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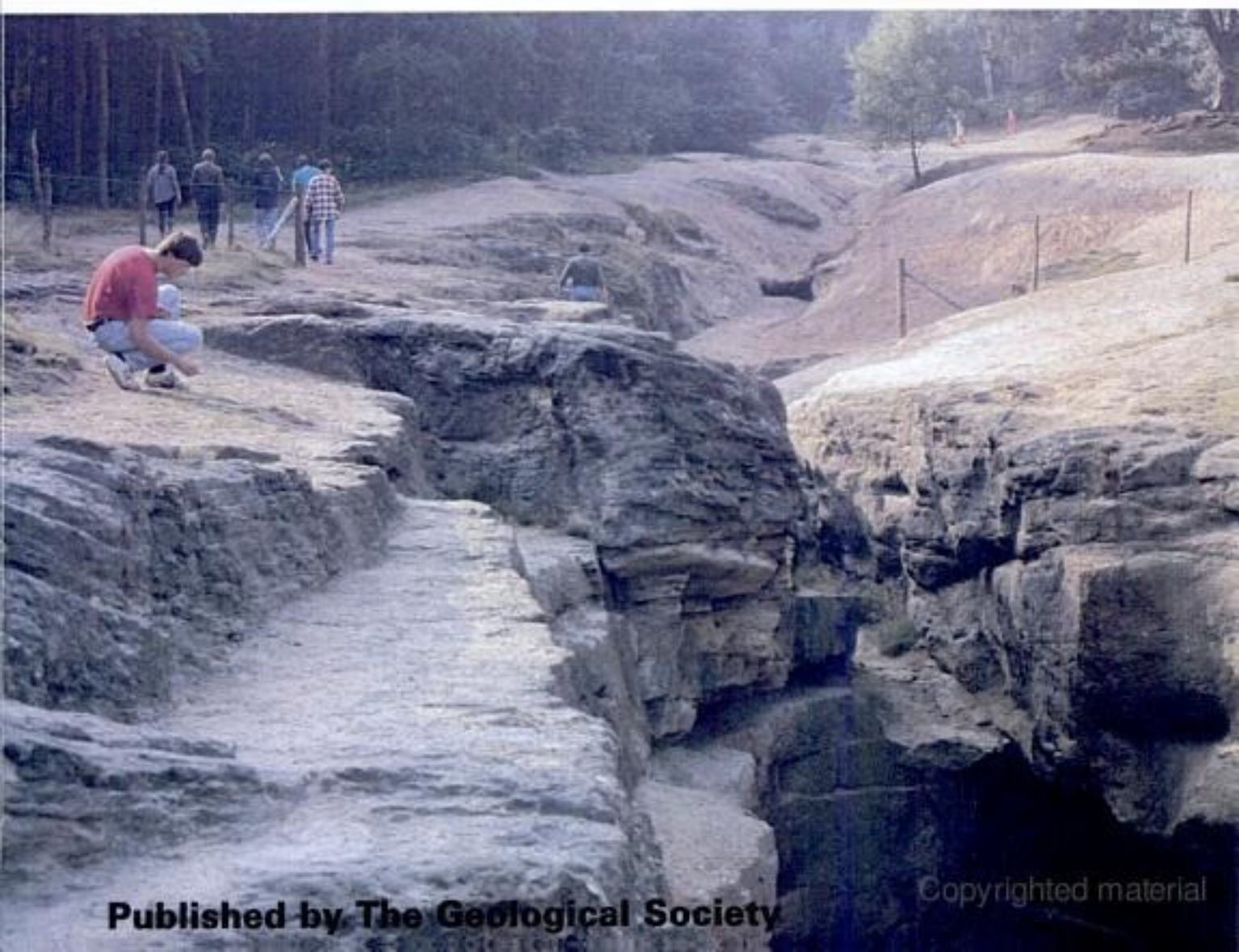
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# The Makapansgat Australopithecine site from a speleological perspective

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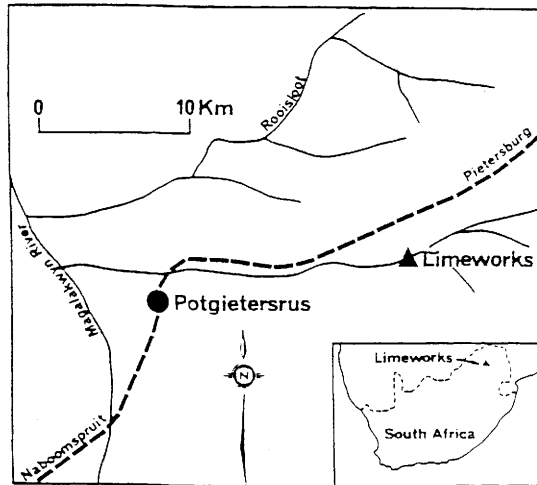
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**Abstract:** Remains of *Australopithecus africanus* from the Limeworks Cave, Makapansgat, South Africa, are believed to belong mainly to a metre-thick, bone-rich, speleothem layer. The flowstone is one stratum among a sequence of speleothems, muds, silts, sands and fine and coarse breccias, the study of which has evoked some disagreement. The limeworkers' excavations revealed some stratigraphic relationships but they have obscured others. Partly because of this, controversy surrounds the supposition about whether there are separated depositional basins within the overall site and, if so, whether strata can be securely correlated. This is important because a reconstruction of an overall stratigraphic sequence was used as a basis for a magnetostratigraphic reversal record and by which the site has been tentatively dated. There is qualification and disagreement about the origin of the various flowstones and the actual depositional environment of the muds and silts. Evidence is presented which rules out some previous interpretations. From the point of view of the Australopithecine fossils themselves, it can be said that the calcite matrix in which they were provenanced was a low-energy environment and that the dense bone accumulation of this layer almost certainly did not arise by the action of floods, as previously supposed. The most likely main cause of the dense accumulation was hyena denning activity. It is clear that further work is needed to see how a reliable overall sequence can be established and that closer sampling is required for magnetostratigraphy.

The Limeworks Cave in the Makapansgat Valley, Transvaal, South Africa (Fig. 1) is well known for its remains of *Australopithecus africanus* from which there are about 30 specimens, the first finds appearing in 1947 (Mason 1988). Despite more than 50 years of research, neither the finds nor the deposits from which they came have been firmly dated and there is no complete consensus on the origins of the deposits or on whether a complete stratigraphic sequence can be reconstructed.

Based on faunal evidence, the Australopithecine deposit, a kind of bone breccia set in grey-white flowstone, is thought to be no younger than 2.5 Ma and as old as 3 Ma (Vrba 1982). This grey to white speleothem is too old for U-Series dating which, by mass-spectrometry, has an upper limit of about 500 ka. The electron spin resonance (ESR) method has not yet been applied to date the enamel of teeth from the site; ESR studies at Sterkfontein have only been partially successful (Schwarcz *et al.* 1994). Recently, U-Pb methods have been developed to date geologically young



**Fig. 1.** Location map of the Limeworks Cave, Makapansgat Valley, Transvaal (Northern Province, South Africa (after Maguire *et al.* 1980).

rocks (Getty & DePaolo 1995) and it has been used successfully to date speleothems, having high uranium content, as young as 250 ka (R. Cliff, pers. comm. 1998). However, a suite of speleothem pilot samples from the Limeworks Cave showed that uranium content is generally low ( $<0.5$  ppm) and the common lead was comparable to the radiogenic lead (work in progress and details to be reported elsewhere).

Perhaps the most promising method to date the site is to compare the reversal magnetostratigraphy of the various layers with the Global Magnetostratigraphic Timescale, which was attempted by McFadden *et al.* (1979). The potential advantage of this method, bearing in mind the current interest in changes in palaeoclimate linked to changes in palaeofauna (Vrba 1996) is that it can potentially provide ages for the whole sequence. The composite section, from the earliest speleothem to the latest breccia, could be placed somewhere between 3.32 Ma and 2.43 Ma. There are problems, however, with the ages so estimated. Firstly, D. Jones & A. Brock (pers. comm.) believe that the sampling density for palaeomagnetism within each subsection was low, which implies that reversal boundaries might have been misplaced. Secondly, sampling was carried out on widely separated subsections, and as Turner (1980), Maguire (1985) and Maguire *et al.* (1985) have noted, it is not clear that a complete composite section was reconstructed reliably. The latter authors believed that there were four depositional basins within the site, and palynological analysis by Cadman & Rayner (1989) and Zavada & Cadman (1993) showed that the deposition between basins was not uniform or synchronous. Thus it is not known if there is an absence of hiatuses or if similar beds are also time-equivalents, as the composite reconstruction for magnetostratigraphy assumes. Lastly, the upper part of the sequence consists of breccias. As McFadden *et al.* (1979) recognized, the interpretation of the palaeomagnetic record of samples taken from this kind of deposit has its own special problems (see later) and, because of the indeterminate palaeomagnetic directions, the upper part of the breccia was essentially unplaced.

In many places, the deposits show rapid lateral changes on a scale of tens of metres or less. A full assessment of these changes, showing the effect they will have on an overall stratigraphic sequence and upon any overall magnetostratigraphy, can only be made by surveying and correlating vertical sections at close intervals. The extant survey work has included long cross sections of broad stratigraphy, but not vertical sections on individual faces. In preparation for further sectional surveying, palaeomagnetic and radiometric work, and to contribute further to the discussion on stratigraphy, we present a number of observations about the mode of speleothem deposition and early sedimentation at the Limeworks site and also include some observations about speleogenesis at Makapansgat. In the tradition of Brain (1958), but differing from him in a number of details, our observations and interpretations are guided by observations from studies of other caves.

### **The Limeworks Cave and its broad stratigraphy**

The cave, formed in Precambrian dolomite of the Transvaal Supergroup, was initially worked for its thick speleothem flowstone by limeworkers from about 1908 to 1936. (In the literature, the flowstone at Makapansgat is often referred to as travertine, meaning cave travertine as opposed to hot-spring travertine.) In order to get at the flowstone, the workers had to blast and remove consolidated and unconsolidated breccia; bones are found in clastic sediments, breccias and in all but the earliest speleothem. There do not appear to be any extant mining records which would indicate the original extent of the deposits but there are still remnants of deposits in some areas or, in the case of some flowstones, traces of them left by negative contact surfaces. Broad stratigraphic sequences have been constructed by Wells & Cooke (1956), by Brain (1958) and by Partridge (1979) and they are in rough agreement. The palaeomagnetic sampling followed Partridge's (1979) reconstructed sequence. Those bone remains containing *Australopithecus africanus* were mostly recovered from the limeworker's dumps, rather than *in situ*, and were nearly all assigned to a later grey flowstone called Member 3, in the notation of Partridge (1979). The outline plan of the cave with the limeworkers' quarries and access cuttings is shown in Fig. 2 and the corresponding composite section is shown in Fig. 3. Massive eroded stalagmitic columns above the Cone mouth, on the surface, indicate that the original roof of the cavern was tens of metres above the present surface.

Between the Main Quarry and the Exit Quarry is a 15–20 m thick cemented breccia essentially separating the two excavated halves of the site. The Entrance Quarry, to the west, leads to the Main Quarry which, on the west side, contains the Classic Section. This, in turn contains, unambiguously, deposits now referred to as Members 1, 2 and 3. To the south and between the Main Quarry and the East Quarry is the Cone, a pile of breccia that has resulted from collapse by undermining. The corollary of this is an inverted funnel mouth to daylight, containing speleothem and about 10 m of breccia and stratified red sediment. Around the Cone mouth, the clastic deposits vary laterally, being free of large clasts adjacent to the back wall, and there are non-cemented sections to the east. Behind the Cone there are short cave passages and alcoves containing early phases of speleothem and another entrance to the southwest. The passages open to the east into the Exit Quarry and an exit cutting, to the side and under which is Horse Mandible Cave. The Exit Quarry contains a short

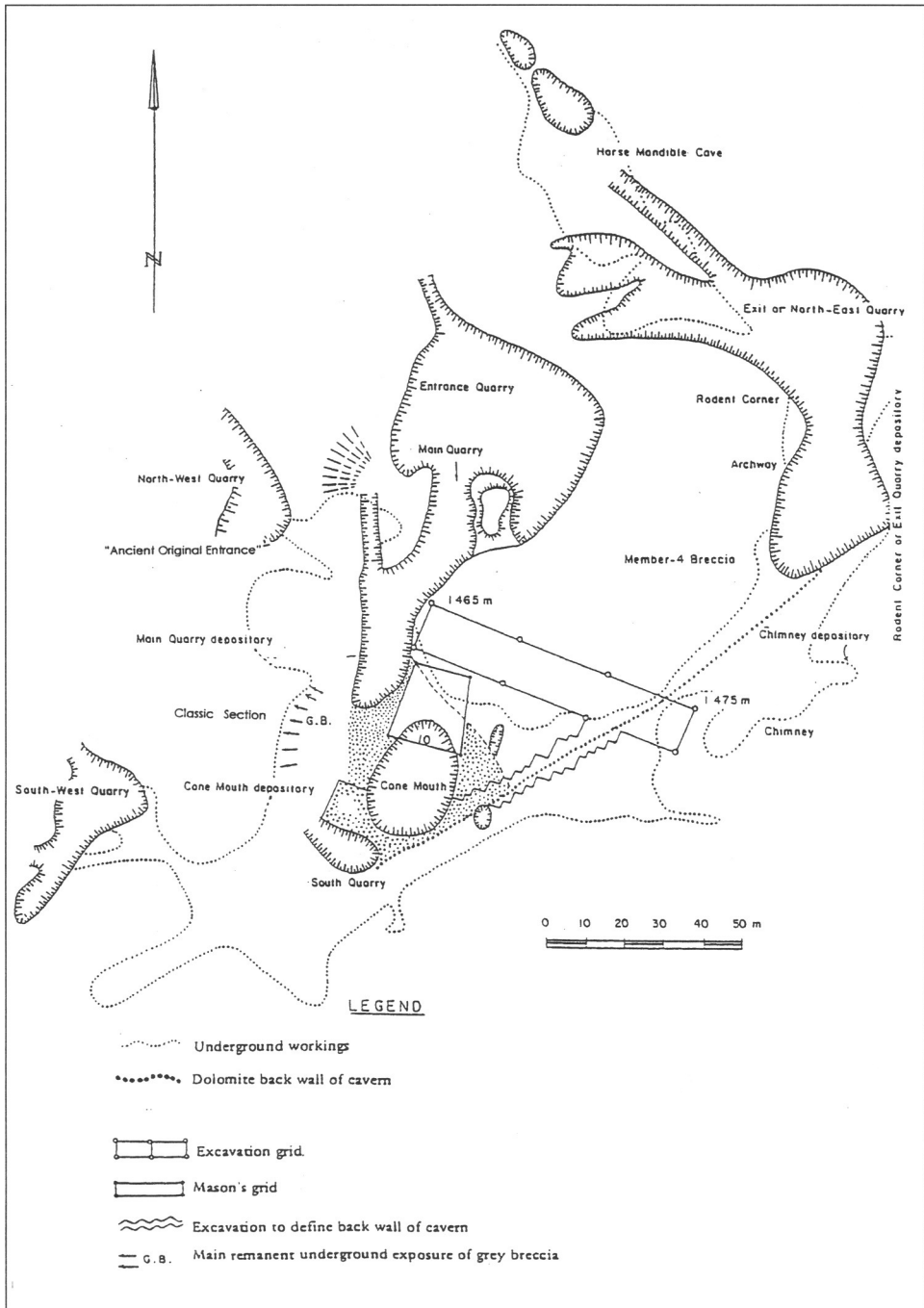
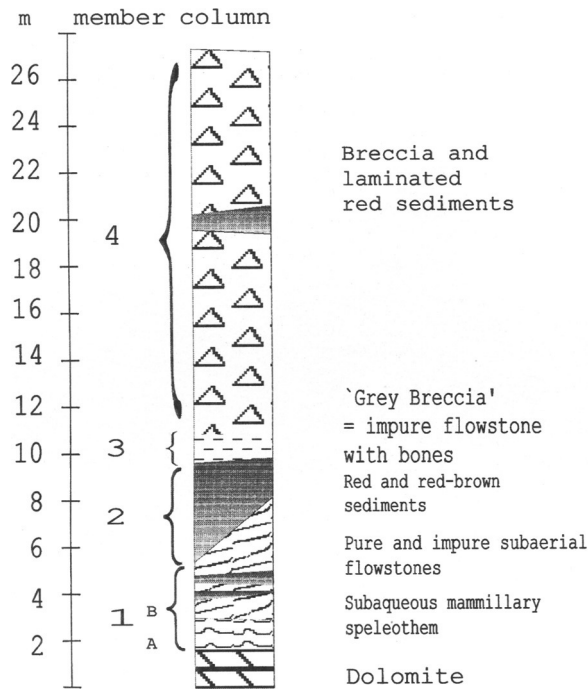


Fig. 2. The Limeworks quarries and underground workings (after Maguire *et al.* 1980).



**Fig. 3.** Composite section of the Limeworks Cave stratigraphy (adapted from Partridge 1979), with subdivision of member 1 into Member 1A and Member 1B. Member 4 includes former Member 5.

tunnel above which is a layer of cemented sediment containing many rodent bones. This area is called 'Rodent Corner' (Fig. 4).

### Description of Deposits

#### *Member 1 (A and B)*

The first major depositional phase, Member 1, is massive stalagmite. Within this member there are two quite distinctive phases, here designated A and B.

The stalagmitic concretions which coat the floor, walls and roofs are unusual mammillary forms. These bulbous concretions protrude in various directions, mostly up and down, but there are no corresponding stalactite-stalagmite pairs as would be the case for normal subaerial, gravity-dominated, deposition. Where the miners have smashed them, they show even deposition over the various undulations (Fig. 5). This is member 1A and, in its earliest phase, exposures in recesses inside the Exit Quarry cave show radiating aragonitic cores with later calcite layering.

In several of the recesses 1A is the end of deposition. There is no other layer apart from a thin coating of dust.

At the base of the Classic Section, a 7 m long exposure shows red-brown staining within the mammillary speleothem, which implies an input of muddy water into the local pool (Fig. 6).



**Fig. 4.** Looking out from the Exit Quarry to Rodent Corner. The wall to the left consists of collapsed roof slabs and breccia with flowstone which once rested against massive speleothem, leaving a gap. The massive speleothem has been mined out. Behind and above these slabs is Member 4 breccia. The tunnel itself was mined through the rhythmites.

*Origins of Member 1A.* It is known that mammillary speleothems form subaqueously (Hill & Forti 1986). Evidently, at the Limeworks Cave, they formed under, and close to, water surfaces from which  $\text{CO}_2$  was allowed to outgas to the cave atmosphere. This caused the water to become saturated with respect to aragonite and calcite, which thereby precipitated under water onto available solid surfaces. It is very likely that, by this time, the actual cave forming streams were no longer extant and that these pools owed their existence to more saturated percolation water from the overlying surface. In all likelihood it would have been the same water that formed the massive speleothem formations and Member 1A and 1B may have been, in part, contemporaneous. The outgassing of  $\text{CO}_2$  from the pools may have been accelerated by the proximal development, to the northwest, of surface collapse and regression. At any rate, an entrance near the Main Quarry is suggested by the red-brown staining within the mammillary forms under the Classic Section. It may well be that, here, regressing collapse was close enough for clastic sediment to enter the underground pools for the first time.

*Member 1B.* This constitutes the bulk of the mined speleothem from the site and probably represented most of the deposition within the interior of the cavern before it became unroofed. Layers of 1B are seen to slope steeply at first and then to lie subhorizontally in and under the Classic section especially around the excavated cavern toward the entrance labelled the 'Ancient Original Entrance'. Undercuts of stalagmitic bosses are seen in the roof. 1B is a light buff to white calcite with thickening



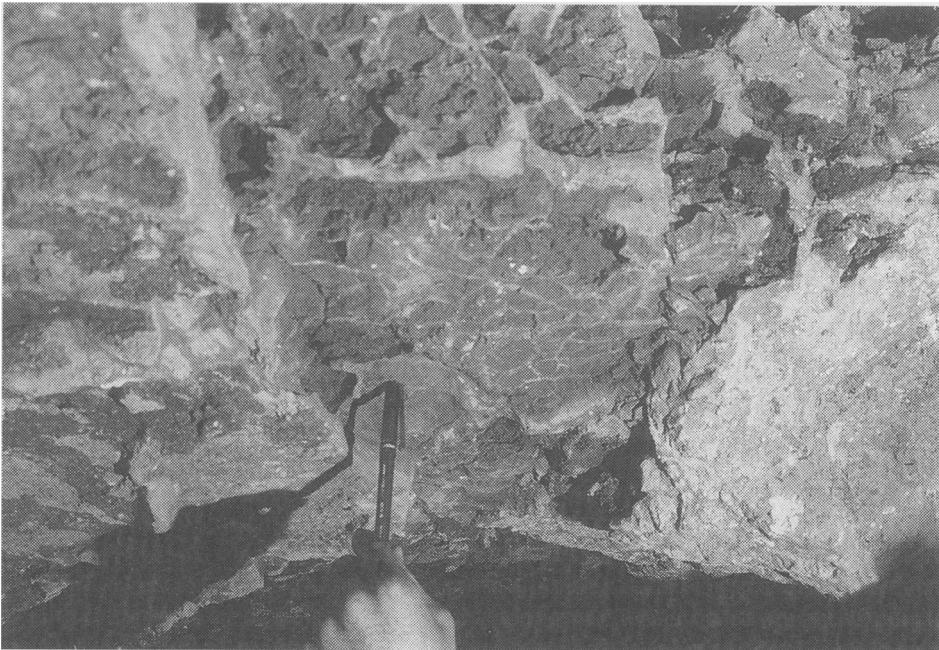
**Fig. 5.** Mammillary speleothems (Member 1A) from the underground workings, viewed from below looking upwards. These forms are about 200–300 mm in diameter.

intercalated series of layers of brown and red-brown sediment. Occasionally the calcite is coloured by this fine sediment. In the roof, within a few metres of the ‘Ancient Original Entrance’, both precipitated and clastic layering is horizontal, and there are several generations of negatives of mud cracks, with varying sizes of mud crack polygons (Fig. 7).

*The formation of 1B in the Classic Area.* The presence of microgours (small ~10 mm rimstone pools), collapsed layers of calcite, and sheet flows that thicken toward the quarry, demonstrate that 1B was formed subaerially from major feed sources near the quarry. As in other limestone caves, these stalagmitic flowtones were supplied by carbonate rich feedwater from fissures in the former roof. The fact that there are thickening intercalations of layers of fine clastic sediment suggests that an entrance was also opening up in the quarry area at this time by progressive roof collapse.



**Fig. 6.** Mammillary speleothem of 1A, with staining between layers, overlain by 1B, beneath the Classic Section.



**Fig. 7.** Mud-crack polygons in several layers, near the top of Member 1B, in the 'Ancient Original Entrance'.

According to Partridge (1975) a large stalagmitic boss occupied the quarry area, before it was removed by the limeworkers, and it is the lower sloping 1B flows of this which are still extant in the quarry area out to the 'Ancient Original Entrance'.

*Member 1A and B in the East Section.* In the east section there are two 2.5–3 m high pillars of calcite left by the miners as supports for Member 2. The base of the outer pillar sits on the dolomite. Great quantities of both 1A and 1B were removed from this area by the miners. The sequence is: 1A, showing aragonite and calcite mammillary forms, up to about 1m or more in thickness, followed by up to several metres of 1B which becomes increasingly contaminated with fine sediment. Above the second pillar, another contributor to impurities in the calcite is a 1 m thick layer of blue to blue-white collophane, most of it crumbly. Evidently this area acted as a bat roost for a while (Hill & Forti 1986; Partridge 1975). Back toward the centre of the cavern these 1B deposits give way to the breccia of the middle section.

*The formation of 1B in the East Section.* As in the Classic Section, 1B stalagmite was deposited into some kind of basin in such a way that whatever the original depositional surface, the final surface was subhorizontal near the cavern walls. Deposition ceased around the margins of the cavities so these lower recesses tend to have only 1A forms.

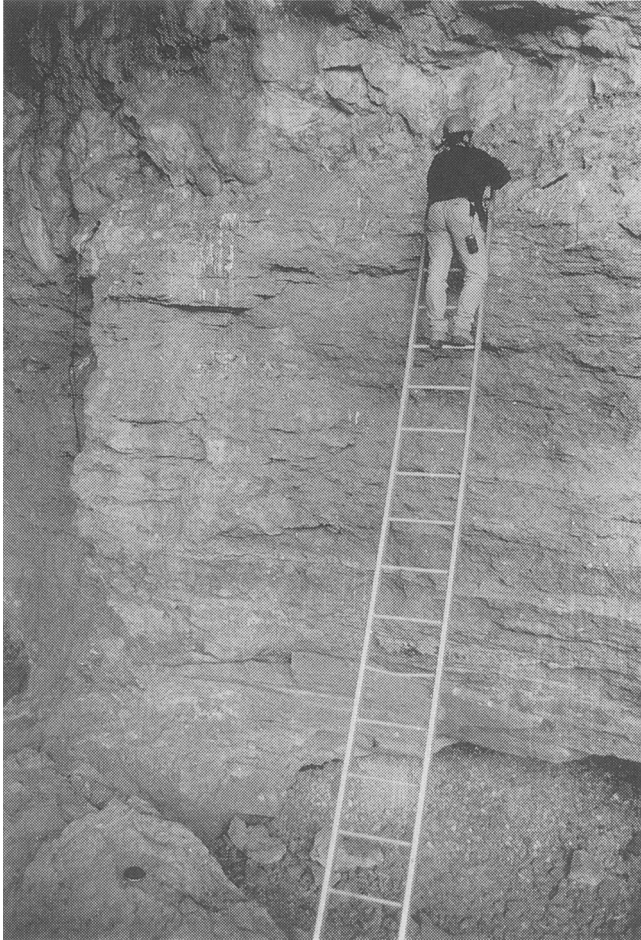
The extensive excavations of the miners and the negatives of flowstone layering, left as an imprint on the breccias, suggest that massive flowstone existed in a roughly horseshoe-shaped arc stretching from the Entrance to the Exit Quarries. In places this massive flowstone was in contact with the wall and was cemented to it. This formed a barrier beyond which sediment could not pass. One notable location is under the roof of the Main Quarry and it accounts for the southern limit of the Classic Section.

## *Member 2*

*Member 2 in the Classic Section.* The fine sediments of Member 2 begin to dominate over deposition of Member 1B flowstone layers and, depending on the exact location, this occurs over tens of centimetres to metres. Ten to twenty metres further away from the entrance, toward the interior of the cave, the sediment was deposited horizontally against Member 1B flowstone where the latter was deposited vertically. At that locality, Member 2 consists of almost 5 metres of thinly deposited layers of purple, red-brown and red-yellow clays and silts with occasional thin partings of calcite (Partridge 1979). It contains fragments of bone and broken speleothems.

*Origin of Member 2 in the Classic Section* (Fig. 8). The sediment is colluvium derived from the surface and was washed in through an entrance that was probably caused by continuing retreat of the surface. Rayner *et al.* (1993) supposed that the sediments were laid down in standing water. It is not necessary to invoke a water-table or standing water to explain either the sediments or their textures. From the presence of the mud crack polygons and thin calcite partings, the simpler explanation is that pools caused by rain events simply dried up.

*Member 2 in the Exit Quarry.* In the area of the columns, clastic impurities occur within the calcites at intervals of tens of centimetres. These are overlain in part by



**Fig. 8.** Member 2 in the Classic Section. The ladder is resting on dolomite bedrock (seen to the left of the ladder); at the base is Member 1A with a vertical remnant of 1B attached to the sediments. The person is at the level of Member 3 and above that is the dolomite cave roof. The region between the deposits and the camera position is inferred to be mined speleothem, Member 1B.

about 2 m of Member 2 red sediments. In the roof, the calcites give way to indurated pinkish clastic sediments and finally, the breccias. This is approximately the same sequence as in the Classic Section though without Member 3. The roof is actually excavated breccia in the northwest and dolomite in the east. Behind and below the columns, there are two recesses; one with no red sediments and one packed with them. Evidently the speleothem barrier to flood-lain clastics was incomplete for the latter.

### *Member 3*

From the Limeworks dumps, *Australopithecus* is mainly represented in Member 3. This is a 1 m thick grey to white flowstone with a dense accumulation of bones and

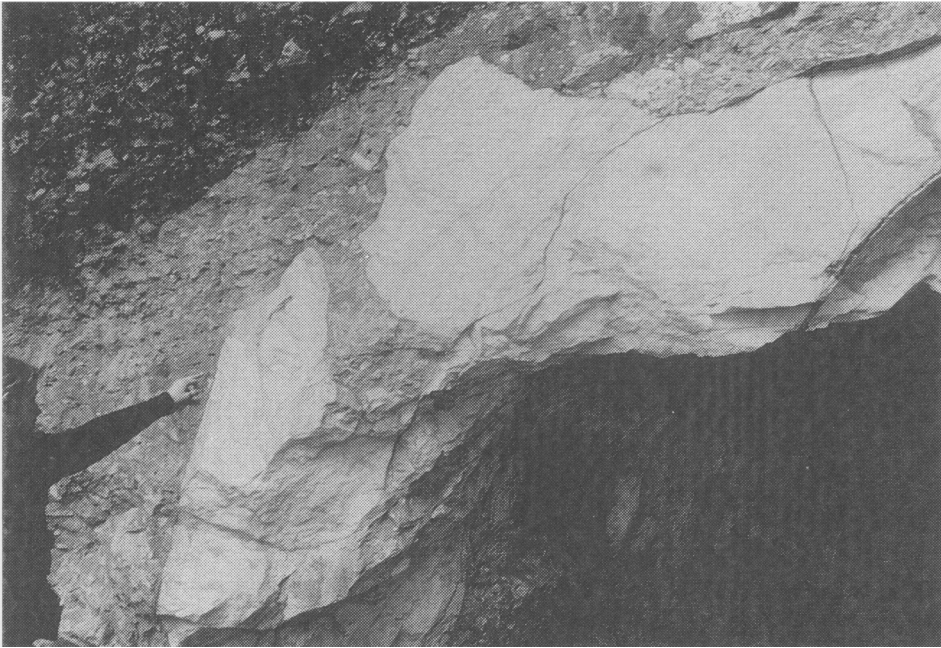
it lies directly on top of Member 2 in the Classic Section (Fig. 8). Member 3 is again visible in the overhanging dolomite roof in another exposure about 10–15 metres further in, among broken stalactites, and where long bones are visible. It is traceable against the dipping dolomite roof to about 1/4 way round the cone to the southwest. There is a 1 m thick stalagmitic deposit containing large bones on the underside of a bulge at the back of the Cone but it appears to lie stratigraphically below the clastic sediments. Member 3 is apparently absent from the Cone round to the Exit Quarry.

In the Classic Section, Member 3 was deposited outside the arc of massive speleothem. According to McFadden *et al.* (1979), the Member 2–Member 3 contact is unconformable, but conformable according to Maguire *et al.* (1985). Member 3 shows sublayers which alternate with vertical stalagmitic wall draperies, as judged by abutment relationships.

The former extent of the whole layer in the area between the Classic Section to the Cone, before the limeworkers undermined and removed it, is unknown, but the existing remnants represent an area of very dense bone accumulation and concentration. From the distinctive damage to bone fragments, Maguire *et al.* (1980) concluded that the bones derive largely from hyena activity and, judging by the sloping disposition of all the deposits in this area, it is very likely that the bones may have rolled into the recesses from dens nearby and higher up. Alternatively, since the layer also contains broken speleothems and sand grains, flowing water has also been invoked as an agent to concentrate the bones against the wall and roof (Brain 1958; Partridge 1979; Maguire *et al.* 1980). This is not easy to reconcile against the observation that the enclosing matrix of the grey breccia throughout is calcitic, consisting of thin (a few mm to several cm) layers of flowstone, which is a low-energy water deposit. In hand sample, the thin calcite layers are separated by air pockets showing that some layers formed as thin rafts on the tops of small gour pools. This kind of formation is common in many caves and is always formed by slow flowing carbonate-rich water. Thus, in comparison with such features in other caves, it is more likely that this area was periodically, perhaps seasonally, wetted, as water seeped down the walls and along the horizontal substrate of Member 2. The precipitation of calcite would form horizontal layers within the bones. Toward the entrance, the uppermost layers of Member 2 and Member 3 abut against vertical stalagmitic flows and wall pillars (half-pillars) which are occasionally seen to be continuous with the horizontal layering, and several generations are represented. Partridge (1979) tended to discount hyena activity as an agent for concentrating the bone so closely against the roof, preferring activity by floods. However, near the Cone, the massive speleothem columns would have provided a rapid change in gradient down which bones might have rolled to lie finally underneath the roof.

#### *Member 4*

*The breccias.* The miners' dumps show that bone remains also came from the lower breccias and *Australopithecus* is represented. The breccias, originally subdivided by Partridge (1979) into members 4 and 5, are now all assigned to member 4 (Partridge, pers. comm.). The breccias are coarse pink to red, containing small to large clasts of dolomite and detached flowstone. On the east side of the Cone mouth, the clasts are rounded cobbles while, on the west side and toward the top, the sequence consists of

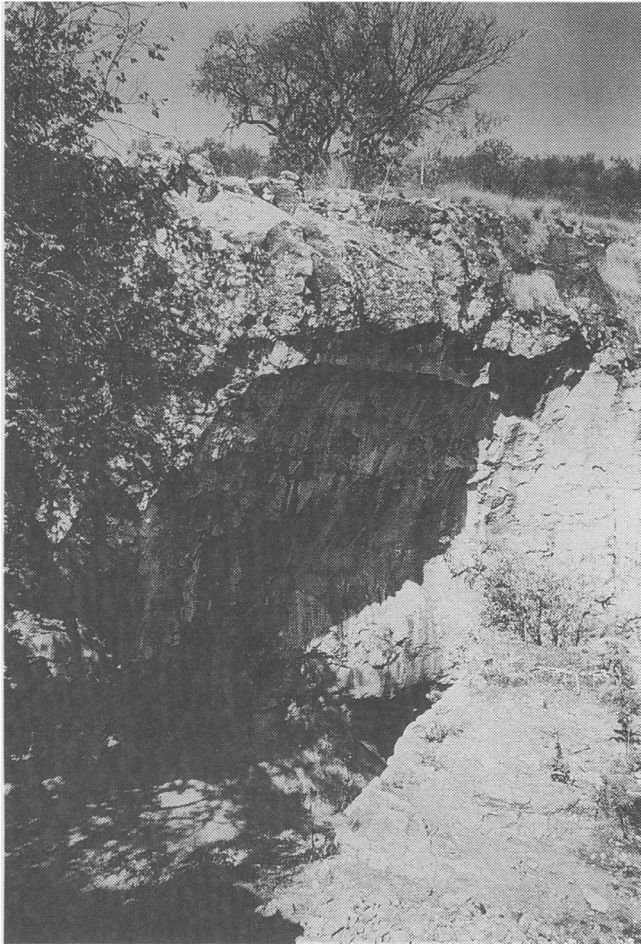


**Fig. 9.** The lower west side of the Cone mouth and eroded parts of Member 1B, the underside of which has been mined out. Member 4 breccia lies above.

both indurated and uncemented stratified clast-free red sediments. Thus the deposits vary laterally from breccias to clast-free equivalents. The clast-free zones imply deposition under a roof. Parts of these layers are cemented by carbonate whereas, a few metres further round, the sediments are unconsolidated. Around the Limeworks site, tree roots have the effect of decalcifying indurated breccia but the effect is restricted to the area of the roots; these are referred to locally as 'mekondos'. In the Cone mouth, however, the unconsolidated strata were probably never cemented. As yet it is not known what the difference the cementation makes to a palaeomagnetic record; most of the samples of McFadden *et al.* (1979) have been taken from cemented sediments.

In the Cone mouth, separated blocks of massive flowstone in the lower part of the breccia exhibit truncated growth layering, indicating that they were partially dissolved before being enclosed in the breccia (Fig. 9). This occurrence was also noted by Maguire *et al.* (1985).

The whole of the area between the two quarries consists of breccia. In the Entrance Quarry, the breccia presents 12 m or more of a negative impression of the former flowstones against which it abutted, and the breccia rests on dolomite. A small section of breccia, referred to as the Partridge Block, can also be found to the west of the Main Quarry between it and the Entrance Quarry. In one or two places some of the subvertical flowstone sheets are still visible (Fig. 10). The ground between the Entrance Quarry to the 'Ancient Original Entrance' is a dolomite 'bridge' which, on the surface, steps down to breccia overlying flowstones and clastics of Members 1 and 2. Apart from this occurrence, most of the breccia was deposited inside the arc of the massive speleothem deposits.



**Fig. 10.** The East Quarry wall showing the negative impression of the flowstone on the breccia, Member 4. The clasts in the breccia can clearly be seen above one extant flowstone layer. The space between the breccia and the camera position was probably occupied by massive flowstone.

*Member 4 at Rodent Corner.* Partway along the Exit Quarry, in an open area known as Rodent Corner, is a short tunnel of about 2 m in height (Fig. 4) which has been created by mining. Partridge (1979) ascribed its cement-indurated red muds and sands to Member 4 and, as such, it was sampled for palaeomagnetism as an aid to completing the magnetostratigraphic sequence. The sediments containing rodent bones are situated above the rhythmites and are probably witness to owl roosts. The rhythmites were later studied by Turner (1980) who believed that the 2 m of cemented sands, silts and clays was an entity separate from the Classic Section. He found that the sequence was made up of about 45 cycles, each about 30–40 mm thick, of coarse sands, fining upwards to sands with mudcracked surfaces. About two-thirds of the way up the sequence, the rhythmites are interrupted by two thin flowstone layers (he refers to this as ‘limestone’, but this is incorrect), the upper one containing cave pearls, and a layer of coarse sand with granular conglomerate. The different palaeomagnetic directions of sequential

rhythmites suggested, somewhat surprisingly, that they were not annual. From Turner's figures, each cycle appears to represent about a thousand years. The significance of this apparently long periodicity is not known.

The flowstone layers and owl roosts indicate that there was still a roof extant at this time. This is also borne out by the presence of cave pearls as these are known to form only by the drip-water agitation of seed-grains (e.g. of sand particles) and by their concentric growth in pools (e.g. Ford & Williams 1989). It can be clearly seen, in the Rodent Corner arch, that the spaces between calcitic roof layers and stalactites are filled with the fine, red, sandy muds. Preceding both of these, apparently, is breccia Member 4 and it seems likely that the rhythmites were winnowed out of the breccia through the large collapsed blocks seen at the edge of M4 in the Exit Quarry (behind the person in the figure). Thus if the rhythmites are the result of winnowing of the eastern extent of M4, it is uncertain how they fit in the stratigraphy with respect to M4 in the Main Quarry and with sediments in the Classic Section.

### **The palaeomagnetism of breccias**

Unpublished palaeomagnetic work carried out on borecores from the breccias at the Sterkfontein Australopithecine site by V. Schmidt show that sequentially cored samples gave near-random orientations mainly due to the fact that samples contained rolled detrital titanomagnetite grains. They have not yielded any meaningful sequence for magnetostratigraphic work. Generally, the problems for the palaeomagnetism of breccias are that (i) most breccias consist of a variety of randomly oriented particles and clasts, each one having its own magnetic signal, (ii) the iron-rich matrix gives a signal which may be related to mechanical effects, such as fine-particle rolling, rather than to the influence of the ambient magnetic field and (iii) if later, iron-rich, cement is involved in diagenesis, then there may be a post-depositional signal which corresponds to a time after deposition of the breccia. The question of whether meaningful signals can be recovered from breccias, such as those at the Limeworks Cave, can only be answered by more exhaustive studies that aim to eliminate or minimize the above problems. The work of McFadden *et al.* (1979) and our own preliminary work shows that magnetically cleaned palaeomagnetic directions can be obtained from these deposits. As is usual (Latham *et al.* 1989), the purer speleothem samples are magnetically weaker

### **Discussion**

Massive subaerial speleothem is forming in many tropical caves today. The main factors are high temperature and humidity, and fast speleothem deposition is the norm (e.g. Ford & Williams 1989). Therefore, does the massive speleothem in the Limeworks Cave bear witness to a much wetter climate at the time? Although the question of palaeoclimate and palaeoecology has preoccupied many researchers working at Makapansgat, we draw attention to the possibility of inferring a more humid earlier climate by the existence of such huge quantities of subaerial flowstone.

On the surface above the cave there are areas of dolomite stripped of vegetation for research purposes (Fig. 2). The area shows numerous solution holes and hollows, up to a few metres deep, occupied either by hardened red breccia or by shrubs and trees with soil. Thus, it is easy to see how seepage water used this kind of pathway to form

stalactites and other speleothems below. A comparison of the depths of modern caves in the valley, where there is very little runoff and very little modern speleothem formation, leads one to suppose that the conditions at the time of chemical deposition in the Limeworks Cave would have been more humid. But other corroborative evidence would be needed to convert the inference to a firmer conclusion. For one thing, we do not know reliably the duration of deposition. It may also be the case that significant deposition of speleothem could not occur until the surface eroded to a point where sufficient seepage could penetrate to the cavern roof.

### **Pools, standing water and water tables**

Examination of the Member 2 clastic sediments has not revealed major flow features such as ripple marks or cross-bedding. This has led a few authors to infer that the deposits from Member 1 to Member 3 were laid down under standing water, which has then been called a water table (Maguire *et al.* 1985) and subsequently labelled as a Plio-Pleistocene water table (Cadman & Rayner 1989; Rayner *et al.* 1993). The presence of mud-cracks does not preclude such a hypothesis if water levels have fluctuated, as happens today in the nearby Peppercorns–Ficus aquifer. Mud cracks can be observed in parts of this cave system, even under a few feet of water, and evidently the level can fluctuate by several metres. The following points, however, argue against the notion of water tables.

(i) In compact limestones and dolomites the phrases ‘aquifer’ and ‘water table’ need to be qualified considerably. Water tables in the classical sense do not exist since these carbonate rocks have very low porosity. Instead, the hydrology of limestones consists of water flowing slowly in linked, totally filled (phreatic) or partially air-filled (vadose) passages. In Southern Africa, Namibia and Zimbabwe, the carbonate rocks often hold water and act like giant storage tanks. (The tourist cave at Chinhoyi, north of Harare, Zimbabwe, with its deep lake, is a good example.) Classically, a porous sandstone will have a water table and its flow will be Darcian; this is not the case for limestones (Ford & Williams 1989).

(ii) Member 1B flowstones are undoubtedly subaerial, and Member 2 clastic sediments lie on top of them and abut against them. Though not impossible, it would be unusual if standing water, for Member 2, returned to alter conditions that had been water-free, for Member 1B.

(iii) Since there are mud-cracks in Member 1B and Member 2, with interbedded subaerial flowstone, it is better to think of the clastic sedimentation as having occurred in ephemeral pools. The runoff formed the pools and the pools then dried out between rainfall events. Flowstones formed on top of the clastics. A similar situation occurs today in Horse Mandible Cave where the disturbed loose red sediments are being mobilized by ephemeral rivulets coming from a mined opening nearby. The deposits dry out rapidly because there is a good current of air.

Thus, for these deposits, the supposed past existence of a water-table could be misleading for the reconstruction of palaeohydrology and of palaeoenvironment.

### **Summary**

After the formation of most of the flowstone and stalagmites, most of the deposition occurred on the inside of the massive speleothem arc as breccias, and the sediments at

Rodent Corner were probably winnowed out from them. In the Main Quarry, deposition also occurred on the outside of the arc between the calcite formations and the 'Ancient Original Entrance' and dolomite walls. Later, when the roof receded further upslope the clastic sediments were entrained as alluvium and colluvium into the Cone area. From one local basin to the next, therefore, contemporaneous, diachronous and sequential deposition can be entertained as possibilities for sedimentary members and sub-members. A retreating entrance for clastic infill forces the possibility of a complex sequence stratigraphy. The grey bone breccia is a spatially limited deposit partway through the overall sequence.

Calcite pilot samples from the exit quarry and from Member 3 in the Classic section carry a weak but measurable, stable, magnetic signal. This supports the findings of McFadden *et al.* (1979) that most of the calcites are accessible to palaeomagnetic analysis for reversal stratigraphy. One core sample from Member 3 shows an intermediate direction (D. Heslop, pers. comm. 1998) and this disagrees with the conjecture of McFadden *et al.* (1979) who reckoned that it might be normal. This again points to the necessity for further palaeomagnetic sampling. The interior Exit Quarry calcite sequence could be used to augment the record since, like Classic Section Member 1B, it overlies 1A without a break. The most promising section appears to be in the south of the Cone where, apart from the possible absence of Member 3, deposition appears to be complete from Member 1 to the top of the breccias. In the Main Quarry, it may be possible to connect the sampling directly from Members 2 and 3 to Member 4 of the 'Partridge Block'. Unfortunately, the overhanging nature of all these exposures means that sampling will be difficult.

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