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The Taung Child then and now:
Commemorating its centenary in a
postcolonial age

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A note from the Editor-in-Chief

At the *South African Journal of Science* we are delighted to have been given the opportunity to host a special issue commemorating the centenary of the publication of the discovery of the Taung Child – a major milestone in science history.

We are grateful for the collegial and steadfast work of the Guest Editors, Rebecca Ackermann, Robyn Pickering, Yonatan Sahle and Lauren Schroeder. As with other special issues, we have paid particular attention to the independence of review processes, with review processes undertaken by our usual editorial team. We did ask the Guest Editors for suggestions of reviewers and expert readers, but we did not necessarily follow their suggestions – we considered these as we would consider suggestions from authors themselves.

We are very pleased, therefore, not only to be publishing a special issue on very important issues for science in our context, but also that, with the kind cooperation of the Guest Editors, we are able confidently to state that all papers in the special issue (and those that were not accepted) were subject to the same levels of rigorous assessment as all other submissions to our Journal.

We thank the Guest Editors for convening and guest editing this special issue, and Associate Editor Jemma Finch, Associate Editor Mentee Tim Forssman, and our in-house team (Phumlani Mncwango, Nadia Grobler and Linda Fick) for their sterling work on this issue. It has been a pleasure to work with them.

Leslie Swartz, Editor-in-Chief

Cover image *Legata la Taung* [Taung Skull] by Motshidisi Leburu

Artist's description of the cover image: My inspiration for this project is from *Darwin's Hunch* and *Our Science, Ourselves*, both written by Christa Kuljian. I created the artwork from a point of emptiness, and ended with tapestry colours, tones and textures that reflect a diverse and controversial history of the Taung Skull.

Tlhaloso ya setshwantsho sa khabara: *Buka ya 'Darwin's Hunch' le ya 'Our Science, Ourselves' ke tsone di nthotloeditseng go dira porojeke eno mme ka bobedi jwa tsone di kwadilwe ke Christa Kuljian. Ke takile setshwantsho seno ka go se itshimololela, mme ka feleletsa ke dirile mebala e e galotseng, mebala e e tswakaneng e e nang le boleng, e e supang hisitori ya methalethale e e aparetsweng ke kgang ya moruthutha ka Logata lwa kwa Taung*.

The Taung Child then and now: Commemorating its centenary in a postcolonial age

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[Translation in Setswana]

The story of the Taung Child discovery is almost legend in palaeoanthropology. In it, Raymond Dart acquires a block of calcified sediment, painstakingly removes the fossil skull from the matrix, and publishes his description of the new species *Australopithecus africanus* in the journal *Nature*[1], only to be rebuffed by the international scientific community, but ultimately vindicated decades later following subsequent discoveries in Africa and the debunking of the Piltdown forgery[2–4]. Dart is portrayed as prescient, and as elevating the importance of Africa in the narrative of human origins.[5] But is this a biased and simplified narrative? This history played out over a period marked by colonialism, racism, racial segregation, and, ultimately, the implementation of apartheid, making the history of human origins research intimately intertwined with the prevalent socio-political landscape. Viewed against this backdrop, and with a contemporary lens, the figure of Dart, and palaeoanthropology on the African continent more broadly, is more complex and worthy of reflection.

In this special issue, published exactly 100 years after Dart's original publication, we bring together a group of African researchers and international collaborators to offer our perspective on the science, history, and legacy of palaeoanthropology in South Africa and beyond. We are particularly interested in exploring how the history of the discovery of early hominins in South Africa, as it played out in a colonial context, impacted the scientific field of palaeoanthropology. Did it promote or limit scientific enquiry? In what ways? What were its cultural effects, and how do they play out in our current context a century later? How might we work to decolonise the discipline and its narratives?

Our decision to mark the Taung centenary by publishing this collection of articles in an open access South African journal, and to centre the voices of South African researchers, was a deliberate one. Too often, African palaeoanthropological heritage is the domain of international teams, with little meaningful collaboration from local African researchers – a phenomenon increasingly being recognised as "helicopter science".[6–8] The paucity of diverse Global South perspectives has done a disservice to the field, and has led to the perpetuation of colonial legacies and practices, while at the same time rendering much of what is going on invisible internationally, as it is not the lived experience of the researchers being centred. In this light, our goal is to celebrate the remarkable science that the discovery of *A. africanus* enabled, but also to probe disciplinary legacies viewed through a critical lens that challenges us to do science better.

The making of Dart's legacy

Two articles in this special issue critically engage with Dart's legacy and how it has been shaped and narrated by him and others. Kuljian reflects on Raymond Dart's legacy, how it was shaped and protected by figures such as Phillip Tobias, and burnished by biographers. The author reviews how Dart's telling of the story of the fossil obscured the roles of some while promoting a "one man one fossil" myth. The author then considers scholars who critically reflected on Dart's legacy, which included problematic practices of scientific racism and colonial influences, and shares findings from the Dart papers at the University of the Witwatersrand Archives, ultimately demonstrating that Dart's legacy is more complicated and problematic than generally appreciated. Kuljian argues that Dart's painful legacy of scientific racism must stand alongside his better-known legacy as the describer of the Taung Child skull.

Ackermann et al. focus on the "explorer" myth, an integral part of Western mentality for more than two centuries, and consider how this colonial idea has shaped aspects of African palaeoanthropology. They interrogate the mythology around Dart, and show how the discovery and reporting of Dart's work on the Taung Child fossil was situated and storied within this explorer narrative. They then expand to consider African palaeoanthropology more broadly, and argue that these outdated concepts have played a role in determining which scientific outcomes are valued and which are not. This is especially true for fieldwork practices, which continue to embody the explorer myth's deeply problematic colonial ideals of Western, masculine, moral and cultural superiority. Finally, the authors propose disciplinary changes to help move us all forward in a manner that creates a more equitable and accessible future for African palaeoanthropology.

Fossil morphology, biology and ecology

Other contributions consider the Taung Child fossil itself and its legacies. Beaudet et al. focus on the Taung Child endocast and its influence on the study of hominin brain evolution and the growth of the field of palaeoneurology. They expand their assessment to the impact of the well-preserved South African fossil record of crania and natural endocasts on our understanding of brain evolution, and review methodological and analytical innovations. They contextualise this within a discussion of current practices and digital data sharing, while also considering ethical issues related to studies of recent human brains as hominin comparators. Schroeder et al. use the jumping point of the discovery of the Taung Child skull to reflect on the importance of, and focus on, skull collecting in palaeoanthropology, contextualised within the history of 'physical' anthropology and its goals of scientific racism. They demonstrate how this has skewed the comparative collections housed in South African museums (although this pattern is seen worldwide), affected species hypodigms, and impacted the discipline more broadly. They argue that an overemphasis on skulls and brain size has biased our understanding of human evolution and has been detrimental by contributing to ideas of human exceptionalism.

Two articles look at dental enamel and what it can tell us about hominin biology and ecology. Lee-Thorp and Sponheimer provide an overview of the various analytical tools, stable light and radiogenic isotopes, and trace element biogeochemistry, as well as the macro- and microscope morphology, used mainly on fossil tooth enamel to investigate hominin dietary and mobility patterns, contextualising this within the pioneering emergence and growth of these research fields in South Africa. The authors challenge Dart's hypothesis that meat-eating played an important role in early hominin diets, and their evolution, showing that the carbon isotope and trace element signatures point to an under-recognised reliance on plant foods; they earmark this role of plants in hominin diets an important direction for future research. South Africa continues to be well positioned at the forefront of new methods for understanding early hominins. Madupe et al. explore the exciting new field of palaeoproteomics, as applied to study fossil hominin and faunal tooth enamel, and demonstrate its potential for illuminating the sex and evolutionary relationships of early hominins. As an example, they demonstrate that proteins are preserved in an *A. africanus* tooth from Sterkfontein, indicating that it is a male individual. They argue that South Africa's exceptionally well-preserved hominin fossils promise new knowledge production as this subdiscipline develops, but also highlight the need to invest in resources and capacity development to achieve this.

Geological and palaeoenvironmental contexts

The context of the fossils has also long been a subject of interest. Weij et al. review the geology, dating and taphonomy of the UNESCO Cradle of Humankind World Heritage Site caves. They look at the role of mining at Taung and the Gauteng Cradle, and how the removal of the speleothem and tufa (known colloquially and historically as 'lime') led to the discovery of fossils at both localities but was not only destructive but also part of a segregated, colonial and apartheid-driven context. In an echo of Ackermann et al., Weij et al. argue that the credit for the discovery of the fossils and the excavation of the sites is disproportionately allocated and that black miners and excavators are virtually erased from the narratives surrounding the fossil sites. They end with a look at current and future areas of geological and palaeoenvironmental research and the recent success in establishing world-class local dating facilities, a message also picked up on by Lee-Thorp and Sponheimer and Madupe et al.

Zooming out from the fossil cave sites, Khosa et al. look at the last 135 years of landscape evolution in South Africa and offer both a review and critical reflection. Dart hypothesised that the landscape and backdrop to the newly described *A. africanus* was a stable dry climate, an idea which Khosa et al. suggest is threaded through the following decades of research and underpins the older models of landscape evolution. They then critique the 'African land surface' model and argue that, while this was a product of its time, it is also a product of outdated colonial thinking in which 'Africa' is treated as a homogeneous, unknowable single entity. They provide a snapshot bibliometric look at the "who of landscape evolution", from which it becomes clear that this research has been dominated by foreign, white academics; building local capacity and training more African researchers is a way to address this imbalance.

Beyond palaeoanthropology: Community and practice

The final set of contributions looks outside the field of palaeoanthropology and considers broader impacts on community, museum practice, and palaeosciences more generally. Tawane et al. provide a unique view of the Taung Child discovery from within. The lead author's background as both a palaeoanthropologist and also someone who grew up in the Taung Municipality provides a position from which the meaning of the Taung Child discovery to the community around the locality of discovery can be probed. A century after the discovery of the iconic fossil, the authors argue that there is little, if any, reason for the local community to celebrate the Taung Child discovery. They suggest that more should be done in this locality with enduring socio-economic problems, not only to give back to the community but also to build trust and foster a sense of belonging.

What is the role of the museum? How are museums addressing unethical legacies? Black et al. reflect on these key questions in their piece focusing on the development of heritage management in South Africa over the past century. They engage with both the legislative and ethical frameworks of the present and discuss how these inform the protection of heritage today. By highlighting key objectives in contemporary heritage management – such as repatriation, community engagement, and public science education – Black et al. offer a depiction of the complex challenges faced in these spaces as they look to the future. Finally, Kgotleng et al. explore the state of affairs of palaeoscience research in southern Africa a century after the milestone discovery at Taung from a policy perspective, as well as that of social cohesion. Their contribution underscores the deeply colonial and largely socially unresponsive research that characterised much of the last century and calls for reforms that promise more equitable and meaningfully inclusive research in the subregion and further afield.

Outside perspective

The special issue articles are prefaced by a front section contribution from the outside. Focusing mainly on Kenya, Mbua provides a perspective on how the Taung Child discovery stimulated palaeoanthropological research in an Eastern African context, highlighting the subsequent redoubling of systematic field and laboratory research across Kenya, Tanzania and Ethiopia. The author then goes on to show that much of the spectacular hominin and palaeontological discoveries in the region were dominated by a few actors, all of Western European descent and predominantly men. While acknowledging encouraging efforts to train African professional palaeoanthropologists over the past decades, Mbua concludes by highlighting the need for better capacity building of African heritage institutions.

Towards a decolonised palaeoanthropology

We have made an effort with this special issue to acknowledge and discuss both the Taung discovery and the research which followed in the setting in which it was undertaken, which was, until 1994, colonial and then apartheid. We make this point deliberately, as science is not an entirely empirical, somehow neutral and pure, endeavour, but instead is deeply embedded in the context and society in which it is produced. As such, we need to view the last 100 years of palaeoanthropological work within its historical and cultural context, reflect on this as a community, and make decisions on how we want our field to develop into the future. There are some key themes that repeatedly run through these special issue contributions that speak to the legacy of colonialism as it impacts palaeoanthropology. We believe they can guide this reflection and realignment of practice in order to decolonise palaeoanthropology.

The colonial framework in which most palaeoanthropological research in South Africa took place enabled the exclusion of almost everyone except a few. Marginalisation and erasure of voices repeatedly emerges as a theme in this special issue. This is particularly true for Indigenous voices, and the legacy of this today is reflected in the paucity of African researchers in palaeoanthropology who are first authors on prominent research or leading international research teams, compared to the number of white international researchers.[8] Much has also been written on the role of diversity in both business and academic research – the so-called 'business case' for diversity[9,10], which presents a compelling case that more diverse teams produce better, more creative and innovative work. This can be taken further in academia, as argued by Burt et al.[11], that, as a sector, we have an additional ethical obligation to work towards making our disciplines more diverse, given the exclusionary nature of science and research. Both cases are applicable to palaeoanthropology; more diverse teams will produce better future work, and as a discipline, we need to actively address this.

A correlated aspect of the colonial framework is the dominance of Western male viewpoints, and this theme threads through almost all the work presented here. While our field has been very productive over the last 100 years and a huge volume of papers has been published, the credit, both in academia and society, has overwhelmingly been accrued by this one demographic, to the exclusion of women and people of colour. This pattern is, however, changing. We sought to add some redress to these imbalances of whose voice is centred and whose is erased through the authorship of this special issue, with high levels of representation by women and Africans (and African women), and call for a more considered and equitable approach to the inclusion of African researchers, technicians, and excavators in the future: in workshops and seminars, on professional bodies, as collaborators and knowledge creators, and in authorship practices.

Another key theme which emerges from this special issue is both the value of and the need for excellent local laboratory facilities in which to undertake research based on the fossils and deposits associated with them. Increased investment in local laboratory facilities and capacity development can facilitate a shift towards local work on the content being led by Africans, and increase pan-African collaboration, dismantling the currently common practice of African researchers instead being drawn into separate existing international networks. As Ackermann et al. discuss, it is important for international funding bodies to increase investment within African palaeoanthropology to facilitate this internal growth and local collaborative networks, thereby breaking down the legacy of colonialism. It is also essential for our local funding bodies, especially the National Research Foundation – which has drastically cut budget allocation to the African Origins Programme in recent years – to more substantially invest in research on our precious fossil heritage, a national asset. We cannot grow local research capacity without this support.

Finally, the colonial legacies discussed above also manifest in a lack of social responsiveness, a theme that emerges across a number of papers featured in this special issue but which is most thoroughly addressed in the writings of Tawane et al., Kgotleng et al., and Black et al. Academic social responsiveness is also referred to as engaged scholarship, where academics engage with non-academic constituencies, using their professional expertise for a public purpose or benefit. In order to create a truly decolonised palaeoanthropology, researchers need to understand that there is value in engaging outside of academia, not merely for the unidirectional dissemination of knowledge, but to enrich communities and co-create a scholarship that is more nuanced, ethical and relevant. We call for researchers to take on board socially responsive practice, and for institutions to hold researchers to higher standards of practice as we enter the next century of palaeoanthropological research and discovery in Africa.

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Palaeoanthropology in Kenya: After discovery of the Taung Child

Significance:

The discovery of the Taung Child was a significant milestone that not only challenged the then-prevailing belief in humanity's Eurasian origins but also inspired a new wave of palaeontological research across the African continent, particularly in eastern Africa. This discovery provided compelling evidence supporting Darwin's theory of an African ancestor for all hominins. The impact of this discovery can be seen in the surge of palaeontological surveys in eastern Africa, which have, over the years, yielded a wealth of fossilised fauna remains, including outstanding hominin fossils from the eastern African sites.

[Translation in Setswana]

Introduction

The Taung Child, a juvenile hominin fossil discovered in 1924 in South Africa, not only stimulated palaeoanthropological research on the African continent but also had a global impact. Raymond Dart[1] designated the Taung Child *Australopithecus africanus* – 'Southern Ape of Africa'. This profound discovery shaped our understanding of human origins and laid the foundation for further research in the field and at African sites. Prior to the discovery of the Taung fossils, several other hominin remains were recovered in Africa, including the Boskop skull by Robert Broom[2] and the Kabwe cranium by Arthur S. Woodward[3]. These finds, however, represent the later period of human evolution as they exhibit more derived features. In contrast, the significant discovery of the Taung Child presented what would be considered an early hominin ancestor, thereby challenging the then-prevailing belief in humanity's Eurasian origins. The claim of an African ancestor of all hominins also ignited a new chapter in the study of human evolution in other parts of the continent.

Dart's interpretation of the Taung fossils was dismissed for a considerable time by renowned scholars of the day, among them Sir Arthur Keith.[4] Keith argued that the fossils were contemporaneous with Middle Stone Age tools found on a river bed near the site of discovery.

In addition, he and others were partly influenced by the Piltdown discovery of a cranium with a large human brain associated with an ape mandible and teeth published by C. Dawson.[5] Many scholars of the time saw the Piltdown skull as ancestral to humans, a view that contrasted with the evidence provided by the Taung Child's tiny brain. Coupled with the then-popular belief of a Eurasian origin of humans, the Piltdown claim further hindered the acceptance of Dart's discovery.

In the 1950s, a pivotal change occurred in favour of Dart's interpretations of the Taung Child, triggered by the jolting revelation that the Piltdown man believed to be a crucial missing link in human evolution was a deliberate hoax.[6] This prompted many scholars to reconsider the Taung Child's significance in the human evolutionary discourse. It may also be worth noting that Broom's work in South Africa was making an impact by the late 1940s, and his volumes between 1946 and 1952 in the *Transvaal Museum Memoirs* were instrumental.

From south to east: The onset of palaeoanthropological research in Kenya

Following the discovery of the Taung Child, the fever for palaeoscience quickly expanded to encompass even more regions of the continent, particularly eastern Africa. In Ethiopia, despite palaeontological work in the Omo Valley having started as early as 1902[7], systematic palaeoanthropological research commenced only in 1967, once F.C. Howell and L.S.B. Leakey joined the French team. It is interesting to note here that this second expedition to the Omo Valley came only after the Piltdown claim was conclusively dismissed, allowing for the global acceptance of Africa as the origin of early hominins. Palaeoanthropological research in Kenya and Tanzania, then British colonies, was well underway by the 1950s. Such a head start in advanced palaeoanthropological research was responsible for the discovery in 1967 of early human fossils in Omo Kibish, Ethiopia, by R.E. Leakey's team from the Kenyan National Museums. Palaeoanthropological research in Ethiopia would only see further discoveries and efforts at capacity building after the discovery of sites in the Afar Rift in 1974.[8]

Influenced by the Taung discovery, and also by Charles Darwin's prediction that our early human ancestors lived on the African continent, Louis and Mary Leakey began their surveys in eastern Africa. They were among the pioneering researchers in the region who significantly contributed to the study of human evolution in eastern Africa.

The couple strongly believed that the East African Rift Valley held the potential for discovering hominin fossils, and their predictions were emphatically proven correct when promising sites emerged in various parts of the Kenyan and Tanzanian rifts.[9–12] These discoveries were proof that ancient hominin remains were not restricted to southern Africa but also occurred in eastern Africa. Interestingly, today, the eastern African sites have yielded far older and more diverse fossils of hominins, e.g. *Orrorin tugenensis* in Kenya dated to ~6 Ma[13], and *Ardipithecus kaddaba* in Ethiopia dated to between 5.8 Ma and 5.5 Ma[14].

Louis and Mary Leakey initially worked at several Stone Age sites, generating substantial data on hominin cultural adaptations during this period.[15] In addition, they worked at some Miocene sites in western Kenya, including the Rusinga and Mfangano islands, where they recovered abundant early Miocene ape fossils, initially designated *Proconsul africanus* by Hopwood[16] and later *Proconsul heseloni* by Walker et al.[17] This ancient ape species was later re-assigned to *Ekembo heseloni* based on significant anatomical features emphasising differences from the genus *Proconsul* by McKnaulty et al.[18] In the early 1950s, perhaps influenced by the global acceptance of the Taung Child as the earliest hominin ancestor, Louis and Mary Leakey moved their research interests to Tanzania, where they spent many years working at the early Pleistocene beds at the Olduvai Gorge. One of their significant discoveries at Olduvai Gorge was the *Paranthropus boisei* skull found by Mary in 1959 and dubbed 'Zinjanthropus'.

After Louis's death in 1972, Mary took over the leadership of palaeoanthropological research activities in Tanzania. In 1974, she shifted her research interests to Laetoli within the Serengeti National Park, where she excavated a track of *Australopithecus afarensis* footprints in 1978[19,20], dated to 3.6 million years. These hominin footprints highlighted the bipedal gait of the species, thus resolving a critical debate at the time. Although Louis Leakey is regarded as the father of palaeoanthropology in eastern Africa, Richard Leakey – his son – tremendously expanded palaeoanthropological research in Kenya by discovering numerous early hominin fossils from the rich fossil-bearing sediments of the Lake Turkana Basin.

Major palaeoanthropological sites in Kenya

Close to 90% of palaeoanthropological fossils in Kenya derive from the Lake Turkana Basin in the country's northwestern part. The Basin contains rich and extensive fossiliferous deposits of Plio-Pleistocene age associated with the ancestral Omo River and its tributaries. These fossil-bearing sediments, known as the Koobi Fora and Nachukui Formations, are located east and west of Lake Turkana, respectively. They are divided into various members spanning the last 4 million years.

The members within these formations have been extensively studied, yielding hundreds of early hominin fossils and footprints, a plethora of faunal remains, as well as some of the earliest known evidence for hominin material culture, including evidence for domestication.

Koobi Fora was discovered by Richard Leakey in 1967 while flying back to Nairobi from the Omo expedition in Ethiopia. At the time, he was a member of the International Omo Research Expedition, coordinated by F.C. Howell, Yves Coppens, and Louis B. Leakey from 1967 to 1973. On one specific flight, Richard flew along the eastern margins of Lake Turkana, where he noticed fossil-bearing sediments along the lake's surrounding areas from above. Upon conducting a subsequent ground survey, he and his team spotted extensive rich fossiliferous deposits containing fossilised animal remains at Koobi Fora that warranted immediate exploration and recovery measures. This discovery necessitated the change of research interests from Omo in Ethiopia to Koobi Fora in northern Kenya. Following these changes, Richard formed the Koobi Fora Research Project in the early 1970s – a multinational and multidisciplinary expedition that was instrumental in the discovery of hundreds of fossilised animal fossils, among them a significant number of early hominin taxa (Table 1).[21–25] The outstanding discoveries include various species of *Homo* and *Paranthropus*, among many others. Similarly, research on the Nachukui Formation within the western Turkana Basin has yielded hominin species, among them a partially preserved *Homo erectus* skeleton (dubbed the 'Turkana Boy') from the Nariokotome member within the Nachukui formation.[26,27] The late Kamoya Kimeu – a renowned Kenyan fossil hunter – is celebrated for the discovery of the 'Turkana Boy' in 1984.

Upon Richard's departure to take up a government position, Meave Leakey assumed the mantle as the Koobi Fora Research Project coordinator jointly with Alan Walker and Kamoya Kimeu. Meave and her team continued palaeoanthropological surveys in the western and eastern parts of the Lake Turkana Basin, where they recovered numerous Pliocene human fossils at Kanapoi and Allia Bay.

Present and future of palaeoanthropology in Kenya

For a significant period in the past, palaeoscience research in Kenya was predominantly undertaken and led by scholars from the Western world. This was due in part to the absence of relevant courses at local universities to equip students with relevant palaeoscience knowledge as well as the limited funding for overseas training. Some Western scholars' reluctance to promote African scholars' participation in palaeoscience was driven by questionable motives and outdated colonial mindsets. This fear of increased competition from local talent hindered African scholars' involvement in the field of palaeoanthropology for a long time.

In the early 1980s, however, a notable shift began. Despite the prevailing difficulties, several Kenyans, propelled by their passion and determination and supported by some well-wishers from the Western world, secured graduate opportunities to study archaeology in Berkeley, California, USA, under the late Prof. Glynn Isaac, himself a son of South Africa, and Prof. Desmond Clark. This marked a pivotal moment, and in the early 1990s, more Kenyans secured sponsorships to study palaeoanthropology and geology at US and European universities. Simultaneously, funding agencies in palaeoscience, e.g. the Leakey Foundation, Wenner Gren, Palaeontological Scientific Trust (PAST) and others, opened programmes for supporting training in palaeoscience, particularly for young African scholars. This period also saw the National Museums of Kenya developing research policies and rules that promoted involvement in collaborative research ventures between visiting international and Kenyan scholars. Such policies significantly increased the numbers of Kenyans trained in palaeoanthropology to hold positions and lead field expeditions.

The research policies at the National Museums of Kenya underscore the importance of building capacity for Kenyans through training, particularly at the graduate level. Under such a requirement, all palaeoanthropological research expeditions in Kenya are required to train at least one Kenyan scientist for a graduate degree. Today, this requirement has boosted the training of Kenyans in palaeoanthropology, and many young Kenyans have benefitted.

Table 1: Hominins discovered from Kenyan sites

Taxon	Site name	Age (Myr)
Orrorin tugenensis	Kapsomin, Baringo	6 – 5.7
Australopithecus anamensis	Lomekwi, West Turkana	4.1 ± 0.1
Kenyanthropus platyops	Lomekwi, West Turkana	3.3 ± 0.1
Australopithecus afarensis	Kantis Fossil Site	3.6
Paranthropus aethiopicus	West Turkana	2.52 ± 0.05
Paranthropus boisei	Koobi Fora, West Turkana, Chemeron	1.70 ± 0.05
Homo rudolfensis	Koobi Fora	1.89 ± 0.05
Homo habilis	Koobi Fora	1.89 ± 0.05 – 1.4
Homo erectus	Koobi Fora, West Turkana	1.6 ± 0.05 – 1.57 ± 0.05

In the recent past, the late Prof. Isaiah Nengo and his team, with their dedication and vision, led the formation of Kenya's first graduate programme in the palaeosciences – the MSc programme in Human Evolutionary Biology – at the Turkana University College (Lodwar). This programme, taught entirely by volunteer international researchers, is exclusively for Kenyan nationals. All students are fully funded, and eight (8) students have completed or are on the verge of completing the programme. Many have since been propelled into top PhD programmes – e.g. Emmanuel Aoron (Harvard University), Pauline Mbatha (University of Helsinki), Linet Sankau (Arizona State University), and Aggrey Minya (University of Memphis).

The collaborative programme between Turkana Basin Institute and the Turkana University College is a boost to Kenyan palaeoscience, and has been instrumental in supporting and fostering promising young graduate students into PhD programmes abroad. This initiative, one of the most successful of its kind, has not only bolstered the individual careers of these students but also the broader landscape of Kenyan science. Many of these students have taken up leadership positions in major fieldwork projects in Kenya – a testament to the programme's impact on the future of the field.

Many local Kenyans are involved in individual and collaborative research ventures as principal or co-principal investigators. For instance, I am the principal investigator of the Kantis Fossil Site Research Project and collaborate with other international scholars on other sites in Kenya. Moreover, an increasing number of Kenyans are now conducting their own palaeoanthropological/palaeontological programmes, such as the West Turkana Research Project in the Turkana Basin, the Koobi Fora Field School and Research Programme, the Nyeri/Laikipia Paleontological Research Project and the Locherangan Palaeontological Research Programme. Of worthy mention is the growing number of Kenyans undergoing graduate studies internationally, whom we expect will take the discipline into the future.

The progress made in palaeoanthropological research in Kenya, and eastern Africa more broadly, over the past 80 years is evident. This success was greatly influenced by the discovery of the Taung Child in South Africa in 1924, which demonstrated that Africa was the birthplace of humanity and sparked interest in fossil field surveys.

It is important to note the significant growth of local scholars who are now actively engaged in palaeoscience research. Their contributions, in the form of scientific papers and data, are shared at the biennial Eastern African Association for Palaeoanthropology and Palaeontology (EAAPP). The EAAPP plays a crucial role in knowledge sharing and mentorship, highlighting the importance of collaboration in our field and creating a sense of belonging within the larger scientific community.

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Declarations

I have no competing interests to declare. I have no AI or LLM use to declare.

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Looking for the origins of the human brain: The role of South Africa in the history of palaeoneurology

In 1925, Raymond Arthur Dart published his description and interpretations of the 'Taung Child' in the journal *Nature*, including a description of the natural brain endocast associated with the face and mandible. Details preserved in the endocast of the Taung Child have opened critical questions and debates about how the human brain evolved, and how to identify and study evidence of brain changes from fossil hominin crania. In this paper, we review and synthesise methodological innovations (how do we study fossil hominin brains?) and critical conceptual shifts (how did the hominin brain evolve?) triggered by the discovery of the Taung Child. In particular, we detail the impact of the study of the well-preserved crania and natural endocasts from the southern African hominin-bearing sites on our understanding of brain evolution and the integration of newly developed analytical tools into research in palaeoneurology (e.g. imaging techniques, 3D modelling). Additionally, we examine how the use of digital replicas of fossil hominin endocasts and the need to study extant human brains to form a comparative platform might raise questions about research practices (e.g. study and exhibition of fossil and extant human brains) and management of such invaluable heritage resources (e.g. data sharing). We finally consider how our view of human brain evolution, and in particular the putative uniqueness of the hominin brain, has changed over the last century.

Significance:

We review and synthesise methodological innovations and critical conceptual shifts triggered by the discovery and description of the brain endocast of the 'Taung Child' by R.A. Dart in 1925. In particular, we detail the impact of the study of the well-preserved southern African hominin crania and natural endocasts on our understanding of brain evolution and the integration of newly developed analytical tools into palaeoneurology. Then, we examine how the use of digital replicas and the need to study extant human brains might raise questions about research practices and management of such invaluable heritage resources.

[Abstract in* Setswana*]

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Introduction

In 1925, Raymond Arthur Dart published his description and interpretations of the 'Taung Child' in the journal *Nature*.[1] In addition to being the first tangible evidence of the African origins of the human lineage and the type specimen of a new hominin genus and species (*Australopithecus africanus*), the Taung Child preserves a natural brain endocast that initiated intense discussions about the mechanisms involved in the emergence of human neuroanatomical specificities (Figure 1A). As such, the description of the endocast by Dart, and subsequent research on the unique South African fossil hominin record by several generations of biological anthropologists, contributed to a new sub-discipline in biological anthropology dedicated to the reconstruction of the evolutionary history of the hominin brain. Consequently, the Taung Child triggered substantial methodological innovations (how do we study fossil hominin brains?) and critical conceptual shifts (how did the hominin brain evolve?). In parallel, the use of digital replicas of fossil hominin endocasts, as well as the need to study extant human brains to form a comparative platform raises questions about research practices (e.g. the study and exhibition of fossil and extant human brains) and management of such invaluable heritage resources (e.g. data sharing).

The impact of the discovery of the 'Taung Child'

How South African fossils changed the way we study brain evolution

In the absence of brain tissues, palaeoanthropologists have to rely on brain imprints preserved on the inner surface of the braincase (endocasts) to reconstruct the hominin brain evolutionary history (Figure 1). The interest of palaeoanthropologists in fossil hominin brains was likely sparked by successive major innovations in neurosciences revealing the intimate relationship between brain areas and functions. For instance, the identification of the role of Broca's and Wernicke's areas in language would probably have opened new perspectives on how to relate fossil crania with behaviours.[2,3] As such, the end of the 19th century and the beginning of the 20th century was marked by the publication of the first observations of fossil hominin endocasts (*Pithecanthropus erectus*[4]; Neanderthal[5]). Those landmark descriptions simultaneously started a long-standing debate about whether the information that palaeontologists derive from the study of endocasts is reliable.[6,7] Within this context, the discovery of the natural endocast of the Taung Child revived the debate about the reliability of the endocast and initiated key comparisons of the internal aspect of the crania with the associated brains in extant chimpanzees that support the presence of major sulcal imprints in the endocasts.[8] Far from being resolved, the debate persists, and South African researchers and institutions have recently played a central role in the discussion by using imaging techniques applied to living humans to quantitatively and directly compare, for the first time, the shape and organisation of the endocast and the corresponding brain[9], although previous direct observations of primate brain and braincase should be acknowledged[10,11].

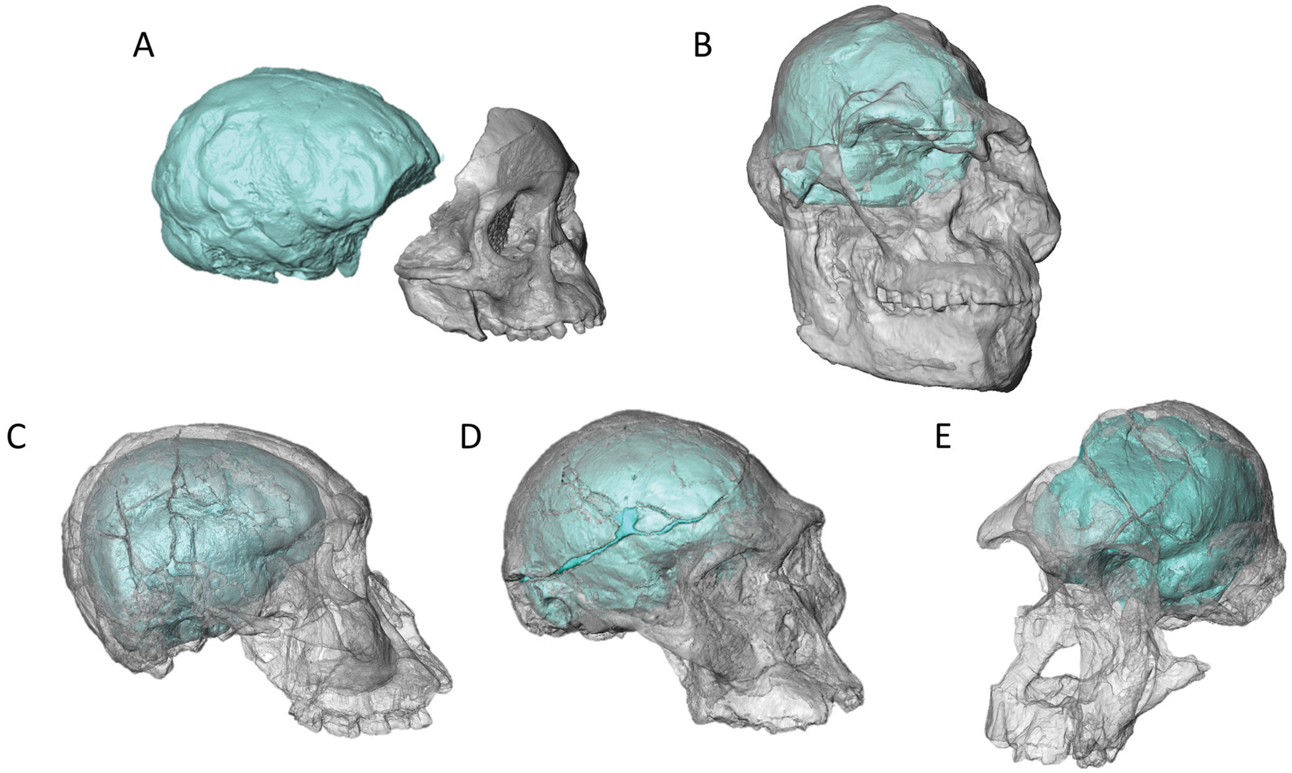


Figure 1: The endocasts of the 'Taung Child' (A) and of some of the most complete southern African *Australopithecus* crania (B: StW 573, C: Sts 71; D: Sts 5; E: StW 505). 3D models derive from surface scanning ('Taung Child') and microtomography.

South Africa has been a leader in the field of virtual biological anthropology since the very beginning of the use of X-rays in palaeontological studies. Early studies using computed tomography were applied to fossil material from the Cradle of Humankind (e.g. MLD 37-38, Sts 71, StW 505; Figure 1) to look at inner features, such as endocranial capacity and vascularisation.[12-14] Additionally, the very first scanning experiment using neutrons in palaeoanthropology was performed on the iconic *Australopithecus* specimen Sts 5 ('Mrs Ples'; Figure 1) at the South African Nuclear Energy Corporation (Necsa)[15], paving the way for future analyses of dense fossil specimens for which X-ray tomography failed to reveal an appropriate contrast between the bone and surrounding matrix[16,17]. Similarly, imaging South African *Australopithecus* crania with X-ray synchrotron radiation was fundamental for observing the fine organisation of the frontal lobe of *Australopithecus*[18] and the intimate details of the braincase[19].

In addition to imaging techniques, the study of South African hominin endocasts contributed to major analytical development. Because the endocast is a complex 3D object, accurately measuring variation in the respective organisation of the lobes and, more locally, brain areas, represents a challenging task (reviewed in [20]). As such, the use of landmarks and semi-landmarks[20], landmark-free surface-based comparisons[21-24] and automated detection of brain imprints[25,26] revealed previously unknown details of South African hominin brains. For instance, surface analysis of the best-preserved South African *Australopithecus* (Sts 5 and Sts 60) and *Paranthropus* (SK 1585) endocasts supported the hypothesis of a more derived brain shape in *Australopithecus* and identified local neuroanatomical specificities in the brain of *Paranthropus*.[24,25] At the same time, computer-assisted analysis of the well-preserved imprints in StW 573, StW 505 and MLD 3a emphasised the necessity of developing new methods for accurately identifying key features, such as the lunate sulcus.[25,26]

The contribution of South Africa to our understanding of human brain evolution

Details preserved in the endocast of the Taung Child have been crucial for opening new discussions about the chronology and processes involved in the emergence of derived neuroanatomical traits in the hominin lineage. Our brain is characterised by a complex structural organisation (i.e. sulcal and gyral pattern) and a prolonged maturation (reviewed in [27]). Interestingly, both aspects could be examined in the endocast from Taung and in the South African fossil hominin assemblage as a whole.

By comparing the endocast of the Taung Child with the brain of living humans and brain imprints in other fossil hominins, Dart identified significant differences used as evidence that *Australopithecus africanus* was a "man-like ape" contrary to early "ape-like man" descriptions of the more recent "Java Man".[1,28] In particular, he noticed that "[…] the sulcus lunatus has been thrust backwards towards the occipital pole by a pronounced general bulging of the parieto-temporo-occipital association areas"[1(p.197-198)]. A human-like posteriorly placed lunate sulcus in the Taung Child would have had substantial evolutionary implications as it would indicate an early reorganisation of the hominin brain. As a consequence, Dart's identification has been intensely discussed in the literature and the possibility of a more "primitive" (i.e. ape-like) configuration of the lunate sulcus and surrounding brain areas has been considered.[29-34] Interestingly, Dart himself corrected his own observations and identifications of brain imprints in the 'Taung Child' (reviewed in [31]), which is a vivid example of the complexity of "reading" brain endocasts.

Following the description of the endocast of the Taung Child, a very detailed description of the endocasts of South African fossil hominins eventually emerged, generating previously unknown knowledge of the neuroanatomical features characterising the brain of extinct species. One of the earliest and most comprehensive descriptions of fossil hominin brain imprints (sulcal and vascular), but also overall dimensions (linear measurements) and shape analysis (superimpositions of contours), focused on the natural and artificial endocasts from Taung, Sterkfontein and Kromdraai.[35] Similarly, pioneer descriptions of the middle meningeal vessels of early hominins were based on specimens from Taung, Sterkfontein and Swartkrans[36], including a previously unrecognised enlarged occipital/marginal sinus system in the Taung Child[37]. Sulcal imprints of iconic specimens in South Africa were further studied in great detail and fuelled critical discussions over the mosaic-like versus concerted evolution of brain areas[29-34,38,39] (Taung, StW 505, SK1585). Knowledge gained thanks to the exceptional quality of the South African fossil record was applied by palaeoanthropologists to the study of eastern African endocasts[40,41], and greatly improved our appreciation of regional and interspecific variation[39,42].

Besides the exceptional degree of preservation of the brain imprints in the Taung Child, the discovery of an immature *Australopithecus* represents a unique opportunity to learn more about fossil hominin brain growth and development. For instance, the interpretation of a possible remnant of the anterior fontanelle in the Taung Child as evidence of late fusion of the metopic suture, and thus prolonged postnatal brain growth, was actively discussed in the literature.[43,44] The comparative analysis of the size of the endocast of the 'Dikika child', found in 2000–2003 in Ethiopia[45], further supported the possibility that a derived pattern of brain growth (i.e. prolonged) might have emerged within *Australopithecus*, although they identified a lunate sulcus in an ape-like rostral location[46].

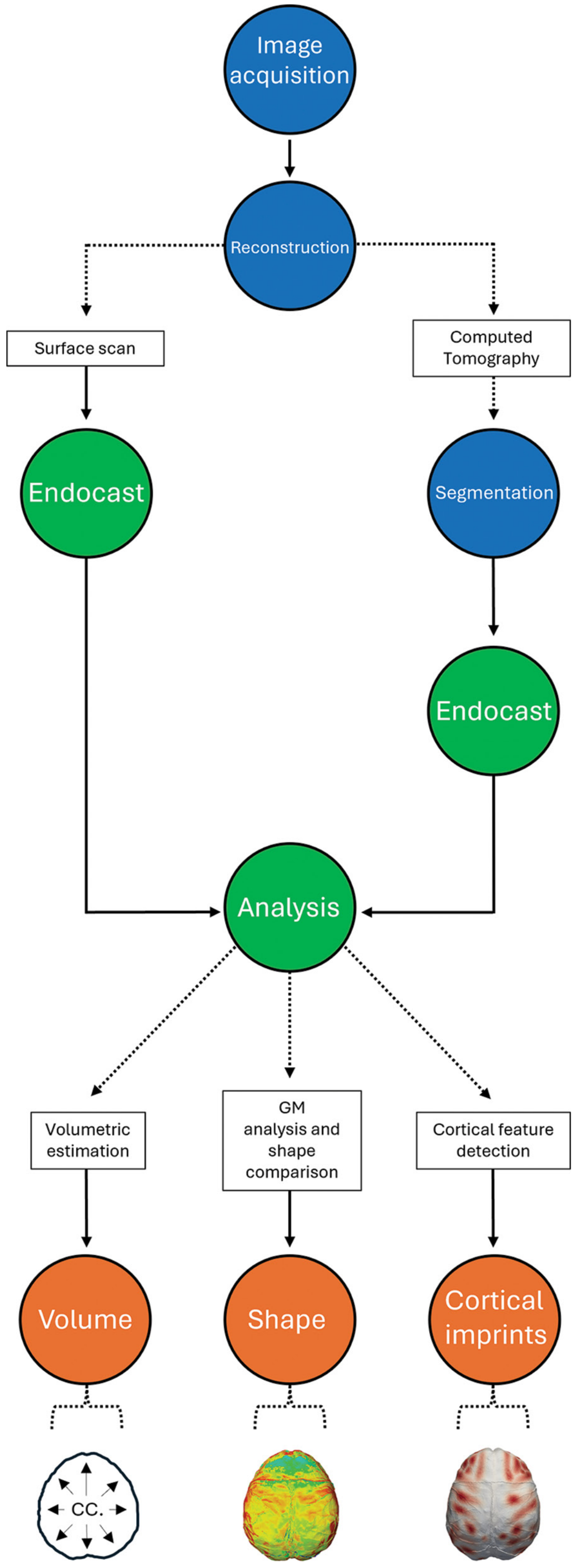
The impact of the discovery of the Taung Child is not limited to the understanding of *Australopithecus* neuroanatomy but is also reflected in the interest of palaeoanthropologists in brain endocasts and their potential in the search for human origins. For instance, the study of the endocast of the small-brained hominin *Homo naledi* found in Rising Star supported the presence of *Homo* species with a brain size similar to *Australopithecus* combined with a derived cortical organisation and rejected allometry as the only factor explaining the human brain specificities.[42,47,48] As such, (re-)analysis of the specimens attributed to *Homo* from South Africa could contribute to the unresolved question of when and how the derived human brain emerged. In particular, conundrums persist regarding the reorganisation of key brain areas, which the examination of South African specimens could help to elucidate. Recent studies of *Homo* specimens dated to 2.03–0.07 Ma from eastern Africa and Eurasia highlight the difficulty of identifying a pattern or evolutionary trends in a highly variable sample, including in crucial brain areas such as Broca's area.[49,50] Although the taxonomic status of some of these specimens is debated, partly due to their fragmentary nature, cranial remains found at Sterkfontein, Swartkrans and Drimolen attributed to *Homo*[51-53] (e.g. StW 53, SK 27, DNH 134) could therefore contribute to the clarification of the chronology of critical changes that affected Broca's area in the human lineage, with potential functional and behavioural implications.

Palaeoneurology today in South Africa

New technologies in palaeoneurology

As previously mentioned, the study of hominin brain evolutionary history is almost completely reliant on cranial endocasts which are replicas of the inner surface of the cranial vault. There are typically two types of endocasts that palaeoneurologists use to study brain morphology in the fossil record. The first type is a natural endocast, such as the endocast of the Taung Child, which is created when fine sediments infiltrate the cranial cavity shortly after death through the cranial foramina and solidify over time.[1] Alternatively, synthetic endocasts are typically created using moulding materials such as liquid latex and Plaster of Paris that are applied to the cranial area of interest.[39] These physical endocasts were analysed using predominantly qualitative methods and provided a platform for controversial debates in part due to the fragmentary nature of data inherent to endocasts, causing observational biases, and in extreme cases a scientific validation for scientific racism.[54] Besides their troubled past, endocasts are the best window into the living brain of our fossilised hominin ancestors and their hominid relatives.[55]

More recently, the introduction of imaging methods into palaeosiences provided palaeoneurology with an improved quantitative empirical approach for studying endocasts and brain evolution in the fossil record (Figure 2). The introduction of computed tomography (CT), 3D laser scanning[56], and, to a lesser extent, magnetic resonance imaging (often used in comparative studies[57]), allows scientists to analyse information quantitatively on a micro level of accuracy and encourages more collaboration as a result of digital data being easily shared through various platforms[58] (e.g. Morphosource). Additionally, CT imaging offers the opportunity to extract endocranial information from some of the most distorted and sediment-filled fossil crania using advanced reconstruction and segmentation techniques. For example, CT imaging enables us to extract the inner surface of the cranial vault through segmentation, where



GM, geometric morphometrics

Figure 2: The typical workflow to analyse endocasts using modern techniques consists of image acquisition using computed tomography or 3D surface scanning to obtain or extract an endocast; following the derivation of an endocast, various analyses can be performed to obtain results.

different materials are defined based on their grey values (determined by tissue densities[59]). Two segmentation techniques are widely used to extract virtual endocasts from fossil crania. The first is manual segmentation, which is more commonly used when fossil crania are filled with sediments (e.g. frontal bone of Taung Child); these sediments are removed to expose the internal table of the cranial vault. Manual segmentation tools are widely available through commercial software such as Avizo (Thermo Fisher Scientific Inc.) or open-source software such as 3D Slicer (www.slicer.rog) to name a few. Alternatively, an automatic segmentation tool can be used to extract the endocast directly from the manually cleaned cranium or from crania that are not filled with sediment. Some specialised open-source segmentation methods are readily available, such as Endex software[60] or, more recently, the R package Endomaker[61]. Both have their advantages and disadvantages, depending on the condition of the cranium.

Following the segmentation and extraction of the virtual endocast, the cranial capacity can be easily calculated, and various analytical methods can be applied in order to calculate shape differences between endocasts using registration techniques or, alternatively, the thin-plate spline (TPS) method[62,63], and surface morphs[64]. Both latter methods are dependent on geometric morphometrics.[63] Additionally, landmark-free surface-based comparisons within which surface deformations between different objects are mathematically modelled as diffeomorphisms were applied to fossil specimens with the objective of quantifying shape differences.[22-24]

In addition to calculating shape differences between endocasts, extensive efforts are being invested in finding ways to automatically detect the imprints of sulci and gyri that the brain imprints on the inner table of the cranial vault. The study of imprints on the surface of the endocasts has extensively improved since the incorporation of 3D imaging techniques. Although visual methods to define sulcal imprints are still used, in some studies, more innovative methods are applied to illuminate sulcal imprints on endocasts. For instance, for the *Australopithecus afarensis* endocast of DIK 1-1 from Ethiopia, the authors used the TPS method to warp a segmented brain of a chimpanzee onto the endocast of DIK 1-1 for comparison. They were able to successfully confirm the rostral ape-like position of the lunate sulcus on the DIK 1-1 endocast using this method.[46] Another method that can be used is the Curvature module in Avizo and various other imaging software to highlight topographical changes on the endocast surface[47]; however, this can be misleading as it still relies on visual observations and does not give quantifiable data on sulcal imprints. More recently, feature detection techniques have been introduced to automatically detect cortical relief on endocasts using a crest line detection method.[65] This method has proven successful in accurately detecting cortical imprints on both fossil and extant human endocasts.[25,50,66] Additionally, this method allows for further analysis of variation of sulcal imprints within species using methods that are typically used in neuroscience.[67]

Methods for studying hominin endocasts have significantly advanced since the discovery of the Taung Child. The rapid advancement of computational methods for analysing imaging data, coupled with ongoing progress in machine learning and artificial intelligence, as well as the expertise on fossil brains developed in South Africa, promise to unveil intriguing mysteries around the evolutionary history of the hominin brain in the immediate future and assist with the subjective nature of the process of identifying brain imprints.[68]

Curation, heritage policy, ethics and dissemination

As detailed in the previous section, fossil hominin endocasts can be studied by palaeoanthropologists as physical or virtual objects. As with any other fossil remains, accessing natural fossil hominin endocasts stored in South African curating institutions (e.g. Ditsong National Museum of Natural History) requires following the procedure established by the *National Heritage Resources Act* (NHRA). The main objective of the act is to conserve, protect, and offer guidance on the management of heritage resources. As such, an application has to be submitted, and access is granted only after careful consideration of the merits of the study and the lack of any detriments that could befall the specimen during the study. However, curating fossil hominin digital endocasts comes with more complexities. Indeed, the situation is dire with regard to digital data[69] and, because of a lack of appropriate infrastructure, records management in most government entities (inclusive of museums as curating institutions) is on the brink of collapse. This lack of infrastructure has created a situation in which the fossil digital data of some museums resides with third parties, because the curating institution is not capable of hosting and managing their own data. Digital data can be passed along to a group of researchers, without due process being followed, as is expected by the curating institutions. Transparency, disclosure and honesty are at times lacking when researchers share digital data.[58] There is still a gap in the legislative frameworks to govern the management of digital data, with the National Policy on the Digitisation of Heritage Resources[70] still in a draft format. Access (open or otherwise) to these digital data/repositories is also yet to be determined by the laws of the country. Open access is believed to have the capacity to address the fragmentary manner in which access to journals and information systems was set up in the past by the apartheid government, which favoured a select few. The belief is that research information and access to data should be set up on a platform that gives equal opportunity to South African scholars and students.[71] Ironically, some of the best-preserved brain endocasts are not subjected to the same extreme scrutiny as most of the well-known preserved hominins in these curating institutions are.

Socially, especially in a South African context, the brain, as a human body organ, is regarded as sacred, and is to be treated with the utmost respect, whether it is fossilised or fresh. When one speaks to the Taung communities about the brain endocast of the Taung Child, one is met with shock, because their traditional and cultural beliefs are that human remains are to be buried, not to be displayed for all to see. The explanation of deep time and accurate scientific information is at odds in this case with the subject of handling and prodding human bodies, which is regarded as taboo, as is donating one's body for research and teaching.[72] In parallel, understanding brain evolution also requires a solid knowledge of the extant human brain through physical or digital (medical imaging) dissection. Contemporary human brains are a requirement for comparative analysis with fossil endocasts, to understand the neuroanatomical underpinnings and associated functional correlates used to inform the narratives about brain evolution. These human brains are sourced from South African health sciences institutions through different modes of consent, which include bequeathal, next of kin and unclaimed. Unclaimed individuals include decedents that have not been claimed by family members; as such, no consent has been provisioned and, in these instances, the inspector of anatomy may "donate" these remains to institutions according to the *South African National Health Act*.[73] Whilst this method of acquiring bodies and brains is legal, it is considered unethical due to the lack of informed consent. However, many institutions in South Africa have made concerted efforts in leading ethical body sourcing in Africa[72]; the School of Anatomical Sciences at the University of the Witwatersrand has been at the forefront of this ethical transition[74]. Good ethical practice, which has not always been a central feature of South African scientific research, is becoming more focused and prominent, evidenced by the inclusion of oversight committees, improved curatorial policies and legislative changes. These interventions garner trust from communities, ensuring their inclusion and donation to the academic programme. Accordingly, it is of the outmost importance that the scientific community is transparent about their research by sharing the findings with a broad public audience, explaining the scientific process and why it requires the use of sensitive material, such as fossils and fresh human brains.

South African scientists invariably contribute to making evolutionary science more visible and understandable to a lay audience. Besides being one of the main tourist attractions in the Cradle of Humankind, the Maropeng Visitor Centre plays an active part in disseminating scientific knowledge and offering educational resources on human origins. Human brain evolution, from Taung to extant humans, represents a key component of the "What makes us human" exhibition and featured in successful exhibits, such as the one entitled "Face to Face: Reconstructing Hominins from the Cradle of Humankind" launched in 2022 and coordinated by Kimberleigh Tommy[75] (Figure 3). Brain evolution being put forward as a major factor shaping human evolution in such popular exhibitions, can likely be considered the result of 100 years of intense research on hominin brains in South Africa, triggered by the exceptional discovery of the Taung Child. This is of particular importance to South Africans due to the fact that the discovery of the Taung Child corroborated to the world that the origins of humankind

Source: Courtesy of EndoMap (reproduced with permission).

Figure 3: Photograph of the exhibit “Face to Face: Reconstructing Hominins from the Cradle of Humankind” launched in 2022 at Maropeng.

were in Africa. In addition, certain studies during apartheid tried to use the human brain as a tool to demonstrate a hierarchy of the endowment of intelligence interracially, which was consequently debunked.[76] Further to which, an accurate understanding of how the brain functions and evolved allowed for the abandonment of earlier egregious ideologies centred on discrimination such as the eugenics movement.

Perspectives

The study of brain endocasts, and the popularity of research on what is considered the most unique and complex organ in extant humans, have certainly contributed to reinforcing the disproportionate interest of palaeoanthropologists in cranial remains over postcranial remains (see Schroeder et al.[77] in this issue) and bias our view on what makes us so special. While the role of the brain in human biological and cultural evolution cannot be denied, the putative exceptional nature of the human brain specificities (i.e. large brain, complex organisation, delayed maturation) is regularly questioned and the uniqueness of humankind reconsidered. For instance, the frontal lobes often feature in research looking for human-specific neuroanatomical traits with behavioural implications, such as the organisation of Broca’s area and language (reviewed in [78]). However, studies on extant great apes have demonstrated that humans do not have particularly large frontal lobes[79] and that this region did not evolve faster than others within our lineage[80]. Moreover, hypotheses suggesting a coincidental emergence of some of the most intriguing characters of the human brain are gaining support (e.g. exaptation of the Broca’s area for language, primary role of the braincase over the brain[81,82]) and question our mechanistic view of human brain evolution while raising new interesting questions (e.g. can we explain human brain evolution?). On a similar note, moving away from the traditional anthropocentric approach, the comparative study of non-related taxa, such as birds, has opened new avenues of research and possibilities to test long-standing evolutionary hypotheses (reviewed in [58]). After 100 years of research on hominin brain evolution, an exciting new journey has begun that will benefit from the development of new technologies (e.g. AI[83]).

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Data availability

There are no data pertaining to this study/article.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors’ contributions

A.B.: Conceptualisation, writing – initial draft, writing – revisions. E.d.J.: Conceptualisation, writing – initial draft, writing – revisions. M.T.: Conceptualisation, writing – initial draft, writing – revisions. B.B.: Conceptualisation, writing – initial draft, writing – revisions. All authors read and approved the final manuscript.

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Unpacking the ‘explorer’ narrative and its impacts on African palaeoanthropology

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The concepts of explorer, expedition, and the combination of the two into the myth of the explorer have been integral parts of Western mentality for more than 200 years. Here we briefly outline the colonial origins of these ideas, and use this crystallised understanding of the explorer myth to consider how African palaeoanthropology in the 20th century and up to the present continues to carry many of these biased, outdated overtones – some more overtly than others. We examine how Raymond Dart and the discovery of the Taung Child were situated and storied within this explorer narrative. We also expand on how these outdated concepts persist in determining which scientific approaches and outcomes are valued and which are not, which in turn has perpetuated extractive approaches to palaeoanthropology and the marginalisation of Indigenous scientists. This is especially notable in fieldwork practices which, to this day, embody the explorer myth’s deeply problematic colonial ideals of Western, masculine moral and cultural superiority. By understanding the mindset behind the discovery and reporting of Dart’s work on the Taung Child, we can better understand why it still holds such sway in palaeoanthropology today, and propose important practical and cultural disciplinary changes that will allow us to move beyond these colonial and masculine ideas in a manner that creates a more equitable future for all scholars.

Significance:

- This paper shows how palaeoanthropology has remained tied to an outdated view of the role of field exploration in science, since the time of Dart’s discovery.
- This is then linked to the disproportionately high number of white men working across Africa who have achieved professional success under this rubric.
- We provide suggestions on how and why the discipline should shift away from glorifying ‘explorer’ science, and towards the work of local African scholars, be it in the laboratory or the field.
- This paper thus contributes to greater awareness of scientific biases, their historical origins, and opportunities for correction.

[Abstract in** Setswana**]

Introduction

The explorer myth in Western Europe emerged from a complex interaction of literary, political, and economic historical developments.[1,2] While 19th century European imperial exploration in Africa can be traced back to the 1400s, it was not until 400 years later that the “exploration of far-off lands” became an integral part of Western Europe’s collective cultural identity.[3] The explorer himself (always a man) was initially distinct from the early travel writer and the later natural historian[1], and often served as an ambassador who facilitated the work of missionaries and traders, and even of natural historian collectors. Their expeditions were journeys that went beyond just travel and engaged in some form of mapping and documenting a new land.[4] The idea of the intrepid European on an expedition, together with the intentional construction of Africa as a dangerous unknown land, combined to form the myth of the explorer.[3]

The timeline of the emergence of the explorer as a distinct identity in Western European thought is important to understand in order to grasp why the explorer mindset is still pervasive, particularly in African palaeoanthropology. We begin by considering how these concepts emerged, and then show how Raymond Dart’s work, particularly on the Taung Child, played a significant role in the field’s development within this mindset. We then consider the continued stronghold of the explorer myth in African palaeoanthropology more generally, and offer suggestions for how to shift this dynamic going forward.

Exploration, Western science, and the expansion of empire in Africa

Until recently, the history of world exploration has generally been considered one of progress, at least from the perspective of the exploring nations, with images of unknown distant lands becoming replaced by scientific knowledge of the world.[1,5] In reality there was a considerable amount of myth-making about the explorers and about the nations they represented.[5] In his 1994 work *The Myth of the Explorer*, Riffenburgh[3] describes how geographical exploration in the 19th century became an integral part of Western mentality. Africa in particular was central to the creation of the explorer.

> *In an era of imperialism and extreme nationalism, when the state was extolled as supreme and the individual was subordinated to, yet made to personify, the nation, men who achieved remarkable feats were more than just popular heroes: they were symbols of real and imagined nationalist or imperialist cultural greatness. Explorers […] were a particularly celebrated genre. They were pictured as journeying into the blank spaces on the globe, where they confronted constant challenges and danger, both natural and human.*[3(p.2)]

The explorers' actions were justified ideologically both by Social Darwinism and the Western demand to ultimately conquer the physical/natural world by "defeating 'barbarism', exporting Christianity, mapping and defining the unknown, and establishing trade" (p. 2). As such, the explorer embodied the collective cultural superiority of the nation they represented (see also[1,6,7]).

Prior to the Industrial Revolution, European engagement with sub-Saharan Africa was limited. The first permanent European building in sub-Saharan Africa, Elmina Fort, was built for Portuguese traders in 1482 by African labourers, and initially served as a settlement for European merchants. It quickly became a central port through which Portugal earned revenue by inserting themselves into the African gold trade and sending enslaved Africans across the Atlantic. This in turn provided the funds for the Portuguese to "discover" the route around the Cape of Good Hope (by following Asian and African sailors), which they reached in 1488, opening the sea trade route between Europe, and Southern and Eastern Eurasia. By the 1600s, France, the Netherlands and Great Britain followed suit in establishing trading posts and settlements around the African coast. But European economic interests in Africa were well served through these coastal settlements for 250 years, precluding a need to operate or explore inland. So, despite the longstanding presence of Europeans in sub-Saharan Africa, the idea of inland 'exploration' did not develop for centuries.[6,8]

When the sociopolitical and technological landscape of Europe began to shift from agrarian serfdom to industrialisation, the demand for natural resources increased. No longer was chattel slavery the primary goal of European exploitation of Africa; Europeans sought to acquire the abundant resources in interior portions of the continent, such as minerals, ivory, and rubber. This dovetailed with the height of what Europeans call their Age of Discovery, and the seeking of new geographies (such as the source of the Nile), people (e.g. pygmies) and flora and fauna (e.g. gorillas). By the late 1800s, Western European policy shifted to what is sometimes referred to as The New Imperialism, which featured an unprecedented pursuit of overseas territories to annex and rule.[9] In 1870, 10% of Africa was under European control; by 1914, as a result of the Scramble for Africa, this increased to almost 90%.[10] Within this seismic geopolitical shift, historians are in general agreement that the explorer was not a mere outgrowth of the invasion, annexation, division and colonisation of most of the African continent, but a facilitator.[3,8,11,12]

One of the key properties of exploration is an exotic setting[13], and Africa was considered remote and primeval. Explorers often storied distant lands as "empty" and thus uninhabited, unclaimed, and free for taking[6,14] – a literary style that distinctly othered Indigenous people[2]. Famously, Africa was mythologised as a Dark Continent in need of discovery and its people in need of enlightenment; Africa and the African were the subject, and the explorer was the intrepid conveyor of said enlightenment.[15] In addition, authority over the natural world began shifting from the church to natural scientists, leading to the data-collection push that dominated the Victorian era, and further creating a desire for exploring lands previously unknown to Europeans.[1,11]

Europeans were also mythologising about themselves, as the process of exploration allowed them to reimagine their heroic efforts as being responsible for "pushing back the frontiers of ignorance and resistance"[5(p.166)].

> *The business of exploration was thus not merely about overcoming distance; it was about the creation of new worlds and the fashioning of new heroic personae. In this perspective, narratives of exploration can tell us as much about the explorers' views of themselves as about the territories and peoples they encountered.*[5(p.166)]

The actors engaging in this process were both distinct and evolving. Travellers or travel writers – typically upper class gentlemen – took the mantle from maritime explorers, heralding the unique challenges that came with exploring inland.[1] The development of a transnational classification system by Linnaeus led to a new agenda among Europeans: that of documenting and classifying the flora and fauna, as natural historians.[1] Essentially, explorers could have multiple intersecting identities, with scientific explorers sometimes also acting as missionaries, traders, pioneers or in other roles.[7] Of course, these explorers were not working alone, and historians now recognise the large numbers of people who accompanied these individuals or facilitated their access, including local porters, guides, leaders, etc., but who have not been written into history or glorified as heroes in the same manner.[16]

During the late 18th and especially the first half of the 19th century, field observation became increasingly standardised through the production of manuals and field guides – an indication of the growing importance of scientific exploration. Ultimately, science itself became a tool of colonialism, and exploration became increasingly undergirded by a practical scientific value along with perceived moral imperatives. By the 1850s, the Royal Geographic Society produced the unique identity of the explorer – embodied in scientific legends such as Stanley, Livingstone, and even Francis Galton – that we still see today: a kind of scientist but operating in service of wider political and commercial (tourism) interests.[6] Early anthropologists trace their origins to these explorers. Forebears of biological anthropology, such as Buffon and Morton, justified the need for finding out more about the people in distant lands and studying them before they "disappeared completely". Studies of 'race' as a key factor underlying human differences, their origins, and especially whether or not human 'races' have one or several points of origin (i.e. polygenism versus monogenism) – and therefore whether some 'races' were more or less human than others – became prominent during the 19th century. Anthropology ultimately provided race-science to validate the need for exploration and political control.[12,17]

Raymond Dart and the study of Taung as "discovery"

> *Raymond Dart, especially, helped to promote the study of physical or palaeo anthropology and to excite a wider public interest in the search for the evolutionary progenitors of modern man. Rather like the Victorian explorers of an earlier era, physical anthropologists uncovered the secrets of the African landscape and paraded their 'discoveries' for the perusal of a curious and receptive audience. In charting the paths of evolutionary development they helped to confirm – by implicit analogy if not outright comparison – the intrinsic superiority of the white races and the inexorable progress of European civilisation.*[18(p.39)]

Raymond Dart was a self-described pioneer, having descended from a stock of early settlers in Australia.[19] He discovered a passion for human evolution and comparative cranial anatomy while at Cambridge. After a brief period of training, Dart's three mentors, Sir Grafton Eliot Smith, Sir Arthur Keith, and J.T. Wilson, recommended him for the newly established position of Chair of Anatomy at the University of the Witwatersrand. Southern Africa could not have been further from the palaeoanthropological action at the time, at least in the view of Dart and his contemporaries in Europe. The centre of human origins was believed to be Asia, and Europe was also yielding a rich fossil record. Dart describes his reaction to being called to this unknown world:

> *The very idea revolted me; I turned it down flat instantly. I did not have, as he well knew, the slightest interest in holding a professorship anywhere; least of all one newly founded, utterly-unknown, as remote as possible from libraries and literature and devoid of every other facility for which I had yearned from earliest sentient manhood.*[20(p.421)]

Yet he ultimately took up the post, a position which soon led to a successful career as a palaeoanthropologist due in no small measure to his acumen at identifying the significance of one South African hominin fossil – the Taung Child – in the story of human evolution.

The details of Dart's serendipitous finding of the Taung Child have been well reviewed[19,21,22] and are further clarified in this volume[23]. Rather than repeat the story, we focus on two points in the context of the explorer mindset in palaeoanthropology. First, although Dart is lauded for the "discovery" of the Taung Child, he made it clear in his biography that he did not actually *discover* the fossil.[19] Indeed, we do not know who did because two crates of specimens from the lime mine at Taung in the Northern Cape were brought to his house by geologist R.B. Young one afternoon in 1924.[22,24] Yet when Dart passed away in 1988 at the age of 95, he was hailed around the world as having *discovered* the fossilised skull of the Taung Child, a humanoid that provided the "missing link" between apes and humans. This may seem like hair-splitting until we consider how his "discovery" came to be storied. According to his obituary in the New York Times, Dart was "the forerunner of some of the most illustrious fossil hunters on that continent, like Dr. Tobias, the Leakey family and Donald Johanson"[25]. From encyclopaedia entries to biographies on the websites of his alma mater institutions, Dart's contribution transformed from one of his astute neuroanatomical skills to one of storying his process of removing matrix from the specimen to "73 days of gruelling chipping and digging"[26]. These imply activities that did not happen: Dart did not travel into the "unknown" parts of Africa to discover the Taung Child, or do the challenging fieldwork himself, both points of which should exclude him from the heroic efforts reserved for the explorer. We need to ask: why the re-storying of his life's work?

To be fair, Dart's relationship with field research was dictated in part by the nature of the South African early hominin sites as mines, starting with Taung. Mine labourers in South Africa were black underpaid migrants who worked under harsh and abusive conditions – not white academics. Later, Dart's colleague Robert Broom more clearly pursued field exploration in his subsequent work in the Cradle of Humankind – which resulted in the recovery of many hominin fossils, including additional members of *Australopithecus africanus* and the closely related *Paranthropus robustus*. But like explorers of an earlier generation, Broom worked under the colonial model of black labourers and white academics. The black workers have been disappeared from history, while Dart's efforts have been reframed (by himself and others) as arduous fieldwork. These are not innocent oversights nor are they unique to Dart, or even to South African palaeoanthropology (as we will discuss later). They affirm that the activity of *exploration* is significantly valued over the equally arduous work of detailed neuroanatomical comparative analysis. To this day, palaeoanthropology exhibits a disciplinary bias towards "missing link" discoveries over slow, steady scientific discernment. By re-framing his work towards this bias, Dart reaped the academic and political benefits of his so-called "discovery" of the (at the time) first australopithecine and earliest human ancestor.

Our second point pertains to Dart's broader research agenda following the Taung discovery, which involved studying living Indigenous South Africans explicitly as models for understanding human ancestors.[27] Most notably, he led the University of the Witwatersrand's Kalahari Bushman Expedition of 1936 where he and his white male colleagues measured, photographed, and casted Indigenous living human bodies.[27–29] Earlier, he had participated in the Italian Scientific Expedition from Cape Town to Cairo, where he tracked a gorilla to be shot, formed his problematic racist ideas about the Great Zimbabwe ruins not being constructed by Africans, and was introduced to the process of making face masks (see detailed discussion of Dart's expeditions in Kuljian[27]). These practices were conducted before Dart arrived in South Africa, with researchers such as Louis Peringuey establishing a growing practice of local race-based anthropometry, including recording the physical characteristics of Indigenous peoples. This in turn was built on a long international history of racist and sexist dehumanisation of Indigenous South Africans, particularly Khoe (e.g.[30–32]). When Dart wrote that the Taung Child skull was representative of "an extinct race of apes *intermediate between living anthropoids and man*"[33] (Dart's emphasis), his interpretations would have been informed by such studies of living Africans, and would have included the attendant implications of them being less human. Broom, a staunch supporter of Dart's ideas following the Taung discovery[34], became a collector of "Bushmen" remains in service of this interpretation[21]. Until fairly recently (and even now in several popular narratives), Dart's engagement in these dehumanising practices was not part of the conversation around his legacy (but see[18,27]), despite being central to the search for, and understanding of, human origins. Such a mindset is consistent with the foundational beliefs of European exceptionalism and the need to 'civilise' Africans that undergirded early exploration and the explorer identity.

While Dart's 'hands-off' approach to collecting fossils, and his strong connection to European centres of Western academic power, are consistent with earlier periods of African colonial exploration described earlier, he also famously stood up to these centres in his decision not to circulate the Taung Child overseas, and to rather keep it for study in South Africa.[35] Moreover, by arguing for the origin of humanity in South Africa, Dart was entering an informal scientific competition for the rights to this title that was decidedly nationalistic.[18] He challenged the narratives of these European centres with their prevailing – and implicitly anti-black – ideas for human origins in Asia or Europe. His argument was widely disregarded by his former mentor and colleagues in Europe and his advocacy came at a price. Dart's subsequent attempts to gain employment back in Britain were unsuccessful, leaving him resigned to remaining in South Africa, and ultimately abandoning engaging in international debates for decades around the relevance of the Taung Child to human origins.[36] So while Dart benefitted from the discipline's colonial/explorer mindset that prioritised discovery over other forms of intellectual contribution, he was also a victim of its emphasis on the exceptionalism of European capabilities/intelligence over any other region.

The explorer myth and its continued stronghold in palaeoanthropology

The explorer myth in palaeoanthropology did not begin with Dart: anthropology as a discipline is rooted in the idea of colonial exploration, tracing its origin in part to organisations such as the Royal Geographic Society.[6] Palaeoanthropology developed as a subdiscipline within this colonial mindset of expedition and discovery[37], and these are still familiar themes today. Yet, the announcement of the discovery of the Taung Child 100 years ago opened the door for palaeoanthropologists to shift their focus to Africa. Treating it as the Dark Continent to be "discovered" by a white man in a pith-helmet is not just a part of Dart's origin story, but of palaeoanthropology's.

While sensibilities around viewing Africa in this way have shifted over the past century, palaeoanthropology continues to elevate the myth of exploration and "discovery" as noble pursuits for Western science. This is manifest in a couple of ways. First, fieldwork in Africa remains focused on discovering and establishing new palaeontological finds that "rewrite" the story of human evolution. This valorisation of fossil discovery has led to an outsized value being placed on finding the "first" of something, or of naming a previously unknown entity (e.g. a new species) regardless of whether it is good science. This plays out in publication currency, with the high-profile scientific journals *Nature* and *Science* the go-to repository for descriptions (and cover photos) of almost all new hominin species in the last century. In this sense, the outdated explorer myth still determines which (and whose) scientific approaches and outcomes are valued and which are not. The Taung Child story is an early example of how the competition between scientists for "firsts" is central to the human evolution story, but it is far from the only example. The tendency to place outsize value on "firsts" has in turn contributed to a proliferation of new genera and species[38] as well as a minimisation of other contributions that are valuable pieces of the bigger puzzle and answer important questions. Together, these practices have done a disservice to the quality of science that is produced in human evolution studies.

Second, palaeoanthropology remains dominated by men from the Global North, and from the Western Hemisphere. This aligns with the prototypical 'explorer', both within the discipline and, perhaps more importantly, within the international press. These values have in turn perpetuated extractive approaches to palaeoanthropology, especially fieldwork practice, with African scholars receiving little to no (or at best, belated) recognition of their talents and contributions, and with African women in particular massively underrepresented in the discipline. Thus, to this day, despite the explorer myth's embodiment of deeply problematic colonial ideals of Western, masculine moral and cultural superiority, it is perpetuated in the practice of 21st century palaeoanthropology. Many books have been written about the dominance of big, bold Western male personalities – "hero" fossil hunters on their quests to discover "missing links" – so we will not detail this here and instead refer the reader to these accounts (e.g.[39–42]). And several of the historical examples of palaeoanthropological exploration across the rest of the continent more clearly align with the masculine heroic global explorer mentality outlined above than Dart's story did. But what is important to note is how the masculine values of competition, dominance, confidence and toughness have become internalised in the discipline, impacting the success and well-being of others.[43] The fact that these Western scientists have historically not actually been the people finding the fossils – more often than not they were discovered by hired black field workers who reaped no academic credit nor headlines – further highlights how palaeoanthropology has modelled itself after colonial exploration.

With this in mind, one of the clearest contemporary manifestations of the explorer mindset is helicopter research, where many of the elements of historical colonial explorers still hold today.[44,45] Helicopter research – also called parachute research or neocolonial science – is increasingly attracting critical attention as a cause for concern (e.g.[46–49]). The practice involves researchers from wealthy (typically Global North) countries conducting short-term research in less resourced regions of the world (typically Global South) with little to no meaningful involvement from local researchers or communities. These extractive practices have been commonplace in human evolution research in Africa (and beyond) over the last century, and have resulted in a persistent dominance of Europe and North America in research outputs to this day. Critics of helicopter research have pointed out that in order to mitigate this practice, communities or local (often early career) researchers must be given power and voice in the form of actively shaping the conceptualisation, design, development and publication of research.[44,46]

Specific fieldwork practices are also problematic, with high-profile projects often controlled by Western researchers whose access to funding leads to them being centred in media coverage, even when the fieldwork teams themselves are composed largely of Africans. Even the clothing often chosen by Westerners recalls the colonial explorer, such as Indiana Jones style hats and vests. This continued glorification of the explorer through the media and into the public realm is a symptom of the colonial mindset of our field persisting until the present.

Where do we go from here?

We recognise that palaeoanthropology is by its nature explorative – so how do you keep the good parts of that while eliminating the bad? We argue that palaeoanthropology needs to look closely at how exploration is conducted and by whom, in order to recognise and eliminate its racist and patriarchal colonially derived explorer elements. The positive aspects of exploration – the excitement of the search for new data, and the thrill of finding it – can still benefit our discipline, attract young scholars, and even secure funders, while purging the deeply problematic elements of the past that diminish other kinds of contributions, but it will take conscious effort. We believe there are three key interventions that need to happen in order to move us to create this culture shift: changing demographics, enhancing African research and support networks, and having tough conversations.

It has been a century since the publication of the Taung Child, and yet we still struggle to identify women in palaeoanthropology who have benefitted from networks of private funding (sponsorship) for their research, and easy access to media coverage (including high-profile talks, tours, quotes, etc.), comparable to their male colleagues. The men who have most obviously succeeded in this system are valued precisely for demeanours and approaches that fit into the explorer archetype developed during colonial times, because this meets the expectations of the funders and funding bodies, but also the public. It does not, however, serve the science of palaeoanthropology and its need for solid evolutionary theory, diverse African-led teams, and the application of sophisticated analytical methods to existing data. Dart's true contribution as an excellent neuroanatomist who was willing to take on the orthodoxy of defining humans is a more critical piece of his story – and substantially less problematic – than his forays into explorer tropes.

It almost goes without saying that, today, people engaged in exploration should reflect a diverse demographic of scientists and storytellers from across the globe (two of us, K.M. and S.A., both women of colour, are among the National Geographic Society's recently named Explorers). At the local level within the realm of palaeoanthropology, South Africa is renowned for its significant fossil discoveries, particularly in the Cradle of Humankind World Heritage Site which has yielded some of the most important hominin fossils in the world. However, African researchers, particularly women, are nearly invisible in palaeoanthropology. This has been the plight of the discipline for a very long time, and much discussion on the matter has taken place in various workshops at higher education institutions. Until recently, no programmes or formal structures had been put in place to address the issue. However, today we see an intentional movement by various institutions, organisations and funding bodies to recruit, support and highlight the research of young Africans in the field. The most notable example in South Africa is the Human Evolution Research Institute at the University of Cape Town whose mission statement elevates diversity and inclusivity to the same level as its scientific goals. We are not naïve in thinking that simply changing demographics will solve our problems; however, it is now a well-established fact that diverse teams produce better outcomes. In the context of the explorer narrative, substantial African representation at senior levels may shift the field's discourse – and value system – away from valorising exploration and discovery, which comes at the expense of other critical advances in understanding human origins. Through this, the mission of palaeoanthropology can be reframed from exploration in the colonial sense to investment in the work and ideas of a diverse, global community of researchers.

Related to this, we need to balance the diverse needs of our science by supporting (and glorifying!) thorough and well-trained scientists and technicians – particularly Africans and women – in addition to explorers and discoverers. This can come about through a shift towards collaborative networks that centre African scholars in knowledge production, thereby changing the dynamics around who produces knowledge and who is excluded from doing so. Meaningful collaborations between foreign and African researchers are not sufficient. We need African networks that encourage cutting-edge research among African institutions to grow our research strength in Africa. There are specific funding opportunities (local and global) that are targeted at exclusively supporting Indigenous/local researchers working on research projects within their home countries, but we would like to see more of these as they play a crucial role in facilitating the changes we propose. Such opportunities financially empower local scientific endeavours and support the movement to limit helicopter/parachute science in support of real collaborative endeavours where Africans have the lead role, and promise to deliver new postcolonial research questions and approaches. In South Africa, the Palaeontological Scientific Trust (PAST) is a funding body that was established 30 years ago and has made an important impact in supporting research and education across the continent, albeit working within a constrained local budget. Internationally, two of the most prominent funding bodies that support palaeoanthropological research and exploration in Africa are the Leakey Foundation and the Wenner-Gren Foundation. In recent years they have supported a growing number of young African researchers and other researchers of colour; however, they still overwhelmingly fund students at Western institutions, maintaining colonial dynamics in training. There are exceptions to this, such as the Wadsworth African scholarship, which focuses on Africans who are trained at African institutions. Another exception is the recent award to one of us (R.R.A.) and colleagues of a Wenner-Gren Foundation Global Initiatives Grant specifically targeted at providing short-term training for African graduate students in laboratories and field sites with African principal investigators, from African institutions.

Finally, we strongly believe that having tough conversations around issues like the one we have focused on in this article is key to helping us move forward as a discipline. We recognise that these conversations can be difficult, and sometimes feel quite personal, but they are necessary for making the kinds of changes detailed above, and for guiding new practice going forward. In this regard, we want to highlight a Wenner-Gren funded workshop to be held in South Africa in 2025, entitled 'Theorising a More Socially Responsive Practice in African Palaeoanthropology', with the goal of co-creating best practice guidelines to help researchers move away from extractive science to a more engaged and ethical research practice that shifts the way palaeoanthropology is done. We are encouraged by this and the other funding developments detailed above and would like to see more such programmes. In particular, we encourage international funding bodies to follow the lead of the Wenner-Gren Foundation, by considering their funding schemes and how they can be used positively to facilitate internal growth in the countries from which palaeoanthropological resources derive, to become leaders in breaking down the legacy of colonisation.

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Data availability

Not applicable.

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We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

R.R.A.: Conceptualisation, writing – initial draft, writing – revisions, funding acquisition. K.M.: Writing – initial draft. S.A.: Conceptualisation, writing – initial draft, writing – revisions. All authors read and approved the final version.

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The development of chemical approaches to fossil hominin ecology in South Africa

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When Dart recognised the fossilised skull of the Taung Child as a hominin ancestor, he also observed that its "sere environment" produced few foods preferred by African apes in equatorial forests. He thus set in motion an inquiry into the dietary and environmental proclivities of fossil hominins. His observations ultimately led him to suggest a strong reliance on meat-eating, later elaborated into a hunting model. Subsequent investigations into the diets of the South African australopithecines led to the development of new approaches including dental microwear, stable light isotopes, and trace element analyses, which together led to a new focus on the prime importance of plant foods, for which there had been little direct behavioural evidence. Here we review why and how stable and radiogenic isotope approaches to hominin diet and residence patterns were developed in South Africa, the problems that had to be addressed, and the subsequent outcomes.

Significance:

We outline how a distinctive set of circumstances in South Africa combined to produce world-leading progress in palaeoanthropological and archaeological research based on fossil isotope biogeochemistry. They include a unique natural and fossil heritage, investment in scientific infrastructure and researchers well-versed in cross-disciplinary science. Together they played leading roles in addressing important questions about African fossil heritage. We point to where we believe future progress is required and we suggest that closer attention is paid to the role of plants because, as the basis of all ecosystems, they represent the most important element in the diets of most primates and hominins.

[Abstract in** Setswana**]

Introduction

Raymond Dart's recognition of the Taung skull as an early hominin in 1925[1] set in motion the discovery of further sites and hominin specimens and taxa in South Africa and later in eastern Africa. The taxa of primary interest in our review of events here are *Australopithecus africanus* from Taung, Makapansgat, and Sterkfontein, and *Paranthropus robustus* from Swartkrans, Kromdraai, and Drimolen. Dart recognised that the dentognathic morphology of the Taung fossil differed from that of extant African apes and believed that the ancient environment of the Buxton Quarry, North Western Province was arid and open compared to the favoured forests of chimpanzees and gorillas.[1] These observations led him to consider how they survived and what they ate in such an apparently unforgiving "sere" landscape. Given the apparent paucity of food favoured by forest-loving apes, Dart began to explore the possible role of animal flesh.[1,2] In the early 20th century, the existence of large-scale environmental shifts in the southern African Pleistocene was not yet recognised, although the extensive freshwater tufas and calcrete deposits associated with Taung attested to wetter periods in the past[3], nor did the associated fauna suggest particularly arid conditions[4].

Dart further developed the meat-eater interpretation based on his findings at the older site of Makapansgat, where he found further *A. africanus* specimens and especially abundant mandibles, distal humeri, and proximal radii and ulnas of varied fauna. He concluded that these remnants were weapons used to hunt and prepare prey, leading to his "osteodontokeratic culture" hypothesis for *A. africanus* behaviour.[5] This interpretation was highly influential and underpinned a belief that early hominins, and by implication humans, were naturally bloodthirsty killers – "not in innocence and not in Asia was mankind born"[6]. Dart's "osteodontokeratic culture" ideas comported well with the "Man the Hunter" framing concept, which remained influential for decades.[7]

Dart's ideas were also testable and ultimately led to the founding of several new, crucially important fields in African palaeoanthropology. The first is broadly related to the formation of bone-rich cave deposits where the South African palaeontologist C.K. Brain dissected the evidence at Makapansgat and similar karst dolomitic sites. He concluded that the bone remnants were rather the products of carnivore damage and depositional fragmentation.[8] In doing so he built a distinctive field of taphonomy related to Plio-Pleistocene cave site processes, and more broadly, to palaeoanthropological site formation processes. The next important outcome was the development from the late 1970s onwards of a suite of quantifiable approaches to examine hominin diet. These included analysis of dentognathic morphology[9], dental microstructure[10], and macroscopic damage patterns from crushing, biting, or chewing food items[11]. Scanning electron microscopy was used for the first time to characterise the microscopic traces of damage on molar surfaces resulting from food processing and consumption[12,13] – an approach well-placed to test the 'hard object' hypothesis first mooted by Jolly[14]. Fred Grine's work at the University of the Witwatersrand showed significant distinctions between *Australopithecus africanus* and *Paranthropus robustus* molar occlusal surfaces, suggesting the consumption of "hard brittle objects" (e.g. hard fruits and nuts) for *P. robustus*, but not *A. africanus*. The latter's molar microwear seemed most consistent with a diet of fleshy fruit and leaves.[12,15]

The suggestion that *A. africanus* had a diet of primarily fleshy fruits and leaves and *P. robustus* ate small, hard, seeds, and nuts could potentially be tested based on their carbon isotope compositions. There is a sharp distinction in carbon isotopes between plants following the C_3 photosynthetic pathway (trees and most shrubs with their fruits and nuts) versus C_4 grasses or sedges (and the animals that eat them). Fortunately, the South

African australopithecine sites fall squarely in regions where the grassy vegetation is dominated by C_4 grasses.[16] Thus, *it was feasible* that carbon isotope analysis might allow one to test such dietary hypotheses. For instance, *A. africanus* should have a diet dominated by C_3 vegetation (as do chimpanzees today) if it ate fleshy fruits and leaves from trees, and the same would be true for hard-object-eating *P. robustus* unless those hard items were derived from C_4 plants (e.g. rhizomes, corms, grass seeds). The apparently insurmountable obstacle was the widely held belief that the original isotopic compositions of fossils should have long since been obliterated by diagenesis. Efforts to overcome such issues required decades of work to explore the potential and overcome the scepticism. This paper is the story of those efforts which were played out principally in South Africa. We will touch on direct extensions of this work in eastern Africa, and on other tools derived from chemistry that may be poised to contribute to the dialogue about early hominin diets. However, the story here, like that of the Taung Child, is largely South African. Other recent reviews are available for those seeking an overview of early hominin diets[17], the isotopic contributions to such research[18], and the diverse geochemical tools used for palaeodietary research[19].

Background and development of stable light isotopes in South Africa

Two South African isotope hubs

By the late 1970s, the value of stable carbon isotope patterns in plants, animals, and humans had become clear following earlier discoveries of a second photosynthetic pathway (Hatch-Slack or C_4) in tropical grasses, structurally and isotopically distinct from plants using the earlier identified Calvin-Benson/C_3 pathway.[20] These differences carry implications for the calibration of radiocarbon dates when ingested by animals and humans. At the Quaternary Dating Research Unit (QUADRU), CSIR, in Pretoria, John Vogel mapped the distribution of C_3 and C_4 grassy vegetation across South Africa, demonstrating the strong influence of rainfall seasonality and growing season temperatures[16] and then that vegetation patterns are similarly reflected in animal tissues today[21] (a publication at the same time as the well-known laboratory feeding study by DeNiro and Epstein[22]) and in the past[23]. At the same time, he began to collaborate with Nikolaas van der Merwe at the University of Cape Town to explore human bone collagen $\delta^{13}C$ patterns in archaeological sites in North America[24] and South Africa[25]. The establishment of a new stable light isotope/geochemical facility in the Archaeology Department, University of Cape Town, shortly afterwards, provided a second hub to address multiple environmental and dietary questions arising in the archaeological and palaeontological records.

A series of fundamental studies to apply stable light, and later radiogenic, isotopes to explore patterns of human diet and mobility followed. These were based on sharply defined archaeological questions and an understanding of broad landscape-scaled variability – they produced the forerunners of what are today sometimes referred to as 'isoscapes'. It was shown, for instance, that while carbon isotopes reflected the proportions of marine foods in the diets of coastal hunter-gatherers[26], nitrogen isotopes did not. Rather, they reflected not only trophic, or marine vs terrestrial inputs as earlier thought[27], but also the influence of regional aridity on plants and animal physiology[28,29]. These effects remain important considerations for understanding modern or archaeological foodwebs in eastern and southern Africa.[30,31]

Beyond bone collagen – bone and enamel biominerals

Early in the 1980s, collagen, the main protein in bone, was the tissue of choice in both carbon (and later nitrogen) isotopes and radiocarbon research because it was relatively well characterised and understood and could be readily and quantifiably purified.[32] The mineral phases of both bone and tooth enamel (calcium phosphate bioapatites) include carbon in the form of substituted carbonate (CO_3^{2-}) from blood bicarbonate as the product of catabolic and respiratory processes.[33,34] Enamel is more stable due to higher crystallinity and long-range order in the form of prisms. But it has a far lower organic content and, as bone collagen had become important in both radiocarbon and palaeodietary research, early efforts to determine whether reliable isotopic information could be extracted from bone concentrated on attempts to remove, chemically, diagenetic components from bone. Two influential publications suggested that archaeological bone bioapatite could[35], or could not[36], be purified to deliver reliable carbon isotope data when compared with bone collagen from the same samples. The first used a protocol developed for radiocarbon dating, applying a dilute acetic acid wash to bone powders, which yielded consistent relationships in $\delta^{13}C$ values between animal bone collagen and bioapatite.[35] This conclusion was disputed based on a study of human and faunal bones, using a different (concentrated) acid wash protocol, which showed significant excursions for the human bones.[36] Both the distinct pretreatment protocols and the inclusion of humans turned out to be important.[37]

A different approach was needed to test whether carbon isotopes in bioapatite could be extended further back in time, which did not rely on collagen $\delta^{13}C$ as the benchmark. The solution was to construct a time-series of bioapatite carbonate $\delta^{13}C$ from fauna with well-understood diets, with a focus on browsers with predictably C_3 diets (trees, shrubs, and herbs) and therefore relatively negative $\delta^{13}C$ values (ca. $-12‰$).[38] The expectation was that diagenesis should shift browser values towards the more positive matrix ($\delta^{13}C$ near $0‰$). Purification protocols were tested for their effects on bioapatite chemistry.[39] The 3 Ma $\delta^{13}C$ time series showed that the sharp distinction between grazers and browsers held even in the oldest samples[38], and, notably amongst the older Plio-Pleistocene samples, enamel was more reliable than bone apatite[39,40]. Enamel has since become the standard tissue of choice in fossil biogeochemical studies.

Pretreatment protocols have nevertheless continued to be a controversial topic, partly because the mechanisms – via internal crystal rearrangement and/or ionic exchange – remained unclear. Experiments monitored by infrared spectroscopy and Isotope Ratio Mass Spectrometry (IRMS) showed that the changes in enamel during fossilisation were primarily rearrangements of carbonate ions rather than external replacement.[41] This suggests that not all forms of diagenesis impact isotopic composition, which remains surprisingly robust in enamel. Some pretreatment protocols can, however, cause shifts in isotopic composition, for instance, even standard Chlorox treatments to eliminate organic components lead to measurable addition of modern carbon to bone apatite carbonate.[42] It seems that a light touch is preferable.

Applications in the fossil record

Stable light isotopes

These findings paved the way for application in the fossil record. Two baboon taxa from Swartkrans, *Theropithecus oswaldi* and *Papio robinsoni*, believed to be C_4 grass and C_3 feeders, respectively, following their dentognathic morphology and the habits of their modern congeners[14], were shown to be sharply distinguishable based on their stable carbon isotope compositions. This finding opened the door for permission to address the diets of hominins in Swartkrans, and later, other sites. Although dental microwear had suggested *P. robustus* ate small hard objects (e.g. seeds or nuts from C_3 plants)[12,15], carbon isotope ratios showed a modest but significant incorporation of C_4-derived carbon. The data suggested that 20–30% of carbon was derived from C_4 plants directly or indirectly via ingestion of animals dependent on those resources. The hominin carbon isotope data were distinct from the baboons present at the site (*P. robinsoni* and the large-bodied *Dinopithecus ingens*).[43] The same pattern was repeated at other sites where *Paranthropus* occurred (Kromdraai, Drimolen).[44] Analysis of older *A. africanus* at Makapansgat Member 3 gave somewhat similar, although more variable results.[45] A similar pattern emerged for Sterkfontein M4.[46] We now know that variability amongst *A. africanus* individuals is higher than almost all other hominins for which we have data.[47] It is greater than that of all cercopithecids from the South African hominin sites combined.[48,49] This variability speaks to occupation of a broad ecological niche.

A high-resolution laser-ablation-based carbon isotope study of molar crown tooth fragments of *P. robustus* and *A. africanus* individuals showed that high inter-individual variability was accompanied by high intra-individual variability in both hominins, speaking again to a broad isotopic dietary niche for individuals and groups.[50,51] It must be acknowledged, however, that the true extent of intra-individual variability is muted by the effects of enamel maturation and inevitable sampling across growth lines even with high-resolution laser sampling. So we must accept some smoothing.[50,51]

These carbon isotope data reflect the mix of C_3 or C_4 plants at the base of the food chain and where multiple carnivores, omnivores, and herbivores are present, they provide a means to interrogate predation patterns amongst the remains. The carbon isotope ratio data suggest that the australopithecines and baboons were most likely targeted by leopards, hyenas, and *Megantereon*, lending support to Brain's 'predated by leopards' hypothesis.[52]

There were broader outcomes that touched on variability in $\delta^{13}C$ of both modern and fossil fauna.[48,53] These data have contributed significantly to a better understanding of niche space, breadth, and overlap amongst modern and extinct animals. At the continental sub-Saharan African scale, large-scale diachronic C_3-C_4 vegetation shifts visible from the pedogenic carbonate $\delta^{13}C$ record of eastern Africa were mirrored in faunal tooth enamel and ratite eggshell $\delta^{13}C$ records, suggesting that the timing of C_4 grass expansion in the Late Miocene began earlier in low-latitude eastern Africa compared to South Africa.[54] Subsequently, analyses of multiple late Miocene herbivore lineages from northern Kenya showed that a switch to C_4 grasses varied between and amongst families. Equids became the earliest dedicated C_4 grazers after 10 Ma, while suids and bovids were slower and more varied in response through time.[55] Patterns related to Plio-Pleistocene hominins are discussed below.

Exploration of the potential and implications of the oxygen isotope ($\delta^{18}O$) composition of enamel in addition to $\delta^{13}C$ occurred in both eastern and South Africa, based on data from both modern ecosystems and the fossil record. Interest in $\delta^{18}O$ was initially directed at inferences related to precipitation[56], but it became apparent from studies of modern and fossil assemblages that dietary and water source related information could be extracted.[57–59] For example, it was observed that water-independent animals had higher $\delta^{18}O$ values than those that drank frequently or lived in water (from which a palaeoaridity index was derived)[60], carnivores had lower $\delta^{18}O$ values than most herbivores[59], and $\delta^{18}O$ values increased as animals fed higher in the canopy[61]. Most isotopic studies now routinely report both isotope compositions and large databases exist for both South and eastern Africa.

Strontium and hominin behaviour

In the University of Cape Town's (UCT's) Archaeometry Laboratory, parallel developments were pursued in the realm of trace elements, mostly Sr/Ca ratios, and later strontium isotopes in collaboration with Geological Sciences. The Sr/Ca approach had long been considered a means to address trophic level, given the known discrimination against strontium in the mammalian gut, resulting in a trophic cascade in simple systems.[62] Initial work focused on developing protocols to extract unaltered or at least minimally altered bone apatite.[63,64] As a result of UCT's proximity to good African mammal collections, strong differences were soon noted in the Sr/Ca ratios of herbivores depending on the nature of the plants they ate. For instance, grazer Sr/Ca ratios were higher than those of browsers, which, in turn, overlapped strongly with carnivores.[65] Although initially surprising, the outcome follows the principles of Sr transport in plants.[66] It suggested that Sr/Ca ratios in fauna were dominated less by trophic level (as assumed for decades) than previously thought and led to the exploration of trace element patterns in tooth enamel rather than bone apatite.[67,68] These patterns showed that grazers, browsers, and carnivores from Kruger National Park and South African australopithecine sites could be distinguished using elemental ratios (Sr/Ca, Ba, Ca, Sr/Ba). Further, application to *A. africanus* and *P. robustus* showed distinctions between the two species, with the former having high Sr concentration and low Ba concentrations that are most consistent with the consumption of underground storage organs.[67] Overall, the trace element data for both australopithecines are consistent with herbivory, although some animal food consumption cannot be excluded. A subsequent study of early *Homo* from Swartkrans suggested it consumed more animal foods than the australopithecines[68], but interpretation of these data remains equivocal[69]. One important outcome of these studies is that we can deduce that plants and their distributions are important determinants of fossil trace element ratios.

A further outcome of this work was the development of strontium isotopes to explore ranging or residence patterns. The highly variable but patterned geology of the Cradle was shown to be reflected in significant strontium isotope differentiation across landscapes.[70] Sillen et al.[70] suggested that hominins could be "tracked" across the isotopically patterned landscape by comparing their $^{87}Sr/^{86}Sr$ values to that of rodents and other fauna whose movement patterns could be reasonably conjectured. Firmly establishing predictable strontium isotopic patterning across the highly varied geology of the Cradle zone was a crucial step in this endeavour that is now considered essential in all such studies.[70,71] Laser ablation analysis of australopith tooth enamel showed that small-toothed (inferred to be female) individuals were more likely to be non-local than the large-toothed (assumed to be male) individuals, suggesting dispersal patterns similar to those of chimpanzees and bonobos.[71] Subsequent work supported this interpretation.[72] New developments in enamel-based palaeoproteomic sexing may allow the finding of female dispersal to be tested with more rigour[73], promising that we may be in a position to distinguish between male and female residence and mobility behaviours.

Beyond South Africa

Many of these new approaches were expanded to hominins and fauna in eastern and central African sites, which span from at least 5 Ma across multiple basins. However, obtaining access to the fossils took years, and only became possible after a small study of Tanzanian specimens of *Paranthropus boisei* and early *Homo*.[74] Van der Merwe and colleagues showed that *Homo* and *P. boisei* had highly distinct $\delta^{13}C$ values. This finding was not unexpected given the large differences in masticatory morphology of these taxa, but the strong C_4 signal in *P. boisei* was unlike that of any living or fossil hominoid encountered previously. The study was hampered by its small sample size: three *Homo* and two *P. boisei* specimens, and, despite the exciting results, such meagre evidence did not convince palaeoanthropologists to abandon decades of thinking about masticatory functional morphology and hominin diet. It was enough, however, on which to base a successful proposal to sample hominins from the National Museums of Kenya by one of us (M.S.), Thure Cerling, and Fred Grine. The result was a flood of new hominin isotopic data.

There is now a large body of data documenting shifting dietary ecologies of fauna and hominin taxa. These data from southern and eastern Africa, as well as from one site in the Sahara, point to increasing engagement with C_4 plants that began at least 3.7 Ma years ago[75], which, while somewhat later than other African herbivore lineages[55], increased in variable degrees until an apogee represented by *P. boisei* in eastern Africa[74,76].

The standout result is that *P. boisei* consumed astonishingly large amounts of C_4 carbon, perhaps 80%, before becoming extinct at about 1.3 Ma.[74,76,77] Their dedicated C_4 diets, with very low isotopic niche breadths, stand in strong contrast to those of early *Homo* in eastern Africa, which were highly variable but mostly C_3 until 1.65 Ma when they encroached on *P. boisei* carbon isotope 'space'.[74,78,79] When the carbon isotope data are combined with evidence from dental microwear[80] and tooth chipping[81] that suggest a folivorous diet, the most likely C_4 resource consumed by *P. boisei* is grass or sedges. This comports well with comparative mammalian studies, as all large-bodied herbivores with *P. boisei*-like carbon isotope composition eat grasses, especially their above-ground parts. The underground storage organs (USOs) of grasses and sedges are also potential candidate foods for *P. boisei*, and there is no reason to expect they were not eaten to at least some extent. The chief argument for USO consumption among *P. boisei* is that its teeth are flat, which is typically what we find in primates that eat hard foods like nuts, and not tough foods like leaves.[9] The main argument against a diet of underground storage organs comes from dental microwear, as primates that eat such foods have heavily pitted and chipped teeth[47,81] because of adherent grit particles. *Theropithecus*, the only grass-eating specialist among the catarrhine primates, also lacks heavily-pitted molars despite the consumption of USOs, but it eats larger quantities of above-ground foods.[82] For the USO interpretation to hold, evidence showing that primates can have diets dominated by USOs without pitting and chipping caused by adherent grit is required (see [83]).

There is also increasing interest in using strontium isotopes to track landscape use among eastern African hominins.[84,85] Recent work has established that there can be Sr isotope differences between gallery forest and savanna grasslands in Uganda[85] (similar to [70] in South Africa), and there is preliminary work establishing Sr isotope isoscapes in Tanzania and Kenya[84]. However, a previous attempt to use Sr isotopes at Olduvai Gorge with non-hominin fossil fauna found that Sr concentrations in fossil enamel were often two to three times higher than Sr concentrations in modern enamel in the area[86], which was consistent with previous work showing enamel can be highly altered at eastern African sites[87]. In contrast, fossil rodent enamel from Sterkfontein and Swartkrans has the same concentration of Sr as modern rodents in the caves today.[88] Thus, diagenesis may yet prove a formidable obstacle to employing Sr isotopes as markers of landscape use in eastern African hominin sites.

Moving forward

So where do we go next? One pressing need is better integration of evidence from the very many palaeodietary data sources (e.g. morphology, carbon and oxygen isotopes, dental microwear, dental chipping). Further, now that we know that ^{13}C-enriched foods were important resources for many hominins, we should re-evaluate these resources in terms of their distribution, abundance, nutritional qualities, and mechanical properties to advance our understanding of hominin diets.[89,90]

Other systems based on metal isotopes (magnesium, zinc, calcium for instance[91–93]) are in active stages of development and could prove useful for addressing questions about hominin diets. In most cases, these are used principally as tools to investigate the trophic levels of fossil taxa, and while there is no doubt that they can separate herbivores and carnivores in aggregate, their mileage varies when it comes to capturing the trophic behaviour of specific taxa (see below). One overarching reason is that the distributions of these isotopes in modern ecosystems, and particularly the reasons for their relative abundances therein, are not well understood from the ground up. We have learnt from strontium trace element studies how complex, and yet how important, this patterned variation at the base of the foodweb can be for palaeodietary interpretation.[65,66] We know that plants can vary in their $\delta^{44/40}Ca$ by species, plant part, leaf age (for woody plants), nutrient transport, and soil composition, but how these patterns map onto African ecosystems is largely unknown.[19] Amongst fauna, differences between herbivores and carnivores can disappear when, for instance, the latter consume flesh but not bones[94] or when the former eat bones, regularly grow antlers, and/or other physiological factors impact $\delta^{44/40}Ca$.[95]

This makes application to hominin fossils hard to justify at present. Calcium isotopes have been applied to early hominins in two cases. The first was principally concerned with the weaning behaviour of *A. africanus, P. robustus*, and suggested longer and more intense breastfeeding in *Homo*.[96] Notably, although not a focus of the study, the results did not support the contention that *Homo* consumed more animal foods.[68] The second study was focused on Turkana Basin hominins, and found that *P. boisei's* $\delta^{44/42}Ca$ values were higher than those of other hominins and contemporaneous mammals.[91] As carnivores *tend* to have low $\delta^{44/42}Ca$ values, this *may* suggest some form of herbivory for *P. boisei*. However, given arguments derived from dental microwear, tooth chipping, and carbon isotope research that *P. boisei* consumed fibrous plants, it is intriguing that *P. boisei* occupies the same calcium isotope space as the bamboo-feeding giant panda (*Ailuropoda*) and *Gigantopithecus*.[97] Beyond this, the results for the Turkana Basin hominins are largely uninterpretable.

One promising new avenue is the extraction of nitrogen isotopes from the infinitesimal organic fraction of enamel. In principle, such data could be used to establish trophic level[98], although variation in plant $\delta^{15}N$ values and animal physiology/diet quality can bedevil such efforts, as evidenced by rock hyraxes and springbok in the Western Cape[26], and elsewhere, mammoths[92], with carnivore-like $\delta^{15}N$ values. Efforts are also underway to measure carbon and nitrogen isotopes in the amino acids of these enamel organic fractions which can reveal trophic levels and differentiate food types that are indistinguishable from bulk analysis alone (e.g. CAM versus C_4 vegetation), and can potentially be informative without extensive baseline work.[92] Still, nitrogen isotope differences between source and trophic amino acids (β) can differ by more than 5‰ between species and plant parts, and diet quality and other factors impact fractionation among trophic-sensitive amino acids[19,99], so interpretation of compound-specific isotope data is not without complications.

We would urge too, given the results from the earlier (essentially) pilot work on trace element compositions of plants and animals, that the patterns of [Sr/Ca] and [Ba/Ca] compositions should be revisited. They seem to offer unique perspectives on the consumption of different plant forms (underground storage organs, leafy material, fruits, etc.) not available by other means.[67] The existing data for *A. africanus* and *P. robustus* suggest distinctions in the consumption of USOs and this approach may be appropriate for addressing the difficult questions about plant use in the fossil record. We are less sanguine about the prospects of such work at eastern African sites, however, given evidence of diagenetic increases in Sr and Ba.[87]

Given the above, there is still much to do if we are to improve our understanding of early hominin diets and, in turn, the ways that hominins competed with each other and other mammals in the context of climatic and environmental change since the Pliocene. There remains some low-hanging fruit for future study, much in the spirit of the work at UCT described above. One is to take a much deeper dive into the plants and mammals of modern African ecosystems to better understand how we can, and cannot, use emerging isotopic dietary proxies. To be clear, this should start with systematic surveys of plants in African ecosystems where, at the bare minimum, many species (including multiple growth forms like trees, grasses, sedges, forbs, and shrubs) are analysed across a series of microhabitats. Existing data make it clear that there should be great variability between such samples[19,91,99], but those data sets are as yet typically small, unsystematic, and not necessarily relevant from the perspective of African palaeodietary research.

The long history of work on carbon and oxygen isotopes shows that it is a long-term effort (~4 decades in the research reviewed above) to understand elemental and isotopic pathways within ecosystems. It has also shown that we underestimate at our peril the importance of plants – their distributions and processes of incorporation of nutrients from soil to plant tissues to animal digestive systems and finally calcified tissues. We suggest proceeding cautiously towards application in hominins, via careful selection of test applications from the present and more recent sites, and then proceeding to work with early hominins. As Nietzsche once noted, "He who would learn to fly one day must first learn to walk and run and climb and dance; one cannot fly into flying."[100] South African scholars are especially well placed to lead us towards such flight, given their history, proximity to materials, and technical capabilities.

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Data availability

Available from the original cited publications.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

J.L-T.: Conceptualisation, writing – the initial draft, writing – revisions. M.S.: Writing – the initial draft, writing – revisions. Both authors read and approved the final manuscript.

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Taung and beyond: The mining history, geology and taphonomy of *Australopithecus* in South Africa

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South Africa is host to the single richest early hominin fossil record worldwide, including many examples of the endemic species *Australopithecus africanus* fossils. This species was first described by Raymond Dart in 1925 from the deposits near the town of Taung. Later, many more fossils, of different species and genera, were found in the caves of the Sterkfontein and Makapan Valleys. To understand this rich and diverse fossil record, we must understand how the landscape formed (cave formation processes) and changed (mining), when this happened (geochronology), and how the fossils were accumulated and modified (taphonomy). Here we provide a review of these themes to mark the centenary of the Taung Child discovery. We mark this moment in our field by critically reflecting on the role of extractive practices, especially centred around past mining of the Caves and the exclusion of many members of research teams. The South African Fossil Hominid sites provide a unique opportunity to expand our understanding of the intersection between human evolution and changing environmental conditions, as the karstic landscape and remnant cave systems preserve both fossils and sedimentary archives of past environmental change. We offer a perspective on future research areas: more standardised excavation practices and techniques to raise the quality of data collected from the caves and new techniques to date and extract palaeoclimate data from cave deposits themselves, to provide novel insights into the world of the early australopiths.

Significance:

This review introduces the reader to the important fossil remains and palaeoclimate archives preserved within South Africa, highlighting the key species *Australopithecus africanus* and marking the centenary of its first description from the site of Taung. We review the geological and exploration history of the South African hominin fossil sites and discuss how they are intrinsically linked. We explore the impact of past extractive practices on the fossil and palaeoclimatic archives for past, current and future research. We go on to emphasise members of research teams who have been crucial to the discovery and recovery of fossils but have often been excluded and remained unnamed.

[Abstract in Setswana]

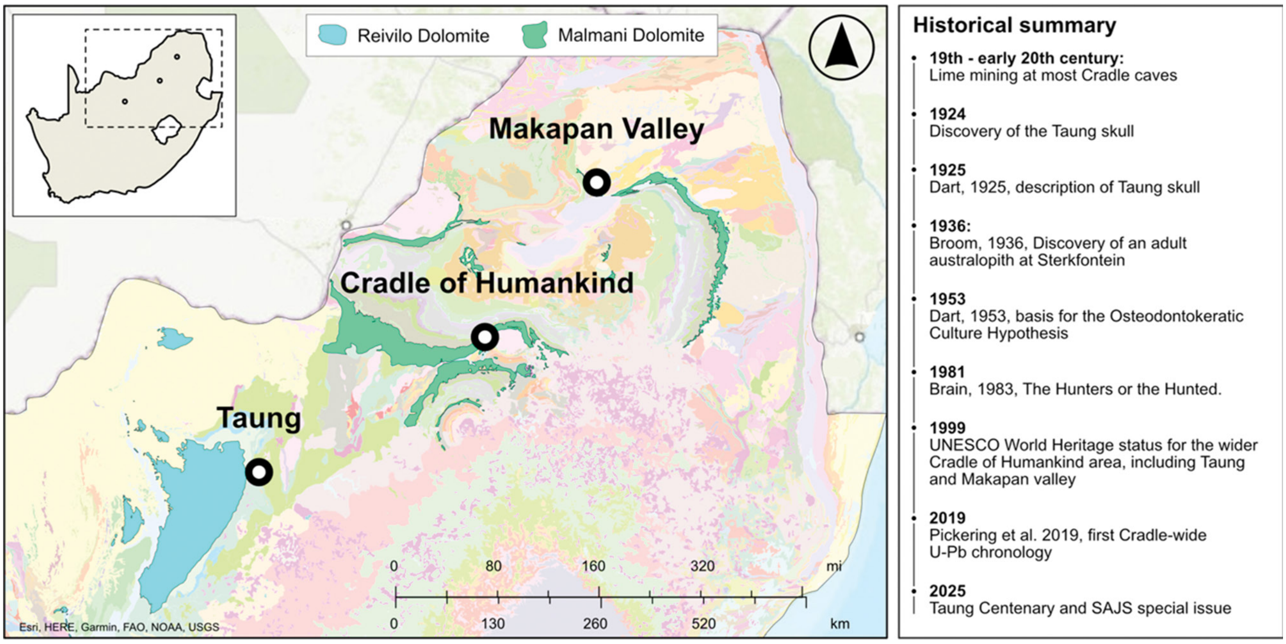
Introduction

Fossils of *Australopithecus africanus* have been recovered from three localities within the UNESCO Fossil Hominid sites of South Africa: Taung, Makapan Valley, and the cave systems of the Cradle of Humankind (hereafter referred to as 'the Cradle'). These caves and palaeocave remnants formed within the Palaeoproterozoic Malmani (the Cradle and Makapan Valley) and Reivilo (Taung) Dolomites within the Transvaal Supergroup[1] (Figure 1). In this contribution marking the centenary of the Taung Child discovery[2], we review the geological history and the early mining history of the South African australopith sites, and how these intersect. We focus on the stages of formation of the caves themselves, the processes through which material is accumulated in the caves, from fossils to speleothems (secondary cave carbonates), and how we use the caves and their contents to place *Australopithecus africanus* in context. We specifically zoom in on past extractive practices on the fossils and speleothems and how these impacted subsequent research, and emphasise people crucial to the history of scientific study who have largely remained unnamed and unacknowledged.

Historically, the bulk of early hominin research in southern Africa has been conducted in the Cradle, as it is by far the most densely packed fossil site in this region with localised cave systems, many of which have yielded hominin fossils. While this contribution marks the centenary of the Taung Child discovery, it is important to look at the wider UNESCO Fossil Hominid sites of South Africa (primarily the Cradle of Humankind and, to a lesser extent, Makapansgat Limeworks in Makapan Valley) to fully understand the history of scientific study. The bridge between the geological history and history of exploration/mining is that the specific geological processes created caves of interest to the mining industry, which, in turn, exposed the significance of the fossil material, marking the start of palaeontological research in South Africa. We go on to highlight the potential of innovative methods to further our understanding of the environmental context of the Taung Child and other key fossils within the UNESCO Fossil Hominin sites of South Africa.

Cave formation, sedimentation and climate dynamics

Previously, researchers divided up the cave sediments of the Cradle (palaeo-)caves into members based on their lithologies, leading to stratigraphies emphasising complexity.[7–12] An alternative is presented by Pickering et al.[13], Edwards et al.[14] and Pickering and Edwards[15]: a simple cave sedimentation model that can be applied to all Cradle sites (Figure 2), albeit with site-specific characteristics and nuances. They show that, at the simplest level, only two sediment types are found within the caves: externally derived, fossil-rich clastic sediments (also referred to as breccia in the older literature) and in-situ speleothems (secondary cave carbonates, including stalagmites,



Source: Adapted from ArcGIS Map Viewer Classic (image attribution: Esri, HERE, Garmin, FAO, NOAA, USGS).

Figure 1: Geological map of South Africa overlain by hominin fossil sites within the UNESCO Fossil Hominid sites of South Africa, including Taung, the Cradle of Humankind and Makapan Valley. The cave sites formed with the Reivilo and Malmani Dolomites (highlighted in blue and green, respectively), which both belong to the Palaeoproterozic Transvaal Supergroup. The dashed rectangle indicates the inset. A timeline of events in the history of the caves and fossils is also provided. Publications referred to in the timeline are references [2–6].

stalactites, and flowstones). The caves we see today (Figure 2; Stage 9) are the result of speleothem and clastic deposition, erosion and sediment infill, mining and excavation. This model builds on previous work by Brain[7], Moriarty et al.[16] and Pickering et al.[13,17,18]. The mode of sedimentation dominant at any one time is closely linked to changes in the hydroclimate[6,19] and to whether the caves are open or closed to the surface above[13,16].

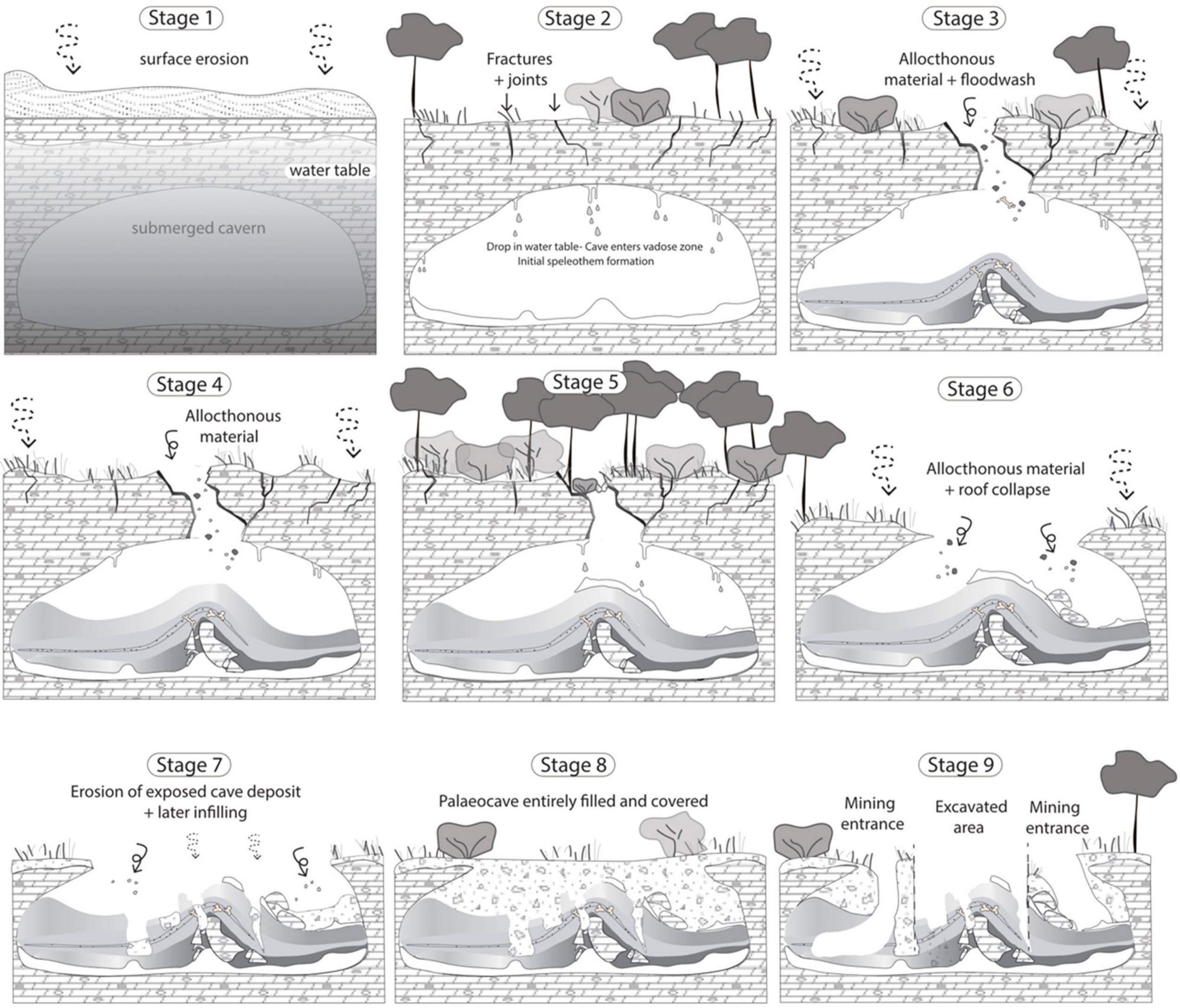
Speleothems can only form when they are uninterrupted by clastic sediment input, thus when the caves are closed or when little to no surface flooding occurs (Figure 2; Stage 2 and 5). Flowstones are horizontally bedded speleothems that form on walls and floors of caves from a central water drip source and are ubiquitous features in all Cradle caves[6,13] (Figure 3). Speleothems, including flowstones, form only under the right climatic conditions when there is sufficient vegetation cover above the cave and water infiltrating the karst. In subtropical, semi-arid regions such as the Cradle, speleothem growth is primarily linked to climatic moisture availability[20], meaning that the presence of flowstones directly indicates wet conditions in the past[13,21]. At all the cave sites considered here, these flowstone layers are interbedded with the fossil-bearing sediments (Figure 3). These externally derived clastic and bone material can, naturally, only enter the cave when there is a direct connection to the surface above the cave.[7,13,22] Such material is generally more readily available and mobilised during periods of relative aridity when sediment mobilisation and episodic flooding occurs. The presence of such material thus suggests that, during that sedimentation mode, the caves were open, and that climatic conditions were relatively dry[6] (Figure 2; Stage 3, 4, 6 and 7). By extension, the fossil record is also restricted to these dry periods, and represents short-lived, highly episodic sedimentation phases, meaning that our understanding of floral, faunal and hominin evolution is biased towards arid-adapted species.[6,13]

The evident cycles of deposition, erosion, and redeposition (Figure 2) in South African cave deposits[23–25] imply that such deposits sample multiple depositional episodes containing a 'climate-averaged' mix of species[25,26]. The available fossil evidence from Taung, Makapan Valley, and the Cradle of Humankind suggests that these regions experienced significant climatic fluctuations with profound impacts on the local environment, influencing the availability of resources and the suitability of the areas for various faunal and floral species survival.[27] Palaeoclimatic reconstruction using fossil fauna and flora, from different sites, points to the existence of mosaic habitats (a combination of open grassland, savannah woodland, and few patches of closed forest) (see Reynolds and Kibii[25]: Table 11) but overall agrees with the dry phase hypothesis. This combination of habitats is reflected in the speleothem carbon isotope signal from the Limeworks Member 1 Collapsed Cone and Buffalo Cave speleothem in the Makapan Valley.[28]

Fossil-bearing sediments formation, calcification and decalcification

The continued solution of dolomitic limestone by meteoric waters passing through fissures or joints leads to the formation of sinkholes and shafts that connect the ground surface to the caverns below.[29] These shafts and sinkholes can serve as natural traps through which animals or other organisms enter the cave and are unable to exit.[30] The openings also act as conduits through which organic and inorganic surface material gets incorporated into the caverns. Over time, organic material gets into contact with mineral-rich water and undergoes mineralisation, where minerals gradually replace the organic matter's original structure, turning it into a fossil.[29] As calcium bicarbonate-rich solutions seep through fissures in cave walls, it cements together the incorporated sediments and bones.[29] Through diagenesis, loose sediment is transformed into solid rock that helps preserve organic materials incorporated within. This process spreads out from vertical drip points in the cave roof, where calcium carbonate drip waters drive the cementation and can be observed at a metre scale and at a micrometre scale in thin sections.[13]

The reverse process, sediment decalcification, occurs when calcium carbonate is removed or dissolved from sediment. Percolation of slightly acidic groundwater through the rock drives this process, leading to chemical weathering and dissolution over time. As the calcium carbonate is removed, the cementing material weakens, and the sediment may become less cohesive and more prone to fragmentation.[5] This process can alter the appearance and integrity of the sediment, potentially leading to the formation of a softer, more porous rock with void spaces. It is also possible that not all sediments become cemented, with lateral variations in levels of sedimentation away from drip points observed in cave systems such as Gladysvale.[13] Clastic sediments are sometimes reworked, leading to the loss of some material and leaving remnant



Source: Inspired by Edwards et al.[14] and Brain[7].

Figure 2: Nine-stage model for cave formation at the Cradle of Humankind following Edwards et al.[14] and Pickering and Edwards[15]. Caves first start to form by dissolution of the host dolomite under phreatic conditions (Stage 1). Once the caves enter the vadose zone, speleothem formation is initiated (Stage 2). When the caves open to the atmosphere, allochthonous material is deposited (Stages 3 and 4). The caves gradually close when increased vegetation blocks the cave entrance, after which increased effective precipitation reinitiates speleothem deposition (Stage 5). The cave deposits are eroded and exposed during Stages 6 and 7, followed by infilling and covering of the cave (Stage 8). Stage 9 shows the modern representation of the caves after mining activity and palaeontological excavation. (Flowstone layers in white; clastic sediments in grey shades.)

deposits adhering to walls – such as those observed at Swartkrans[19] – or (re-)incorporated into other sections of a cave system – as has been described at Sterkfontein Caves.[31,32]

Dating the caves, their infills and the fossils

There are several analytical techniques well suited to dating fossil cave sites and remains. The method used depends on the type of material (clastic sediment, speleothem, bone, tooth enamel) and the suspected age. Due to the limited range of methods applied to dating the Taung site, we refer to the wider UNESCO Fossil Hominid sites of South Africa (including Taung, the Cradle of Humankind and Makapan Valley).

To date, only palaeomagnetic analysis alone has provided an age for the Taung Child[33], with a depositional age of 3.03–2.61 Ma[33]. The Taung sites are formed within tufa, a secondary calcium carbonate deposit, unlike the Malmani dolomites which host the Cradle caves. From the beginning, the Taung Child skull was considered to have come from a cave named Dart Pinnacle which formed through this tufa[2], but an alternative explanation argues that fossil deposition took place during a period of tufa formation[33,34], although this has been contested[35].

Within the Cradle, fossils occur in clastic cave fill which exists in discrete packages sandwiched between extensive, horizontally bedded speleothems and are referred to as ‘flowstone bounded units’ (FBUs). In comparison, key early hominin fossils in eastern Africa are preserved between volcanic ash beds, allowing for potassium/argon (K/Ar) or argon/argon (Ar/Ar) dating, which brackets fossils and provides accurate radiogenic age estimates.[36,37] The lack of any volcaniclastics within the Cradle led many to dismiss these sites as ‘undateable’, leading to early preference for biochronological dating based on eastern African age estimates, based on the first appearance datum (FAD) and last appearance datum (LAD) of a species, from dated and secure stratigraphic contexts.[38] However, this method is not without its flaws. Biochronology is based on the assumption that the fauna and hominins in different regions existed around the same time period under similar ecological and environmental conditions, and does not consider possible variations in the biogeography of the regions. The possibility of differences in the species being compared as a result of geographic isolation and their independent evolution paths due to their respective environments is also not considered.[39,40] Finally, the existence of species appears to be affected by environmental conditions limiting the utility of

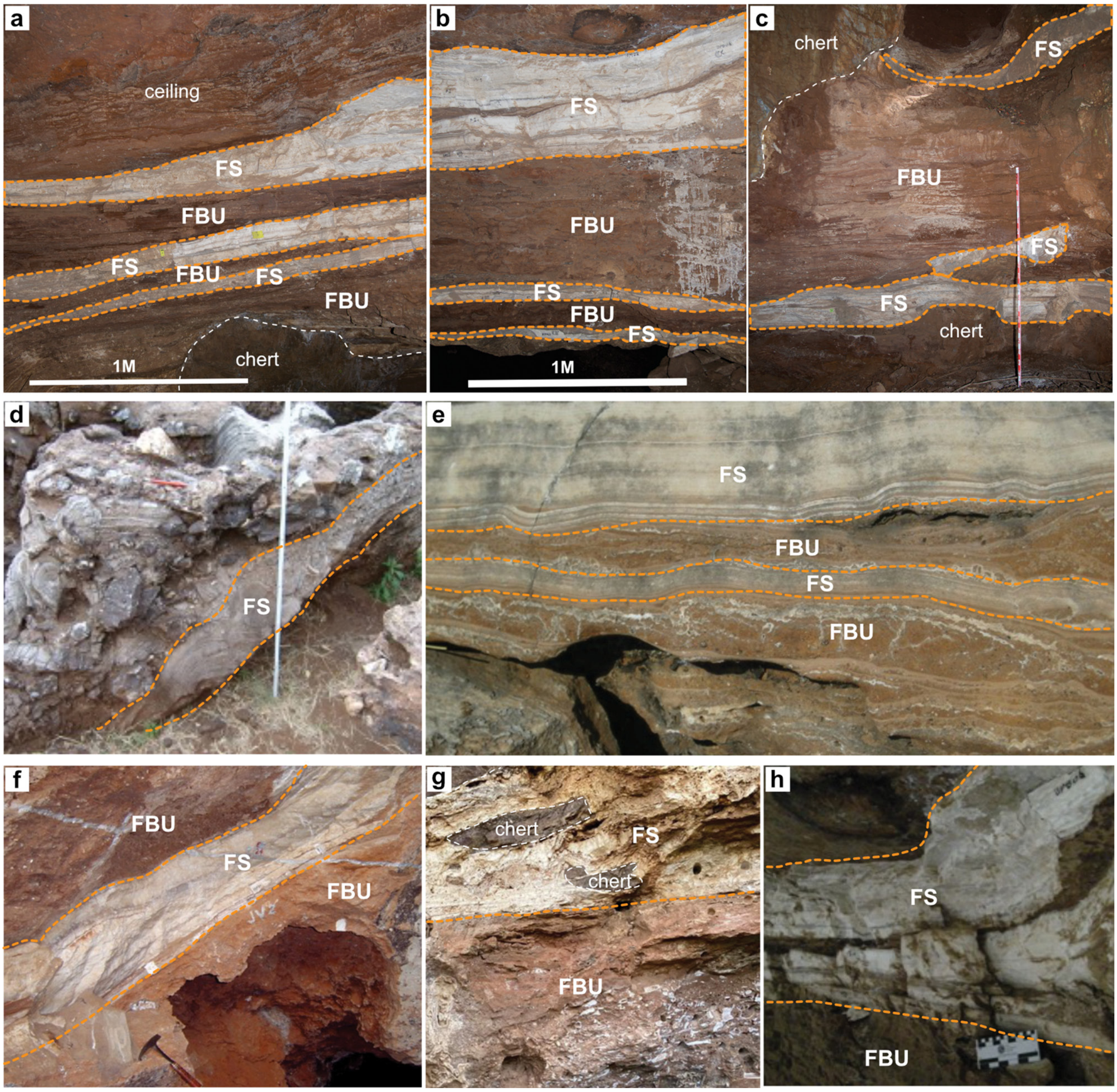


Figure 3: Flowstone-bounded units (FBUs) from fossil-bearing cave sites in South Africa. These FBUs and flowstone (FS) sequences are ubiquitous features across the Cradle and Makapan Valley: (a–c) Bolt's Farm, (d) Cooper's, (e) Makapansgat Limeworks, (f) Swartkrans, (g) Gondolin and (h) Bolt's Farm.

the fossil fauna as a dating tool.[41] Although absolute dating is preferred, biochronology remains useful to provide chronological context when multiple absolute dating methods provide inconsistent results, as shown recently by Frost et al.[42]

The most widely applied dating technique is palaeomagnetism – a correlative technique which measures changes in Earth's magnetic field as they are recorded in rocks and sediments and makes comparisons against known archives (e.g. Geomagnetic Instability Timescale [GIT] and Geomagnetic Polarity Time Scale [GPTS]). Ideally, palaeomagnetic records will be anchored by some form of radiogenic date, i.e. uranium-lead (U-Pb), electron spin resonance (ESR) dating or cosmogenic nuclide dating. The applicability of palaeomagnetic techniques relies on the completeness of a sediment package and a thorough understanding of the depositional or formational environment.[43] As well as Taung, palaeomagnetic analysis has been applied at Makapansgat[33] and a number of Cradle sites including Bolt's Farm[14,44], Sterkfontein[45], Drimolen[46], Gondolin[47], Gladysvale[48] and Kromdraai[49]. Cave deposits are often complex and multi-generational, with erosional events in a sequence.[32] Moreover, the stratigraphic sequences are often thought of as representing short time periods where few changes in magnetic polarity might be expected or numerous enough to correlate to the GIT or GPTS without help from other dating methods, such as biochronology[47,50] or absolute dating[51–53]. The results of palaeomagnetic investigation at major fossil sites over the last 20 years have, however, been remarkably uniform.[8,41,47,50,54]

Dating speleothems directly is possible with the radiometric U-Th and U-Pb technique. The U-Pb method is well established and usually applied to small resistant silicate minerals such as zircon. Indeed, the challenge was adapting the sample preparation and measurement protocols to be applicable to carbonate minerals[55] on much younger time scales, such as the last few million years[56]. Given the ubiquity of flowstones in the South African caves, and their interbedded depositional positions between the fossil-bearing sediments, they make ideal targets for dating with the U-series (U-Th for the last 500 ka and beyond this U-Pb), and can be seen as analogous to the volcanic tuff layers from the eastern African hominin sites in providing ages for the fossils sandwiched between them. The limiting factor in using this method is the initial concentration of uranium in the flowstones, which, if below a threshold value (around 1 part per million or 1 ug/g), the amount of lead produced during the relatively short time window of a few million years is below the detection limit of even the most sophisticated mass spectrometers. This issue is overcome by mapping the distribution and concentration of U and its daughter isotopes (Th and Pb), either by phosphor imaging or laser ablation trace element mapping[17,57] and selecting the ideal layers (high U, low Th and Pb) for subsequent dating. This approach has led to the successful dating of almost all the caves in the Cradle, and is best applied in conjunction with palaeomagnetic analysis of the same sequence of cave deposits (for recent examples see [6,14,44,45]). Makhubela and Kramers[58] experimented with U-Th/He dating of flowstones from various Cradle sites and offer this as an alternative dating technique for instances where U-Th and U-Pb are not suitable.

Cosmogenic nuclide dating aims to apply a chronology to the evolution of landscapes, including erosion and fluvial incision rates, sedimentary deposition and soil formation.[51] In the Cradle, cosmogenic nuclide dating has been applied, both to study landscape evolution[51] and to date fossiliferous deposits with mixed results[59–61]. An attempt to date the near complete *Australopithecus* specimen 'Little Foot' (StW573) from Sterkfontein via cosmogenic nuclide burial dating resulted in an age of 3.67 ± 0.16 Ma.[60] More recently, Granger et al.[61] reported a cosmogenic nuclide isochron burial date of 3.41 ± 0.11 Ma for the 'lower middle' of member 4 (M4), and a simple burial age of 3.49 ± 0.09 Ma for Jacovec Cavern. Later, reinterpretation of the age and burial model for StW573 concluded an age of <2.80 Ma.[62,63] This younger age was more parsimonious with the chronology previously established by radiometric (U-Pb, palaeomagnetic) and faunal age estimates (<2.80–2.20 Ma[40,41,64]). The overestimation of age estimates from cosmogenic dating of cave sediments could be linked to recycling of quartz within a multigenerational cave system.[31,62,63]

The Witwatersrand gold rush and cave exploration and mining

Palaeontological and archaeological discoveries in South Africa are heavily intertwined with gold rushes and cave exploration/mining.[65] Both have played important roles in shaping the history and culture of South Africa, and continue to be areas of interest for historians, palaeoscientists, geologists, and adventurers alike (see Ackermann et al. this issue[66]). One of the most significant gold rushes in South Africa was the Witwatersrand Gold Rush, which began in 1886 and led to the discovery of the world's largest gold deposits.[67] The substance known colloquially as 'lime' was important for this early mining industry and was extracted for agriculture and for the purification of gold.[68] In the 1880s, gold minings used cyanide to separate the gold from host rocks[69], with lime used as a cost-efficient reagent for pH control[70]. The lime, also referred to as quicklime, was produced from the calcination of calcium carbonate deposits ($CaCO_3$)[70], leading to the search for local sources of carbonate and the prospecting and exploration of nearby caves (now preserved in the Cradle). To open up the caves to access the speleothems, the miners used dynamite, which was particularly destructive to fossils and also the surrounding sediment matrix.[65] While the fossiliferous blocks of sediment were not processed in the kilns, they were utilised in paving the roads for easier movement of the horse-drawn caravans, as well as in sealing entrances to speleothem-rich caves from other limestone prospectors. The blasting of the caves, though it provided easy access to the underground caverns, resulted in loss of fossils and compromised reconstruction of cave stratigraphy, in addition to complicating interpretations of cave taphonomy. Although blocks of fossil-bearing sediments were certainly not transported between caves, they were, in some instances, inadvertently mixed where the cave contained multiple depositional sequences (e.g. Bolt's Farm[71]). To date, it has been almost impossible to associate ex-situ breccia blocks with the exact stratigraphic loci from which they originated. There has, however, been one study which recovered a fragment of a primate tooth from an ex-situ block and successfully located a remaining piece of the same tooth from in-situ sediment at Waypoint 160, Bolt's Farm.[72]

Hierarchy in mining and its relevance to fossil discoveries

The first formal mining operations in South Africa were established in 1852[73], and South Africa saw a peak in mining activity and exploration over the turn of the 20th century, with industries including diamonds in Kimberley, gold in Johannesburg and lime in Taung.[74] As these mining operations expanded, they became micro-communities that represented the broader racial and cultural disparities across the country. Mining operations were led by white European men, whose names appear in our history books today.[75] In contrast, the remaining workforce was made up of migrant black workers from across southern Africa[76] and, from 1901 onwards, a contingent of imported Chinese men[77]. These men worked in cramped and hazardous situations, leading to over 69 000 mineworker deaths between 1900 and 1993, and more than a million were maimed or seriously injured.[78] As was characteristic of the nation at that time, these people of colour took all the risk, remained largely nameless through history, and saw very little of the subsequent economic rewards. Although they were obviously around, there is no mention of women in the literature, meaning they are also erased from these histories, and that only white men received credit for the mining and fossils, and everyone else (including women of all colours) was historically excluded.

Mining activity was divided into two factions: the 'unskilled' labour contingent made up of people of colour and the 'skilled' overseers who dictated how operations were run.[74] After the Boer War and the establishment of the new Union under the British Commonwealth in South Africa, stricter regulations were introduced, alongside broader regulations, that imposed higher taxes and the 'pass law' explicitly designed to force black people to accept employment at whatever wages that white people were willing to pay.[79] It was under these conditions that the Buxton-Norlim Limeworks were founded.

Quarrying at Taung began after World War 1 (c. 1918) by the Northern Lime Company, and formally closed in 1977 under the name Pretoria Portland Cement Company Limited (commonly PPC Cement). The economic boom of the country was underpinned by the discovery of both diamonds (mostly from Kimberley, discovered in 1867) and gold along the Witwatersrand Reef in Johannesburg (c. 1886[74]). The original mine workers at Taung were men from the surrounding Buxton and Norlim Villages. These supposedly unskilled workers had an integral understanding of the landscape, as their people had occupied the Taung landscape since the Batlhaping Ba-Ga-Maidi tribe first moved to the area in c. 1830.[80] Oftentimes, it was these lower-income workers whose experience determined where it was best to uncover not only precious metal seams, but later, fossil deposits as well. To date there are no details on who the workers at Taung were during the years surrounding the recovery of the Taung Child fossil.

What is known is that life for these mine workers was dangerous and short. Many migrant workers, whose families lived distantly, died in mine hospitals and were considered "unclaimed".[81] Raymond Dart famously began amassing human bodies for the newly established University of the Witwatersrand Medical School and mining operations provided one stream of available "materials".[82] Their names have been lost to history and their contributions have been largely ignored by European historians until recently.[82,83]

There is some shift in the ethos surrounding people considered "technicians". For example, Stephen Motsumi and Nkwane Molefe were acknowledged for the critical role they played in the discovery of Little Foot, the *Australopithecus prometheus* partial skeleton.[84] Similarly, the Drimolen Fossil Hominid team chose to honour the long-serving site manager, Simon Mokobane, by nicknaming the *Homo* aff. *erectus* specimen, DHN 134, Simon, after him.[46] These attempts to recognise the roles that these often-unnamed persons play in the uncovering of internationally acclaimed fossil hominins is a step in the right direction; however, more needs to be done to change the long-standing status quo observed within the southern African palaeosciences[85] (see also Kgotleng et al. in this issue[86]).

Challenges and biases introduced by lime mining

Mining activities in South Africa have played a pivotal role in the discovery of fossil hominins, with finds like the Taung Child skull capturing the attention of the scientific community worldwide. However, alongside these discoveries, come ethical concerns surrounding the exploitation of natural resources and the cultural ownership of palaeontological finds. Questions arise regarding the transparency of fossil disclosure and the extent to which fossils found by miners were properly documented and donated to institutions, such as the Ditsong Museum (see Black et al. in this issue[87]).

Most Cradle sites were exploited for lime during the 19th and early 20th centuries, although there are few records of these activities during this time and almost no scientific or historical studies were done (to the best of our knowledge). Mining removed large amounts of cave carbonate, often transported and combusted in on-site lime kilns, such as those seen at caves like Gondolin and Bolt's Farm.[47,71] It was not until the discovery of an adult australopith[4], commonly known as 'Mrs Ples', that the South African caves attained a new level of importance. Focus shifted to their exploration as potential archaeological and palaeontological repositories[88], especially those subjected to lime mining as large portions had already been opened up, providing an opportunity to assess the in-situ sections and the mine dumps for fossils.[68] As much as lime mining drew attention to these caves, it also led to the extraction and damage of both the caves and fossils, with early extractions using dynamite to blast sections away.[65] The importance of fossil and archaeological material does not emerge only from their discovery, but also from their stratigraphic context providing a relation to the material with which it is found with and a baseline for other aspects of research, such as chronology and palaeoclimatic reconstruction. Some important hominin fossils have been recovered from mine dumps, such as the enigmatic Gondolin molar GDA-2; however, only inferences can be made on their possible origin.[89]

The Osteodontokeratic culture and later cave taphonomy research

Discovery of the Taung Child prompted further exploration into similar lime-rich deposits across South Africa. These included the White Limes Limited Limeworks, a crude quarry operation in the Makapansgat Caves, Limpopo Province.[90] Soon after this mining operation began, there was a push for it to be recognised as a national monument, which prompted mining operations to move elsewhere and for palaeontologists to have greater access to fossil-bearing caves.[90] By 1957, a large sample of the latter had been discovered from several of these sites, namely, Taung, Sterkfontein and Makapansgat.[90] The skeletal material recovered raised a curious question: of the hundreds of australopith bones recovered, not one was a limb bone. Rather, there was a high frequency of cranial elements[90,91] (see also Schroeder et al. in this issue[92]).

These unique assemblages, with their peculiar skeletal representations, when viewed from the lens of the researchers who had just lived through two major global wars[93] (see also Kuljian in this issue[94]), seemed like the remains of a violent butchery site. The bones of large fossil ungulates were blackened and broken. Dart used the Makapansgat Member 3 material (and augmented his argument with the associated faunal remains from the Taung assemblages[90,95]) as the basis to introduce his Osteodontokeratic Culture Hypothesis (ODK). The ODK, as it has come to be known, posited that our early ancestors were blood-thirsty apex predators, who roamed the southern African landscape killing everything in their path "slaking their ravenous thirst on the hot blood of victims and devoured livid, writhing flesh" and then using the bones, teeth and horns of their kills as weapons or tools[3(p.209)]. This was used to explain modern human violence[93]: it was an inherited behaviour from our predecessors. Dart's hypothesis was controversial[96,97], like his original hypothesis that the Taung Child represented an early human ancestor; however, in this instance, he was wrong. Washburn[96] went on to show that deposits at Makapansgat were the result of a now-extinct large hyaenid feeding (also see Maguire et al.[97]).

One researcher in particular, Charles Kimberlin Brain, began to develop alternative explanations for the accumulation of fossil bones based on his excavations at Swartkrans Cave in the Cradle. Brain revolutionised the field of taphonomy by including a range of different observational and actualistic experiments. These included not only the accumulating behaviours of hyaenids, but also expanded to show that leopards (*Panthera pardus*) were capable of amassing large ungulate fauna into cave systems below their preferred tree caches.[5] He also included work on porcupines, abiotic accumulators and human activity. This type of observational research changed the field of taphonomy and introduced a new era of actualistic taphonomy, and replaced the ODK as the conceptual framework in which fossil assemblages are assessed.

Cave taphonomy also offers perspectives on palaeoenvironments, palaeoecology, and the relationships that would have existed between living things and cave systems over time. Although earlier researchers were primarily concerned with the taxonomic composition of vertebrate remains in the caves in South Africa, the last seven decades have seen a concerted effort in reconstructing depositional histories and cave taphonomy. Reconstructing the complex taphonomic history of fossil assemblages has taken a multiproxy approach, including geochronology[9,17,40,51,98], depositional and preservation processes, taphonomic agents, and taphonomic modification[5,25,99,100]. More so, taphonomic studies have become specialised in differentiating between mammalian (leopard, hyaenid, hominin, foxes, etc.), reptilian (crocodile[101]) and avian accumulators[102], as well as abiotic accumulating agents (such as wind and waterwash[103]). The accumulating agent can contribute to variation in concentrations of fossils, laterally and/or vertically within a fossil deposit. These include carnivores, porcupines, death trap, fluvial transport, birds of prey and hominins. After deposition, faunal assemblages underwent post-depositional modifications including mineralisation, plastic deformation, and weathering prior to discovery and retrieval.[104]

Taphonomic studies on the direct impact of mining on fossils have not been done. That said, the broader impact of dynamite blasting for speleothems in caves has certainly impacted cave geology and interpretation, with nearly every site in the Cradle of Humankind preserving a fossiliferous 'miners dump'. Several of these dumps (such as that of Gondolin mentioned above[89] and those of Bolts Farm[105]) have been explored and retain critical taxonomic information, although anchoring these specimens into the broader context of the site geology and stratigraphy is near impossible. In some instances, such as *Australopithecus prometheus* 'Little Foot' and *Australopithecus sediba*, fossil finds in the dumps have been placed in actual in-situ stratigraphic locations in the caves and turned out to be the discovery of partial skeletons.[84,106] Early writers, such as Eitzman[91], recount instances of how mining operations destroyed large portions of the record and these accounts are well summarised by Dusseldorp[107]. Unfortunately, despite mining operations in the Cradle having ended many decades ago, gold mining operations further afield still impact on the integrity of the Cradle, with mine effluent threatening the local environment and waterways.[108]

The curious case of the Taung Child's taphonomy

The Taung Child is, to date, the only known hominin specimen recovered from the pink clay and siltstone (PCS, aka 'Pink Fill') deposits, formerly the Dart Pinnacle[34], which are believed to have derived from a river system bisecting the Ghaap Escarpment[109]. This is unusual in that most sites with early hominin remains have more than one specimen; many preserve near-complete skeletons (Strekfontein, Malapa, Rising Star), with occasionally even several hominin genera. The single occurrence of the Taung Child has prompted investigation into the skull itself, looking for taphonomic markers to explain it being fossilised alongside a vast array of other taxa, dominated by small primates.[2,38,96,110]

In his description of the Taung faunal assemblage[111], Dart observed four types of damage which he attributed to the hunting habits of early australopiths: depressed fractures and punctures, basi-cranium removal, cranium crushing and mandible distortion, and V-shaped nicks.

These features identified in the faunal assemblage, and the Taung Child skull itself, are now attributed to eagle activity.[112] Additional taphonomic features have now been recognised (see Baker[113] for a full list). Three extant species are suggested as potential analogues for a hypothesised Plio-Pleistocene bird of prey based on their size and ability to carry such large prey items: Verreaux's eagle (*Aquila verreauxii*); crowned eagle (*Stephanoaetus coronatus*); and martial eagle (*Polemaetus bellicosus*). Subsequent research argued that the crowned eagle left the most similar markings on the crania of small primates.[114–116] However, both Berger and Clarke[112] and Baker[113] agree that it is likely impossible to attribute the Taung Child accumulation to any one species of raptor, as there is major overlap in their taphonomic markings and also that ecological variability plays a large role in prey selection and feeding behaviours between even the same species of eagle. Similarly, without a comprehensive assessment of the large-bodied raptor populations present in southern Africa during the early Pleistocene, attributing any taphonomy to an extant raptor would be limiting. More work is required to explore the Taung faunal collections and possibly to explore the large avian materials to attempt to narrow down a possible accumulator.

Prospects of cave research and conclusions

Much of the clastic sediments and speleothems were removed or displaced during mining in the late 19th and early 20th centuries. Consequently, invaluable parts of the fossil record, within the clastic sediments, and the climatic record archived by the speleothems were lost. Nonetheless, the antiquity of *Australopithecus africanus* and other hominins is now well understood and constrained through the dating of fossil deposits and flowstones.[6,33,44]

The missing piece of the puzzle, however, is understanding how climatic and environmental change influenced the rise and demise of *Australopithecus* and other hominins. Speleothems are invaluable archives, recording such changes via multiple proxies. Despite having lost the bulk of speleothem deposits due to mining activities, flowstones are still ubiquitous features in the Cradle and Makapansgat caves and provide an under-studied resource for palaeoclimatic and -environmental reconstructions. Speleothem and fluid inclusion stable isotopes, coupled with analyses of the abundance of GDGT lipids (TEX_{86}) within the same speleothems, allow for direct comparison of the two palaeothermometry methods and thus provide robust temperature reconstructions[117,118] and will shed light on the regional temperature changes over multiple glacial-interglacial cycles and millions of years. Fluid inclusion stable isotopes also quantify rainfall amounts and source and allow for direct comparison with the Global Meteoric Water Line (i.e. the global annual average, linear relationship between oxygen and hydrogen isotope ratios in meteor water). Producing such a multi-proxy record from the already dated cave sites will allow us to test the hypotheses of earlier studies, that is, that in the wider Cradle region: (1) rainfall variability is modulated by orbital precession[119], (2) the two alternating sedimentation modes, speleothem vs. clastic, represent wet and dry conditions, respectively[6], and (3) orbital eccentricity cycles (100, 400 and 2400 ka) influenced long-term aridity trends in southern Africa[120].

Another important and recent research development is the establishment of world-class dating facilities in South Africa. Historically, the lack of such facilities in the country, and in fact on the continent, meant that all U-Th and U-Pb dating of speleothems was done overseas, where analytical costs were high and there was very limited investment in local human capacity building. The new dating capabilities at several universities (including the University of Cape Town and the University of Johannesburg) allow for in-country analysis, leading to both job and critical skills development within South Africa and the African continent.

One of the major challenges in South African cave research is the lack of standardised methodology and excavation protocols. Research teams use different methods for collecting and analysing data, making it difficult to compare results across studies/sites as different research teams bring their own experience, perspective and knowledge and thus their own way of conducting research. This leads to differences in excavation practices, sampling methods and data recording. To clarify the depositional and post-depositional histories, future studies must incorporate new technologies and analytical techniques. For instance, advances in imaging, geochemical analysis, and data modelling offer exciting opportunities for a more comprehensive understanding of past ecosystems and the processes that shaped them. The integration of advanced technologies, such as LiDAR scanning and 3D mapping, to create detailed 3D models of cave systems can provide valuable insights into their formation and development over time, and provide detailed data with which to test taphonomic interpretations.[121] Computed tomography scanning offers a non-destructive three-dimensional macroscopic and microscopic view of internal structures of sediments revealing the overall composition, frequency, location, orientation, size and alignment of constituent clasts and fossils.[122] Micromorphological analysis uses petrographic thin sections of cave sediments and flowstones and transmitted light microscopy to document site formation processes and stages of formation and is necessary as part of a multidisciplinary dating of fossil-bearing sites.[14,44,52,123]

To our best knowledge, none of these techniques described above has been applied to understanding depositional processes and environmental change at Taung. While more challenging for tufa deposits, the Taung carbonates could be dated with U-Th and U-Pb to refine the existing palaeomagnetic ages. Additionally, trace element analyses could provide valuable palaeohydrological proxy data, further improving our understanding of the environmental context of *Australopithecus africanus* at Taung. Similarly, additional work on the faunal assemblages, very little of which has been revisited in the past two decades (last assessed in McKee[124]), would be valuable to situate the palaeoenvironmental and taxonomic diversity of the western interior of southern Africa for a critically underrepresented period of the early Pleistocene. The faunal materials associated with the Taung Child have not been analysed to the same extent as those in the coeval Cradle deposits.

The history of South Africa's palaeontological and archaeological discoveries is closely linked to gold rushes and cave exploration (see Ackermann et al. in this issue[66] for more). As miners searched for lime sources, they explored caves, leading to exposure of fossiliferous deposits, including some of the world's most important hominins. The formal mining operations reflected the racial and cultural disparities across the country, with white European men leading the operations while black migrant workers from southern Africa and imported Chinese men comprised the remaining workforce. These mining expeditions caused the loss of clastic sediments and speleothems, including valuable parts of the fossil and climatic records. As the demand for lime declined and there was a recognition of the palaeontological and archaeological potential of the deposits at Taung, the Cradle and Makapansgat, research began on the cave formation processes, depositional sequences, palaeoenvironment, taxonomic compositions of fossil fauna and flora, and the taphonomy of the assemblages. Even 100 years later, there is still enormous scope for work to be done on the existing deposits, using new techniques and methods, as well as exploring for new fossil-bearing deposits. Today, South Africa is positioned to offer world-class research into speleology and fossil analysis, with the establishment of dedicated speleothem dating and 3D imaging labs that are bound to provide a more comprehensive understanding of past ecosystems and the processes that shaped them and drive us into the next century of cave and fossil research.

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Data availability

There are no data pertaining to this study/article.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

R.W.: Conceptualisation, methodology, writing – initial draft, student supervision, project management, funding acquisition. S.E.B.: Conceptualisation, methodology, writing – initial draft, writing – revisions, project management. T.R.E.: Conceptualisation, methodology, writing – initial draft, funding acquisition. J.K.: Conceptualisation, methodology, writing – initial draft, writing – revisions, project management. G.L.: Conceptualisation, methodology, writing – initial draft. R.P.: Conceptualisation, methodology, writing – initial draft, funding acquisition. All authors read and approved the final manuscript.

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The ground beneath our feet: A critical reflection on 135 years of landscape evolution models for southern Africa

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In his 1925 paper describing the Taung Child fossil, Dart makes various assertions about the landscape around Taung, inferring past climate dynamics, and the role these factors play in the evolution of our early prehuman relatives. He argues that this region of southern Africa is dry today and has been for much of the Cenozoic. This notion of long-term aridity and stability has dominated perspectives on southern African landscape evolution. Here, we present a review of this field, starting with the foundational studies from the late 1890s, which underpin Dart's hypothesis. We examine the work of 20th-century researchers who developed models of landscape evolution; however, almost all of these models have been qualitative. With technological advancements, new quantitative techniques have emerged to provide evidence of landscape evolution events and to test previous models, and we present a brief overview of these methods. We call for reflection on the framing and languaging of many of these landscape models, specifically the 'African land surface' model. While the evidence of a homogeneous and stable landscape is continually being challenged through scientific advancement, this terminology is rooted in outdated colonial thinking. We also note that the key narratives that have driven research on landscape evolution have been largely shaped by selected prominent Western-based scientists. As we mark the centenary of the Taung discovery, we look toward a new era of landscape evolution research: one characterised by technological advancements and more diverse, local teams that will produce more quantitative, nuanced models for southern Africa and create richer, more dynamic backdrops for our own human evolution.

Significance:

We provide a review of over 100 years of models used to characterise landscape evolution in southern Africa. We argue that it is essential to reconsider current models of landscape evolution and assess their relevance in the southern African context. With technological advancements, we must question whether these models remain applicable or require revision. As scientists, we should also re-evaluate the terminology used in scientific dialogue to ensure it accurately reflects evolving perspectives. Finally, while the use of qualitative and quantitative methods have their unique benefits, we consider the application of more quantitative methods of landscape dating to test the existing models and build new, more complex ones.

[Abstract in** Setswana**]

Introduction

The 1925 publication describing the Taung Child fossil in South Africa by Dart[1] marks the beginning of what we recognise today as the modern discipline of human evolution or palaeoanthropology. The role of the physical landscape in human evolution, including our understanding of where, how, and when our genus and species emerged, has been a central focus since the early days of the discipline. In the article, Dart[1] frequently references the landscape in which this, in his words, "ultra-similan and pre-human stock" existed and presenting several key points that have shaped much of the last 100 years of research into the landscape and palaeoenvironmental reconstructions associated with human evolution sites and key hominin fossils. He argues that the presence alone of the fossils of *Australopithecus africanus*, as well as the cercopithecid monkeys also recovered from Taung, is surprising given that,

> *at this extreme southern point in Africa [...] one does not associate with the present climatic conditions obtaining on the eastern fringe of the Kalahari Desert an environment favourable to higher primate life.*[1]

He goes on to argue that "it is generally believed by geologists that the climate has fluctuated within exceedingly narrow limits in this country since Cretaceous times"[1], implying that the current landscape and climate conditions in the Taung region have varied very little for hundreds of millions of years. He concludes that "it was only the enhanced cerebral powers possessed by this group [the australopithecines] which made their existence possible in this untoward environment"[1]. This assertion reveals the early link between hominin fossils and their environments, highlighting two key themes: first, the dryness of the regional landscape, and, second, that there has been very little climatic change for millions of years, implying equally little change in the physical landscape.

The southern African landscape is, at first order, determined by the extensive variety of its underlying geology, dating back as far as the Archaean. However, while the region has an undoubtedly long geological history, the present-day landscape and physical environment into which Dart's australopithecines evolved, have been shaped by a broad range of tectonic, topographic, and climatic events, both on the surface and subsurface.[2] Dart's 1925 assertion that there has been little change in the landscape and climate of the region is not without basis – for much of the Cenozoic (from 66 Ma to recent times), southern Africa was considered to have experienced a period of geomorphological stability, with only modest and localised uplift, subsidence, and erosion (see Andreoli et al.[3], Bierman et al.[4] and Glotzbach et al.[5]). Partridge and Maud[6], in their 1987 review of the geomorphic evolution of southern Africa, however, alluded to the mid-Miocene to late Pliocene minor and the late Pliocene to Holocene major uplifts that challenged the notion of the stability of the region[6], thereby contributing to the suggestion that the landscape is more dynamic than Dart inferred and that, during the Cenozoic, geomorphological processes of weathering, erosion, and deposition have contributed to the formation of most of the landscapes and landforms observed in southern Africa today[2].

Landscape evolution in southern Africa

Since the early 20th century, the evolution of the southern African landscape has been the subject of great geographic and geomorphological interest[7-12], with several ideas and models postulated about its development. The evolving climate and surface processes driven by the climate have shaped the landscape over various spatial and temporal scales and rates, exposing a variety of geologic time periods to the surface[2], such as the Late Jurassic-aged Great Escarpment[13] and 2.02 Ga Vredefort impact structure[14,15]. While we recognise the effects of topography on landscape development, resulting from dynamic uplift and subsidence due to mantle convection[16], we do not address this topic here.

Various studies have explored the development of the southern African landscapes over time, with a focused interest in mountain-building processes[17,18], river processes[19-23], slope development[23,24], soils and soil erosion[25-29] and alluvial fans[30,31]. Most of these studies have focused on the relationships between geomorphology and exogenic factors, such as climate and anthropogenic effects, and how they contribute towards shaping the evolving landscape. Unlike Dart's early declaration of a uniformly dry west, we now recognise considerable variations in moisture availability during different Quaternary phases, evidenced by the development of pans, lakes, caves, and springs in wet phases, and the formation of dunes in dry phases (e.g. Kalahari Desert), as determined from the dating of river and dune deposits using luminescence dating.[32] Other studies that have linked landscape development to the changes in climate and palaeoclimate include work done by Mills et al.[33] in the Eastern Cape Drakensberg area and the recognition of climate changes in the Neogene, as recognised to have had an effect on the landscape by Knight and Fitchett[34] (see also Fitchett[35] for more on the effects of climate on the environment in the Holocene).

In this contribution, to mark the centenary of the original Taung paper, we critically examine the longstanding theme of a dry, unchanging landscape as the backdrop for human evolution in southern Africa. We expand our focus beyond Taung, and assess the models invoked to describe and characterise the southern African landscape and its evolution. We look at how and where these intersected with the growing field of human evolution – as one thing Dart[1] was correct in predicting was that more fossils would be found. We go on to look at this review of the evolution of the southern African landscape through a lens of decolonisation and argue that it is time to both diversify the scope of the theoretical models and build local capacity in South Africa. Specifically, we emphasise the need for new geochronological tools and techniques to test these models and advocate for a broader, more inclusive base of researchers in this field.

Models of landscape evolution: An historical overview

Landscape evolution studies began in the 19th century and are associated with Western-based L. Agassiz, J.W. Powell, G.K. Gilbert, W.M. Davis and A. Penck.[36] In the 20th century, key South African geologist A. du Toit, Australian geomorphologist C. Twidale, Austrian geologists E. Seuss and W. Penck, as well as British geologists and geomorphologists J. Wellington, L.C. King, F. Dixey and A. Goudie, began using the southern African region to develop and test theories of long-term landscape evolution[37-39] (see Appendix A of Partridge and Maud[6] for an Africa-wide summary). Qualitative field observations dominated the earlier published literature[7–11,40], while, in later literature, analytical and quantitative approaches emerged[28,37-39,41-43]. Here, we present a review and summary of the last 135 years of landscape evolution in southern Africa, in chronological order and grouped into subsections, starting from the foundational publication in 1889.[44] This was done to achieve an overview of the various models presented and a sense of the evolution of scientific thought around landscape evolution. This special issue marking the centenary of the description and naming of the Taung Child is the ideal place to explore past landscapes and critically reflect on past practice, as well as to provide a base from which to look forward to future research directions.

1890s

One of the most commonly applied landscape evolution models in the South African context, the Davisian model of Davis, suggests that landscapes evolve in a sequential form after an initial uplift.[45] This initial uplift, as shown in Figure 1A, is then followed by age-related landform development (i.e. weathering and erosion processes) from youth, through maturity to old-age low-relief peneplains where, through the erosion and transport of weathered material, the landscape flattens into a low, featureless plain over time – a peneplain. Simply put, in this

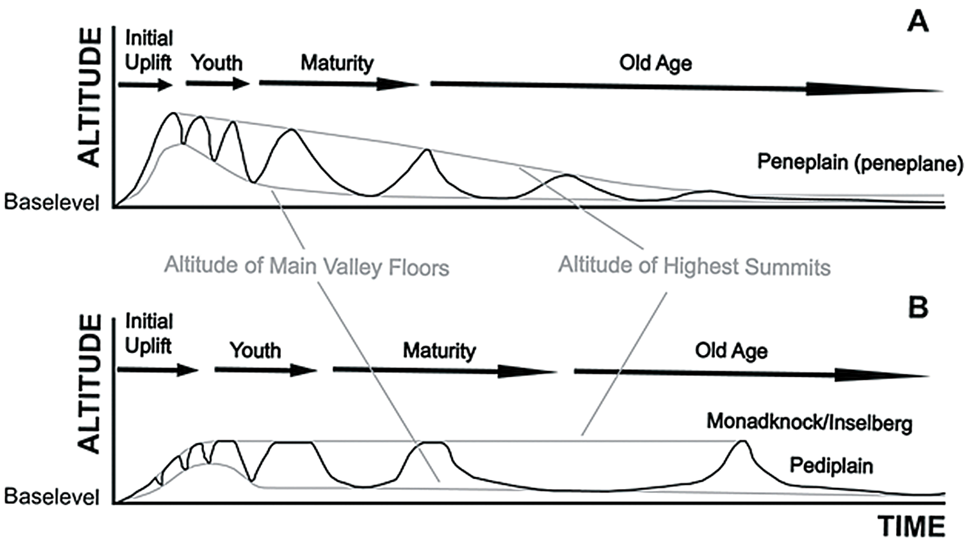


Figure 1: (A) The Davisian (peneplanation) model (the geographical cycle) based on descriptions by W.M. Davis (1899).[45] (B) The pediplanation model of erosion based on descriptions by L.C. King (1955).[10]

model, the landforms are seen as progressing through three stages: youth, maturity, and old age. According to Davis[45], these changes are well defined and work towards the surface process until they reach the end product development of the peneplain. The idea underlying this model is that, because of weathering and material transport along river valleys, land surface denudation widens with time, producing low-relief peneplain surfaces that represent the local land surface stability of the river system.[45]

In his model, Davis emphasises three crucial factors in shaping landforms: structure (lithological folding, faulting, jointing, and other such structural characteristics), process (weathering and erosion) and time. Changes in structure are related to geomorphic processes that occur over time. Time is somewhat of a complex factor in that it not only serves as a temporal metric but also as a process itself, driving the inevitable progression of landform changes, thereby necessitating the comparison of the landscape over a time process to decipher the evolution of the landscape.[45] Davis's theory posits that landforms change in an orderly manner under uniform external environmental conditions. He aimed to provide a basis for genetic classification and systematic description of landforms.

1900–1960s

Between the 1900s and 1960s, du Toit, Wellington, Dixey and King dominated southern African landscape evolution research. While mainly qualitative, their contributions remain foundational and underpin much of the subsequent quantitative research. Focusing mostly on the evolution of major drainage systems, du Toit[7], a geographer, excelled at field observations, a critical geological tool. His model of landscape evolution was dominated by qualitative field observations that involved describing and documenting landforms and landscapes. In 1954, he was the first to embrace Davis's concepts of cyclic periods of landscape evolution, which included tectonic uplift during the Neogene and Quaternary periods.

Like du Toit, Wellington relied on field observations.[11,46-49] He played an important role in the division of southern African regions, which he termed physiographic regions, and in describing regional drainage patterns and morphologies.[48] Wellington suggested that the South African physical landscape was the result of downwearing in a single, constant, and ongoing cycle of erosion and used the example of very large sequences of Karoo rocks that had been removed since the breakup of Gondwana. Wellington pointed out the significance of lithology and structure in his interpretation of the South African landscape – an observation which could explain only the conservation of landforms and not their origin.[11]

Dixey looked at erosion cycles in central and southern Africa, and, like King[7] after him, suggested multiple erosion cycles, different from those summarised by Partridge and Maud[6]. Dixey[50,51] identified two or more erosion surfaces in several central and eastern African countries, attributing these cycles to the varying erosion resistance of underlying lithologies. He suggested that the Jurassic cycle of erosion (later referred to by King as 'the African landsurface'; herein referred to as the African surface) seemed to have been more effective in eroding than subsequent cycles.[50] Dixey also recognised the stability of the African land mass and its exposure to periodic uplift.[51] In 1955, he was the first to acknowledge the applicability of the pediplanation model of landscape change in arid and semi-arid settings.

Through field observations, King[52] grouped erosion surfaces and referred to them as an older 'African surface' and younger 'post-African surfaces'. He compared sediment build-up in coastal regions to argue that the 'African surface' graded to sea level during the late Cretaceous to early Miocene, giving credibility to Dixey's proposed surfaces while proposing the new terms.[52] Additionally, he proposed that crustal erosion prompted isostatic uplifts of the continental margin, thus adding elevation to the Great Escarpment.[6,10,13] He proposed backwearing by pediplanation as an alternative process of landscape development.[10] King elaborated on the concepts and deliberated a pediplanation "landscape cycle" for the development of the southern African landscape (Figure 1B[10]). However, Wellington expressed reservations about King's idea of a peneplain of subcontinental extent inherited from Gondwana.

1980s–2000

In the development of landforms, Twidale explored the idea of etches, their development and how they contribute to the evolution of landscapes.[53] Etches develop in two stages: (1) solution, hydrolysis and hydration and (2) differential degradation of material and structurally controlled subsurface weathering at the base of granitic bedrock. As a result, the regolith is generated at the base of the rock.[54] Due to the southern African region being well known for its planation surfaces, a surface that implies stability and deep, intense weathering[54], from work done by Dixey[50,51,55] and King[52] and summarised by Partridge and Maud[6], it was accepted that etch surfaces would be well developed in the region. This was especially due to the evidence of planation surface development from laterite and silcrete surfaces, because of a passive period.[6] From the processes that promote etch development, we can assume that they are evidence of a quiescent time with little to no tectonic activity.

In their 1987 review, Partridge and Maud[6] suggested that the notable large-scale features of South Africa's landscape were a result of the development of irregular but continuous flat surfaces that occur at various altitudes throughout the region. While it was King[52] who coined the term 'the African landsurface', Partridge and Maud[6] went on to describe these main flat surfaces, based on observable lateral stratigraphy and degree of weathering across the region, as:

i. *The African surface* (85–42 Ma)*:* spanning between the late Jurassic/early Cretaceous to the end of the early Miocene.

ii. *Post-African I surface* (19–15 Ma)*:* spanning from the early to mid-Miocene to the late Pliocene, a minor uplift ranging between 150 m and 300 m.

iii. *Post-African II surface* (7–3 Ma)*:* spanning the late Pliocene to the Holocene and resulting in the uplift of approximately 900 m of the eastern margin.

While there is a 20-year gap in the literature review between the 1960s and 1980s, it is important to note that after King's model and until Partridge and Maud's adaptation, there have not been any more explicit landscape evolution models that have come out of southern African research.

2000s to present: Introduction of new quantitative methods

In 2012, Twidale[56] argued that every model that relied on Davisian deductions had either been altered, dropped, or replaced. However, certain landscape concepts, elements, or processes, some identified nearly two centuries ago, although incidentally, are still recognised as influential in shaping landscape characteristics.[56] These observations highlight the need for updated data and modern recommendations in landscape evolution studies. While past hypotheses developed through qualitative methods have contributed valuable insights, they often relied solely on field observations, without supporting quantitative data, limiting our understanding of landscape evolution. Recent advancements in quantitative geochronological research enable us to test these earlier ideas and analyse cause-and-effect relationships that qualitative research could not fully explore. For instance, the concept of the 'African surface' was initially grounded in qualitative observations without quantitative validation. We propose that such models can now be rigorously tested using advanced quantitative methods.

Over recent decades, various methods have emerged to investigate landscape evolution, allowing for empirical testing of some of the previously proposed qualitative models. Computer-based systems, for instance, have replaced handheld maps, although they still require ground-truthing. Geochronology has become a common approach for examining landscape change, and integrating these techniques provides a more comprehensive view of landscape dynamics. Chronologically constrained data enable us to quantify rates of landscape change (e.g. using cosmogenic radionuclides), allowing comparisons with known tectonic and climatic events rather than assigning these by inference.

Tinker et al.[57] investigated the balance between onshore erosion and offshore sediment accumulation in South Africa since the break-up of Gondwana. They hypothesised that the rate of onshore denudation matches the volume of offshore sediment accumulation. Using geological and sedimentological data, they quantified sediment flux from land to sea and found a significant correlation between hinterland erosion rates and offshore sediment deposition. This suggests that South African landscapes have been shaped by this dynamic, enhancing the understanding of geomorphological processes over geological time scales. Their work aligns with landscape evolution models in southern Africa such as the King and Davisian models, by providing empirical data on uplift and erosion rates. Tinker et al.[58] quantified Mesozoic exhumation in the Southern Cape using apatite fission track thermochronology, linking significant exhumation events during the Mesozoic to the current geomorphological landscape. This underscores the importance of historical geological processes in shaping contemporary geomorphology.

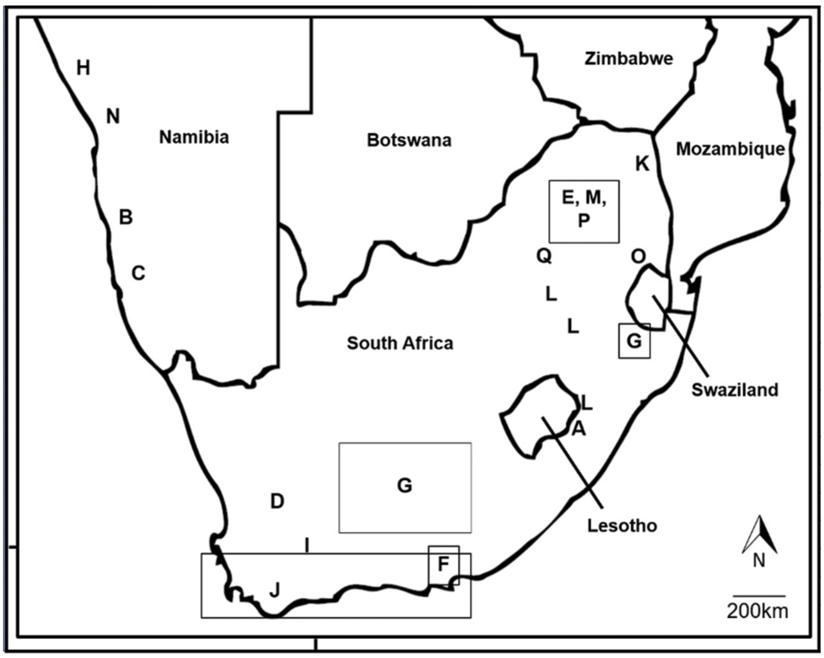
Recent geochronological data, particularly from cosmogenic radionuclides, show variable rates of landscape denudation across southern Africa. For example, average apparent cosmogenic ^{10}Be-derived denudation rates at the Cradle of Humankind's Rising Star Cave, a spatially extensive area, were determined to be at a range of $3.05 \pm 0.25 – 3.59 \pm 0.27$ m/Ma[59], while Dirks et al.[42,43] determined a range of landscape change between 0.86 ± 0.54 m/Ma (from chert dykes) and 4.15 ± 0.37 m/Ma (from river erosion). In the interior plateau, Keen-Zebert et al.[60] determined variable rates of dolerite bedrock erosion along river channels using ^{3}He with values ranging from 11 m/Ma to 255 m/Ma, a very wide range for a regional study. Along the eastern Great Escarpment, Makhubela et al.[61] determined variable rates of erosion with a wide range of 1.8–24 m/Ma along different sections of the same landform.

Scharf et al.[62] found steady-state topography comparable with low denudation rates on the unique alpine-like topography in the Cape, while Tinker et al.[58] identified periods of increased and decreased exhumation, indicating variable landscape responses using apatite fission thermochronology (see also Baby et al.[63-65] for examples of uplift history in the South African plateau and western margins). Decker et al.[66] and Makhubela et al.[67] provide summaries of the extent of cosmogenic radionuclide studies conducted in southern Africa. From these examples, we see that, while the southern African landscape has long been considered stable, rates of landscape changes within the same geomorphic landforms can exhibit a wide range.

The application of chronologically constrained data in determining landscape dynamics is relevant in many aspects of geo- and palaeoscience research, but here we draw attention to its relevance to human evolution. Contrary to earlier assumptions, our early prehuman relatives did not necessarily evolve in a steady, unchanging, dry landscape – it seems much more likely that southern Africa was a more dynamic place than previously recognised. Evidence from hominin-bearing caves in the Cradle of Humankind[42] suggests that this region experienced significant, and repeated, shifts in local hydroclimate, fluctuating between wetter and drier conditions. This finding suggests that hominins evolved in a dynamic, changing landscape, rather than a stable, arid environment as postulated by Dart[1].

Figure 2 shows the spatial extent of geochronological data (mostly from cosmogenic radionuclide studies) that exist for the southern African region, showing that, with such temporal differences determined for the region, there are still knowledge gaps that need to be filled in order to fully review, with confidence, whether some of the previously postulated models are still relevant and can still be applied to how the landscape has developed over time. This underscores the need to reconsider terms such as 'the African surface' and adopt terminology that reflects both spatial and temporal evidence.

Owing to advancements in geological disciplines such as lithostratigraphy, chronostratigraphy and even biostratigraphy, Botha[76] calls for an evolution of terminologies in the southern African landscape. He identifies shortcomings in the current South African mapping practices since geological records were started ~170 years ago. Noting the reliance on lithological descriptors and the lack of formal biostratigraphic units, he claims that these practices lead to inconsistencies and difficulties in correlating geological units across different regions, for example. To address these shortcomings, he proposes the use of formal nomenclature based on lithodemic stratigraphy, which characterises geological units based on lithological properties and terrain morphology, providing a more systematic and standardised approach to geological mapping. He emphasises the interdependence of geological processes and landform development, positing that geomorphological features are a direct reflection of underlying geological processes, believing that landscape evolution models aim to explain how historical geological events have shaped contemporary landscapes, highlighting the dynamic interactions between various geological agents over time.



	REFERENCE	DENUDATION RATES (m/Ma)
A	Fleming et al.[37]	1.4–62.3
B	Bierman and Caffee[39]	1.1–18.2
C	Cockburn et al.[68,69]	0.3–15.6
D	Kounov et al.[31]	0.95–4.82
E	Dirks et al.[42]	2.6–15
F	Erlanger et al.[70]	24.4–86
G	Decker et al.[28]	0.9–18.9
H	Matmon et al.[71]	1.2–19.2 (94.3 outlier)
I	Kounov et al.[31]	0.3–1.5
J	Scharf et al.[62] Bierman et al.[4]	1.98–7.95 3.4–6 (16.1 outlier)
K	Chadwick et al.[72] Glotzbach et al.[5]	3.3–7.8 2.2–9.7
L	Keen-Zebert et al.[60]	11–255
M	Dirks et al.[43]	0.9–8.3
N	Matmon et al.[73]	0.7–6.6
O	Makhubela et al.[61]	1.8–23.9
P	Makhubela et al.[59]	2.2–12.8
Q	Khosa et al., in prep.[74]	0.8–3.7
R	Khosa, in prep.[75]	13.1–45.7 1.0–18.9

Figure 2: Southern African map showing spatial extent and temporal data (denudation rates) of existing cosmogenic geochronological data on landscape evolution studies. Blocks show spatial extent of study reach, where some studies (e.g. J) share similar study reach boundaries.

Botha employs practical methodologies that include field surveys using systematic data collection from various geological formations and landforms, providing empirical evidence for his theoretical constructs and geospatial analysis, and utilising remote sensing and Geographic Information System technologies to analyse and visualise geological and geomorphological patterns, enabling detailed mapping of landscapes, and sedimentological studies, where there are investigations into sediment composition and distribution that inform on past environments and depositional processes.

Botha[76], in agreement with Partridge et al.[77], suggests that geomorphic provinces are necessary for geological interpretation. Here, each province reflects specific geological histories and processes, facilitating a better understanding of landscape evolution and natural resource management, where knowledge of geomorphic provinces aids in effective management and conservation of resources. This is because different provinces exhibit varying geological characteristics and stratigraphic correlation, where geomorphic provinces could serve as reference frameworks for correlating stratigraphic units, which enhances understanding of regional geological variations. Botha proposes changing terminologies to enhance the understanding and correlation of Cenozoic deposits across South Africa, for example.

Why it is time to move on from 'the African land surface'

Andreoli et al.[3], Bierman et al.[4] and Glotzbach et al.[5] have previously suggested that the southern African landscape is a relatively stable and tectonically passive region, and, as such, landscape evolution processes are assumed to be slow, steady, uniform and consistent throughout the Cenozoic. Geomorphological evidence for the so-called peneplains suggests their continued preservation in the southern African landscape.[34] Data from cosmogenic nuclides, thermochronology and the accumulation rates of offshore sediments, further suggest that the topography of southern Africa is ancient and has been stable since the end of the Cretaceous 66 Ma ago.[37,41,57,58,66,69] However, owing to post-formational denudation, these surfaces seem to occur in the landscape at varying altitudes[2], raising the question of the stability and passivity of this region. The concept of an 'African land surface' has existed since the late 1940s, and has arguably been the dominant theoretical framework within which most of southern African geomorphological research has been undertaken. We have traced this concept back to King[52] who grouped erosion surfaces and referred to them as an older 'African surface' and younger 'post-African surfaces'. While this framework has persisted over time, it is important to note that King's publication initially cited no prior research, and yet, while we cannot negate his contribution, the concepts have been accepted and are still considered as true 40 years later, even without quantitative data to support them.[4] Partridge and Maud[6] further examined the development of various erosion surfaces, establishing a connection between distinct uplift stages and localised modifications to the fluvial drainage pattern. Collectively, this became the basis for a long-held narrative that the southern African landscape could be interpreted spatially based on stratigraphic correlations using the evidence of surfaces with weathered profiles, for example, calcrete and laterite layers. This view posits that landscapes across southern Africa are old with irregular but continuous flat surfaces, so-called 'African surfaces'. Beyond these three episodes, the stability hypothesis further predicted that the landscape evolution of southern Africa was slow and steady, with minimal change over a long time period. This concept of landscape stability is also evident in Dart's 1925 publication, as referenced in our introduction.

The challenge of recognising the different 'African surfaces' lies in the assumption that surfaces of similar altitude share comparable ages and, consequently, have experienced the same tectonic activity.[4,56] According to Blumel and Eitel[78] and Marker et al.[79], the correlation of surfaces with these weathered profiles that formed over time by chemical and physical processes, would imply a greater likelihood that the surfaces are instead of composite ages.

Du Toit[80] and King[40,81] suggested a close relationship between geomorphology, topography and geology in southern Africa. This paints a picture of complexity, with the landforms and landscapes of different ages, inferring that they had evolved differently in multiple places and at various times, thus a single interpretation for their evolution would be an injustice to the processes.[60] Both tectonic and climatic processes have been ascribed as the driving factors behind the landscape evolution in southern Africa and echoed by Knight and Fitchett, respectively.[36,40]

Aside from the weak evidence for single, old, stable land surfaces, there is a further issue with the 'African surface' hypothesis: one of language. The term 'Africa' is used loosely here, as all the publications cited here focus solely on southern Africa, with many centred specifically on South Africa. Yet, this hypothesis has been generalised to encompass the entire continental landmass of Africa – an area of 30 million km^2, consisting of at least eight climatic regions and today comprising 54 countries – reducing it into a single, homogeneous mass. This simplification erases the continent's heterogeneity and loosely applies both scientific hypotheses and language, echoing the colonial era and colonial thinking. The expectation that an entire continent could be represented by a single or even three surfaces reflects an inadvertently colonial mindset. Notably, there is in fact *no* strong evidence for these so-called 'African surfaces', and existing models of landscape evolution remain largely qualitative. Examining these models requires moving beyond the scientific limitations of the time and considering the colonial context in which they were conceived and the lasting influence of colonial assumptions on theories of landscape evolution.

Once recognised, the impact of colonial thinking needs to be addressed. A straightforward and easily achievable measure is the evaluation and re-assessment of language used in fields such as geomorphology.[82] We argue that it is time, for many reasons, to move away from using phrases like 'the African land surface'. Employing regionally appropriate and specific terms, potentially informed by spatial extents of landforms and landscapes or quantitively derived temporal data, would represent a shift away from colonial frameworks. We are hopeful that an increase in quantitative studies on landscape evolution in southern Africa will inspire new models, such as those presented by Botha[76] and, with this, foster the adoption of more precise and contextually appropriate terminology and language.

The who of landscape evolution

Geologists and geomorphologists from the early 20th century have made an invaluable contribution to understanding the development of the southern African landscape. It is important to note, however, that these landscape evolution studies in the Global South, and particularly in southern Africa, have mostly been dominated by researchers from the Global North. We base this assertion on an analysis of 44 authors who have contributed to landscape evolution studies in southern Africa (using first name as an indicator of gender, last name as an indicator of ethnicity, and affiliation as a marker of geographical location), which indicated that this field is predominantly composed of male researchers, most of whom are based in the Global North, and only a minority of whom are affiliated with South African institutions (Figure 3).

Advancing the field of geomorphology requires that, as a science, it should be based on observable facts, robust hypotheses, and models based on quantifiable theory with repeatable and verifiable methods. Local experts have called for improved experimentation with radiometric experimental techniques.[31] We contend that, over longer time periods, radiometric methods have improved utility spanning over aeons. For the latter part of the Cenozoic, geochronological techniques, such as the measurement of terrestrial cosmogenic radionuclides using accelerator mass spectrometry, offer critical information.[82,83]

Conclusions

The southern African landscape has been a subject of interest for the last 135 years for multiple reasons, including the various drivers behind its evolution since the start of the Cenozoic. Several models to explain modern observations of the landscape and the processes driving their evolution have been put forward, all of which rely on qualitative, descriptive data. Beyond the three tectonic episodes of the so-called 'African surfaces', the stability hypothesis predicts that the landscape evolution of southern Africa is slow and steady, with little change over a long time period. However, the landscape and resultant landforms that we see today cannot be attributed

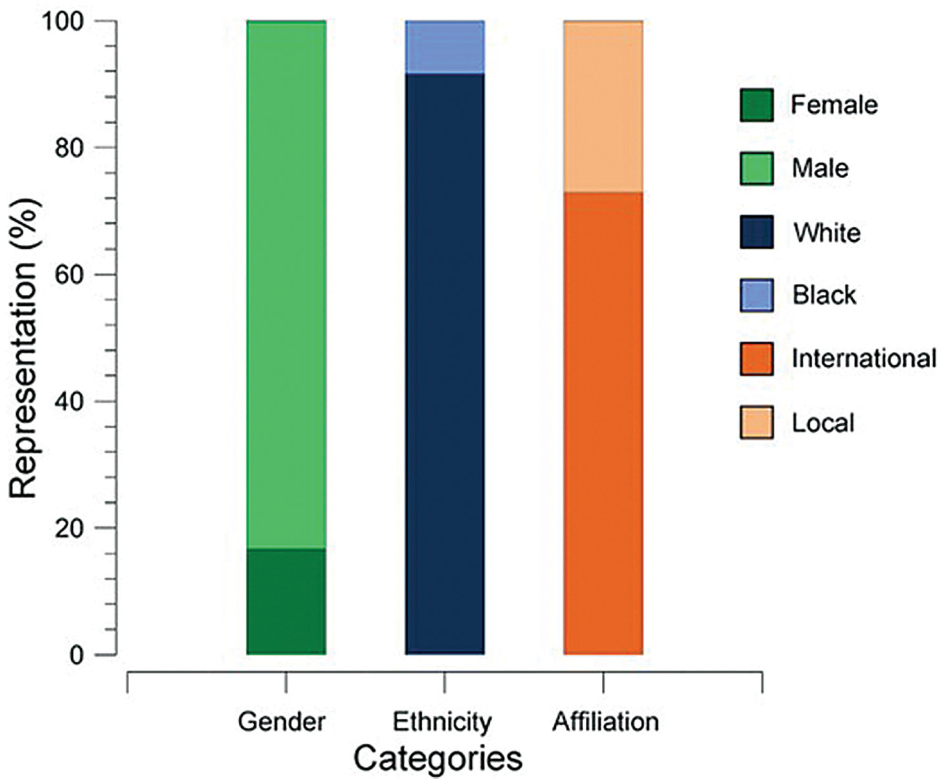


Figure 3: Stacked column chart showing the demographics of 'the who' of landscape evolution studies in southern Africa.

to either a single time period of formation or a single forcing mechanism, but ought to be viewed as transient features that change through time.[2] Detailed quantitative studies looking into the differences between rates of landscape change and factors contributing to landscape evolution across southern Africa have been undertaken for some regions, like the Cape[37,57,58,68] and the Cradle of Humankind[41,43,59], and we look forward to seeing more quantitative studies like these.

From Figure 2, we note that many of the studies conducted have focused on areas along the Great Escarpment and Cradle of Humankind, which is understandable based on their significance to the history of the southern African landscape and human origins. There are spatial gaps that are not being addressed and we strongly recommend considering studies within the interior plateau regions outside the Cradle of Humankind, perhaps from the Free State Province towards the Northern Cape region.

We also look forward to a diversifying of 'the who' of landscape evolution and more local teams doing more locally relevant work in southern Africa. This is not a new idea – there have been previous calls for the decolonisation of the practitioner landscape in geology in South Africa.[84] There is a growing body of thought and literature calling for an introspection of geosciences and articulating the need for change, especially change in the demographics of geoscientists.[85] We look forward to both a new generation of landscape models, based on measurable erosion rates and exposure ages, led by a new generation of more diverse, local geoscientists, to keep filling in the backdrop to the evolution of our own, distant, prehuman relatives.

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Data availability

There are no data applicable to this paper.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

R.K.: Conceptualisation, methodology, data collection, data analysis, validation, writing – the initial draft, writing – revisions, project leadership, project management. V.M.: Writing – revisions, student supervision, funding acquisition. K.K.: Writing – the initial draft, writing – revisions. R.P.: Conceptualisation, methodology, writing – the initial draft, student supervision, project leadership, project management, funding acquisition. All authors read and approved the final version.

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Hominin heritage: How institutional repositories are managing collections, collaboration and repatriation

In this article, we discuss South African heritage management, and how it has shaped the role institutions play in protecting heritage 100 years ago versus today. Museums and universities are in a difficult position as they address past unethical archaeology and palaeoanthropology practices while implementing transformation and decolonisation approaches to protect and share heritage inclusively. We outline some of the complexities that museums, universities, and heritage bodies face in navigating human evolution research, site and material access, potential returns, repatriations or reburials, curation and the development of accessible educational content in a contemporary context.

Significance:

Museums, heritage agencies and universities have been the custodians of archaeological and palaeoanthropological heritage for a long time. In the past, conserving heritage was more about advocating race-based scientific study and advancing the colonial agenda. One hundred years later, this landscape has changed, but is not perfect. The complexities of heritage management, museum curation and collection, repatriation, and how we teach and share human evolution are many. Those navigating these complexities strive for a transformed and inclusive custodianship in an often difficult socio-political landscape, while simultaneously protecting and sharing our heritage.

[Abstract in** Setswana**]

The colonial influence on heritage management

South Africa has a long history with legislated heritage management; however, historically, this has been primarily based upon the protection of the country's colonial history. The preoccupation with collecting archaeological artefacts for local and international (particularly Europe) viewing was popular during the colonial era, particularly in the late 1800s and early 1900s. To help conserve some of this heritage and curb the export of certain objects, the Union of South Africa established the first heritage protection legislation with the *Bushman Relics Protection Act of 1911 (no. 22 of 1911)*.[1] Although the act was directed at conserving rock art, it was also designed for use against the illicit trafficking of San and Khoe human remains.[2] During this time, southern African indigenous communities were targeted for the study of racial types. At least ten museums and learning institutions collected skeletal remains as part of their physical anthropology and human comparative collections. These practices also led to the trade in human remains for financial gain during the colonial era.[2] Body traders often sold human remains together with rock art and other hunter–gatherer-associated archaeological artefacts to institutions abroad.[2] Museums also took part in systems of donation and exchange, creating large skeletal collections in the Global North and some colonies, for use in race-based scientific research.[3] These and other collecting practices have, over time, led to the formation of human skeletal repositories across South Africa, many of which still hold archaeological remains.[4] The *Bushman Relics Protection Act* set the stage for the development of multiple legislative interventions over the next 88 years that would help protect archaeological sites and material culture in South Africa. These include, among others, the *Natural, Historical and Monuments Act (no. 6 of 1923)*, the *Natural and Historical Monuments, Relics and Antiques Act (no.4 of 1934)*, and the *National Monuments Council Act (no.28 of 1969)* (see several summaries[1,5–9] of these legislative acts, their usefulness, and their amendments).

Although these Acts helped protect archaeological material, access to the material was not strictly controlled. As the curators on this paper have observed for existing archives and from personal communications, during this time, collections were accessed through agreements, handshakes, and letters. Loans and analyses of artefacts, fossils, and human remains were conducted with relative ease through museums and other institutions, predominantly providing foreign researchers access to unique finds.

Current legislative framework

Post-apartheid, the need for a new paradigm became more apparent to ensure that past inequalities were redressed, and that the heritage landscape was representative of all inhabitants of South Africa. In response to this need, the *National Heritage Resources Act (no. 25 of 1999)* (NHRA)[10] was promulgated and fully replaced the apartheid-era *National Monuments Act*. The NHRA represented a significant milestone in South Africa's heritage conservation efforts by providing a comprehensive framework for the identification, protection, and management of heritage resources. It established the South African Heritage Resources Agency (SAHRA) and introduced mechanisms for the declaration of national heritage sites, the protection of archaeological and palaeontological resources, and provisions for public participation and consultation in heritage management processes. The establishment of a three-tier system (national, provincial and municipal) was a major departure from the previous legislation (the *National Monuments Act No. 28 of 1969*[11]). It also made provision for restitution and repatriation and the registration of private collections, and significantly expanded the scope of the national estate. Within this new legislation, the rights of the public and access to their heritage were preserved. Although the NHRA draws heavily on the principles enshrined in documents such as the Burra Charter and the World Heritage Convention, it sought to introduce a system of heritage management reflective of the country's constitution, with special emphasis on the importance that heritage plays in defining our cultural identity, spiritual well-being, and nation building.[5] It is considered to be one of the most progressive pieces of heritage legislation[12] and upholds the principle that South Africa's heritage is finite and non-renewable, and that it must be managed in a sustainable manner to ensure its continued conservation. To ensure this, it includes an integrated and interactive system of management of national heritage resources to promote good governance at all levels, and to empower civil society to nurture and conserve their legacy. However, a lack of funding and the devolution to the full three-tier system hinders the implementation of the Act.

Where previous legislation loosely defined objects under protection[11], today, any sampling procedures on archaeological material or palaeontological specimens, or any export of a heritage object, requires a SAHRA permit as regulated by the NHRA. A permit is issued only after the proposal has been scrutinised by a series of professionals. A holding facility or repository (e.g. museum) provides access to collections and must also provide permission for any destructive analysis (based on ensuring the overall integrity of the collection), prior to a SAHRA permit being issued. Despite the significant steps that have been taken to transform the management of the national estate in line with the Constitution of South Africa, including the reinterpretation and reforming of public symbols and spaces[13], the transformation of the palaeosciences remains slow and most investigations (as observed via SAHRA permits; see Supplementary table 1 which reflects permits issued by SAHRA, not including other sampling and excavation permits issued by provincial heritage agencies) in these fields are driven by foreign researchers. Although not legislated, SAHRA requests that a South African researcher be a participant in any international research team. They are often tasked to be the permit holder and the South Africans involved are not always invited to contribute meaningfully to research and publication. One of the key factors behind such a policy is to ensure opportunity for skills transfer. Not all cutting-edge or sophisticated analyses and methodologies are available in South Africa and ensuring involvement of local scholars provides an opportunity for early career scientists to be exposed to these types of research projects, thus building South African palaeoscience capacity. Later-career, well-established South African researchers or museum curators are often targeted to fulfil this role but, in our experience as curators, seldom are South African students and early career researchers approached. As outlined in Supplementary table 1, of the 119 SAHRA permit applications for 2023 for export, analysis or site excavations of an archaeological nature (across fauna, hominin, and artefact studies), there are 24 primary international permit holders (No. 1–24 in Supplementary table 1). These exclude permit applications by South Africans based at foreign institutions. Of the remaining 95 permits, 50 of them are linked to international research teams in the form of collaborations, applications on behalf of, or joint projects (No. 25–119 in Supplementary table 1). Permits have been issued based on proposal and affiliation with a local established researcher or museum curator. SAHRA policy indicates that temporary and permanent export permits should be given to curators, but, failing that, they are given to the principal researcher. There is no way to determine how involved local researchers and curators are in these projects, but, in our experience as curators, collaborators and permit holders, they are not always participating investigators but are rather included to comply with SAHRA policies. This means that up to 62% (74/119) of SAHRA permitted archaeological research in South Africa for 2023 was likely run and funded internationally. This includes the 24 foreigners who hold permits to South African sites and the 50 international parties involved in permitted projects.

Access to the collections at museums and other institutions is managed through institutional policies and their internal standard operating procedures. These precepts are informed by the country's legislative Acts. The *Cultural Institutions Act (no. 119 of 1998)*[14] provided for the establishment of certain institutions as declared cultural institutions under the control of councils and establishment of a National Museums Division. As much as these legislative precepts are scribed on paper, the implementation of them still leaves room for improvement. The NHRA does not guarantee the protection of heritage resources within the country. Legislation has failed with regard to community involvement and difficulties in enforcing the law.[7] Museums and other institutions have in the past years been faced with claims on human remains and calls for returns, reburials and repatriations. Archaeologists working with human remains collections have referred to the NHRA for guidance, but, in the Act, human remains are considered heritage objects and there is little structure regarding reburial claims or repatriation efforts. Curators have also consulted the *Human Tissue Act (no. 65 of 1983)*[15] and its subsequent amendments to help navigate the process of managing donated remains and their research. However, this Act is directed at cadaveric remains or those held at medical facilities and has never fully met collection needs.

A newly developed National Policy on the Repatriation and Restitution of Human Remains and Heritage Objects[16] provides some hope for future guidance. This policy was ratified by parliament on 16 March 2021 and clearly outlines a claims process and management strategy for human remains collections. It also states that any human remains considered fossils or sub-fossils are excluded from repatriation. It continues to demonstrate that, although claims can be made on these individuals or any others, it is unlikely that a claim on human remains dated older than 500 years would be successful due to the inability to "demonstrate clear genealogical, cultural or ethnic continuity far into the past"[16]. This new policy has also made provision for the establishment of a Repatriation and Restitution Office. As an arm of SAHRA, once fully functional, this office will be able to direct enquiries, manage claims and fulfil or refuse repatriation requests.

The lack of capacity within legislative bodies for monitoring and evaluating the conservation, preservation and safekeeping of heritage objects is becoming a great concern. There are no clear instructions on how communities are to be involved concerning objects linked to their own heritage, and even though attempts have been made, the management authorities of the sites and, in some cases, the local curating institutions, are yet to make significant strides regarding this.

National museums in South Africa have a heritage asset management policy, encompassing, but not limited to, collection access, operating procedures, loan practices, storage conditions etc. Generally, curators, guided by the policies and procedures of their individual organisations, control access to collections. This access may be requested by academic researchers, scholars, content creators (broadcasting), as well as the general public. The existence of procedures and guidelines is to ensure a fair and legal process is followed. However, in our experience as curators, there have been (and in some cases, still are) legacy and unsaid biases towards applicants. As curators of significant collections, we have also observed that not all excavated materials are being handed over to museums in compliance with permit conditions, and researchers often grant access to these materials rather than curatorial staff at recognised institutions. Examples of these include large-scale investigations at important sites across South Africa. Many of these research programmes have external research laboratories that run multiple projects simultaneously. Access to these excavated materials is generally limited to select scholars and researchers, as dictated by the principal investigator. We have found that some permit holders of archaeological and hominin fossil sites hold onto selected recovered material for years beyond the permit cycle without formally handing it over to the curating institution, and do so only after publication. Some, even after publication, do not make these remains available for other researchers to study, ignoring their agreement with both the SAHRA and the accredited repository.

This influences the degree of access that certain researchers have had to collections. The SAHRA has recently updated their procedure, and, soon, permit holders will need to produce a letter from the curator indicating the receipt of excavated material at the relevant repository as part of their final permit report. No new permits or extensions will be granted without this. The SAHRA has also observed illegal destructive sampling. For example, in 2016, a researcher sampled a well-known fossil skull without permission, although a retrospective permit was issued for the work. In another instance in 2022, fresh sampling of previously tested sections at a fossil site was noticed by SAHRA officials, again without a permit. These are only a few of many incidents involving the disregard of heritage legislation that we have all experienced with some regularity. Many of these cases are confidential, and, if details were shared, may put researchers at risk, making the power dynamic within the heritage space difficult to navigate.

Collections

The University of the Witwatersrand and Ditsong Museum of Natural History house the largest fossil hominin collections in South Africa, representing about 40% of Africa's early fossil hominin record. These collections include the Taung Child, holotype of *Australopithecus africanus*[17], the world's first early fossil hominin discovery, Mrs Ples (Sts 5), the first complete adult skull of *Australopithecus africanus*[18], as well as the type specimens of *Paranthropus robustus*[19], *Australopithecus prometheus*[20], *Australopithecus sediba*[21] and *Homo naledi*[22]. The remains of *A. africanus* (StW 413 and Sts 13), *A. prometheus* (StW 573 – 'Little Foot'), *A. sediba* (MH1 and MH2) and *Homo naledi* (LES1 – 'Neo') represent six of the ten known partial to complete early hominin skeletons in the world; the other four are from eastern Africa. There are a number of isolated more recent Middle Pleistocene specimens housed elsewhere in South Africa, e.g. the Florisbad cranium[23] is housed at the National Museum of Bloemfontein and the Saldanha calvarium[24] is held at Iziko Museums of South Africa in Cape Town. These 'prehuman' hominin fossils are dated from 3.6 Ma to 236 ka and there are also many isolated elements associated with the aforementioned taxa and possibly as yet unidentified species belonging to the genera *Australopithecus, Paranthropus* and early *Homo*. Collectively, these represent a substantial record of human evolution, a massive resource for the international scientific community, and opportunities for contributing to the public understanding of science.

Although many of these examples are considered relatives of modern humans, their morphology is distinctly different from recent modern humans. They are therefore not considered human in many institutional human remains policy definitions, which only refer to "humans" and not a species. Even the NHRA does not differentiate. Most fall within the pre-modern evolution of *Homo sapiens*. These are therefore not subjected to the same legal and ethical procedures that recent modern humans are. Free and, as far as possible, open access to these collections is given to bona fide researchers, via an access application process through the respective institution's access advisory committees or panels.

However, these fossil collections also contain some isolated skeletal remains of early and more recent *Homo sapiens*, ranging from 260 ka to ~10 ka ago. Examples reside at various institutions, including Iziko Museums of South Africa (from sites such as Klasies River Mouth, De Kelders, Blombos, Sea Harvest etc.), the University of the Witwatersrand (e.g. from the Border Cave site), the East London Museum (the Hofmeyr cranium[25]), as well as the Ditsong Museums of South Africa. To date, this material has been treated similarly to the older hominins, being "ancient" and not subject to ethical approval for study, but still requiring access and study approval from an institutional access advisory committee. It was presumed that the small numbers of human skeletal remains were of such antiquity, that no living group of people could claim ancestry or restitution. This has remained the case with the newly developed National Policy on the Repatriation and Restitution of Human Remains and Heritage Objects.

These and more recent archaeological remains were also used for comparative purposes, and this was considered acceptable at the time, as these are laboratories for the study of human origins. In 2017, the University of the Witwatersrand School of Anatomical Sciences approached the Evolutionary Studies Institute (ESI) to audit all human remains within the institute to identify and remove unethically obtained remains and align with the School of Anatomical Sciences' policy that all human remains should, as a rule, be housed at the School. This also included individuals that were officially on long-term loan from the School of Anatomical Sciences as the ESI may not "own" any human remains. The dilemma was that, as a laboratory that studies early human origins, comparative human remains are essential, together with those of the great apes and other primates. Several representative human skeletons were permitted to remain for comparative purposes, but the use of archaeological remains, without the necessary permissions, was prohibited. Fossil human remains reside within the fossil hominin collections, subject to the rules and regulations of the institutions, in recognition that human remains *sensu stricto* are also subject to the broader human remains policies.[10,15,16]

At Iziko Museums of South Africa, human remains collections are governed by an internal policy[26] and are only accessible through application review, both internally and by an external advisory committee. Fossils, Middle Stone Age context hominin remains, human remains and human casts are all considered part of the human remains collection and are housed in varying storage sections at the Iziko South African Museum's Archaeology Unit. The Unit has investigated the ethics of its collection and worked in consultation with academics, researchers, and descendant community leadership across southern Africa[27] to identify those human remains collected illicitly or unethically in an effort to rehumanise and return them to their place of origin[28]. Those identified have been deaccessioned (removed from the museum inventory and national register) and are no longer museum objects. Research on human remains continues, but only on those individuals collected via permit as indicated in the legislation.

Ancestral claims and who counts as human?

In 2016, a delegation that self-identified as San visited the ESI, making claim to the Border Cave 3 (BC3) infant skeleton that was excavated in 1941[29] from the Howiesons Poort (HP) 1 RGBS layers dated to 74 $\pm$ 4 kya by electron spin resonance dating[30–33]. The delegation of about ten people, from different parts of South Africa, claimed that they are the descendants of the original Border Cave people, who were displaced during the Mfecane and that they wished to pay tribute to the BC3 individual through a traditional San ceremony.

They brought many documents, including scientific papers and books in support of their claim and a kaross specifically made by an elder, to symbolically place over the skeleton, as, in their culture, the deceased baby should not get cold. It was explained that, for an individual who lived so long ago, it would be difficult, if not impossible, for us to acknowledge them as direct descendants; however, support in principle for their wish to pay tribute was given. The delegation stated that the temporal context of a human had nothing to do with their level of humanness, as we recognise this individual to be the same species as us, and therefore they require the same level of respect as any human from an extant population. The ritual could not be carried out on that day, as making fire within the laboratory is prohibited. The intention was to plan a ceremony at a more appropriate and practical venue. Subsequent correspondence indicated that the San representatives wished to carry out the ritual at Border Cave, and had approached the government for support, although no support was given. To date, nothing further has been heard on this matter. For the first time, those who curate ancient fossil hominins were challenged on how we conduct work around fossil human remains, and confronted by a group of living people claiming to be associated with such remains. Since then, Iziko Museums of South Africa has had some correspondence with descendant communities in the Eastern Cape querying the possibility of the return and reburial of the Klasies River Mouth hominin remains[34–36] (dated 110 ka – 65 ka[31]). However, no further contact with the museum has been made in this regard.

Even though ancestral claims to much older fossil remains are rare, there have also been several attempts for the Taung Child (Taung 1/U.W.1-1) to be returned to the North West Province, including requests for reburial. After all, it was the scientists who claimed that the Taung Child is our ancestor and the fact that it was older than 2 ma, and not human, was irrelevant to the community making the claim.

Another interesting scenario around fossil human remains was a recent study on ancient human DNA from Plover's Lake, Gauteng.[37] The very fragmentary remains consisting of isolated teeth and post-crania were initially dated from flowstones to be more than 60 ka.[38] The site therefore became known as a Middle Stone Age hominin-bearing locality. However, DNA sampling of several human and faunal specimens revealed DNA of African farmers and domestic cattle.[37] Subsequent C14 dating suggested that the human remains were no older than 500 years bp. This is an example of a collection that had been curated and studied as ancient fossil humans, and now falls within the realms of practically historical antiquity. In another example, Ditsong National Museum of Natural History curates a skeleton, TP1, discovered at the Springbok flats.[39] The locality of the discovery was initially thought to be of Middle Stone Age origin[40]; however, more recently, the skeleton was dated to between 20 ka and 11 ka[41]. Despite the relatively young age of the skeleton, as opposed to the fossil hominins in the collection, the skeleton is subjected to similar standard operating procedures as the entire collection. It is not treated as a recent human at all.

Another recent consideration is around the discovery of *Homo naledi*[22,42] – a hominin identified and described prior to dating. Much of this species looks primitive but was subsequently dated to between 335 ka and 236 ka.[43] This is astonishingly recent for a species that displays characteristics of hominins from around 2 ma ago. Nevertheless, several features of the skeleton are virtually indistinguishable from those of modern humans.[44,45] The time when *H. naledi* lived is contemporaneous with early *Homo sapiens* and their relatives and hybridisation between *H. naledi* and another hominin is not inconceivable. Furthermore, the *H. naledi* remains are not 'fossilised' but still organic and considered sub-fossil. Should molecular studies on such material be successful and yield human DNA or proteomic results, would the human status of such a species change? There is also a provocative hypothesis, that *H. naledi* may have interred its dead[42,46,47] and even practised rock art[48,49]. This hypothesis is not supported by the broader scientific community[50], but it does offer an opportunity for discourse on complex behaviours. Burial, from an archaeological perspective, provides a hard, material record of a behaviour that is deeply spiritual and meaningful. It allows scientists to trace the emergence of beliefs, values, and other complex ideas that appear to be uniquely human. Although the purported evidence for these symbolic behaviours has been criticised in the literature, the possibility that a primitive, small-brained hominin could have engaged in the deliberate disposal of its dead challenges the conventional thinking about the distinction between modern humans and earlier species.

Even though the laws, ethics, rules, and regulations pertaining to fossil human relatives are no different from those applied to any other fossils, when it comes to what are arguably fossil early or modern humans which lived long before they could be associated with any extant group, there is a point where lines become blurred. Human remains policies have been based on the premise that humans have a special status when deceased.

Repatriation and the museum

After the recognition of the first democratically elected government, museums were used as a source of reconciliation and social cohesion, a mandate most museums are still trying to achieve or implement. This has been particularly difficult for many institutions due to South Africa's past. Shrouded in a legacy of race-based scientific research, grave robbery and human trafficking, extractive research practices, exclusion, and apartheid, it may be difficult for some colonially established museums and institutions to gain full trust and acceptance from the South African public, and particularly from indigenous communities. Most issues with human remains derive from early human evolution research and archaeological collections. At present, museums still collect human remains, predominantly from CRM (contract archaeology) work and impact assessments. During these archaeological mitigations, immediate reburials are often not possible and the individuals are therefore brought to museums for storage and protection (as per the NHRA) until such time as they can be reburied. While museums and institutions await further legislative developments and the resourcing of the newly initiated Repatriation and Restitution Office, curators have worked to develop strategies to liaise with descendant communities[51] and have networked broadly to facilitate reburial efforts and processes for human remains and heritage objects[27,52].

There have been a few successful repatriations and reburials of Khoesan descendant individuals held in archaeological or physical anthropological contexts. Most notable are the repatriation of Sarah Baartman from the Musee de l'Homme in Paris 2002[53], the return and reburial of Klaas and Trooi Pienaar from the Natural History Museum collections in Vienna in 2012[54], and the local reburial of the Sutherland Nine from the University of Cape Town to identified communities in the Northern Cape in 2023[52]. But these repatriation and reburial processes are incredibly slow. Iziko Museums of South Africa, for example, has been actively trying to rebury unethically collected human remains for a decade.

Community consultations have been successful, but the practicalities of community and government consensus, funding, and establishing processes, hinder progression. Because of these delays, museums are seen as a hindrance to returns and are often criticised in the public domain.[55,56] But the problems extend beyond repatriation. Some older museums may be reminders of colonial and apartheid erasure practices that have in the past been highlighted in exhibitions, educational content, collecting practices, and curatorial engagements.[57] Today, many museums in South Africa are trying to move forward responsibly, demonstrating their accountability for past harm. In short, local museums are trying to reframe how they represent heritage, people, places and things within and amongst a pan-African movement to decolonise museum spaces.[57–60]

The museum's place in the South African school

Teaching, sharing, and learning archaeology and human evolution is critical to ensuring the growth of the next generation of diverse researchers, museum professionals and heritage practitioners within the discipline.

There are various obstacles to this, including that the school curricula, support material and textbooks designed to underpin teaching and learning of evolution are often inaccurate[61] or incomplete. However, in South Africa today, Grade 12 textbooks have substantial sections on evolutionary theories and human evolution. Teacher training may be lacking or insufficient and museums are often asked to step in and teach these themes. Compounding this is the feeling of educators that they poorly understand the topic and that their "flawed understanding is transferred to those attempting to learn it"[61]. Also, there is a resistance to human evolution in South Africa which has its roots in a complicated history of inequality, erased identity, religious education, and racism.[62] Religious and cultural beliefs among the diverse backgrounds of South African educators and learners can also have a huge impact on how human evolution is taught and viewed. Many teachers have not been adequately exposed to human evolution as it was excluded from South African curricula under the old Christian National Education system which was the basis of school education from the 1960s to 1990s nationally.[63] Today, traditional narratives within which the subject is taught disconnect human evolution from the way it is understood among different communities in South Africa. This has resulted in some teachers using methods that are not appropriate for dealing with the topic's complexity and controversy.[64]

To assist teachers and reach a broader public audience, Iziko Museum frames its new exhibitions and associated educational content on human evolution as a narrative that moves away from archaeological language and older classifications, categories and visuals[65], e.g. time periods, representations of people and races, heritage 'ownership' or using a narrative of superiority or simplicity across race, gender, belief, or background. The museum also addresses the lack of accurately translating concepts and scientific words from English to African languages. The museum uses new translation methodologies to make science more accessible to diverse audiences.[66] These efforts are not only about revisiting history but also reimagining it through inclusive narratives that reflect the diverse cultural and historical backgrounds of its audience.

Museums and their educational programmes act as resources to contextualise and strengthen teaching practice in these thematic areas, either passively when museum educators present lessons and workshops to schools, or actively when museums run teacher training workshops. It is interesting to note that both human evolution and Indigenous social history offer narratives of our origins, and it is these with which teachers need support.

The past ten years of teaching have done much work in positioning school learning areas as societally contextualised compartments. South Africans are accustomed to this compartmentalisation, which can include lived realities which accommodate simultaneous multiple worldviews, including organised religion, Indigenous cosmologies, community ritual, and formal education, all superimposed on a backdrop of multilingualism. In the national schooling curriculum, the sciences have been presented as a valid societal worldview, enabling educational institutions such as Iziko Museum to present Indigenous social history alongside cutting-edge science.

The future of public human evolution education

Through educational workshops, interactive tours, and collaboration with educators, several South African museums strive to provide a comprehensive understanding that resonates with school-going learners' lived experiences. These initiatives are crucial in dismantling barriers erected by previous educational frameworks and in promoting a more egalitarian and accurate representation of human evolution, palaeoanthropological research, and, by extension, cultural diversity. The integration of exhibits, museum collections, and broader content into school curricula, alongside the provision of materials in multiple local languages (when possible), serves to democratise knowledge and make learning a more inclusive and engaging experience for all.

The integration of museum exhibits, particularly those at the forefront of palaeoanthropology, into the school curriculum offers a revolutionary way to address the historical residue of an education system shaped by colonialism and apartheid. By meticulously selecting content that both aligns with and expands upon the national curriculum, museums like the Iziko South African Museum play a crucial role in recalibrating students' understanding of human history. By presenting a multifaceted view of human evolution and cultural heritage, students are encouraged to critically evaluate the complexity and diversity of human history beyond the oversimplified narratives of the past. An example of this is the new Humanity exhibition which opened at Iziko South African Museum in September 2023 (see Kgotleng et al. in this issue[67]). In museums globally, the history of human evolution is often presented as a chronological story of male exploration and discovery. In South Africa, narratives in schools and media tend to highlight figures like Raymond Dart, Phillip Tobias, Lee Berger, and other predominantly white, foreign male researchers linked to major fossil finds in the region. In contrast, the Humanity exhibit focuses on the rich diversity of South Africa's people and the origins of that diversity. The exhibition is the result of a dynamic collaboration among South African and African researchers, academics, community leaders, and representatives from various interest groups. This collective effort has created a decolonised exhibit in which the narrative is authentically African and shaped by shared ownership that has been well received by the public.[68] We note good progress in some museums post-apartheid, while in others, not much transformation is evident in the displays exhibited. Some displays are still inclined towards the colonial and apartheid era[69] and there is still a noticeable disconnect between the current developments in the cultural, historical and scientific advancements (discoveries) that are yet to be included in the shared story lines. This educational strategy is pivotal in promoting a more nuanced and inclusive understanding of humanity's journey, fostering a generation of learners equipped to appreciate and engage with the richness of our shared heritage in a global context.

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Data availability

All relevant data have been included in this paper. Additional data are publicly available on the SAHRIS platform and are openly accessible via this link: https://sahris.org.za/.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

W.B.: Conceptualisation, data collection, validation, writing – the initial draft, writing – revisions, project leadership. B.Z.: Data collection, validation, writing – revisions. M.T.: Data collection, validation, writing – revisions. G.A.: Data collection, validation, writing – revisions. P.H.: Data collection, validation, writing – revisions. All authors read and approved the final manuscript.

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Contesting a legendary legacy: A century of reflection on Raymond Dart and the Taung skull

In 1925, Raymond Dart published his description of the Taung Child skull, which he named *Australopithecus africanus*, thereby making a pivotal contribution to the field of palaeoanthropology. While recognising Dart's central role in the field, this paper reviews the historiography of two aspects of Dart's legacy. First, this paper explores how, over time, Dart's telling of the story of the Taung fossil obscured the role of geologist Robert Young and promoted the myth of 'one man, one fossil', rather than the reality that all scientific efforts reflect the work of a team. Then the paper shifts to review Dart's belief in race typology, and his disturbing anthropological practices. These beliefs and practices were not questioned in the era of racial segregation and apartheid, and they carry painful legacies into the fields of anatomy, anthropology and palaeoanthropology. Dart's legacy was upheld during his lifetime and was further protected for another 25 years after his death by Dart's protégé and successor, Phillip Tobias. However, critical reflection on Dart's legacy of scientific racism began in the 1990s and continues today. Dart's important contribution to palaeoanthropology, the description of the Taung skull, continues to eclipse other more negative aspects of his legacy. This paper reviews scholarly writing on Dart's overall career, confirms this legacy of scientific racism, and argues that it stands alongside his legendary legacy of the description of the Taung Child skull.

Significance:

- The case of the Taung skull illustrates that palaeoanthropology is a matter of teamwork, and serves as a reminder to look for and document the team of people involved with fossil finds, rather than attributing them to one person.
- The Raymond Dart papers and Dart's publications at Wits University provide evidence of Dart's promotion of race typology and scientific racism.
- While Raymond Dart's significant contribution describing the Taung skull is secure, his overall legacy should be reassessed.

[Abstract in** Setswana**]

Introduction

Raymond Dart had just turned 32 years old in February 1925 when he published his famous article in *Nature* describing the Taung Child skull, which he named *Australopithecus africanus*. Dart lived for more than another 60 years – passing away in 1988 at the age of 95. This paper reviews how, over time, Dart's telling of the story of the fossil obscured the role of geologist Robert Young and promoted the myth of 'one man, one fossil', rather than the reality that all scientific efforts reflect the work of a team. This paper also explores Dart's belief in race typology, and his disturbing anthropological practices, which were not questioned in the era of racial segregation and apartheid, and that carry painful legacies into the fields of anatomy, anthropology and palaeoanthropology. The paper reviews scholarly writings on Dart's overall career, shares findings from the Dart Papers of the Wits University archives, confirms this broader legacy of scientific racism, and argues that it needs to stand alongside the description of the Taung skull as part of Dart's overall legacy.

The myth of 'one man, one fossil'

Today, because of contemporary accounts, we know that geologist Robert Young hand-delivered two pieces of rock to Raymond Dart in late 1924.[1–4] Yet, in Dart's 1959 memoir, *Adventures with the Missing Link*, Young was not there and Dart tells the story as a romantic drama playing out in the Johannesburg heat.[5] Dart writes that, as a 31-year-old Head of the Department of Anatomy at Wits University, he reluctantly put on a pair of black tuxedo trousers and a white shirt. The Darts had offered their Melrose home as the venue for a friend's wedding and soon the guests would arrive. Dart was to be the best man. Cursing his collar, Dart moved to the window and glanced outside. He saw two men coming up the driveway, staggering under the weight of two large boxes, and immediately his mood improved. He had been waiting for this delivery, and it had nothing to do with the wedding.[5] Yet the arrival of the boxes was not the whole story.

Just weeks earlier, Dart had been pleasantly surprised when one of his students in the Department of Anatomy, Josephine Salmons, arrived at class with an ancient baboon fossil. This part of the story has always been told consistently by Dart. The fossil that Salmons showed him had been embedded in limestone that had been blasted out of the Buxton Limeworks in Taung, about 400 kilometres southwest of Johannesburg, as lime was needed for gold processing. Salmons had seen the fossil by chance. The manager of the limeworks, A.E. Spiers, had shown the fossil to E.G. Izod, the director of the Northern Limeworks Company, who carried it to Johannesburg where he showed it to his son 'Pat' Izod, who in turn showed it to Salmons. Salmons asked Izod if she could borrow the skull and show it to Dart.[1,5,6]

According to sources at the time, as well as his later memoir, as soon as Dart saw the ancient primate fossil in the rock, he showed it to his geologist friend and Wits colleague Professor Robert Young. Looking at the fossil together, Dart and Young were excited by the idea that there might be more ancient skulls to be found at Taung. Young knew the quarry at Taung – Buxton Limeworks – and he knew the local quarryman, Mr De Bruyn, who had been blasting at Taung for some time, and gathering fossils from the rock. Young told Dart that he was heading to Taung soon, and that he would consult with De Bruyn and report back.[2,5]

In late October or at some point in November 1924, De Bruyn blasted out a fossilised brain cast that he thought might not be from a baboon. He showed the two blocks of stone to his manager, who in turn showed them to the visiting Professor Young. Young decided to carry these two pieces of rock personally on the train back to Johannesburg. However, before he left Taung, he arranged for many other pieces of promising breccia to be boxed and sent on the train directly to Professor Dart – these were the boxes that showed up on the day of the wedding.[2,3]

This is where Raymond Dart's telling of the story in his 1959 memoir differs from the newspaper coverage in 1925. According to Dart's memoir, and the repetition of the story for decades, Dart ran out the door to investigate the boxes, and prised open the lid, saw the mould of a skull, and knew immediately that it was not another baboon skull like the one Josephine Salmons had brought him.[5]

Yet, the local newspaper coverage at the time[2(p.25)], Dart's 7 February 1925 article in *Nature*[1], and a letter sent to Dart by geologist Robert Young in February 1925[7], give a different story. Dart had not found the brain cast and skull in either of the two wooden boxes of rubble. It was Robert Young, the Wits geology professor, who carried these pieces of breccia back from Taung personally, and he hand-delivered them to Dart. For decades, this piece of the story was lost. Dart's telling of the story in his memoir minimised the role Young played at Taung and did not mention at all that it was Young who had delivered the fossils.[2,3,5]

The distinction between receiving a couple of rocks from a railway delivery service or from the hands of Robert Young might not be critical if it were not for the fact that the fossil from Taung would make Dart an internationally renowned scientist. What Dart's successor in the Department of Anatomy, Phillip Tobias, described as the "chain of discovery" – from the labourers in the mine to the supervisor De Bruyn, to the mine manager, to Professor Young to Raymond Dart, as well as the important role played by Josephine Salmons – would turn out to be the most important fossil hominin find of the 20th century. It would make a monumental contribution to our understanding of human evolution.[2,3,8]

On 7 February 1925, the same date that Dart's article describing the fossil appeared in *Nature*, Young wrote a letter to Dart on a small folded card; he congratulated Dart on the discovery and the glory it would bring him and the University of the Witwatersrand.[7] Three days earlier on 4 February, an article had appeared in *The Star* in Johannesburg with the headline "Blasted Out: How Professor Young Found the Skull". In an effort to set the record straight, Young wrote to Dart, "…the part I played at Buxton in the actual finding of the skull was to select amongst the specimens, the piece of rock containing it from some fragments of rocks and minerals laid aside in the quarry by the quarryman …I do not think it of any particular importance who 'found' the skull, and I mention the matter here merely because of the heading to the report...I had no intention of claiming anything, however small, that was not my due."[7]

In Dart's *Nature* article, he acknowledged that he was "manipulating the pieces of rock brought back by Prof. Young"[1]. A research note in *Nature* later that year read: "It will be remembered that the limestone block from which Prof R. Dart chiseled out the fossil skull of *Australopithecus africanus* was brought to him by his colleague Dr. R. B. Young."[4] Yet this aspect of the story was lost over the years, and Young was largely written out of history.[2,3,5,9,10] Young passed away in 1949, and by the time Dart wrote his memoir a decade later, Young played no role in delivering the skull to Dart.[5] The memoir was published 35 years after the fossil find, so memory lapses are likely, and Dart may have felt that finding the skull in the boxes of rubble made for a more dramatic story.[2,3]

In 1946, Robert Broom wrote that "The specimens were placed in Dart's hands in November 1924."[11(p.12)] Dart's successor at Wits, Phillip Tobias, grew up hearing the story in the 1950s and 1960s without much mention of Young, a version that circulated for decades.[2,3,12(p.22)] In 1974, the Johannesburg-based Museum of Man and Science published a booklet written by Roy Terry to commemorate the 50th anniversary of the Taung skull.[9] The popular booklet did not include references, and was distributed widely. It stated that the rock containing the skull "was crated together with other rocks and sent to Dart in Johannesburg"[9(p.7)]. It was only in 1984 that Tobias reviewed contemporary sources and reassessed Young's role in his publication, *Dart, Taung and the Missing Link*. Tobias concluded that it was likely that the boxes of breccia were shipped, but that Young carried the critical pieces of rock.[2] "It is clear from these re-interpretations", Tobias wrote, "that history should assign a greater role to R.B. Young in the chain of discovery"[2(p.26)].

In 2006, Tobias wrote a paper for the *Transactions of the Royal Society of South Africa,* again detailing the exact sequence of events surrounding the Taung skull and the "neglected role of Professor R.B. Young"[3]. But Tobias's meticulous research did not fully reinstate Young's role in the story. In 2003, for example, Bob Brain wrote an article for *Nature* commemorating Dart and the Taung skull, and he lifts the story straight from Dart's memoir[10], as did a Leakey Foundation podcast in 2019[13].

Unlike Young, Josephine Salmons was consistently credited by Raymond Dart. He claimed that she was the person who inspired him to search for fossils in Taung, and he published a photo of Salmons in his memoir.[5] Without her input, Dart might not have become a world-famous palaeontologist. Little is recorded about Salmons' later life. She completed her BSc and honours degrees, and all but her final year of a medical degree at Wits before she married Cecil Jackson and had two children. She did not continue with a scientific career and, in April 1950, she died of cancer in Scottburgh in Natal at the relatively young age of 48.[8,14]

It would not be the last time that someone who played a crucial role in a fossil find, like Robert Young, would defer to the lead scientist, and fade away from the historical record. This was a pattern that would repeat itself in palaeoanthropology in Africa again and again for the next century. Under segregation and apartheid, African labourers and assistants who helped build the careers of scientists, faced challenges very different from Young, yet they too received little attention or applause and their life stories faded from view. For example, Daniel Mosehle and Saul Sithole worked with Robert Broom at Sterkfontein and Kromdraai[8,15], and George Moenda was instrumental in finding evidence of fire at Swartkrans with Bob Brain[8,16]. Steven Motsumi and Nkwane Molefe identified the spot in the rock where they had been working with Ron Clarke to find Little Foot.[8,17] There is a need for greater acknowledgement of these individuals, a discussion which has begun in more detail elsewhere.[8,15–19] Science of all kinds is a matter of teamwork, collaboration and the sharing of ideas.[8,17–19] This story of the Taung skull can serve as a reminder to look for and document the team of people involved with fossil finds, rather than attributing them to one person.

Decades of glowing praise

European scientists were sceptical of Dart's claims about Taung at first, even calling Dart's claims "preposterous"[5(p.45),20], and it took more than 25 years for the international scientific community to accept the significance of the Taung skull[20–22]. Yet, the reaction in South Africa to Dart's 1925 announcement was generally one of excitement. The University of the Witwatersrand was barely three years old and the university council congratulated Dart for his contribution to science and the distinction he brought to the university, and named Dart the Dean of the Wits Medical School within months of the paper.[8] Jan Smuts, previously South Africa's prime minister, who was then the president of the South African Association for the Advancement of Science (S_2A_3), sent Dart a warm letter of congratulations calling Dart's discovery "epoch making"[5(p.36)]. He suggested that it was "calculated to concentrate attention on South Africa as the great field for scientific discovery, which it undoubtedly is"[5(p.37)].

Many South Africans saw Dart as a scientific hero[23,24(p.2),25(p.231)] – an image that continued for the rest of his life. His heroic legacy was promoted by Robert Broom[11,12], Dart's memoir[5], and a 1984 biography written by Tobias: *Dart, Taung and the Missing Link*.[2] In the early 1980s, Wits historian, Bruce Murray, wrote that Dart was "the man who put the medical school and indeed the University, truly on the map"[26(p.179)]. At an international conference held in Johannesburg to honour the 60th anniversary of the discovery of the Taung skull, Dart was showered with high praise for his work.[24(p.24)] His obituaries celebrated his tenacity and acknowledged that he "revolutionized the study of human origins"[24,27].

After Dart passed away, his legacy was further protected for another 25 years by Tobias, who saw Dart as a father figure.[25,28,29(p.219)] Francis Wheelhouse and K.S. Smithford published a reverential biography of Dart in 2001, *Dart: Scientist and Man of Grit*[23], which was based largely on Wheelhouse's PhD dissertation of 1998 which concludes that "by his sheer vitality and drive, [and] his inspired vision . . ., he lifted the University of the Witwatersrand to world prominence"[30]. In addition to praising his "major discovery of *Australopithecus africanus*", Wheelhouse applauded his many contributions in "anthropology, human migrations and culture"[30].

There are countless documents, articles, websites, and blogs that refer to Dart and the Taung skull.[2,10,13] But there is a large body of work that Dart pursued in the 1920s and 1930s related to physical anthropology, race typology, and cultural diffusion that is not often mentioned, and deserves greater attention. It was after Dart's monograph about the Taung skull was rejected by London in 1929 that he set aside his work with ancient fossils until the mid-1940s. In the intervening years, he turned to these other interests in comparative anatomy and the study of living humans.[8]

Other areas of Dart's work – long unexamined

As soon as Dart arrived in South Africa in 1922, and before describing the Taung fossil, he started a human skeleton collection. He had seen these collections in Europe and the UK, where the motivation for starting them was to understand comparative anatomy and race.[8] He was especially impressed by the Terry Human Skeleton Collection in St. Louis in the USA, where anatomists looked especially at the skeletons of people indigenous to the Americas and took interest in a hierarchy of race.[31]

Many scientists at the time believed that humans could be divided into separate, distinct and pure racial types – which we now know is not the case.[32] Dart believed that race typology, which classified humans by their physical characteristics, was an important aspect of physical anthropology, as did Robert Broom[32,33(p.38)] and Matthew Drennan[24(p.13),33(p.42),34(p.157)] in South Africa, Robert Terry[8(p.49)] and Alec Hrdlicka[33(p.30)] in the USA, Lido Cipriani[35] in Italy, and many others across Europe and the UK[33(p.26)]. Dart was particularly interested in the anatomy of the people of southern Africa, especially the San and the Khoi, and he believed that understanding their anatomy would give him a clue to understanding race typology and human evolution.[24,33]

In 1936, Dart led a major Wits expedition of scientists to the Kalahari.[8,33,36] The Wits scientists relied on the work of Donald Bain, a former farmer and hunter. Knowing that many local people were struggling to find food and water, Bain offered them rations of both. He brought them together from various places across the Kalahari to an area called Tweerivieren. It was at this temporary camp that the Wits academics conducted their research.[8,33,36,37]

Focusing on physical anthropology, Dart and his assistant took cranial measurements and measured facial characteristics. They recorded eye colour and hair texture and wrote their findings on the cardboard tags. Dart's two 1937 journal articles, published in the Wits journal *Bantu Studies,* make disturbing reading, as he gave special attention to the measurements of the external female genitalia. He believed that taking measurements and photographs of intimate body parts would contribute to the effort to confirm racial types.[38,39]

After the measurements were completed, the scientists led each person to a second tent to have their face mask taken.[40] Dart had learned the face mask technique on an earlier Italian expedition led by Attilio Gatti through Somalia, Ethiopia and the Congo. Lido Cipriani, an Italian physical anthropologist, had developed a technique to gather face masks by moulding plaster of Paris onto the faces of living people. Cipriani believed in the superiority of Italians and the inferiority of Africans and later worked for the Italian Race Office. Dart saw this process as a significant new methodology in the field of physical anthropology.[35,36] There were no standard procedures in place in 1936 for seeking a research subject's consent. The ethics of taking these casts and measurements was not questioned by the scientists at the time.[41]

Dart and his assistant Eric Williams took 70 face masks of nearly all the adults and some of the children at the camp at Tweerivieren. From then on, through to the 1980s, almost every expedition from the Wits Department of Anatomy to study living people across Africa included taking face masks. Today at Wits, there are over 1000 masks in the Raymond A. Dart Collection of African Life and Death Masks. While the entire collection was on display for almost a century, the current curators have placed most of them in storage, leaving several on display for teaching.[40,42]

After returning from the Kalahari in 1936, Dart wrote that Bushmen "are, as it were, living fossils, representative of the primitive state of all mankind, mementos of our primaeval past"[24(p.11)]. Dart was not the only person using this term "living fossil". Jan Smuts used the offensive and dehumanising term as well.[43(p.249)] Living human beings are not fossils. Yet Dart and Smuts both supported the establishment of a San reserve, similar to the reservations for Indigenous people in the USA. The legislation did not pass, but it is one example of how the push for segregation existed in South Africa long before apartheid.[24,33]

Throughout his career in the Department of Anatomy, Dart's views on race typology influenced numerous students, including Alexander Galloway[33(p.42),34(p.157)], Laurence Wells[34(p.157)], Hertha De Villiers[33(p.62)] and Phillip Tobias[24(p.29),33(p.62),44(p.226)]. It was decades later that physical anthropology started to shift to a post-typological way of thinking that was influenced by statistics and genetics.[8(p.115)] In 1958, the physical anthropologist Ronald Singer critiqued race typology in South Africa, and yet its influence carried well into the 1960s and 1970s.[8(p.120),45] The Raymond A. Dart Collection of Modern Human Skeletons and the Raymond A. Dart Collection of African Life and Death Masks expanded, and the anthropological practices used by the Department were not questioned within the academy for over 70 years, certainly not publicly by scholars or anatomists while Dart was alive. It was not until the demise of legal apartheid that scholars began to critique Dart's career and influence.

Beginning to critique scientific racism in the 1990s – Dubow, Burns and Abrahams

Saul Dubow published the first full-length study of the history of scientific racism in South Africa in 1995, entitled *Scientific Racism in Modern South Africa*. His chapter on physical anthropology discussed Dart and critiqued the concept of race typology, measurement and classification. "The objectification of the observed by the observer is heightened by the clinical detachment and steely technical terminology used in the description of the bodies of others", wrote Dubow[33(p.31)].

In his 1996 paper 'Human Origins, Race Typology and the other Raymond Dart', Dubow continued his investigation and argued that "Assumptions of intrinsic racial difference and notions of superiority and inferiority are so embedded in Dart's lifework that it is impossible to assess his contribution to anthropological knowledge in isolation from this fact."[24(p.12)] Dubow's important point is not yet embraced by many palaeoanthropologists, scholars and historians almost 30 years later.

Phillip Tobias took over from Dart as the Head of the Department of Anatomy at Wits Medical School in 1959. As a student of Dart's in the 1940s and 1950s, Tobias fully embraced race typology.[44(p.226),46] In 1951, 15 years after Dart's expedition, Tobias made his first of many trips to the Kalahari to study the San. Each of these trips involved measuring every part of a person's anatomy, as Dart did, including women's labia.[47]

One of the first scholars to write critically about Phillip Tobias as a protégé of Dart, and about Dart's broader influence, was Catherine Burns in her PhD at Northwestern University in 1995. Drawing on her dissertation research, she presented a paper to the Centre for African Studies at the University of Cape Town in May 1996 titled 'Bantu Gynaecology: The Science of Women in South Africa, 1920-1960'. Burns deplored the fact that scientists, medical scholars and anthropologists, including Dart and his students, placed a focus on measuring black women's physical and sexual characteristics as a means of defining racial types.[24(p.11),48,49]

Yvette Abrahams was another important critic of racist and sexist scientific practices. Abrahams published her article 'The Great Long National Insult' in 1997, describing the sexual obsession that Europeans held with the Khoi and the San as long ago as the 1600s. Her research and writing about Sarah Baartman made an important contribution, bringing an analysis of race and gender to the history of science in the 1800s.[50] And Dart and his (mostly) male colleagues brought these anthropological practices into the 20th century.

In the mid-1990s, Phillip Tobias had private correspondence with Alan Morris, who had been his PhD student in the 1970s and 1980s. Morris had become the Director of the Department of Anatomy at the University of Cape Town, and he wanted to write about race typology and racism, but Tobias discouraged him. Tobias argued that physical anthropology had not had an impact on apartheid.[8(p.224-225)] He protected Dart's legacy for decades in his writing, public speaking and teaching.

Skeletons in the cupboard and science and spectacle – Legasick, Rassool and Hayes

In 2000, Martin Legasick and Ciraj Rassool of the University of the Western Cape published *Skeletons in the Cupboard.* While the book did not focus on Dart in particular, it offered the first review of the involvement of South African museums in the human skeleton trade in the early 20th century, which set the scene for Dart's own collection.[51] The book was a turning point relating to collections at universities and museums in South Africa.

In 2002, Ciraj Rassool and Patricia Hayes published a chapter entitled 'Science and Spectacle' in which they provided a thorough description of the Dart-led Wits Expedition at Tweerivieren in 1936 and the Empire Exhibition held at the Wits campus in Johannesburg in 1936 and 1937. The chapter focused on the life of /Khanako, a woman from the Kalahari that Dart met on his expedition.[36] Rassool and Hayes's chapter made clear that Dart and his promotion of race typology turned /Khanako from an individual person to a "generalized type"[36(p.150)].

While Rassool and Hayes cited Dubow's critique of Dart and physical anthropology, they argued that little of the literature to date had "made a connection showing how science and the spectacle worked together"[36(p.121)]. Abrahams had emphasised this connection in relation to Sarah Baartman in the 19th century, but more work was needed to critique scientific racism in the 20th century.

Rassool and Hayes recorded that Matthew Drennan, Dart's counterpart at the University of Cape Town's Department of Anatomy, took casts of /Khanako's head, her hand and her pelvis and her labia.[36(p.127-129)] They referred to /Khanako's daughter /Keri-/Keri as well, writing that /Keri-/Keri's face mask, her body and her skeleton had been held by Dart's department at Wits University after she died. "A visit in 1996 showed that her skeleton meant to be in storage as item A43 in the Dart Collection had gone missing."[36(p.137)]

In addition to the Wits Expedition and the Empire Exhibition, Rassool and Hayes wrote about Dart's skeleton collection, his face masks, and his use of photography as tools of anthropology. "For Raymond Dart and his colleagues, research at Tweerivieren and Frankenwald enabled the physical characteristics of the bushmen to be compared to the fossil record whose analysis was making Dart and his department famous."[36(p.140)]

Another critique in the 2000s – Derricourt

In addition to Dart's promotion of race typology, and his disturbing anthropological practices, Dart believed in another fatally flawed concept – cultural diffusion. He believed that there was a racial hierarchy, not only in terms of physicality, but also in terms of cultural development. Dart believed that Mapungubwe and Great Zimbabwe were not built by the local African population, but by foreigners who had travelled to southern Africa centuries ago.[15,52] Dubow explored this topic in 'The Other Raymond Dart'[24(p.16-24)]. Thirteen years later, in 2007, Robin Derricourt, an archaeologist from Australia, took up this issue as well in his article 'The Enigma of Raymond Dart' in *The International Journal of Historical African Studies*. Derricourt wrote that "Dart's proselytizing of non-African influence on African culture was well outside his area of expertise. It was however a passion."[28(p.271)]

Both Dubow and Derricourt pointed out that Dart had been greatly influenced by Sir Grafton Elliot Smith, who had promoted the theory of cultural diffusion.[24,28] One month after Dart published his article about the Taung skull in *Nature*, he published another *Nature* article declaring his diffusionist views, stating that the people of southern Africa were influenced by ancient visitors from the Near East who "not only visited their territories and carried off their denizens, particularly their women, but also intermarried with them and settled down amongst them, bringing to them novel arts and customs"[52]. Derricourt wrote that Dart's career and "the fate of his views, raise questions about the nature of science in the early twentieth-century 'colonial' culture and the particular world of white South Africa's emerging ideologies"[28].

Dubow argued that most scholars in anthropology, even eminent American anthropologist Sherwood Washburn, in 1985, failed to see the importance of looking at Dart's career in its entirety. "There is a convenient silence about central aspects of his research agenda", wrote Dubow[24(p.25)]. "This includes Dart's vital role in the hugely misconceived race-typology projects of South African physical anthropology and his passionate advocacy of cultural diffusionist theory."[24(p.25)]

Derricourt went further to argue that "South Africa was receptive to ideas that would not challenge the racial categories that reinforced perceptions of power and difference – and Dart helped to deliver up these ideas"[28]. Like Dubow, Derricourt suggested that "for white South Africa, a racial typology model reinforced assumptions, political needs and economic structures in the interwar years"; he went on to say that, after World War II, "ideas of racial typology hardened in South Africa as they were being dissolved in science"[28].

As a result of Taung's acceptance, Dart's status grew enormously. Derricourt argues that, as a result, public criticism by others in the field was "muted and indirect"[28]. In Dart's later life, some scientists were "unwilling to say in print what they thought in private", wrote Derricourt, who also suggested that the Dart papers in the University of the Witwatersrand archive had not been utilised fully by scholars to explore these dynamics.[28]

Both Dubow and Derricourt remarked that Phillip Tobias remained loyal to Dart and often came to his defence, which had a significant impact on Dart's reputation.[24,28] Tobias wrote a great deal of glowing material about Dart, including a tribute on his 75th birthday, and an obituary.[53,54] From the time Tobias took over from Dart as Head of the Department of Anatomy, for over 35 years, he continued to take face masks at each expedition across southern Africa.[42] And he added 2000 human skeletons to the Dart Collection well into the 1980s. Tobias did not write about Dart's expansion of the human skeleton collection, nor how Dart came to have /Keri-/Keri's skeleton in his possession. In all of his many journal articles, essays and interviews, as well as in his own autobiographical documentaries and books, Tobias protected Dart's legacy.[8,24,53,54] In his 2012 paper, 'Human Remains and Disciplines of the Dead', Rassool pointed out that Tobias had crafted his own legacy to protect Dart's.[55] Tobias died in 2012 at the age of 86.

After Tobias's death in 2012 – growing reflection on scientific racism

The scholars reviewed in this paper – Dubow, Burns, Abrahams, Rassool, Hayes, and Derricourt – and the arguments they present about Dart's scholarship, have not received the attention they deserve. Dart's achievement with the Taung skull has overshadowed all of his other work.

Several months before Tobias passed away, Alan Morris, who had previously argued with Tobias, wrote an analysis of physical/biological anthropology in South Africa. Morris suggested that Dart, Tobias and many of their colleagues were not "directly involved in the implementation of the apartheid policy"[34(p.S152)]. However, Morris made the point that their long-time support of race typology "provided a solid growth medium in which the government policies could develop without credible scientific opposition"[34]. Morris applauded "the crumbling" of race typology in the late 1950s and 1960s, but lamented that "the public conception of race still remains firmly in a typological mold"[34(p.S160)].

In 2022, Morris published *Bones and Bodies: How South African Scientists Studied Race.* While Morris's introduction states that he was against the historical racism in physical anthropology, the body of the book does not offer a critical approach to the field and its early practitioners. In fact, Morris documents and defends the contributions of physical anthropologists, including Matthew Drennan, much more than he critiques them. Morris states that Dart had a "complicated legacy", and suggests that Dart believed that "politics was separate from science"[56(p.186)].

In 2014, science writer and author Christa Kuljian began research for *Darwin's Hunch: Science, Race and the Search for Human Origins*. While Tobias had previously protected access to the Dart papers, they were now more fully available. Inspired by Dubow, Rassool, and Hayes, Kuljian searched for information about how /Keri-/Keri's skeleton became part of the Dart Collection. Looking through the Dart papers in the Wits Archives page by page, she found alarming correspondence explaining that Dart, back in 1939, had secured /Keri-/Keri's remains before she died of pneumonia in a hospital in Oudtshoorn.[8]

In addition to shining more light on Dart's disturbing anthropological practices, *Darwin's Hunch*, published in 2016, focused extensively on Tobias's body of work. The book illustrates that Tobias's prolific writing left out parts of Dart's history, and aspects of Tobias's own work and practices. Especially in the wake of apartheid, they were being recognised and described as scientific racism.[8,18,24,28,33,53,54]

Dubow wrote that Dart was liberal and that he didn't have strong political views.[24] Derricourt and Morris said that Dart was politically moderate and that he drew a line between his politics and his science.[28,34] Kuljian, however, focused on how there was an interactive relationship between the social and political context and the science. She wrote that Dart's mix of thinking about skeletons, race, cultural hierarchy and human evolution "did not stay in the laboratory at Wits"[8(p.56)]. Dart took his beliefs into the public realm. One example of this is Dart's decision to give evidence about race in court. Kuljian cites two newspaper articles from the Dart papers in the Wits University Archive dated in 1929, the same year that Dart argued that Great Zimbabwe was not built by Africans. On the witness stand, he gave a technical statement on "the question of 'colour' in Europeans and natives". *The Rand Daily Mail* reported that Dart examined a Mrs Neff and declared that she was not white and had "coloured blood in her veins", resulting in her being charged with the illegal possession of alcohol.[8(p.56)] At the time, the term "coloured" was used to describe people of mixed ancestry, and was later used as an apartheid racial classification.

Dart testified in a second case against another woman, Mrs Batty. *The Star* reported that Professor Dart "swore that she was not coloured", thereby defending the three liquor stores that had sold her alcohol. As a witness for the defence, Dart declared he "could find no physical feature in her constitution which could be considered diagnostic of a coloured person". He produced a skin colour chart used by ethnologists and concluded that Mrs Batty's skin colour proved that she was European.[8(p.56)]

Kuljian further reflected on Dart's legacy of scientific racism in the Steve Biko Bioethics Lecture in September 2023, and the related article in the *South African Journal of Bioethics and Law*.[8,41,57]

Conclusion

In the 1990s, Dubow suggested that historians of science were beginning to explore the area of science studies and the sociology of science, and that they were departing from the "great man" tradition of scholarship.[24(p.26)] What Dubow suggested 30 years ago is important to historians of science today; it is important to view Dart's career as a whole, not only by looking at its most prominent part. It is important to understand Dart, not only as a hero, but also as a human scientist shaped by the colonial thinking of his time. In the last 30 years, many scholars have explored multiple aspects of his scholarship, and have described Dart's more complex legacy.

How will scholars view Raymond Dart in 2075 on the 150th anniversary of his description of the Taung Child skull? They will certainly look back at this 2025 special issue and see our mistakes and blind spots. Hopefully, future scholars will accept that science is influenced by its social and political context, and agree that Dart's painful legacy of scientific racism stands alongside his legendary legacy of having described the Taung skull.

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Data availability

All the data are included in the article itself.

Declarations

I have no competing interests to declare. AI was not used in the preparation of this paper.

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The children of Taung: Journeying from a rural village to the global stage: The perception of the local community and views regarding the development of the site and the curation of the skull

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The iconic Taung fossilised skull is widely known for its primacy as Africa's first palaeoanthropological discovery with universal scientific relevance. Yet the details surrounding its discovery and current status remain an enigma to the community of Taung Village. A comprehensive conservation of the site, which was listed as a UNESCO cultural heritage site of outstanding universal value 25 years ago, is yet to be completed, much to the chagrin of the local communities. The noticeable disconnect between the management authorities and scholarly institutions probably adds to the slow development in regard to continued research and public engagements at the site. In this paper, we discuss the current state of the site and the ongoing development, as well as the knowledge gap and the lack of inclusiveness of the Taung local inhabitants regarding the site.

Significance:

We look at the discovery of the Taung skull from the perspective of all stakeholders of the site. The discovery of the Taung skull shaped the story of the evolution of humankind, and was a robust discussion for decades. To the Taung community, it did not have much influence on their daily existence, but rather became a mystery, still not understood by many. The paper presents the complex stakeholder relationships, challenges at the site, and the wishes of the Taung people regarding the skull.

[Abstract in** Setswana**]

Background to the site of discovery

Socio-political and economic situation in Taung at the time of discovery of the fossil

The year 2024 marked the 100th anniversary of the discovery of the Taung skull. In the context of this prominent jubilee, our view is that this heritage is more than just a fossil hominin discovered in the middle of rural South Africa. When viewed within the context of its locality and period of discovery, it is a potential resource for education, a sense of belonging, and cultural and economic development. We assess the role that these factors have, and could have, played in the story of the Taung Child and its journey to being a heritage resource of world renown.

The Taung skull was discovered in the village of Buxton, in Taung, in 1924, during the height of the lime mining activities of the Northern Lime Company, established in 1907 in the then Northern Transvaal, South Africa. Taung is located on the southern stretch of today's North West Province. From its discovery, the skull found its way to the School of Anatomy at the University of the Witwatersrand (Wits) for examination by Raymond Dart, and a scientific announcement about its discovery was made in 1925.[1] To date, only the face, mandible and brain endocast have been recovered and described. For some time, its significance to the human evolutionary story and its position in the evolutionary tree were questioned and challenged by some Western scholars.[2,3] However, as will be discussed, its role as a propeller of palaeoanthropological studies and a find that shaped the human evolution family tree is currently globally recognised.[4]

In contrast with the Western academic sphere, the skull remains a mystery with little to no heritage significance for the townspeople of Taung. To date, the people of Taung know very little about the discovery and the details surrounding the current existence of the skull. Any education or engagement about the skull is gathered through high school teaching, as prescribed by the national curriculum. In this paper, we assess the interface between this palaeoanthropological discovery and the local community and how the science has impacted the average Taung child. We conclude that the discovery of the skull has thus far had no significant positive impact on the average contemporary child of Taung. The skull serves no motivational purpose amongst the community of Taung, nor does it bring socio-economic benefits for them. There is no sense of pride, or of ownership with regard to the site and its finds.

We acknowledge the influence that the discovery of the skull had on Buxton Village in Taung; it put the village on the global scientific map. The site of discovery, the Taung Skull World Heritage Site (TSWHS), is now an extension of the UNESCO World Heritage Site Listing, the Fossil Hominid Site of South Africa. The sites are situated in three provinces in the country: Gauteng, the North West and Limpopo Province.[5] However, outside a palaeoanthropological context, its effect has been negligible. A small town encompassing about 106 villages within the Greater Taung Local Municipality, Taung is administered under traditional leadership, with three main tribal branches: the Batlhaping boo Phuduhutswana, Batlhaping boo Maidi and Batlhaping boo Mothibi.[6] Although the tribes are currently under traditional leadership, political power has increasingly shifted towards the elected political office bearers.[7] The area is today plagued by socio-economic challenges, similar to localities of its kind across South Africa. Today, the average inhabitant of Taung is a black African with a median age of 22 years old.[8] In 2019, the district recorded 52% female inhabitants compared with 48% male inhabitants. Men are mostly migrant labourers, leaving the district for employment elsewhere in the country. The upper poverty line is defined by Statistics South Africa as the level of consumption at which individuals are able to purchase both sufficient food and non-food items without sacrificing one for the other.[9] In 2020, more than half (55.8%) the population in the district were reported to live below the poverty line (with an average income per month of ZAR1000). The main sources of employment are government sectors and retail businesses, with few informal seasonal farming jobs.

The region is plagued by high levels of poverty and dependency on social service grants due to the high rate of unemployment.[9] The entire Dr Ruth S Mompati District, which is inclusive of the Greater Taung Local Municipality, had a dependency ratio of 75.98% for the year 2020. This ratio is estimated to increase to 76.01% by 2026.[10] In 1925, the economic outlook of the area was not much different. The discovery of the Taung Child took place after the enactment of the *Natives Land Act of 1913*, by which the "natives" were dispossessed of their lands and confined to only 7% of the arable land in the country.[11] Villages within Taung most probably relied heavily on pastoralism and subsistence agriculture to survive during those days. The then southwestern Transvaal where the Taung Native Reserve was located faced recurrent droughts and locust plagues which caused agricultural losses, the main source of employment for black labour. These inadvertently contributed to the rise in (lime and diamond) mining activities.[12] Africans from various parts of the country came to work on the diggings. However, by the mid-1920s, just before the discovery of the Taung skull, mining projects in the Taung magisterial district faced turmoil and alluvial diamond mining was de-proclaimed. Poverty, gambling and stock thefts characterised the area. It thus seems likely that the average inhabitant of Taung at the time of the fossil discovery was faced with socio-economic turmoil and an uncertain future.

A view from the community: Past and present

While it is difficult to ascertain the views of the local community during the time of the discovery due to the lack of records, it is likely that most of the community members, possibly the traditional leaders too, were not even aware of the discovery at the time, or, if they were, it was of little concern to them given the socio-economic circumstances. The discovery took place during the mining era, which had started in the late 1800s. Mining workers, who potentially were local and migrant black labourers, might have been privy to the discovery of the skull, although they likely had no knowledge of its final destination, let alone its significance. There is no evidence of any attempt to communicate with the local mine workers and the community about the discovery at that time. Neither was there any acknowledgement, let alone credit, given to the local miners who discovered the skull.

This pattern continued long after the discovery, and continues today. Over half a century after its discovery, the skull was still the subject of numerous scientific headlines (e.g.[13-15]); however, engagement with the people of Taung continues to be negligible to none. Locally, at Taung, there is still an extreme lack of information about the skull, what it is and what it represents, and the overall significance of the discovery within the evolutionary sciences and as a World Heritage Site. Heritage in post-colonial Africa has enormous potential for contributing towards developing the continent. Various policy prescripts have been enacted which proclaim to develop the palaeosciences; one notable plan is the South African Strategy for the Palaeosciences.[16] This document identifies goals to address the development of the discipline. We quote its first goal, which is relevant here:

> *…to transform the minds of South Africans so as to instil a sense of pride and provide the intellectual content to their African heritage so as to make them informed and responsible citizens, and to engage all sectors of society in palaeosciences matters, through information on discoveries that will allow them to appreciate the special place of South Africa in the story of life and humanity on Earth*.[16]

As a response to this directive, several public funding schemes, such as the National Research Foundation's African Origins Platform[17], Genus Palaeosciences funding, and some private donors, have extended funding support to researchers to undertake scientific research in conjunction with community outreach. However, extreme bias towards researchers as recipients of this engagement is observed, contributing to maintenance of the status quo. The National Research Foundation evaluation of the Centre of Excellence (2018) noted the inadequate transformation of the palaeosciences to be inclusive of African researchers, and also highlighted that the demographics of the Centre of Excellence remain dominated by white South Africans and foreign postdoctoral researchers.[18] As in the past, and despite an increasing number of emergent researchers of black African heritage, the lead scientists that are granted access to the fossil continue to be white researchers of European descent. Furthermore, not much initiative has been taken by researchers to address the knowledge gap that exists within the locales of their research, and the Taung community is no different.

Based on recorded and published research enterprises, since the discovery of the Taung skull in 1924, the site has been the subject and destination of five major research expeditions: by Peabody and colleagues (1947–1948), McKee (1983–1993)[19], Partridge (1985), Beaumont (1982)[20], and, most recently, Kuhn and colleagues (2012)[21]. However, none of these research expeditions makes mention of engagement with the research by the local community. At the time of Peabody's expedition in the 1940s, South Africa had just formally enacted the apartheid legislation, while Taung remained under the jurisdiction of the Taung Native Reserve. Therefore, engagement between Europeans and locals was not encouraged. Local communities in the past would be resourced as general labourers, with very limited interaction with researchers. Thirty years into the dawn of democracy, the relations between researchers and the community of Taung have not improved at all. Researchers partake in scientific excavations only to recover fossils and other relevant samples, and leave without undertaking any public engagement. Common public outreach practices, even in the form of educational activities, have never been implemented.

The first instance of engagement with members of the local community in respect of the Taung skull is not mentioned in academic journals, even though engagement between research institutions curating the fossil and the public of Taung has been ongoing for over a decade. The following quote vividly reflects the views of the local community: "We are living beyond the poverty line, whereas having the area with a massive historical background. We urge the North West provincial government to put pressure on the Witwatersrand University to return the skull to its origins."[22,23] In the face of lack of development of the site, it is no wonder that the community seeks restitution of a potential source of economic development through the fossil skull.

Goal 4 of the South African Strategy for the Palaeosciences[16] speaks to the interface between the community and fossil heritage to "ensure that South Africa's palaeoscience heritage is well managed so as to attain international standards of heritage management and ensure that the country's palaeoscience heritage is well managed and used for the benefit of current and future generations". However, from our perspective, the relationship between heritage management authorities, as major stakeholders and custodians of these heritage sites in the country, universities as the knowledge producers of heritage objects, and local communities has not been effectively managed.

South Africa has an unsavoury past in which researchers who discovered heritage objects (particularly fossils) treated them as their own private property. Since its discovery, ownership of the Taung Child has been a bone of contention between the curatorial facility and the local community. Unlike Dart who indicated ownership of the skull and even affirmed its status as his property, his successor at Wits' Department of Anatomical Sciences, Phillip Tobias, understood his role as guardian of the fossil and not necessarily as its private owner.[24] The Taung skull is a heritage resource under the national estate. Since the passing of the *Bushmen Relics Act* in 1911, several legislative amendments have been enacted to provide protection and conservation measures for heritage resources in the country. Ownership, or perceived ownership, or the task of protecting and safeguarding such resources, comes with accessibility to such heritage resources – a privilege that the masses lack.[25,26] The fact that the Taung community has no access to the skull is exacerbating the ownership discussion, as the owner is perceived to have more rights and access to the specimen.

It is unfortunate that Dart's territorial practice is still very much in practice, even with all the legislative Acts in place regarding heritage management in the country. The *National Heritage Resources Act of 1999*[27] pronounces access to heritage resources to promote the use and enjoyment of these resources by diverse communities – scholarly and public. Although access to heritage objects in the country is provided based on the curating institution's policies, the academic community has far more extensive access due to the fact that they produce scholarly materials on these resources; even among the community itself, access can be influenced by several factors, such as perceived relations with the founding scientists. In his autobiography, Dart alluded to the Taung skull belonging to him when he remarked that:

> [p]*erhaps, like Davidson Black* [who had revealed Peking Man to the world], *I should have travelled overseas with my specimens to evoke support for my beliefs, and I was presented with this opportunity. The Witwatersrand Council of Education wrote to say they appreciated that, because of the lack of comparative material in the form of anthropoid skulls of corresponding age, it would be impossible for me to perform a satisfactory monographic study of the Taungs* [sic] *skull in South Africa. The Council said they were willing to defray the expenses of my going to England for this study provided I donated the skull to the university. After careful thought, I decided I could not be bound by such a conditional undertaking, nor was I prepared to absent myself for so long a time from the young department* [of anatomy] *and my newly established home.*[28(p.51)]

Since its inclusion on the UNESCO World Heritage List in 1999, access to the main Taung site has been restricted to comply with the World Heritage Convention's requirement for states to protect these resources. Ndlovu's[26] question concerning access resonates: whose heritage is it? If the people of Taung have no access to the fossil specimen or the World Heritage Site, then the question remains: who has unabated access to these sites in their ancestral land?

Addressing the knowledge gap through science engagement

We believe that two layers of engagement with the Taung community are essential for developing the site and broader area via the palaeosciences. At the core of this lies effective scientific engagement and awareness, which will inform the heritage value of the site, while the historical and existing context within which the discovery was made should also be celebrated. The previously held science engagements at the site highlight the importance of flagging these engagements as a necessary teaching aid.

Several initiatives have been taken by non-profit organisations to address and improve the lack of basic knowledge about the Taung skull within the village and surrounding communities. Between 2008 and 2010, national Heritage Day celebrations and exhibitions were hosted within Taung, targeting scholars and the community associated with this iconic discovery. These celebrations were organised by a local non-profit organisation called the Taung Skull Consortium, in collaboration with the University of the Witwatersrand. During these celebrations, school learners and members of the public were educated about the significance of the skull, its discoveries and the role these discoveries played within the field of palaeoanthropology. The school learners were also introduced to the topic of evolution, as it is part of the national curriculum.

During these activities, teachers highlighted the challenges of teaching evolution in schools. However, this issue is not exclusive to the teachers within the Greater Taung area. Teachers in South Africa in general face challenges teaching human evolution for several reasons, such as the need for more teaching resources (e.g. replica casts) and personal perceptions of the topic.[29] Evolution was included in the national curriculum in 2008.[30] Therefore, the majority of the teachers currently teaching it did not study this topic at tertiary level. This creates a lack of confidence of the teachers in terms of their own knowledge of the subject, let alone in teaching the prescribed lessons.

To exacerbate the issue, even though South Africa is a secular state, the majority of the country (82%) identify as Christian, and, in the North West Province, the percentage is even higher.[31] Evolution is a very controversial and contentious subject in Taung, due to the perception of it being against the biblical story of Creation. Teachers with strong religious beliefs are conflicted in teaching the subject. Even when they understand the concept well, they tend to not deliver it with passion and encouragement to learners. In our own experience, teachers have complained about the available textbooks not being consistent in presenting the subjects, and the six weeks allocated to teach the subject is insufficient, considering its complexities.[31] This tends to lead to more confusion amongst learners, and an opportunity is lost to educate them as a captive audience about a subject relevant to the heritage history of the country.

All the interactions listed here, from the very beginning of research work at the site to the modern teaching of human evolution in local schools, highlight the glaring lack of knowledge among the local communities about the site and the concept of evolution in general. This proves a very noticeable disconnect between the palaeosciences and the communities of Taung. We therefore call for effective scientific engagement with the local community to encourage a positive understanding of the science of the Taung skull.

The Taung skull as a heritage resource

The second layer of engagement revolves around the heritage value of the skull and the site. This ties in with the communication on the issue of the return of the skull to Taung. In the past, several discussions between the management authority and the University of the Witwatersrand have taken place regarding the return of the Taung skull to the area for permanent curation in its original village. It is interesting to note that, when initial discussions of this return of the skull were hosted, Tobias[24], who was then Professor and Head of Anatomical Sciences at Wits, had called for repatriation of heritage objects to their countries of origin. However, he was stern in his assertion that repatriation should only be considered in terms of countries and not local communities[24], thereby excluding the possibility of the Taung skull leaving the University and being returned to the local community.

The relationship between the heritage management authority and the University of the Witwatersrand, as the curator of the Taung skull, is important for the management of the site and the fossil skull. This is a resource-heavy endeavour which requires financial support. University researchers have access to funding platforms (notwithstanding the gruesome application processes that do not automatically guarantee success), and heritage management authorities have access to government allocations to conserve heritage sites, although these allocations have shrunk substantially over the years. Despite these resources at the disposal of the research communities, and the mandated role to be played by the management authority, the development at the site solely relies on the allocation from the provincial and local governments. A collaborative approach between these stakeholders could go a long way in achieving this goal, especially putting together financial resources to maximise efforts in implementing identified projects at heritage sites.

In our experience, the Taung community still feels excluded from the development at the site and, as expressed by some community members to the media, feelings of aggrievement are standard towards the *expatriation* of the fossil to Johannesburg and the minimal development that nomination as a World Heritage Site has brought.[23]

We argue that, perhaps, the lack of investment in the communities where these well-known fossil specimens were discovered can be attributed to feelings of entitlement by the researchers considered responsible for the 'discovery'. Dart certainly set the tone for this behaviour and the way in which community engagement in human evolution has developed in the decades since. Access to these heritage objects was, and still is, limited to researchers or well-connected community members. Regardless of the legal statutes in place, access to these rare finds is still influenced by the scientists who continue to establish themselves as the de facto heritage owners and decision-makers. Because palaeoscience is not yet a transformed and inclusive science discipline, it is still a challenge for people of colour to have access to these research resources – a situation that could change with collaborative initiatives. It should be noted that, in most cases, to most African researchers, these collaborative partnerships are scarce, and might be available as a compliance measure for government grant conditions to be met. The possibility of the Taung community ever having a chance to see the original skull is currently very slim, and one that relies on several stakeholders having open, candid discussions about the skull and its true meaning and value to the people of Taung.

Some infrastructural developments have been advanced at the site (Figures 1 and 2) in order to preserve its universal value and prepare for the possible imminent return of the Taung skull, as an investment towards local tourism and socio-economic developments of the region.[10] The ablution facilities, internal roads and fencing are still under construction and will continue to be funded in the 2025 financial year.

The project was phased, with different phases budgeted for by the North West Department of Economic Development, Environment Conservation and Tourism (DEDECT). According to DEDECT, the department budgeted about ZAR460 million for infrastructure development from 2013 until 2025, but has spent about ZAR240 million to date. The outstanding infrastructure developments are scheduled to be implemented in line with the Medium-Term Strategic Framework (2020–2025). The interpretative centre or the intended museum is not yet operational. The site is not accessible to visitors at high capacity, but educational tours on Environmental Studies and Geography are currently presented at the site.

Darmas[32] and Darmas and Manyane[33] noted that the Taung community indicated their need for more knowledge about the site, and to be involved in the decision-making process for the site. According to the community members, these initiatives from the management authority will increase the community's level of support of the developments taking place at the site. The Taung Skull National Heritage Site Management and Master Planning process lists community participation as one of the 'outputs' to be achieved.[34,35]

During the process of drafting the Integrated Development Plan (IDP), of which the Taung Skull Infrastructure Development Programme is a part, community consultation did take place, although the frequency of consultation and the numbers of community members it reached are not reported.[36,37]

The 2022/2023 Greater Taung Local Municipality IDP indicates 114 community-based planning meetings, to plan and draft the IDP, and a total of 4954 residents who attended these meetings. The Greater Taung Local Municipality recorded a population of about 202 000 in 2022. The residents attending these meetings are a small fraction of the entire population. Several reasons could be cited for the limited attendance, such as residents not being aware of the meetings, or being informed of the meetings at short notice. These would have an adverse effect on the level of community participation.

However, the efforts of the management authority and researchers working on the site are yet to be intensified with regard to the involvement and inclusion of the Taung community, in order for the community to be apprised of the development status and all the research and knowledge production taking place at the site. Management authority of the site seems, at this stage, to not be fully effecting its stakeholder engagements with the Taung Community. There must be extensive community engagement, especially during the legislative processes, including budget appropriations. The site lies 'off the beaten track' and very far from major economic centres in the country, which possibly adds to its lack of appeal for prospective research projects by researchers.

Looking towards the future: Heritage's socio-economic benefits in the face of poverty

While site development activities at Taung took such a long time to realise, and are by no means adequate, there has been significant

Figure 1: The Powerhouse before and after refurbishment at the site.

Figure 2: The Mine Manager's house before and after refurbishments at the site.

development that merits credit to the management authority. The infrastructure of the site was developed to include the old mine/heritage buildings, archaeological and palaeontological sites, mining history and the existing topography. The restoration, upgrades and refurbishments of the buildings were done for alternative uses, but still provided for interpretation of their previous uses. This was done to highlight and accentuate the site's lime mining history and heritage significance through historical architecture. Minimal intervention was made to the landscape to maintain the authenticity of the site, thus blending the facilities and planned activities into the visual and physical landscape.

Several infrastructure projects have been completed, and some are at an advanced stage. The completed infrastructure developments are Thomeng Road, the Mine Manager's office (Figure 2), the powerhouse (Figure 1), museum, stone cottage, picnic ablutions, community boreholes, and network infrastructure. The now operational 10 km Thomeng Road is 8 km of asphalt and 1.7 km of paving and parking. The powerhouse has been restored for use as an academic/research facility. The building is complete, and is spacious enough to accommodate multiple offices and has enough open space for lab work and shelving of heritage materials. The old mine manager's office has been restored to serve as the site manager's office. The building has been restored to its original 1940s Victorian design and emulates the materials used at the time, such as the pull-up wooden window frames and Oregon pine flooring.

The museum consists of a cluster of three old mine buildings fused together as one building to serve as an historical and educational exhibition space, auditorium and ablutions. This allows for secure vault and private storage space for fossils. It will also serve as a central security control unit for the entire site and key visitor facilities on site. The stone cottage is operational, and has already been handed over to the Baphuduhucwana Traditional Council in the village to serve as their sub-office and provide services such as issuing of proof of residence letters. The incomplete projects so far are the Thomeng ablutions, trails and signage of the site and fencing of the core area.[37]

The conservation of heritage sites is mostly not prioritised, or managed well, at local government level, compared to other societal issues such as health services and economic development.[38] Local governments tend to leave most of the responsibilities of heritage site administration within their vicinity to concerned provincial and national government bodies. The lack of local investment in the site itself most definitely affects several aspects regarding the development of the site. However, it is worth noting that the Dr Ruth S Mompati District and the Greater Taung Local Municipality have made provisions for the development of the site. The District Development Model, as an intergovernmental relations mechanism, allows for collaborative measures between all three spheres of government. A single strategic and focused joint-up plan (One Plan) has been drawn up, targeting key strategic areas worth improving within the district. The One Plan reflects and focuses on issues such as economic positioning, spatial restructuring and environmental sustainability, to name a few. The Taung Skull Fossil Site is listed as part of the One Plan project identified by the Dr Ruth S Mompati District for implementation to improve the district's economy. The Greater Taung Local Municipality 2021/2022 IDP[10] and the Dr Ruth S Mompati District IDP fifth generation[39] list in detail the identified projects from the One Plan to be carried out at the site for the financial years from 2021 to 2024. The following are listed as projects to be undertaken: completion of Thomeng ablution, Taung Skull WHS fencing of the powerhouse complex, Taung Skull WHS – entrance complex and parking, Taung Skull WHS restaurant and Taung Skull – protection of sensitive sites, to name a few.[10,40]

The site also has a wetland feature at Thomeng Waterfalls that serves as a popular local tourist destination, attracting a high volume of visitors, and it is also used for spiritual cultural activities. The wetland also serves to meet socio-economic needs such as providing a source of water for irrigation purposes, crop production and fishing.[40] The management authority faces challenges in implementing conservation plans for the wetland because of the abovementioned roles and dependencies that the wetland serves within the community. The situation could be remedied by an extensive educational and awareness programme, that will in turn strengthen stakeholder engagement and aid an informed level of community participation in regard to the conservation of the site, and the use of natural resources in a responsible and sustainable manner, so as to efficiently manage and conserve the site.[41-44]

Recommendations

The impact of limited funds allocated towards heritage management in South Africa and the Taung Skull World Heritage Site is negligible and unsustainable[42], because the hard truth is that heritage is not a well-funded mandate. Collaborations funded through public–private partnerships are essential to increase resources for the management of heritage, towards a common cause.

Engagement and centring of local communities as critical stakeholders are essential in the conservation, safeguarding and managing of their heritage. Their buy-in, as indigenous and original site conservators, is a critical resource towards heritage conservation. Including communities as stakeholders in the developing process of the integrated management plan would promote a sense of ownership for the communities. It would also reduce any chances of vandalism of the sites. Even with cultural and spiritual practices and beliefs attached to the site, communities will most likely use these resources sparingly and sustainably, because they view the site as their own.

To re-enforce all these initiatives, awareness, education and promotion of the site are essential steps, as a large part of the population are not aware of this invaluable heritage. Education and awareness of the laws that govern these sites is likely to encourage a sense of duty towards site conservation and management, and ultimately contribute towards sustainable conservation. Complete denial of access to these sites, either for preservation or as part of the legacy of the past, defeats the purpose of heritage ownership and its conservation.

Conclusion

The Taung fossil site is integral to the history of the people of Taung, and so are its finds. The manner in which the communities at Taung previously were, and still are, excluded as stakeholders from activities taking place at the site can no longer be accepted as the norm. The inactive research status and current lack of public engagements are discouraging efforts to capitalise on its unique universal value, and maximise its possible socio-economic returns. A lot more ought to be done, with each stakeholder owning up to its respective accountabilities, and addressing the elephant in the room concerning the unpleasant legacies and current status of the site. Transparency is key regarding the discussions on and future plans for the Taung skull. We therefore stress a collaborative, consultative and participatory stakeholder engagement for a well-managed and conserved site, yielding extensive research outputs and an empowered community. As we celebrate the centenary of the pivotal discovery that positioned Africa as a focal point in human evolutionary studies, it must be with a beacon of hope to redress the wrongs of the past and begin a new century – one in which genuine inclusiveness and compassion are mediated by our shared heritage whose discovery was possible because of Taung as an African site.

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Data availability

All data pertaining to this study are included.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

M.T.: Conceptualisation, methodology, data collection, data analysis, validation, data curation, writing – initial draft, writing – revisions. D.W.K.: Conceptualisation, methodology, data collection, data analysis, validation, data curation, writing – initial draft, writing – revisions. B.B.: Conceptualisation, methodology, data collection, data analysis, validation, data curation, writing – initial draft, writing – revisions. All authors read and approved the final manuscript.

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Results from an *Australopithecus africanus* dental enamel fragment confirm the potential of palaeoproteomics for South African Plio-Pleistocene fossil sites

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The southern African Late Pliocene to Early Pleistocene hominin record is abundant and exhibits a high taxonomic diversity with three genera represented: *Australopithecus, Paranthropus* and *Homo*. Hominin fossil diversity and variation are often contextualised within other fossil assemblages or modern/extant counterparts. However, the incompleteness of the fossil record, sample selection bias and taphonomic condition of the specimens themselves constrain interpretations of diversity and variation within and between species. Thus, species identification and the nature of the observed variation are frequently debated. Palaeoproteomics can help improve our understanding of taxonomic variation, as demonstrated by the recently generated proteome of *Paranthropus* specimens from Swartkrans. Here, we demonstrate protein preservation for an *A. africanus* specimen from Sterkfontein Member 4, Sts 63, using minimally invasive analysis, and identify it as belonging to a male individual. We then discuss some of the current limitations of palaeoproteomics and how we can potentially overcome them. Although it is still in its infancy for Plio-Pleistocene hominin fossils, palaeoproteomics has the potential to help unravel the causes of observed morphological variation. Lastly, we strongly believe that the involvement of African researchers at all levels of this research, including leadership, is of great importance.

Significance:

We have successfully determined the biological sex of an *Australopithecus africanus* specimen (Sts 63) from Sterkfontein Member 4 with the age range of 3.5 to 2.01 Ma, with a high degree of confidence, and we have assessed the extent of protein preservation. These discoveries hold significant implications for our understanding of sexual dimorphism and intraspecies variation as observed in African Plio-Pleistocene hominins.

[Abstract in** Setswana**]

Introduction

Since the discovery of the Taung Child a century ago[1], South Africa has been a world leader in palaeoanthropology research. Much of this work has focused on understanding and interpreting the similarities and differences in the southern African Pleistocene fossil record and their relationships to hominins across the wider African continent. A key area of research is the study of early hominin taxonomy, phylogenetic relationships and variation, both among ancient taxa and between them and our species, *Homo sapiens*. Today, South Africa is well positioned to unpack these relationships, as it has a rich and taxonomically diverse hominin fossil record, particularly at sites located in the UNESCO World Heritage Site of the Cradle of Humankind. Important or iconic finds and specimens include individuals assigned to *Australopithecus africanus, A. sediba, A. prometheus, Paranthropus robustus, Homo erectus*, and *H. naledi*, with some of these species living contemporaneously[2].

A consequence of this rich and diverse fossil record is that there is considerable interindividual variation that can be attributed to numerous factors, including the potential sampling of morphological variation between species (i.e. taxonomic diversity), as well as variation within species (i.e. sexual dimorphism, inter-locality variation and microevolution/temporal depth variation). Teasing apart the presence of these different contributors to variation can be challenging.[3,4] As an example, *P. robustus*, a taxonomic group only found in South Africa, has been subject to varying hypotheses explaining the underlying causes of variation. Lockwood et al.[5] hypothesised that the variation in *P. robustus* is due to sexual dimorphism. However, the discovery of DNH 155, a purported male individual, and dental remains from the site of Drimolen attributed to *P. robustus* showing a less robust morphology than some of the material from the site of Swartkrans, led to the hypothesis that the observed variation is due to temporal depth variation[6,7] rather than a high degree of sexual dimorphism[5,8]. In particular, as DNH 115 is presumed male and more gracile relative to the presumed male individuals of Swartkrans and Komdraai B, the authors then hypothesised that the Drimolen collection is older than Swartkrans and Komdraai B.[6] Further analysis of dental remains of *P. robustus* from both Drimolen and Swartkrans suggested the variation may be due to different specimen compositions across localities.[9] This inter-locality variation hypothesis was corroborated by work on the differences in temporal bone shape and size in specimens from Drimolen, Swartkrans and Kromdraai B.[10] Nevertheless, it is noted that inter-locality variation and high sexual dimorphism hypothesis does not contradict the temporal depth hypothesis.[9,10]

Similarly, the *Australopithecus* assemblage from Sterkfontein, South Africa, is highly variable morphologically, and it is suggested that there are multiple species of *Australopithecus* (*A. prometheus* and *A. africanus*) found in Member 2 and Member 4 that are thought to have overlapped.[11,12] It is also hypothesised that there may be another

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species in Member 4 besides *A. africanus*.[13] In addition, the variation observed has been proposed to be due to temporal depth[14,15], as Member 4 spans about 600 thousand years (ka)[16,17]. In both cases, for *P. robustus* as well as the Sterkfontein *Australopithecus* assemblage, controlling for sexual dimorphism by confidently attributing the sex of individuals would contribute significantly to our understanding of the underlying causes of variation.

Enamel palaeoproteomics studies of fossil hominins

Palaeoproteomics is the study of proteins from fossilised material, and it exists at the intersection of multiple disciplines: chemistry, molecular biology, archaeology, palaeontology, palaeoanthropology, palaeoecology, computational biology and history.[18,19] Mineral-bound proteins have recently been shown to survive deeper in time and in warmer regions[20] relative to DNA[21]. In 2009, Nielsen-Marsh et al.[22] demonstrated the feasibility of extracting enamel peptides from late Pleistocene Neanderthal specimens using a trypsin-aided digestion process coupled with matrix-assisted laser desorption/ionisation (MALDI) sequencing. Their analysis successfully identified sex chromosome linked amelogenin-specific[23] peptides, highlighting the potential of this technique in ancient protein studies.

A few years ago, a study employed a digestion-free peptide extraction protocol[24] and liquid chromatography coupled to tandem mass spectrometry, which generated the dental enamel proteome of the extinct *Gigantopithecus blacki* dated to 1.9 Ma from Chifeng Cave, China[25]. Using the same technique, Welker et al.[26] recovered proteins from *Homo antecessor* and *H. erectus*, providing the oldest genetic information for the genus *Homo*. For the *H. antecessor* specimen, they recovered amelogenin-Y (AMELY), demonstrating that it belonged to a male individual, while there was no detection of an AMELY signal for the *H. erectus* specimen. These studies demonstrated the feasibility of using the enamel proteome to understand fossil variation from temperate and subtropical regions of the world. In these contexts, the enamel proteome can provide both tentative phylogenetic signals and confident biological sex identification of ancient male individuals.

One of the major questions that arose from the above studies is whether it is feasible to recover ancient proteomes from an African context, given the differences in ancient climate, geology and taphonomy. Subsequently, the southern African *Paranthropus* dental enamel proteome demonstrated the feasibility of palaeoproteomics[27] and the potential of investigating within-species variation within the African context. Here, we aim to demonstrate the potential of using a minimally invasive extraction protocol, expand the sample set of southern African hominins being analysed via palaeoproteomics and further explore fossil variation through a genetic lens. In this work, and in recognition of the centenary of the announcement of the species *A. africanus*, we report a palaeoproteomic profile of specimen Sts 63 (Figure 1), morphologically identified as *A. africanus*, from Sterkfontein Member 4. We then provide additional examples from a recent palaeoproteomic investigation of *Paranthropus*[27] and further discuss the current limitations of palaeoproteomics. Finally, we discuss the challenges of transformation, focusing on how it can be achieved through meaningful and impactful collaborative efforts that build capacity in Africa.

Methods

Permission for temporary export and sampling (permit IDs 3026 and 3079) was granted by the South African Heritage Resource Agency for palaeoproteomic analysis of Sts 63 (Figure 1), an *A. africanus* molar fragment, with no significant morphology preserved, from Sterkfontein Member 4.

Biomolecular preservation

Chiral amino acid analysis was undertaken on enamel (± 5 mg) from Sts 63 following the protocols of Dickinson et al.[28] After bleaching, the specimen was divided into two fractions: one for determining free amino acids (FAA) and one for quanitfication of the total hydrolysable amino acids (THAA). The concentration of the intra-crystalline

Figure 1: The analysed Sts 63 molar fragment (no orientation could be identified).

amino acids and their extent of racemisation (D/L value) were then quantified using RP-HPLC (Agilent 1100 series HPLC fitted with HyperSil C18 base deactivated silica column [5 µm, 250 x 3 mm] and fluorescence detector) following a modified method of Kaufman and Manley[29]. To provide estimation of intra-crystalline protein degradation, D and L ratios were measured for the following amino acids: aspartic acid and asparagine (Asx), glutamic acid and glutamine (Glx), serine (Ser), alanine (Ala), valine (Val), phenylalanine (Phe), isoleucine (Ile), leucine (Leu), threonine (Thr), arginine (Arg), tyrosine (Tyr) and glycine (Gly).

Etching extraction

Sts 63 peptides were extracted using a minimally destructive extraction method, specifically acid etching, as first demonstrated by Stewart et al.[30] Briefly, the sample surface was first cleaned using molecular biology grade water, the varnish coating was gently scraped off, and then the surface was wiped with low dust laboratory tissue (Kimtech) to remove debris. To further clean the surface, a volume of 130 mL of 10% v/v trifluoroacetic acid (TFA) was placed into the cap of a 0.5 mL Eppendorf tube and the sample was manually held so that the surface of the sample was in contact with the acid solution for an initial 15 s. The tube and acidic solution were then discarded. The acid cleaning step was done twice. The sample was reintroduced to the new 10% TFA in the new tube, and contact was maintained for a total of 10–15 min, with visual inspection every 3–5 min. The acidic solution (sample extract) was removed from the 0.5 mL tube cap and placed into a fresh Protein LoBind Eppendorf tube and the cap was washed with 100 mL 10% TFA and combined with the sample extract. C18 StageTip[31] peptide concentration/clean-up was performed as described by Cappellini et al.[24] and Taurozzi et al.[32] An extraction blank was prepared simultaneously with the sample.

Liquid chromatography with tandem mass spectrometry analysis

The peptides were eluted with 30 µL of 40% acetonitrile (ACN) and 0.1% formic acid (FA) into a 96-well mass spectrometry (MS) plate from the C18 StageTip.[31] They were then resuspended in 4 µL of 5% of ACN 0.1% TFA. The solution containing the peptides was analysed through liquid chromatography with tandem mass spectrometry (LC MS/MS) following protocols published for palaeoproteomics samples.[24,33] Peptide separation took place on a 15-cm column (75 µm inner diameter), in-house laser-pulled and packed with 1.9 µm C18 beads (Dr Maisch, Germany), on an EASY-nLC 1200 (Proxeon, Odense, Denmark) connected to an Exploris 480 mass spectrometer (Thermo Scientific, Bremen, Germany), on a 77-min gradient with wash-blanks in between the injections of samples to hinder cross-contamination.

Data analysis

The files generated by the mass spectrometer in the '.raw' file format were then processed using MaxQuant version 2.1.0.3[34], to confidently match the spectra against peptides from a custom-made reference database of amelogenin proteins of extant *Homo sapiens*, publicly available ancient hominins, and members of *Pan, Gorilla* and *Pongo* downloaded from Uniprot and NCBI and translated in-house[35]. The peptide identification was performed, setting the digestion parameter to unspecific, and the minimum length for unspecific peptides was set to seven amino acids. In the main search, the peptide mass tolerance was left at 4.5 parts per million (ppm), also leaving the setting of the fragment mass tolerance at 20 ppm.

The Andromeda threshold score for both unmodified and modified proteins was set to 40, to filter out peptide spectral matches (PSM) with a low-quality score. No fixed post-translational modifications were set. Glutamine and asparagine deamidation, oxidation of methionine, oxidation of proline, oxidation of tyrosine, phosphorylation of serine/threonine/tyrosine, ornithine conversion from asparagine, and N-terminal pyroglutamic acid from glutamic and aspartic acids were all included as possible variable modifications.

Proteins included in the database of common contaminants provided by MaxQuant, for example, proteinaceous laboratory reagents and human skin keratins, as well as reverse sequences, were manually removed and not considered any further. Similarly, proteins detected in the laboratory blank were not considered further.

Results

A total of 142 amino acids was recovered for both AMELX and AMELY, with 118 peptides, 4 unique to AMELX and 3 unique to AMELY (Table 1). Thus, we were able to identify Sts 63 as belonging to a male individual, with the confident detection of three specific AMELY peptides (Figure 2). Subsequently, we observed similar diagenetic markers as seen in Cappellini et al.[24], Welker et al.[25,26] and Madupe et al.[27], i.e. the peptide length distribution and rate of deamidation, albeit at higher amounts (Figure 3A and 3B). Moreover, we observed higher levels of intra-crystalline protein decomposition in Sts 63 relative to *Paranthropus* specimens from Swartkrans, including higher levels of racemisation (conversion of the L-amino acids to their D-form). The high intra-crystalline protein decomposition patterns in the enamel are consistent with a closed system behaviour, thus indicating that the recovered proteins are endogenous to the enamel matrix (Figure 3C). The higher levels of intra-crystalline protein decomposition are consistent with radiometric dating that indicates Sts 63 (Sterkfontein Member 4) is older than the *Paranthropus* specimens studied in Madupe et al.[27] (Swartkrans Member 1).

Discussion

A preliminary protein profile of **A. africanus**

Studies carried out on ancient hominin specimens allow us to start to unpack whether hominin morphological variation is due to sexual dimorphism, taxonomic differences or potentially other forms of variation. However, these studies are still in their infancy. Madupe et al.[27] reported the recovery of the enamel proteome from four *Paranthropus* teeth dated to ca 2 Ma[36] from Swartkrans, South Africa. The most abundant enamel proteins, namely enamelin, amelogenin and ameoloblastin, were recovered as part of the suite of proteins sequenced via tandem mass spectrometry. The identification of AMELY-specific peptides and semi-quantitative mass spectrometry data analysis enabled confident identification of the biological sex of all the specimens. Intraspecies amino acid sequence variation was also observed among the four *Paranthropus* specimens, corroborating independent observations made on morphology.[37] The recovered molecular data also confirmed the taxonomic placement of *Paranthropus* within the hominin clade, which formed the outgroup of the clade, including *H. sapiens*, Neanderthals and Denisovans.

In contrast, the analysis carried out here on Sts 63 is via a minimally invasive extraction protocol, which generated a minimal proteome (Table 1). Excitingly, this allowed us to confirm the presence of ancient proteins

Table 1: Summary statistics of the number of peptides, protein sequence coverage and the total amino acids recovered in each protein. The amelogenin lengths refer to the human versions: ensemble transcript ENSG00000125363 for AMELX and ENSG00000099721 for AMEY.

Protein ID	Total number of peptides	Unique peptides	Percentage coverage (%)	Sequence length	Total amnio acids recovered
Amelogenin X	67	4	41.9	205	86
Amelogenin Y	51	3	27.1	206	56

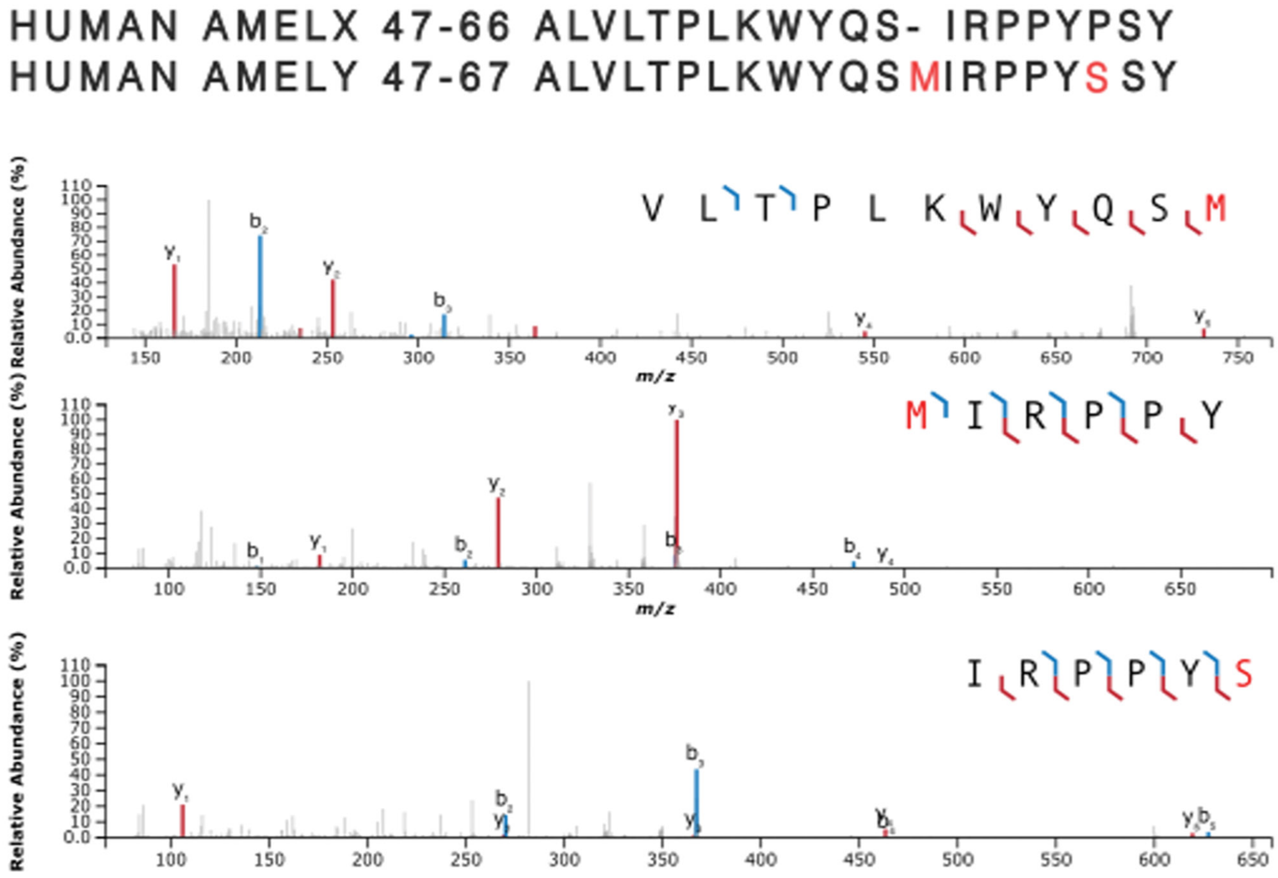

Figure 2: The top frame is the human AMELX (position 47 to 66) and AMELY (position 57 to 67) aligned, and highlighted in red are the two different amino acids in the alignment; with the insertion of methionine (**M**) in position 59 and a serine (**S**) at position 66 instead of a proline (P) in the AMELX corresponding position. Below that are three peptide-spectrum matches from *Australopithecus africanus* Sts 63 for human AMELY with **M** and **S** highlighted in red. Note peptide spectrum graphs plot mass-to-charge (m/z) values of ions on the *x*-axis, as measured during the mass spectrometric analysis of peptide fragments, and the relative peak abundance (%) on the *y*-axis. The red peaks represent y-ions, which are generated from fragmentation at the C-terminal side of peptide bonds, and they correspond to red bars between amino acids in the peptide sequence. The blue peaks represent b-ions, which result from fragmentation at the N-terminal side of peptide bonds, and they correspond to blue bars between amino acids in the peptide sequence. These peaks are matched to the theoretical spectrum of the peptide, aiding in the identification of the peptide sequence. This figure was generated using the publicly free site www.proteomicsdb.org/use/ by inputting MS2 mass to charge ratios.

in the sample, and to identify the sex of Sts 63 as male, confirming the potential for these studies using material from Sterkfontein. However, we are currently limited in the scope of a comparative analysis with *P. robustus*, which will require a larger *A. africanus* enamel proteome generated from extracting higher amounts of enamel from additional individuals. Moreover, in South Africa, species of *Australopithecus, Paranthropus* and early *Homo* were contemporaneous, and, ideally, phylogenetic comparisons based on genetic data should include information from all these taxa, allowing us to answer important questions about sexual dimorphism and taxonomic relationships. This is an exciting avenue for future research.

Consequently, this raises the question of whether hominins outside the South African Cradle cave systems will also have sufficiently good preservation for ancient protein recovery. The fossil *A. africanus* tooth studied here, as well as the *Paranthropus* specimens studied by Madupe et al.[27], were all recovered from cave sediments composed of re-mobilised soil outside the cave[38]. It is possible that favourable protein preservation is due to factors specific to these systems, including rapid fossil accumulation and relative aridity.[27,39] However, there are currently no published hominin protein preservation data on fossils recovered from other sites in South Africa and no data from open-air fossil sites, particularly in eastern Africa, where the very different depositional environments are known to have detrimental diagenetic consequences for enamel preservation.[40] Expanding palaeoproteomic studies of enamel outside the Cradle cave system context will therefore require considerable exploration of preservation – an important future avenue for research into African Plio-Pleistocene hominins.

The current limitations – and future opportunities of palaeoproteomics

Palaeoproteomics provides deep-time genetic data that were previously inaccessible. The ancient genetic data allow us to draw tentative hominin phylogenies and study interspecies and intraspecies variation, sexual dimorphism, and temporal depth variation. These are all incredibly exciting breakthroughs that are poised to revolutionise our understanding of human evolution. However, there are still some limitations and pitfalls to overcome.

As amelogenin-X is expressed in both female and male individuals, it is challenging to identify female individuals unambiguously; absence of evidence (e.g. no detection of AMELY) does not always mean evidence of absence. Currently, there is no experimental way of positively identifying male individuals with a deletion of the amelogenin-Y gene – a condition that has been documented in modern humans[41,42] and in a Neanderthal individual[43]. Additionally, in this current iteration of the palaeoproteomic workflow, male individuals whose amelogenin-Y protein has been degraded below instrumental detection limits due to diagenesis will also be misidentified as female. Several recent attempts to identify females through semi-quantitative analyses have proven fruitful.[27,44-46] However, these methods rely on having at least one positively identified

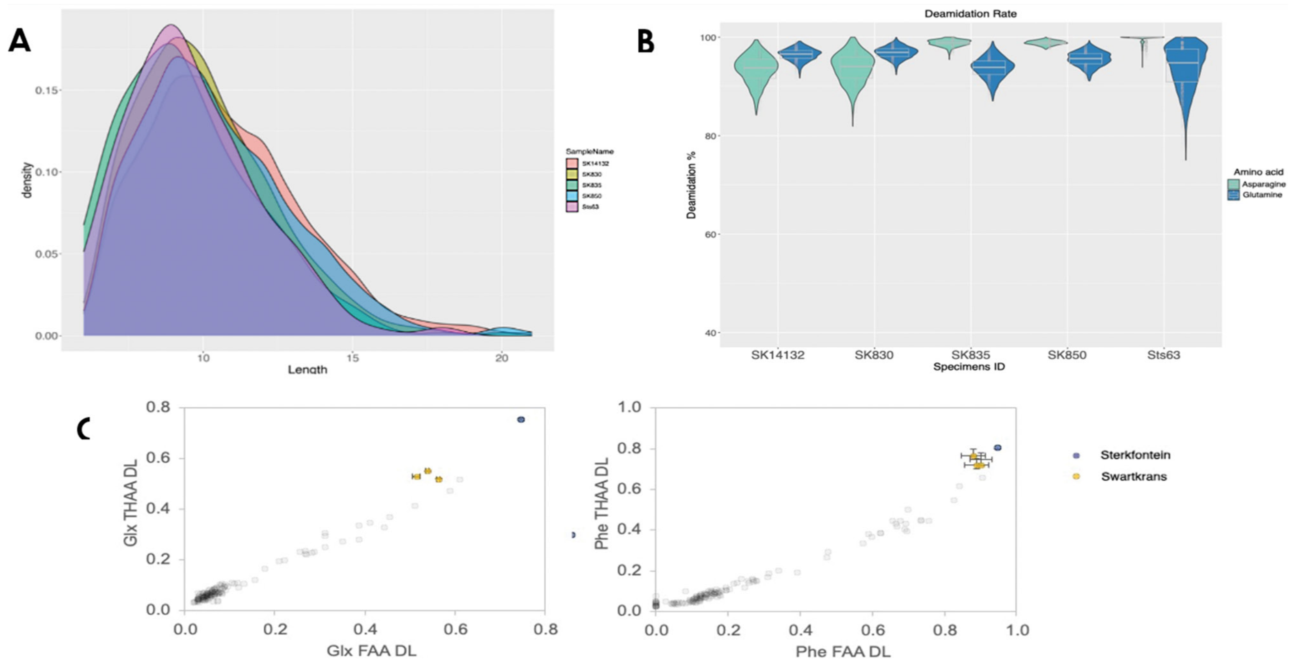

Figure 3: Diagenetic modifications of the Sterkfontein *Australopithecus africanus* Sts 63 relative to the Swartkrans *Paranthropus* specimens from Madupe et al.[27] (A) Peptide length distribution is skewed toward shorter fragments due to spontaneous terminal hydrolysis, with the *x*-axis indicating the peptide length and the *y*-axis indicating the density distribution of peptide lengths. (B) Asparagine and glutamine deamidation levels, with the *x*-axis indicating the specimens and the *y*-axis showing the percentage of asparagine and glutamine deamidations in each specimen. (C) Free amino acid (FAA) vs total hydrolysable amino acid (THAA) racemisation for glutamine/glutamic acid (Glx) and phenylalanine (Phe), with the Sts 63 specimen in blue being higher than the Swartkrans specimens in yellow. A reference data set of previously analysed enamel is shown in grey to indicate the expected correlation between FAA and THAA racemisation for closed-system enamel.

male individual in the sample to establish a probabilistic framework. Therefore, currently, confident semi-quantitative female detection is sample-set dependent.

Another important consideration is the small amount of genetic information currently retrieved by enamel palaeoproteomic analysis. Proteins only represent the expression of the exonic part of the genome, and the ancient enamel proteome is not particularly rich, counting only about 12 proteins.[24-26] Furthermore, enamel proteins are hydrolysed by proteases in the final phase of amelogenesis during tooth maturation. Specifically, matrix metalloproteinase-20 (MMP20) and kallikrein-related peptidase 4 (KLK4) break down enamelins, amelogenins, ameloblastins and amelotins[47,48], leaving in mature dental enamel only a limited subset of the protein sequences initially synthesised. Furthermore, phylogenetic incongruence, in which evolutionary trees constructed from individual genes differ from each other and from the expected species trees, affects the accuracy of the phylogenies we generate from enamel proteomes.[49] For this reason, phylogenies built with this approach are based on amino acid sequences only a few hundred amino acids long and cannot be considered very informative.[50]

In Madupe et al.[27], the authors emphasise that the observed phylogenetic placement of *P. robustus* is tentative due to the size of the recovered proteome, and here we did not include a reconstructed phylogeny as the minimally invasive peptide extraction protocol resulted in a very small proteome, making any phylogeny even less reliable. For comparison, in the initial phases of a DNA analysis, researchers relied on short DNA sequences, such as portions of the mitochondrial DNA (mtDNA). Although these studies provided preliminary insights, they had limitations. They did not detect gene flow between Neanderthals and modern humans because they focused on uniparentally inherited markers.[51] This approach masked the complexities of interbreeding and gene exchange among different hominin groups. Only later, with the introduction of high-throughput next generation DNA sequencing[52,53], did more comprehensive genomic analyses reveal these phenomena[54-56]. For proteins, we are already seeing glimpses of technology improving modern proteomic modes of data acquisition with single-molecule protein sequencing[57], the merits of which are discussed by Paterson et al.[50]

Final thoughts

The relatively new field of palaeoproteomics has the potential to revolutionise our understanding of Plio-Pleistocene hominin diversity in southern Africa, and possibly in Africa more broadly. Recent and ongoing studies have demonstrated its application in interpreting morphological variation. Madupe et al.[27] observed the presence of substantial molecular variation within *Paranthropus*, in addition to identifying biological sex. Additionally, here we have presented the protein preservation of a specimen identified morphologically as *A. africanus*. This is the first step to attempt the recovery of the enamel proteome for this specimen. In addition to the preliminary palaeoproteomic characterisation, we also identified the sex of the specimen and validated the endogeneity of the recovered enamel proteins. The studies of *Paranthropus* proteomes, combined with the initial palaeoproteomic analysis of the *A. africanus* specimen presented here, demonstrate the feasibility and utility of palaeoproteomic studies in South Africa. Even though palaeoproteomics is still in its infancy and caution should be used in interpreting the results, it is still poised to be able to answer some of palaeoanthropology's most fundamental questions about sexual dimorphism, variation and phylogeny.

Future studies should focus on improving protein recovery and on increasing the breadth and depth of amino acid sequence coverage, as well as on the number of studied samples and taxa. Moreover, less destructive protein extraction methods need to be explored. Currently, the most common approach is to extract proteins by destructively sampling approximately 100 mg of dental enamel. In the future, alternative methods, such as the minimally destructive method used in this study, would make the application of palaeoproteomics more broadly applicable.

Palaeoproteomic research is a new and burgeoning field that has the potential to increase our understanding of the deep past. We see huge potential for the application of palaeoproteomics in understanding Plio-Pleistocene hominin diversity. As we have explored here, a lot of work still needs to be done, and this provides a unique and exciting opportunity for this field to be developed collaboratively, together with African researchers at the forefront. In this current special issue, Lee-Thorp and Sponheimer[58] provide historical examples of how meaningful collaboration can be achieved and how it led to the field of fossil biogeochemistry expanding via the investment in scientific infrastructure and capacity building in South Africa. To actuate this, we are currently working on establishing an ancient biomolecules laboratory in South Africa, so that at least the first part of the palaeoproteomics workflow can be carried out in Africa, in collaboration with international labs for the sequencing part of the workflow. This would mean that fossils could be sampled locally with no need for them to leave the continent. This would represent a big step in ensuring both capacity building and the safety and safekeeping of African heritage.

In conclusion, palaeoproteomics research is at the cusp of remarkable discoveries, making this an ideal time to develop new ways in which research could be done. We also want to emphasise that palaeoproteomics should not be another field of study in which marginalised communities are left out, or in which parachute/helicopter[59] science takes place. We can take the initiative in this nascent research field to halt colonial science[60-62] and to realise that research is greatly improved by meaningful co-creation and collaboration[63]. Knowledge comes in different forms and diversity improves the quality of research.[64] We are excited by what lies ahead.

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Data availability

The mass spectrometry proteomics data have been deposited to the ProteomeXchange Consortium (http://proteomecentral.proteomexchange.org) via the PRIDE partner repository with the data set identifier PXD054431.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

P.P.M.: Conceptualisation, data collection, sample analysis, data analysis, writing – the initial draft, writing – revisions, project leadership, project management. F.M.: Data collection, sample analysis, data analysis. M.D.: Data collection, sample analysis, data analysis, writing – revisions. A.J.T.: Data collection, sample analysis, writing – revisions. M.M.: Data collection, sample analysis, writing – revisions. M.T.: Provided the specimens. C.M.: Writing – revisions. N.H.: Writing – revisions. K.P.: Writing – revisions. L.S.: Writing – revisions, student supervision. C.Z.: Writing – revisions. J.V.O.: Funding acquisition. R.R.A.: Conceptualisation, writing – revisions, student supervision, project leadership, project management, funding acquisition. E.C.: Conceptualisation, writing – revisions, student supervision, project leadership, project management, funding acquisition. All authors read and approved the final manuscript.

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Why heads matter in palaeoanthropology: The impacts and consequences of collecting skulls

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This piece reflects on the importance of and focus on heads – especially the collecting of skulls and its impacts – in alpha taxonomy, biological anthropology, and Western science more broadly. We consider how the announcement and overall discovery story of the Taung Child revolutionised our understanding of hominin cranial evolution, but also fit within these skull-collecting objectives and contributed to the palaeoanthropological fixation on the skull. We contextualise this within the history of 'physical' anthropology in light of its initial goals in scientific racism, and consider how this process of skull collecting has become normalised in the discipline as a result of this history. As evidence for this, we quantify the possible effects of skull-collecting by collating available data on the number of skulls versus post-crania curated in a representative South African collection and compare the number of skulls versus post-cranial hominin fossils that form part of species hypodigms. We also explore how the ownership of skulls and ownership of narrative in the discipline have been intertwined throughout its history. Finally, we focus on how this early overemphasis on skulls, and especially brain size/intelligence, may have skewed our understanding of human evolution and contributed to ideas of human exceptionalism.

Significance:

- The discipline of palaeoanthropology has a history of skull-focused research rooted in skull collecting and racist research.
- Historial skeletal collections and holotypes of fossil hominins are skull-biased.
- The Taung Child fossil postcranial remains were not included in the original study, which reflects this skull-centrism.
- Palaeoanthropologists need to recognise biases in research choices and the context from which our field developed.

[Abstract in Setswana]

The Taung Child – not just a head

In February 1925, the world was introduced to a fossil declared to be an "intermediate between living anthropoids and [humans]"[1(p.195)]. The discovery was a juvenile skull, with a well-preserved face and mandible, as well as a relatively complete endocast, and was designated *Australopithecus africanus* (the southern ape from Africa) and nicknamed the Taung Child. The announcement – and publications afterward – failed to mention, however, that the skull was not the full extent of the discovery. There were also associated postcranial remains. In the "rock mass containing the facial fragment", the "distal ends of the forearm bones and the small phalanges were present", wrote Australian-born Raymond Dart.[2(p.22)] Dart, who had spent weeks preparing the skull using his wife's sharpened knitting needles, "strove to develop [the postcrania] without success, as they were so friable", adding that "portions are still visible in the stone"[2(p.22)]. While preparing phalanges is undoubtedly significantly more difficult than preparing a skull, the decision to take the preparation no further (as well as the uncertainty around the location of that block of stone to this day) reveals an interesting truth: the skull itself was privileged.

In a science that emerged three-quarters of a century earlier from a European fascination with measuring human skulls in the service of scientific racism, the skull had long held much attention.[3] Focusing on humans' large brains as a defining feature of evolutionary history, 19th-century European naturalists sought to glean information ranging from cognitive capacity to geographical history and even degree of "morality" from the shape of skulls.[4] This partiality to anatomy above the neck was apparent in the discussions of the earliest fossil finds, beginning with the original Neanderthal individual from Feldhofer Cave unearthed in 1856 – the first fossil hominin to gain recognition as an ancient human ancestor. As the specimen rose to scientific importance, debates centred on the "thoughts and desires" that once dwelt within the cranium, and replicas of only the partial cranium circulated across Europe, leaving the associated postcrania behind as a footnote in Germany.[5]

This skull-centrism persisted into the 20th century despite a growing fossil record in Europe and Asia, and a recognition that bipedalism (and the significant modifications it made to the skeleton) was a significant evolutionary adaptation. When the juvenile fossil was blasted from a quarry seven miles southwest of the Taung railway station in 1924[6], the growing evidence for fossil hominins was nonetheless still extraordinarily sparse and piecemeal, and, with the exception of the much younger (now known to be 299 000 years old[7]) Kabwe cranium found in 1921, nonexistent in Africa. Truly ancient-looking finds were rare, partial, and scattered across the globe in ways that made generating narratives challenging, and nothing as old or ape-like as the Taung Child had been found. No consensus existed around topics like where the origin of humankind was located, whether bipedality preceded brain growth, and overall how to recognise a human ancestor.

So when Dart received a block of breccia in late 1924, central questions about human evolutionary history remained open. Yet, despite such uncertainty, certain hypotheses and assumptions were widely subscribed to by naturalists. The most prevalent assumption centred on the importance – and early emergence – of the large brain. Anatomists like Dart's mentor, Grafton Elliot Smith, hypothesised that an increase in brain size was the *first* distinctively human trait to have evolved, preceding upright walking, tool making, and other adaptations. "It was not the adoption of the erect attitude that made [humans] from an ape", Elliot Smith argued the year before Taung was published, but instead the "gradual perfecting of the brain"[8(p.39)]. It follows, then, that the skull would be the most important aspect of an ancestor.

Dart, too, favoured the skull in terms of its theoretical contribution, declaring it precisely the piece of anatomy needed to identify a significant, transitional human ancestor. While some others claimed "if missing links are to be traced with complete success, the foot, far more than the skull, or the teeth...will mark them as Monkey or Man"[9(p.195)], Dart, agreeing with his mentor, declared this "preposterous"[2(p.58)]. Instead, the skull told the anatomist everything they needed to know about the creature's character, behaviour, posture, and taxonomic status. Notably, Dart and Elliot Smith agreed on the skull's importance despite disagreeing on the timing and significance of increased brain size. Following Elliot Smith's logic that the brain led the way in human evolution, the Taung Child with its small brain, not to mention its location in Africa, was all wrong as a candidate for human ancestor. Yet, as a neuroanatomist, Dart argued that the *organisation* of the brain revealed that *Australopithecus* had "shot ahead of all apes in intelligence"[2(p.210)]. Thus, Dart elevated his specimen to a position of prime importance *despite* its small brain – seemingly a feature that would preclude it from an important evolutionary role. Indeed, he turned the small brain size around to be the central significance of the fossil. This illustrates that, regardless of the theoretical commitments a scientist had about the expansion of brain size, the skull was seen as the key to unlocking the human evolutionary story.

The Taung Child clearly contributed to the palaeoanthropological fixation on the skull, but the head-collecting objectives of the discipline go well beyond this important find. In this article, we use the discovery of the Taung Child as a jumping-off point for further interrogating the focus on skulls in alpha taxonomy and its history in racist research. We demonstrate that skull-centrism in palaeoanthropology is widespread, as evidenced by a skeletal inventory from a well-known historical South African human skeletal collection, as well as what bones comprise type specimens of currently recognised hominin species, and that this has impacted hypothesis generation and narrative construction in the discipline.

Heads on a mantle, scientific racism and taxonomy

How can we understand the privileging of the skull in palaeoanthropology through the lens of the Taung Child and what can we learn from such skull-centrism? Importantly, this theme pervades the entire story, as the Taung skull even found its way to Dart through *another* skull, that of a cercopithecoid monkey loaned by Mr E.G. Izod, Director of the Rand Mines. That specimen had sat proudly on the mantle of Pat Izod's home, the son of E.G. Izod, to be recognised by anatomy student Josephine Salmons and brought to Dart at the University of the Witwatersrand, instigating his interest in the area.[1(p.195),10(p.40)] This cercopithecoid skull was not only an important moment in the history that led to the Taung Child discovery, but also its placement, as a curiosity on a mantle, provides a poignant image that exemplifies the history of skull collecting in scientific pursuits. This skull-centric approach was consistent with the history of 'physical' anthropology, and we would argue that the process of head collecting has remained normalised in the discipline as a result of this history.

The long sordid history of body (skeleton) and especially head (skull) collecting is intertwined with Euro-colonial conquest, dehumanisation, and white supremacy.[11,12] Beginning in the late 18th and into the early 19th century, colonial violence extended beyond conquest and colonial expansion to the looting of objects of cultural significance, collecting of specimens of natural history importance, and the acquiring of humans (including body parts, skeletons, and living people) from colonies as trophies (e.g.[13–15]), curiosities, exhibitions, and scientific study[16–19]. The collection of human remains through grave robbing, murder, trophy-collecting and warfare, served a dual purpose for colonisers and colonial explorers.[20,21] First, it was used as a method of subjugation and a grotesque exertion of colonial power (e.g.[22]), and second, it was central to the scientific advancements of these colonial powers at a time when race science was being developed. These human remains were considered important "scientific" evidence for the inferiority of Indigenous peoples to justify their colonisation, enslavement, and genocide[15], with anthropologists, physicians, and anatomists involved in their study, and the skull as the main subject of interest.[3]

Building on the previous taxonomic classification of *Homo sapiens* into four racial "subspecies" (as well as a fifth category that has been called a racist and "non-geographical grab-bag", *Homo monstrosus*[23]) by Carl Linnaeus in his Systema Naturae[24], Johann Blumenbach divided living humans into five human groups based on the study of his large collection of skulls[25–27]. Although there is disagreement about whether Blumenbach himself was an active participant in race science and therefore a proponent of the superiority or inferiority of certain races (as argued by Junker[28]), his classic image of five human skulls in a row, with the Georgian "Caucasian" individual in the centre – reflecting a Eurocentric prejudice – inspired the development of race science alongside methods of craniology, craniometry and phrenology. This iconography also features prominently in early physical anthropology works (Figure 1).

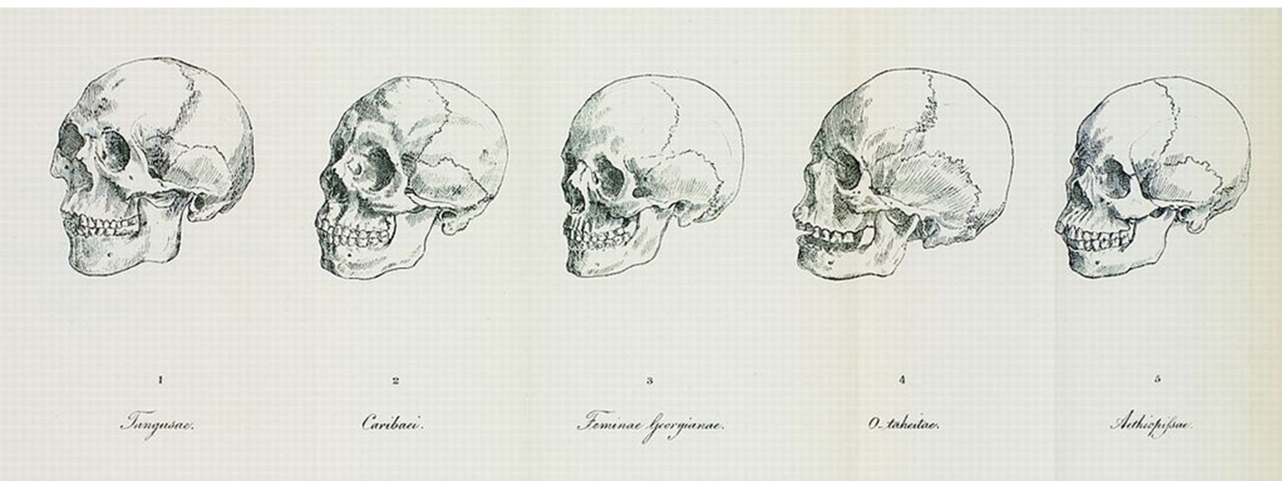

Image source: Johann Friedrich Blumenbach, public domain, via Wikimedia Commons.

Figure 1: Blumenbach's five skulls[27], labelled *Tungusae, Caribaei, Feminae Georgianae, O-taheitae,* and *Aethiopissae,* depicting his characterisation of Mongolian, American, Caucasian, Malayan and Ethiopian races.

Early physical anthropology in the 19th century was seen as a way to scientifically validate race, defined as a physical disposition, as well as the complete race complex, which also included behavioural, intellectual and character differences between human groups.[29–33] At this time, the skull was considered the key to understanding human races and behaviours.[34] Essentialist ideas from phrenology (the idea that mental traits/faculties could be predicted on the basis of scalp morphology) influenced the belief that the brain's faculties, including character strengths and weaknesses, revealed themselves through the skull.[35] Although phrenology lost its appeal and support in the mid-19th century, concepts spilled over to physical anthropology and its racist and typological beginnings.

One major debate that raged during this time, rooted in Euro-Christian theology, was whether human races were of monogenetic or polygenetic origin. Monogenists believed that there was a common origin for races in the deep past (and that some had "degenerated") whereas polygenists argued for different origins and therefore different species.[36] To find evidence for these different viewpoints, scientists required vast collections of skulls to study. These were systematically collected by all means necessary and subsequently commodified and traded through international colonial trade networks.[15] Museums and other academic institutes in Europe and their settler colonies amassed thousands of human remains obtained from the latter, with skulls making up the majority of these collections. This skull bias reflects the importance placed on skulls for racial typology, but also the durability and transportability of skulls compared to other skeletal elements.[14] Prized in these collections were the "near-extinct primitive races" that were decimated through colonial warfare and disease; another level of colonial dehumanisation.[20] For example, in the USA, physical anthropologist Samuel Morton, inspired by Blumenbach's five skull based races, acquired a large collection of crania (n=867 when he died in 1851[13]) to provide evidence, through measurement of cranial features and cranial volume, for the polygenetic origin of races and the idea that Indigenous people (Americans in his case) had smaller brains and therefore lower intelligence.[32] Morton relied on an extensive network to collect these crania, which were acquired through grave looting and warfare.[15,37]

When Charles Darwin published *On the Origin of Species* in 1859 promoting a monogenetic view of humans[38], it triggered an even greater investigative frenzy among scholars of race to test and/or refute this theory, as most at the time followed the polygenetic school of thought[39]. It is important to note here that monogenetic views were not necessarily non-racist. Even Darwin, whose theory of evolution via natural selection seemingly supported a monogenetic origin, argued in *The Descent of Man* in 1871 that, although there was common descent, the differences between races through geographic isolation were subspecific and each subspecies had different mental faculties – a reflection of his bias as a 19th-century Eurocentric scientist[40] (as discussed in detail by Fuentes[41]). With Darwin's theory of evolution, specifically the evolution of humans from an ape ancestor, what also occurred was a conceptual change from the horizontal view of Blumenbach's skull forms to a "vertical ranking of Blumenbach's varieties"[42(p.234)] by many scholars, which essentially created a hierarchy of humanness[43]. Thomas Huxley's influential view that there was a bigger difference between human races than between the lowest or most "primitive" race and great apes[44], which was supported by the writings of Ernst Haeckel[45], epitomised this change, leading to the widespread proliferation of scientific racism. The pre-Darwinian skull-centric anthropology now had an evolutionary framework.

Skulls and their power

Collections of human remains across the world ballooned in the late 19th and early 20th centuries. As a way to legitimise the scientific study of race (and racism), quantitative statistical methods for examining human differences became popular[46], necessitating greater sample sizes – a trend that occurred in conjunction with the gradual growth of the fossil record of human evolution. Scholars at the time needed examples of "primitive" human races for their "evolutionary" analyses and played a prominent role in both the study of Indigenous peoples and the collection and trade of bodies, and especially skulls.[15]

Anthropological collections around the world were amassed for race science by powerful researchers in the field, including Samuel Morton (discussed above), Paul Broca and Aleš Hrdlička, who all engaged in dubious collection and preparation practices, and colonial powers such as Germany that violently collected thousands of skulls to populate their research institutes (as described in[13,15,43,47,48]). The importance of skulls for these scientists was obvious. In his manual, *Directions for Collecting Information and Specimens for Physical Anthropology*[49], Aleš Hrdlička, the founder of the *American Journal of Physical Anthropology* wrote: "The skull…preserves the zoological as well as the racial characteristics of the individual, and also the general form and size of by far the most important human organ, the brain."[49(p.8)] These collections also created a competition amongst colonial powers.[20] As Joost Van Eynde notes, "national collections in London, Paris, Berlin and elsewhere in Europe and America competed with one another for these limited human resources"[50(p.7)]. Collections also provided the necessary data for narrative building in anthropology and beyond, thus giving researchers affiliated with collections power over early theories about human evolution and human variation.

In South Africa, museums and institutes were not immune to this human remains collection frenzy and competition.[20] Scotland-born palaeontologist Robert Broom was both collector and trader of human remains in the late 1890s and early 1900s, sending indigenous South African skulls to the University of Edinburgh after sometimes repulsively using his stovetop to prepare the bones.[17,51] Some of the individuals that he acquired, usually through disturbing means, also ended up at the McGregor Museum in Kimberley, for which Broom served as the unofficial curator, where they were described using a racial typology.[17,52,53(p.130)] Broom's motivation for his collecting practice was race science and especially craniology, a method he used to argue for the prehistoric nature of living Khoesan peoples.[51,53]

Louis Péringuey, then curator of Anthropology at the South African Museum, was inspired by comments made in 1905 by A.C. Haddon, president of the British Association for the Advancement of Science, to collect anthropological data on "primitive" native races within colonies that were dying out.[54] He proceeded to accumulate skeletons for his museum collection through trade, excavation, and grave plundering.[54,55] Péringuey collected close to 200 individuals, most of them skulls, and together with collaborators analysed this collection under the belief that "Bushmen" essentially represented the missing link between apes and other human races[56], and separated individuals into different Indigenous types[20,54,55]. In addition, Péringuey initiated the body-casting programme at the South African Museum to preserve a physical reproduction of these 'pure' "dying races".[54] These casts were also studied within a racial typology and formed the basis for the controversial "Bushman diorama" that was finally closed in 2001.[20,57,58]

Raymond Dart was introduced to the idea of human skeletal collections in 1921 as a Rockefeller Fellow visiting Robert Terry in the Anatomy Department of Washington University in St. Louis, USA, just two years before he immigrated to South Africa as the Chair of Anatomy at the University of the Witwatersrand.[59–62] He also visited the Anatomy Department at Case Western Reserve University in Cleveland, USA.[59] Both of those institutions had skeletal collections based on cadaver material of known age and sex, and Dart made it a priority to assemble a comparable collection at the University of the Witwatersrand.[59] For Dart's collection, before 1958, the skeletons came from donations and unclaimed bodies, with a bequeathment programme additionally (and increasingly) contributing to the collection after 1958.[59] The collection also includes several skulls labelled as having no provenience.[59] In addition to the skeletal collection, Dart, in collaboration with Lidio Cipriani, also amassed a large collection of facemasks through sometimes questionable and coercive acquisition practices between 1927 and sometime in the 1980s.[63] Like the body casts at the South African Museum, they were utilised in typological research and race science.[63]

Upon Dart's retirement in 1958, the collection was named The Raymond A Dart Collection of Human Skeletons.[62] Soon after, in 1959, a massive flood in the basement where the collection was stored caused the mixing of bones, affecting a substantial portion of the skeletons.[59] As discussed by Dayal et al.[59], this led to the construction of a new collections facility and the installation of new shelves with a decision to separate the skulls from the postcrania because "a proportionally larger number of researchers had been interested in the study of skulls only"[59(p.326)]. This illustrates very clearly that the skull-centrism of the discipline extended at least into the 1950s.

Today, an examination of the collection of human skeletons at Iziko South African Museum in Cape Town (previously South African Museum) reveals the extent of this skull-centric bias (Table 1). This collection was further split into those that were accessioned before 1960 and after 1960. About half of the individuals in the collection have accession date information. Of the 1013 individuals, 55% are represented by skull remains, and 45% are full skeletons. Indeed, in her extensive skeletal inventory of individuals housed across seven South African institutions, Tessa Campbell[64] demonstrated this skull-centrism by showing that skulls are present at a much higher frequency than postcrania (Figure 7 in [64]).

When split by period, the pattern shows up more obviously before 1960. Out of the 364 skeletons accessioned before 1960, 48% are skulls, and 38% are skulls and postcrania. After 1960, 35% are skulls, and 51% also include postcrania. A chi-square test of independence indicates that the relationship between the date of accession and skeletal element is statistically significant, χ^2 (2, $N = 597$) = 9.97, $p < 0.01$. This indicates that the skull-centric bias in collecting was more pronounced prior to 1960.

Heads and species hypodigms

In the history of physical anthropology, there is a direct link between scientific racism and its manifestations (e.g. study of living people, skeletal collections, head collecting) and the study of human evolution. In South Africa, this played out very clearly. Not only was Dart growing an extensive skeletal collection of primarily Indigenous Africans, biased towards heads, but he was also deeply involved in studies of living Indigenous southern Africans.[51,65] The San or "Bushmen" and the Khoe, in particular, had been the subject of scientific curiosity long before the first fossil hominins were found and became a focus of Dart's resea rch.[17,20,21,46,51,55] Together with the coelacanth and cycad, the "Bushmen" were seen as "living fossils" – assumed to be unchanged from early human ancestors – and collected and researched as such in southern African museums[51] (and "The fossil complex" as discussed in[66]). Like many other indigenous groups, they were studied, and their bodies collected, because they were believed to be inferior to, and less evolved than, Europeans. As such, they were believed to provide insight into primitive peoples and human evolution.[46,51] As Witz and colleagues contend, "At the center of this collecting impulse, conducted through the representational machine of the expedition, was the bushman body, promising to enable direct racial connections to be made between the findings of the new sciences of physical anthropology and paleoanthropology, and providing clues to discovering some of the paths of evolution."[66(p.183)]

For any new fossil discovery, comparative taxonomic assessments of difference or similarity are made with species hypodigms that revolve around a holotype or "type specimen" – a specimen that serves as a morphological guide for comparisons. When we consider type specimens for hominin taxa – both prior and subsequent to the discovery of the Taung Child – we see that species diagnoses are overwhelmingly made on the basis of craniodental and mandibular material. Supplementary table 1 provides a list of currently used species names in palaeoanthropology and their type specimens, including which bone(s) make up those type specimens. This table was compiled using the Origins nomenclature resource on Paleo Core (https://paleocore.or g/origins).[67] The type specimen for every single species is either only a skull or skull fragments (including mandibles/teeth) or includes a skull/fragments as part of the type specimen. This does not mean that the description of the species relies solely on these type specimens; for 22 out of 26 species, or 85%, the type specimens consist of *only* skull remains. Even with the recognition that craniodental preservation in a taphonomic sense is generally better than that of other skeletal elements[68], meaning we expect more skull remains in the fossil record, this skull-centric alpha taxonomy is true also for recently described species that have been systematically excavated and which include some postcrania (*Homo luzonensis*[69]), and those that have substantial postcranial material (*Homo naledi*[70]). For *H. naledi*, the choice of the holotype is striking, as Berger et al.[70] discuss at length the "mosaic" morphology evidenced in hominin species with complete skeletons – i.e. some aspects of the skeleton align more closely with one taxon and other aspects with another – cautioning that, "we must abandon the expectation that any small fragment of the anatomy can provide singular insight about the evolutionary relationships of fossil hominins"[70(p.23)].

Scientific racism first developed into a legitimate area of inquiry before the discovery of hominin fossils, meaning that the entrenchment of scientific racism into palaeoanthropology occurred in concert with early historical hominin discoveries. Taking this further, the race-based approaches to considering humankind, which is essentially (unjustifiable) taxonomy below the species level for *H. sapiens*, almost certainly influenced decisions to base hominin taxonomy largely on skull morphology. Or said another way, the decision that what was found represented a new species was only confidently made on the basis of skull differences. This makes sense given the importance of heads in race science and the fact that comparative human collections used for species diagnosis were skewed towards skulls. The same "objective scientific" methodologies and measurement techniques/instruments like callipers are also used in both pursuits: to put people in distinct typological categories in the service of scientific racism and to characterise fossil hominins.[45]

But aren't heads the best for species diagnosis?

Researchers might argue that skulls are simply more taxonomically diagnostic than postcranial remains, which explains our emphasis on them, and that our argument for a connection is therefore correlation but not causation. The supposed lack of phylogenetic usefulness of

Table 1: Skeletal inventory of a South African human skeletal collection

	All individuals	Cranium and postcranium[b]	Cranium and mandible	Cranium only	Mandible only	Total number of skulls[c]	Postcranium only
Iziko[a] (whole collection)	1013	452 (382)	143	364	51	558	116
Iziko (accessioned after 1960)	233	118 (100)	37	29	16	82	29
Iziko (accessioned before 1960)	364	138 (110)	53	99	18	170	44

[a]Iziko South African Museum in Cape Town, South Africa

[b]Numbers in parentheses represent the number of individuals with mandibles

[c]Total includes the number of individuals with only mandibles, only crania, and both crania and mandibles

postcranial morphology is often attributed to the assumption that postcranial morphology is more reflective of function and behaviour, thus increasing the probability of homoplasy specifically in cladistic analyses.[71,72] However, a large body of research suggests that is not always true, and even historical data suggest that other parts of the skeleton might be as valuable for taxonomy. Studies across multiple mammalian taxa have shown that levels of homoplasy are similar for postcranial, dental and cranial traits, with postcranial traits of the primate skeleton even shown to be less homoplastic than craniodental characters.[73–75] Postcranial traits have also been successfully used to reconstruct phylogenetic relationships, for example in papionins and hominins.[76,77] Furthermore, some recent studies of living primates have indicated that other regions of the skeleton, such as the humerus, os coxa, and scapula, would be just as, and sometimes more, effective for species/genus/family differentiation.[78–82] Studies have also shown a much lower efficacy for some regions of the hominoid skull, including humans, for reconstructing phylogenetic relationships.[83,84] This is related to the recognition that morphological evolution and divergence have been influenced by multiple evolutionary processes (natural selection, genetic drift, gene flow), and not all traits represent an adaptation (see discussion in [85]). For hominins, this new understanding has highlighted that certain regions of both the skull and postcranium are more reflective of non-adaptive processes, making these regions less subject to homoplasy and therefore better for determining phylogenetic relationships.[85]

For the Taung Child discovery, as discussed above, we know that postcranial material existed, but it not only did not make it into the scientific publication of Taung[1], it appears to have been lost historically. Ironically, finding postcrania of *A. africanus* (Stw 14) ended up being the nail in the coffin for any arguments that this species was not a bipedal human ancestor, demonstrating the importance of postcranial material in this particular instance. More recently discovered hominins like *H. naledi* have also illustrated how important it is to have information from entire skeletons to accurately understand the complex nature of human evolution.[70] This raises the question: if the postcranial material for Taung had been examined, would acceptance have happened earlier? Or differently? Might it have shifted the hypodigm for the species in a manner that affected how future taxa were evaluated?

As another example, brain size, a characteristic long linked with taxonomy and humanness, and, ironically, the main trait that influenced the initial scepticism about the Taung Child, may not be particularly useful for interpreting either. We now know that hominin brain size did not increase linearly; instead brain size has been variable, within and between taxa, both through time and also in contemporaneous groups from ca. 2 Ma right up to the recent past. For example, *Homo erectus* (sensu lato), and early *Homo* in general, had a wide range of variation[86], as do living humans (*H. sapiens)*. Some large-brained *H. erectus* and small-brained *H. habilis* were contemporaries capable of tool-making, but very different in brain size. Small-brained *H. floresiensis* also lived at the same time (and presumably space) as large-brained hominins, and had cultural capabilities.[87] Neanderthals had very large (on average) brains – larger than *H. sapiens* – an enigma to palaeoanthropologists, given that historically they were considered less capable despite their large brains (although we now know that is not true[88]).

Conclusion: Why does it matter?

This link between scientific racism, research on bodies, and especially heads, and human evolution studies reframes the story of the Taung Child discovery – and indeed both prior and subsequent hominin species discoveries – in a new way. The discovery is embedded in a history and practice that inevitably impacted the interpretation of the fossil find (see also [65]) and contributed ultimately to the skull-centrism of palaeoanthropology. It is essential that we break the link between racism and human evolution, and recognise the ways in which their interconnectedness has impacted our field and shaped its legacy. Discussions about the ethics of comparative collections, the practice of repatriation and restitution (e.g.[89,90]), as well as thoughtful critiques of ancestry estimation in forensic science[91], have moved our broader discipline forward and have paved the way for palaeoanthropologists to look inward.

The tendency to centre skulls in palaeoanthropology has affected the lens through which we interpret the past in multiple ways. First, it has potentially skewed the historical trajectory of the field. Focusing on heads and not on postcrania might mean that evidence for human evolution was overlooked or downplayed in its importance, as evidenced, for example, by the disregarding of the Taung postcrania. Second, an overemphasis on skulls has potentially skewed how we narrate the story of human evolution. Palaeoanthropologists have been obsessed with measuring head/brain size and shape, and linking this to intelligence and capabilities, right from the beginning of the discipline, an obsession that comes directly out of race science. The focus has been on why our heads are bigger or smaller (e.g. intelligence), what fuelled it (e.g. meat-eating), and what advantage it gave us (e.g. culture). Large brains are embedded in humanness, even though we now know that even small-brained hominins appear to have had the capacity for culture. Moreover, comparative primatology, and studies of other organisms (e.g. octopus), are telling us that large mammalian brains are not central to intelligence, or may not be directly tied to meat-eating (e.g.[92]). In this sense, a focus on heads/brains may also have contributed to ideas of human exceptionalism.

Going forward, it is important to recognise the biases that underlie our research choices. Why have we been so insistent on linking brain size to intelligence and capabilities, even in the face of intra- and interspecific variation that illustrates that this is not true? How do we move beyond this skull-centrism? Obviously, with modern techniques, we have the capability to fully examine the entire skeleton. Improved excavation approaches, including the ability to CT scan breccia and the like to identify materials embedded in rocks, give us the capability to identify and prepare (virtually) even the most friable material, including the arm and hand bones of the Taung Child should they ever be located. However, fully moving away from a head-centred approach is going to require a conscious shift in mindset, and the understanding that we risk being typological and essentialist by not shifting our approach. We just have to do it!

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Data availability

Data captured in Table 1 of this study are available on request from the curator of the Iziko South African Museum. Data captured in Supplementary table 1 are freely available via https://paleocore.org/origins/nomina/.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

L.S.: Conceptualisation, writing – the initial draft, data collection, writing – revisions, data analysis, data curation. P.M.: Conceptualisation, writing – the initial draft. R.R.A:: Conceptualisation, writing – the initial draft, data collection, writing – revisions. All authors read and approved the final manuscript.

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100 Years of palaeo-research and its relevance for transformation and social cohesion in South Africa

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Australian-born Raymond Dart arrived in South Africa in 1922 and subsequently gave the name *Australopithecus africanus* to the fossilised juvenile skull discovered by mine workers in Taung, North West Province. After this discovery, and its announcement in 1925, the discipline of palaeoanthropology grew exponentially on the continent. This centennial milestone necessitates reflection on the role of science in society, with a critical look at the relationship between palaeosciences, the theories of human evolution, and the researcher's interaction with southern African Indigenous peoples. Here we examine the palaeoanthropological scientific practice in southern Africa and suggest ways to decolonise science, and its narratives, in the future. To achieve meaningful transformation and social cohesiveness, we discuss measures to counter the wrongs of the past through meaningful and socially responsive practices such as equitable funding schemes, meaningful collaboration, and doing away with 'helicopter research'.

Significance:

Palaeoscience practice and narratives in southern Africa are in need of decolonisation. We call for meaningful transformation and social cohesiveness, through measures to counter the wrongs of the past. To do this, we suggest meaningful and socially responsive practices such as equitable funding schemes, meaningful collaboration, and doing away with 'helicopter research'.

[Abstract in** Setswana**]

Introduction

Despite Botswana gaining independence from British colonial rule in 1966, Zimbabwe in 1980, and South Africa's apartheid ending 30 years ago, southern African states have yet to develop into nations that are integrated beyond race, ethnicity, and class. Furthermore, the persistence of inequality has fuelled conflict between various groups in southern Africa, including xenophobic attacks, tribalism, ethnic power struggles, and racism. The region's socio-economic challenges have hampered equality and social cohesion, which is a necessary component of inclusive growth.

Palaeo-research in southern Africa plays an important role in the building of new democratic societies and forms the basis of many African countries' postcolonial identities as well as the reclaiming of their prehistorical advancements. Similar to many scientific disciplines, its roots lie in colonial imperatives of domination of European settlers in the colonies, which opened up new areas of research and developed new fields of study. These became the driving force behind colonial science, which was used to aid in colonial imperialist expansion.[1–3] The culture of local resource and population exploitation from which colonial science was founded, translated to the view of science in colonies as European achievements.[4] The regional dominance of South African palaeoscience research, specifically human evolution related disciplines, means that biases that emanate from the practice of palaeosciences in South Africa impact beyond its borders to the culturally linked neighbouring states, even after their independence. The announcement of the Taung juvenile fossil, dubbed the Taung Child, by Raymond Dart in 1925[5] propelled professionalisation of the palaeosciences in South Africa, the wider region, the continent, and beyond. With it came a change of perspective towards one that reinforced the notion of Africa as the place of origin of humankind, as speculated first by Thomas Henry Huxley[6] and later reinforced by Charles Darwin (1871)[7]. That change reverberated globally, and, depending on where the news was received, there was either excitement or apathy for this newly affirmed position for the continent.[8] With this announcement also came the motivation to unearth more remains and to explore what else lay beneath the continent's soil to support or challenge this new position. The trajectory of human evolution studies and associated disciplines changed forever. Despite assuming a centre stage globally, in southern Africa, the discipline's course would be enmeshed in the region's socio-political turmoil of the next century. While this is not the popular narrative associated with the discovery of the Taung Child, the processes associated with the announcement are not devoid of controversy linked to racial attitudes and the practices of the time.

Undoubtedly, the announcement of the Taung Child was influenced by the Union of South Africa through entrenchment of racial segregation and the notion of white superiority, which was ultimately legislated through apartheid in 1948. The discovery also took place against the backdrop of the newly propagated *Natives Act* of 1923[9], which advocated for the restriction of African migrant workers in town and laid the foundation for the *Group Areas Act*[10] that followed in 1950. This exclusionary and racist legislature led to the erasure of historical facts about the fossil's discovery. For example, the only mention Dart makes of how the fossil landed in his hands is that of a student who brought the cercopithecoid fossil remains to his office and the consulting geologist who later brought additional fossil specimens for his examination.[5] Central characters and events in this discovery only reference the geologist, the mine manager and academic staff at the University of the Witwatersrand, all of whom were white men. Not a single mention is made in Dart's published works of the black mine workers who could have possibly manually unearthed these fossils.[11] This set the tone for the practice of palaeosciences in the region and elsewhere on the continent. Erasure of black characters in the stories of these finds is a trend that persists to date.[12]

Discovery of the Taung Child and the birth of palaeosciences in southern Africa

Raymond Dart's announcement of this seminal fossil specimen influenced the direction that palaeoanthropological discoveries and announcements were to take. After the discovery of the Taung Child, subsequent major discoveries, such as the 1932 discovery of the Florisbad fossil cranium and its possible taxonomic association with early *Homo sapiens*[13], the 1938 announcement of *Paranthropus* at Kromdraai[14], the 1947 announcement of Mrs Ples (now attributed to *Australopithecus africanus*) at Sterkfontein[15], and the 2013 discovery of *Homo naledi* in the Rising Star Cave system[16] followed the same route in their practice. Not a single article by the 'discoverers' or authors acknowledges the manual labourers who likely played a critical role in the discovery. Post discovery and prior to writing manuscripts, the research process relies heavily on support staff to prepare and, at times, preliminarily analyse the specimens. The practice of acknowledging all researchers in the scientific process is almost non-existent and remains largely the same for 100 years, now with the exception of a couple of research teams which have acknowledged and co-authored with technicians involved in the research.[17,18]

Recognition of Raymond Dart as a pioneer of African palaeoanthropology[19] initiated, and indeed entrenched, the centralisation of certain individuals, even in the face of growing recognition of the multidisciplinary nature of the field. This practice over time has inevitably cultivated a system in which only a single individual is depicted as *the* hero, overshadowing, if not entirely suppressing, the existence of other contributors involved in the process. While the political environment of the time would not have provided an opportunity for black people to lead research, acknowledgement of all contributors would have set a good precedent. These eminent personalities drive the research agenda and, ultimately, the future of research through their training practices. With this idolised recognition also comes easier access to research permits, funding, and other support structures, which further reinforces the influence of these few individuals.

The centre stage placement of a few idealised researchers with colonial influence[19] perpetuates the marginalisation and disenfranchisement of local researchers of African heritage and research on African soil. In other southern African countries such as Botswana and Zimbabwe, the demographics are not as skewed. However, in South Africa, most researchers do not reflect the country's demographics. Black academics are a minority in academia, while they are the country's demographic majority. In an acknowledgement of issues like these, and to bring about inclusive change, the UNESCO stakeholder engagement and communications guide of 2017 calls for full and effective participation of Indigenous peoples as stakeholders and rightsholders in the process of managing and presenting heritage, in accordance with a human rights based approach, while acknowledging the evolution's global legacy.[20]

Collaboration and diversity of voices for inclusive palaeosciences

In the scientific milieu of the 21st century, cooperation and a diversity of perspectives are unquestionably the way forward in research, particularly when it comes to the study of human evolution and the examination of human remains. Genuine collaborative and inclusive research endeavours promote a sense of belonging and address negative publicity. This was observed in the call to rebury ancestral human remains held in the then South African Museum's collections. This call to action was provoked by past scientific misconduct, including the collection of and race-based scientific research on individuals of African descent and casting of living San individuals and exhibitions of their likeness.[21,22] It is evident that including local academics and community members in the research process is crucial for both cultural preservation and site conservation. Certainly, one method to encourage public interest and support for the discipline is to make the process and the content more accessible to the public through innovative and decolonised approaches that could be brought about by structures such as the !Khwa ttu San Heritage Centre and the Hunter-Gatherer Archaeological Research Project (HARP).[23,24]

There is a growing recognition that multivocality is crucial in the scientific construction of social cohesiveness.[25] The central point of multivocality is a participation that encompasses more than just increasing the number of voices, groups, and persons involved – but one that also considers how marginalised groups can participate meaningfully in research and its interpretation by being given a platform to speak and be heard.[26] To provide an opportunity to participate actively in research platforms, there is a need for scientific methods that cater to the non-Western voice. As Hodder states, "reflexivity is a process that calls on scientists in archaeology and palaeosciences to reflect on the scientific practices from research design to field methods, writing, publishing, and presentation of the past"[26]. By recognising historical and current issues with positionality in human origins disciplines, multivocality has the ability to re-centre science away from egotistical and self-indulgent practices, as has been done in the HARP project.[23]

In palaeosciences today, the historically marginalised, silenced and decentred subaltern voices that claim some form of affiliation to archaeological remains have been awakened, engaged, and are currently eager to explore their heritage and identity, and to tell the stories of their past. All researchers are part of the academic community that has the scientific responsibility to protect heritage. Because all heritage is essential to the discipline's future, neglecting these voices exposes the heritage to a singular, simplistic perspective. This neglect prompts us to consider social cohesion and transformation (or the lack thereof) linked to the legacies of the past as well as the paths that have since been taken to rebuild cooperation and collaboration to create spaces that are encouraging unity. These shifts are necessary for a scientific community that is socially sensitive. It allows the discipline to produce genuinely inclusive research and narratives that may be accepted by the broader scientific community, while also taking into consideration the realities of other stakeholders.

Perspectives towards transforming the discipline

It is impossible to ignore the role of museums and universities in any discussion related to transformation of the discipline of human evolution specifically, and palaeosciences in general. They are the custodians of the region's heritage and are responsible for enabling access to a variety of objects and specimens. With a history of supporting race-based research, collecting, and extractivism, museums and educational institutions were knowing participants in the often racist foundations of palaeoanthropology and related disciplines.[12] Most colonial- or apartheid-established institutions were a product of their times, meaning they were managed and run in a manner that met the socio-political standing and needs of the government, the scientific community, and the elite or ruling class. For over a century, this system facilitated access to artifacts, fossils, and human tissue (often informally) for select institutions, publics and scholars. These institutions enabled the mishandling of Indigenous people, affording scientists inhumane liberties, objectifying their bodies in the name of racial science.[27]

Today, institutions try to change these legacies of misusing human remains and objects by restricting access, making sure that research proposals are based on sound science, and ask relevant, discipline-specific questions. Institutions in South Africa that hold archaeological, fossil, and physical anthropological collections, such as Ditsong Museum, Iziko Museums of South Africa, the University of the Witwatersrand, and the University of Cape Town, among others, have access processes linked to ethical guidelines and access application evaluation committees, which safeguard against perpetuating old practices.[23,24] Many southern African institutions and museums, such as the Marange Community Museum in Zimbabwe[28], are encouraging local participation in large-scale, internationally driven, palaeoanthropological and archaeological projects, knowledge exchange, and student opportunities in the hopes of changing the landscape and strengthening the African palaeo-community. Although researchers are not always required to have a local co-principal investigator for museum access, they are, for example, asked to exchange knowledge in return for access to collections.[29] This can be in the form of a talk, a workshop, some training, and in some cases, collaboration. But is a talk or workshop sufficient to change colonial legacies? The short answer is no. Although strict policy and access requirements are in place in most museums and institutions in South Africa, and there is intention to drive transformational change, palaeosciences is not seeing a drastic change in palaeoanthropological and archaeological research toward truly collaborative projects that are fully inclusive and demographically representative at all stages of research planning, execution and publication.

Research and human capital support

In South Africa, government funding bodies such as the National Research Foundation (NRF), and the continent's most prominent private funder, the Palaeontological Scientific Trust (PAST), direct funds towards supporting decolonisation initiatives. The question remains: who are the recipients of this purported research and training support? Our research demonstrates that the trend of funding support is still in favour of projects led by white male researchers over black and female researchers.[30] Various student funding programmes exist that have generated at least 157 000 master's and PhD graduates between 2010 and 2020.[31] When we look at the standard measure of research productivity, bibliometric analysis[32] of research productivity in palaeosciences – as well as the broader sciences, the results point to a non-transformed picture. Analysis of research outputs of permanent staff at ten universities and six museums in South Africa shows a bias towards white male productivity, with below average outputs by black people, irrespective of gender. In 2023, there were 66 permanent palaeoscience positions across these 16 institutions in South Africa.[30] Data indicate that the beneficiaries of this support are the same eminent personalities who continue to dominate positions in research, suggesting that most of the graduates will not be absorbed into permanent work.

Establishing a platform for multivocality and unifying global narratives, requires levelling the playing field through access to funding opportunities for all scientists, regardless of their gender, colour, nationality, or other characteristics. Researchers need to commit to creating outputs that reflect a new narrative while simultaneously training more scholars of colour to change the palaeoanthropological scientific landscape. Should the current situation continue, there will be a lack of know-how in the understanding of the region's human past and a reliance on stories narrated by Westerners without the involvement of local scientists. This will create an information divide in Indigenous perspectives within the discipline. A higher level of representation and engagement is made possible through engaging and training local and Indigenous participants. Regardless of their nationality, gender, or socio-economic status, we can ensure the development of different voices and increase the number of research collaborators and ties between scientists in the region by training local-based archaeologists.

Science education and awareness

It is primarily the duty of palaeoscientists to disseminate their findings to interested parties and establish a connection between the public and their research. Schools, colleges, universities, museums, and historical places are spaces for this education to take place. These are the main venues for the public to interact with exhibitions and archaeology. However, the discipline in southern Africa is impacted by the legacy of colonialism.[33] As a result, current practices in museums and heritage management in post-colonial southern Africa persistently reflect the influence of colonial legacies, leading to the gradual erosion of Indigenous knowledge linked to our heritage.[34] Masiteng[35] demonstrates Ditsong National Museum of Cultural History's practices that still mirror colonial methodologies in policies relating to the acquisition of human remains, and that allow inadequate and often racialised handling of human remains.

These issues can be traced back to the history of education in South Africa. The notion of 'evolution', whether it pertains to human development or microbiology, was not included in any of the curricula developed under the previous Christian National Education (CNE) system in South Africa.[36] In order to prepare white and black children for their respective superior and inferior roles in South African social and economic life, the Christian National Policy stipulated, among other things, that all education should be founded on Christian National principles and that white children should receive a separate education to black children.[37] The Christian National curriculum eliminated "anti-biblical" ideas such as evolution, and students were indoctrinated into the Christian National Principles' worldview. This curriculum, according to Dean and Sieborger[38], presented a version of history that "omitted, distorted, or vilified the role of blacks, 'coloureds', and Asians in the country's past". Subsequently, hominid evolution was included in the interim History syllabus of the New Qualification Framework (NQF) for the first time in 1995, post-apartheid.[38]

A lack of human evolution education is not unique to South Africa. Botswana also inherited socio-political structures that benefitted from the devaluation of Africa and its history. The school curriculum in Botswana, one that appears to be an integral component of the white supremacist culture in South Africa, is deemed dangerous by prominent social activist Sandy Grant.[39] There is a lack of palaeosciences specialists who study and teach hominid evolution in Botswana; the country is, therefore, dependent on specialists from neighbouring countries and the West. Similar to Botswana, there is a paucity of human evolution research and sub-disciplines of palaeosciences in Zimbabwe. This is largely attributed to post-colonial economic and political issues that have pushed researchers out of Zimbabwe in favour of relocating to South Africa. Consequently, much of the curriculum on human evolution taught in universities, especially on Zimbabwe's Stone Age archaeology, relies on work conducted during the colonial period in the 1960s and 1970s by white male archaeologists, many of whom interpret Zimbabwe's archaeology through colonial mindsets.[40]

In her study of relationships between science and society, Dawson[41] concludes that scientific practices are shaped by structural inequalities, and, as a result, are far from public. She drew data from low-income, minority ethnic groups to map their participation (or non-participation) in science communication and how they perceived their inclusion or exclusion. Dawson's[41] research demonstrates that scientific practices construct a narrow public view that reflects or is biased towards the shape, values and practices of dominant groups. This finding suggests that participation in science communication operates in similar ways to Bourdieu's[42] theory of social reproduction via arts, education and cultural participation. It states that restricted access preserves cultural capital for dominant groups through exclusion of the marginalised.

The importance of the role Africa had in the evolution of life is countered by the widespread racist colonial rhetoric of Africa as the 'dark continent' with 'primitive natives', as captured in Henry Stanley's soliloquy[43], which creates a negative legacy for the continent. It is undeniable that those perceptions that are still entrenched in the public's mind have created a barrier to understanding human evolution.

In addition, the legacy of creationism, and in the case of South Africa, religion and radical politics (seen in Afrikaner nationalism shaped by Hendrik Verwoerd when he designed apartheid)[44], have impacted race relations as a formal part of the South African school curriculum. This has filtered into the general public's reality through continued creationism beliefs, and contributes to the contention between evolution and religion which continues today.[45]

Chisango and colleagues[46] report on racial misconceptions of the theory of evolution in Zimbabwe, and demonstrate that there is opposition to evolution among university students. In their study, they established that misconceptions of biological anthropology negatively correlate with acceptance of both the theory of evolution and science. The point of departure being the study of biology in high school, which correlates with the students' tolerance of evolution science. This study, and a similar one[47], demonstrate the dangers of the absence of, or minimal meaningful public awareness and engagement with, the youth who are likely to be present and future key agents of change. We echo Sutherland and L'Abbe's[48] emphasis on the importance of the understanding of human evolution science, considering the region's growing decolonisation and palaeosciences contribution to the appreciation of the diversity and heterogeneous nature of our society.

Practical solutions to drive effective transformation and social cohesion

Towards a socially responsive discipline

Museums in southern Africa provide archaeologists with a platform to communicate their research outcomes to the public; however, based on economic stability, their capacity varies across the region. While a few South African museums opened exhibits on human evolution in the 1990s, most archaeological sites and museums in the subregion continue to cater primarily for a Eurocentric audience.[49] Furthermore, local communities may not always be able to afford the admission or entry fees. Consequently, access to museums and public interpretation centres remains a challenge in the subcontinent. For museums that are accessible to local visitors, the display readings, even in most community museums, are too often solely in English and at a reading level that non-native English speakers may not easily understand. The Taung Skull

World Heritage Site Management Authority has recently built a museum with an underground vault. This new development was expedited with the locals' hope for the return of the original skull specimen to Buxton and the subsequent flow of tourists who want to see the original skull. Irrespective of the socio-politics associated with this endeavour, the current museum's interpretation of Africa's palaeosciences should be accessible to the local community of Taung and its surroundings.

To address some of these issues in southern Africa, specifically in South Africa, efforts have been made to include members of marginalised communities in the planning and design of exhibitions. One example of this effort is the recently opened "Humanity" exhibition at the Iziko South Africa Museum, Cape Town, which reimagines the story of human evolution by focusing on the diversity of modern humans and how we came to be this way.[50] It centres on the rich history of people in Africa and South Africa. By doing this, it retells the story of our beginnings as one of intelligence, inventiveness, and perseverance across ages.[50]

The Botswana National Museum implemented a travelling exhibition in the 1980s known as 'Zebra on the wheels' that operated across the nation, sharing artefacts and narratives. The mobile museum is complemented by the radio programme *Museum oo tshelang* (translated 'Living Museum') and the Zebra's voice magazine.[51] This initiative not only broadens museum services and public engagement in the museum spaces but also contributes to the improvement of local museums. The radio programme, magazine and mobile museum, complete with artefacts, visit schools in the country, aiming to pique the public's interest through intellectual stimulation through museum services about the history and cultures of the people of Botswana.

Zimbabwe has also introduced community museums as alternative forms of cultural displays and active decolonial strategies, fostering transformation.[52] The BaTonga, Marange, and Nambya Community Museums engaged local communities by promoting their cultures and languages[52], presenting the traditions, scientific knowledge, beliefs, and ingenuity of local communities. They exemplify an ongoing social and cultural transformation led by Indigenous people, involving the creation, adaptation, and revision of Western museological frameworks that persist within national museums in Zimbabwe.[53] In Mozambique, the Nwadjahane National Heritage Site and open museum, which is a site memory of the first president of Frelimo, Eduardo Mondlane, is a community-based and -owned heritage site where locals create and own the interpretation of the site.[54]

Apart from these challenges faced by museums, most countries in southern Africa grapple with the challenge of community estrangement stemming from historical trauma. One instance of how local inhabitants were uprooted and denied access to their ancestral lands is when the government repossessed land through the World Heritage inscription. This situation is evident in places such as Matobo Hills and Domboshava in Zimbabwe and Tsodilo Hills in Botswana.[55–57] People lose their land rights when a location is designated as a protected national or international monument, creating a conflict of interest between local inhabitants and tourist access. On the other hand, these problems can be addressed through active community involvement and site custodianship. Collaboration between researchers, local scholars, and communities is a viable solution to end the exclusion of the public from the study process.[56]

Sustainable infrastructure development

Scientific colonialism and the current practice of scientific exclusion and misrepresentation of local scientists from the Global South are driven by financial and infrastructure resource domination by the West. The local government's policy, South African Strategy for the Palaeosciences, identifies various limitations associated with lack of infrastructure that supports core and applied research in the country.[58] This has a direct impact on scientific narratives developed about the region. An example is when Chan et al.[59] published a paper titled 'Human origins in a southern African palaeo-wetland and first migrations' in *Nature*. This publication made its way to major media outlets and local media in Botswana and surrounding regions. According to the authors, "anatomically modern humans" originated approximately 200 000 years ago in the Makgadikgadi-Okavango palaeo-wetland of southern Africa, which was then a vast network of palaeolakes and the hub of fertile lands. These findings locate this "homeland" in southern Africa by using mitochondrial DNA data as a stand-in for population data. These assertions are challenged by fossil evidence which demonstrates the presence of *Homo sapiens* traits predating 200 000 years ago across other regions of the continent.[60] In general, current research indicates that the evolution of *Homo sapiens* has been marked by a multitude of distinct derived and primitive traits throughout time and space, and these findings do not point to a single point of origin. Chan et al.'s[59] study generated dubious conclusions that misrepresent the science surrounding human origins in Africa, yet it was able to obtain widespread media coverage, wide distribution of data, and the involvement of a wide range of interest groups. In a subcontinent that suffers from high levels of illiteracy, misinformation about science is likely to lead to irreparable damage, generating mistrust of scientific facts and the scientific process, which may lead to increased ignorance.

Intensive and systematic research infrastructure development must be targeted by the government, through funding institutions, to strengthen local institutions and researchers' ability to conduct independent research. Removing the global power imbalance that persists in palaeontology, with researchers in the Global North having a monopoly on research data[61], would create an environment conducive for local research growth.

Transforming a sustained human capital

Within the region and the continent, funding and support for the whole human capital development work chain is critical to avoid gaps in support. The current model of providing equitable funding to students but less for research jobs has proved ineffective for the support of permanent staff. Engagement between government departments such as the South African Department of Sports, Arts and Culture and the Department of Science, Technology and Innovation, private funding agencies and stakeholders, should be explored to support new vacancies for graduates as well as in-job training of emerging researchers to fully participate in research.

We propose structural and ideological transformation of the discipline to facilitate decolonisation of palaeosciences human capital as well as knowledge production and dissemination. Active and meaningful transformative processes that transcend existing boundaries built by theory and practice carry the ability to transform societal practice.[62] As suggested by some authors[63,64], we propose a reflexive dialogue as the basis for generating impactful change. A successful example of this is when the South African Strategy for the Palaeosciences was developed in 2012.[58] During this period, under the tutelage of the now Department of Science, Technology and Innovation (DSTI) and the National Research Foundation (NRF), various sectors of the discipline were engaged in determining pillars essential for the development of the disciplines. This strategy calls for a demographic and developmentally transformed discipline that focuses on all pillars of the field, empowering museums, supporting universities, creating awareness and making South Africa a tourism destination.

At the core of this proposed transformation is a complete rethinking of the research status quo, which requires the urgent attention of policy implementers, as well as funding agencies. The practice of developing and archiving perceptually good policies, such as the Palaeosciences Strategy, without their full implementation, is at the backdrop of some of the major issues faced by many African governments. Schlemmer[65] asserts that the lack of policy implementation in South Africa is a factor of authorship, which mostly lies with paid consultants who hold no accountability nor likelihood of implementation and renders these statutes ineffective. He proposes that policy should be accompanied by a likelihood of implementation rating and be written by senior public officials who will be accountable for its application.

Awareness, education and leadership for change

The solution lies in structures and processes that facilitate a paradigm shift towards a socially responsive discipline. The foundation of this fundamental change lies in investment and transformational pedagogy (inquiry and leaner dialogue-based learning), which starts at existing structures, such as human and ideological resources transmitted by the discipline.[66]

The crux of this unlearning is employing leaders as agents for change. The impact of transformational leadership on organisational culture is a fully fledged discipline.[67] Studies demonstrate that transformational leadership's regulatory role in organisational climates has a huge impact as change agents. Up to now, the status quo in palaeosciences has remained for reasons not yet scientifically explored. However, it is very likely that the leadership's apathy towards the post-colonial regime affects the discipline's status quo, which is out of touch with the region's socio-economic realities and contributes to the slow pace of transformation.

Central to this engagement of leadership, some authors[68–70] advocate for transformative learning in the context of unlearning deep class, racial and gender inequalities entrenched by the region's colonial past. Relearning and revision of stereotypes and attitudes is likely to lead to revised perspectives and behaviours required for change. Mezirow's[71] position is that of disorienting dilemmas which trigger reflections, and introspection of entrenched paradigms that guide meaningful change, i.e. transformative learning. This creates a new reality in which transformative learning is created.[72] Another layer to this structured approach lies with responsive educational practices on disciplinary foundational principles and is required to engage in decolonial thought that may have a snowball effect on public engagements on the subject.

Into a transformed and socially cohesive future

While some strides have been made towards a transformed palaeosciences for social cohesion, with institutions such as Iziko Museums of South Africa and the University of Cape Town's collaboration in the development of the Humanity exhibition, among others, adopting a transformative and inclusive approach to research, group representation, and knowledge sharing, a great deal must be done by the discipline. In this paper, we have demonstrated the need for a decolonised and inclusive approach towards change that involves all stakeholders to accelerate the century-long overdue change. Dart's pioneering spirit brought Africa the impetus to develop palaeoanthropology during a time when inclusivity was a far-fetched thought, and illegal. As the field celebrates the centenary of the discovery and announcement of the Taung Child, we should pause to ask the tough question: what lessons do we carry from our forebears into the future? The answer lies in looking into the future and developing genuine and meaningful interventions to create the desired state of the discipline.

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Data availability

The data supporting the results of this study are available upon request to the corresponding author.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare.

Authors' contributions

D.W.K.: Conceptualisation, methodology, data collection, data analysis, validation, data curation, writing – the initial draft, writing – revisions, project leadership, project management. S.B.: Data collection, data analysis, validation, writing – revisions. W.B.: Data collection, data analysis, validation, writing – revisions. P.C-M.: Validation, writing – revisions. All authors read and approved the final manuscript.

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