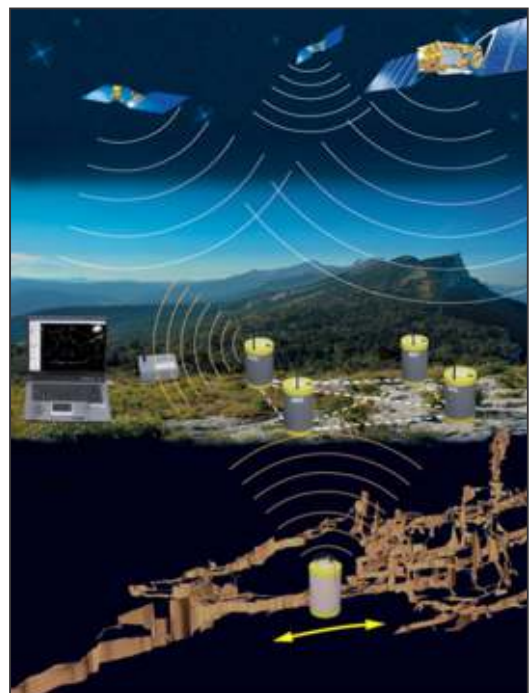
The receivers are placed on the surface, roughly on top of the underground passage to be measured.

They are automatically self-located using GPS. The underground transmitter sends a signal that is detected by the receivers located at the surface.

The computer then calculates the exact position and visualises it, making it possible to follow the moving object in real time covering a surface of 300 m x 300 m without the need to move the surface receivers.

A smaller, lighter version is being developed (less than 2.5") as well as a waterproof version (ipx 8, up to 100 m) and will become available in 2011.

More information can be found on the website of InfraSurvey or on the website of ISSKA: [here](#) and [here](#).



## Expedition to Botswana's Aha Hills to search for caves

*Alan Grant and Dave Ingold*

*An expedition took place, in conjunction with and with extensive support from the Government of Botswana, to search the dolomitic outcrops which form the Aha Hills of north-western Botswana. Two caves were known in the area and the focus of the trip was to search the hills for other speleological events. Only two very small fracture caves were found but investigation of the two known caves corrected the surveys and indicated their uniqueness. The report details the expedition, the findings on the known caves and recommends further cave searches take place across the Aha Hills but the main effort should be concentrated in the hills to the south of Aha.*



Fig 1

The period of the expedition was 5th to 13th April 2009. It was organised by: the Speleological Exploration Club, under the auspices of the South African Spelaeological Association. The expedition was planned in conjunction with the Botswana Government who provided extensive moral support and guidance.

Expedition Leader was John Dickie, and the team consisted of: Lewis Coosner, Selena Dickie, Bruce Dickie, Matthew Dickie, Roger Ellis, Bob Eyre, Alan Grant, Clint Howes, Dave Ingold, Peter Kenyon, Sharron Reynolds.

Several dolostone outcroppings occur in north-west Botswana (Fig 1) and caves have been discovered in the Gcwihaba Hills some 40km south of Aha. Gcwihaba Hyena's Hole Cave, previously called Drotzky's Cave, is known for its

extensive secondary cave formations. 19 kilometres further south lie the Koanaka Hills which also have yielded two significant caves. A theory was postulated that these caves were the resurgences for water absorbed in the dolomitic regions to the north – the Aha Hills. These 700-million year old limestone/dolomite/marble hills straddle the border with Namibia at 19 degrees 47 minutes South and 21 degrees East. They rise ~300 metres from the flat Kalahari scrub. The estimated area of the whole hill range is some 245 square kilometres.

The weakly metamorphosed and folded chert-rich dolomite and limestone of the Aha hills originated in late-proterozoic times (Ref. 2, Key and Ayres, 2000). They are metamorphosed to noticeably lower grade than the nearby cave-rich Gcwihaba and Koanaka hills. The hills stand out as inselbergs from the surrounding unconsolidated Kalahari sands and are covered in dense vegetation. Where the rock is exposed, it is heavily weathered into sharp pinnacles and ridges up to a metre high and is abounded with cracks, fissures and solution tubes seldom more than a few tens of centimetres across.

The expedition was formed to explore the Aha Hills to the north-west of Gcwihaba in order to:

- assess the dolomites of the area and potential for new cave discovery;

- try to find further caves to the two recorded on a SASA expedition in 1979 and
- re-explore these known caves;

This area was chosen because it has received little interest in the past and appeared to hold great potential beyond the two caves. Whilst the planned trip was recognised as of very short duration to fully explore the ~24 square kilometres of the central Aha Hills, this visit was expected as a pre-cursor for future detailed examination of the area if new caves were found or the potential for caves was considered to be reasonable.

Discussion of the trip was commenced with the Botswana Government through existing contacts and extensive logistical support was offered, very gratefully accepted and structured.

No useful maps could be found of the area. Best data was gleaned from Internet research, Google Earth satellite imagery, LandSat images and enhanced satellite images provided by De Beers through their prospecting work. See Fig 2: the Aha Hills. Aerial photographs of the area were later provided, on site, by the Botswana Government.

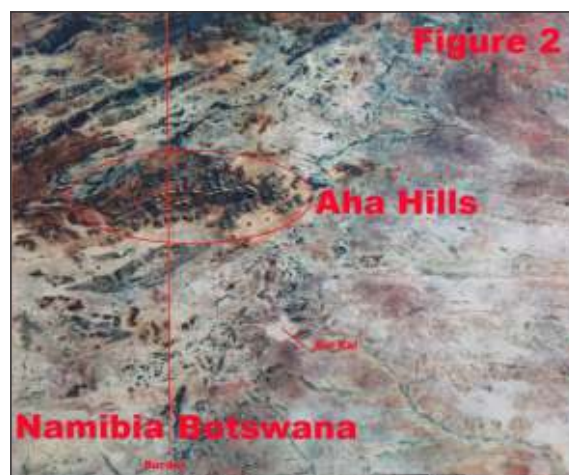


Fig 2

### The Expedition

Our 12-member team met outside Krugersdorp, South Africa, at 05h00 on Sunday 5th April and traveled in four vehicles to cross into Botswana at 08h30. We were met by two Botswana government personnel and guided to the centre of Gaborone where we parked and unloaded our vehicles and trailers onto a local truck and drove to Gaborone Airport for the flight to Maun.

In Maun we were met and transported to the Sedia Hotel for the night. Owing to restrictions on meat imports into the country we had planned to buy meat for the expedition in Maun the next morning; as we were in the hotel by 14h30 we made a quick change of plan and rushed off to the local supermarkets to get supplies to save time the next day. We had arranged to meet wildlife photographer Tim Liversedge later at his home and there and over dinner later at the hotel, he recounted his visits to the Aha Hills, his knowledge of the known caves and of the snakes, scorpions and other inhabitants of the area.

### Monday 6th April

In Land Cruisers, with equipment truck following, we began the drive to Tsau on tarred roads at speeds of up to 120km/hour. Just after that village we turned onto a sand road where speed dropped initially to 60 km/hour then soon to 30 km/hour. In many places 12 km/hour or less was necessary to negotiate the deep sand and tight curves. We passed through the Gcwihaba hills and finally made our planned campsite by 17h30 just as the sun began to set. The evening was spent setting up camp, cooking the evening meal and enjoying the seldom-felt tranquility in this, one of the most remote parts of Africa. Our Botswana government assistants and a representative of the Botswana Museums Department were also making camp and setting up water bowzers – the nearest water to our camp-site was many kilometres away so we were extremely grateful for such magnificent logistical support.

The campsite location and adjacent hills are shown below in Fig 3.

### Tuesday 7th April

After breakfast, which coincided with dawn at 06h15, we made our first venture into the adjacent hill



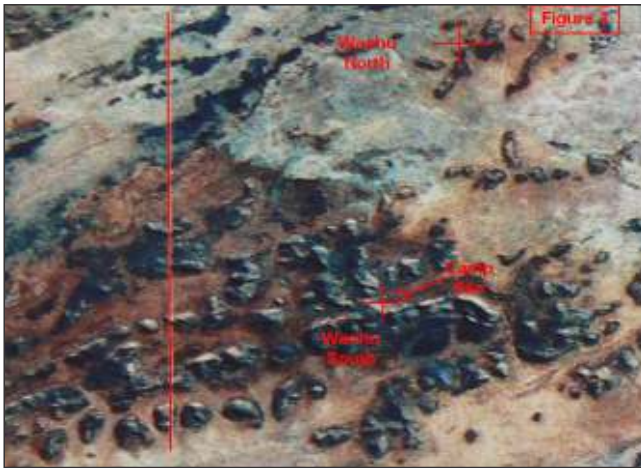


Fig 3

and discovered the problems facing us. The scrub-bush is mixed with tall Morula, Baobab, and Acacia trees, the many varieties of the last having thorns which range from 'hooking, snagging and vicious' to 'downright murderous.' As this is renowned Black Mamba (one of the world's most venomous snakes), Puffadder (responsible for most snake bites on the African continent) and Horned Viper country plus the home to many venomous scorpions one tends to tread carefully over the sharp and deeply weathered dolomite rocks which lay beneath the undergrowth. Add in the steep contours of the hills and it should be apparent that this was no

easy walking country. One Mamba was spotted but it disappeared quickly at the sound of voices and footfalls.

To cap it off, there were Blackjacks: the seeds of this alien weed are far worse than the milder cousin which grows in South Africa. The Aha variety has several hooked barbs at the tip that not only catch onto skin and clothing, so that the receiver becomes a walking imitation of a hedgehog but, when the seeds are removed from clothing, the barbs remain and itch the skin mercilessly. Various other seeds and seed-pods have spikes and snags to catch onto clothing so that by the end of a minute's journey into the bush even one's shoelaces became painful to undo.

As an additional deterrent, struggling through the bush, watching for snakes, scorpions, loose rocks and thorns, whilst trying to avoid as many blackjacks as possible, the caver hunter can't keep his eyes on the ground too long or he'll wander into the several-metre wide, very sticky web of the Golden Orb Spider. This fearsome-looking green and black beastie is some 10 cm long and quite a scary sight when seen up close!

After returning to camp for a quick lunch we set off to explore the next hill to the west of the camp, encountering the same problems with the same result – no new caves.

Despite these problems our two ventures into the bush managed to cover a large area of the hills adjacent to the campsite and also confirmed the location of one of the known caves – Waxhu (SAN name for most caves, meaning 'House of God') South.

We were tired – very tired! – from the efforts of the day but the promise of undiscovered caves made us plan better for the next day as we devoured our very welcome and needed evening meal

The day was planned for three separate treks into areas most likely, from aerial photographs and satellite images, to contain caves. Now that we were familiar with the problems government personnel were conscripted into the search and, after showing them the entrances to Waxhu South Cave for them to understand the nature of what we were looking for, the teams were delivered by truck to the starting points. This day's sortie saw the three teams of cavers and others, head into the hills to the west of the camp-site. Each team spread into a 'skirmish-line' across the flank of their hill and, with the help of two-way radios and shouting to keep in contact, searched as much of the ground as possible seeking any cavities or depressions that would indicate cave entrances or sink-holes. None were found apart from a small fracture cave, about two body-lengths long, that followed the contour of the hill rather than penetrating into it. A diagram of the cave is shown below.

Returning to camp for a late lunch gave chance for discussion of the proposed afternoon's activities, with the majority tackling a further search whilst a couple of cavers rigged and descended into Waxhu South cave. This cave consists of several small entrance holes in the rock but just three manageable entrances. The biggest is a short pitch of about 6 metres, requiring single-rope-technique (SRT), then rope-assisted descent down a rubble slope before a second pitch and scrabble across bat guano seething with spiders, centipedes and roaches. The final climb to the bottom is down over loose rubble. A fairly large colony of bats occupies the cave. The cave is bare of any formations with most of the walls and loose fill being of insoluble sand, sandstones, metamorphosed quartzite and shales.

#### Small cave found in the Aha Hills Botswana.

The cave was located on the north west facing hillside at the upper shoulder of the hill face. The rock was mixed dolomite.

Location S19°46.202 E21°00.711 Elevation 1225 m



Drawing estimated by P Kanyon & C Howes

1 m



The areas searched so far and on subsequent days are shown in Fig 4 below.



Fig 4

#### **Thursday 9th April**

Having planned the areas to be searched during the previous evening, the three teams were again trucked to their relevant starting points where they split up and set off into the hills. Many hours of searching began in different directions, using the team members again in 'skirmish lines' to scout along the flanks of the hills. In all cases, it was difficult for the team personnel to keep in direct contact owing to the difficulties of the terrain already described but efforts were continuously directed to ensure the searches

were as comprehensive as possible. Again, no caves were found although a large Puffadder was!

A reconnaissance of Waxhu North cave's surface layout was made to assess equipment needs for the planned descent in the coming days.

On this day it had been decided to search the hills to the east of the main north-south dirt track bisecting the hills and to the southeast where a known quarry had once been active in providing material for road construction. The three teams were again trucked to their respective areas where they set off in the now well-established search technique of the "skirmish line". All the teams covered their target areas without finding any new caves, although much of the dolostone was even more prominent in this region. The team covering the hills to the west of the main dirt road did encounter a very large and lazy Puffadder, which added to their tribulations but proved no risk to their health.

In the afternoon several government personnel interested in exploring Waxhu South cave were given SRT training and three, along with several cavers descended into the cave. Sharron located a colony of ~100 Horseshoe bats – later that evening she picked up three different bat-emissions at 23/24kHz, 37kHz and 53kHz with her bat detector. Everyone was out of the cave by 20h00 and ready for a good meal.

Scorpions were hunted around the camp – Sharron had brought two UV torches to help with this as

scorpions fluoresce under this light. Photographs were taken then and next morning to help identify the species.

### **Saturday 11th April**

The bulk of the team set out for Waxhu North cave to rig and descend this strange sink-hole. The other members set off for a final exploration of hills to the south of the quarry where features identified on the aerial photographs were of particular interest. No caves were found however.

Waxhu North cave is a very slight depression in the flat bush and would be easy to miss or, for the unwary, to stumble into. A shallow cone of sandy ground has fallen into the deep sink-hole. Safety ropes were placed around the hole to prevent accidents and all personnel approaching the hole clipped their safety lines into them. The pitch was rigged as a Tyrolean: a main static rope over the top and centre of the hole, anchored to a large Morula tree on one side and several sturdy bushes in series on the other. The descent rope was also tied to the tree then to a pulley on the main rope. John ventured to go first, hitched his descender onto the rope and pulled himself out for a look into the pitch. Satisfied with the rigging, he abseiled down to the first ledge 20 metres underground. Alan joined him, taking another 100 metre rope along with him. Selena, Lewis and Sharron joined them with Sharron also taking down the impact drill and anchors. A small roost of bats was found in the cave.

The wall was bolted twice and John descended, eventually to the floor of the cave – this was hampered by the extreme need for deviations and the necessity of many rope-protectors. He explored the lower levels of the cave, adding about 20 metres to the survey and also noting that the previous surveyor had mixed up the orientation of the lower part. He reported later that this was “one scary cave as everything is loose and very dangerous!”

Once everyone was safely out, the cave was de-rigged, the site cleaned and cleared and the trek made back to the truck for return to camp.

In the late afternoon another three government persons tackled Waxhu South cave and, like the three the previous night, showed good caving and rope skills plus plenty of courage.

Later that evening we all, along with our hosts, drove around to a San camp in some nearby hills. We were entertained with some traditional dancing and singing.

### **Sunday 12th April**

At 04h00 activity began to break camp and vehicles were loaded with personnel and equipment to leave at 07h00. We returned to Maun just after midday for a lunch at Riley's Hotel. After we had eaten a very welcome meal, we transferred our personal gear from the Land Cruisers into a Quantum bus that would take us to our overnight point at the Xere Motel in Rakops, which we reached at dusk.

### **Monday 13th April**

After a hearty breakfast we left the motel at 06h45, boarded our Quantum bus and set off for Gaborone. The trip back was long and uneventful but frequent stops to stretch legs and survey the surroundings relieved the tiredness. Dodging cows, donkeys and goats during the first half of the journey added to the interest but as Gaborone hove into sight the team was glad the long journey was over. We thanked our driver for bringing us back safely and complimented his professional skills. We transferred all the equipment and personal stuff back into our own vehicles and trailers and, within the hour, we were heading for the border and home, arriving late in the night.

## Discussion of known caves

### Waxhu South Cave — S19° 46,680' E21° 02,496'

The cave has formed in the north-facing slope of the largest hill in the area in well developed karst surface topography. The entrance, which is 22m higher than the Kalahari-sands infill between the hills, consists of several small holes that join the main chamber almost immediately. Separating the passages in the westerly cluster of entrance holes is an interesting orange-coloured breccia that contains free floating clear yellow crystals of barite. This cave (Fig 5) is one large chamber 52m deep, 12m wide and 40m long.

The floor consists of unconsolidated talus, which slopes down towards the west in accordance with the dip and dip-direction of the local strata. Large deep piles of bat guano form below colonies of horseshoe bats (*Rhinolophus* spp.), the depth of the guano piles indicates a long term residence by the bats and a caver will easily sink knee deep in the guano. Any water collecting in the cave drains out at its lowest point, marked as “drain hole” in figure 5. The walls have dirt marks a metre above the current floor level and these marks slope towards the drain hole. These marks record a previous floor level which has dropped and the lost material probably accumulated in a lower open cavity therefore it is quite possible that the cave continues below the current floor level.

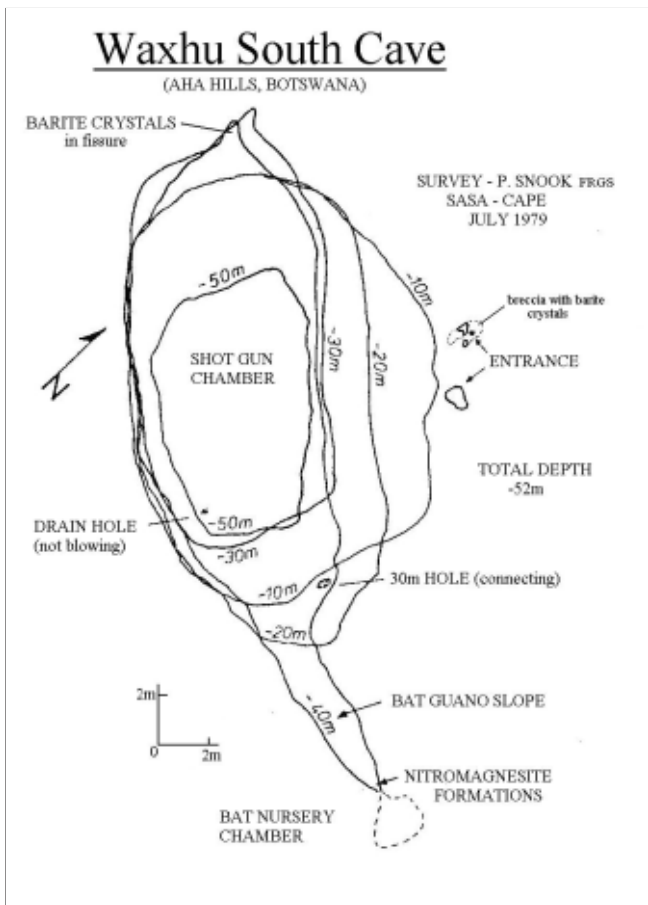


Fig 5. Survey for Waxhu South cave, adapted from the 1979 survey.

The geometry of the cave is clearly defined by a ten metre wide zone of numerous anatomising planer features striking north-west south-east and dipping almost vertically. Veins and Vugs filled with barite, as well as the peculiar breccia by the entrance lead to the interpretation that the cave formed within a fault zone.

Figure 6, A roughly north-east south-west section of Waxhu South cave; this view is in the plane of the proposed anatomising and brecciated fault zone.

### Mineralogy

Large clusters of euheadral barite crystals, some over 4cm long, are found throughout the cave. Many single crystals are found loose in the bat guano slope leading up to the bat nursery chamber on the east side of the cave, and on the western side they were traced back to a small horizontal fissure, 10cm high and 50cm wide, with its top and bottom coated with spectacular honey yellow crystals (Fig 5). These crystals are also found in the breccia by the entrance as residual fragments distributed within matrix. Fragments vary in size between 2mm and 10cm while on average they are less than 2cm across. Transparent tabular crystals of gypsum were collected from inside the cave

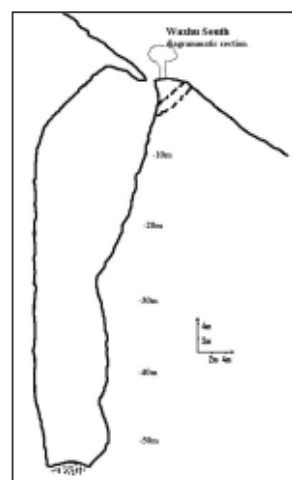


Fig 6. A roughly north-east south-west section of Waxhu South cave; this view is in the plane of the proposed anatomising and brecciated fault zone.



and small, dirty, urine-coloured stalactites of nitromagnesite about 10cm long are seen growing from the boulder choke by the nursery chamber, these were identified by X-ray diffraction by the geological survey in Pretoria in 1979 (Craven 1980). This is a rare cave mineral derived from bat guano, which only forms in low humidity environments of less than 78% humidity (mineral data publishing, 2001) and is more commonly seen as just fine white crusts on surfaces (Martini and Kavalieris 1978).

### Caving

This cave can be descended on a single rope with some good stout trees for anchors by the entrance. When descending it is best to tend to the easterly side of the initial 20m long slope to avoid loose rock and, as the rope does not hang free, a number of rope protectors are needed to avoid rope damage over sharp edges. The meandering descent route requires a slightly longer than expected rope, greater than 60m free-length. There is also a high rock-fall potential from several points in the cave so great care must be taken.

### Waxhu North Cave — S19° 43,532' E21° 03,489'

Original and corrected surveys of this cave are shown below.

### Description

The cave formed 50m off to the side of a small hill 6km north from the main range of hills. The first 5m is unconsolidated sand forming a funnel shaped pit, below this the cave extends down a fissure to a depth of 70m. At -40m there is a definite widening and sand covered slopes at their angle of repose. The floor, at -70m, is fine sand and narrow cracks extend laterally. It appears that the cave has formed on the intersection between a major crack and less resistant rock layers which are orientated less than 10° off vertical. There is a large colony of horseshoe bats in this cave producing a pungent odour and mounds of guano.

### Mineralogy

At the bottom of the shaft there was a high concentration of ammonia reported by John Dickie, the only member of our expedition to descend beyond the second ledge by the kudu skull (Figure 8). Evaporite minerals derived from bat guano would be expected and may or may not be present (Martini, 1996). Apart from a few calcite watermarks, the cave is barren of any speleothems.

### Caving

This cave is a far greater challenge to descend than Waxhu South. It is best to separate it into 3 pitches, the first pitch is rigged with a Tyrolean traverse between trees to position the abseil rope over the entrance: the second pitch at -20m now sports two bolts from which to abseil and the third pitch has huge rope abrasion and rock fall hazards so extreme care must be taken. And to spice things up, an exceptionally large black mamba – estimated by Tim Liversedge as well over 4 metres - had been

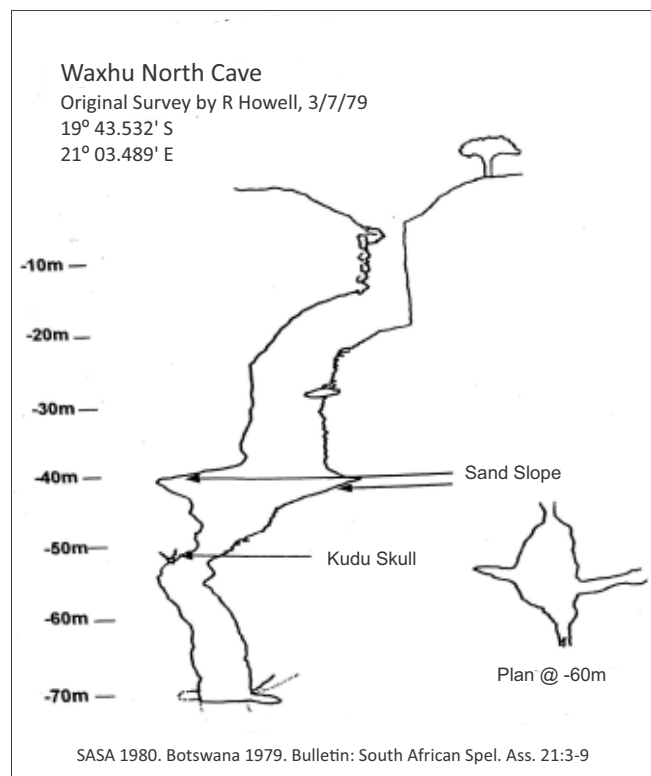


Fig 7. Original survey of Waxhu North.

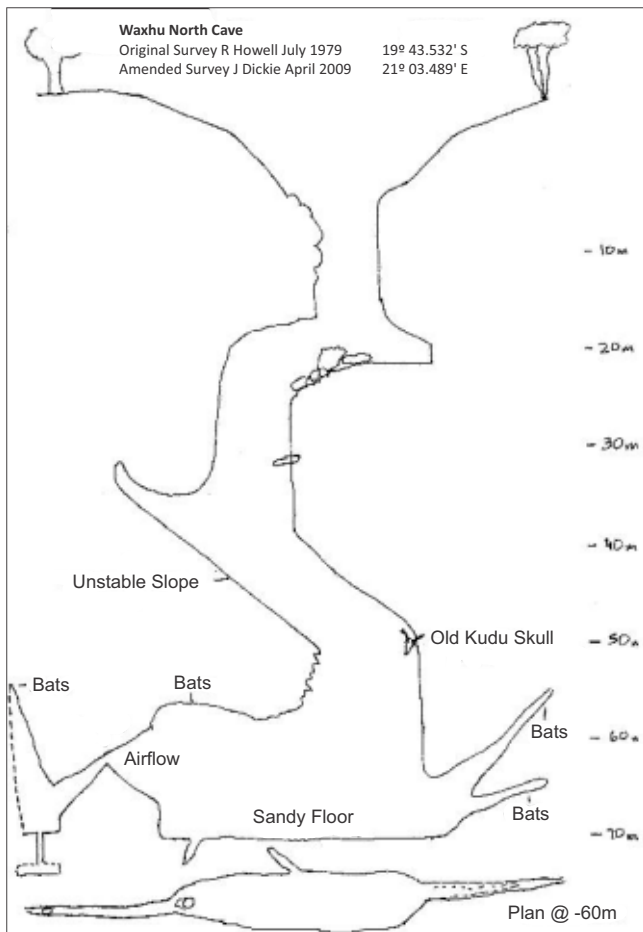


Figure 8. Corrected survey of Waxhu North.

observed and studied at the cave entrance cone a month before the expedition.

### Conclusions

A rough calculation of 12 cavers @ 6 hours per day for 5 days yields 360 man-hours of hunting for caves on this expedition. Adding in the very welcome assistance from the Botswanans (12 men @ 6 hours per day for 3 days = 216 man-hours) shows that around 576 man-hours were expended without finding any significant new caves.

Whilst vast areas of the greater Aha Hills were not explored during this visit, the fact that no caves were found in any of the most-likely areas indicates that, statistically, very few caves will exist in the region. This is supported by the observations of Waxhu South and Waxhu North caves in that they both appear to be 'fault' caves and not solution caves. The complete absence of any secondary cave formations in either cavity suggests that water has played little part in their creation.

From a caving perspective, the remoteness of these caves, as well as their vertical nature, makes their exploration a serious proposition. Falling rocks pose a huge danger as there are few safe places yielding protection on or near the bottom of the pitches. This view is reinforced by abandoned helmet, torch and damaged ropes found by us at the bottom of Waxhu South.

The Aha hills cover a great area and the exposed dolostone is extensive. One would expect that the area would harbour many notable cave systems like those observed in the Gcwihaba and Koanaka hills. The two known caves do not fit the general morphology that one would expect and that is seen in the nearby groups of hills. It seems logical to assume that these caves did not form as usual phreatic dissolution cavities but possibly other more unusual factors played a roll in their formation.

Distinct structural origins can be assumed for both caves. Waxhu North appears to be controlled by a combination of joints and less resistant shaley layers in the steeply dipping dolomite. It is evident that the exact site must have been very preferential to the formation of a cavity as it formed below several metres of sand. Waxhu South with its not-commonly-seen cave features indicates an abnormal speleogenesis that is probably related to tectonics, faulting and hydrothermal fluid flow then solution by meteoric water.

It seems that for caves to form in these hills, unusual circumstances are needed and this would explain why there is a significant lack of caves. It is extremely probable that the region of Aha extending into adjacent Namibia will be of the same nature as described above in the Botswanan region.

The dolomites and limestones of the region covered in this search were all severely weathered and fragmented with only minor holes of up to ~200mm diameter and depths of less than a metre with the

exception of the larger hole described above. In many places the overlying rock was loose and separated from the bedrock beneath.

Six volunteers from the Botswana government were given SRT training and, once proficient, descended, explored and climbed out of Waxhu South. This experience should benefit them for future exposure to caves.

The survey of Waxhu North cave was found to be confused. It has now been re-drawn and included in this report.

### Recommendations

Although a few significant caves could exist in areas not explored during this expedition – or even overlooked in the searched areas because of the difficulties encountered and described - it is considered probable that they will be of a similar nature to Waxhu North and South caves: fault caves rather than solution caves and will have negligible impact on water collection, preservation or distribution in the area. It is evident from the vegetation that the Aha region receives more rainfall than the dolomites to the south-east; no significant stream-beds were found thus indicating that rain is quickly absorbed into the dolostone and sand.

Whilst statistically it is unlikely that significant caves exist close to the searched area, exploration outside that area may find different conditions. It is thus felt that further exploration of the greater Aha area could be warranted but the bulk of effort in cave-hunting should be concentrated to the south of Aha, namely in the Koanaka and Gcwihaba areas which have both shown the presence of solution caves.

### Thanks

The team extends enormous thanks to the Botswana Government and its chosen representatives for the considerable help with logistics, negotiation with local communities and cave searching. Without any of this help it would not have been possible to do so much, nor in the limited time available.

To Tim Liversage: thanks to you and your lovely wife, June, for your hospitality and so willingly sharing your extensive knowledge of the Aha region with us. The information gained from you helped so much.

The authors thank their fellow cavers who made the trip exciting, informative and fun. Whilst everyone played an important role, special mention must go to Sharron - who took responsibility for provisioning and cooking all meals and succeeded spectacularly – and to Selena who provided considerable help with cooking and feeding tired, hungry cavers despite their own tiredness.

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## Armageddon Cave

*Steven Joseph Tucker*

### 13 January 2013

It was the 13th of January 2013 when the Speleological Exploration Club's monthly trip was a visit to two small caves south of Westonaria. Oosthuizen's Cave was visited and after it we visited Fault Cave to check whether the water levels had gone down and allowed access to the cave. After we dug open the blocked entrance we soon found that the water levels had not lowered. After this Colin Redmayne-Smith wanted to show us a large sinkhole that had fallen in within the last 20 years. The sinkhole is



Photo of the sinkhole by Rick Hunter



The dark overhang as seen from above – Photo by Dave Ingold

20 metres wide and approximately 50 metres deep. The sides of the sinkhole were all Pretoria Shale and there was no sign of dolomite. Not a good sign, but there was a dark patch to the south east that looked like an overhang, and even if there was nothing at the bottom it would be a great rigging exercise.

### 19 January 2013

A week later we were back at the sinkhole with a group of 11 cavers. John Dickie and Colin R-S rigged the entrance. The sinkhole is in an open field with no large trees or any other objects to anchor to, so cars were parked on each side of the sinkhole with a rope attached to each car and held up from the sides of the sinkhole by a bipod. The rope runs across the sinkhole as a Tyrolean; with a second rope, the main descending rope, attached to a vehicle and then running across the Tyrolean on a pulley.

Gerrie Pretorius was the first to abseil, but the rope was too short! Fortunately he noticed before even getting to the stopper knot. A second rope was lowered to him for him to attach to the one he was on. Connecting two ropes with a

double fisherman knot whilst on solid ground with people available to double check your knot is a relatively simple matter. Doing this whilst hanging four stories above the floor of an unexplored sinkhole and far below the assistance of other cavers and having to immediately trust your life to that knot is an entirely different matter. Therefore Gerrie decided to climb back up the rope. When he was back on the surface he said that he saw what looked like a large passage leading off from the bottom of the sinkhole.



Tyrolean across the sinkhole – Photo by André Doussy

The entrance was re-rigged with a longer rope and I was next to descend. This time the rope was long enough and I got to the bottom. At the bottom was a large entrance and all I could see beyond it was blackness! I shouted to the others that there was a cave to be explored and the next person should follow. I made my way slowly down a very steep slope which went down a vertical distance of 50 metres into a very large chamber with a massive boulder pile in the middle of it. I went straight in the direction that the slope had gone down. I had soon gone far into the chamber and could barely see the entrance so I waited for Lindin Mazilis to enter the cave. When I saw him I said that I was going in deeper and that he should follow. Soon after, I saw a wall in front of me. Dread filled me as I believed the cave had ended. The chamber was massive, over 120 metres long and 50 metres wide, but we wanted more.



The first descent of the sinkhole – Photo by Dave Ingold

Walking along the side of the wall we noticed a large passage heading further into the cave. By this time John Dickie had joined us. The three of us went along this passage. It was a very wide and tall passage and carried on for 300 metres until we were stopped by a vertical pit in the floor that was as wide as the passage and about five metres across and seven deep. Beyond this we could easily see another 50 metres of passage, but had no way of crossing the pit. We returned and on the way back, just before the entrance chamber John found a passage leading off from the main passage. This passage was only 35 metres long, but had some stunning aragonite crystals and John named it Hoary Passage. Whilst we had explored the passage, Irene Kruger, Selena Dickie and Sharron Reynolds had entered the cave. Dave Ingold, Colin, Horst Muller, Pete Kenyon and Gerrie stayed on surface. Sharron found a series of crawls to the North of the entrance slope that was part of the entrance collapse area. This was named Sharron's Alcove. We did not survey on this day, but estimated that we had gone approximately 400 metres from the entrance. This later turned out to be very accurate as we had actually gone 430 metres from the entrance. Except for the small side passages that were close to the entrance and the first chamber the cave was all one big passage, with only a single boulder choke through which we climbed through a slightly narrow section.



Passage between the entrance chamber and the boulder choke with a person for scale – Photo by André Doussy

Beyond this we could easily see another 50 metres of passage, but had no way of crossing the pit. We returned and on the way back, just before the entrance chamber John found a passage leading off from the main passage. This passage was only 35 metres long, but had some stunning aragonite crystals and John named it Hoary Passage. Whilst we had explored the passage, Irene Kruger, Selena Dickie and Sharron Reynolds had entered the cave. Dave Ingold, Colin, Horst Muller, Pete Kenyon and Gerrie stayed on surface. Sharron found a series of crawls to the North of the entrance slope that was part of the entrance collapse area. This was named Sharron's Alcove. We did not survey on this day, but estimated that we had gone approximately 400 metres from the entrance. This later turned out to be very accurate as we had actually gone 430 metres from the entrance. Except for the small side passages that were close to the entrance and the first chamber the cave was all one big passage, with only a single boulder choke through which we climbed through a slightly narrow section.





Looking down the second pit with ladders in place  
– Photo by André Doussy

Whilst we were crossing the pits the others were exploring and surveying their way to us. Gerrie went down another route south of the entrance pit, close to the entrance. When he entered it hundreds of bats flew out of the chamber and therefore we named it Gerrie's Bathole. At the end of this chamber was a large drop of about 35 metres that would be explored on another day. Gerrie also found a second passage of almost 70 metres length on the Southern side of the entrance chamber. This one was further away from the entrance.

The others surveyed up to us and we told them of the predicament. However when John shone a better light down the second pit we saw that the far side was in fact not vertical, but only a steep slope of loose rocks. So we dropped down the ladders and John climbed down and up the other side. From there he walked on until a third pit was found, the biggest of the lot. This one was 19 metres deep and 35 metres across. We only had the two ladders we had used at the second pit.

### 16 February 2013

John, Selena, Irene, Gerrie, Sharron, Bruce Gibbings and I went to attempt to cross the pit and survey the cave. Our method to cross the pit was to take a large extendable ladder down the cave. Two pieces of five metres each could extend to nine metres. Bruce and I carried the ladder in to the pit and climbed down with the intent of moving it across to the other side and climbing out, but the long ladder was unwieldy and we climbed out on the entrance side of the pit. Our next option was to lower the ladder across the pit and crawl over it. Crawling over an unstable ladder three stories above the floor is scary, but Bruce had no problem in crossing it. I soon followed and we walked on. We only managed to go about 20 metres when there was another pit. This one was much larger, 14 metres deep and 30 metres across. We had two caving ladders with us, so we could get down into the pit, but we did not go down as we had no way to climb up the other side.



The new method of crossing the first pit  
- Photo by Steven Tucker of André



Others climbed down to also see the third pit and survey up to it. I then dropped down the ladders on a rope, so the ladders could be used at the third pit. The two ladders along with some slings were just long enough for John to climb into the third pit. On the far side there was a vertical wall this time! We could not continue further, although it could be seen that the passage continued. The only option was to bolt up the far side on a future trip. We reattached the ladders at pit two and exited the cave.

When we finally exited the cave it was 19:00, an hour after our expected cut-off time to exit the cave. By that time Pete Kenyon had phoned 12 cavers, all with SRT experience to be on standby in case we did not exit the cave soon. We were just in time before the final call went out for a rescue team to come looking for us. It does make you feel safe knowing that if there really was an emergency, others are available to assist. Also, this time we were hauled out of the cave! Much better than the long climb.



Tyrolean crossing of Dickie's Pit (The third pit) – Photo by André Doussy



First large section after the third pit – Photo by André Doussy

When the survey was completed we realized that we had traveled a straight line distance of 570 metres from the entrance. The more interesting thing was that at the bottom of the third pit, John had been 210 metres vertically below the surface, a new record for dry caves in South Africa. The previous record was West Driefontien at 183 metres (Martini 1982), and had stood as a record since the fifties. A third observation came from Pedro who believed that the cave might have been formed by the Vredefort Dome Impact.

### 09 March 2013

For a big push we decided to do two days in the cave over a weekend. This time we went prepared for anything. A drill, drill bits, hammer, 100 metres of rope, 7 caving ladders, SRT kits and lots of karabiners. We were John, Gerrie, Jacques Behr, André Doussy and I.

We rigged the drop at Gerrie's Bathole and

abseiled down, only to find a second drop of 15 metres, which we also abseiled into. Here we found a small passage that was perpendicular to the main passage. On one side it went underneath the entrance chamber to a small drop and on the other side, away from the entrance chamber it went to a collapse in the passage that could be bolted up. At both sides there were possibilities, but they were not very good, so we climbed back up and proceeded to the third pit. After a long day we got a lot of gear to the top of the third pit and ready to assault the bolting to get up the other side. John and Jacques started putting up a rope across the first pit to avoid crawling across the ladder in the future. We finally arrived back at the entrance at 21:30, after 11 hours underground and luckily we were hauled out of the cave again! Hauling really is much faster when a large group does a big vertical drop.

### **10 March 2013**

The next day it was John, André, Selena, Bruce Dickie, Dave Ingold, Rick Hunter and I. John, André, Rick and I went to the third pit to start bolting. We needed to bolt up approximately ten metres, but only managed about six metres. Bolting was very slow as we had little experience in bolting up a climb and the many loose and unstable rocks made choosing anchor points very difficult. Often we would only find out that a rock was loose after hanging on it! Also the bolting of the Bathole on the previous day and this day had run down the batteries of the drill. We would need to go back and continue on a future trip.

### **24 March 2013**

John, Rick, Gerrie and Bruce Dickie went back to the cave. Rick and Gerrie surveyed Sharron's Alcove. John and Bruce continued to setup the rope across the first pit and broke away some loose rocks along the side of the pit. This enabled a person to clip a safety line onto this rope and walk across a thick chert ledge on the side of the pit. The ladder was no longer needed. The next goal was to put up a Tyrolean across the second pit. The ladder climb down the pit was dangerous as a lot of very big loose boulders had the potential to tumble down on top of whoever was climbing the ladder. Therefore, for safety sake a Tyrolean would be setup to cross the pit and avoid the dangerous boulders. The near side of the Tyrolean was bolted and ready to be completed on a next trip.

### **31 March 2013**

The next trip was just a week later when John and Rick went to complete the bolting on the far side of the second pit. They completed the bolting there and put up a Tyrolean and tested it and it worked perfectly. Now the double ladder climb at the second pit could be avoided completely. We had the same plan for the third pit as its sides were just as dangerous. This time we needed to have the Tyrolean ready to be put up as soon as the bolting up the far side was completed. So on this day the near side of the third pit was bolted and ready to have the Tyrolean setup on it. Now we needed to get back to the vertical bolting!

### **06 April 2013**

On this trip it was only John and I. We were going to try and get up the other side of the third pit. John bolted up a distance, then I tried, but soon I could not go any further as the rock became horribly loose and fragile. John wanted to try again, but when he got to the top he decided to try and climb sideways rather than bolt further up. After a very long and slow sideways climb, trying his best to dislodge large chunks of rock onto me, he got across the climb and was on the other side of the pit!

By now we were running out of time and still had a lot to do. John did a quick walk down the far side passage to see its potential. After walking a straight-line distance of 250 metres he had gone through a more narrow passage into a massive section of the passage, back into a slightly smaller section and back into a very large section, which still continued, but he stopped there. How he managed to stop, I don't know, but he returned with a vision of a large ongoing passage that was walkable!



When John got back he pulled up the rope that went across the pit and started putting in bolts on the far side. After the rope was rigged we tied a second rope to the Tyrolean for me to bounce on from the bottom to test the bolts. It held me easily and John used the Tyrolean to cross back to the near side, although we did need to put in extra anchors on the far side before the Tyrolean saw regular use. We then exited the cave after a very successful day that had ended more than 800 metres away from the entrance.

### 14 April 2013

This trip was a tourist trip. We had a lot of inexperienced cavers going down the cave and we took them across the first and second pit and up to the start of the third pit. In total we took 12 persons into the cave. On this trip Pedro Boshoff and Herman, another geologist, were in the cave. They confirmed Pedro's earlier idea that the cave was formed by the Vredefort bolide. They would need to take samples on a future trip and date these to confirm the date. Whilst they were there they identified some unusual formations in the cave. At the bottom of the entrance slope is a completely black flowstone speleothem, which was identified as a manganese speleothem. Also in the entrance chamber is a broken-off stalactite or stalagmite that shines blue or green depending on its thickness. This, they identified as a formation rich in cobalt. In Gerrie's Bathole, some straw-like stalactites were identified as being iron oxide. With a large group we were once again hauled out of the cave and eventually we were pulled out with a straight haul which is only 20 seconds to the top! Fun!



The second large section after the third pit – Photo by André Doussy



The third large section after the third pit – Photo by André Doussy

### 20 April 2013

John, Gerrie, Rick and I were back at the cave to improve the Tyrolean across pit 3. By now pit 3 had been renamed to Dickie's Pit, as John had been the first person in the pit, the first person across the pit and the first to cross it by Tyrolean. On this trip John and I went ahead to add bolts to the far side of Dickie's Pit. I had very little time as I needed to get back for a trip to Knocking Shop in the afternoon. So after bolting the two of us rushed off down the massive passage to see where it ended.

We had walked through the two large sections John had seen before, then a third large section, before a very high and long passage that lead downwards into a collapse area. Here a climb could be done over the collapse and down the other side and the passage continued along more narrow sections until a large chamber was found with a massive ball of mud on the floor. Here the chamber split into



Large passage past the third pit – Photo by André Doussy

two narrow sections, but I stopped at this chamber. We had gone another 700 metres before I had to turn back and head off to my second trip for the day.

John had continued through both of these narrow sections, with the one on the left going further and finally it split into two sections again. The one to the left ended in a 20 metre drop. The right handed one ended in a collapse area, with a small hole in the roof. He had continued a further 150 metres beyond the point where I stopped. In total he was 1.65km from the entrance at that point. This is in a straight line from the entrance and not the actual distance traveled as the passage is not completely straight and this does not take into account the up and down sloping of the floor which increases the walking distance beyond the straight line length.

Whilst John and I had explored the back ends, Rick and Gerrie had gotten up to the large collapse area and discovered an interesting side passage that turned out to be the deepest point in the cave.

### **18 May 2013**

John, Gerrie and I spent the day doing a line survey of the main passage from the entrance to the last large section of passage, where I had stopped previously. After 6 hours of surveying just the straight line we had a number for the depth of the cave. 259 metres! Far beyond West Driefontein's depth! This is the deepest dry cave in South Africa and the third deepest cave in Southern Africa overall, after Boesmansgat at 315 metres and Mawenge Mwena at 305 metres.

In hindsight it was a mistake to do only a quick line survey as subsequent trips have not added much to the survey, especially regarding passage width and height etc. The idea of surveying a passage again at a later stage is nice in theory, but rarely happens in reality.

### **02 June 2013**

John and I looked around Sharron's Alcove for possible sections to push there, but found none. We then continued to the third pit. We wanted to put a steel cable across the pit as it would ease the crossing of the pit for future trips and be much safer than a rope. John spent time checking how many anchors and ropes etc. would be needed to anchor the steel cable effectively and I carried on with the survey at pit three and back from that point. On the way out of the cave we checked some drops between boulders in the main passage, but found nothing interesting.

### **23 June 2013**

John, André and I took the steel cable, kindly donated by local company Haggie Rand, into the cave up to the third pit. André took some proper photos of the third pit and some with me on the rope for scale. We then took photos of the second pit and first pit and back up to the boulder choke. The photos look great and really give an idea of the actual size of the passage. I can barely be seen in some of the



photos compared with the size of the passage. John had found another passage off the entrance chamber, this time on the northern side and up a climb. This passage was only about 40 metres long, but was interesting as it had large iron oxide formations, including stalactites and flowstones. John had also started adding bolts to the near side of the third pit in preparation for the steel cable. Eight bolts in total were calculated to be needed on each side of the pit as a lot of tension is put onto a steel cable Tyrolean.

### 06 July 2013

John, Rick, Bruce Gibbings and I were back at Armageddon. We went down the passage and had just passed Hoary Chamber when we found a second side passage to the left that we had somehow managed to miss on all previous trips. The passage is very large and how we missed it, I have no idea. Bruce climbed up a very steep slope into a higher section that is very flat and wide. From there we went back in the direction of the entrance and found a large opening in the floor which looks down into Hoary Chamber. There was also a section with a lot of aragonite in it. We continued on towards the entrance and the passage got lower. For the first time we actually had to crawl in the cave. This crawl then turned back towards the main passage and eventually opened up into a balcony overlooking the passage from high up. Rick named it Peekaboo Alcove.



Boulder choke at the deepest part of the cave – Photo by André Doussy



Entrance as viewed from below – Photo by Rick Hunter

At the third pit John continued adding bolts to rig the steel cable. The rest of us continued past the pit with ladders and dropped down some small holes along the sides of the main passage. The longest of these is only about 30 metres of passage, so they are insignificant in the total survey. A lot of minor question marks were checked off.

### 27 July 2013

John, Rick, Bruce Gibbings and I went in to put up the steel Tyrolean across

Dickie's Pit. The cable attached to the near side, but was too long to be attached on the far side. On the far side we could therefore only join the cable to one bolt. We needed to return and make the cable shorter and anchor it properly.

### 17 August 2013

John, Gerrie, Rick, Allen Herweg, Irene, Pedro and I went back to the cave. The cable was shortened and properly anchored on both sides. Now it could be used regularly and is much safer than a rope. The rope across the second pit was replaced with a thicker rope. Some excess equipment was carried out of the cave. Samples of rocks were taken by Pedro to be dated. We used a car with a home-made capstan on a drive-wheel to haul cavers out of the cave for the first time.

### 31 August 2013

John, André, Rick, Irene, Antonie Meyer, Pedro, Herman and I returned to the cave. This was primarily a photography trip, to get some photos of the cave beyond the third pit. A small side piece was found at the deepest point of the cave that needs to be surveyed as it will add to the maximum depth of the cave.

### 15 September 2013

John, Selena, Bruce Dickie, Rick, Gerrie, André and I went into the cave. John, Bruce, Selena and André went to the furthest point in the cave and tried to get down the deep hole on the left hand side. They dropped down two ladders, but it was still not long enough to get down. So they surveyed the small passages in this section and left the ladders in place for a next trip.

The rest of us surveyed around the entrance chamber and surveyed Iron Alcove, the passage to the north of the entrance chamber with the large iron oxide formations. We next went into Sharron's Alcove to explore a blowing hole that Rick and Gerrie had found previously. This hole went to a series of small crawls with very blue limestone deposits on some parts of the roof as well as something that looks like spiegeleisen. Therefore it was named Rainbow Passage. At the end of the crawl we found a vertical drop of ten metres into a chamber about 15 metres wide. This was on the other side of the sinkhole from the entrance chamber and we believed we had found the route that would lead us into more endless passage on the other side of the sinkhole.

### 21 September 2013

John, Rick, Gerrie and I went back to the cave to explore Rainbow Passage further. We dropped down the hole with a single ladder. This was into a collapse-type chamber with a lot of loose rocks. The area



Caught in the act of abseiling into Armageddon by Google Earth

had some blowing holes, but they are through solid rock and blasting in this section would be very dangerous. Expanding mortar would be an option, but the whole area is extremely hazardous. We surveyed the section and went back up to the sinkhole. Here we had a proper look at a blowing hole at the bottom of the sinkhole. This hole blows strongly, but is in shale and



would probably need roof supports if a major digging project is undertaken. With the air blowing in the Rainbow Passage and the air in this hole a major extension could be on the south western side of the sinkhole. This was the last section we believed had great opportunities. Now all of the easy extensions were eliminated and we believed we had reached the end of any major discoveries in Armageddon.

### 20 December 2013

John, Selena, Bruce Dickie, Matthew Dickie, Rick, Dirk van Rooyen and I went to the deepest explored part of the cave, back to the vertical drop that could not be climbed down previously. This time a third ladder was attached and Dirk, Rick and I climbed down. It was only a 50 metre passage that was perpendicular to the main passage. We then went to look at the other side, where there was a hole in the roof. This was definitely a bolting opportunity.

### 22 February 2014

John, André, Pieter Theron, Christo Saayman and I went to the back of the cave and bolted up a nine metre climb. At the top of the climb we got through the boulder choke and into a new section of the cave. We were in another large passage. At first a large drop needed a rope to get down. Next a very difficult climb was negotiated by Christo and he dropped down the last piece of rope for us to climb up and down on. Next a large chamber with a very interesting formation was found. The formation consists of various strands of iron oxide. They resemble dreadlocks and were named Rapunzel's Dreadlocks. These strands together form something over a metre wide and six and a half metres tall. We continued along the main passage and soon we were at a large drop and could see that the passage continued, but we had used up all rope and had no ladders with us. The cave was not finished yet and we were now 1840 metres away from the entrance in a straight line.



Iron oxide formations in the newly discovered section  
– Photo by Christo Saayman

### 15 March 2014

John, André, Rupert Stander and I went back to the new section. Rupert quickly found that there was in fact a way to get down into the extension where we had stopped the previous time. A steep slope and small squeeze was the way through. This led to a very muddy passage that continued for about a hundred metres further. The passage ended in a vertical mud wall 25 metres high. There is a small possibility that it could continue at the top, but getting up there would be nearly impossible.

On the way to this section John had found a small crack in the large chamber that extended. We then went to survey this crack and after a few narrow sections and a ladder climb we got back into walkable passages and soon we reached another large chamber. At the end of the chamber was a drop. We had a discussion on whether it should be dropped on this trip with minimal equipment or left for a next trip. Half said this trip and half said a next trip, so the section was named Mutiny Alley. We finally decided to drop it on this trip and John climbed down and into the next chamber. It had two possible extensions, but both required more equipment to continue. At this point we were 1940 metres from the entrance.

**10 May 2014**

Pedro and Herman took some geological measurements for the studies on the cave. Rick took a large group of inexperienced cavers to the deepest part of the cave and on the return they were all hauled out by John's car. I put a second rope over the second pit, so it is now a double rope Tyrolean. I also surveyed hoary chamber and the parts that lead to Peekaboo Alcove.

**11 May 2014**

Lewis Coosner and I took a large group to the first big section on the far side of pit three. We were again hauled out from the entrance.

**29 June 2014**

John, Bruce, Christo, André and I went to the very back ends of the explored Armageddon to attempt the two possibilities. We chose the biggest first and dropped down three ladders in a passage that continued for about 50 metres. There was a small possibility of crossing a ledge and climbing up, but the walls are solid mud and will make this nearly impossible. We next dropped a ladder down the smaller extension and through some crawls it became slightly bigger again but soon stopped, although there is a bolting opportunity. We bolted up a part of the way, but the rock is very loose and unstable and progress was painfully slow. We managed to get halfway up and then time forced us to exit the cave.

Trips are now very long. Driving to the cave and back takes two or three hours. A fast moving team can rig and abseil into the cave in an hour, then move to the back of the cave in another four hours of fast caving and only then can we start to push the limits of the cave. We usually spend about four hours pushing the limits of the cave, and then it is another four hours back to the entrance and an hour and a half to climb the rope and derig the entrance. We are bordering on the limits of what can be done in a single day of caving. If any new extensions are found we simply have to sleep at the back of the cave to get any proper exploration done. This however increases the amount of equipment a person needs to carry making progress much slower.

The cave has over three kilometres of surveyed passages and the survey is not yet complete. From Rainbow Passage to the final bolting opportunity is a straight line distance of two kilometres, a figure only beaten by Congo, which is 2455 metres from the entrance to its furthest point (Martini 1982). At just over 260 metres depth, it is the deepest dry cave in South Africa. The studies that are being done by Pedro indicate that due to its formation during the Vredefort impact, it is probably the oldest dateable cave in the world at 2.023 billion years old (McCarthy et al 2005)! Significantly more than the previous oldest dateable caves in the world, the Jenolan Caves, which come in at only 340 million years (Armstrong et al 2007). The cave has certainly been one of the most significant discoveries in South Africa in recent times and shows that big discoveries are still possible after sixty years of organized caving in South Africa and the cave has not even been fully explored yet!

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# Armageddon Cave Survey

South Africa

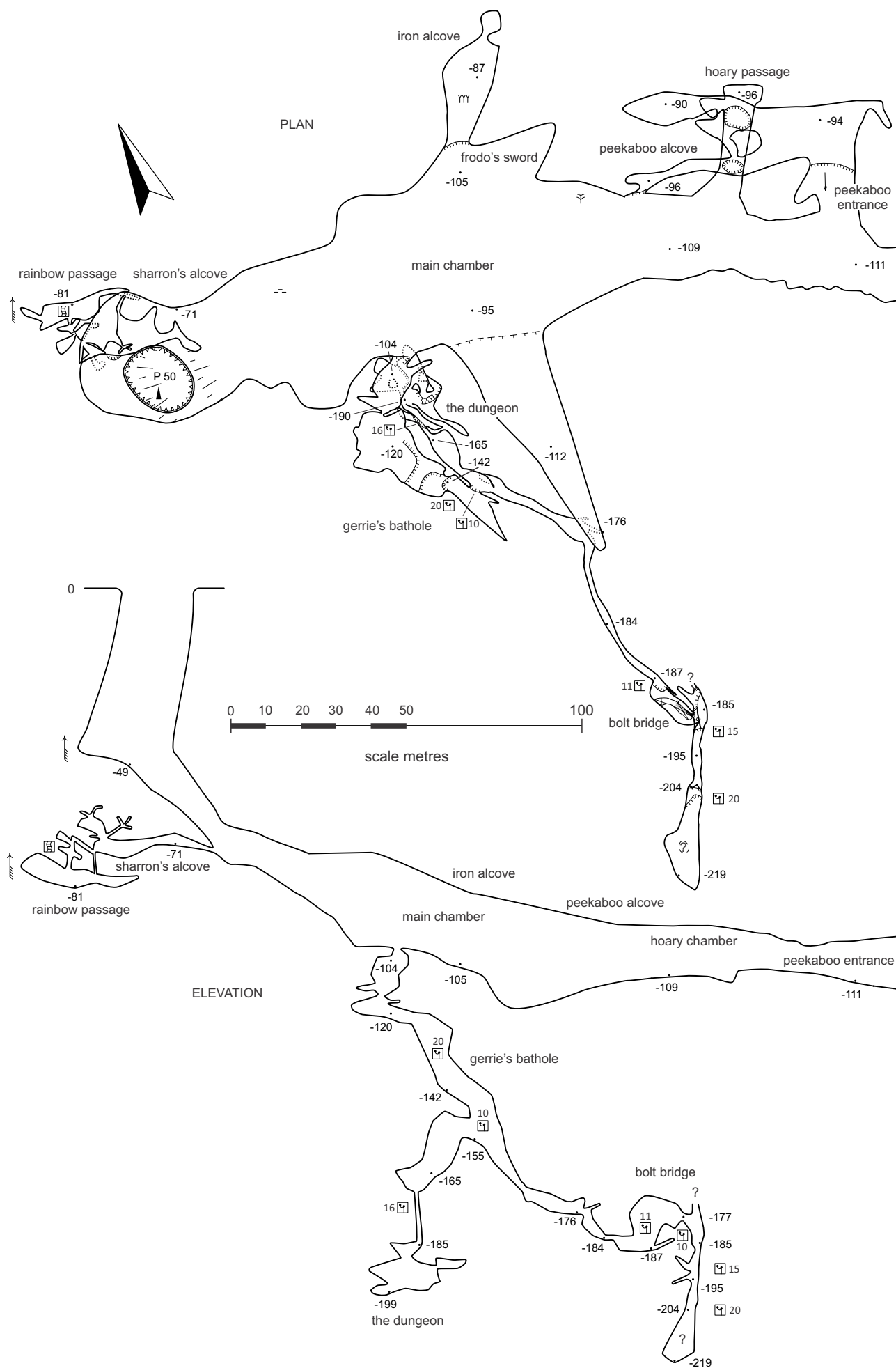
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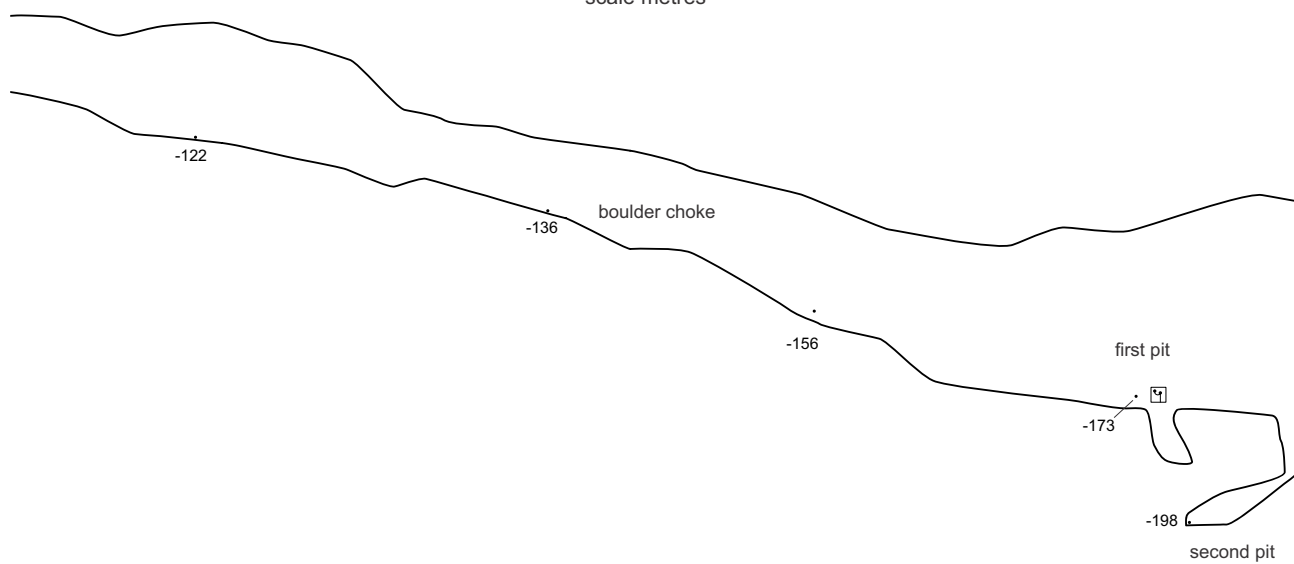
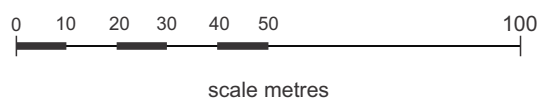
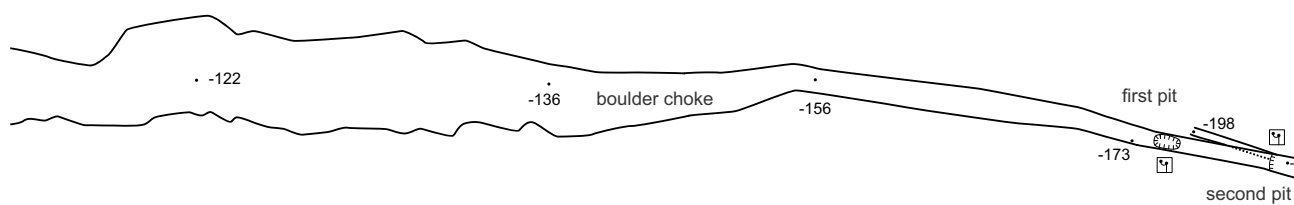
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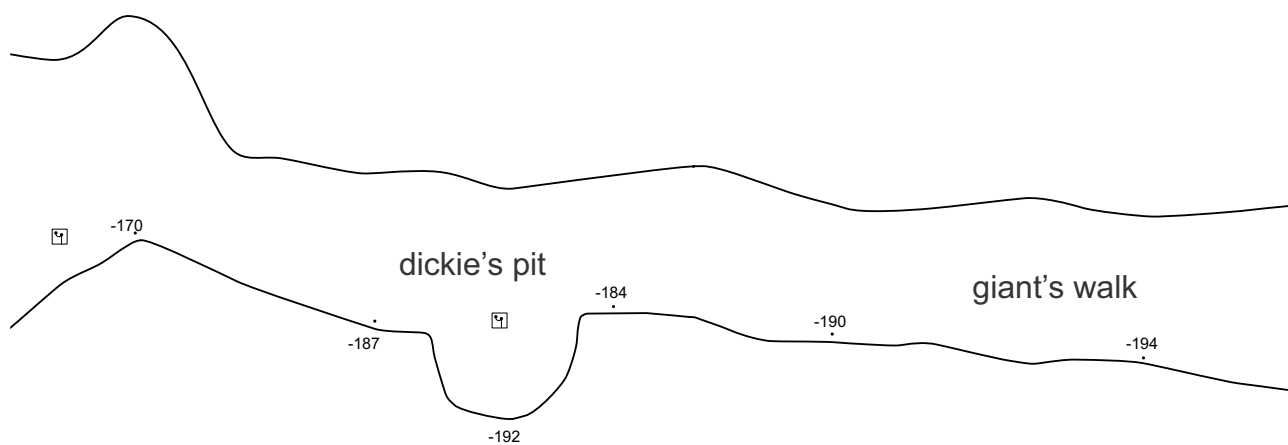
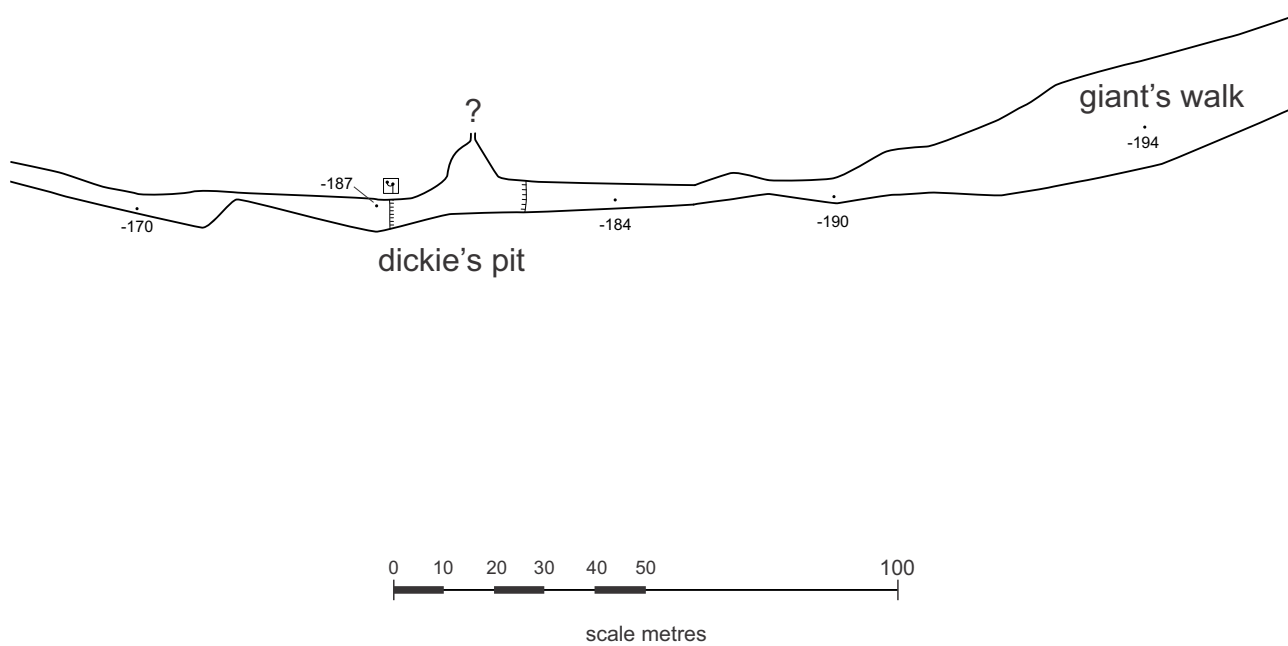
2013 – 2015

Survey Team:	Steven Tucker	Veronica van der Schyff
	John Dickie	Chris Serfontein
	Gerrie Pretorius	Pieter Theron
	Carson McAfee	Dirk van Rooyen
	Rick Hunter	Bruce Dickie
	André Doussy	Matthew Dickie
	Christo Saayman	Selena Dickie
	Rupert Stander	Terence Stewart

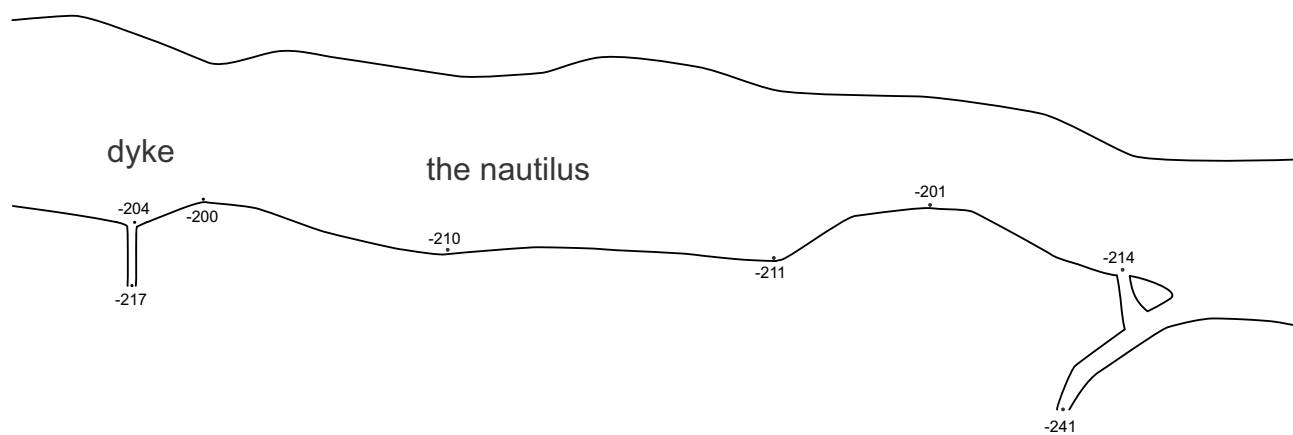
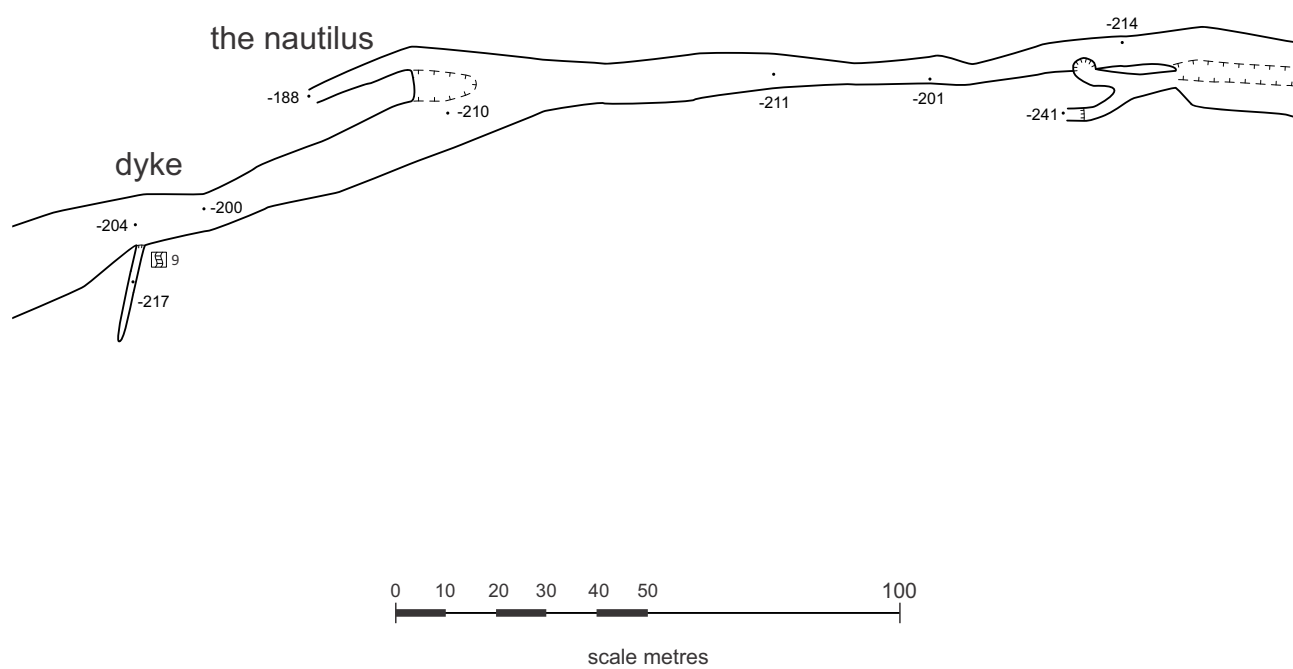
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		ceiling step		ladder

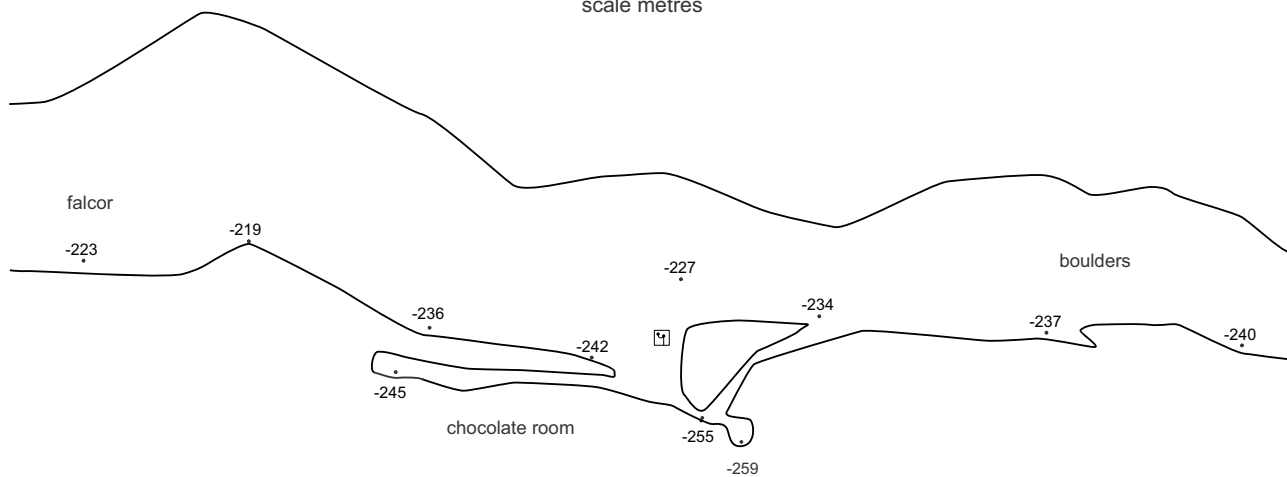
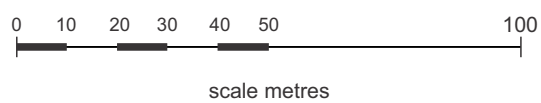
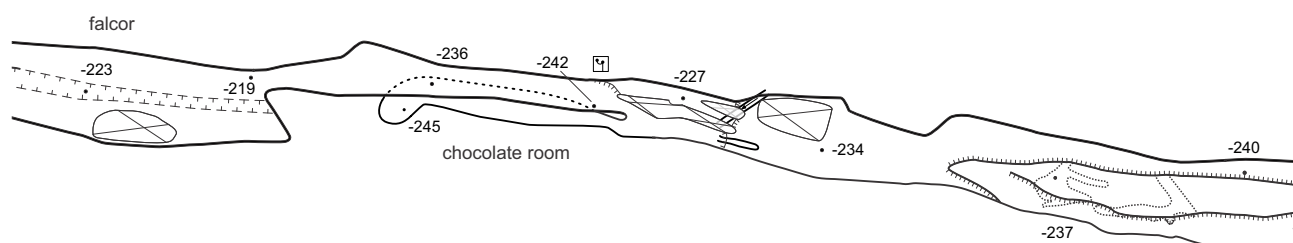


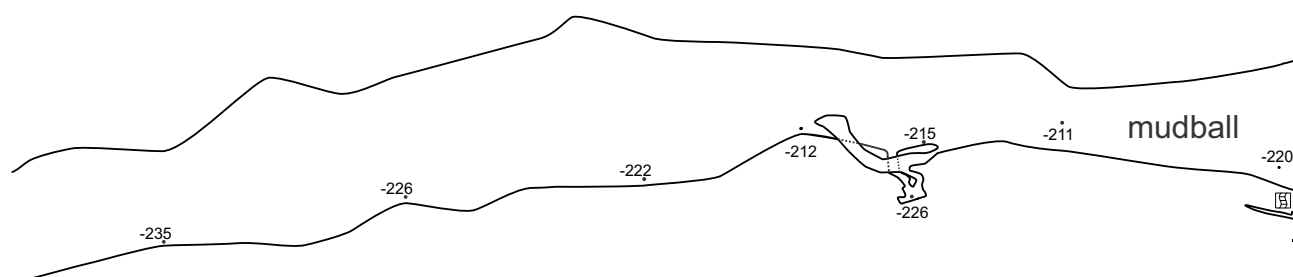
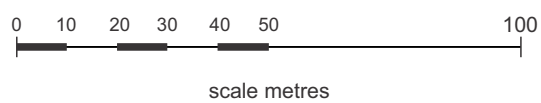
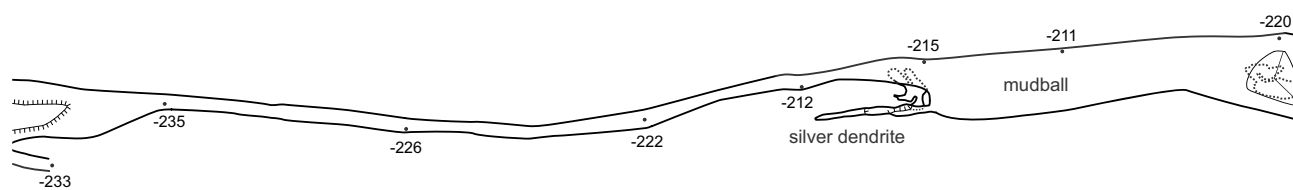




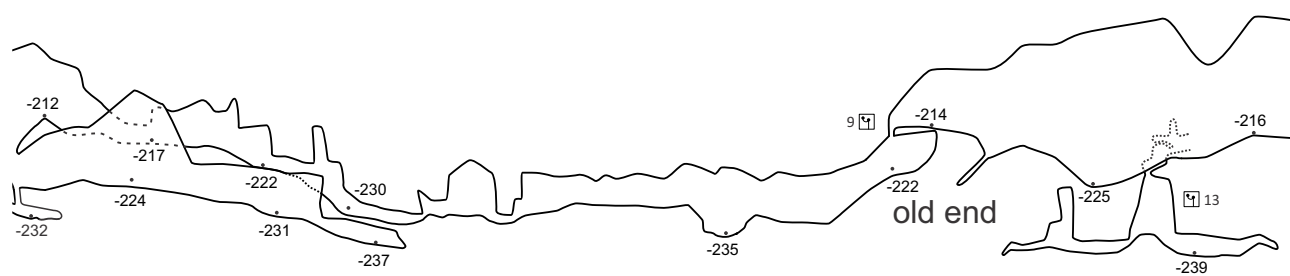
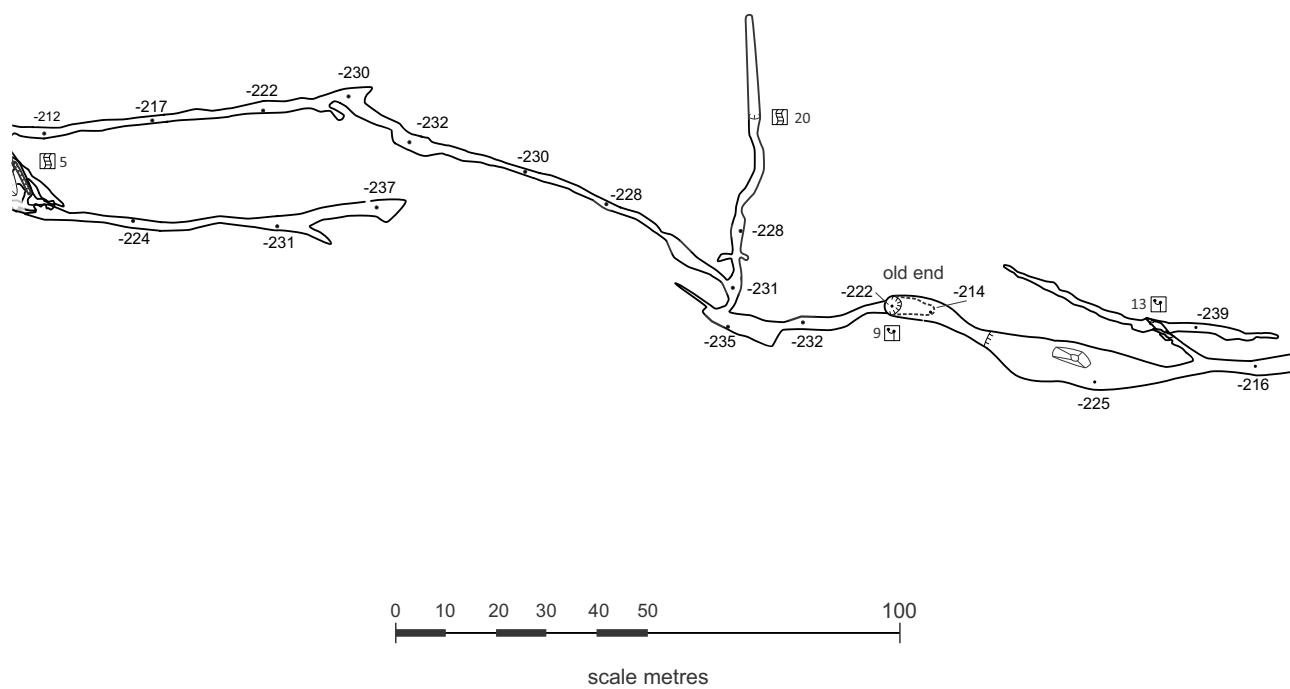


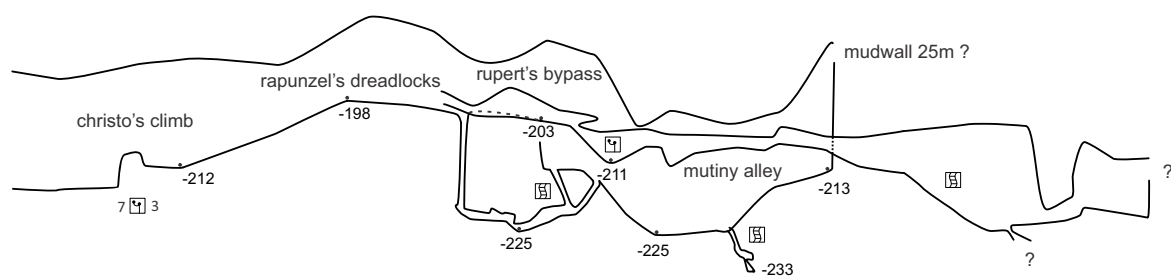
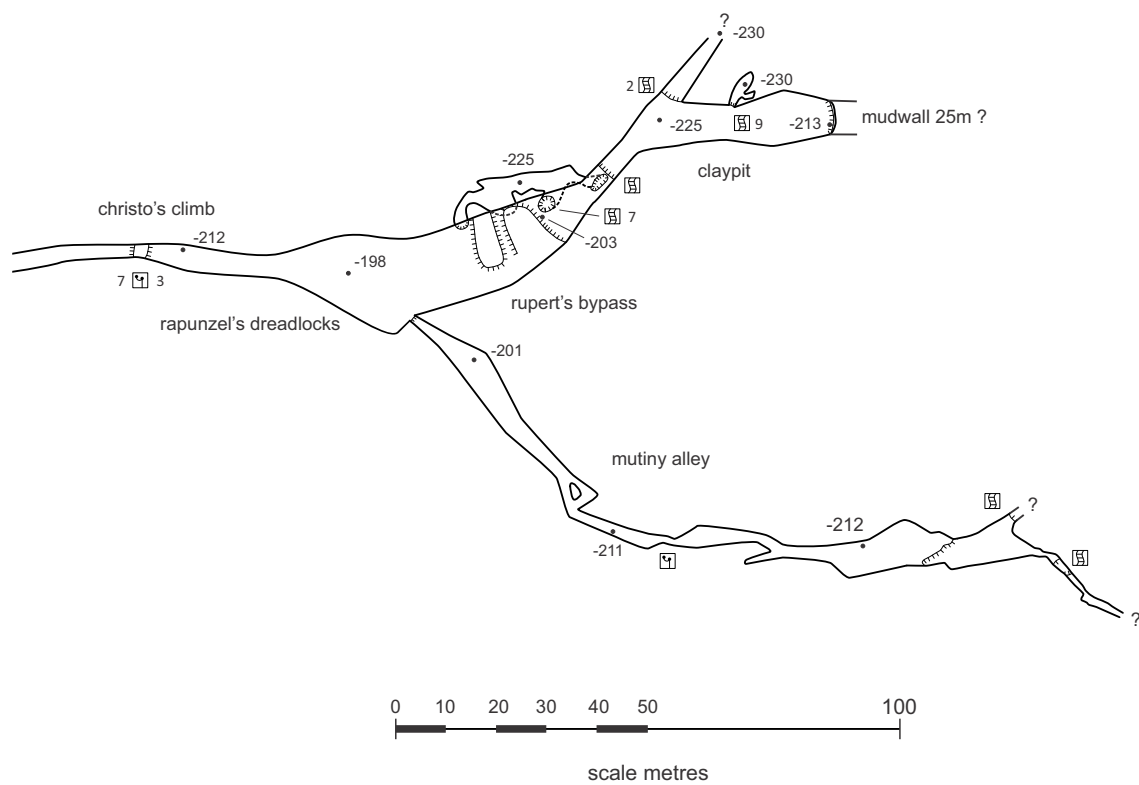












# **BOTSWANA GWIHABA HILLS PROJECT**

*Pete A Kenyon*

Report on the expedition to the G2 cave, Botswana. April 1st to 9th 2010

The survey of G2 and inspection of Bone and Blue Caves

## **Acknowledgements**

The members of the Speleological Exploration Club and the South African Spelaeological Association would like to thank the representatives of Botswana Defense Force, the Botswana National Museum and the Botswana Government for the opportunity and the assistance offered during this investigation.

## **Team Members**

The investigation was put together in relatively short time and all members of SASA were approached to be part of the work.

## **SEC / SASA Team Members**

John Dickie-*Group Leader*, Selena Dickie, Mathew Dickie, Bruce Dickie, Sharron Reynolds-*Bat Survey*, Lewis Coosner, Alan Grant-*Surveyer*, Pete Kenyon-*Reporting*, Greg Justus, Heidi Stapylton.

## **OP Team**

TL Moloko-*Private Secretary to the President*, G Kenalemanga-*Driver*

## **National Museum**

Uaitse Ledimo-*Geologist*

## **Botswana Defense Force - Escort**

Shadrack Pulamoeng-*SGT*, Victor Gabampotse-*L/CPL*, Goitsrmango Phaladze-*L/CPL*, Mompoti Snetsho-*L/CPL*

## **Water Bowser**

RB Ranjo-*PVT*, T Mpalo-*CPL*

## **Background**

Following on from the development work carried out by CERAC and initial visits by CERAC / SEC under the acknowledgment of SASA it was proposed that the cave known as G2 be accurately surveyed as well as an inspection of the Koanaka Hills area caves known as Bone and Blue Cave. A recommendation on these caves would follow from this work. The bat species present in these and in Gcwihaba (formerly Drotskys Cave) would be noted. This report is presented in a similar format to that of the previous CERAC submitted report for continuity.

## **Objective**

The accurate survey of G2 and inspection and recommendation for G2, Bone and Blue Caves. An assessment of the bat species present in Gcwihaba, Bone and Blue caves. A possible infra red photographic measurement of the surface would be carried out and possible points of close contact by the cave G2 with the surface identified from the survey.

## **Expedition Diary**

### **Friday April 2nd 2010**

Depart Johannesburg South Africa. The total driving would be 2 777 km by the completion of the trip.



The cars used were two 4x4 and a high clearance 2x4. Due to the sand conditions the 2x4 did get stuck on several occasions which was not unexpected.

### **Saturday April 3rd 2010**

The group drove in three cars arriving at Gcwihaba camp site early on April 3rd. This day was used to set up camp and confirm the objective with the National Museum representative and logistical issues with the BDF.

An initial proposal that the Botswana representatives would supply an infra red camera and operator was unfortunately misunderstood and an operator with a borehole camera was made available. As this was not necessary he was asked to return to Gaborone.

An inspection of the bats in the nearby Gcwihaba Cave was carried out and confirmed the presence of Slit faced, Commersons Leaf nosed and Dents Horseshoe Bats.

### **Sunday April 4th 2010**

All ten SEC members plus attendees of the Museum and BDF descended the cave borehole entrance and split into two survey parties. The final survey will note the names of all involved as the teams changed members on occasion and there was an intentional degree of overlap of the survey margins.

### **Monday April 5th 2010**

Ongoing survey of G2 and photographic record was taken. The cave was noted as being 27°C and 100% humidity at the entrance and throughout most of its length.

### **Tuesday April 6th 2010**

Ongoing Survey of G2. It was generally agreed by all team members that the cave is one of the finest examples of an untouched decorated system we have seen. The formations are highly unusual and in some cases quite spectacular.

### **Wednesday April 7th 2010**

The group packed camp and departed for BDF camp at Koanaka hills. The group arrived in the afternoon and set up camp as well as a short inspection of the hill K1. Some interesting slots were observed and a full inspection of the back of this hill would be useful.

### **Thursday April 8th 2010**

The group inspected Bone cave where a large thriving population of bats was noted. Given the relatively few formations in the cave and the high density of bats it is recommended this cave be visited as infrequently as possible.

The group then drove to Blue cave. This is a very interesting cave with a population of cave dwelling (troglodyte) rodents. Signs of these animals were seen but not the creatures themselves. This cave has some interesting blue shaded rock walls and remarkably well defined dripping pools containing formations similar to "cave pearls" but more linear than spherical. Again a large and thriving bat population was noted.

### **Friday April 9th 2010**

The group packed camp and departed the Koanaka hills. This was delayed due to a clutch problem on one of the cars which was repaired on site by the driver and BDF assistance (Sgt Shadrack Pulamoeng). The route taken for return was to pass the Blue Cave Hills and follow the border road until departing right for XaiXai onto the better rock road. This was fine apart from rainy conditions making the last 80 km very difficult.

### **The survey of G2 Cave**

The cave was surveyed using two key teams of 3 to 4 people. The cave was split into the main section starting from the entrance and that of the main inner section where the main incline begins to descend and separate from the main section. A cave survey is a two dimensional representation of a three dimensional space and as such the appearance can often be complicated with passages above and below the main line of the cave. In this instance the cave is relatively simple and the survey can be seen to represent this.

### **Survey Methodology**

The measurements required to produce an accurate survey are the distance, inclination and direction between survey points and the width and height of the passage or chamber at each survey point.

The equipment used to do this is a "Lica Disto" laser distance meter, we use two of them, a Shetland Attack Pony digital compass and inclinometer and a Brunton compass. This enabled two survey teams to work simultaneously. All measurements as well as detailed sketches were recorded in field books, these books took a little strain in the dirty and humid conditions. A number of survey points were labeled with aluminum tags, these were usually positioned at passage intersections where several survey legs diverge.

The measurements were processed using a computer to solve calculations but was mostly drawn by hand to produce a to-scale plan-view survey of the cave.

### **Survey accuracy**

Also referred to as Survey Grade and follows the BCRA guidelines. A Grade 1 survey is inaccurate where no measurements have been taken, while a Grade 5 survey requires each angle measured to be within 1° and each distance to be within 10cm. A Survey class; A, B, C or D is combined with this describing the detail of the passage walls. "A" refers to all detail based on memory while "C" implies that passage dimensions were recorded only at survey stations. The majority of G2 Cave was surveyed to BCRA 5C, a good standard, while small sections were done to a lesser Grade due to time constraints.

A loop closure error is a useful way to gauge whether these requirements have been met. A maximal error can be solved for and if the errors fall within these guidelines then the grade has been met. In the Case of G2 Cave the majority of loop errors fell within acceptable limits.

### **Future work required**

The use of two separate teams working in tandem in an unfriendly environment may have caused errors to be introduced. Some of these are obvious and easily rectified but others will not have been picked up.

### **Further work is required to:**

- Rigorously check the survey for mistakes; this is especially important if it is to be used for the positioning of possible future entrances.
- Finish the survey and accurately resurvey sections of the cave that did not receive our full attention on this visit.

### **Bat Population Survey**

The species present in Gcwihaba, Bone and Blue Caves were identified and an assessment of the population size taken. This was carried out by Sharron Reynolds of SEC and the Bat Interest Group of Gauteng. G2 is sealed and no bats are present.

### **Methodology**

A full survey was not possible due to lack of manpower – however we did manage to erect 2 nets on

the 4 nights we were in the area which were monitored between 6pm and 11pm each night, unfortunately did not have luck catching bats in the nets. We were able to catch by hand in the cave, 8 Commerson's bats, (1 Female & 7 Males) based on colour and 1 Common slit-face bat and 4 Dent's horseshoe bats. We were able to sex the bats, take forearm measurement & weigh the bats.



Measurement of bat forearm

### Species present

(*Hipposideros commersoni*) – Commerson's leaf-nosed bat

(*Nycteris thebaica*) – Common slit-faced bat

(*Rhinolophus denti*) – Dent's horseshoe bat

We were able to catch by hand three different species of bats in the Gwihaba Cave. All species are known to be present in large numbers in the cave. As recorded in Peter John Taylor's book *Bats of Southern Africa* this cave is known to have a colony of approx 600 Common Slit-faced Bat. We were able to confirm based on photographic evidence that these bats are still present in large numbers.

The Commerson's leaf-nosed bat was found in a colony of approximately 200 to 300 in one section of the cave known as MOAB although there were smaller pockets of them in different area's of the cave – we did not take down equipment to measure humidity or temperature in the cave but this chamber did seem to be a little warmer than the bigger open chambers where the Dent's and Common slit-faced bat were found. We also noticed a high number of dead bats and older skeletons. One of the Commerson's leaf-nosed bats caught had recent injuries to wing bones and a second one caught had unusual pimple like injuries on the wing conducive to a snake bite. Weights ranged between 105g and 145g. Forearm length ranged between 101mm and 117mm.

Dent's horseshoe bats weight ranged between 5 and 7 grams and forearm length ranged between 42 and 43mm.

Due to the sensitivity of the Common Slit-faced bat, no measurements were taken. A photographic record was done and the bat quickly released.

All bats were released at the entrance of the cave the same evening they were caught. Very few parasites were seen on the bats.

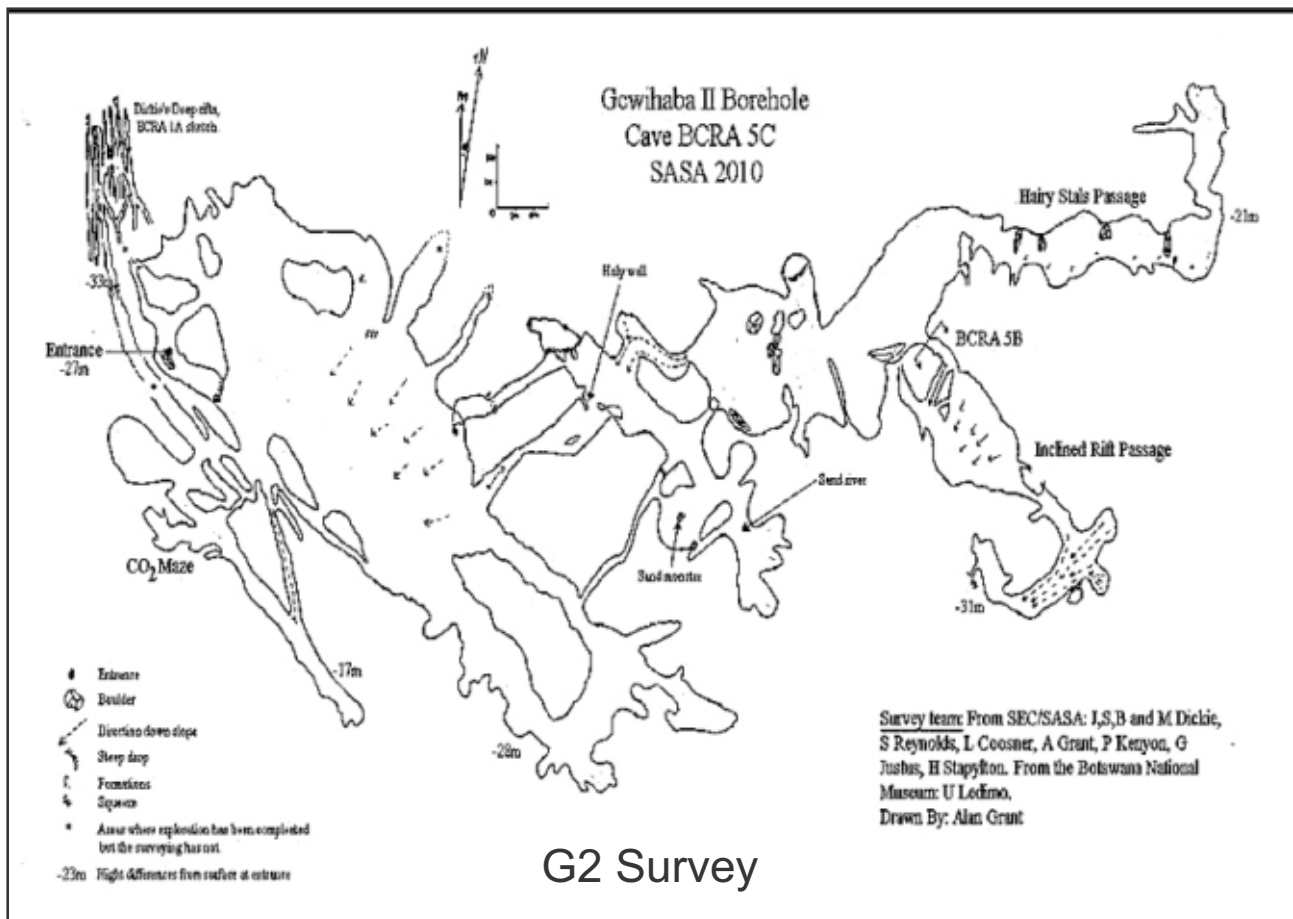
Large numbers of horseshoe (probably Dent's) 100–200 were found in Blue cave with a smaller colony of Slit-faced bats probably 50–100.

### Recommendations

The following are recommendations or guidelines as to what would be the best practice to preserve the caves integrity and fauna.

### G2 Cave

There needs to be demarcated areas using stainless steel or aluminium poles and oxidation resistant tape or rope indicating where one can walk when in proximity to the formations. Standard hazard marking tape has been known to oxidize requiring removal of the unsightly remains of the tape.



The proposed survey drawing needs to be compared to the actual conditions underground to ensure accuracy. This should be done to align the cave with the surface topography and previous magnetic studies.

Access to the cave should be restricted to small experienced groups.

### Bone Cave

It is felt access to the cave should be restricted to ensure the bat population does not experience any unnecessary stress.

### Blue Cave

The “cave pearl” formations should be demarcated areas using stainless steel or aluminium poles and oxidation resistant tape or rope indicating where one can walk when in proximity to the formations.

### Conclusion

The survey of G2 and the assessment of Bone and Blue Caves, whilst being of a short time period has provided a valuable map of the G2 cave and assessment of the bat species currently inhabiting caves of the region.

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Private Sec. to the President [tmoloko@gov.bw](mailto:tmoloko@gov.bw)





Large 2.5 m wide ribbon formation at top of main chamber in G2



Fallen stalactite in G2



Stalactites at the top of canyon in G2



"Hairy Stal" with root growth, approx 15 cm high in G2



Bat Lady - Sharron Reynolds



Project Leader - John Dickie

## A new troglobitic ideoroncid pseudoscorpion (Pseudoscorpiones: Ideoroncidae) from southern Africa

Mark S. Harvey & Gerhard Du Preez

The Journal of Arachnology • 42:105–110 • 2014

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**Gerhard Du Preez:** Unit for Environmental Sciences and Management, Potchefstroom Campus, North-West University, Private Bag X6001, Potchefstroom 2520, South Africa.

**Abstract** - The first blind African species of Ideoroncidae is described from a cave in northwestern Botswana, *Botswanoncus ellisi*, representing a new genus and a new species. Apart from the complete lack of eyes, it is also unusual in having the lowest recorded number of trichobothria of any adult ideoroncid with 17 on the fixed finger and nine on the movable finger.

The pseudoscorpion family Ideoroncidae comprises 13 genera and 70 species found in Africa, Asia and the Americas (Harvey 2013; Harvey & Muchmore 2013). The majority occur in tropical ecosystems, but some occur in drier regions such as the southwestern USA and Mexico, Chile and Argentina, and the deserts of the Middle East. Ideoroncids have the combination of two unique morphological features, supernumerary trichobothria and the sub-basal position of the median maxillary lyrifissure (Harvey 1992; Harvey & Muchmore 2013). Another unusual feature, the division of the median genital sac of the male genitalia into two distinct parts, is also found in some species currently attributed to the family Syarinidae (e.g., Vachon 1938, 1954, 1969; Chamberlin 1952; Mahnert 1980; Harvey 1992).

The African ideoroncid fauna (Fig. 3) consists of four genera, *Afroroncus* Mahnert 1981, *Dhanus* Chamberlin 1930, *Nannoroncus* Beier 1955 and *Negroroncus* Beier 1931 (Harvey 2013). The genera *Nannoroncus* and *Afroroncus* are restricted to forested habitats in Kenya (Mahnert 1981). Three species of the genus *Dhanus* are known from the island of Socotra located off the Somali coast (Mahnert 2007). This genus is otherwise known from the Middle East (Afghanistan and Iran), India and



Figures 1, 2.—1. The type locality of *Botswanoncus ellisi*, Diviners Cave, Botswana (Photo: Gerhard Jacobs); 2. Roots of the fig tree (*Ficus cordata*): the specimens were collected from the soil below the roots.



southeast Asia (Harvey 2013). *Negroroncus* is the most widespread African genus, being found throughout Kenya, eastern Democratic Republic of Congo and northern Tanzania, as well as individual outlying species from Zimbabwe and the Republic of Congo (Mahnert 1981; Harvey 2013).

Among a small collection of pseudoscorpions taken from a cave in the Gcwihaba region of northwestern Botswana, the junior author found a small ideoroncid that completely lacks eyes (Fig. 4). Eyeless ideoroncids are elsewhere only known from the New World: *Albiorix anophthalmus* Muchmore 1999 from a cave in Arizona, USA (Muchmore & Pape 1999), *Ideoroncus anophthalmus* Mahnert 1984 and *I. cavicola* Mahnert 2001 from Brazil (Mahnert 1984, 2001) and five species of *Typhloroncus* 1979 from caves in Mexico and epigeal ecotypes in the US Virgin Islands (Muchmore 1979, 1982, 1986; Harvey & Muchmore 2013). The only cavedwelling ideoroncids from Africa are *Negroroncus aelleni* Vachon 1958 from the Republic of Congo and *N. jeanneli* Vachon 1958 from Tanzania (Vachon 1958), but neither species is completely eyeless, even though the eyes are small (Vachon 1958).

An initiative by the Botswana government to discover and explore unknown caves with the aim to promote caving in the tourism industry led to the discovery of several caves with no natural openings in the northwestern Gcwihaba region of Botswana. These caves were discovered through gravimetrical surveys of dolomitic outcrops. This technique identifies isolated subterranean cavities that are subsequently penetrated by means of drilling 700 mm vertical shafts. In 2010 efforts led to the discovery of a cave system named Diviners Cave. The drilled shaft, with a surface entrance altitude of 1056 m.a.s.l., penetrates through 50 metres of rock into the cave. Exploration revealed an extensive cave system (Fig. 1) at several levels, with chambers of up to up 180 meters in diameter. Within the sealed cave we found areas where the roots of wild fig trees (*Ficus cordata*) penetrate the caves associated with sand and water drips. In these areas we found a

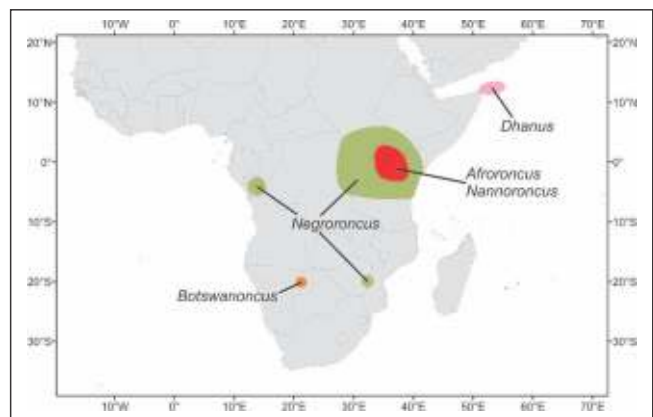


Figure 3.—Distribution of ideoroncid genera in Africa.



Figure 4.—*Botswanoncus ellisi*, new species, female holotype, prior to dissection, dorsal aspect.

diversity of invertebrates including diplurans, centipedes and termites. Although the cave does not reach the water table, the relative humidity exceeds 95% with a fairly constant temperature of 27°C ( $\pm 2^\circ\text{C}$ ). Prior to drilling to open the cave, the system was under a high CO<sub>2</sub> pressurized atmosphere, making the circumstances in which the cavernicoles survived quite different from other natural caves in southern Africa.

Our study of the specimens revealed a number of unusual features, including the lowest number of trichobothria thus far recorded for an adult ideoroncid (Table 1), and a short arolium that lacks a ventral hook-shaped process. Apart from being a distinctive new species, we also suggest that it represents a previously undescribed genus. Therefore, we here provide a description and name the species to highlight its distinctive morphology and habitat.

## METHODS

The specimens examined in this study were mainly sampled with pitfall traps. Each trap was neatly buried in the soft sand associated with wild fig tree roots (Fig. 2) and half-filled with 75% ethanol. Also, some specimens were caught by hand or extracted from soil samples using Berlese funnels. These specimens are lodged in the Western Australian Museum, Perth (WAM) and the

Table 1.—The recorded number of trichobothria found in adults of genera of Ideoroncidae. Variant numbers are shown in brackets.

	<i>eb</i>	<i>esb</i>	<i>est</i>	<i>et</i>	<i>ib</i>	<i>isb</i>	<i>ist</i>	<i>it</i>	<i>b</i>	<i>sb</i>	<i>st</i>	<i>t</i>	Fixed finger, total	Movable finger, total	Reference
<i>Afroroncus</i>	1	1	6	1	4	1	5	1	2	1	1	6	20	10	Mahnert (1981)
<i>Albiorix</i>	1	1	6	1	4–5	1	5–6 (4)	1	2	1	1	6	20–22	10	Harvey & Muchmore (2013)
<i>Botswanonus</i>	1	1	6	1	3	1	3	1	1	1	1	6	17	9	This study
<i>Dhanus</i>	1–3	1	5–9	1	3–6	1	5–12	1	2–4	1	1	6–8	23–31	11–14	Mahnert (1984, 2007)
<i>Ideoroncus</i>	1	1	6	1	4 (5)	1	4–6	1	2	1	1	6	20–21 (22)	10	Mahnert (1984, 2001); Harvey & Muchmore (2013)
<i>Mahnertius</i>	1	1	6	1	5	1	6	1	2	1	1	6	22	10	Harvey & Muchmore (2013)
<i>Muchmoreus</i>	1	1	6	1	4	1	5	1	2	1	1	6	20	10	Harvey & Muchmore (2013)
<i>Nannoroncus</i>	1	1	6	1	4	1	5	1	2	1	1	6	20	10	Mahnert (1981)
<i>Negroroncus</i>	1–2	1	6–10	1	4	1	5–6	1	2–3	1	1	6–7	20–26	10–12	Mahnert (1981); Vachon (1958)
<i>Nhatrangia</i>	2	1	9	1	6	1	9–10	1	4	1	1	8	30–31	14	Mahnert (1984)
<i>Pseudalbiorix</i>	1	1	6	1	4	1	5	1	2	1	1	6	20	10	Harvey et al. (2007)
<i>Shravana</i>	1	1	6	1	5	1	7	1	3	1	1	7	23	12	Mahnert (1984)
<i>Typhloroncus</i>	1	1	6	1	4–5	1	6–7	1	2	1	1	6	22	10 (11)	Muchmore (1986); Harvey & Muchmore (2013)
<i>Xorilbia</i>	1	1	6	1	5	1	6	1	2	1	1	6	22	10	Mahnert (1984, 1985)

Table 1.—The recorded number of trichobothria found in adults of genera of Ideoroncidae. Variant numbers are shown in brackets

KwaZulu-Natal Museum, Pietermaritzburg (NMSA), and were studied using temporary slide mounts prepared by immersion of the specimen in lactic acid at room temperature for several days. They were then mounted on microscope slides with a 10 mm coverslip supported by small sections of 0.25 or 0.35 mm diameter nylon fishing line. After study the specimens were returned to 75% ethanol with the dissected portions placed in 12 x 3 mm glass genitalia microvials (BioQuip Products, Inc.). Specimens were examined with a Leica MZ–16A dissecting microscope and a Leica DM2500 compound microscope, the latter fitted with interference contrast, and illustrated with the aid of a drawing tube attached to the compound microscope.

Measurements were taken at the highest possible magnification using an ocular graticule. Terminology and mensuration mostly follow Chamberlin (1931), with the exception of the nomenclature of the pedipalps and legs, and with some minor modifications to the terminology of the trichobothria (Harvey 1992), chelicera (Judson 2007) and faces of the appendages (Harvey et al. 2012).

The description was compiled using the DELTA (DEscription Language for Taxonomy) Editor computer program, version 1.0-Beta (available at <http://code.google.com/p/open-delta/> (Dallwitz et al. 1999)).

## SYSTEMATICS

### Family Ideoroncidae Chamberlin 1930

#### Genus *Botswanonus* gen. nov.

**Type species**—*Botswanonus ellisi* new species

**Diagnosis**—*Botswanonus* is the only ideoroncid genus with a short arolium that lacks a ventral hook on the arolium. It also differs from other ideoroncids by the presence of only 17 trichobothria on the fixed chelal finger and nine trichobothria on the movable chelal finger (Table 1) (Figs. 11, 12), and from all other African ideoroncids by the complete lack of eyes (Fig. 5).

**Description**—*Adult female (male unknown)*: Chelicera (Fig. 9): hand with 5 setae; movable finger with 1 sub-distal seta; all setae acuminate; galea present, simple, long and slender; lamina exterior absent; serrula exterior connected to chelicera finger for only part of length; not modified to form velum; rallum (Fig. 10) with 4 blades, all with anterior spinules, basal and sub-basal blades shorter than others.

*Pedipalp* (Fig. 8): long and slender. Fixed finger with 17 trichobothria (Figs 11, 12): *eb*, *esb*, *et*, *isb* and *it* regions each with 1 trichobothrium; *est* region with 6 trichobothria; *ib* region with 3 trichobothria; *ist* region with 3 trichobothria; *et* slightly distal to *it*. Movable finger with 9 trichobothria (Figs. 11, 12): *b*, *sb* and *st* regions each with 1 trichobothrium; *t* region with 6 trichobothria. Chelal teeth (Fig. 11) juxtadentate, with fixed finger chelal teeth low and flattened, and movable finger chelal teeth low;



venom apparatus present in both chelal fingers; venom ducts of medium length, terminating midway between *it* and *est* in fixed finger and basal to *t* in movable finger; nodus ramosus not inflated.

**Cephalothorax:** carapace (Fig. 5) sub-rectangular; anterior margin slightly convex; with 4 setae on anterior margin and 2 on posterior margin; furrows absent; eyes completely absent. Manducatory process somewhat pointed, with 2 apical setae; median maxillary lyrifissure situated sub-basally.

**Legs:** femora I and II much longer than patellae I and II, respectively; femora III and IV about same size as patellae III and IV, respectively; metatarsi shorter than tarsi; subterminal tarsal seta acuminate; arolium about same length as claws, with slight medial division (Figs. 6, 7); ventral hook-shaped process absent. Abdomen: tergite I with 2 setae; spiracular plates each with 1 seta; medial sternites without suture line; pleural membrane uniformly longitudinally striate; stigmatic helix present; anus situated between tergite XI and sternite XI.

**Genitalia:** female: with gonosac covered in small acetabula.

**Remarks** —The arolium of *B. ellisi* is about the same length as the claws (Figs. 6, 7), and therefore resembles the New World genera *Typhloroncus* and *Xorilbia* Harvey and Mahnert 2006, the African *Negroroncus aelleni* Vachon 1958, and the Asian *Dhanus siamensis* (With 1906), which have arolia that are slightly shorter than the claws. The remaining ideoroncid genera have arolia that are clearly longer than the claws. It differs from these genera with short arolia by lacking the ventral hook of the arolium. It further differs from all other ideoroncids by the reduced number of trichobothria, with only 17 on the fixed finger and nine on the movable finger (Table 1, Figs. 11, 12).

**Etymology** — The genus is named for its occurrence in Botswana, combined with the last five letters of *Roncus*, a common pseudoscorpion stem which has been thought to be derived from the Latin *runco*, “living in weeds” (Parker 1982). It is to be treated as masculine.

*Botswanoncus ellisi* sp. nov.  
Figs. 4–12

**Material examined**—**Botswana:** *North-western District:* holotype female, Diviners Cave, Gcwihaba region, 20° 08' 32.2" S, 21° 12' 36.6" E, 19 October 2011, G. Du Preez (WAM T125604). Paratypes: 1 female, same data as holotype except 13 March 2012 (WAM T130804); 1 female, same data as paratype (NMSA-Pse 026870).

**Diagnosis**—As for genus.

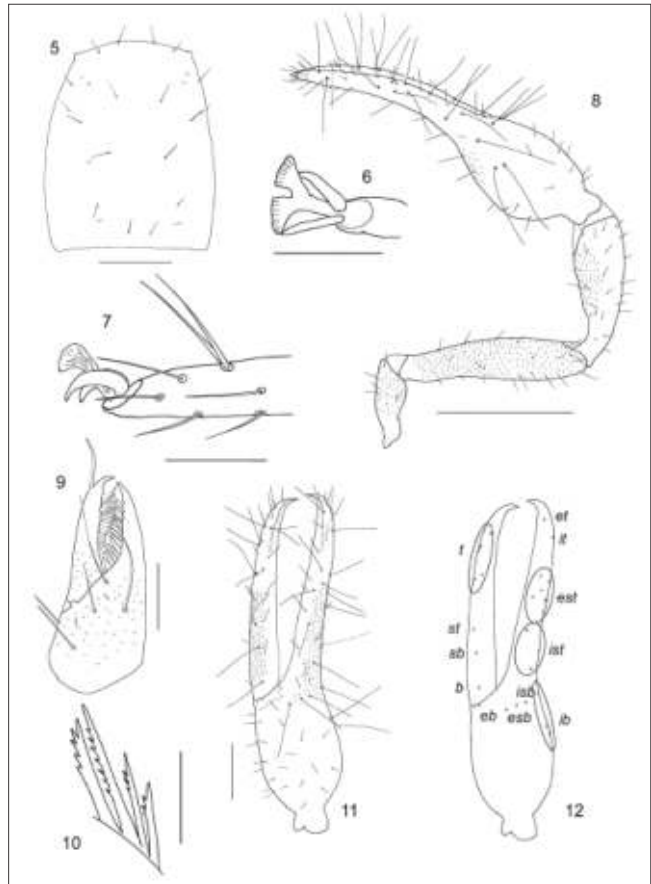
**Description**—*Adult:* Color: pedipalps, carapace, chelicerae and coxae light red-brown, tergite I and legs pale brown and remainder light yellow-brown (Fig. 4).

**Setae and cuticle:** setae long, mostly straight and acicular; most cuticular surfaces smooth and glossy, with exception of pedipalps and chelicera, which are finely granulate.

**Chelicera (Fig. 9):** ca. 50% length of carapace; surface reticulate; cheliceral hand with 5 setae; movable finger with 1 sub-distal seta; all setae acuminate; galea present, simple, very long, slender and slightly curved; fixed finger ca. 7 teeth, each approximately same size, small; movable finger with ca. 8 teeth, each approximately same size, small; exterior and interior condylar lyrifissures present; serrula interior with 18 blades; lamina exterior absent; rallum (Fig. 10) with 4 blades, all with anterior spinules; basal and sub-basal blades shorter than others.

**Pedipalp (Fig. 8):** long and slender; trochanter and femur granulate, prolateral margin of patella and chelal hand granulate, retrolateral surfaces of fingers granulate, all other surfaces smooth; setae acicular, straight or nearly so; trochanter with anterior margin rounded, 2.85 x; femur cylindrical, without trichobothria, 4.57–5.01 x; patella cylindrical, with strongly pronounced pedicel, with 3 lyrifissures, 2 at distal end of pedicel and 1 in middle of pedicel, 2.99–3.25 x; chelal hand ovoid,

external chelal condyle small and rounded, internal chelal condyle small and rounded, chela (with pedicel) 3.91–4.14 x, chela (without pedicel) 3.71–3.92 x, hand (without pedicel) 1.26–1.32 x, movable finger 1.93–2.54 x longer than hand (without pedicel). Fixed finger with 17 trichobothria; movable finger with 9 trichobothria (Figs. 11, 12); *eb*, *esb* and *isb* in straight row at base of finger; *ib* region situated dorsally in the middle of chelal hand; *eb*, *esb*, *et*, *isb* and *it* regions each with 1 trichobothrium; *est* region with 6 trichobothria; *ib* region with 3 trichobothria; *ist* region with 3 trichobothria; *et* slightly distal to *it*; *b*, *sb* and *st* regions each with 1 trichobothrium; *t* region with 6 trichobothria; not ventrally displaced, or *st* situated much closer to *b* than to *t*; trichobothrium *t* acuminate. Both fingers straight in lateral view; chelal teeth juxtadentate (Figs. 11, 12); fixed finger chelal teeth low and flattened; venom apparatus present in both chelal fingers, venom duct of medium length, terminating midway between *it* and *est* in fixed finger and basal to *t* in movable finger; nodus ramosus not inflated.



Figures 5–12.—*Botswanaoncus ellisi*, new species, female holotype: 5. Carapace, dorsal; 6. Tip of left tarsus IV showing claws and arolium, dorsal; 7. Distal end of left tarsus IV, lateral; 8. Right pedipalp, dorsal; 9. Left chelicera, dorsal; 10. Rallum; 11. Left chela, lateral; 12. Left chela, lateral, showing trichobothrial pattern. Scale lines 5 0.05 mm (Figs. 6, 7), 0.1 mm (Figs. 9, 10), 0.2 mm (Figs. 5, 11, 12), 0.5 mm (Fig. 8).

**Cephalothorax:** carapace (Fig. 5) sub-rectangular, 1.20–1.39 x longer than broad; anterior margin slightly convex; epistome absent; lateral margins slightly convex; posterior margin straight; with 18 setae, arranged 4: 4: 4: 2: 2: 2; setae subequal in length; furrows absent; eyes

completely absent. Manducatory process somewhat pointed, with 2 apical setae, both setae approximately equal in length; maxilla with 5 additional setae; maxillary shoulder absent; median maxillary lyrifissure present, situated sub-basally, strongly curved, U-shaped; posterior maxillary lyrifissure present, strongly curved. Coxa I about same width as coxa IV; anterior margin of coxa I with process near foramen; coxae I–IV of ♀ with setae arranged 4: 5: 4: 4.

**Legs:** femora I and II much longer than patellae I and II, respectively; femur I and II without basal swelling; femora I and II with primary slit sensillum directed transversely; femora III and IV about same size as patellae III and IV, respectively; femur + patella IV 3.89 x longer than broad; tibiae III and IV without obvious tactile seta; metatarsi III and IV with long tactile seta, situated medially; tarsi III and IV without tactile seta; metatarsi and tarsi of all legs not fused; metatarsi shorter than tarsi; subterminal tarsal seta acuminate; claws smooth; arolium about same length as claws, with slight medial division (Figs. 6, 7); ventral hook-shaped process absent (Fig. 7).

**Abdomen:** tergites straight, without suture line, setal formula ♀, 2: 4: 4: 4: 5: 6: 6: 6: 6: 6: 6 (arranged T1TT1T): 2; arranged in single rows; sternites, without suture line, setal formula ♀, 6: (1) 2 (1): (1) 4 (1): 8: 8: 8: 8: 8: 8: 6 (arranged 1T2T1): 2; setae of anterior genital operculum (sternite II) of ♀ very small; posterior tergites and sternites with several tactile setae; glandular setae absent; pleural membrane uniformly longitudinally striate.

**Genitalia:** female: with gonosac covered in small acetabula.

**Dimensions (mm):** Female holotype (with paratypes in parentheses, where applicable). Body length 2.28 (2.16–2.25). Chelicera 0.313/0.132, movable finger length 0.200. Pedipalp: trochanter 0.314/0.110, femur 0.685/0.150 (0.659–0.722/0.141–0.144), patella 0.545/0.182

(0.502–0.550/0.163–0.169), chela (with pedicel) 1.182/0.302 (1.136–1.250/0.295–0.302), chela (without pedicel) 1.12 (1.072–1.184), hand (without pedicel) 0.380 (0.390–0.397), movable finger length 0.732 (0.689–0.768). Carapace 0.564/0.471 (0.584–0.596/0.419–0.435). Leg I: femur 0.330/0.080, patella 0.160/0.070, tibia 0.250/0.049, metatarsus 0.152/0.039, tarsus 0.337/0.032. Leg IV: femur +patella 0.521/0.140, tibia 0.324/0.071, metatarsus 0.228/0.046, tarsus 0.328/0.040.

**Remarks**—*Botswanoncus ellisi* exhibits some moderate modifications for cave existence, including the complete lack of eyes (Figs. 4, 5) and pallid coloration (Fig. 4). The appendages, however, are not especially elongated as in the other troglobitic ideoroncids *Albiorix anophthalmus* Muchmore 1999 from Arizona, USA and several *Typhloroncus* species from Mexican caves, which have long, slender appendages consistent with a permanent cave-dwelling lifestyle (Muchmore 1982, 1986; Muchmore & Pape 1999; Harvey & Muchmore 2013).

Only two other pseudoscorpion species have been recorded from Botswana. *Nanolpium subgrande* (Tullgren 1908) and *Beierolpium deserticola* (Beier 1964) (Tullgren 1908; Beier 1964), both in the family Olpiidae, making it one of the least known countries for pseudoscorpion diversity (Harvey 2013).

**Etymology**—This species is named for the renowned caver Roger Ellis, who facilitated GDP's trip to Botswana. Roger has devoted over 40 years to the discovering, surveying and conserving of caves in southern Africa.

## ACKNOWLEDGMENTS

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# Hairy Stalagmites, a new biogenic root speleothem from Botswana

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### Hairy Stalagmites, a new biogenic root speleothem from Botswana

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**Abstract:** Ngamiland in northwestern Botswana hosts the Gcwihaba Caves which present unique subterranean environments and host speleothems never before recorded. Cave atmospheric conditions can be extreme with temperatures as high as 28°C and relative humidity nearing 99.9%. Within Dimapo and Diviner's Caves peculiar root speleothems that we named 'Hairy Stalagmites' were found. These stalagmites are closely associated with the roots of Namaqua fig (*Ficus cordata*) trees that enter the cave environment in search of water. Pieces of broken stalagmites were sampled from Dimapo Cave for further investigations. Stereo and electron microscopy revealed that the Hairy Stalagmites consist of multiple intertwined tubes created when thin films of  $\text{CaCO}_3$  are deposited around fine lateral roots. The importance of the roots is substantiated with evidence of calcified epidermal cells, apical meristems and epidermal imprints. The development of these stalagmites starts when roots accumulate on the cave floor in the vicinity of a water drip and a root nest is created to capture the water. From this point the roots grow upwards (positive hydrotropism) allowing the development of the calcite structure, and as  $\text{CO}_2$  diffusion and evaporation occurs,  $\text{CaCO}_3$  is deposited. The environmental conditions necessary for the growth of Hairy Stalagmites, as well their developmental mechanism, are discussed and illustrated.

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## INTRODUCTION

The hypothesis that biological interactions may somehow play a role in the deposition of secondary chemicals in caves was first suggested by Beaumont (1676) and was later described by Tournefort (1704). Speleothems were even considered, due to the presence of inner growing layers, as true 'rock plants'. At the end of the 18th and beginning of the 19th centuries, the most common speleothem types were often represented as parts of trees with stalactites as roots, stalagmites and columns as trunks, and helictites as leaves or flowers (Forti, 2001). However, at the beginning of the 20th century, any biogenic involvement in the formation of speleothems was ruled out as a better understanding of the main chemical mechanisms was achieved. Yet, in time, it became evident that micro-organisms may play some role in the formation of speleothems (Hill, 1976), while roots were reported to induce the development of peculiar speleothems such as showerheads and rootsticles (Hill & Forti, 1997). Today, it's generally accepted that plants (mainly roots) can passively advance the development of speleothems by enhancing capillary migration of water to structures where evaporation occurs (Forti, 2001). Also, it has recently been shown that microbial communities can actively influence the genesis

and development of certain subaqueous and/ or vadose speleothems (Melim et al., 2001; Barton & Northup, 2007; Dodge-Wan & Deng Hui Min, 2013).

Roots are the single portion of a tree which may somehow contribute towards speleothem development, however, it is presumably rare in deeper parts of caves since roots generally do not reach depths greater than several metres. Nevertheless, the morphological effects induced by roots over speleothems are evident. The surfaces of roots that enter cave voids may serve as pathways for the flow of seeping water and, if environmental conditions are favourable, the precipitation of  $\text{CaCO}_3$  (calcium carbonate). This mechanism causes the development of peculiar stalactites and columns with a tilted and often anastomosed shape over which several pseudo-helictites grow. These speleothems have globally been observed with the same characteristics and are normally called 'rootsicles' (Hill & Forti, 1997). In wet tropical environments the root apparatus of large trees may become the main driving force for the development of peculiar cone-shaped stalactites known as 'Showerheads', which were first described from Brazilian caves (Lino, 1989) and later observed in many other tropical areas (Hill & Forti, 1997). Winkelhofer (1975) was the first to describe root stalagmites from sandstone caves in Germany which were later reported from the Czech Republic and other countries of Central Europe and Northern America (Bunnell, 2010; Pavuza & Cech, 2013). In all of these cases the root stalagmites either developed in the twilight zone or in total darkness. They were described as conical and/or cylindrical dense networks of several coniferous roots that may reach up to 60 cm in height. The voids that formed within the networks consisted mainly of living terminal roots often coated by symbiotic fungi, and were filled with sandy grains and organic matter; the latter being the product of mucilaginous excretion and/ or decay of the roots. A smaller part of the network was formed by thicker and/or skeletal roots directly linked to the mother tree. Owing to the chemical composition of the host rock, no part of the root stalagmite was covered by a calcite crust.

The developmental mechanism of root stalagmites was initially described by Jenik & Kopecky (1992). Kopecky & Jenik (2001) recognized the dripping of water over a sand floor as the fundamental factor allowing for the development of these biogenic speleothems. In fact, only where dripping water impacts a root, do thin new roots grow upwards and towards the water drip (positive hydrotropism). This allows for the development of conical and/or cylindrical root stalagmites of which the height and diameter depends mainly on the energy of the water splashing on them, as well as on the availability of sand grains. Until recently, root stalagmites have globally been discovered in about 40 locations including from the Czech Republic, Poland, Austria, Slovakia, Hungary, Sweden, Spain, South Africa, Australia, and the United States (Mlejnek, 2010). Most of these caves were formed in sandstone or in other non-carbonate rocks (for example granite and gneisses). Root stalagmites were first discovered in a carbonate environment in 1987 during the exploration of Pofadder limestone cave (Namibia), of which a written report was only published nine years later by Marais et al. (1996). These root stalagmites developed below dripping points, were typically 20 cm tall, 3-4 cm wide, and consisted of densely packed thin rootlets. However, the presence of calcite incrustations was not reported. A few other limestone (or marble) caves (Bunnell, 2010) also host root stalagmites of which only one or two are partially covered by thin calcite crusts (Pavuza & Cech, 2013). Nevertheless, the organic component of the stalagmites is by far the most dominant.

Peculiar root stalagmites, called Hairy Stalagmites due to the fineness of their roots, have recently been discovered in dolomite caves in Botswana. These root stalagmites are peculiar since they are almost entirely composed of calcite with roots only visible on top of still-active growing speleothems. In the present paper the microclimate of the relevant cave, the morphology and chemical composition of the Hairy Stalagmites, as well as the proposed mechanism responsible for the development of this new type of root stalagmite, are discussed.

## **GEOLOGICAL SETTING AND CHARACTERISTICS OF STUDY AREA**

### ***Ngamizand: Botswana's host of subterranean realms***

The Gcwihaba Caves, first explored in 1932 by Marthinus Drotsky and initially known as Drotsky's Caverns, are located in Ngamiland in the northwestern part of Botswana (Cooke, 1975). These caverns have facilitated various scientific expeditions, including paleoclimatic (Cooke, 1975; Railsback et al., 1994), paleontological (Robbins et al., 1996) and mineralogical (Martini, 1996)

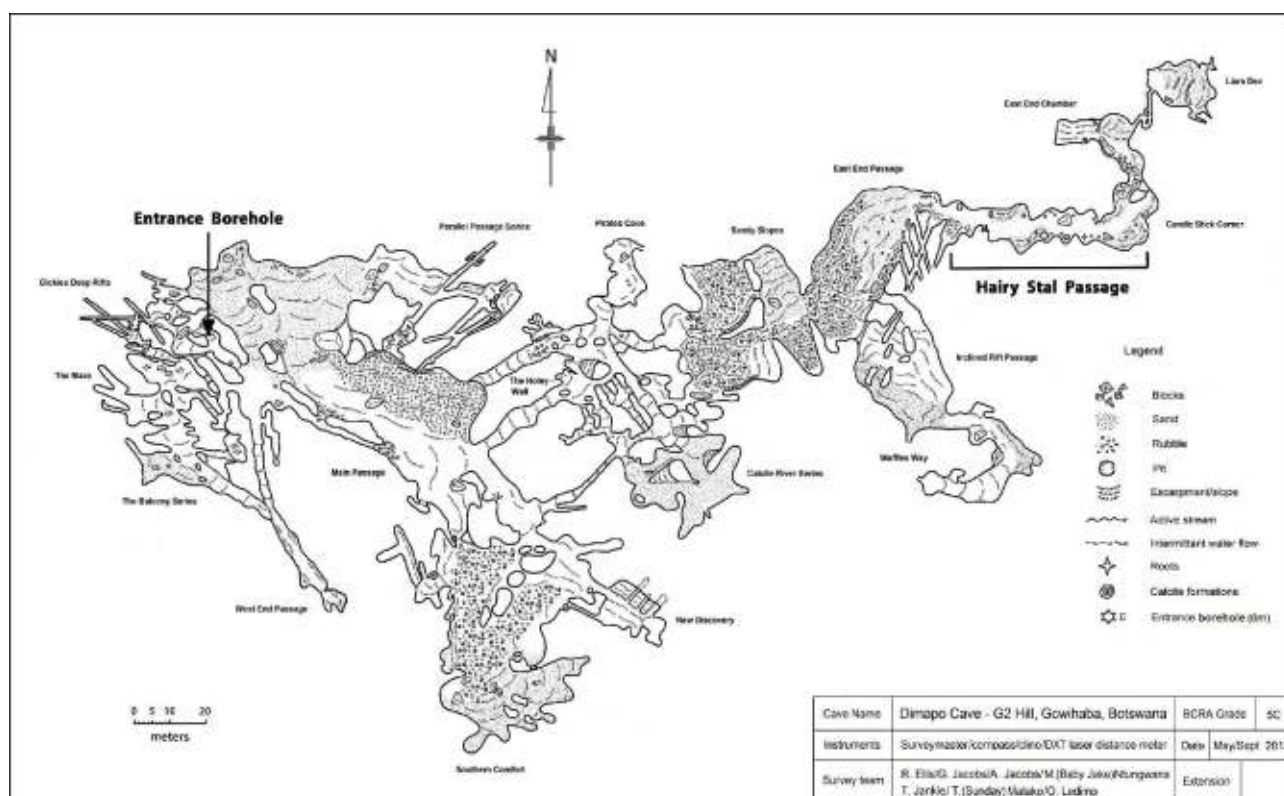


Fig. 1. Map of Dimapo Cave with the location of the Hairy Stalagmites ('Hairy Stal Passage') (Drawing provided by Roger Ellis).

studies, but have, however, only been visited by a small number of tourists. Subsequently, the government of Botswana initiated the Gcwihaba Caves Project which aims at discovering new cave systems for the purpose of establishing an economically viable tourist destination. As part of the project, ground gravimetric surveys were conducted in order to identify cavities isolated below surface. Entry into these cavities was gained by drilling 600 mm diameter vertical shafts that penetrate on average 50 m below surface (Ellis, 2011). Until the beginning of 2014, five new caves have been penetrated of which three are extensive systems. Within two of these systems, Dimapo ( $20^{\circ}1'12.34''$  S,  $21^{\circ}21'38.41''$  E) and Diviner's ( $20^{\circ}8'32.20''$  S,  $21^{\circ}12'36.60''$  E) caves, Hairy Stalagmites were discovered.

Diviner's and Dimapo caves are located in the Koanaka and Gcwihaba Hills respectively; both hills form part of the Koanaka Group stratigraphy (Key & Ayres, 2000; Ellis, 2011). The latter is located in the Precambrian Damara Sequence of Ngamiland (Carney et al., 1994; Williams et al., 2012) and consists of greenschist-facies marble (Singletary et al., 2003). The surface landscape forms part of the Kalahari Desert which is classified as a semi-arid region with shrub savannah vegetation. Rainfall in the desert varies from 400 mm to 450 mm per annum and temperatures from  $-8.5^{\circ}\text{C}$  to  $42.2^{\circ}\text{C}$  (Kennedy et al., 2012). Namaqua fig (*Ficus cordata*) trees naturally occur in the region, however, are mainly associated with the named hills. Preliminary field investigations have revealed that the trees found on Koanaka Hill directly overlie Diviner's and Mongongo ( $20^{\circ}8'47.05''$  S,  $2^{\circ}12'27.08''$  E) caves. It is perceived that the specific location of the trees holds relation to their usage of the subterranean cavities as a water source, thus, ensuring their survival in the desert. Fig tree roots have been reported at a maximum depth of 120 meters below surface in Echo Caves (Ohrigstad, South Africa) (Kutschera, 1991).

### **Characteristics and features of Dimapo Cave**

Dimapo Cave developed along a fault line as shallow as 40 meters below surface, and represents the main system where Hairy Stalagmites were sampled and studied. As illustrated by Fig. 1, the system is characterized by vast chambers, arrays of parallel passages, flowstone formations such as 'Calcite Mountain' (Fig. 2), slopes of infiltrating Kalahari sands, and extensive boulder fields. Dimapo Cave, as well as the other drilled caves, present microclimates atypical to southern Africa's caves. Durand et al. (2012) reported average temperatures of  $17^{\circ}\text{C}$  in the Bakwena Cave (Irene, South Africa). However, temperatures within the drilled caves (Botswana) can reach as high as  $28^{\circ}\text{C}$  with 99% relative



humidity, which nears 99.9% in boulder areas associated with Hairy Stalagmites. It is believed that the Namaqua fig trees utilize the subterranean environment, mainly due to the high humidity levels that result in water flowing along the roots. However, there are numerous water drips throughout Dimapo Cave, which are 'hunted' by roots extending over the cave floor. These roots, in association with the respective water drips, facilitate the development of the Hairy Stalagmites.

The Hairy Stalagmites are found within Dimapo Cave at the northeastern end of the cave system; a 10 to 15 m wide passage known as 'Hairy Stal Passage' (Fig. 1) which extends 60 m in an easterly direction, after which it continues 30 m north and ends in an alcove. On both sides of the passage are banks of infiltrating sand overlain by roots.



Fig. 2. A flowstone formation referred to as 'Calcite Mountain' in Dimapo Cave (Photo by Anton Jacobs).

## METHODS

Inactive and partially broken Hairy Stalagmite samples were carefully collected during September (spring) 2013 from Dimapo Cave (Botswana) by using a hand spade. Care was taken to avoid any direct skin contact. The cave atmospheric conditions were measured with a calibrated Vaisala thermo hygrometer (HMI41) which was left undisturbed for 15 minutes to ensure stable and accurate readings. The samples were stored in cushioned plastic containers, sealed, and transported to the North- West University (Potchefstroom, South Africa) and University of Bologna (Italy) for further analyses.

During all analyses, samples were handled using latex gloves and stored at room temperature in airtight containers. In order to study the surface features of the speleothem more closely, a Nikon AZ-100 (Amsterdam, Netherlands) stereo microscope and FEI Quanta 250 FEG (Bruno, Czech Republic) scanning electron microscope (SEM) with integrated software was used. Stereo light micrographs were taken with a digital camera by making use of the Nikon NIS-Elements software package that creates multilayered-image micrographs. For SEM, smaller pieces of speleothem were sputter-coated with gold/ palladium. A small piece of uncoated Hairy Stalagmite was used to analyse the chemical composition of the speleothem substrate with energy-dispersive spectroscopy (EDS) by using an Oxford X-max 20 SDD detector and INCA software.

## RESULTS AND DISCUSSION

### *The Hairy Stalagmites*

Most of the Hairy Stalagmites found in Dimapo Cave are 'dead' (Fig. 3); calcite deposition has ceased most likely due to climatic variability and is indicated by the absence of Namaqua fig tree roots associated with the structure of the speleothems. It was noted that more than 90% of the speleothems were stagnant, however, some were 'alive', as roots were directly associated and intertwined with their structure (Fig. 4). Typically, roots travel along the cave strata and where intercepted by a water drip, give rise to many smaller rootlets and root hairs; an interconnected



Fig. 3. A 'dead' Hairy Stalagmite that has collapsed and regrown over time with roots associated with the base of the speleothem.





Fig. 4. Namaqua fig tree roots associated with an active Hairy Stalagmite. The roots create a nest at the top of the speleothem which captures the water from the drip (Photo by Anton Jacobs).

web of roots is created which plays a vital role in the development of the speleothem. The dimensions of the different Hairy Stalagmites vary greatly; some are only a few centimetres tall, while others tower over one meter. Generally, the Hairy Stalagmites are three to five centimetres in diameter. The latter, as well as the speed of growth of the speleothems, is most likely affected by: (1) the sustainability and volume of the water source, (2) the concentration of dissolved  $\text{CaCO}_3$ , and (3) the kinetic energy locked within each water drop. The amount of kinetic energy, determined by the distance of travel and diameter of a water drop, affects the dispersion of it upon impact (Salles et al., 2002) and thus possibly the initial base thickness of the speleothem.

### Microscopy investigations

Multilayered-imaging micrographs revealed that the entire structure consists of multiple intertwined tubes (Fig. 5). The tubes were initially formed around a network of lateral roots that originated from several horizontally-growing roots on the cave floor. The initial Hairy Stalagmites, also referred to as nests, consist of a network of modified roots that grow upwards.

Lamont & Lange (1976) referred to them as stalagmiform roots.

The individual tubes were studied more closely with the SEM. The inner surfaces of the calcite tubes



Fig. 5. Micrograph of the external surface of a Hairy Stalagmite illustrating the intertwined calcite tubes that constitute its structure.

showed the presence of both calcified epidermal cells, as well as epidermal root imprints (Fig. 6) that were sporadically found in close proximity to one another. Rarely, entire calcified root fragments (Fig. 7) were observed inside the Hairy Stalagmites. Intact calcified cells in the tubes were mostly root apical meristems (Fig. 8). Root caps appeared to be well preserved as their anatomical attributes were clearly visible as a population of thin-walled, isodiametrically-shaped cells (Fig. 8). The coarse granular texture of the root tips points to the calcification of a mucilaginous substance called mucigel that is normally secreted by root cap cells. Further back from the root tip, root imprints were predominantly observed and only occasionally intact calcified

epidermal cells. In root fragments there was no evidence of calcified cortex cells, but the epidermis appeared to be multiseriate and the cell layer underneath the outermost epidermal layer was also calcified (Fig. 7). A cross section (Figs. 9; 10) revealed that no organic matter remains within the tubes because of the complete decomposition of dead roots. This process is important for nutrient recycling as it constantly makes nutrients available for new root growth and has important implications for the maintenance of the cave and above-ground ecosystem.

A possible explanation for the presence of both replicas and calcified cells is that some roots were alive when calcification occurred, while others were already dead. Calcified cells point towards rapid  $\text{CaCO}_3$  biomineralization while the roots were still alive. Replicas are the consequence of physical

precipitation of calcite around already dead roots. The dead roots subsequently disintegrate and leave epidermal imprints on the calcite. The presence of both types of rhizoliths may highlight the role of the root itself in the calcite deposition process. Living, respiring roots add  $\text{CO}_2$  to their surroundings, which may produce  $\text{H}_2\text{CO}_3$  in the presence of  $\text{H}_2\text{O}$ . Subsequently, higher acidity levels will produce a carbonate rich solution. This solution may penetrate intercellularly and also impregnate cell walls. As the calcite reprecipitates, it effectively preserves cell structure relatively quickly.

However, water removal through absorption by mature living roots may concentrate the carbonate solution and also contribute to  $\text{CaCO}_3$  precipitation, but mostly to the formation of calcite tubes surrounding the roots. Since there is no or limited impregnation and reprecipitation of cell walls and intercellular spaces by the carbonate solution, only epidermal imprints are left after the decomposition of organic material. The zone of cell division in the root tip consists of a population of actively dividing cells and hence high respiration rates. The more common preservation of the root cap cells in root tips, rather than older cells in mature root regions, points to the role of  $\text{CO}_2$  from respiring roots during calcifications of cell structures. However, although biogenic processes may be involved in the calcification of some cells, it is probably a less dominant process than the physical processes involved during the precipitation of  $\text{CaCO}_3$  around individual roots. The calcified tube walls are thin (10-20  $\mu\text{m}$ ) which indicates an overall slow rate of precipitation around each root. The EDS analysis (47.8%  $\text{CaO}$ , 3.8%  $\text{MgO}$ , 0.7%  $\text{SiO}_2$ , and 47.8%  $\text{CO}_2$ ) revealed that the tubes consist of more than 95% of  $\text{CaCO}_3$ .

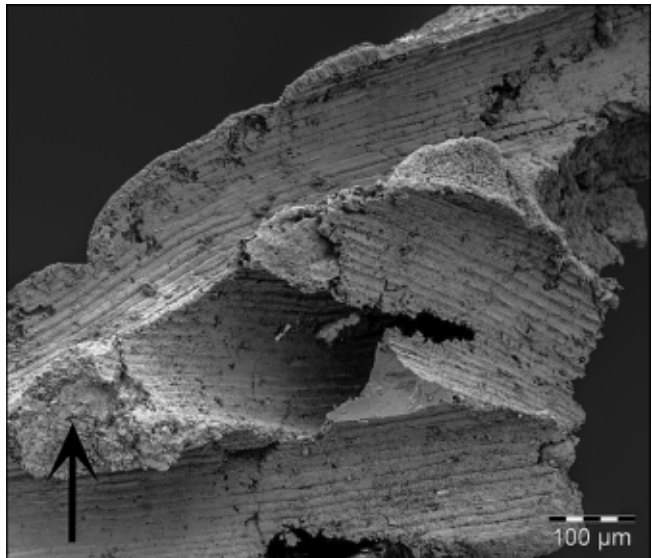


Fig. 6. Scanning electron micrograph showing root epidermal cell imprints created as  $\text{CaCO}_3$  was deposited over the roots. Inter-tube cavities are sometimes partially filled with calcite (arrow).

### ***The developmental mechanism of a Hairy Stalagmite***

When considering the development of a Hairy Stalagmite, several conditions are necessary for both the deposition of calcite, as well as the calcification of roots. The following conditions, however, are generally required for the development of any root stalagmite:



Fig. 7. Scanning electron micrograph showing intact calcified root fragment with calcite partially surrounding the bottom part of it.

1. Trees and/or bushes of which the roots are capable of penetrating the underlying cave must cover the aboveground landscape. Thus, the depth of cave development may not exceed the limit of root penetration.
2. The cave environment must serve as a sufficient and sustainable water source.
3. Dripping water should contain dissolved  $\text{CaCO}_3$ .
4. Dripping inside the cave must be constant and provide sufficient water to avoid the desiccation of the roots, however, the cave floor must remain dry enough to induce positive root hydrotropism.

The following additional and specific conditions are required for the development of a Hairy Stalagmite:



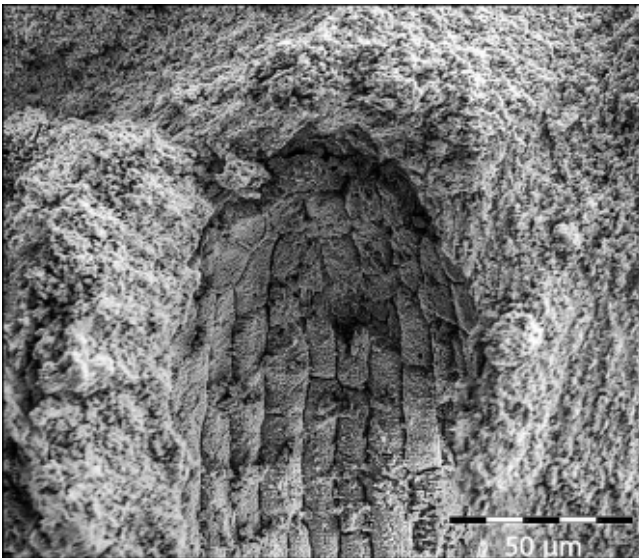


Fig. 8. Scanning electron micrograph showing root tip that contains calcified and isodiametrically-shaped thin-walled root cap cells and young epidermal cells in the zone of cell division.



Fig. 9. Scanning electron micrograph of a cross section of multiple calcite tubes showing that all organic matter has either been decomposed or calcified.

1. Dripping water must either be slightly undersaturated or slightly oversaturated with  $\text{CaCO}_3$ . This is required to facilitate the development of Hairy Stalagmites and not typical speleothems (stalagmites and/or flowstones). If high supersaturation conditions were induced, it would result in rapid calcite deposition, thus burying the roots inside the formed structure.
2. Water flow, as a result of water dripping, should be minimal to allow for the deposition of calcite and to avoid the transport of deposited particles.
3. The relative humidity of the cave atmosphere must remain high in order to prevent the desiccation of the root tips, however, below 100% to avoid condensation of  $\text{CO}_2$  rich water over the roots, which will hinder calcite deposition.
4. Dying-off and degradation of the roots associated with the Hairy Stalagmites should be slow enough in order to facilitate adequate calcite deposition and structure forming.

The development of a Hairy Stalagmite can only occur when all of these conditions are met, explaining why these speleothems are a rare phenomenon. The developmental mechanism can be sub-divided into five stages of which a description follows:

Stage one is initiated when roots from the surface penetrate the cave and travel along the cave walls and floor until they reach a constant water dripping point (Figs. 11 A; 12). The water stimulates the growth of several small hydrophilic upwards (positive hydrotropism) growing roots, creating a rounded root nest (Figs. 11 B; 13). As root growth continues, the nest enlarges, while

the impact of the droplets creates a deepening depression in the center. The concave shape of the nest and its increasing central depth progressively reduce the impact of the water drops, which subsequently prevents droplets from escaping it. The lateral expansion of the nest stops when all of the dripping water is contained within it. Furthermore, the lateral roots facilitate capillary migration of water towards the external part of the nest where calcite deposition processes are active. Nearing the end of this stage, most, if not all of the droplets, are kept within the root nest, which is substantiated by the absence of calcite deposition in the form of layered structures over the external surface or around the base of the stalagmite.

During the second stage (Fig. 11 C), the rounded root nest with a central depression captures and disperses water by capillary action throughout the nest. Supersaturation of  $\text{CaCO}_3$  is possibly induced by several different reactions. Within this peculiar micro-environment,  $\text{CO}_2$  diffusion and  $\text{H}_2\text{O}$  evaporation may not be the only mechanisms involved in calcite deposition, especially since the high relative humidity and  $\text{CO}_2$  partial pressure of the cave atmosphere will inhibit these processes. Other biologically driven mechanisms, including selective water uptake by roots through a biological film (Klappa, 1980) and mineralizing microbial colonies within the biological film around the roots (Cacchio et al., 2012), may also facilitate the deposition of a thin layer of calcite around the roots, thus, creating

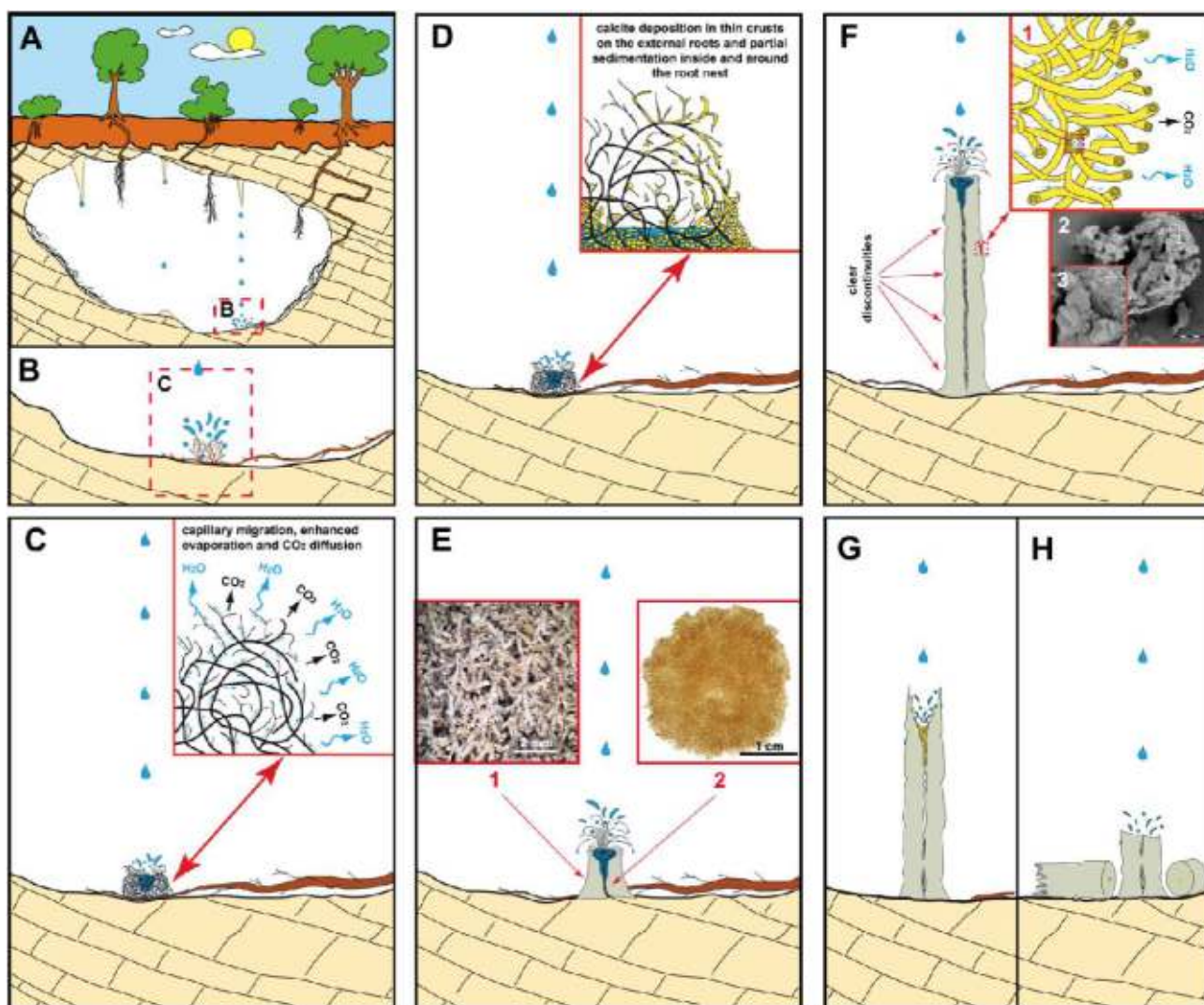


Fig. 11. The developmental stages of the Hairy Stalagmites: A) Roots of Namaqua fig trees migrate along the cave floor in search of water; B) Associated with a constant water drip, fine lateral roots grow upward creating a nest which traps the water; C, D) Evaporation and  $\text{CO}_2$  diffusion allows for calcite precipitation within the nest; E) The process leads to the development of a Hairy Stalagmite of which the entire structure consists of calcite tubes (1), with no remaining organic material (2); F) Alternating dry and wet periods were recorded within the structure of the Hairy Stalagmite as variations in its diameter with the deposition of calcite euhedral crystals in the inter-tube cavities (1-3); G, H) After the internal roots have died, the upper nest disappears and the dripping starts eroding the inner part of the Hairy Stalagmite leading to its collapse.

calcite tubes (Fig. 11 D). The force of the water drops impacting the structure causes the partial detachment of some of the newly formed calcite crust. The detached calcite grains accumulate on the cave floor along the perimeter of the nest. A conical-shaped sandy deposit is formed, becomes enlarged and hardened, and ultimately serves as a protection barrier that prevents the detachment of the thin calcite layers from the individual lateral roots. Calcite deposition continues towards the core of the nest, covering new roots, thickening calcite films surrounding others, and fuses the root structures together, while also partially filling inter-tube cavities (Fig. 6). Since water is constantly introduced at the center of the nest, supersaturation of  $\text{CaCO}_3$  and thus calcite deposition is significantly inhibited. This, together with the impact force of the water drops, causes the core structure to be weaker than the rest of the stalagmite.

In the third stage a true Hairy Stalagmite is formed (Figs. 11 E; 4), characterized by a constant



Fig. 12. Dripping point on the cave floor 'hunted' by roots, which marks the start of the development of a Hairy Stalagmite.





Fig. 13. Root nest created during the first stage of development of a Hairy Stalagmite.

external diameter and vertically growing roots near the core. The calcite films inhibit the growth of the roots by clogging the vascular system, which prevents the roots from conducting water and food. This ultimately leads to the death of most of the roots. However, since the external diameter of the stalagmite remains relatively constant, it is evident that the roots die-off at a specific rate as root lifespan and radial growth is inhibited by the calcification process. After the organic matter has decomposed, the remaining calcite films (10-20  $\mu\text{m}$  thickness) become an intricate network of interconnected hollow tubes (Fig. 10). Some root epidermal cells and root tips are calcified (Figs. 7; 8), while other roots have died before any calcification could take place, as only root surface imprints are visible inside the calcite tubes (Fig. 6).

The described process of Hairy Stalagmite formation may last for several years, creating speleothems over 1 m tall. Discontinuities visible

as indentations in the external diameter (Fig. 11 F) are most likely induced by the reduced frequency of dripping during the dry season, which will also lower the relative humidity of the cave atmosphere. Thus,  $\text{H}_2\text{O}$  uptake by roots, evaporation, and  $\text{CO}_2$  diffusion are enhanced close to the external surface (Fig. 11 F1). These combined processes are also responsible for the deposition of calcite crystals (Fig. 11 F2-3) in the voids that exist between the formed calcite tubes. While the calcite linings over the roots consist of small elongated crystals with a highly porous structure, the calcite deposited in the inter-tube cavities and on the surface of the Hairy Stalagmites has an entirely different morphology. The former is the result of alternating deposition and re-dissolution of calcite most likely controlled by biogenic processes that subsequently give rise to a high amount of  $\text{CO}_2$ . On the contrary, the calcite in the cavities and on the surface of the Hairy Stalagmite consist of euhedral non-porous crystals (Figs. 14; 15) which suggests a slow but continuous deposition process controlled by evaporation and/or enhanced  $\text{H}_2\text{O}$  uptake by roots during the dry season. As a result, the external surface of the stalagmite is more hardened. Due to the above described process, only the roots growing vertically along the dripping line survive. However, as they reach the open space above the partially hardened nest, they

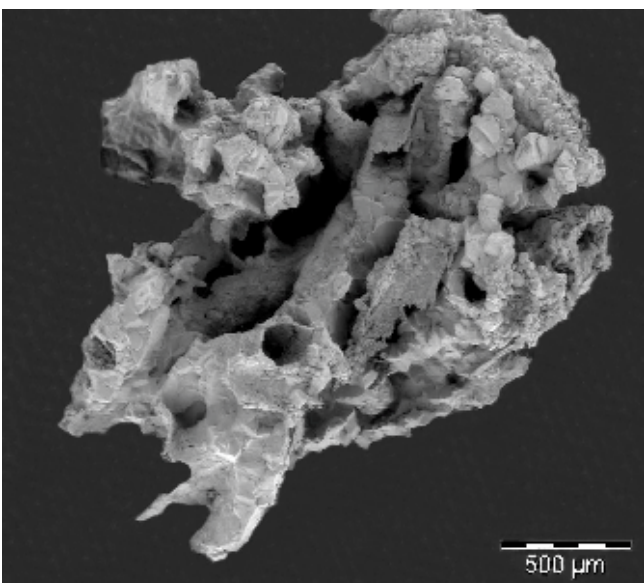


Fig. 14. Scanning electron micrograph showing euhedral calcite crystals that formed near the surface of a Hairy Stalagmite.

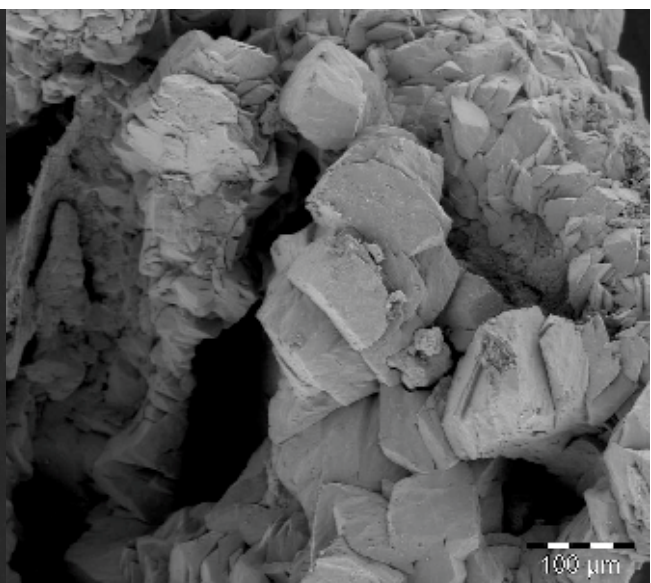


Fig. 15. Close-up view of calcite crystals formed on a Hairy Stalagmite.

create an elaborate umbrella structure (Fig. 4) which allows the further development of the Hairy Stalagmite.

The fourth stage (Fig. 11 G) is related to the decay of the Hairy Stalagmite, which is influenced by the availability of water, the rate of calcite hardening, and the height of the structure. As the Hairy Stalagmite becomes taller, the roots within the structure may break as they become more fragile and exposed especially during the dry season. Also, if water dripping ceased for a period of time, the roots may become petrified. Consequently, the root nest at the top of the stalagmite will die and disintegrate, leaving the stalagmite exposed to the impact of dripping water. Direct contact between the water drops and the calcite structure will progressively degrade it and block the tubes with calcite fragments.

Finally, during the fifth stage (Fig. 11 H), the Hairy Stalagmites become unstable without the support of living roots. Furthermore, the impact of falling water drops is no longer cushioned by the root nest. If enough force is generated, the Hairy Stalagmite may break and collapse (Fig. 3), most likely at an area of weakness closer to the base of the speleothem. An area of weakness is probably the result of incomplete calcification and may also explain the discontinuities (Fig. 11F) that were observed in the external diameter of the stalagmite. If conditions again become favorable, the portion of the Hairy Stalagmite left standing may be recolonized by roots. This marks the start of the development of a new Hairy Stalagmite continuing from the third stage.

## FINAL REMARKS

Hairy Stalagmites, a new type of biogenic speleothem, consist of both calcite tubes and calcified root cells, and are peculiar specimens representing biogenically-formed speleothems. Their development is strongly controlled by an intricate set of both atmospheric and abiotic conditions, most likely sensitive to climatic variations. The required conditions explain why the Hairy Stalagmites have only been observed in caves previously sealed. In order to preserve this unique environment together with this new type of speleothem, it is necessary to conserve not only the cave atmospheric conditions, but also the surface landscape that hosts the Namaqua fig trees. Therefore, with the Botswana government's efforts to create a tourist destination, adequate measures should be considered to insure the sustainability and function of the caves and surface landscape.

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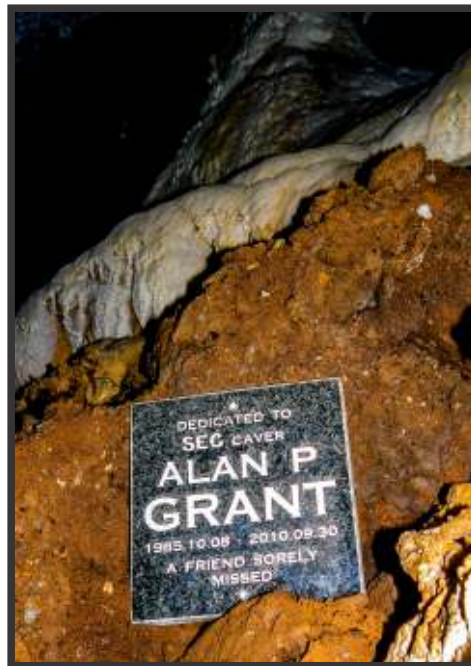


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It grieves me to record the demise of a great young caver, friend, budding geologist and co-author, Alan Grant. He was an avid caver with an enquiring mind and is sorely missed. A plaque has been placed in memory of him in his favourite cave, Knocking Shop. *Dave Ingold*.

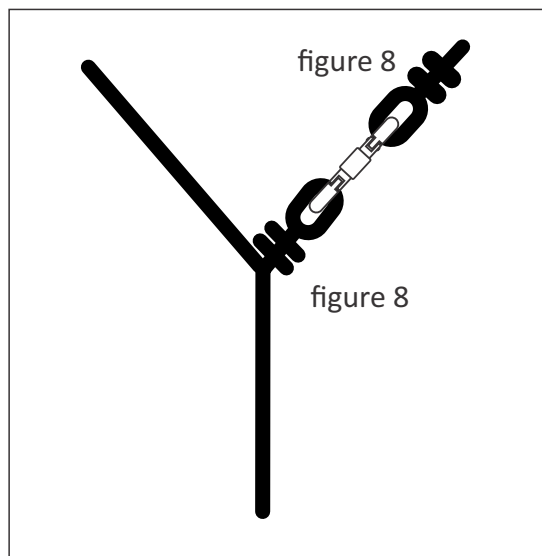


## Figure 9 R-S knot

*Colin Redmayne-Smith*

This knot came about over 20 years ago due to what might have been a fatal disaster. Four cavers had descended into Apocalypse Cave. It has an entrance pitch of 50 metres and passages totalling 14 kilometres. This is South Africa's longest cave. The four were on a pushing trip and had been underground for over 12 hours. When they started to ascend the 50 m pitch it was completely dark. Covered in mud and tired they ascended the pitch safely. They packed up their equipment and hauled the rope out of the shaft, but were unable to untie the knot, so they stuffed the rope into the bag and left for home saying that at the weekend they would clean all the tackle and sort out the rope.

Unfortunately, no one was able to untie the knot, so they cut off 20 m of the 100 m new rope. They then decided to cut open the knot to inspect it. What they found was the 11 mm rope had compressed inside the knot to about 6 mm.



They had used a figure 8 on a large Y hang.

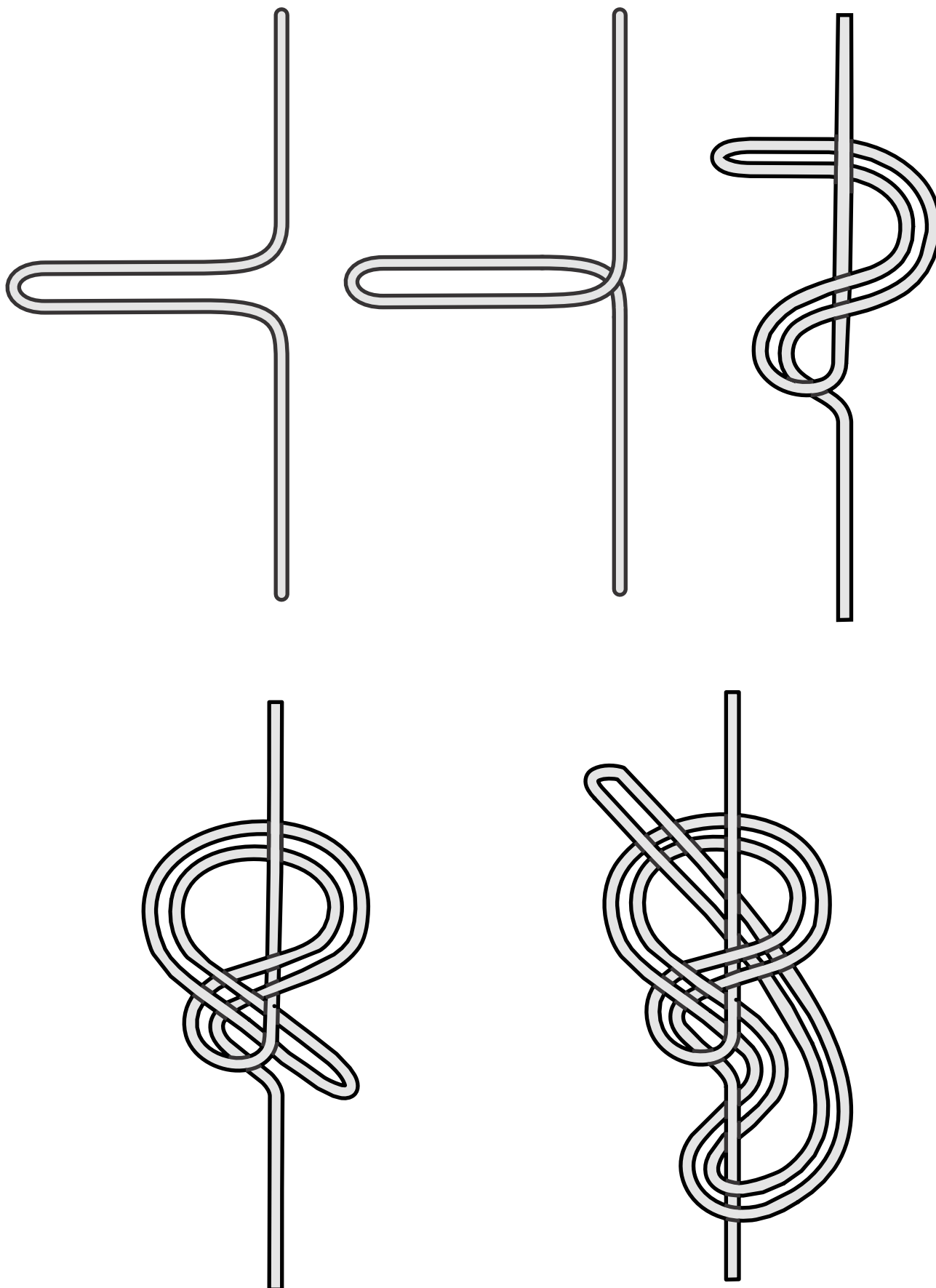
I thought at the time there had to be a safer method.

I then worked with a figure 9 knot, being stronger than a figure 8, and found that an in-line figure 9 could be tied in the middle of a rope.

But the secret was in the method of connecting the large Y hang.

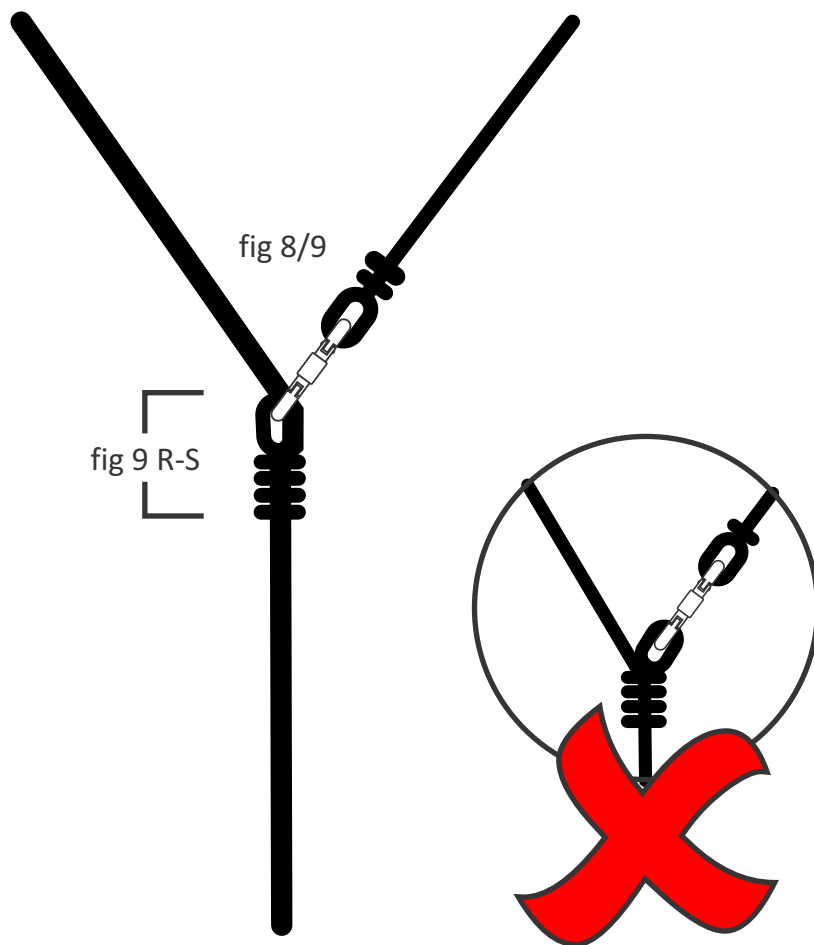
This method as shown below has been used ever since and with great success on our large sinkholes and can even be used with an in-line figure 8 knot. The in-line figure 8 had just been published at that time by the French and they had called it the figure 8 Romain.

## Tying a 9 R-S

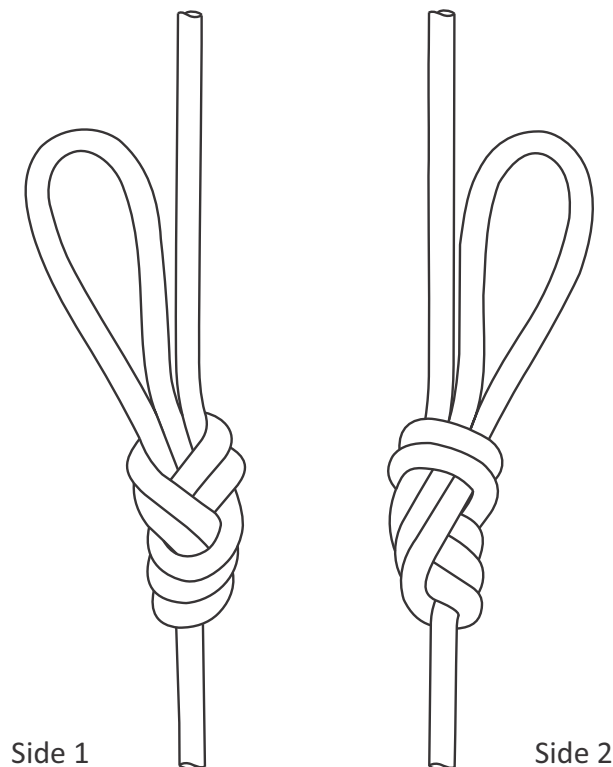




## A Good Way to Rig a Large Y Hang



Dressed and Set — figure 9 R--S



## Ettien's Sinkhole

*Rick Hunter*

On May 17, 2015, we descended Ettien's Sinkhole located at Westonaria, south of Johannesburg. Those present were: Rick Hunter, Lindsay Hunter, John Dickie, Selena Dickie, Terrence Stewart, Elize Ganswyk, Colin Redmayne-Smith, Horst Muller and Gerrie Pretorius. It was rigged with a standard tyrolean traverse using two vehicles and a bi-pod. I started with a 60 m rope but realised that it did not reach the bottom, so attached a further 50 m. The descent was incredibly slow and difficult due to the weight of the rope through the stop. At approximately 40 m, I reached the knot and the start of the dark zone. I began testing for CO<sub>2</sub> from that point on using my lighter. The air felt clammy, but no significant deterioration in air quality. Passing the knot, I still had approximately 30 m to descend, of which, some of it was against the side. The chamber opened up into a bell shape with a debris cone in the centre. There were no formations, only mud. My impressions were that this is an active sinkhole and will most likely sink lower, possibly opening up. It would be advisable to revisit in a few years to check if it has opened into a system. The depth was 74 m. Descent time was  $\pm 30$  minutes and ascent time  $\pm 20$  minutes.

