Geoheritage (2024) 16:63
https://doi.org/10.1007/s12371-024-00964-8

ORIGINAL ARTICLE

Africa Alive Corridors: Transdisciplinary Research based on African Footprints

B. Linol[1] · M. Doucouré[1] · J. Anderson[1] · F. Toteu[1,2] · W. Miller[1] · P. Vale[1,3] · P. Hoffman[4] · G. I. H. Kerley[5] · R. Auerbach[1] · C. Thiart[1,11] · M. Meghraoui[6,10] · N. Dhliwayo[1] · J. Master[1] · F. Genin[1] · T. Dembaremba[7] · B. van Heerden[1] · J. Unite[1] · A. May[1] · P. Mathias[1] · M. Minguzzi[8] · T. de Wit[1,9]

Received: 16 November 2023 / Accepted: 9 May 2024

Abstract
The idea of Africa Alive Corridors (AAC) evolved from Gondwana geological mapping to a comprehensive, more inclusive and dynamic approach to transdisciplinary research known as Earth Stewardship Science. Twenty designated corridors explore the geo-biological and cultural heritage of different regions of Africa over various periods, from deep time to the Anthropocene. Each corridor reveals a specific lens through which to investigate some of the rich scientific narratives embedded within it. The concept also facilitates learning and knowledge exchange across numerous disciplines: archeology, geology, geophysics, oceanography, glaciology, biology, botany, ecology, agriculture, engineering, spatial statistics, social sciences, and the humanities. This contribution analyses ten selected corridors in southern and western Africa, the Congo Basin, East Africa, and Madagascar. The various research themes explored include Earth impact hazard, origins of humankind, Snowball Earth, coastal food systems and conservation, the biogeography of lemurs, human settlement dynamics in Cameroon, tectonically linked earthquake occurrences in Algeria and Morocco, modelling land-use changes in the Western Rift Valley, trades and civilizations of the Mali Empire, Mbira music, and contemporary art. The ongoing work on these—and ten other—corridors has considerable potential to host new international collaborations to develop the links between society and natural sciences in Africa. Ultimately, AAC will benefit all stakeholders, especially the youth, in understanding and responding to societal needs and current global challenges.

Keywords Citizen science · Geo-heritage · Geo-hazard · Geo-health · Conservation

Introduction

Africa Alive Corridors (AAC) are all about journeys through Africa's autobiography, with everyone as a stakeholder. They encompass 4 billion years of the continent's geological, biological, and cultural evolution. Therefore, their scope is gigantic, investigating various scales, from deep time to the Anthropocene, and local to global. The overall AAC concept highlights that Africa is colossal, covering more than 20% of Earth's land surface and is home to more than 1.4 billion people. After the biological Big Bang, some 550 million years ago (Ma), life evolved on the African plate, a fragment of the Gondwana supercontinent, and it adapted to rapid climatic fluctuations, including those during the last glacial period that ended approximately 15 thousand years ago (ka). Today, with the current challenges of global warming and a predicted 2°C temperature increase by 2100, there are increasing threats to human health, food security, and social-economic development, and thus a more urgent need for resource and cultural stewardship, "Towards stemming the Sixth Extinction" (Anderson 1999; de Wit and Anderson 2003; Anderson and de Wit 2008; Toteu et al. 2010).

A corridor means a running place or a wide passage. In AAC terminology, it represents a trail for scientific research along which communities collectively explore the natural and cultural heritage within it (Fig. 1). The corridor names identify the individuality of each designed path and its associated time window:

J. Master and F. Genin are deceased.

Extended author information available on the last page of the article

Published online: 27 May 2024

1. **Cradle to Cradle**, Swaziland to South Africa, 3.5 billion years ago (Ga) to Present
2. **Snowball Earth**, Namibia to Angola, 1 Ga to 500 Ma
3. **Great Karoo**, Lesotho to South Africa, 325 Ma to 175 Ma
4. **African Pole of Rotation**, Cameroon to Nigeria, 200 Ma to Present
5. **Colliding Continents**, Morocco to Tunisia, 200 Ma to Present
6. **Lemur-Chameleon**, Madagascar, 65 Ma to Present
7. **Lungs of Africa**, Democratic Republic of Congo to Tanzania, 8 Ma to Present
8. **Eastern Rift Valley**, Ethiopia to Malawi, 5 Ma to 150 ka
9. **Western Rift Valley**, Uganda to Tanzania, 5 Ma to Present
10. **Homo Sapiens**, South Africa, 140 ka to 60 ka
11. **Khoisan Kalahari**, Namibia to Botswana, 60 ka to Present
12. **Saharan Paradise Lost**, Tunisia to Chad, 22 ka to Present
13. **Valley of Pharaohs**, Egypt to Sudan, 3100 to 30 Before Christ (BC)
14. **Nubian Nile**, Sudan to Ethiopia, 3000 BC to Present
15. **Songhay's Timbuktu**, Senegal to Nigeria, 700 to 1600 Anno Domini (AD)
16. **Mapungubwe-Great Zimbabwe**, South Africa to Zimbabwe, 900 to1700 AD
17. **Mirror of History**, Western Sahara to Nigeria, 1400 AD to Present
18. **Zambezi River**, Zambia to Mozambique, 1800 AD to Present
19. **Sixth Extinction**, Somali to Sudan, 1940 AD to Present
20. **Carbon Footprint**, Algeria to Egypt, 1900 to 2010 AD

Twenty nodes demarcate each of the twenty corridors; these are sites of exceptional value to science and humanities. They often correspond to biodiversity hotspots, world heritage sites, and geo-parks (Fig. 1). Their designation is conceptual and negotiable. As such, they may well be subject to revision (Anderson et al. 2008). However, once the AAC program is fully implemented across the continent, each node is expected to have practical applications that promote sustainability, heritage co-curatorship, and entrepreneurship. Such applications include geo-tourism, mitigation of natural hazards, and understanding the health impacts of climate change, as defined below.

– Geo-heritage encompasses landscapes, building stones, and minerals that convey a unique story of the planet. These features are used for conservation, science communication and research, providing a sense of place with historical, cultural, aesthetic, and religious values (Errami et al. 2015; Neto and Henriques 2022; Matshusa and Leonard 2023).
– Geo-hazards include all processes at the Earth's surface that can threaten life and the environment. These include earthquakes, volcanic eruptions, landslides, and tsunamis (Meghraoui et al. 2016; Guettiche et al. 2017; Salama et al. 2020; Rouwet et al. 2021).
– Geo-health is at the intersection of geology, ecology, and health sciences. It measures potential health risks associated with air and water pollution, toxic waste, radiation, consuming crops contaminated with trace elements, extreme temperatures, and the like. It is a community-engaged research (Selinus et al. 2013; Mouri 2020).

In this context, AAC forms an overarching research program with vast potential to develop a coherent body of knowledge called Earth Stewardship Science, based on the corridors, or 'African Footprints'. Notably, there are no other similar concepts, highlighting the need to address current gaps in explaining and understanding geo-heritages, geo-hazards, and geo-health within Africa. This is especially important for improving education and system services. It opens the door to shaping a new way forward from which to seek consilience and explore sustainable solutions for the planet and its people.

Background

Earth Stewardship Science is rooted in the understanding that the planet is a unique and shared natural heritage, for which all are responsible, and each accountable. It emerges from the recognition that national boundaries restrict know how to deal with issues of common real estate, i.e. the global Commons. Mostly, humankind struggles to share world resources equitably and is not yet able to govern the world's Commons peacefully. A deepening consensus suggests that without rigorous scientific analyses, greater imagination, and intense negotiation between economic and political interests, humankind faces extinction along with much of the rest of life on Earth. Thus, bringing science, imagination, and this negotiation together in order to save the planet is the main task ahead (de Wit and Anderson 2003).

The setting of AAC brings together the fields of 'science', where the latter is used in the broadest sense of the word, covering all aspects of 'scientific' enquiry as a systematic enterprise to build and organize knowledge in the form of testable explanations and predictions across the natural, social, health, and engineering disciplines. Such body of knowledge can be rationally explained and reliably applied (Linol et al. 2020).

AAC uses Earth Stewardship Science as its foundation to explore Africa's natural and cultural heritage along

selected corridors that are characterized by spatial and temporal milestones of life on the continent (see list above). This transdisciplinary approach, in which art and music are key to storytelling and curatorship of knowledge along the corridors, defines the method used in this paper. Its implementation is through syntheses of the corridors, including research on geological and biological heritage with associated ecosystems and resources, cultural and religious heritage, and trade and economy. Geographical Information System (GIS) linked to mapping is used for geospatial context and visualization of attributes. An attempt has been made to describe the corridors in order of spatial significance, and from early life on planet Earth to the Anthropocene, and not in the sequence of AAC numbering (Fig. 1).

From Gondwana Alive to Africa Alive The AAC concept originated during the creation of the geological map of Gondwana in the 1980s (de Wit et al. 1988). Rock sequences correlation and plate reconstructions enabled the identification of several piercing points that facilitated reconfiguring the position of the continents through time. Such sites have a significant bearing on the study of the origin and evolution

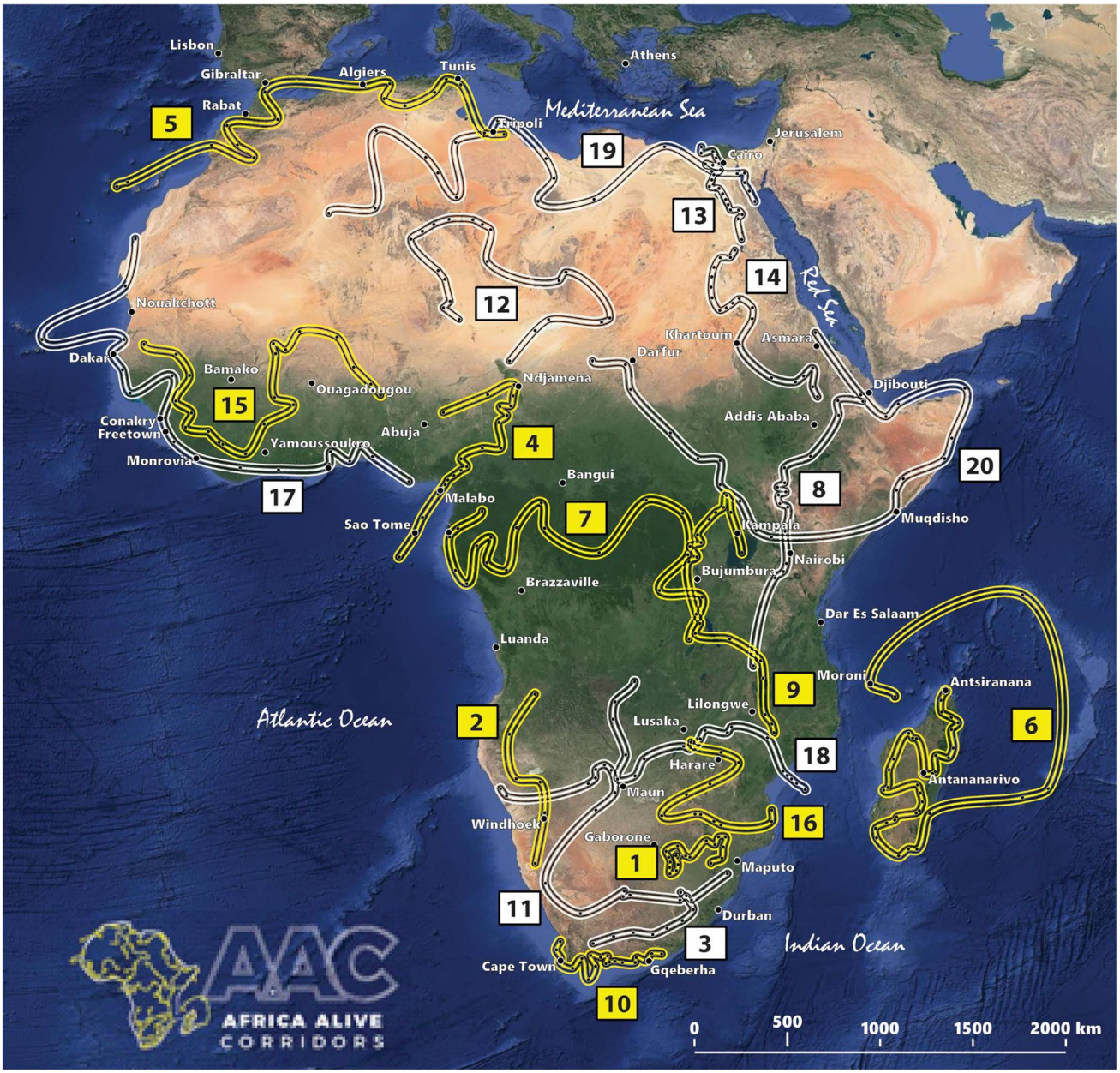

Fig. 1 AAC map towards a life history of the African continent. The twenty corridors are the ideal playgrounds for transdisciplinary research, facilitating Earth Stewardship Science. Highlighted in yellow are the ten corridors investigated in this study

of Africa and related changes in life and regional climate during formation of the Atlantic and Indian Oceans. The first booklet and publication to emerge from this work was "Towards Gondwana Alive – Promoting Biodiversity and Stemming the Sixth Extinction". This work highlights a new, more holistic approach to understanding the supercontinent by merging biology and human culture with geology (Anderson 1999; de Wit and Anderson 2003). Placed at the center of human (*Homo sapiens*) evolution, Africa became the prime target of AAC research and a new map of the continent was then created (Anderson et al. 2008; Anderson and de Wit 2008). Here, the autobiography of Africa is told along twenty corridors, each with twenty heritage nodes, crisscrossing all of its 55 countries. The idea is to encourage more people to become custodians of over 4 billion years of unmatched and irreplaceable African heritage in order to—as the Rock song puts it—"create a new tomorrow".

The Prototype The first corridor prototype to be established was AAC No. 4 – African Pole of Rotation (Toteu et al. 2010). It explores African heritage along the Cameroon Line that crosses northeast Nigeria, Cameroon, Equatorial Guinea, and the São Tomé and Príncipe islands; and how its unique natural environments have enabled a great diversity in social-cultural organization, including language, architecture, music, and art (Fig. 2). As with each other corridor, the ongoing research tells a unique chapter of the African story. Below, we re-visit some of the opportunities and challenges associated with this and other selected corridors.

Colossus Amongst the Continents

AAC No. 1 – Cradle-to-Cradle South Africa is undoubtedly a geological hotspot (Anderson et al. 2008). The Cradle-to-Cradle Corridor runs from the Makonjwa Mountains through the Vredefort Dome and Tswaing Crater to the city of Pretoria, also known as Tshwane (Fig. 3). The cradle of life is symbolically represented by the earliest known fossil bacteria preserved in pillow lavas of the Barberton Greenstone Belt (Furnes et al. 2004; Grosch et al. 2009; de Wit et al. 2018). Some of the world's oldest rocks are preserved in this area, including komatiitic basalt, banded chert, conglomerate, ripple-marked sandstone, and iron-banded formation. Despite being one of the best-studied legs of the corridor, geology continues to question if plate tectonic processes operated on Earth during the Archean period (4.0–2.5 Ga).

Near Potchefstroom, the UNESCO site of Vredefort Dome is the world's oldest impact structure, dated at ca. 2.0 Ga (Jahn and Riller 2009). With a diameter of ~ 250 km, it corresponds to an asteroid of about 15 km in diameter. It is hard to imagine the effects that this gigantic asteroid impact had on both life and surface of the Earth. For comparison, on 15 February 2013, the explosion of an asteroid only 20 m in diameter and about 30 km above the ground at Chelyabinsk, Russia, equated to ~ 500 kilotons of TNT, i.e. more than 20 times the energy of the 1945 Hiroshima atomic bomb (Popova et al. 2013). Earth impacts with an explosion of such magnitude are predicted to occur once a century. Therefore, telescopes are being used routinely to locate near-Earth objects and model their trajectories to identify potential hazards (https://www.jpl.nasa.gov/asteroid-watch).

The Cradle of Humankind is located 65 km southwest of Tswaing Crater (Fig. 3), the youngest Earth impact along the corridor, dated at ca. 220 ka (Kristen et al. 2007). On the other hand, hominid fossil remains are found in dolomitic caves dated between 3.2 and 1.3 Ma (https://www.maropeng.co.za). These include *Australopithecus africanus*, the Taung Child, Mrs Ples and Little Foot, as well as the skeleton of *Homo naledi* dated at ca. 300–200 ka (Robbins et al. 2021). The geochronology thus indicates that early humans must have witnessed the fireball at Tswaing Crater. More recently, Middle Stone Age sites in South Africa are primarily located along the southern coastal region (Wadley

Fig. 2 Promoting African heritage through art. Contemporary materiality in the form of clay sculptures around the Home of the Nok in northeast Nigeria celebrates one of the first West African cultures. It explores the potential for indigenous models of memorials

Fig. 3 AAC No. 1 – Cradle-to-Cradle, celebrating life on Earth since 3.5 Ga. This corridor connects the Barberton Greenstone Belt with archaeological sites of the Cradle of Humankind, where excellent hominid fossils are preserved. It also features some of the best-studied asteroid impacts on Earth: the Vredefort Dome (2.0 Ga) and Tswaing Crater (220 ka)

2015), suggesting a vital population migration following this Earth impact. The trend of migration has broadly reversed direction since the Witwatersrand gold rush in the 1880s, leading to the establishment of the city Johannesburg, also known as Jozi, which is the 8th largest African city, with > 5 million people (https://www.statssa.gov.za). This settlement is associated with increasing geo-health and social mining challenges (Fig. 4).

AAC No. 7 – Lungs of Africa With a nearly circular area of 3.7 million km^2, the Congo Basin is the second largest drainage basin in the world after the Amazon, and is sometimes called "the lungs of Africa". Continuously fed by rainy seasons

Fig. 4 "Paradox of Plenty", human relationships with minerals and the Marikana mine massacre, August 2012, South Africa. The three artworks use paint recipes that incorporate platinum smelter fines and other material from the mines; they form part of the Geo-Barcodes series from Mines: Complicit Geographies (see also: https://artafricamagazine.org/complicit-geographies-jeannette-unite-minerals)

north and south of the equator, its main rivers: the Congo, Kasaï, Oubangui, and Likouala-Sangha, are some of the most potent contributors to the global Ocean and climate (Linol et al. 2019). Much of the basin's surface lies between 300 and 400 m above present-day sea level, and it is covered by tropical rainforests and swamps that host one of Africa's most critical mammalian hotspots, including the chimpanzees and gorillas with whom modern humans share their evolutionary history (Fig. 5).

The earliest divergences among living primates are estimated to have occurred around 80–70 Ma, based on molecular phylogenetic reconstructions (Herrera and Dávalos 2016; Pozzi and Penna 2022), and all the early divergences of lorisoids occurred in the western part of the Congo Basin, which thus appears to have been at the heart of early primate evolution (Masters et al. 2017). Around 8–7 Ma, one lineage led to gorillas (*Gorilla* spp.) and the other eventually led to the emergence of *Homo sapiens*. It is hence possible that the split between *Homo* and *Pan* (chimpanzee) species occurred along this corridor.

Stone tools of the Lupemban industry attest to the presence of hunter-gatherers specialized in forest activities from at least the Middle Stone Age (Taylor 2021). Today, the Central African Foragers, variously known as 'Pygmies' or 'autochthon', represent the largest and most active group: their lineages being traced back to 130 ka, they are also the most distant ancestors in the human family tree (Patin and Quintana-Murci 2018). They have invented hundreds of names for forest animals and plants, and the rainforest is at the center of their spiritual and intellectual life. There is much to learn from their indigenous knowledge to improve geo-health. For instance, bushmeat is an essential source of food along the corridor, but in recent years, bushmeat-related activities have been associated with deadly diseases like the Ebola virus (Peros et al. 2021).

The Congo Basin is a mineral giant with large reserves of gold, copper-cobalt, diamond, uranium, tin-coltan, and oil and gas (de Wit et al. 2015). It represents a significant challenge for mining linked to the 4th industrial revolution, a technological transformation consuming abundant rare earth metals used in electronics. However, most central African countries have some of the lowest gross domestic product indicators in the world, and with limited access to electricity, many rely on wood fuel. A much greater and sustainable energy supply could come from the Inga Dams along the Lower Congo as these dams have the potential to supply half of the total electricity needed across the continent (Gnassou 2019).

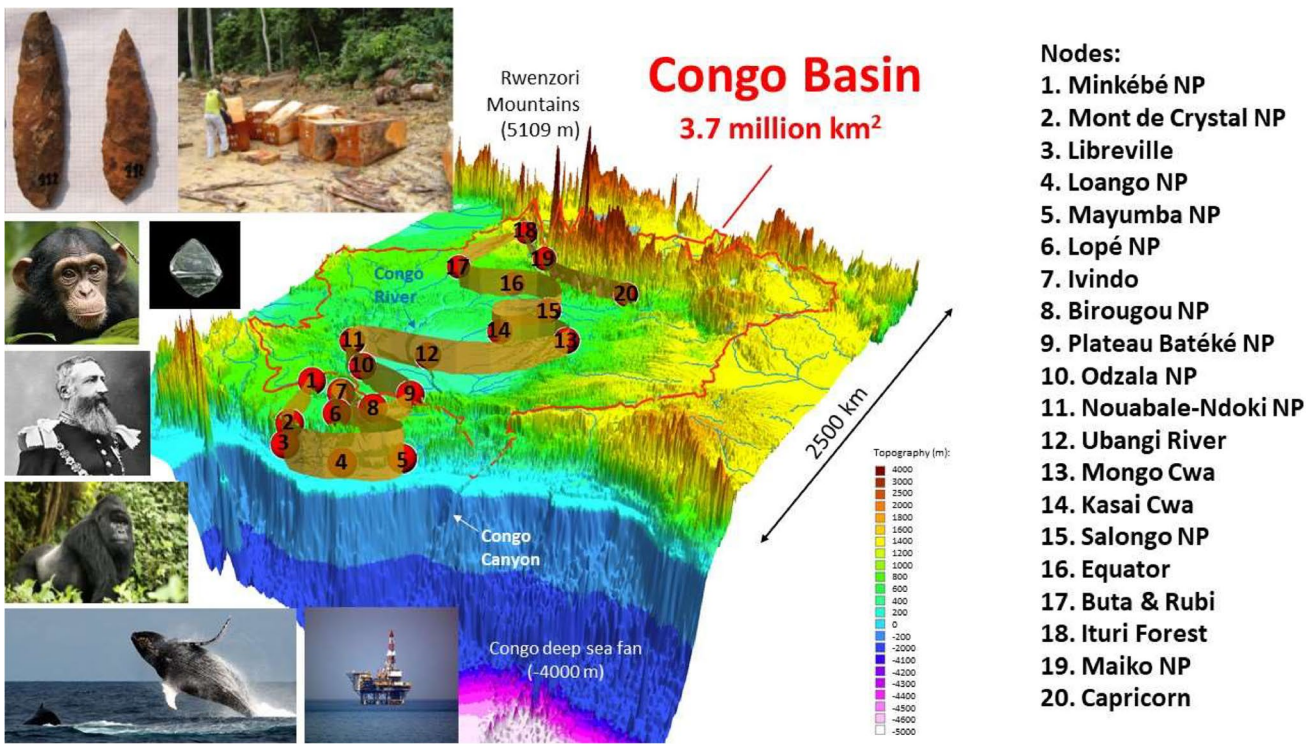

Fig. 5 AAC No. 7 – Congo Basin, or Lungs of Africa, womb of hominids. This corridor straddles the equator from the Atlantic coast, through numerous national parks (NP) of the rainforest, to the foothills of the Ruwenzori, Virunga, and Mitumba Mountains. The region's mineral and hydropower potential is colossal, yet many countries are among the poorest in the world, typifying the resource curse in central Africa

From Deep Time to the Anthropocene

AAC No. 2 – Snowball Earth Seawater absorbs most of its solar energy, but sea ice reflects it. If cooling causes polar ice caps to grow, additional cooling occurs because solar absorption is reduced. If sea ice was to grow until it half-covered the Ocean, its growth would become self-sustaining and unstoppable, covering the entire Ocean in less than 400 years (Donnadieu et al. 2003; Voigt and Abbot 2012). Surface temperature at the equator would fall to -30 °C, causing sea ice to reach a 1 km thickness, bringing total darkness to the liquid Ocean below. Water vapor sublimated from the sea-ice surface would collect as snow on the continents, causing glaciers and ice sheets to thicken and flow, leaving diagnostic ridges of boulder-clay at their margins (Pierrehumbert et al. 2011).

As a global phenomenon, glacial deposits of Snowball Earth are found everywhere where surficial deposits of appropriate age are preserved (Hoffman et al. 2021). Nowhere are they so informatively exposed as on the ancient continental margins of northern and southern Namibia, which, for 60–72 million years, faced each other across a frozen sea (Fig. 6). The oceans were not frozen forever. Plate tectonics continued, and CO_2 emitted by volcanoes accumulated in an atmosphere without rain to remove it. After millions of years, the resulting greenhouse effect and solar absorption by dust-laden and melting ice triggered global meltdown on a millennial timescale.

When the first of two tandem pan-glacial episodes occurred in late Precambrian times, more lineages of microbial life had evolved than now exist. Those that survived had previously colonized diverse supra-glacial and peri-glacial habitats in polar regions and mountain tops, just as they do today (Vincent et al. 2000; Vincent and Laybourn-Parry 2008). When ice margins moved to the equator, those lineages moved there as well, their habitat areas were enlarged, and the cruelty of winter reduced. When the meltdown finally came, some retreated with the ice margins, while others exploited the vacant sunlit oceans. Molecular genetics of living organisms appear consistent with polar-alpine ancestry (Stoeck et al. 2007; Becker 2013; Zhang et al. 2021). All living things descended from the survivors of Snowball Earth.

AAC No. 10 – Homo Sapiens Imagine the life of an early modern human (*H. sapiens sapiens*) on the Southern Cape coast of Africa, who happens to be pregnant and harvests seafood at low tide. She has access to limpets and mussels, and her unborn baby is nourished uniquely: the long-chain fats containing DHA (Docosahexaenoic acid) are available to enhance the baby's brain and vision. Access to seafood in the diet of unborn children and young infants has helped human species take a significant step forward in cognitive development (Parkington 2010). In addition, the *Fynbos* floral kingdom, endemic to the Cape, includes many nourishing and medicinal plant species that have provided a unique resource for food since these early times.

The coast became a secure point of reference for subsistence of the indigenous communities, thanks to the ingenious design of fish traps: the most ancient infrastructures, built with stones, in the intertidal area to trap fish and other marine species in a sustainable fashion (Fig. 7). The development of these hand-made infrastructures, older than 2–3 ka, represented a tremendous forward leap because sourcing food became more systematic and regular harvests could be produced (Minguzzi 2021; Pattrick et al. 2022). Beginning with the arrival of the settler colonialists and continuing during the apartheid regime, the First Indigenous Peoples of South Africa have experienced an escalation of inequality and oppression, leading to a radical interruption of their intimate ties with the Ocean. The fish traps that still exist today represent an inestimable value link to the message of a regenerative approach to coastal management. They constitute a vital resource for marine life of all forms. They are essential features of the cultural heritage based on environmental sustainability and thus should be used as a template to shift the modern development and management paradigm along the corridor.

Food systems have developed in complexity, initially allowing permanent settlements. First, villages, then towns and cities evolved. Urbanization allowed the specialization of human skills, and as humanity's capacity to produce food surpluses progressed, other human activities became possible. Initially, settled agriculture made a significant contribution to civilizations. However, over the past century, their sustainability has become questionable as biodiversity is impacted by monocropping and the use of synthetic fertilizers that pollute soil and rivers (Auerbach 2020). The alternatives offered by agro-ecology have considerable potential (Fig. 8). Recent research along the corridor has shown that the application of organic compost and crop rotations significantly improve soil fertility and crop quality, as well as reduce the overall farming cost (Mashele and Auerbach 2016).

In Africa, 8,792 designated protected areas represent > 4 million km^2 of land, equivalent to 14.33% of the continent, and 2.5 million km^2 of Ocean, equivalent to 16.67% of its marine and coastal areas (https://www.protectedplanet.net/en). These places are recognized as tools for conserving plants and animals, but the number of endangered species is continuously rising. Why? Landscapes and seascapes are typically heterogeneous regarding habitat quality, hosting different species with individuals of varying fitness. When specific habitats are unavailable, species move to a less optimal habitat, adapt,

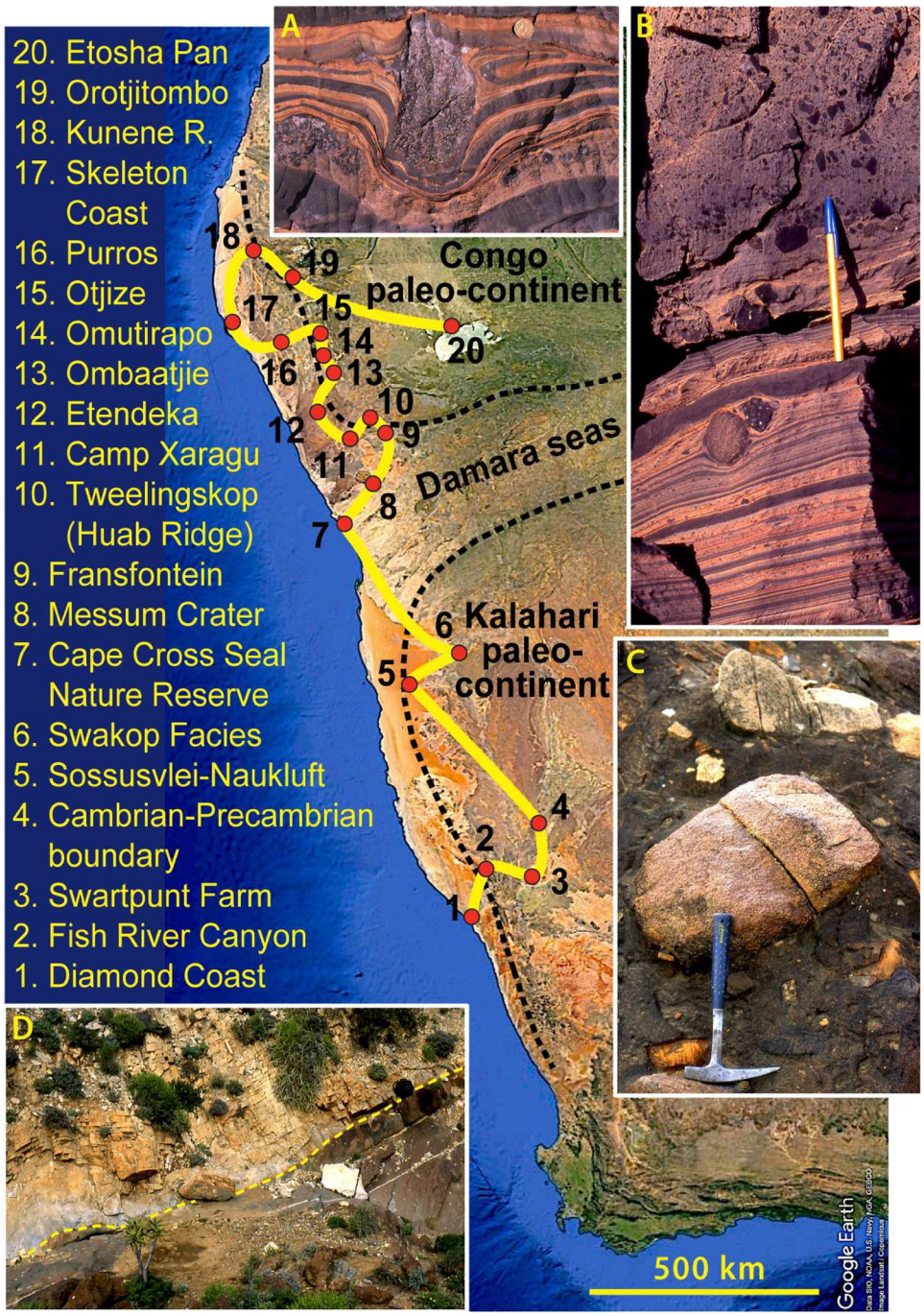

Fig. 6 AAC No. 2 – Snowball Earth, and the ancestry of primary producers. This corridor extends from southwest Angola through Namibia to northwest South Africa to include Cryogenian rock sequences of both, the Sturtian (717 – 661 Ma), and the Marinoan (646 – 635 Ma) glaciations. Flanking the Congo Craton, (**A**) ice-rafted dropstone, and (**B**) a marine ice advance sequence of the Ghaub Formation are preserved within the Otavi Belt. North of the Kalahari Craton, carbonate-dominated shelf-slope successions include (**C**) polymictic Sturtian tillite (the Numees Formation), and (**D**) cap dolomite (upper left) above the Marinoan Namaskluft tillite (lower right), Namaskluft, Namibia

and eventually become refugee species. They are characterized by an ecologically and evolutionary poor fit to their habitat, and the density of the individual rapidly decreases (Kerley et al. 2020). In AAC No. 10 – Homo Sapiens, the Cape Mountain Zebra and Knysna Elephant are mostly restricted to habitats with a low diet quality (Fig. 9). Historically, they occupied a much wider region of South Africa, including savannas, grasslands, and subtropical thickets (Lea et al. 2016; Moolman et al. 2019). This anomaly has resulted in refugee populations over the past three hundred years. The global relevance of this pattern lies in the fact that ~ 13% of the 4,785 mammal species have suffered range contractions over the last six thousand years, with an associated decline of their niche dimensions or habitat quality. This leads to an increased extinction risk (Britnell et al. 2023).

Fig. 7 In AAC No. 10 – Homo Sapiens, a sequence of events along the South Coast led to the exploitation of marine resources using fish traps (left), and the restauration of sacred water rituals by KhoiSan peoples (right). This heritage shows the intimate knowledge and harmony of the First Peoples of South Africa with nature, which must be better understood and valorized (see also "The Spirit of Water": https://vimeo.com/534102794)

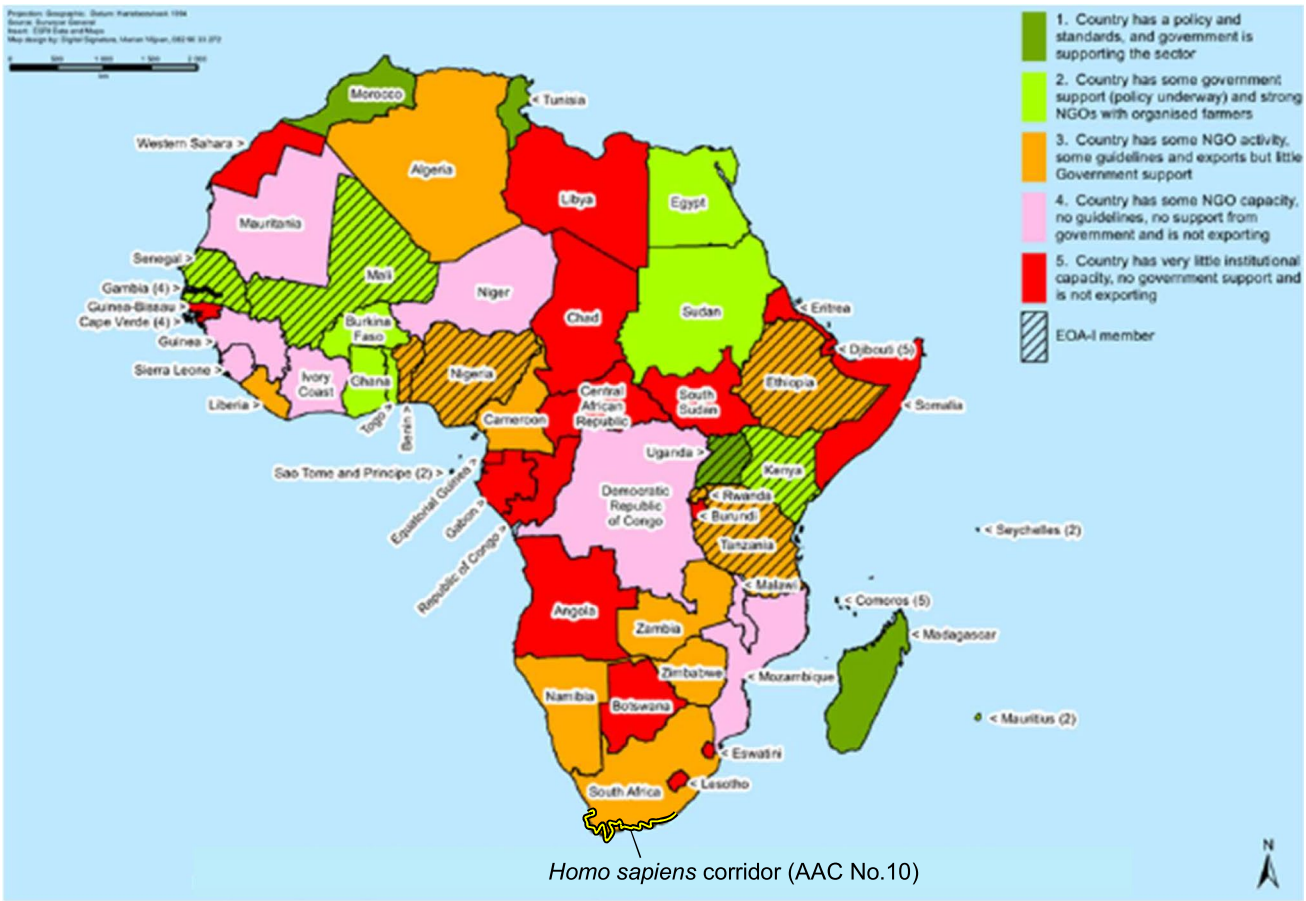

Fig. 8 Ecological agriculture status of the 55 countries of Africa. The continent has limited support for ecological farming and does minimal food exports (Auerbach et al. 2021)

Life on a Moving Plate

AAC No. 6 – Lemur-Chameleon Madagascar is the only place on Earth where lemurs occur, and they are extraordinarily diverse. It is also home to more chameleon species than elsewhere (Raxworthy et al. 2002). How did this happen? Species colonization of Madagascar has a long history of storytelling and hypotheses, including primates rafting and swimming or even flying in thunderstorms (Fig. 10). These explanations remain to be verified using geology and phylogenetic biogeography (Masters et al. 2021). The difficulty is that Madagascar is separated from the east coast of Africa by 415 km at closest points, and oceanic currents in the

Fig. 9 Examples of refugee species in AAC No. 10 (Fig. 8). What are equids doing in grass-poor habitats, and what are savanna elephants doing in forest habitats? The option of reintroducing these species to a different, more optimal habitat needs to be tested

Fig. 10 "The Land Over There" is a stop motion animation that explores how fine art, fiction, and multimodal storytelling can be used to highlight environmental issues. The images show the extraordinary travel of a lemur to Madagascar (https://www.youtube.com/watch?v=xstlWH3-arI&t=307s)

Mozambique Channel do not favour species movements from one landmass to the other. Plate reconstructions show that this situation existed since at least 120 Ma. However, the plants and animals in Madagascar only evolved somewhere between 90 and 30 Ma.

Today, there are five living families of lemurs in Madagascar (Masters et al. 2013); only two families represent their closest living relatives in Africa, the Lorises and Galagos. This suggests that on a much larger area of the African continent, there has been less diversification as compared to that on Madagascar Island. It is also the case for the chameleons, which have an extraordinary diversity on Madagascar, including the smallest and largest chameleons in the world. Other remarkable species do not exist anywhere else, like the tenrecs, giant jumping rats, and fossa carnivores. In addition, a few hundred years ago, there would have been elephant birds, giant lemurs, and dwarf hippopotamuses as indicated by the fossil record (Fig. 11).

Research findings from the seafloor of the Indian Ocean have provided evidence of three short-lived land bridges between Africa and Madagascar, at 66–60 Ma, 36–30 Ma, and 12–5 Ma, which strongly support a geo-dispersal model for the colonization of Madagascar (Aslanian et al. 2023). This makes the Lemur-Chameleon Corridor an ideal location to understand how biodiversity is generated. The fauna is associated with a unique endemic flora of predominantly African affinities, such as the southern xerophytic thicket. Plants, like mistletoes, were possibly brought by frugivorous birds that dispersed their seeds on the island, but today Madagascan mistletoes are mainly dispersed by mouse lemurs (Génin et al. 2022). This further suggests that geographic dispersal involves entire co-evolved systems. Similarly, the

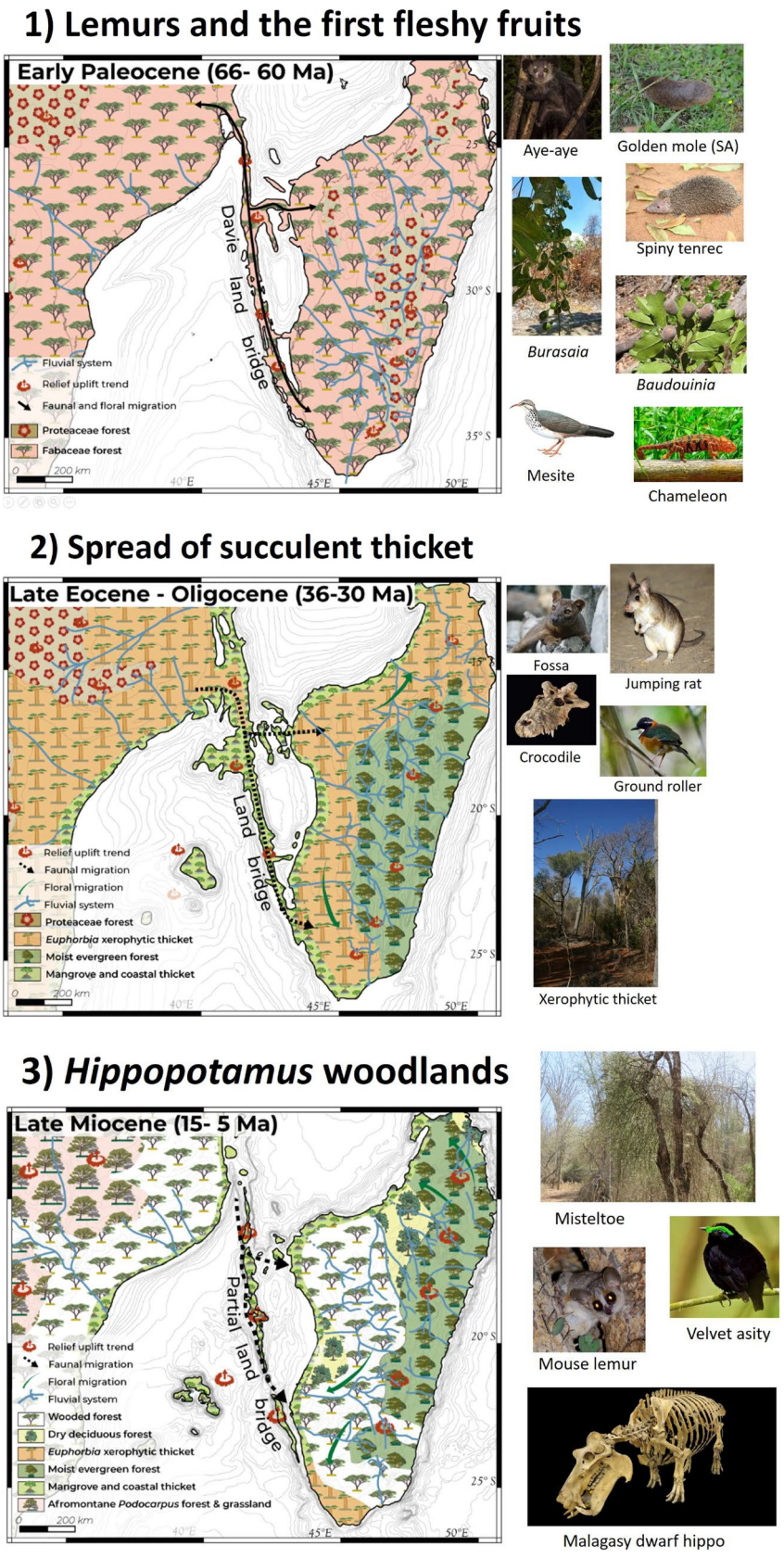

Fig. 11 Madagascar was colonized often during: 1) Early Paleocene, 2) Late Eocene–Oligocene, and 3) Late Miocene. The geodynamic history has resulted in a vibrant and unique biodiversity along AAC No. 6 – Lemur-Chameleon (Fig. 1)

First Peoples of Madagascar co-adapted with their habitat; they brought rice cultivation and the Malagasy language from Indonesia with some Swahilis words from East Africa.

AAC No. 4 – African Pole of Rotation The Cameroon Line is a large-scale volcanic structure that extends from the islands of São Tomé and Príncipe, through Cameroon to northeastern Nigeria (Adams 2022). This more than 1,600 km long chain of massifs and active volcanoes has influenced many aspects of the surrounding life and the 11 million people in its vicinity (Toteu et al. 2010). This is particularly evident in the archeological record of Nok sculptures dating back to the Iron Age, between 1500 BC and 500 AD (Breunig and Rupp 2016). These sculptures are primarily figurines, often with triangular heads and elaborated hairstyles, found near the Jos Plateau. Although these artefacts' social role remains unknown, their proximity to burial sites suggests a usage in funeral rituals. Thus, the Nok heritage presents a unique opportunity to explore indigenous memorials based on West African knowledge (Fig. 2). In this context, art is educational and encourages people to better understand ancient civilizations.

The social and cultural organization along AAC No. 4 – African Pole of Rotation reflects the diversity of ethnic groups. The dynamics of their settlement had various causes, including European-driven slave trade in São Tomé and Príncipe islands, conquests by different ethnic groups from the Adamawa Plateau, Arab slave raids from the North, and Fulani Djihad pushing many inhabitants to seek refuge in the Galim-Atlantika-Mandara Mountains. Fertile soils also contribute to higher population densities, especially along the southern slopes of volcanic mountains (Fig. 12). Over centuries, this settlement history has given rise to firmly hierarchically structured civilizations, characterized by Kings and Fons in the South, and Sultans and Lamibe in the North (Fig. 13). The settlement dynamics have not only contributed to language diversity but have also shaped various social-economic, cultural, and spiritual habits of the people. For example, the modern distribution of religious beliefs reflects the level of impact of Islam and Christianism on traditional forms of worship. Additionally, the corridor faces modern challenges related to political instability and maritime insecurity. The violence goes across borders, extending across the Central African Republic, Democratic

Fig. 12 Architecture along AAC No. 4 (African Pole of Rotation) depends on the type of ecosystems in which people live: **A** wooden (carabot) houses in the mangrove region (AdobeStock 227216646); **B** raffia bamboo house in Bandjoun palace, West Cameroon (credit: S. Capochich); **C** Bafut Palace, Northwest Cameroon (credit: Mylene and Christian); **D** organization of the compound of a traditional dignitary in Bamougoun, West Cameron (credit: S.F. Toteu); **E** Mousgoum dome-shaped house, northern Cameroon (credit: F. Essomba); **F** mud and stone houses in Mokolo Montains, northern Cameroon (credit: S.F. Toteu)

Fig. 13 From rich volcanic soils to colorful festivals, the communities of Cameroon highlands celebrate the unifying gift of nature, a tradition that goes back more than six hundred years ago. Left) Kounagang Festival occurs every 50 years: a parade of secret societies, Bamougoum, West Cameroon (credit: P. Tchoubé Sadeu). Right) Nekang Festival happens every three years: crowdy event, youth parade after initiation, and parade of the King (credit: P. Tchoubé Sadeu)

Republic of Congo (DRC), Benin, Togo, Ghana, and Côte d'Ivoire. These maybe exacerbated by ethnic tensions, weak governance, and historical conflicts.

AAC No. 5 – Colliding Continents In Maghreb mythology, the trembling of the Earth's surface is explained by the concept of the planet rebounding between the horns of a titan bull (Fig. 14). Further mythologization comes from the accounts of early geographers Ibn Battutah and Ibn Khaldoun, who described the occurrence of earthquakes and tsunamis in North Africa during the 14th Century (Meghraoui et al. 2021). Since then, the theory of plate tectonics has provided a better understanding that these localized land movements result from uplift of the Atlas Mountains due to the Alpine orogeny since about 40 Ma (Meghraoui and Pondrelli 2012).

A substantial number (> 120) of earthquakes have been recorded in AAC No. 5 – Colliding Continents (https://www.ngdc.noaa.gov/hazard/earthqk.shtml). The majority occurs near major cities, particularly near Alger, where a large portion of the population resides (Fig. 14). On average, about 30 earthquakes are detected yearly, some resulting in major disasters, as summarized below.

- The 1980 El Asnam earthquake, magnitude of 7.1, led to 5,000 causalities and some $2 billion in losses. This event created about 40 km of surface rupture and a more than 4 m vertical slip.
- The 1992 Cairo, or Dahshur earthquake, measuring 5.8 in magnitude, resulted in 560 fatalities and losses amounting to some $3–4 billion, including damage to historic monuments. This event originated from an East–West orientated normal fault.
- The 1994 and 2004 Al Hoceima earthquakes in Morocco, with a magnitude of 5.9 and 6.4 respectively, collectively caused 628 victims and $80–400 million in losses; neither of these two events produced surface ruptures (Akoglu et al. 2006).
- The 2003 Zemmouri earthquake, with a magnitude of 6.8, caused 2,278 causalities and some $5 billion in losses. This earthquake generated a tsunami, exacerbating coastal damages (Beldjoudi and Delouis 2022).
- The 2023 Al Haouz earthquake, with a 6.8 magnitude and 4.9 magnitude aftershock, resulted in more than 2,900 fatalities. Damage is estimated to be about $10 billion (https://earthobservatory.nasa.gov/images/151847/

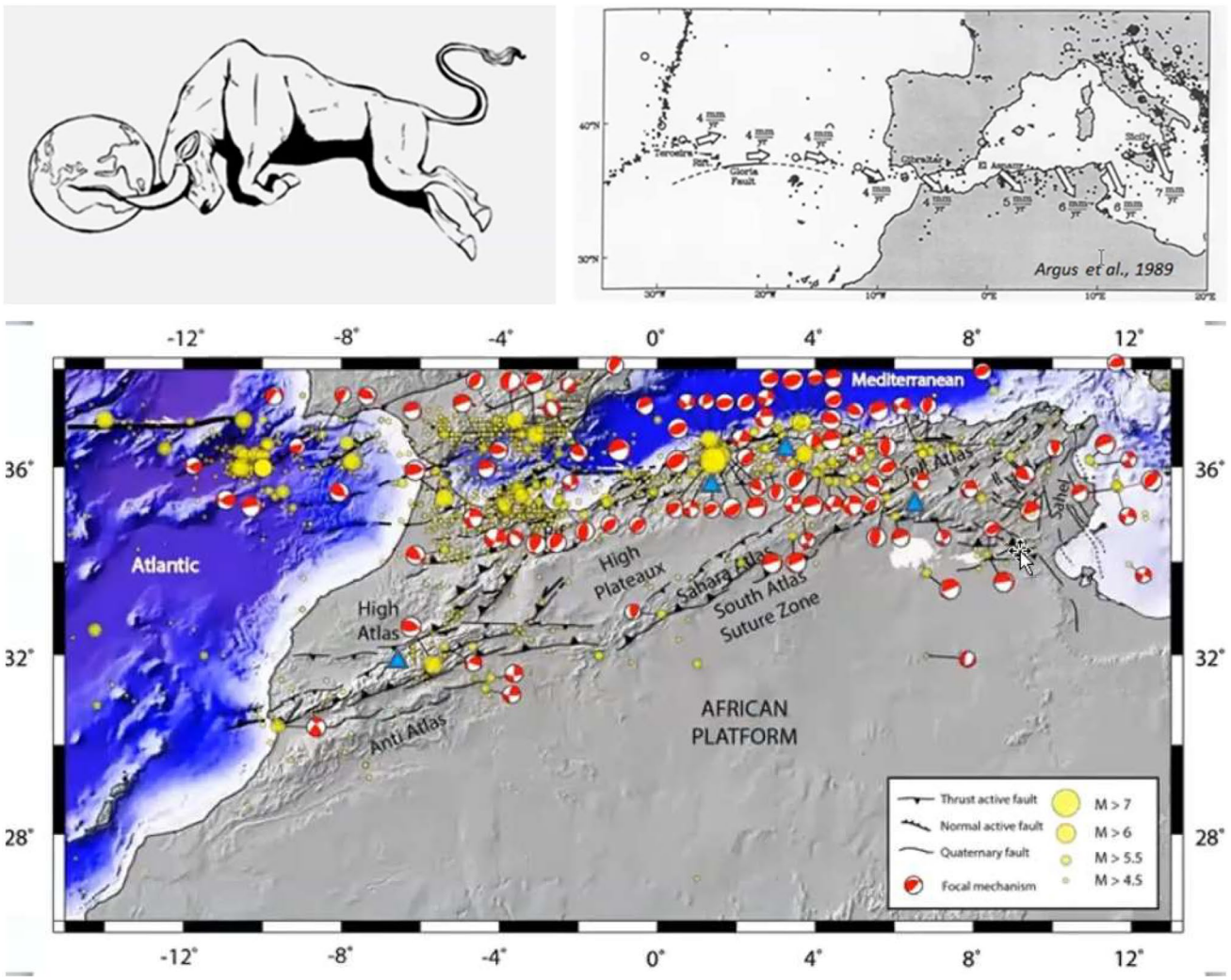

Fig. 14 From myth to reality, earthquake damage is a significant aspect of the oblique active deformation in North Africa. Left) The bull holding the globe expresses the earthquake when jumping from one horn to the other. Right) GPS measurements reveal an anti-clockwise rotation of the African plate with respect to Eurasia, with a convergence rate of 4–5 mm/yr. Bottom) Earthquakes in the Maghreb region are largely reported as early as during the Numidian and Roma times, and they illustrate the seismotectonic characteristics of North Africa (Meghraoui et al. 2016). Blue triangles are the highest topographic peaks that range from 1985 to 4167 m

devastation-in-morocco; https://reliefweb.int/disaster/eq-2023-000166-mar).

The magnitude of earthquakes and their proximity to urbanized areas are the most critical parameters that control the extent of impact, as most damage results from building collapse. Consequently, probabilistic maps and seismic hazard assessment models are developed (Guettiche et al. 2017; Mourabit et al. 2014). These require the calculation of slip velocities and return time for moderate to strong earthquakes, which implies a better understanding of crustal deformation and seismic cycles. The method is based on detailed mapping of fractures, encompassing their geometry, styles and prevailing stress conditions, and computing location solutions for the recorded earthquakes (Meghraoui et al. 2016; Moudnib et al. 2023). These datasets are also valuable for geo-resources exploration (Linol and Dhansay 2023).

AAC No. 9 – Western Rift Valley The Africa plate is breaking into two across fracture systems of the East African Rift that extends from the Afar Triangle through eastern DRC to Malawi, over more than 3,000 km (Michon et al. 2022). This system has developed a long interconnected series of lakes, including Mwitanzige (Lake Albert), Rwitanzigye (Lake Edward), Tanganyika, and Nyasa (Lake Malawi), which host an extraordinary biodiversity, primarily known for its cichlid fishes (Salzburger 2018). The region is also

the most populated of the continent, with more than 700 million people currently (Linard et al. 2012). With projections indicating a population surge to 1.4 billion by 2050 and urban areas are expected to expand dramatically, sustainable planning is urgently needed (Assede et al. 2023).

Using land-cover change models based on satellite imagery spanning the past 20 years, expansion and contraction rates are computed for distinct land types, including: urban areas, croplands, forests, wetlands, and grasslands. The time-series data extracted from the maps are then used to train Markov chain models, which in turn serve as the basis for predictive analyses (Miller 2022). Across the different lake basins of the Western Rift Valley Corridor (Fig. 15), the main drivers of land-cover change identified by these probabilistic models are the proximity to human activity and infrastructure, croplands, and the existing tree cover. In 2018, cropland and tree cover extended across 48% and 33% of the river basins, respectively. By 2060, these values are predicted to decrease by 10%, and urban areas will increase by more than 130%. This urbanization is also predicted to be most intense along the lake shorelines: in Goma, Gisenyi, and Cyangugu around Lake Kivu; in Bujumbura and Kigoma near Lake Tanganyika; and Kyela, Kaporo, and Karonganear near Lake Malawi. Rapid deforestation due to agriculture is evident in these areas and extends throughout the Nyungwe and Kahuzi national parks and the Mitumba, Poroto, and Kipengere Mountains. That said, substantial afforestation is modelled near the Katavi Plains. These results provide a basis for regional development and emphasize the importance of new GIS mapping by young researchers and students along the corridor. It also opens opportunities for local entrepreneurship such as in eco-tourism, which plays a role in conservation and heritage curation (Van Heerden 2020).

Culture and Resource Stewardship

AAC No. 15 – Songhay's Timbuktu Gold came to symbolize youth, power, wealth and, above all, eternity. Early European geographers began writing in the 9th Century about West African kingdoms below the Sahara Desert when they heard of massive quantities of gold to be found along this corridor (Conrad 2010). During pre-colonial times, the Ghana Empire first dominated trade routes and exchanges to the Middle East and across the Mediterranean Sea. Founded in the 13th Century, the Mali Empire after that expanded to encompass the entire western region, Senegambia, and most of the Niger River. Its most renowned King, Mansa Musa, or "King of the King", is well known for his pilgrimage to Mecca in 1325 and his library in Timbuktu, which became the world's first university of transdisciplinary sciences (Fig. 16).

The Songhay Empire followed the Ghana and Mali empires until the Moroccan invasion in 1951. These three successive major kingdoms laid the foundations for Walata, Djenne, and Timbuktu to become the cultural and commercial centres of Western Sudan, eclipsing those of North Africa and producing Arabic-language black literature in the 15th and 16th centuries (Fauvelle-Aymar 2018). Diplomatic relations were established; ambassadors were exchanged between Mali and Morocco, and Malinke students were sent to study in Morocco. Education became a central part of the interface between conquests and people. The interactions and exchanges, in turn, consolidated commodity trading through a network of brokers (Fig. 17).

While Islam was the foundation of much of the history along the corridor, the narrative would only be complete with the Dogon culture. The Dogons of Mali had a deep knowledge of celestial navigation that contributed to the tribe's survival; life and death are integral to this. They plotted the orbits of various universes and star systems in the 13th Century, corroborated by scientific observations only between 1860 and 1970 (Rogers 2007). It is also now known that the trans-Saharan region is underlain by Precambrian basement rocks of the West African and East Sahara Shields and their associated sedimentary basins. These form the foundations of significant geo-resources along the Songhay's Timbuktu Corridor, and along its northeastern contiguous corridor AAC No. 19, where the largest oil reserves of Africa are to be found. Trade in all sorts of commodities flourished in the Mali Empire, mainly between the South and the North, and through to the trans-Saharan routes, covering the present-day countries of Senegal, Nigeria, Mali, Ghana, Benin, Togo, Burkina Faso, Côte d'Ivoire, Liberia, Sierra Leone, Guinea, Guinea Bissau, and Gambia.

AAC No. 16 – Mapungubwe-Great Zimbabwe Mapungubwe and Great Zimbabwe are remnants of large kingdoms that flourished between 900 and 1700 AD across northern South Africa, Zambia, Zimbabwe, and Mozambique. These sites hold immense cultural significance (Huffman 2009; Kumbani 2020), not only for their historical importance but also for their strong connection to indigenous peoples like the Venda and Shona. Numerous national parks and large protected areas also occur along the corridor (e.g. Mana Pools, Nyanga, Mapungubwe, Limpopo, Kruger, Bazaruto).

The rise and fall of southern Africa's greatest empire was fuelled by geological formations of the Zimbabwe Craton and Limpopo Belt, which comprise rich mineral resources, including copper, gold, and tin. These civilizations were also constructed around the availability of rainfall for

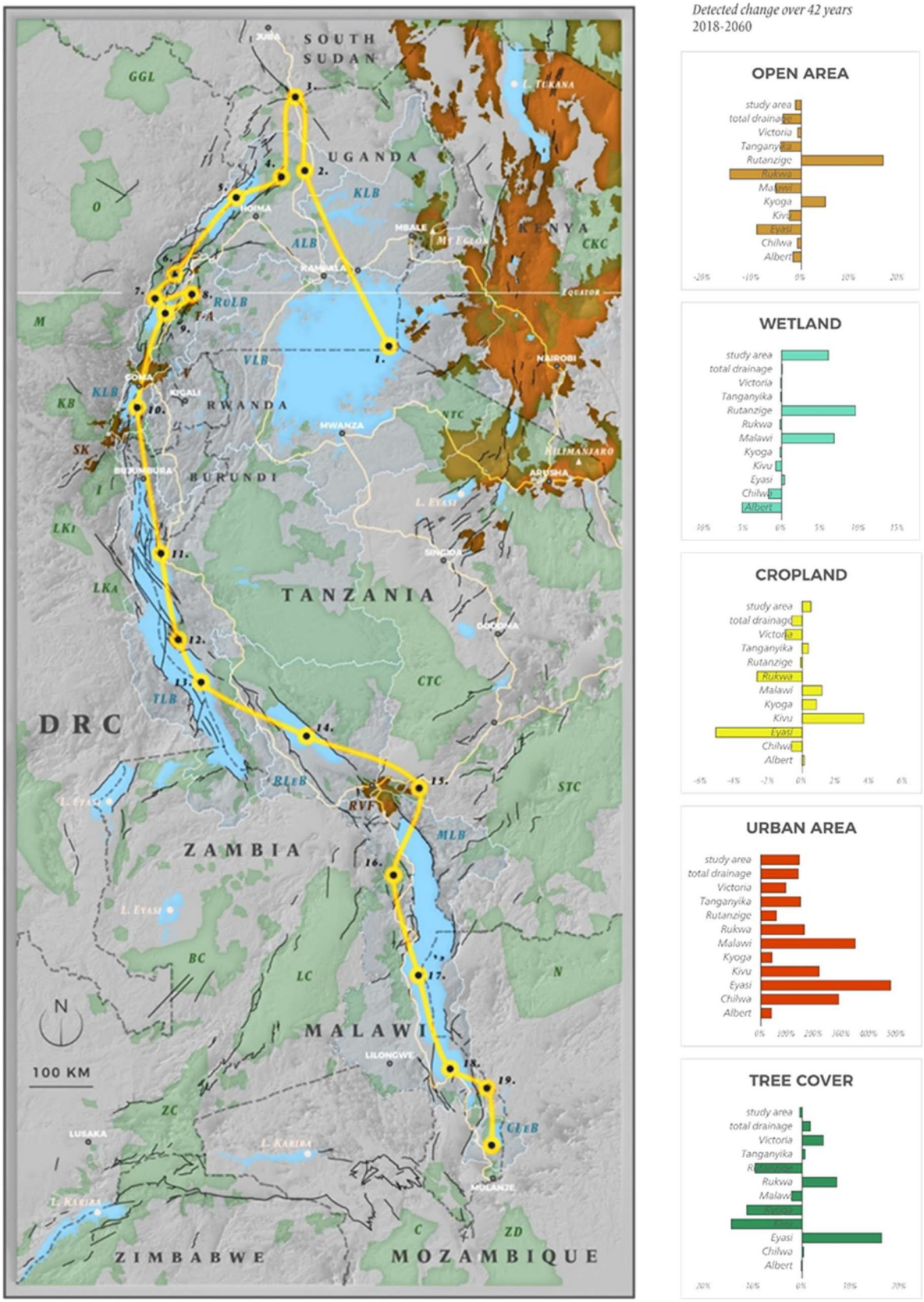

Fig. 15 AAC No. 9 – Western Rift Valley, an extreme fish diversity in the great lakes of East Africa (see Miller et al. 2024 for details). Projections of 200 to 500% increase in urban areas and croplands by 2060 significantly augment the risks of water pollution and biodiversity loss

Fig. 16 AAC No. 15 – Songhay's Timbuktu, key civilizations of the Niger and Senegal rivers. (Left) Great Mosque, Timbuktu, Mali (www.britannica.com); (Right) detail of the 1375 Catalan Atlas, one of the most significant maps in the Western medieval world, depicting Mansa Musa seated on his throne with a golden orb (Photo by Fotosearch/Getty Images)

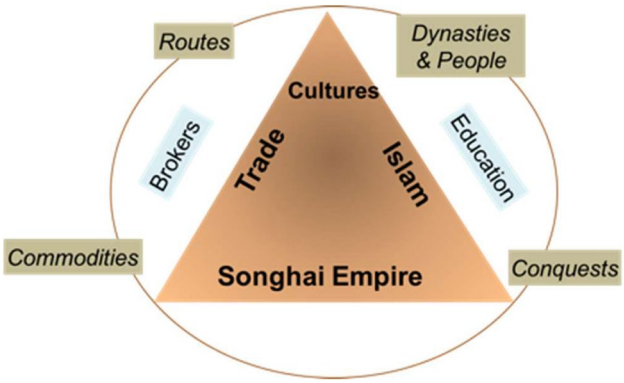

Fig. 17 The Songhai Empire is represented as the nexus between dynastic conquests and trade routes for commodities, which characterize the Songhay's Timbuktu Corridor, with a footprint of cultures dominated by brokers and Islam education

Fig. 18 Playing mbira carries an identity. African music focuses so much on rhythm, combining polyrhythms and cross-rhythms, engaging the audience through call-and-answer, and is characterised by the repetition of basic short melodies and multi-phrases in songs

agriculture, and trade routes to the coast of the Indian Ocean, as well as having deep spiritual significance. The soundscape was one of their essential cultural elements, including the sounds of birds, human activities like herding and grain pounding, and music (https://ich.unesco.org/en/15com). While extensive work has been carried out to understand and preserve the monumentality of these historical sites, the unquantifiable connections between the people and the environment often need to be addressed (Sinamai 2018). A better understanding of ethnic relations can be derived from music and musical instruments, stressing the need to valorise this unique heritage (Berliner 1993; Turino 2010).

The mbira instrument plays an essential role in African music. Many different types exist, each with a unique essential arrangement of keys with differing appearance and tonal quality (Tracey 2015). The keys are randomly but strategically placed, unlike conventional arrangements where notes in a scale are placed next to each other. Their layout aligns with the convenience of playing the music (Fig. 18). The harmonic structure follows the Shona chord cadence, reminding of the melodies that contributed to the Mapungubwe-Great Zimbabwe Empire many centuries ago.

Music provides an ideal platform for understanding cultural heritage. The creative component encompasses subconscious and spiritual aspects that can serve as independent facilities for mapping social relations. The development of instruments, music compositions, and playing patterns reveal their origins and the extent of interactions between cultural groups. These sentiments extend beyond the African continent. For example, the "Blues", a music genre dated to the 1860s, is considered to have originated in the Songhay's Timbuktu Corridor. If this is so, it was likely taken outside Africa during the slave trade. It exemplifies the challenge of defining an additional corridor: AAC No. 21 – 'Out of Africa' that celebrates the African diaspora and dispersion of cultural elements like African music (Fig. 19).

Fig. 19 Out of Africa' map highlighting a million miles of genetic information (DNA) trails in spreading African heritage, including the first emigration of *Homo sapiens* around 70 ka, the discovery of coffee around 800 AD, and the emergence of Jazz & Blues in the late 19th Century. The profound African footprints call for greater communal understanding and appreciation

External influences in the development of music and instruments should be considered. It is also important to recognize the complications associated with creating a balance between preserving and advancing music. This is due to a need for formal means and other limitations related to sharing indigenous knowledge and cultures. For example, specific information is reserved for certain family members, with instruments like the mbira and uhadi traditionally associated with males and females. More work is wanted to develop the links between anthropology and music.

Discussion

Across the world, many are trying to imagine a new beginning in times of change marked by global pandemics and deep-seated political convulsion. Starting with the French Revolution in the 18th Century, a succession of significant historical events has profoundly conditioned the general understanding of how humans should live in community during the modern era. In this, the go-to unit for social order is the nation-state. However, the numerous crises have highlighted the state's limitations under the commanding idea

of sovereignty as suitable vehicles of governance, identity, and shared responsibility. By traversing borders and uniting natural sciences with the humanities and social sciences, the designated corridors help people imagine new ways forward and different possibilities of societal organization. AAC research opens towards alternative ideas of how modern humans should perceive and interact with their environment. Learning across multiple disciplines provides a deeper understanding of exploring this more 'insightful voice' and how to become 'good ancestors' towards global stewardship (Krznaric 2020).

Central to this is water: the lifeblood of Africa, and which must be available, safe, and accessible to all (https://www.unwater.org). The water supply for each person must be sufficient for personal and domestic use, including drinking, sanitation, washing of clothes, food preparation, and hygiene; furthermore, water must be devoid of microorganisms and toxic substances. Achieving these common sustainable goals requires protecting and monitoring water-related environments, which offers a vast opportunity for the growth of citizen science (Dhliwayo 2020). Enhanced collaboration between scientists and local communities facilitates better identifying environmental issues, knowledge gaps, and social barriers. This partnership also enables the implementation of an adapted methodology that empowers various stakeholders, especially the youth (Fig. 20). Over the recent years, the increase in citizen science data reflects the growing enthusiasm and willingness of the public to engage with the environment.

The toolbox available for developing Earth Stewardship Science comprises an array of spatial analysis techniques and GIS. The latter effectively organizes, spatially joins, and analyzes layers of data, enabling the formulation of more holistic solutions. This process also facilitates the quantification of stewardship indicators and enhances data accessibility, thereby increasing interaction between people and their environmental contribution (Turnbull et al. 2020; Pandeya et al. 2021). The outcomes can generate new interactive maps and applications aiding in data collection, learning through online courses, and monitoring stewardship progress or decline over the years. Public feedback presented in summarized formats, like tables and word clouds (Fig. 21), assists in the post-evaluation of the intended engagement with the community.

The proposed alternatives within AAC encourage more participative science to promote sustainability, heritage co-curatorship, and potentially entrepreneurship. Since African youth constitute the most significant proportion of the population, more training interventions are needed, including educational initiatives in schools. Although the familiar chain of STEM subjects – Science, Technology, Engineering and Mathematics – are essential, Earth Stewardship Science suggests that without an appreciation of the Arts, which include the humanities – as in STEAM – there is little understanding of the present and past, let alone the future (de Wit and Booth 2016). Incorporating AAC into the curriculum at the undergraduate level can alert a younger generation to the possibilities it offers.

Fig. 20 Sustainable water management using Citizen Science and youth skills development in AAC No. 10 – Homo Sapiens (see also: https://aeon.org.za/wp-content/uploads/2018/12/AEON-Shale-Gas-Report-2018.pdf). Trainees from a local community near Cradock in South Africa work with geoscientists to collect borehole water data and feed the database Commons using a mobile app called "Xoras"

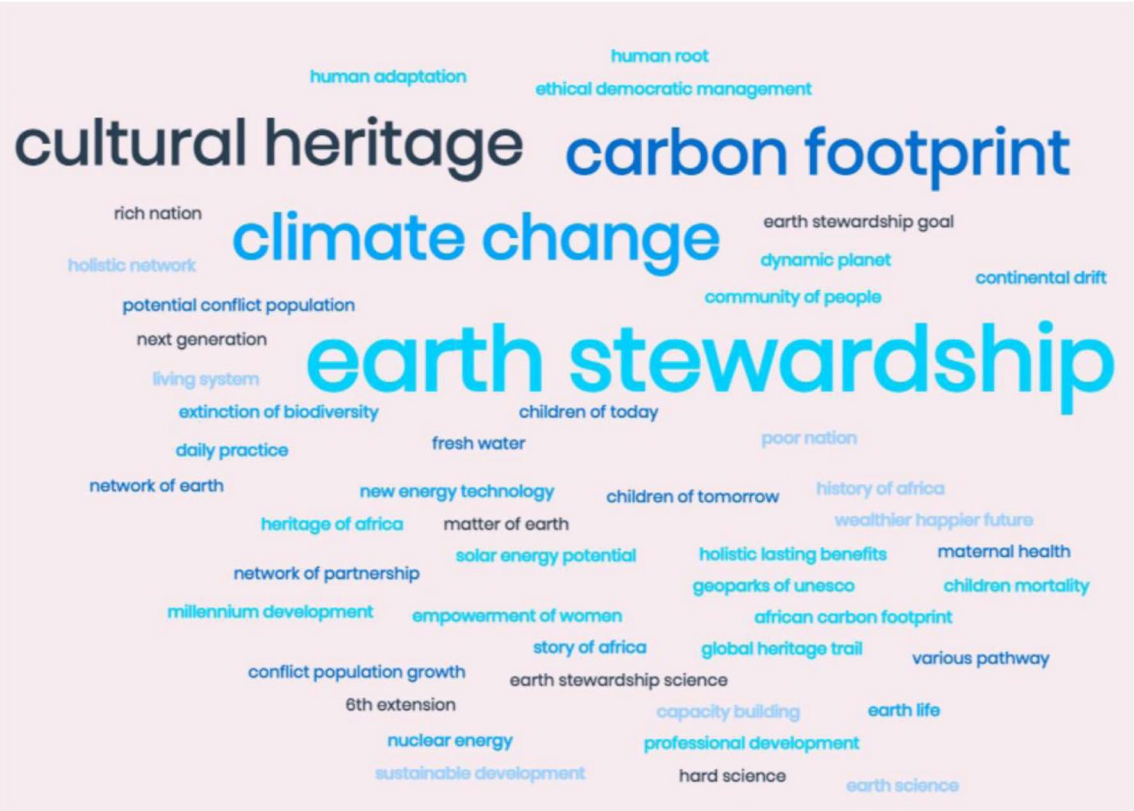

Fig. 21 Word cloud showing the most important concepts from AAC: "forging a new future for the people of Africa by the people of Africa" (Toteu et al. 2010)

Conclusion

As is plain, the AAC program offers numerous opportunities and challenges for conducting transdisciplinary research linked to African footprints, encompassing education, food systems, geo-health, natural hazards and geo-resources management, biodiversity preservation, spatial data analysis, and eco-tourism. The corridors focus on rich cultures and natural heritage from which new research can benefit all. By celebrating African heritage – and contemporary life – along these corridors, conservation is assured for future generations. This study incorporates the essential layers of citizen science and art to stimulate innovative ideas for a collaborative way to develop Earth Stewardship Science. This development becomes increasingly critical in the present context of adapting to global changes. Reaching the agenda for sustainable development goals requires a holistic and collaborative approach using local resources, indigenous knowledge, and international partnerships to solve environmental and social-economic challenges. It is about imagining a different future across all twenty corridors on the continent of Africa.

Acknowledgements This paper results from the AAC workshop, held 17-19th May 2022, which was dedicated to memory of Maarten de Wit. It is AEON contribution No. 208 and Iphakade publication 281, funded through the NRF/DST (Global Change Grand Challenge) and a research grant (129345) to B. Linol. The two reviewers and the editor, Kevin Page, are thanks for their input and comments.

Funding Open access funding provided by Nelson Mandela University.

Data Availability The data that support the maps and findings are available on request from the corresponding author.

Declarations

Conflict of Interest All co-authors approved this publication. The authors declare that they have no conflict of interest.

References

Adams A (2022) Insights into the source of magmatic hot-lines: Forty years of geophysical studies of the Cameroon Volcanic Line. Front Earth Sci 10:838993

Akoglu AM, Cakir Z, Meghraoui M, Belabbes S, El Alami SO, Ergintav S, Akyüz HS (2006) The 1994–2004 Al Hoceima (Morocco) earthquake sequence: Conjugate fault ruptures deduced from InSAR. Earth Planet Sci Lett 252:467–480. https://doi.org/10.1016/j.epsl.2006.10.010

Anderson JM, de Wit M (2008) Africa Alive Corridors. A continental network of earth, life and cultural heritage. Geobull Geol Soc S Afr 51:11–25

Anderson J, Mashua T, de Wit M (2008) Africa alive corridors. Quest 4:56–59

Anderson J (1999) Towards Gondwana Alive. Assoc. Berger, L, De Wit M, Fatti LP, Holm E, Rubidge B, Smith G, Thackeray F, Van Wyk B (eds) Gondwana alive society, vol 1. Pretoria, p 140

Aslanian D, Pellen R et al (2023) The postulation of intermittent land bridges as an explanation for reiterated colonization events of Madagascar by African vertebrates: An in-depth review and novel insights in honour of the late Judith Masters and Fabien Génin. Earth Sci Rev 246:104585. https://doi.org/10.1016/j.earscirev.2023.104585

Assede ESP, Orou H, Biaou SSH, Geldenhuys CJ, Ahononga FC, Chirwa PW (2023) Understanding Drivers of Land Use and Land Cover Change in Africa: A Review. Curr Landsc Ecol Rep 8:62–72. https://doi.org/10.1007/s40823-023-00087-w

Auerbach R (2020) Organic food systems: meeting the needs of Southern Africa. CABI

Auerbach et al (2021) Sustainable African food systems. - https://www.researchgate.net/publication/379237284_Sustainable_African_Food_Systems_Status_analysis_of_the_55_African_countries_and_policies_for_making_Africa_Food_Sovereign_and_Food_Secure_Prof_Raymond_Auerbach_Dr_Edith_Kareko-Munene_Dr_Myles_Oelofse. Accessed 15 May 2024

Becker B (2013) Snow ball earth and the split of Streptophyta and Chlorophyta. Trends Plant Sci 18:180–183. https://doi.org/10.1016/j.tplants.2012.09.010

Beldjoudi H, Delouis B (2022) Reassessing the rupture process of the 2003 Boumerdes-Zemmouri earthquake (Mw 6.8, northern Algeria) using teleseismic, strong motion, InSAR, GPS, and coastal uplift data. Mediterr Geosci Rev 4:471–494. https://doi.org/10.1007/s42990-022-00090-z

Berliner P (1993) The soul of mbira: Music and traditions of the Shona people of Zimbabwe. University of Chicago Press

Breunig P, Rupp N (2016) An Outline of Recent Studies on the Nigerian Nok Culture. J Afr Archaeol 14:237–255. https://doi.org/10.3213/2191-5784-10298

Britnell JA, Zhu Y, Kerley GIH, Shultz S (2023) Ecological marginalization is widespread and increases extinction risk in mammals. Proc Natl Acad Sci 120:e2205315120

Conrad DC (2010) Empires of Medieval West Africa: Ghana, Mali, and Songhay. Infobase Publishing

De Wit M, Anderson JM (2003) Gondwana Alive Corridors: Extending Gondwana Research to Incorporate Stemming the Sixth Extinction. Gondwana Res 6:369–408. https://doi.org/10.1016/S1342-937X(05)70994-1

De Wit M, Booth P (2016) Iphakade is Earth Stewardship Science. S Afr J Geol 119(1):3–14

De Wit M, Jeffery M, Bergh H (1988) Geological Map of Sectors of Gondwana Reconstructed to Their Disposition 150 Ma 1: 10 000 000. AAPG

De Wit M, Guillocheau F, De Wit MC (2015) Geology and resource potential of the Congo Basin. Springer Science & Business Media

De Wit M, Furnes H et al (2018) Paleoarchean bedrock lithologies across the Makhonjwa Mountains of South Africa and Swaziland linked to geochemical, magnetic and tectonic data reveal early plate tectonic genes flanking subduction margins. Geosci Front 9:603–665. https://doi.org/10.1016/j.gsf.2017.10.005

Dhliwayo N (2020) Creating citizen-science for groundwater monitoring prior to potential shale gas development in Cradock (South-Eastern Karoo, South Africa). PhD thesis, Faculty of Science, Nelson Mandela University, p 277. http://hdl.handle.net/10948/48224

Donnadieu Y, Fluteau F, Ramstein G, Ritz C, Besse J (2003) Is there a conflict between the Neoproterozoic glacial deposits and the snowball Earth interpretation: an improved understanding with numerical modeling. Earth Planet Sci Lett 208:101–112. https://doi.org/10.1016/S0012-821X(02)01152-4

Errami E, Brocx M, Semeniuk V (2015) From geoheritage to geoparks, Case Studies from Africa and Beyond. Springer International Publishing Switzerland

Fauvelle-Aymar F-X (2018) L'Afrique ancienne: de l'Acacus au Zimbabwe: 20000 avant notre ère-XVIIe siècle. Belin ed, Paris

Furnes H, Banerjee NR, Muehlenbachs K, Staudigel H, de Wit M (2004) Early Life Recorded in Archean Pillow Lavas. Science 304:578–581. https://doi.org/10.1126/science.1095858

Génin F, Mazza PP, Pellen R, Rabineau M, Aslanian D, Masters JC (2022) Co-evolution assists geographic dispersal: the case of Madagascar. Biol J Lin Soc 137:163–182. https://doi.org/10.1093/biolinnean/blac090

Gnassou L (2019) Addressing renewable energy conundrum in the DR Congo: Focus on Grand Inga hydropower dam project. Energ Strat Rev 26:100400. https://doi.org/10.1016/j.esr.2019.100400

Grosch EG, McLoughlin N, de Wit M, Furnes H (2009) Drilling for the Archean roots of life and tectonic Earth in the Barberton Mountains. Scientific Drilling 8:24–28

Guettiche A, Guéguen P, Mimoune M (2017) Economic and Human Loss Empirical Models for Earthquakes in the Mediterranean Region, with Particular Focus on Algeria. Int J Dis Risk Sci 8:415–434. https://doi.org/10.1007/s13753-017-0153-6

Herrera JP, Dávalos LM (2016) Phylogeny and Divergence Times of Lemurs Inferred with Recent and Ancient Fossils in the Tree. Syst Biol 65:772–791. https://doi.org/10.1093/sysbio/syw035

Hoffman PF, Halverson GP et al (2021) Snowballs in Africa: sectioning a long-lived Neoproterozoic carbonate platform and its bathyal foreslope (NW Namibia). Earth Sci Rev 219:103616. https://doi.org/10.1016/j.earscirev.2021.103616

Huffman TN (2009) Mapungubwe and Great Zimbabwe: The origin and spread of social complexity in southern Africa. J Anthropol Archaeol 28:37–54. https://doi.org/10.1016/j.jaa.2008.10.004

Jahn A, Riller U (2009) A 3D model of first-order structural elements of the Vredefort Dome, South Africa — Importance for understanding central uplift formation of large impact structures. Tectonophysics 478:221–229. https://doi.org/10.1016/j.tecto.2009.08.007

Kerley GIH, te Beest M, Cromsigt JPGM, Pauly D, Shultz S (2020) The Protected Area Paradox and refugee species: The giant panda and baselines shifted towards conserving species in marginal habitats. Conserv Sci Pract 2:e203. https://doi.org/10.1111/csp2.203

Kristen I, Fuhrmann A, Thorpe J, Röhl U, Wilkes H, Oberhänsli H (2007) Hydrological changes in southern Africa over the last 200 Ka as recorded in lake sediments from the Tswaing impact crater. S Afr J Geol 110:311–326. https://doi.org/10.2113/gssajg.110.2-3.311

Krznaric R (2020) The good ancestor: How to think long term in a short-term world. Random House

Kumbani J (2020) Music and sound-related archaeological artefacts from southern Africa from the last 10,000 years. Azania: Archaeol Res Afr 55:217–241. https://doi.org/10.1080/0067270X.2020.1761686

Lea JMD, Kerley GIH, Hrabar H, Barry TJ, Shultz S (2016) Recognition and management of ecological refugees: A case study of the Cape mountain zebra. Biol Cons 203:207–215. https://doi.org/10.1016/j.biocon.2016.09.017

Linard C, Gilbert M, Snow RW, Noor AM, Tatem AJ (2012) Population Distribution, Settlement Patterns and Accessibility across Africa in 2010. PLoS ONE 7:e31743. https://doi.org/10.1371/journal.pone.0031743

Linol B, Dhansay T (2023) Brittle tectonic evolution of Gondwana: implications for shale-gas and groundwater exploration. Geol Soc London Spec Publ 531:131–148. https://doi.org/10.1144/SP531-2022-194

Linol B, de Villiers S, de Wit M (2019) Accelerated Contribution of the Paleo-Congo River to Global Seawater 87Sr/86Sr Change Following Eocene-Oligocene Collapse of the African Surface. Geochem Geophys Geosyst 20:1937–1953. https://doi.org/10.1029/2018GC007984

Linol B, Miller WD, Rensburg C, Schoeman R, Bezuidenhout L, Genin F, Morkel B, Dhliwayo N, Jeppesen K, Dlakavu S et al (2020) Earth Stewardship Science—Transdisciplinary Contributions to Quantifying Natural and Cultural Heritage of Southernmost Africa. Remote Sens 12(3):420. https://doi.org/10.3390/rs12030420

Mashele N, Auerbach RMB (2016) Evaluating crop yields, crop quality and soil fertility from organic and conventional farming systems in South Africa's southern Cape. S Afr J Geol 119:25–32. https://doi.org/10.2113/gssajg.119.1.25

Masters JC, Silvestro D, Génin F, DelPero M (2013) Seeing the wood through the trees: the current state of higher systematics in the Strepsirhini. Folia Primatol 84:201–219

Masters JC, Génin F, Couette S, Groves CP, Nash SD, Delpero M, Pozzi L (2017) A new genus for the eastern dwarf galagos (Primates: Galagidae). Zool J Linn Soc 181:229–241. https://doi.org/10.1093/zoolinnean/zlw028

Masters JC, Génin F et al (2021) Biogeographic mechanisms involved in the colonization of Madagascar by African vertebrates: Rifting, rafting and runways. J Biogeogr 48:492–510

Matshusa K, Leonard L (2023) Proposed Governance Model for Geotourism and Geoheritage in South Africa and the Implications for Africa. Geoheritage 15:19. https://doi.org/10.1007/s12371-022-00783-9

Meghraoui M, IGCP-601 and Group, W (2016) The seismotectonic map of Africa. Episodes 39:9–18

Meghraoui M, Pondrelli S (2012) Active faulting and transpression tectonics along the plate boundary in North Africa. Ann Geophys 55:955–967

Meghraoui MA, Hinzen K-G, Malik JN (2021) Paleoseismology, Archeoseismology and Paleotsunami Studies. In: Alderton D, Elias SA (eds) Encyclopedia of Geology, 2nd edn. Academic Press, Oxford, pp 636–655. https://doi.org/10.1016/B978-0-08-102908-4.00127-2

Michon L, Famin V, Quidelleur X (2022) Evolution of the East African Rift System from trap-scale to plate-scale rifting. Earth Sci Rev 231:104089. https://doi.org/10.1016/j.earscirev.2022.104089

Miller WD, Anderson J, Doucouré M (2024) The importance of geodiversity in understanding and conserving the Western Rift Valley Corridor. Ecol Soc. (in press)

Miller WD (2022) Spatial and temporal analysis of the critical zone in the Western rift valley corridor: towards earth stewardship science in East Africa. PhD Thesis, Faculty of Science, Nelson Mandela University, p 225. http://hdl.handle.net/10948/59771

Minguzzi M (2021) The Spirit Of Water: Practices of cultural reappropriation. Firenze University Press https://doi.org/10.36253/978-88-5518-316-1

Moolman L, Ferreira SM, Gaylard A, Zimmerman D, Kerley GIH (2019) The decline of the Knysna elephants: Pattern and hypotheses. S Afr J Sci 115:1–7

Moudnib LE, Timoulali Y, Nouayti A, El Abbassi M, Bouka M, Nouayti N, Mhammdi N (2023) Seismotectonic model of High-Middle Atlas Junction (Morocco) derived from earthquake focal mechanism and stress tensor analysis. Model Earth Syst Environ 9:2407–2423. https://doi.org/10.1007/s40808-022-01630-0

Mourabit T, AbouElenean KM, Ayadi A, Benouar D, Ben SA, Bezzeghoud M, Cheddadi A, Chourak M, ElGabry MN, Harbi A, Hfaiedh M, Hussein HM, Kacem J, Ksentini A, Jabour N, Magrin A, Maouche S, Meghraoui M, Ousadou F, Panza GF, Peresan A, Romdhane N, Vaccari F, Zuccolo E (2014) Neo-deterministic seismic hazard assessment in North Africa. J Seismol 18:301–318. https://doi.org/10.1007/s10950-013-9375-2

Mouri H (2020) Medical Geology and its relevance in Africa. S Afr J Sci 116:1–2

Neto K, Henriques MH (2022) Geoconservation in Africa: State of the art and future challenges. Gondwana Res 110:107–113. https://doi.org/10.1016/j.gr.2022.05.022

Pandeya B, Buytaert W, Potter C (2021) Designing citizen science for water and ecosystem services management in data-poor regions: Challenges and opportunities. Curr Res Environ Sustain 3:100059. https://doi.org/10.1016/j.crsust.2021.100059

Parkington J (2010) Coastal diet, encephalization, and innovative behaviors in the late Middle Stone Age of southern Africa. In: Cunnane SC Stewart KM (eds) Humain brain evolution, pp 189–202

Patin E, Quintana-Murci L (2018) The demographic and adaptive history of central African hunter-gatherers and farmers. Curr Opin Genet Dev 53:90–97. https://doi.org/10.1016/j.gde.2018.07.008

Pattrick P, Minguzzi M, Weidberg N, Porri F (2022) Ecological value of the earliest human manipulated coastal habitats: Preliminary insights into the nursery function of a pre-colonial stonewalled fish trap in South Africa. Reg Stud Mar Sci 52:102266

Peros CS, Dasgupta R, Kumar P, Johnson BA (2021) Bushmeat, wet markets, and the risks of pandemics: Exploring the nexus through systematic review of scientific disclosures. Environ Sci Policy 124:1–11. https://doi.org/10.1016/j.envsci.2021.05.025

Pierrehumbert RT, Abbot DS, Voigt A, Koll D (2011) Climate of the Neoproterozoic. Annu Rev Earth Planet Sci 39:417–460. https://doi.org/10.1146/annurev-earth-040809-152447

Popova OP, Jenniskens P et al (2013) Chelyabinsk Airburst, Damage Assessment, Meteorite Recovery, and Characterization. Science 342:1069–1073. https://doi.org/10.1126/science.1242642

Pozzi L, Penna A (2022) Rocks and clocks revised: New promises and challenges in dating the primate tree of life. Evol Anthropol: Issues News Rev 31:138–153. https://doi.org/10.1002/evan.21940

Raxworthy CJ, Forstner MRJ, Nussbaum RA (2002) Chameleon radiation by oceanic dispersal. Nature 415:784–787. https://doi.org/10.1038/415784a

Robbins JL, Dirks PHGM et al (2021) Providing context to the Homo naledi fossils: Constraints from flowstones on the age of sediment deposits in Rising Star Cave. S Afr Chem Geol 567:120108. https://doi.org/10.1016/j.chemgeo.2021.120108

Rogers A (2007) The making of Cosmic Africa: the research behind the film. African Skies/ Cieux Africains 11:19–23

Rouwet D, Németh K, Tamburello G, Calabrese S (2021) Volcanic Lakes in Africa: The VOLADA_Africa 2.0 Database, and Implications for Volcanic Hazard. Front Earth Sci 9:717798

Salama A, ElGabry M, Meghraoui M, Moussa HH (2020) Preliminary tsunami hazard map for Africa. Arab J Geosci 13:981. https://doi.org/10.1007/s12517-020-06010-5

Salzburger W (2018) Understanding explosive diversification through cichlid fish genomics. Nat Rev Genet 19:705–717. https://doi.org/10.1038/s41576-018-0043-9

Selinus O, Alloway B, Centeno JA, Finkelman RB, Fuge R, Lindh U, Smedley P (2013) Essentials of medical geology: revised edition. Springer

Sinamai A (2018) Melodies of God: the significance of the soundscape in conserving the Great Zimbabwe landscape. J Commun Archaeol Herit 5:17–29. https://doi.org/10.1080/20518196.2017.1323823

Stoeck T, Kasper J, Bunge J, Leslin C, Ilyin V, Epstein S (2007) Protistan Diversity in the Arctic: A Case of Paleoclimate Shaping

Modern Biodiversity? PLoS ONE 2:e728. https://doi.org/10.1371/journal.pone.0000728
Taylor N (2021) Lupemban. Oxford University Press
Toteu SF, Anderson JM, de Wit M (2010) 'Africa Alive Corridors': Forging a new future for the people of Africa by the people of Africa. J Afr Earth Sc 58:692–715
Tracey A (2015) The system of the mbira. Afr Music J Int Libr Afr Music 10:127–149. https://doi.org/10.21504/amj.v10i1.1229
Turino T (2010) The Mbira, worldbeat, and the international imagination. World Music 52:171–192
Turnbull JW, Johnston EL, Clark GF (2020) LESI: A quantitative indicator to measure local environmental stewardship. MethodsX 7:101141
Van Heerden BI (2020) The drivers of sustainable triple bottom line business performance in Africa Alive Corridors heritage nodes. PhD thesis, Nelson Mandela University, p 326
Vincent WF, Laybourn-Parry J (2008) Polar lakes and rivers: limnology of Arctic and Antarctic aquatic ecosystems. Oxford University Press
Vincent W, Gibson J, Pienitz R, Villeneuve V, Broady P, Hamilton P, Howard-Williams C (2000) Ice shelf microbial ecosystems in the high arctic and implications for life on snowball earth. Naturwissenschaften 87:137–141
Voigt A, Abbot DS (2012) Sea-ice dynamics strongly promote Snowball Earth initiation and destabilize tropical sea-ice margins. Clim past 8:2079–2092. https://doi.org/10.5194/ep-8-2079-2012
Wadley L (2015) Those marvellous millennia: the Middle Stone Age of Southern Africa. Azania: Archaeol Res Afr 50:155–226. https://doi.org/10.1080/0067270X.2015.1039236
Zhang H, Sun Y, Zeng Q, Crowe SA, Luo H (2021) Snowball Earth, population bottleneck and Prochlorococcus evolution. Proc R Soc B 288:20211956

Authors and Affiliations

B. Linol[1] · M. Doucouré[1] · J. Anderson[1] · F. Toteu[1,2] · W. Miller[1] · P. Vale[1,3] · P. Hoffman[4] · G. I. H. Kerley[5] · R. Auerbach[1] · C. Thiart[1,11] · M. Meghraoui[6,10] · N. Dhliwayo[1] · J. Master[1] · F. Genin[1] · T. Dembaremba[7] · B. van Heerden[1] · J. Unite[1] · A. May[1] · P. Mathias[1] · M. Minguzzi[8] · T. de Wit[1,9]

✉ B. Linol
bastien.linol@mandela.ac.za

M. Doucouré
moctar.aeon@gmail.com

J. Anderson
jmanderson.gondwana@gmail.com

F. Toteu
sftoteu@yahoo.fr

W. Miller
macwazmac@gmail.com

P. Vale
petercjvale@gmail.com

P. Hoffman
paulfhoffman@gmail.com

G. I. H. Kerley
Graham.Kerley@mandela.ac.za

R. Auerbach
Raymond.Auerbach@mandela.ac.za

C. Thiart
Christien.Thiart@uct.ac.za

M. Meghraoui
m.meghraoui@unistra.fr

N. Dhliwayo
Nyaradzo.Dhliwayo@mandela.ac.za

T. Dembaremba
s212385674@mandela.ac.za

B. van Heerden
barbara.integrate@gmail.com

J. Unite
jeannetteunite@gmail.com

A. May
mey.angel6@gmail.com

P. Mathias
pwavidonmathias@gmail.com

M. Minguzzi
Magda.Minguzzi@mandela.ac.za
https://architecture.mandela.ac.za/Department-of-Architecture-Engagement-and-Transfor/Indigenous-Knowledge-Systems

T. de Wit
tjaartus@gmail.com

[1] Africa Earth Observatory Network-Earth Stewardship Science Research Institute, Nelson Mandela University, Gqeberha, South Africa

[2] Institute for Geological and Mining Research, Po Box 4110, Yaoundé, Cameroun

[3] Centre for the Advancement of Scholarship, University of Pretoria, Pretoria, South Africa

[4] School of Earth & Ocean Sciences, University of Victoria, Victoria, BC, Canada

[5] Center for African Conservation Ecology, Nelson Mandela University, Gqeberha, South Africa

[6] Institut Terre et Environnement - CNRS UMR 7063, University of Strasbourg, Strasbourg, France

[7] Department of Chemistry, Nelson Mandela University, Gqeberha, South Africa

[8] School of Architecture, and Institute for Coastal and Marine Research, Nelson Mandela University, Gqeberha, South Africa

[9] Institute of Mine Seismology, Hobart, Australia

[10] Algerian Academy of Science and Technology, Algiers, Algeria

[11] Department of Statistical Sciences, University of Cape Town, Cape Town, South Africa