Makapansgat Limeworks stratigraphy and the singular case of Member X

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Within the infilling sequence of the western Limeworks a newly recognized unit, Member X, lies stratigraphically between the Member 1 massive speleothem and the Member 2 red silts. Member X consists firstly of a subaqueous mammillary layer that is ubiquitous to the whole of the Limeworks. It is succeeded by a series of intercalated clastic sediments and calcite-rich layers that is confined to the area between the Original Ancient Entrance and the Classic Section and which is terminated by a second subaqueous carbonate layer. The evidence suggests that surface sediments were washed into a carbonate-rich pool created by seepage water and, from the presence of several articulated skeletons, the Original Ancient Entrance during this phase appears to have acted as an animal trap. There are a few blocks of Member X to be found in the Limeworks dumps that have been placed in the Member 2 rows but which should be prepared separately. From the evidence of the intercalated carbonate and clastic layers it appears that Member X was deposited slowly at first and then speeded up probably because erosion caused retreat of the entrance. Member X has several unusual features including a unique pseudo-breccia layer of co-deposited calcite-mud formations, deposition of aragonite that increases with height, and calcite-aragonite layers that invert the stratigraphy on overhanging walls and ceilings but not on the floors.

Keywords: Makapansgat, Member X, stratigraphy, chronology, Kitching.

INTRODUCTION

The earliest deposits of the Limeworks are the huge stalagmites, flowstones and columns that formed an irregular arc-shaped wall round the outside of the main cavern (Speleothem Arc) and which were extracted by the lime workers in the first half of the twentieth century. Subsequently, as the roof eroded, the precipitation of speleothem was succeeded by collapse blocks and surface runoff from above the cave. Partway through the unroofing phase of the cave, animals such as hyaenas, big cats and porcupines used parts of the cave for denning. One large area on the western side – the Classic Section – is well known for its Grey Breccia (Member 3) the remains of which show that it once contained dense bone accumulations to the local roof. The remains of Australopithecines have been scavenged from the Grey Breccia dump material and from roughly equivalent parts of the central repository that we have called the Central Debris Pile (Latham *et al.* 2003; Latham *et al.* 2007).

A stratigraphy for the Limeworks based on the layer-cake model was constructed by Wells & Cooke (1956), by Brain (1958) and by Partridge (1979) who introduced the Member system for the supposedly successive deposits. Member 1 is the massive speleothems, Member 2 comprises red silts (mainly on the western side). Member 3 is the Grey Breccia, and Members 4 and 5 (which is really one unit) constitute the pink breccia deposited on the inside of the Speleothem Arc in the centre of the fossil cavern. The idea of a single succession was criticized by Maguire *et al.* (1985) who recognized that different areas constituted different repositories of infill. Subsequent stratigraphic reconstructions by Latham and co-workers have concentrated mainly on the fossil-rich western side of the Limeworks and they have used a modified form of the Member notation to describe it. Further work has shown that another episode of deposition occurred between Member 1 and Member 2, sufficiently distinct to have been separated out, and it is here called 'Member X'.

In the area known as the Original Ancient Entrance at the northwest end of the site, the pediment flow of one of these massive Member 1 speleothems is overlain by up to 1 m of sloping and horizontal subaerial flowstones. Member X overlies these speleothem deposits. Latham *et al.* (1999, 2003) showed that the Member 2 red silts of the western Limeworks and the Classic Section were also carried in by periodic floods through an old entrance centred on what is now referred to as the Original Ancient Entrance (OAE). It was in order to resolve ambiguities in the ongoing palaeomagnetic re-analysis that prompted further stratigraphic work, and this has revealed complexities in the layering, including localized stratigraphic inversion of layers in the western deposits.

THE STRATIGRAPHY OF MEMBER 1 TO THE MEMBER 2 RED SILTS

Figure 1 shows the position of the so-called Original Ancient Entrance. This mined feature occupies part of what was once an exit (resurgence) for the original formative stream and then, upon abandonment, a point of ingress for clastic sediments resulting from slope wash. The passage now forms a **U** loop in long section, one arm being the North Alcove to the Main Quarry and the other arm being an upward trumpet-shaped ramp to the exterior surface. This latter arm is now eroded at the surface and, except for the mined western half, is still filled with sediments of Member X and Member 2. The sediments in the actual OAE are at their lowest point and constitute a small, irregular, sedimentary basin. Current excavations on the surface, by T. Crawford, K. Kuykendall, J. McKee & J. Maluleka, for *in situ* bone, have revealed the eastern dolomite wall of this passage and the continuation of the

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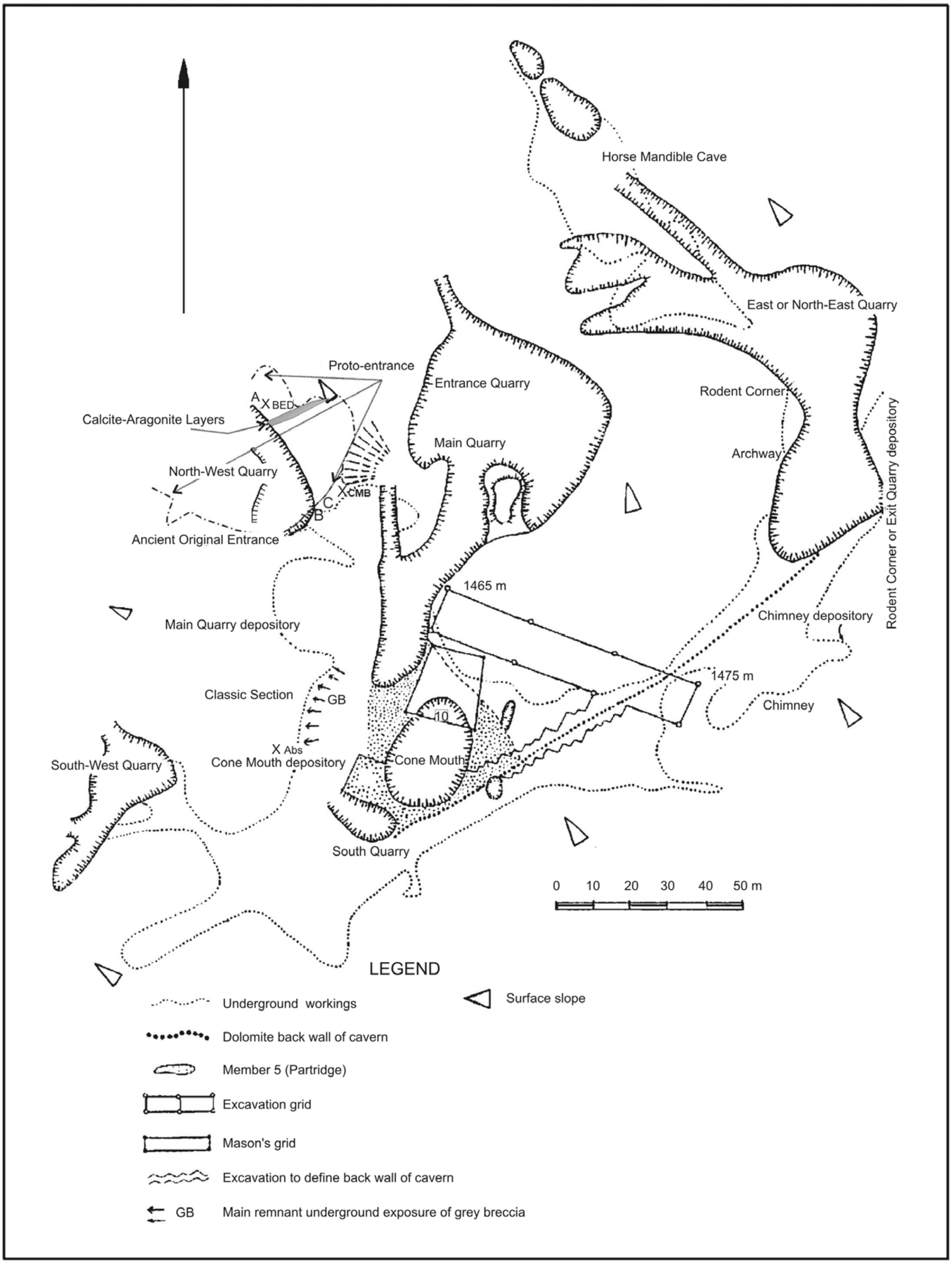

Figure 1. Map of the Limeworks site (after Maguire *et al.*1980), with the proto-entrance centred on the Original Ancient Entrance. The dot-dash line indicates the approximate extent of Member X. The position of the two articulated skeletons and hyrax skull mentioned in the text are marked A, B and C.

roof brow from the western side. Latham *et al.* (2003, 2007) discuss how Member 2 extends along to the end of the Classic Section and upwards onto the faulted buttress of the Main Quarry. This latter is the inner side of the so-called Partridge Block on which the hominid partial cranium MLD 37/38 was found by James Kitching in 1958.

Stratigraphically the sequence in the western Limeworks (excluding the Entrance Quarry) is: (1) massive speleothem of Member 1 with pediment flows down to the basin of the OAE, (2) subaerial flowstones deposited down from the exterior which lap onto the pediment flows, (3) Member X, and (4) Member 2. The latter consists of both red silts

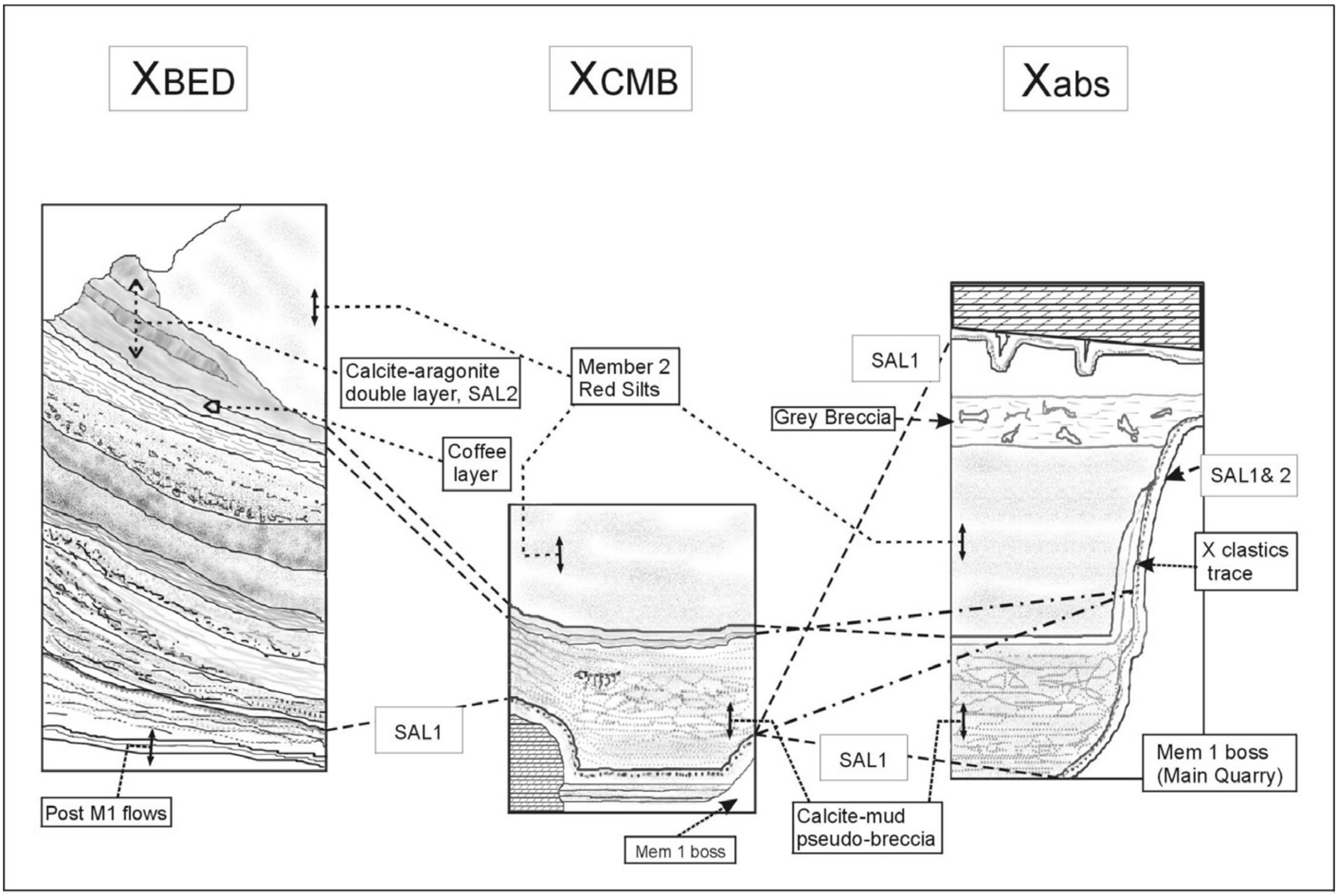

Figure 2. Sketch of the stratigraphy of Member X for three locations, X_{Bed} (bedload), X_{CMB} (calcite-mud breccia) and X_{Abs} (where the clastic layers are absent). Height dimensions are about 5 m bottom to top. The thickness of the strata, particularly Member X clastics, varies widely from place to place and so are approximate in this schematic diagram.

derived as hillwash from above the OAE and several intercalated calcite pediment flows coming from the speleothem bosses in the Main Quarry.

THE STRATIGRAPHY OF MEMBER X

Figure 2 illustrates how the stratigraphic thickness and the sedimentology of Member X are highly varied, and that the Member consists of three fairly distinct sub-units.

Sub-unit 1 – Subaqueous Layer 1 (SAL1)

This begins with about 4 to 7 cm of calcite mammillary layering (subaqueous layer 1, SAL1) that is uniformly deposited over the whole of the Limeworks including the alcoves behind the Collapsed Cone, the Exit Quarry, Rodent Corner and Horse Mandible Cave. This deposit exceeds the height of the Grey Breccia and reaches the level of the overhanging roof in this area. It reaches to within 3 m of the top of the Partridge Block. Sections through SAL1 in the basin of the OAE show that it was laid down fairly evenly (around stalactites as concentric layers) the later layers being progressively contaminated with very fine mud. This layer points to the likelihood that a carbonate-rich pool existed at this time throughout the whole of the former Limeworks cavern.

Sub-unit 2 – Clastic sediments

In the excavated area down to the OAE there follows a series of sloped, fining upward layers of clastic sediments intercalated with sets of calcite raft clasts or thin (<1 cm) subaqueous calcite layers, or both. These clastic layers result from surface runoff ('hillwash' in the Maguire *et al.* [1980] terminology) into a pre-existing pool leaving bedload of angular to subangular clasts (mostly <1.5 cm) and suspended load, each layer becoming finer down-slope. The equivalent interior floor facies contains only the suspended load. Clasts are of dolomite or chert from the country rock in a matrix derived from red-brown soils. The earlier layers outside the OAE are laid down on a slope (near the centre of the former passage) of about 20°. The slope of the last layers has increased to about 30°. This means that the bed load, in being deposited immediately on the slope, served to increase its angle of repose and was set in place by subsequent calcite flows and by calcite cementation, whereas the much finer suspended load of mud was dispersed throughout the rest of the basin, reaching as far as the distal end of the Classic Section. We have found no evidence of slumping or rescouring of the slope deposits.

Sub-unit 2 – Calcite-mud pseudo-breccia

Underneath the OAE the clastic component consists of only the suspended load, and it was laid down at the same time as the calcite. It formed either thin lenticular layers of calcite and mud layers or a pseudo-breccia of calcite in mud and mud in calcite in about equal thicknesses set at mostly low angles (Fig. 3). It is not a normal calcite-raft

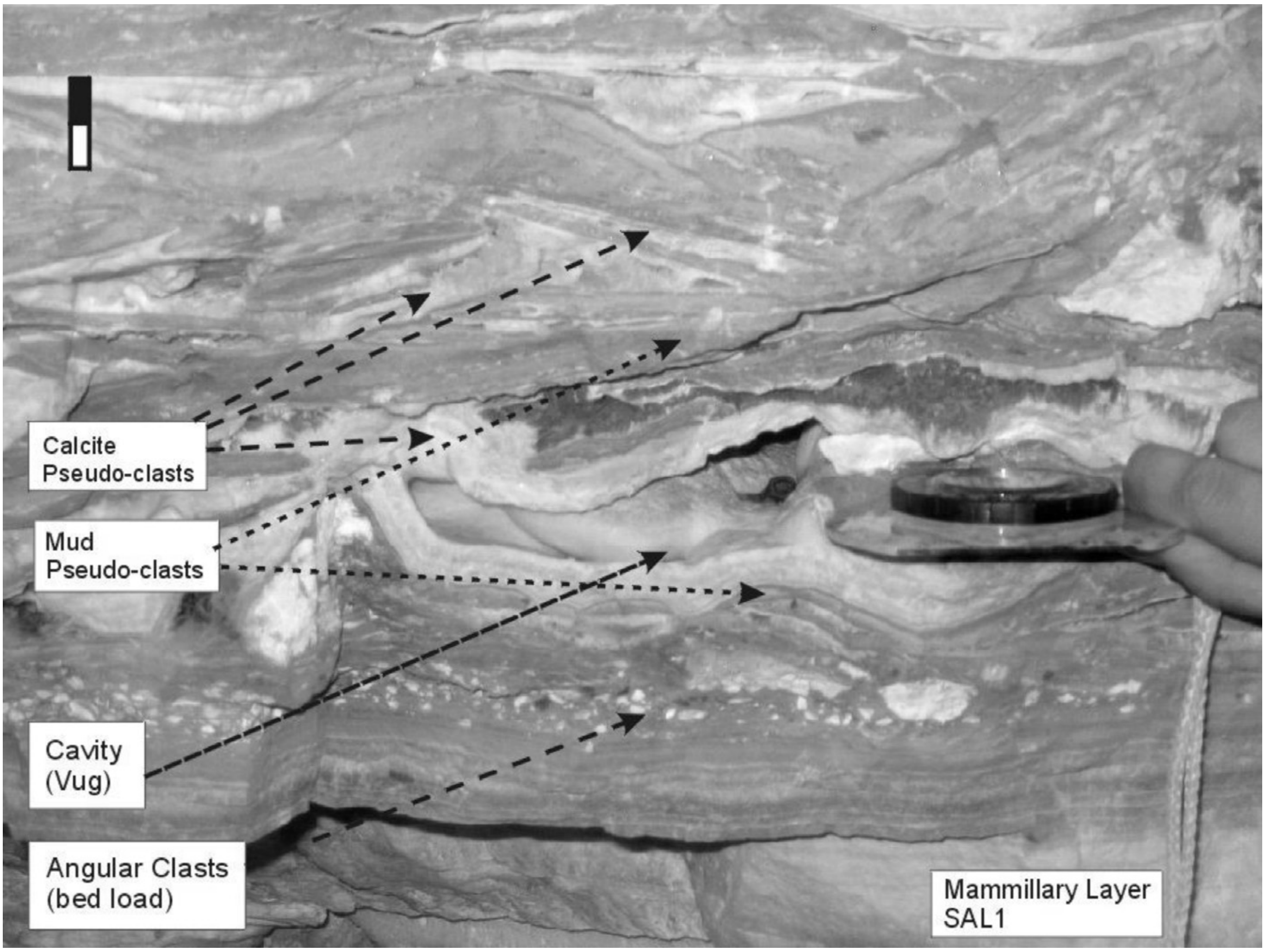

Figure 3. Photograph of the calcite-mud pseudo-breccia. The scale bar is 2 cm.

breccia, as Schrenk (1984) appears to have thought. For the formation of a normal calcite-raft breccia, thin calcite rafts precipitate out on the surface of very still carbonate-rich pools and finally reach a thickness in their growth where surface tension can no longer support the increased weight; they then sink to become incorporated in the sediment. The calcite with mud formations of Member X, however, formed below the surface at the same time as each other so that each is seen to have terminated the other and to have prevented the other from growing as contiguous layers. The calcite formations, sometimes with thicknesses exceeding a centimetre, even enclose quite large holes where there may once have been entirely carbonate solution with no mud at all. The calcite must either have disrupted the normal layering of the mud or the pool was so still that self-attraction by Van de Waal's forces between finest clay particles helped to segregate the mud from the calcite. The extraordinary effect is that the calcite formations do not occur in the mud and the mud does not contaminate the calcite formations – each component is free of the other.

Sub-unit 3 – Calcite-aragonite layers

In the OAE the last sediment layer of Member X is a fine brown mud about 5 cm thick. It coats all horizontal surfaces though, as with all sediments of Member X, it attenuates to a smear on overhanging and vertical surfaces. On top of this coffee-coloured layer is another cream-white calcite layer about 4 cm thick. The extraordinary thing is that higher up in all places of the western Limeworks this last carbonate layer becomes firstly a thicker calcite-aragonite layer up to 15 cm thick and then a calcite-aragonite double layer. It coats all surfaces, including floors (outside on the excavated area of OAE) (Fig. 4) and roofs and existing speleothems of the Main Quarry and it therefore represents a second subaqueously deposited layer (subaqueous layer 2, SAL2) and it formed, as did SAL1, under the surface of a deep carbonate-saturated pool. This time however the pool was not as deep as for SAL1, and the sediments deposited in the pool are confined to this part of the western repository. We have not been able to find it anywhere else in the Limeworks.

STRATIGRAPHIC INVERSION AND THE ABSENCE OF THE CLASTIC STRATA

When slope material representing sub-unit 2 was washed inside the entrance (Fig. 1), the suspended fraction was carried as far as the end of the Classic Section where it was stopped from going any further into the central Limeworks cavern by the massive speleothem boss (part of the Speleothem Arc) that was joined at that point to the dolomite wall. In those places where the pool was confined

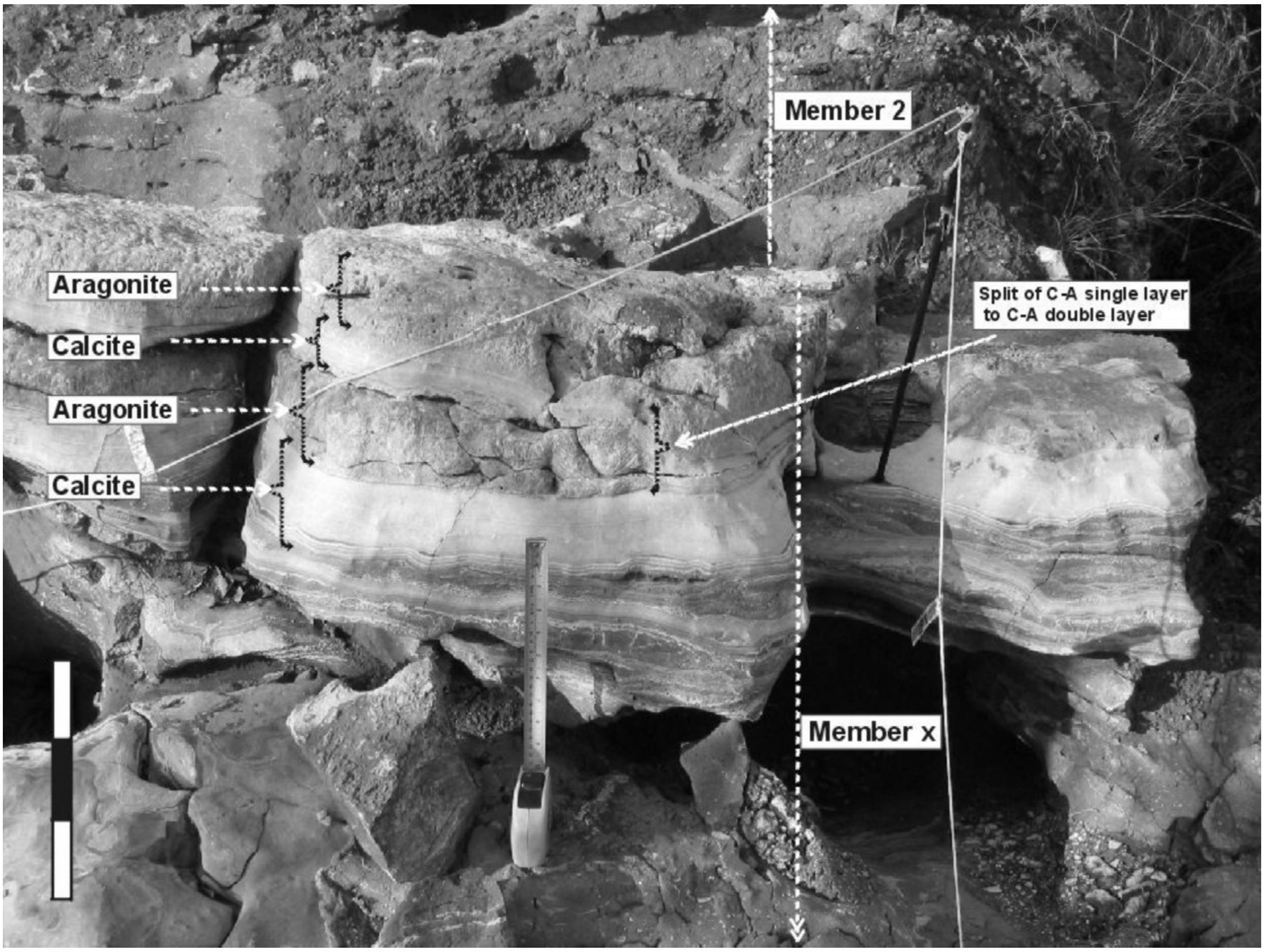

Figure 4. The calcite-aragonite double layer on the bevelled surface of the Original Ancient Entrance. The scale bar is 30 cm.

by vertical walls or vertical speleothem or where there were stalactites there was no clastic deposition at all except for a very fine dark line, less than a millimetre thick, sandwiched between the two subaqueous layers. In effect the dark line is the very finest of the clastic deposits and could easily be missed at a cursory glance. It may also be noted that where the two subaqueous layers are deposited on roof surfaces they therefore represent localized inversions of the stratigraphy. On sub-horizontal slopes the stratigraphic succession including Member X is normal.

CONDITIONS FOR THE FORMATION OF MEMBER X

The formation of all sub-units of Member X could have occurred only under a deep carbonate-rich pool. The impression is of a pool that was formed by copious amounts of drip water coming through the roof of the main cavern (this was some time before the main roof began to collapse) where evaporation was low (the cavern was enclosed except for the early proto-entrances) and where the water could not drain away because of the U-shaped nature of the cave exits or entrances. Then a new configuration of the exit brow in the area of the OAE allowed ingress of sediment from the surface, slowly at first (the first contaminated layers in the SAL1) and then more rapidly (the clast laden debris of the sedimentary layers). Evaporation of water to the outside and ingress of new carbonate water from the interior would ensure that the water stayed saturated, so producing the calcite-mud pseudo-breccia. Then more unroofing of this exit or of the Limeworks cavern itself ensured the rapid evaporation of the pool to produce the calcite-aragonite layers of SAL2 and the start of Member 2 times.

What length of time does Member X represent? SAL1 is finely layered and together with the lower calcite-clastic layers probably formed over a long period of time, in the order of 100 kyr or more. Subsequently, outside the OAE, the fining upwards layers become thicker (0.5 to 2 cm) which strongly suggests that clastic sedimentation speeded up. The metre or so of these later layers may represent just a few thousand years. Inside the OAE the final SAL2 is only 3 cm thick and it probably represents a period as short as a thousand years or less. We conjecture that it represents the ultimate drying out of the former fixed pool as its feed sources were captured elsewhere due to the unroofing of the main cavern.

FAUNAL REMAINS IN MEMBER X

The articulated skeleton of a small bovid, attributed to *Makapania broomi* (Schrenck 1984) in the calcite-mud breccia under the OAE is fairly well known. A few metres away a skull near the inner wall has been identified by Kaye Reed (pers. comm.) in 2003 as that of a hyrax. More bones have been found in this Member X including the articulated skeleton lying on the sloping strata from the cleared surface that is thought to be of a small bovid (T. Crawford, pers. comm.) and which awaits preparation at the University of the Witwatersrand. These and a few other remains of whole bones or of more-or-less complete skeletons of small animals indicate that the pool acted as a trap. (Bones resulting from denning and predation would be fractured and disarticulated as they are in Members 2 and 3.) One might speculate that animals entering the cave and attempting to drink were not able to get out again. The alternative hypothesis, that the bones represent carcasses brought in by floods, is less likely. There are a few pieces of Member X in the Lime dumps and they should be prepared separately. They have the potential to provide specimens of late Miocene or early Pliocene age in contrast to those from Members 2, 3 and 4 which probably belong to mid to late Pliocene times (Partridge 2000).

After SAL2, the sedimentary regime above, and inside of the OAE changes quite markedly to the red silts of Member 2. Here the input is from surface run-off which created underground pools and dried out after each event; the evidence for this are the repeated generations of mud cracked layers in Member 2 (Latham *et al.* 1999, 2003). Could this sudden change in sedimentation style be due to the beginning of the roof fall of the Limeworks cavern itself? This is a working hypothesis that might be tested by further data. At any rate the bone breccias of Member 2 are, this time, due to denning animals as is evident from the splintered large bovid bones. The den in the Main Quarry lies on a former shelf of a stalagmite pediment flow and the Grey Breccia, representing a quite long period of denning, lies stratigraphically partway through Member 2 (Latham *et al.* 2007).

CONCLUSIONS

The three sub-units of a newly recognized unit, Member X, that was thought to be deposited in the early Pliocene, was formed in a more-or-less permanent pool that in its early stages reached all of the Limeworks cavern. The subaqueous calcite and aragonite testifies to the fact that this pool was supersaturated in carbonate for most of its history. Clastic sediments, confined to the western repository of the Limeworks, were washed into the pool from the direction of the current Original Ancient Entrance and the articulated skeletons of a few small animals appear to indicate that this part of the cave acted occasionally as a trap. The carbonate-rich pool, with its input of fine suspended sediment, resulted in a pseudo-breccia of calcite and mud bodies – a speleothem form that is thought to be unique to this cave. The phase ended when the pool became so saturated that it deposited, at greatest depths, one calcite layer; at medial depths, a calcite-aragonite couplet; and at shallowest depths, a calcite-aragonite double couplet. As the deposition of aragonite is mostly controlled by Mg and, possibly, by elevated temperature, then it is possible that the final calcite-aragonite phase was the result of a significant unroofing of the main cavern, which would have brought in warmer air masses, and increased the evaporation of the pool. The higher levels of the pool would be more concentrated in the lighter Mg that preferentially promotes the growth of aragonite over calcite. There is skeletal material in blocks in the lime dumps that recognizably belongs to Member X. These blocks should be prepared and archived separately from the later Member 2 material.

Member X was first so dubbed by Tafline Crawford who used percussion caps to extract the bovid in the surface exposure of the stratum in 2004. This work and the continuing stratigraphic work at the Limeworks was supported by a U.K. NERC grant (NER/A/S/2000/0034) to Bob Cliff (Leeds) and to Alf Latham (Liverpool), by an NSF grant (BCS-0128770) to Jeff McKee (Ohio State University) and by a Leakey Foundation grant to Alf Latham.

This paper is dedicated to the memory of James Kitching, of the Bernard Price Institute for Palaeontology, University of the Witwatersrand, and his work at the Limeworks over several decades, and is a contribution to his Festschrift. The University of the Witwatersrand Makapansgat acquisitions book amply shows that the majority of hominid fossils known from the Limeworks, were found by him between 1947 and 1958 including MLD 37/38.

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