

## »INTO THE PAST«: SOUTH AFRICAN HERITAGE OBJECTS AND THE POTENTIAL BENEFITS OF APPLYING NEUTRON BASED HIGH RESOLUTION TOMOGRAPHY

### Heritage objects in South Africa

#### Government regulations

Heritage objects in South Africa include »places and objects to which oral traditions are attached, or which are associated with living heritage; objects of historical and cultural significance; objects associated with leaders; historical settlements; landscapes and natural features of cultural significance; archaeological and paleontological sites; graves and burial grounds, including ancestral and royal graves; graves of traditional leaders and graves of victims of conflict; as well as sites relating to the history of slavery in South Africa« ([www.sahra.org.za/about/heritage-objects](http://www.sahra.org.za/about/heritage-objects)). Heritage objects discovered prior to 1999 are considered property of institutions. Importantly, responsibility for these objects extends to preservation as well. For purposes of the present work, only heritage objects related to archaeological and palaeontological sites are discussed.

Recognizing deficiencies in the existing system, the South African government passed legislation in 1999 (i. e., the National Heritage Resources Act, No. 25) creating the South African Heritage Resources Agency (SAHRA). SAHRA has been tasked with overseeing treatment of the precious South African National Estate (i. e., sum total of heritage objects in the country), and explicitly mandated with identifying, protecting, and promoting South African heritage objects. More information on SAHRA regulations can be found on their website ([www.sahra.org.za](http://www.sahra.org.za)). An important simultaneous change of note took place in 1999, pertaining specifically to ownership of South African heritage objects. All heritage objects dis-

covered subsequent to 1999 become the property of the people of the Republic of South Africa.

Additional roles of SAHRA have taken on increased importance subsequent to 1999. SAHRA is the lone organization in the Republic of South Africa that is legally able to authorize the collection of heritage objects and issue site excavation permits. This effectively means that heritage objects must be collected with the express knowledge of SAHRA, and presumably that some greater scientific purpose has been motivated to SAHRA in order to permit these activities. Of equal importance, SAHRA has the responsibility to authorize loans of heritage objects, particularly those that are exported beyond the borders of the Republic of South Africa. In general, the creation of SAHRA has provided much greater awareness of the tremendous value of South African heritage objects.

#### Scientific significance

When recalling significant South African heritage objects, several hominin fossils spring to the forefront of one's mind, including the Taung Child, Mrs. Ples, »Little Foot«, and most recently *Australopithecus sediba*. The Taung child was the first australopithecine (*A. africanus*) discovered anywhere in the world (Dart 1925). Klasies Rivermouth Cave, South Africa has provided one of the earliest examples of anatomically modern *Homo sapiens*, and the earliest in southern Africa (Rightmire et al. 2006). As noted above, however, South African heritage objects by definition extend well beyond human fossil material collected from the UNESCO World Heri-

tage Site in the Cradle of Humankind. South Africa is home to the earliest evidence of symbolic human behavior, in the form of a shell bead necklace from Blombos Cave dated to approx. 75,000 years (d'Errico et al. 2005). South Africa is also home to the earliest bone projectile point, in the form of the Sibudu Cave bone projectile point dated to approx. 60,000 years (Backwell/d'Errico/Wadley 2008). San culture has been extended backwards to approx. 40,000 years by the discovery of organic artifacts from Border Cave (e.g., a mixture of beeswax and *Euphorbia* resin, with other inclusions of note, used for hafting projectile points) (d'Errico et al. 2012). High resolution imaging of material culture heritage objects has not been frequently attempted, although questions that would benefit from non-destructive internal imaging of heritage objects, such as those mentioned above, abound. Bradfield (2013) examined internal structure of experimental bone projectile points in order to find signatures of use-related damage. Currently, investigation of internal damage in the Sibudu bone point is underway (Backwell et al. in prep.).

Beyond this assortment of heritage objects, South Africa has an equally rich and unique contribution to the study of life on earth from much earlier periods. Archean microfossils, some of the oldest fossils found on earth (c. 3.4 billion years old), are known from the Barberton region of South Africa (Altermann/Kazmierczak 2003). The oldest fossilized evidence of multicellular organisms and much of the present knowledge of early fish diversity comes from the South African fossil record (Rubidge 2005). The fossil record from the Karoo of South Africa preserves much of the diversification of all three groups of tetrapods namely anapsids, diapsids, and synapsids – and because of the chronologically extensive nature of the Karoo succession, it is the best record of therapsid mammal-like reptiles, which document the origins of mammals (Rubidge 2005). The Karoo fossil record also holds a diversity of early dinosaurs, including the earliest known eggs and embryos (Reisz et al. 2012). Yet another unique aspect of the vast fossil record in South Africa is that it extends to either side of the mass extinction event at the Permi-

an-Triassic boundary approx. 251 million years ago (Shen et al. 2011), which is considered the greatest extinction event of biodiversity in the history of life on earth (Benton 2005).

### Using high resolution imaging techniques to extract information

Applying neutron tomography to the study of heritage objects, such as fossils, is a relatively new endeavour. The promise of new insights coming from this application is exciting, although there are still a few obstacles minimizing the potential advantages. Unlike X-ray based high resolution radiography technologies such as high resolution computed tomography (CT) and synchrotron scanning, which can achieve spatial resolutions under 10 microns, and in some cases even submicron, neutron tomography is comparatively more limited in obtainable spatial resolutions (i.e., best scenarios are approx. 40 micron or more). Solutions for other limitations, such as activating rare earth elements in geological samples or fossils, have improved dramatically over the last several years. As neutron tomography continues to experience technological advances, these limitations will undoubtedly lessen, making the benefits increasingly attractive. For example, in situations where dense materials (e.g., iron oxides) create penetration problems for existing X-ray based methods, different contrast capabilities of neutron tomography may eventually offer another suitable option for non-destructively obtaining high resolution images of samples.

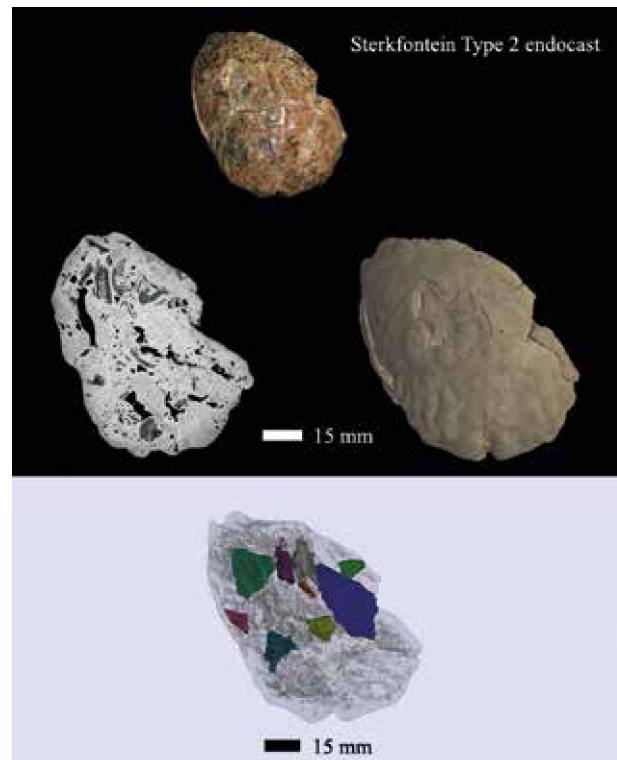
X-ray based high resolution CT and synchrotron technologies provide a number of crucial benefits in working with heritage objects, particularly those from South Africa. In palaeontological contexts, often a block of stone either fully encases or partially encases a fossil. It is not always feasible to physically prepare such a fossil from surrounding stone either because it is too fragmentary (e.g., see Val et al. 2011), or perhaps because its structure is too delicate to withstand physical preparation processes (e.g., see Churchill et al. 2013). In either case, obtaining a

series of high resolution images permits in silico extraction of the specimen without risking damage to specimens, ensuring sufficient recovery of even the smallest bones while simultaneously preserving their relative positional information. In addition, this exploratory function is valuable not only to »directed« searches of stone, but also to true random exploration of stone thought to contain fossils.

In a recent study using synchrotron technology, Fernandez and colleagues (2013) discovered a complete skeleton of a poorly known Permian amphibian (*Broomistega putterili*) inside a fossilized ichnofossil (burrow cast). In this case, scanning the fossilized burrow in order to obtain high resolution images permitted visualizing the unexpected, complete skeleton. Moreover, the high resolution images obtained by synchrotron technology provided an opportunity to visualize otherwise unrecoverable information on the geological processes of the burial event.

In some cases, the stone surrounding a fossil is of great value and cannot be removed. During fossilization, internal spaces such as a cranial cavity may fill with matrix that hardens and preserves a negative image of the inner surface of the object (e. g., inner table of a cranium). Several such »natural« casts of the endocranial surface (endocasts) have been recovered from the well-known site of Sterkfontein in the Cradle of Humankind, South Africa. Recent high resolution images obtained by CT technology have shown that these may contain fragments of the original cranium associated with the endocast (fig. 1). In this case, as with the burrow example noted above, information would be lost if the stone was removed physically. Fossilized feces (coprolites) are another example whereby stored information, such as hair (Backwell et al. 2009), may be more successfully extracted using non-destructive high resolution images.

Another noteworthy outcome of high resolution imaging, thus far restricted to X-ray based technologies, is the opportunity to reconstruct fragmentary fossils and analyze their shape by subjecting segmented surfaces to geometric morphometric analytical approaches. Using internal structures, such as



**Fig. 1** Sterkfontein Type 2 »natural« cast of endocranial surface. Top: superior view photograph of specimen (scale not included). Middle left: specimen in an equivalent position, with a single transverse slice extracted from high resolution X-ray computed tomography image data. Notice faint blue outline surrounding a cranial fragment inside. Middle right: rendering using same image data, showing high resolution surface details. Bottom: same surface rendering, but in semi-transparency, and using multiple colors to visualize segmented cranial fragments inside, some of which preserve identifiable features. – (Photo K. J. Carlson).

trabecular struts, external morphology, and surface curvatures, one can align fragments with very high precision (DeSilva et al. 2013; Schmid et al. 2013). In other cases, by mirror-imaging existing pieces, missing pieces from opposite sides can be estimated. This is particularly useful when attempting to estimate linear dimensions or volumes of incomplete structures, e. g. endocasts (Carlson et al. 2011). High resolution imagery also offers opportunities for analyzing tiny internal structures, such as trabecular meshes, in order to extract information on structural loading of bones (Ryan/Ketcham 2002; Su/Carlson in print; Zeininger et al. 2016).

As technological advances are made in neutron tomography, it could provide another incredibly useful tool in addition to X-ray based technologies with

which to explore stone/matrix for fossils. Different material contrast offered by neutron tomography relative to X-ray based technologies, in some situations, may provide an even better opportunity for extracting information from heritage objects in the ways described above, or using yet to be developed analytical approaches.

## Conclusions

The South African Heritage Resources Agency is tasked by the South African government with overseeing the collection of heritage objects within the

country, and also with regulating loans to scientists who wish to export them beyond the borders of the Republic of South Africa. Importantly, heritage objects in South Africa include fossils and non-fossils, and collectively hold considerable international scientific importance in a diverse range of past events from the origins of life on earth to the origins of symbolic behaviour in modern humans. Neutron tomography, synchrotron tomography, and high resolution computed tomography (i.e., microCT) are powerful non-destructive research tools for extracting otherwise inaccessible scientific information from heritage objects. As advances in each of these techniques are realized, the study of heritage objects stands to greatly benefit as well.

## Acknowledgements

I would like to thank Burkhard Schillinger and Frikkie De Beer for the invitation to participate in the NINMACH conference. I also would like to thank Stephany Potze for her encouragement to participate as well. Finally, I thank Lucinda Backwell, Bruce Rubidge, and Bernhard Zipfel for their helpful discussions regarding South African heritage objects.

## References

- Altermann/Kazmierczak 2003: W. Altermann / J. Kazmierczak, Archean microfossils: a reappraisal of early life on Earth. *Research in Microbiology* 154, 2003, 611-617.
- Backwell/d'Errico/Wadley 2008: L. Backwell / F. d'Errico / L. Wadley, Middle Stone Age bone tools from the Howiesons Poort layers, Sibudu Cave, South Africa. *Journal of Archaeological Science* 35, 2008, 1566-1580.
- Backwell et al. 2009: L. Backwell / R. Pickering / D. Brothwell / L. Berger / M. Witcomb / D. Martill / K. Penkman / A. Wilson, Probable human hair found in a fossil hyaena coprolite from Gladysvale cave, South Africa. *Journal of Archaeological Science* 36, 2009, 1269-1276.
- Backwell et al. in prep.: L. Backwell / K. J. Carlson / T. Jashashvili / L. Wadley / F. d'Errico / J. Bradfield, The application of high resolution computed tomography to understanding potential functions of ancient bone tools (in prep.).
- Benton 2005: M. J. Benton, When life nearly died: the greatest mass extinction of all time (London 2005) 336.
- Bradfield 2013: J. Bradfield, Investigating the potential of micro-focus computed tomography in the study of ancient bone tool function: results from actualistic experiments. *Journal of Archaeological Science* 40, 2013, 2606-2613.
- Carlson et al. 2011: K. J. Carlson / D. Stout / T. Jashashvili / D. J. de Ruiter / P. Tafforeau / K. Carlson / L. R. Berger, The Endocast of MH1, *Australopithecus sediba*. *Science* 333, 2011, 1402-1407.
- Churchill et al. 2013: S. E. Churchill / T. W. Holliday / K. J. Carlson / T. Jashashvili / M. E. Macias / S. Mathews / T. L. Sparling / P. Schmid / D. J. de Ruiter / L. R. Berger, The upper limb of *Australopithecus sediba*. *Science* 340, 2013, 1233477-1-1233477-6.
- Dart 1925: R. A. Dart, The Man-Ape of South Africa. *Nature* 115, 1925, 195-199.
- d'Errico et al. 2005: F. d'Errico / C. Henshilwood / M. Vanhaeren / K. van Niekerk, Nassarius kraussianus shell beads from Blombos Cave: evidence for symbolic behaviour in the Middle Stone Age. *Journal of Human Evolution* 48, 2005, 3-24.
- d'Errico et al. 2012: F. d'Errico / L. Backwell / P. Villa / I. Degano / J. J. Lucejko / M. K. Bamford / T. F. G. Higham / M. P. Colombini / P. B. Beaumont, Early evidence of San material culture represented by organic artifacts from Border Cave, South Africa. *Proceedings of the National Academy of Sciences of the United States of America* 109, 2012, 13214-13219.
- DeSilva et al. 2013: J. M. DeSilva / K. G. Holt / S. E. Churchill / K. J. Carlson / C. S. Walker / B. Zipfel / L. R. Berger, The lower limb and mechanics of walking in *Australopithecus sediba*. *Science* 340, 2013, 1232999-1-1232999-5.
- Fernandez et al. 2013: V. Fernandez / F. Abdala / K. J. Carlson / D. C. Cook / B. Rubidge / P. Tafforeau / A. Yates, Synchrotron reveals Early Triassic odd couple: injured amphibian and aestivat-

- ing therapsid share burrow. *PLoS One* 8: e64978. DOI:10.1371/journal.pone.0064978.
- Reisz et al. 2012: R. R. Reisz / D. C. Evans / E. M. Roberts / H.-D. Sues / A. M. Yates, Oldest known dinosaurian nesting site and reproductive biology of the Early Jurassic sauropodomorph *Masospondylus*. *Proceedings of the National Academy of Sciences of the United States of America* 109, 2012, 2428-2433.
- Rightmire et al. 2006: G. P. Rightmire / H. J. Deacon / J. H. Schwartz / I. Tattersall, Human foot bones from Klasies River main site, South Africa. *Journal of Human Evolution* 50, 2006, 96-103.
- Rubidge 2005: B. Rubidge, Re-uniting lost continents – fossil reptiles from the ancient Karoo and their wanderlust. *South African Journal of Geology* 108, 135-172.
- Ryan/Ketcham 2002: T. M. Ryan / R. A. Ketcham, Femoral head trabecular bone structure in omomyid primates. *Journal of Human Evolution* 43, 2002, 241-263.
- Schmid et al. 2013: P. Schmid / S. E. Churchill / S. Nalla / E. Weissen / K. J. Carlson / D. J. de Ruiter / L. R. Berger, Mosaic morphology in the thorax of *Australopithecus sediba*. *Science* 340, 2013, 1234598-1–1234598-5.
- Shen et al. 2011: S. Shen / J. L. Crowley / Y. Wang et al., Calibrating the end-Permian mass extinction. *Science* 334, 2011, 1367-1372.
- Su/Carlson in print: A. Su / K. J. Carlson, Comparative analysis of trabecular bone structure and orientation in South African hominid. *Journal of Human Evolution* (in print).
- Val et al. 2011: A. Val / K. J. Carlson / C. Steininger / J. Kibii / C. Churms / B. F. Kuhn / L. R. Berger, Application of 3D techniques to identify fossil remains: an elephant shrew hemi-mandible from the Plio-Pleistocene site of Malapa (Gauteng, South Africa). *South African Journal of Science* 107, 2011, 70-74.
- Zeininger et al. 2016: A. Zeininger / B. A. Patel / B. Zipfel / K. J. Carlson, Trabecular architecture in the StW 352 fossil hominid *calcareus*. *Journal of Human Evolution* 97, 2016, 145-158.

## Summary / Zusammenfassung

### »Into the Past«: South African Heritage Objects and the Potential Benefits of Applying Neutron Based High Resolution Tomography

Heritage objects discovered in South Africa after 1999 are the property of the people of the Republic of South Africa. The South African Heritage Resources Agency is tasked by the South African government with overseeing the collection of these objects, and also with regulating loans that require their export beyond the borders of the Republic of South Africa. Many of these objects are of considerable international scientific importance, and include early evidence of symbolic and advanced cognitive behaviour in modern humans, the first australopithecine fossil ever found (i.e., the Taung Child), evidence crucial to unravelling the origins of mammals (i.e., therapsid mammal-like reptiles from the Karoo), and some of the oldest fossils on earth. Non-destructive imaging techniques, such as neutron tomography, synchrotron tomography, and high resolution computed tomography (i.e., microCT) are becoming increasingly vital research tools for extracting otherwise inaccessible scientific information from these objects. The study of heritage objects stands to benefit tremendously from advances made in each technique during the coming years.

### Keywords

fossils / non-destructive / reconstruction / evolution / imaging

### »In die Vergangenheit«: Objekte des südafrikanischen Kulturerbes und der potenzielle Nutzen der Anwendung von neutronbasierter hochauflösender Computertomographie

Kulturgut, das nach 1999 in Südafrika entdeckt wurde, ist Besitz des Volkes der Republik von Südafrika. Die South African Heritage Resources Agency, das Büro für Südafrikanisches Kulturerbe, hat von der Südafrikanischen Regierung die Aufgabe bekommen, das Sammeln dieser Objekte zu überwachen und auch über Leihgaben zu verhandeln, die eine Ausfuhr aus der Republik von Südafrika erfordern. Viele dieser Objekte sind von großer internationaler wissenschaftlicher Bedeutung. Dazu zählen frühe Zeugnisse des symbolischen und fortgeschrittenen kognitiven Verhaltens des modernen Menschen oder das erste *Australopithecus*-Fossil, das jemals gefunden wurde (sog. Kind von Taung), Nachweise, die unerlässlich sind, um die Ursprünge der Säugetiere zu erkunden (d.h. Therapsiden, säugetierähnliche Reptilien aus der Karoo), und einige der ältesten Fossilien der Welt. Zerstörungsfreie Prüfmethoden wie die Neutronen-Tomographie, Synchrotron-Tomographie und hochauflösende Röntgen-Tomographie (microCT) werden immer mehr zu Werkzeugen von entscheidender Bedeutung, um wissenschaftliche Informationen aus diesen Objekten zu erhalten, die anderweitig nicht zu bekommen sind. Die Untersuchung von Objekten des kulturellen Erbes wird in den kommenden Jahren gewaltig von den Fortschritten profitieren, die in jeder dieser Techniken gemacht wurden.