APPENDIX 1
ABSTRACTS

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PICKERING, R[1,2], Hancox, P. J[2], Berger, L.R[1], Grun, R[3], McCulloch, M[3]. & Mortimer, G[3],
2004, A well dates record of terrestrial climate change and sedimentation for the last 500ka in a South African hominin bearing cave: 32nd Int. Geol. Congress., 2004, Abs. Vol., pg 534

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Gladysvale Cave is one of the more recent cave sites within the Cradle of Humankind World Heritage Site to produce hominin specimens, with the first hominin fossils being found only in 1992. Among the massive and generally poorly stratified breccias of the South African hominin bearing caves, the breccias at Gladysvale are unique in that they are both well stratified and well preserved. The deposits are also well exposed from the blasting of lime miners in the 1920s, and the more recent excavations of the decalcified areas of the deposit. The breccias at Gladysvale Cave can be divided into clastic and chemical sediments, which occur as stratified breccias and laminated flowstones. The flowstone horizons can be used to divide the deposit into Flowstone Bounded Units (FBUs). Previous studies in Australia have shown that these flowstones represent wetter climatic periods, during which cave entrances were restricted, allowing for flowstone development. The clastic sediments conversely represent drier periods, during which sediments and bone were washed into open caves.

Several flowstone horizons from the internal deposits at Gladysvale Cave were dated using Uranium series dating at the Australian National University. These dates suggest that the Gladysvale flowstones are also growing during warm, wet interglacial periods. Therefore the glacial and interglacial climate changes of the last 500ka have played a major role in the control of the nature and rate of sedimentation at Gladysvale Cave.

The clastic sediments, which potentially contain hominin and archaeological remains, are therefore highly episodic in nature and represent snapshots in time. Although Gladysvale Cave does not have a rich hominin or archaeological assemblage, this record of climate change, spanning from 500ka to 10ka, may serve as a climatically forced chronostratigraphic framework for other less well stratified and dated sites, which do record the major advances of human evolution over the last 500ka.

Geoscience Africa, University of the Witwatersrand, Johannesburg, 12 – 16 July, 2004

R PICKERING[1], P.J Hancox[2], J. A Lee-Thorp[3], R Grün[4], M. McCulloch[4], G.E Mortimer[4], L.R Berger[1], 2004, A well dated record of terrestrial climate change and sedimentation for the last 500ka from Gladysvale Cave, South African, *Geoscience Africa Conference, Abstract volume, University of the Witwatersrand, Johannesburg, South Africa*, pg 518

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Gladysvale Cave is one of the more recent cave sites within the Cradle of Humankind World Heritage Site to produce hominin specimens, with the first hominin fossils being found only in 1992. Among the massive and generally poorly stratified breccias of the South African hominin bearing caves, the breccias at Gladysvale are unique in that they are both clearly stratified and well preserved. The deposits were exposed from the blasting of lime miners in the 1920's, and the more recent excavations of the decalcified areas of the deposit. The Gladysvale Cave breccias can be divided into clastic and chemical sediments, which occur as stratified breccias and laminated flowstones. Studies in Australia have shown that these flowstones represent periods with wetter when cave entrances were restricted, allowing for flowstone development, and that flowstone horizons can be used to divide the deposit into various Flowstone Bounded Units (FBUs). By implication, the clastic sediments conversely represent drier periods, during which sediments and bone were washed into open caves.

Several flowstone horizons from the internal deposits at Gladysvale Cave were dated at the Australian National University using Uranium series MC-ICP-MS (Multi-collector Inductively Coupled Plasma Mass Spectrometry). Despite the low uranium levels and problems of detrital contamination, flowstones from throughout the stratigraphy and from the proximal to distal reaches of the deposit, yielded reliable and robust dates. The younger deposits at Gladysvale are both older and younger than previously thought, and cover the period of the Late Mid Pleistocene to Holocene, providing a record of terrestrial climate change and sedimentary response for periods within the last 500ka. The dates suggest that at Gladysvale flowstones grow as the climate moves *out of* interglacial and interstadial periods, when there must have been a water surplus and increased effective precipitation. A break in flowstone growth from approximately 12ka to 7ka corresponds to a break seen in other speleothem records from the Makapansgat Valley, suggesting that although this was a warm time, evaporative conditions prevailed that were not conducive to speleothem growth.

Stable light isotope analysis of the flowstones and intercalated breccias, as well as modern flowstones and cave roof dolomite was undertaken at the University of Cape Town.

The $\delta^{18}O$ values are fairly invariant, with little variation between flowstone and breccia units. The $\delta^{13}C$ values show more variation between the units, with breccias being on the whole more enriched, suggesting a climate conducive to C4 grasses. The flowstone layers have more depleted $\delta^{13}C$ values, suggesting a climate more suited to C3 vegetation. The $\delta^{13}C$ values need to be interpreted with caution, as the source of the $\delta^{13}C$ signal recorded in the breccias and flowstones is slightly offset. The breccia signal is likely a more direct reflection of the vegetation outside the cave as the breccias consist of remobilised soil washed into the cave, while the flowstones grow from water passing through this soil horizon and dolomite roof and into the cave.

The combined U-series dates and stable light isotope values point to a strong climatic control on the nature and rate of sedimentation at Gladysvale Cave. We propose that the flowstone layers grew during damper (and still warm) periods following interglacials and interstadials. The nature of the flowstones suggests that the cave was completely closed during some of these periods, producing clean flowstones, and more open during others, causing detrital contamination of flowstones. Conversely, the clastic sediments were washed into the cave during periods that were cooler and more arid. These breccias are therefore highly episodic in nature and represent snapshots in time. The record of climate change control on the Gladysvale sediments may serve as a climatically forced chronostratigraphic framework for other less well stratified and dated sites, which do record the major advances of human evolution over the last 500ka.

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P.J.Hancox[1], D Brandt[1], G.Kendall[1], T S McCarthy[1], R.PICKERNG[1,] S Tooth[2] and S.Woodborne[3], 2004, The Maandagshoek alluvial fan system and evidence for widespread periods of alleviation and stasis across the interior of South Africa during the past 150 000 years

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Numerous alluvial fans, coalesced fans and alluvial aprons cover the mountain foothills in the semi-arid Steelport region in Mpumalanga and the Northern Province, South Africa. The fan at Maandagshoek, approximately 20km northwest of the town of Steelport, is surrounded by hills with a local relief of up to 300m, which are composed predominantly of pyroxenites, norites and associated chromitites of the Upper Critical Zone of the Bushveld Complex. The Maandagshoek fan has been intensively researched as part of a broader project on the response of alluvial systems to Plio-Pleistocene base level and climatic change. Three main ephemeral feeder channels drain the catchment, and disgorge from the mountain front at the apex of the fan, which is 1km at its widest point and 3.3km in length from the apex to the toe. Across this distance the fan surface falls some 140m in elevation, and changes in gradient from $\pm 5^{o}$ at the apex to $\pm 2^{o}$ at the toe. In the proximal-medial reaches the fill is some 18-20m thick, thinning distally to less than 4m at the toe. The local base level for the fan is the deeply incised, seasonal Moopetsi River, which drains southeast to the Steelport River, itself a tributary of the Olifants River. Donga (gully) erosion of the fan has exposed parts of its internal stratigraphic architecture showing the fan fill to be characterised by a number of stacked, fining-upward cyclic successions.

Within the various successions a number of units have been delineated based on their colour, bulk chemistry (XRF), mineralogical properties (optical studies and XRD on clays), total organic carbon content and granulometric properties. Each of these cycles begins with medium to coarse-grained horizontally and cross-stratified pebbly sand and grades upwards into sandy clay and clay. These fining-upward cycles represent periods of alluvial sedimentation that are overprinted by pedogenic modification, which forms the upper clayey units.

The absence of active range-bounding faults or obvious evidence of neotectonic activity in the area argues against a tectonic control on these cycles. The dynamics of this fan (and others in the region) are therefore rather interpreted in terms of landscape response to cyclic

changes in climate and base level, and as such the fan sediments are recorders of palaeoclimatic change.

Dating of the Maandagshoek fan sediments has proved problematic due to the lack of quartz grains and the paucity of organic carbon and fossils. Radiocarbon dating has however provided various ages (4220±60, 12280±110 and 22500±290-29800±780BP) for calcretes in correlative fluvial terraces of the Moopetsi River, some 8km southeast of the fan [1]. The terrace sediments have recently been dated by our team, and record periods of alluviation at circa 13.5, 37-41 and 110-125ka.In light of these findings, it is of interest to note that similar aged cycles of sedimentation, followed by stasis, have been documented in other fluvial and cave settings, and correspond to periods of calcrete formation in pans in a number of locations across the interior [2].Dates for periods of alluviation in dryland fluvial settings have also recently been acquired from fossiliferous (Florisian Land Mammal age) sediments along the Modder River, a left bank tributary of the Riet River. The fossil site, informally known as Erfkroon, is situated some 60km west-northwest of Bloemfontein in the western Free State. The included Florisian fauna is dated as between 400-100ka [3]. Efkroon has also been extensively gullied and documents at least five episodes of erosion, alluvial terrace formation, overbank deposition and donga fill. OSL and ESR dating techniques have been successfully applied and preliminary dates cluster at ±180, 110 and 24ka. Periods of formation of pan calcrete in the same region as Erfkroon cluster at between 174-180ka and 24ka and strongly suggest periods of evapotransipative excess at these times. Coupled to the pan calcrete dates, the findings at Erfkroon suggest that dryland fill is more prevalent during arid periods.

Current research (Pickering et al, this volume) on the flowstones and clastic cave sediments at Gladysvale Cave, in the Cradle of Humankind World Heritage Site, also suggest a strong climatic control on the nature and rate of cave sedimentation for the last 200ka. MC-ICP-MS (Multi-collector Inductively Coupled Plasma Mass Spectrometry) U-series dates for several flowstone horizons at Gladysvale; show that warm, wet periods, following interglacials and interstadials, were conducive to flowstone growth. Stable light isotope analysis of $\delta^{13}C$ and $\delta^{18}O$ on the flowstones and intercalated breccias corroborates this finding, and suggest that clastic sediments were washed into the cave during periods that were cooler and more arid, most likely during glacial/stadial periods. However, not all documented glacials/stadials have a sedimentary response within the cave fill and it seems therefore that some threshold needs to be crossed before active sedimentation begins.

The similarity between the timing of stasis (paleosol and flowstone development) and clastic sediment input and calcrete development, in widely separated fan, river, pan and cave settings, suggests a subcontinental control during the past 150 000 years, relating to large scale (glacial-interglacial, stadial-interstadial) climatic fluctuations. Although more absolute dates are required, predictive models may now be generated for periods of sedimentation and stasis in the interior of South Africa that may act as templates within which further research on Late Pleistocene and Holocene sedimentary environments may be undertaken.

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PICKERING, R[1,2], Hancox, P.J.,[2] Lacruz, R[1] & Berger, L.R.,[1] 2003, The Stratigraphy of The Pleistocene cave deposits at Gladysvale Cave (South Africa): A key to understanding climatically controlled cyclic cave fills, *XV Biennial South African Society for Quaternary Research Conference, Johannesburg*, pg 32-33

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The Plio-Pleistocene cave deposits of South Africa have yielded important hominid fossils and have been the focus of much research. However the stratigraphy, sedimentology and chronology of the actual sedimentary strata remain poorly understood. Gladysvale Cave, apart from being an important hominid site, contains a well-stratified cave fill sequence. Using the model of Moriarty *et al* (1999) the stratified sedimentary strata of the Peabody Chamber have been divided into discrete units of clastic material, bounded by flowstone layers. These clastic units are thus termed Flowstone Bounded Units (FBU's). The flowstone layers are thought to represent hiatus periods of no clastic sediment deposition and therefore divide the clastic material into chronostratigraphic units. The sequence of FBU's can be further grouped into three Flowstone Bounded Intervals (FBI's). The Peabody Chamber sequence is a distal fan sequence, and is correlatable to the sequence in the exposed outer chamber. Current research at Gladysvale is focused on the three dimensional sedimentary architecture and chronology of the internal Pleistocene deposits, and an investigation into the link between climate change and sedimentation. Moriarty *et al* (1999) argue that cave sedimentation is climatically controlled, with clastic material accumulating during drier periods and flowstone growing during wetter periods. This model will be tested using oxygen isotopes, as shown by Ayliffe *et al* (1998). The packages of sedimentary material can thus be correlated to wetter or drier periods as indicated by the oxygen isotope profile. This work will provide a more complete understanding of spatial and temporal cave fill processes and controls at Gladysvale Cave, which could eventually allow for a better understanding of the other cave sites within the Cradle of Humankind World Heritage Site, and other Plio-Pleistocene terrestrial sites.

References:

Moriarty, K.C, McCulloch T.M., Wells R.T. & McDowell M.C., 1999, *Palaeogeography, Palaeoclimate, Palaeoecology* 159: 113-143

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PICKERING, R[1], Hancox, P.J.[1] & Berger, R.L.[2], 2002, The Stratigraphy of the Peabody Chamber, Gladysvale Cave: Key to understanding sequence boundaries within cyclic cave fills, *Palaeontological Society of South Africa Biannual Conference Volume*, pg 38

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Gladysvale and the other cave sites in the Cradle of Humankind World Heritage Site have yielded world famous hominin fossils. While these sites are palaeontological superlatives, the sedimentology and stratigraphy of the cave fills, despite the work of several authors, remain poorly understood. This is due to the complex nature of the cave fill sediments (breccias), which are usually accumulate without marked stratification. Gladysvale Cave is unique in this respect as, apart from being an important hominin locality, it contains a well-stratified cave fill sequence. Work for this project has focused on the Peabody Chamber, where the sediments are well-stratified and well exposed. The stratigraphy and sedimentology of this sequence has therefore been intensively studied and shows that the sequence as preserved on the back wall is a distal fan sequence, and that this may be correlatable to the sequence in the exposed outer chamber. This study has also shown the nature of the cave fill to be highly episodic, being composed of numerous cyclic clastic sequences, bounded by flowstones. Using the model of Moriarty *et al* (2000) in which cave deposits form in cyclic sequences, the clastic sediments of the Peabody Chamber have been divided into discrete units, with boundaries marked by the flowstone layers. These flowstone layers are thought to represent hiatus periods of no clastic sediment deposition and can therefore divide the clastic material into chronostratigraphic units. Moriarty *et al* (2000) also suggest that cave sedimentation is linked to changes in climate, with clastic and chemical sequences accumulating in drier and wetter periods respectively. This approach to cave geology, including the relationship between sedimentation and climate change, has great potential for the documentation and modelling of cave fill processes, as well as correlation between Gladysvale and other Plio-Pleistocene cave sites.

Reference:

Moriarty, K.C, T.M. McCulloch, R.T. Wells & M.C. McDowell, 2000, Mid-Pleistocene cave fills, megafaunal remains and climate change at Naracoorte, South Australia: towards a predicative model using U-Th dating of speleothems, *Palaeogeography, Palaeoclimate, Palaeoecology* 159, 113-143

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Hancox, P.J[1], Lacruz, R[2], PICKERING, R[1] & Berger[2], L.R, 2002, The Stratigraphy and Sedimentology of the Plio-Pleistocene Gladysvale Cave site: a key to understanding correlatable sequence boundaries within cave fills, *16th International Sedimentological Congress Abstract Volume*, Rand Afrikaans University, pg. 143

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Gladysvale made headlines in 1992 as the first new Plio-Pleistocene hominid site to be discovered in South Africa in nearly half a century. In the ten years since this discovery, the cave has been extensively excavated and has proved to be unique in that it contains a well stratified cave fill sequence. This is of critical importance as most of the other cave sites in the Cradle of Mankind do not have marked stratification, and individual sequences are notoriously difficult to date or correlate. Apart from being a richly fossiliferous Plio-Pleistocene hominid locality, Gladysvale is therefore also important in that it contains a well-stratified cave fill sequence. Presently, five main episodes of cave fill are known, which, based on the fauna and provisional ESR dates, seem to have occurred from around 2Ma, with major clusters of dates of sediment and bone accumulation at ±1.4-1.2Ma, 800-600ka, and 215ka to present. Preliminary palaeomagnetic results support the ESR dates.

The stratigraphy and sedimentology of the ±1.4-1.2Ma and 800-600ka sequences have been intensively studied and show that the sequence as preserved on the back wall of the upper chamber (the Peabody Chamber) is a distal fan sequence which is correlatable up dip to proximal fan, and cone sediments, exposed in the outer chamber. This is the first time in a South African cave deposit that such proximal to distal changes have been documented. This study has also shown the nature of the cave fill to be highly episodic; being composed of numerous cyclic flowstone bound clastic units (FBU's). Packages of flowstone bound units stack into flowstone bound intervals (FBI's) that are separated from overlying units by thicker accumulations of clean flowstone. The basal terminations of the bedsets of the overlying interval strongly downlap onto the top of the underlying flowstone. At places the tops of individual flowstones may show evidence of dissolution prior to the onset of renewed sedimentation.

It is here postulated that such flowstone bound intervals represent sedimentation in response to changes in climate. In this model the thicker flowstones with little or no sediment contamination, represent periods of above average rainfall, good vegetational cover outside the cave, and a restricted or closed cave entrance. Clastic depositional sequences represent more arid climates, less vegetational cover, and better runoff and sediment supply. The

recognition of FBU's and FBI's in the cave has proved critical to understanding the timing of fill, especially where radically different lithologies are juxtaposed, due to multiple cave openings supplying sediment to the cave floor at the same time. This feature is well documented in the current cave mouth, where steeply easterly dipping pebbly cone breccias interdigitate with, and are onlapped by, fine grained gently northerly dipping distal fan deposits of the middle (800-600ka) sequence. Although lithologically very different due to the proximities of their various point sources, both deposits are bound at their base and top by the same correlatable flowstones. Above the top of the middle sequence, a major change in sedimentary style in the sequence, and marked disconformity, indicates the termination of this period of fan deposition. The overlying sequence, provisionally dated via ESR at 214±37ka, downlaps strongly onto the underlying fan surface, and documents more proximal fan sedimentation, believed to have been sourced from a cave opening, to the northeast of the entrance that supplied the sediment to the lower sequence, following the de-roofing of the outer cave. Based on the provisional ESR dates, this disconformity may represent a substantial period of non-deposition in the upper chamber of the cave. The younger fan sequence is also richly fossiliferous, and may also be subdivided into a number of flowstone units.

As flowstones as old as 500 000 years have recently been dated in Australia using thermal ionization mass spectrometry (TIMS), it is hoped that this technique can be applied to obtain high resolution dating of the flowstones within the younger fan. Coupled to ESR dates of bovid tooth enamel in the intervening clastic units, this would effectively allow for both the fill and the encapsulating flowstones to be dated, allowing accurate estimates of the duration of both fill and flowstone capping events. During this timeframe these could be more effectively tied to previously documented climatic changes for the past 200ka, especially from sites such as the Tswaing crater fill.

Overall this research may also have important implications for other cave fills in the region, as if terriginous and chemical sedimentation is in fact related to changing climate (i.e. externally forced) then sequence boundaries marked by flowstone accumulations in Gladysvale should be correlatable in all the cave sequences in other parts of the Cradle of Humankind.