EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:

https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Reports supporting requests for additional beam time

Reports can be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** Analysis of dental development in fossil hominins from Malapa, a new Plio-Pleistocene site in South Africa.	**Experiment number**: EC 521
Beamline: ID17, ID19	**Date of experiment**: from: 12/2/2010 to: 23/2/2010	**Date of report**:
Shifts: 12 on each	**Local contact(s)**: Dr. Paul Tafforeau	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Prof. Lee Berger

Dr. Paul Tafforeau *

Dr. Kristian Carlson

Dr. Tea Jashashvili

Report:

1. Aim of the proposal

In August 2009, my colleagues and I submitted a proposal to image the skull of a new hominin recently discovered from the site of Malapa in the Cradle of Humankind. At the time, material from the site was still being analyzed and studied. It was clearly Plio-Pleistocene based on associated fauna, but little else was known of its geochronological age. It was unclear upon initial discovery whether the hominin fossils should be attributed to *Australopithecus africanus*, *Homo* (*habilis*), or whether the material belonged to a new taxon. The primary aim of the experiment was to assess an age-at-death for the individual represented by the partial skull, and to assess its developmental pattern. The secondary aim was to digitally extract the delicate cranium from surrounding matrix and restore it for further study.

2. Current status of the project

In February 2010, we successfully scanned craniodental material that was attributed to the juvenile male (MH 1). Subsquently, additional material has been recovered and attributed to this individual, while some material previously attributed to this individual is no longer considered to be from MH 1. Results of the imaging conducted at the ESRF led to much

better visualization of external and internal anatomy (e.g., the endocast) than results obtained from previous acquisitions using medical computed tomography.

2.1 Reconstruction of the MH 1 endocast

After digitally extracting the endocast of MH 1, we conducted a systematic evaluation of its surface morphology and dimensions. Its overall size is more chimpanzee-like, and even small for an australopith, but its surface morphology appears to be more derived (e.g., *Homo*-like) compared to other australopiths that we analyzed. The observed and quantified surface morphology of MH 1, when combined with its small volumetric size, lends support to the idea that neural reorganization occurred prior to neural enlargement in human evolution. The more derived surface topography of MH 1 also supports the notion that *A. sediba* could be a better candidate ancestor to *Homo* than *A. africanus*).

2.2 Age-at-death and dental development

Synchrotron-based imaging of the craniodental remains of MH 1 has provided the initial age-at-death estimate. Preliminary results were presented at a 2014 international conference, and a manuscript is in preparation. The preliminary results suggest that MH 1 was much younger at death than anticipated (< 10 years), particularly when using a human developmental schedule. In fact, the developmental schedule appears to be more chimpanzee-like than human like. Along with other non-adult fossil hominins studied using the protocols developed by Paul Tafforeau and colleagues at the ESRF, it appears that australopith development was much faster overall than appreciated. The pattern exhibited by MH 1, thus characterizing *A. sediba*, is presently being compared to other australopiths in order to study evolutionary differences in their development.

2.3 Study of feeding mechanics of A. sediba

Evidence obtained from MH 1 microwear studies suggests that *A. sediba* was a hard object feeder. In order to assess this finding using an independent line of evidence, a mechanical analysis of the MH 1 cranium was performed. This study used the partially restored digital MH 1 cranium that was based on segmentation of synchrotron image data. Initial indications are that the MH 1 cranium it is not optimally structured to produce the requisite bite forces that a hard object feeder should exhibit. While *A. sediba* may have been capable of consuming hard objects, it seems unlikely that this food source would have substantially influenced the craniofacial evolution of this species. This work is currently being written up as a manuscript (see below).

2.4 Taxonomic affinities of A. sediba

Early attempts to use the same partially restored digital MH 1 cranium based on segmenting synchrotron image data have focused on determining whether there would have been substantial morphological change to the late juvenile cranium before the attainment of adult morphology. Using growth trajectories of female and male chimpanzees, gorillas, and humans to simulate remaining craniofacial development of the MH 1 cranium, preliminary indications are that any remaining growth would have minimally altered cranial features. It appears that current morphological affinities of *A. sediba* based on the juvenile cranium would not have changed even were MH 1 to finish growth and reach adult status. This work is currently being written up as a manuscript (see below).

3. Future work plan

3.1 Additional endocast comparisons
We are continuing to pursue comparisons of the MH 1 endocast with additional australopithecine and *Homo* endocasts. Of great interest in the next phase of this project will be comparisons with *Homo erectus* endocasts, and possibly earlier *Homo* taxa as well.

3.2 Full cranial virtual reconstruction
We are continuing to segment the synchrotron image data in order to finish extracting the entire MH 1 partial cranium from surrounding matrix. Once this is completed, displacement and any deformation will be corrected, and the virtual cranium will be restored in order to facilitate publishing a final description. Afterwards, a 3D printout will be produced, casted, and distributed world-wide amongst colleagues.

3.3 Additional comparisons of hominin feeding mechanics
Inclusion of the current digitally restored MH 1 cranium in comprehensive studies of hominin craniofacial structure, and its function during feeding behavior, continues. The team of researchers conducting these studies uses finite element modelling in order to study craniofacial design and particularly its structural capability of resisting forces generated by feeding on hypothesized dietary items. This gives insight into hominin craniofacial evolution. Additional comparisons with other hominin specimens, and other hominin taxa, are planned.

Current list of publications in journals and conferences

Carlson, K.B., de Ruiter, D.J., McNulty, K.P., DeWitt, T.J., Berger, L.R. (**2015**) Estimation and comparison of the adult cranial morphology of *Australopithecus sediba* using developmental simulation. American Journal of Physical Anthropology 156 (suppl. 60): 101. Published abstract for a conference presentation given at the American Association of Physical Anthropologists 84th annual meeting, St. Louis, MO, USA.

Carlson, K.J., Stout, D., Jashashvili, T., de Ruiter, D.J., Tafforeau, P., Berger, L.R. (**2011**) Interpretations of the endocast of Australopithecus sediba (MH 1). PaleoAnthropology 2011: A5-A6. Published abstract for a conference presentation given at the Paleoanthropology Society annual meeting in Minneapolis, MN, USA.

Carlson, K.J., Stout, D., Jashashvili, T., de Ruiter, D.J., Tafforeau, P., Carlson, K., Berger, L.R. (**2011**) The endocast of MH 1, *Australopithecus sediba*. Science 333: 1402-1407.

Le Cabec, A., Tafforeau, P., Smith, T.M., Carlson, K.J., Berger, L.R. (**2014**) Dental development of the *Australopithecus sediba* juvenile MH1 determined from synchrotron virtual paleohistology. American Journal of Physical Anthropology 153 (suppl. 58): 166. Published abstract for a conference presentation given at the American Association of Physical Anthropologists 83rd annual meeting, Calgary, Canada.

Ledogar, J.A. et al. (**2014**) Constraints on feeding biomechanics in Australopithecus sediba. American Journal of Physical Anthropology 153 (suppl. 58): 166. Published abstract for a conference presentation given at the American Association of Physical Anthropologists 83rd annual meeting, Calgary, Canada.

Ledogar, J.A. et al. (**2015**) Bony facial buttressing in South African australopiths: a finite element analysis. American Journal of Physical Anthropology 156 (suppl. 60): 199-200. Published abstract for a conference presentation given at the American Association of Physical Anthropologists 84th annual meeting, St. Louis, MO, USA.

Strait, D.S. et al. (**2015**) Principal strain orientations during biting in the faces of chimpanzees and australopiths. American Journal of Physical Anthropology 156 (suppl. 60): 298. Published abstract for a conference presentation given at the American Association of Physical Anthropologists 84th annual meeting, St. Louis, MO, USA.

In prep manuscripts

Carlson, K.B., de Ruiter, D.J., DeWitt, T.J., McNulty, K., Carlson, K.J., Tafforeau, P., Berger, L.R. Developmental simulation of the adult cranial morphology of *Australopithecus sediba*.

Ledogar, J.A. et al. Constraints on feeding in Australopithecus sediba: implications for evaluating dietary adaptations in extinct organisms.

Abstract of publications

Carlson, K.J., Stout, D., Jashashvili, T., de Ruiter, D.J., Tafforeau, P., Carlson, K., Berger, L.R. (**2011**) The endocast of MH 1, *Australopithecus sediba*. Science 333: 1402-1407.

The virtual endocast of MH1 (*Australopithecus sediba*), obtained from high-quality synchrotron scanning, reveals generally australopith-like convolutional patterns on the frontal lobes but also some foreshadowing of features of the human frontal lobes, such as posterior repositioning of the olfactory bulbs. Principal component analysis of orbitofrontal dimensions on australopith endocasts (MH1, Sts 5, and Sts 60) indicates that among these, MH1 orbitofrontal shape and organization align most closely with human endocasts. These results are consistent with gradual neural reorganization of the orbitofrontal region in the transition from Australopithecus to Homo, but given the small volume of the MH1 endocast, they are not consistent with gradual brain enlargement before the transition.

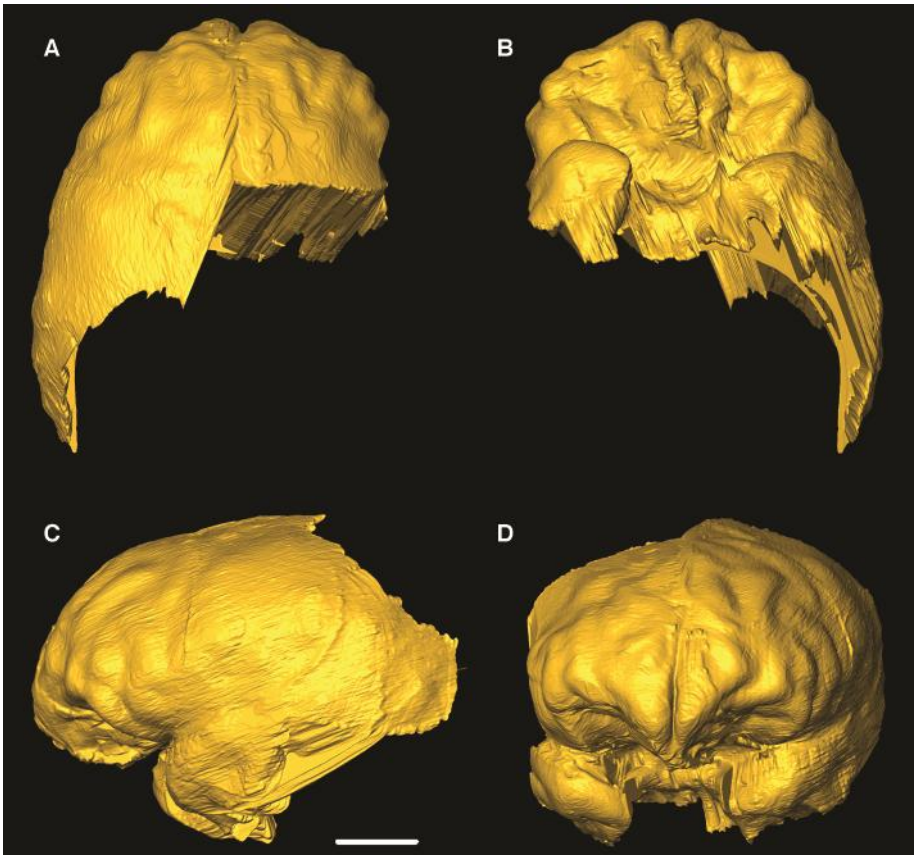

Figure 1. Virtual endocast of MH 1 in (A) superior, (B) inferior, (C) left lateral, and (D) anterior views. Scale bar is 2 cm.