The chronostratigraphy of the Anthropocene in southern Africa: Current status and potential

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Abstract

The process for the formal ratification of the proposed Anthropocene Epoch involves the identification of a globally isochronous stratigraphic signal to mark its starting point. The search for a Global Boundary Stratotype Section and Point (GSSP), a unique reference sequence that would be used to fix the start of the epoch, is in progress but none of the candidate sections are located in Africa. We assessed the currently available stratigraphic evidence for the possible markers of the Anthropocene in southern Africa and found that, although most markers have been identified in the region, the robustly dated, high resolution records required for the GSSP are very sparse. We then assessed the extent and stratigraphic resolution of a range of potential natural archives and conclude that a small number of permanent lakes, as well as marine sediments, corals and peats from selected locations in southern Africa could provide the temporal resolution required. With sufficient chronological control and multi-proxy analyses, one of these archives could provide a useful auxiliary stratotype thereby helping to confirm the global reach, and extending the utility, of the selected Anthropocene GSSP.

Introduction

The scale and extent of human impacts on our planet has resulted in the proposal that they should be reflected in a new geological time period - the Anthropocene Epoch. The inclusion of this within the formal International Chronostratigraphic Chart, would thereby end the current Holocene (Zalasiewicz et al, 2015; Waters et al 2016). Although the term is widely used, the Anthropocene has yet to be formally recognised, and considerable debate continues regarding its recognition and the date at which it may have started. The Anthropocene Working Group (AWG), the task group established by the Subcommission on Quaternary Stratigraphy (SQS) to consider the evidence for the new epoch, currently favours the mid-20th century for a starting point (Zalasiewicz et al, 2015) and this is the definition we use here.

One criterion for the formal recognition of the Anthropocene is for a defined, globally isochronous signal that may be used to identify its starting point. A marker for this will be fixed within a unique reference stratigraphic succession known as a Global Boundary Stratotype Section and Point (GSSP), widely known as a ‘golden spike’. For the Anthropocene, a range of contemporary natural archives may be considered, including lake and marine sediments, ice cores, peat sequences, corals, speleothems and tree rings. Furthermore, because of the sharp increase in a range of socioeconomic indicators and Earth system responses starting from the mid-20th century (Steffen et al 2015), a vast array of potential markers also exists. For example, changes in sediment transport (Fontanier et al 2018; Owens 2020), trace metals, nuclear fall-out and stable isotopes (Waters et al 2018), persistent organic pollutants (Gałuszka et al 2020), microplastics (Bancone et al 2020; Ivar do Sul and Labrenz, 2021), anthropogenic deposits (Ford et al 2014) and various industrially derived components of the black carbon continuum (Rose 2015; Han et al 2017) have all been suggested.

Currently, the AWG are exploring the stratigraphic signals of a broad selection of markers in natural archives. These have been selected to include sites with robust chronological constraints over at least approximately the last 100 years, a high stratigraphic resolution (annual or better) and from which considerable data already exist. Lake sediments from China and North America, marine sediment cores from California and the Baltic Sea, peats and speleothems from Europe, corals in Australia and the Caribbean, and Antarctic ice cores are all under consideration. However, only two of these potential sequences are located in the Southern Hemisphere and none on the African continent (Head, 2019).

In Africa, as elsewhere, the concept of the Anthropocene has been considered within a variety of contexts and across a number of disciplines (Zalasiewicz et al., 2021). Hoag and Svenning (2017) discussed the Anthropocene in Africa against a backdrop of long-term environmental change (e.g., desertification, megafauna loss) and their drivers, not only climate and increasing population, but also changing agricultural practices, colonialism and capitalism. Hecht (2018) used the frame of the Anthropocene to consider the political and ethical implications for uranium mining in Gabon while also highlighting the inequalities of the impact caused by such resource exploitation. From a more biophysical perspective, Odada et al (2020), suggest that marked increases in sedimentation, degradation of water and terrestrial ecosystem quality, and associated biodiversity loss have occurred in East Africa since the mid-20th century, thereby supporting this start date for the proposed epoch.

In southern Africa (here defined as south of 17° S), a rapidly developing industrial sector and a rising population have resulted in an increasing range of stressors to ecosystems. Expanding urbanisation, the release of pollutants from industrial emissions (Monna et al., 2006; Josipovic et al., 2011) including a continued reliance on fossil-fuels (Marais et al., 2019), the continued use of DDT to control vector-borne diseases (Sereda and Meinhardt, 2005; Humphries, 2013) and inputs to waters from acid mine drainage (McCarthy, 2011) are all widely reported, while Turton (2018) adds contamination from urban sewage to this list. Furthermore, the effects of a range of pollutants on southern African environments is well recognised. Riverine and lacustrine plants, fish, sediments and aquatic birds have been shown to contain a contaminant burden that includes elevated accumulations of trace metals (Kotze et al., 1999) and organohalogens (Bouwman et al., 2008; Nakayama et al., 2010; Wepener et al., 2012) resulting in detrimental effects to growth and development including endocrine disruption (Barnhoorn et al 2004). The transfer of these pollutants to rural communities reliant on fish consumption and the associated risk to human health has also been reported (Volschenk et al., 2019). Despite this, in southern Africa there has been little consideration of the recent historical records for these contaminants or other potential indicators that might be considered markers for the Anthropocene. Indeed, stratigraphic data for these are relatively scarce (Rose et al., 2020), as they are in many regions of the southern hemisphere. Therefore, the aims of this paper are to assess the currently available evidence for Anthropocene stratigraphic markers within southern Africa and then to consider how natural archives in the region could be used to contribute to the global debate on its chronostratigraphic definition.

Markers

A wide range of anthropogenic markers are under consideration for the onset of the Anthropocene (Table 1). These include markers for which the epoch is their first occurrence in the stratigraphic record (e.g., plutonium isotopes) while for others it is a dramatic change in their abundance due to unprecedented human activity. Southern Africa has a wealth of palaeoenvironmental evidence recording long-term human evolution, occupation and environmental change. However, fewer data and studies are available on historical successions of potential Anthropocene markers from environmental archives at a sufficient resolution to record changes from the early to mid-20th century and up to the present day.

Radionuclides

A key element for identifying the mid-twentieth century is the stratigraphic presence and succession of isotopes from atmospheric nuclear weapons testing that occurred after 1945 CE. Isotopes of caesium (^{137}Cs, ^{134}Cs), americium (^{241}Am) and plutonium (^{238}Pu, $^{239-240}$Pu) are commonly used to determine chronologies of archives accumulating over the last 70 years. Generated during thermonuclear detonations, these isotopes record the onset of atmospheric testing (c. 1952), as well as their increase, peak (c. 1964), and decrease following the Limited Test-Ban Treaty. Plutonium isotopes have been recorded in southern African soil samples (Hardy et al., 1973; Salmani-Ghabeshi et al., 2018) as well as peat deposits in Madagascar (Rääf et al., 2017) recording global fallout from testing. The accidental break-up of the SNAP-9A satellite in 1964 also contributed a unique signature of Pu isotopes over the region (Chamizo et al., 2020; Holm et al., 2015) (Figure 1), although its coincidence with peak fallout from the nuclear testing period makes it difficult to resolve in profiles (Rääf et al. 2017). Other examples of Pu isotopes in environmental archives in the region have not been reported.

Atmospheric fallout of caesium (^{137}Cs) has been used across southern Africa in studies of soil/sediment erosion and accumulation (Foster et al., 2007; Mighall et al., 2012; Owens and Walling, 1996; Quine et al., 1999). Lower historical deposition rates of ^{137}Cs in the region have been identified due to its latitude and climate, as rainfall patterns govern the fall-out of both natural and artificial radionuclides and control the quality of radiometric records (Appleby et al., 2001). As a chronological marker, ^{137}Cs can be affected by factors that blur the timing of both its onset and peak. However, its effectiveness as a dating marker has been confirmed in the region by independent chronologies (Foster et al., 2007; Humphries et al., 2010; Walling et al., 2003) and by comparisons with historical flood event deposits (Foster et al., 2007; van der Waal et al., 2015).

Although a naturally occurring, albeit short-lived ($T_{½}$ = 22.3 years), radionuclide, the use of ^{210}Pb along with artificial radionuclides is an essential verification process for the correct age to be attributed to Anthropocene successions. Lead-210 has been used in the region independently (Kading et al., 2009; Orani et al., 2019; Tabares et al., 2020), to provide both a check for down-core changes (Das et al., 2008a; Rääf et al., 2017; Rose et al., 2020) as well as to extend ^{14}C dating to the present (du Plessis et al., 2020; Fontanier et al., 2018; Haberzettl et al., 2019; Stager et al., 2013; Wündsch et al., 2016).

SCPs

There are only two published records of spheroidal carbonaceous fly-ash particles (SCPs) from southern Africa. However, these datasets show the potential for SCPs to record regional and local atmospheric deposition of contaminants from fossil fuel combustion. A mid-twentieth century increase in local power production is shown in North End Lake, Port Elizabeth, South Africa, with SCP sediment concentrations rising from less than 1,000 to almost 8,000 per gram dry mass (gDM^{-1}) in the mid-20th century (García-Rodríguez et al., 2007). In Lesotho, SCPs were detected in co-located lake sediment and wetland cores post-1970 and 1980 respectively (Rose et al., 2020). Concentrations in Lesotho are an order of magnitude lower than at Port Elizabeth, due to the absence of local sources.

Microplastics

There is a deficit of studies on the origin, transport and depositional fate of plastics in southern Africa (Khan et al., 2018). As elsewhere, plastic has been released into natural environments for decades due to mis-managed waste streams. South Africa releases 0.09 – 0.25 million tonnes of plastic waste a year into marine settings, making it one of the highest in the world, while other coastal nations of southern Africa release less, equivalent to 'global North' industrialised countries (Jambeck et al., 2015). A considerable amount of research has attempted to monitor, quantify and determine the fate of macro- and microplastics in South African coastal and marine settings as well as their impacts on ecosystems (Cefas Marine Litter Team, 2020; Naidoo et al., 2015; Ryan, 2020; Verster et al., 2017). Quantification of its land-based origins, its release due to ineffective waste management and transfer to coasts is, however, limited (Dahms et al., 2020; Weideman et al., 2019). Stratigraphic evidence of increasing and diversified polymers accumulating in the coastal environment in southern Africa comes from a solitary study of microplastics in an undated core collected in 2012 from Durban harbour (Matsuguma et al., 2017).

Persistent organic pollutants and polycyclic aromatic hydrocarbons

Persistent organic pollutants (POPs) are present in southern African ecosystems, soils and sediments derived from industrial and agricultural sources (Quinn et al., 2009). Organochlorine pesticides, along with polychlorinated biphenyls (PCBs), dioxins and furans (PCDD/Fs) and brominated flame retardants (BFRs) have all been reported in southern African aquatic ecosystems (Berg et al., 1992; Gerber et al., 2016; Greichus et al., 1977; Verhaert et al., 2017; Viljoen et al., 2016). Organochlorine pesticides (principally DDT) were first introduced to the region in the 1940s-1950s for malaria control but were restricted later after recognition of their harmful ecological effects (Tren and Bate, 2001). In South

Africa, the pervasiveness of organochlorine pesticides has led to aquatic ecosystems and sediments having some of the highest organochlorine residues reported anywhere in the world (Buah-Kwofie and Humphries, 2017). Although also introduced anachronistically, the widespread use and persistence of these chemicals in environmental matrices, indicate a high potential as markers of the Anthropocene in southern Africa. However, only two studies that have a 20th century stratigraphic dimension exist in the region. First, a record of polycyclic aromatic hydrocarbons (PAHs) from urban run-off in Zeekoevlei in the Western Cape (Das et al., 2008a) and second, sediment archives of very low PAH and POPs concentrations derived from long-range transported atmospheric deposition in the upland lake Letšeng-la Letsie, Lesotho (Rose et al., 2020).

Stable carbon and nitrogen isotopes

Significant changes in the composition of organic matter in environmental archives are marked by preserved variations of stable carbon and nitrogen isotope ratios ($\delta^{13}C$ and $\delta^{15}N$). Natural differences in these variables occur in archives due to landscape evolution of ecosystems, while human activities may also be recorded. In the Anthropocene, stable isotope variations are usually more abrupt, unprecedented and coincide with other human impact indicators. In southern Africa there are numerous sites (lakes and wetlands) where recent eutrophication, fossil fuel emissions and vegetation changes can be recorded by stable carbon and nitrogen isotopes, in conjunction with other paleoenvironmental proxies (Das et al., 2008a, 2008b; Ekblom and Gillson, 2010; Gordon et al., 2012; Kunz et al., 2011; Rose et al., 2020; Tabares et al., 2020). However, due to the combination of organic materials and sources that contribute carbon and nitrogen to environmental archives, it is essential that stable carbon and nitrogen records are interpreted within multi-proxy studies (e.g., McFadden et al., 2005)

Sedimentary and geochemical markers

Direct industrial disturbance to sedimentary archives and the formation of new anthropogenic deposits have occurred in parallel to the long history of sub-surface mining in the region; including extensive alluvial, dune, and offshore deposit placer mining (Asabonga et al., 2017; Rogers and Li, 2002). Although human-induced vegetation changes, cultivation, soil erosion, and deposition are not unique to the Anthropocene in southern Africa, soil erosion events that occurred in the 20th century are recorded in dam deposits (see below) and an increase in erosion and sediment transport is observed post-1950 in marine and terrestrial records from Madagascar (Fontanier et al., 2018; Rabesiranana et al., 2016) and East Africa (Odana et al. 2020).

Elevated concentrations of trace elements often associated with industrial activity (e.g. Zn, Cu, Pb, Hg, As) may be found due to naturally rich and diverse metalliferous deposits in the region that have been exploited for centuries. However, Anthropocene chemostratigraphy is predicated on the identification of elements in environmental matrices that are elevated far above background concentrations and spread widely due to industrial extraction, refining, tailings waste, and combustion of fossil fuels (Podolský et al., 2015). Toxic concentrations of metals are found in wetland sediments downstream of South African gold mining areas, due to the abundance in mine tailings of ore-associated metals and acid mine drainage (Humphries et al., 2017; McCarthy and Venter, 2006). Dated core profiles of trace elements associated with industrial and urban waste, and fossil fuel combustion are also found in

South African wetland and Namibian coastal sediments and show a post-1945 increase in metals (Orani et al., 2019)., including mercury, where accumulation rates increase from less than 20 µg m^{-2} yr^{-1} in pre-Anthropocene sediments to a peak of more than 150 µg m^{-2} yr^{-1} in the 1990s/2000s (Kading et al., 2009).

Accumulations of metals in sediments of reservoirs constructed in the 20th century have been a focus of various studies due to their potential for uptake into ecosystems that are important for aquatic food resources (Håkan Berg et al., 1995; Franchi et al., 2020; Greichus et al., 1977; Tendaupenyu and Magadza, 2019). However, only a few examples of trace metal profiles from well-resolved lake sediments spanning the onset of the Anthropocene exist in the region in two shallow, eutrophic lakes affected by urbanisation (Das et al., 2008b; 2008c; García-Rodríguez et al., 2007) and a remote upland site in Lesotho with evidence of long-range atmospheric deposition of metals from fossil fuel emissions (Rose et al., 2020) (Figure 1).

Ecological markers

Intensification of human pressures through land-use change for cultivation, hunting, and introduction of invasive species has led to widespread loss of native species and degraded biodiversity. This process has accelerated with population growth and intensity of cultivation, but has been a long-term process with, for example, significant extinctions occurring in the 19th century and earlier with European colonisation (Grab and Nash, 2020). Vegetation changes are recorded by changes in pollen types and abundance, with the appearance of non-native and cultivated species, such as maize, and co-occurrence of charcoal indicating clearance for agriculture (du Plessis et al., 2020; Ekblom and Gillson, 2010; Neumann et al., 2011; Tabares et al., 2020). Mid-twentieth century vegetation changes, e.g., plantations of Eucalyptus used for timber, can be observed in well-resolved pollen chronologies (Tabares et al., 2020) or where planting dates for silviculture are recognised (Turner and Plater, 2004). Both long-term and more recent impacts of human activity are also recorded by diatom frustules preserved in aquatic sediment successions. An intriguing prospect of potential Anthropocene research comes from a combination of diatom and stable nitrogen isotope records from laminated and ^{210}Pb-dated Namibian offshore sediments where multiple core records reveal a deterioration in denitrification and oxygen balance over the last 50 years (Emeis et al., 2009).

Natural archives

Although the distribution of published data on possible Anthropocene markers within robustly dated natural archives is limited within southern Africa (Figure 1), there is considerable potential for further exploration and analysis of sequences from a range of archive-types across the region.

Lacustrine sediments

Lake sediments have been widely used around the world to show historical trends of potential Anthropocene markers and many have sediment accumulation rates appropriate for high resolution studies (Rose et al., 2011). While GIS modelling, confirmed by satellite imagery, identified 973 lakes in Madagascar alone (Bamford et al., 2017), in other countries of southern Africa the number of permanent water bodies potentially providing an uninterrupted, continuously accumulating sediment record is limited. Magadza (1992) noted that the general southernmost limit of permanent, natural lakes in southern Africa is a line between Lake Mweru and Lake Malawi (c. 10° South), with only three lakes in Botswana, one in Namibia, several coastal lakes in Mozambique and South Africa, and none in Lesotho, Swaziland (now eSwatini) and Zimbabwe. However, more detailed national studies have identified additional lakes. For example, in South Africa, the National Biodiversity Assessment (Van Deventer et al., 2019) lists eight permanent natural freshwater systems with a depth of more than 2m while other published studies indicate additional lakes especially in northern KwaZulu Natal. These include Bhangazi North and South (Hart and Appleton, 1997), Lakes Shazibe and Mgobozeleni (Bate et al., 2016), the Richards Bay lakes (Cyrus and Martin, 1988) and the Mpumalanga Lake District (MLD; e.g. Wellington, 1943). Furthermore, in the Afromontane region of the Drakensberg-Maloti mountains that form the border between South Africa and Lesotho, there are hundreds of small water bodies, locally known as tarns, although only a few are semi-permanent (Dunnink et al., 2016). Elsewhere in Lesotho, Rose et al (2020) obtained a sediment core from Letšeng-la Letsie in the southern Drakensberg-Maloti, a dammed water body on the site of a smaller pre-existing lake.

Uncertainties around the precise number of lakes notwithstanding, there is a limited number of lake sites in South Africa and Lesotho that could be used for Anthropocene studies in the region, mostly clustered in specific coastal regions or the MLD. By contrast, Mozambique has c.1,300 lakes, of which 20 have an area of more than 10 km^2 (AUDA-NEPAD, 2019). In southern Mozambique, there are many lakes and lagoons among the dune systems of the coastal plain (Allanson et al., 1990), a number of which have been used in palaeolimnological studies. Permanent lakes are scarcer in other countries. In Namibia, Etosha Pan, which has been considered perennial in the past (Hipondoka et al., 2006) may locally reach 10m depth in wetter years (Mendelson et al., 2013), but is now largely a dry or very shallow saline pan, as are the nearby Omadhiya Lakes (Mendelson et al., 2013). The only true Namibian lakes are associated with collapsed sinkholes in karstveld geology with two striking examples near the mining town of Tsumeb; Lake Otjikoto, with a diameter of only c. 100m, but a depth in excess of 75m (Tabares et al. 2020), and the larger Lake Guinas, with a diameter of 140m and a depth of 153m (Goudie and Viles, 2015). Elsewhere, a few small permanent spring-fed waterholes lie on the gravel plains of the Namib-Naukluft Park (Kok and Grobbelaar 1985) while in the extreme north-east, the wetlands of the Linyanti swamps in the Caprivi region along the Botswana border include oxbows and lagoons on the Kwando and Linyanti Rivers. Botswana itself also has oxbows and lagoons on the rivers feeding the Okavango Delta which may offer potential for palaeolimnological studies. Zimbabwe has no natural lakes (Sanyanga and Mhlanga, 2004; Nduku and Robarts 1977), only pans and vleis (see below), as well as a number of large dams, while eSwatini has no natural lakes, but several dams.

While permanent natural water bodies are scarce, there are vast numbers of ephemeral water bodies variously known as pans, vleis or dambos, included within the various classification systems proposed for wetlands (e.g. Tooth and McCarthy, 2007; Ollis et al., 2015; de Klerk et al, 2016). Any seasonally flooded depression which holds water after rain is generally referred to as a pan in southern Africa (Lancaster, 1978). The seasonal or ephemeral nature of most pans indicates a potential loss of surface material during periods of desiccation, suggesting that a continuous stratigraphic record may be unlikely. However, as the dominant wetland type across much of southern Africa, their potential for Anthropocene palaeoenvironmental studies remains largely unexplored.

Dams (used here in the local context to include the dammed water body) may offer opportunities for palaeolimnological studies on the Anthropocene. Their utility is determined by their construction date, while stratigraphic integrity is affected by management regimes linked to water level changes or interventions such as dredging. Some of the older, large dams in South Africa were studied as early as the 1920s and 1930s, (e.g., Hartbeespoort Dam; Allanson, 1988), while Schuurman (1932) and Weintroub (1933) described the flora and fauna of pans and dams such as Wemmer Pan, Brakpan and Florida Lake dam in Johannesburg during the 1920s. The South African national register of dams (wall height >5m) shows that large dam construction started in the 1800s, with a major acceleration in the 20th century. Of 5,636 registered dams (to November 2019), 25 were built pre-1900 and 339 pre-1950. Small farm dams are more abundant, but their ages are generally unknown. Mantel et al. (2017) estimated that there are 165,000 in South Africa alone, while in Zimbabwe, Marshall and Maes (1995) counted 10,747 reservoirs from small farm dams to those greater than 100 ha and with the oldest dating back to c. 1900 (Magadza, 1992; Sanyanga and Mhlanga, 2004) (Table 2). There is limited information on the distribution of small dams in other countries of the region, but larger dams are included in the UN FAO AQUASTAT database (AQUASTAT, 2021). The numbers and ages of the oldest recorded dams for countries in southern Africa are shown in Table 2, but these figures are only estimates as they include some empty/breached dams as well as some under construction at the time of the inventory. While the date of construction is not recorded for many dams, older ones undoubtedly exist in some or all countries and may provide useable palaeolimnological records.

Peatlands

Peatlands, mires, and bogs are relatively rare in the southern African landscape although broad definitions of these environments vary between countries. Joosten (2009) lists peatland areas as shown in Table 2 although other estimates differ. There are 635 peatland points in the South African National Peatland Database, with most located near the wetter east and south coasts and more than half on the coastal plains of northern KwaZulu Natal (Van Deventer et al., 2019). Some of the most extensive are found in Maputaland, e.g., the Mfabeni Mire, reported to be the oldest peatland in the world (45,000 years) and Mkuze Mire, the largest in South Africa (7,265 ha) (Grundling and Grundling, 2019). While some pristine examples of peatlands still occur in southern Africa many, like the Vasi North peatland, are degraded or have been destroyed by a range of pressures. These include drainage for agriculture or forestry, removal by opencast mining, desiccation and burning, and even damage by invasive small mammals like ice rats and gerbils (Grundling and Grundling, 2019). Most inland wetlands are also in a poor ecological condition with 68% of the total spatial extent categorised as ecological category 'D/E/F' (meaning heavily to severely/critically modified) while less than 15% are in a natural to near-natural ecological condition (category A/B) (Van Deventer et al., 2019).

Palaeoenvironmental studies using peat sequences from southern Africa have focussed on climate, archaeology, hydrological, and vegetational changes at low temporal resolution over the Holocene and longer timescales (e.g., Wright et al., 1999; Finch and Hill, 2008; Neumann et al., 2008; 2010; Baker et al., 2017; Backwell et al ,2014). Fitchett et al. (2016a) reviewed multiproxy palaeoenvironmental and archaeological studies in Lesotho including southern Africa's highest altitude wetland at Mafadi (defined as a "bog" with peat inclusions) (Fitchett et al., 2016b). Few palaeoenvironmental studies using peats have focussed on the Anthropocene timescale despite the increasing intensity of a range of direct and indirect human induced pressures. Pollen from exotic plantation species has been used to determine peat accumulation rates (1-2 cm yr^{-1}; Thamm et al., 1996) and maize pollen has been identified in 20th century sections of long cores from Lake Sibaya (Neumann et al., 2008). McCarthy and Venter (2006) found evidence of increasing concentrations of trace metals (including lead and uranium) and phosphorus attributed to the establishment of the Witwatersrand (Johannesburg) conurbation in the late-19th century, and gold mining using carbon-dated peat cores from the Klip River wetland (the top 1m represented 120 years), concluding that the peat record provided a “useful barometer of anthropogenic activity in the catchment”.

Marine sediments

Marine sediment cores have been taken from both the eastern and western coasts of southern Africa, as well as off Madagascar. Along the west coast, most marine sediment records have been used to interpret changes over millennia, although at least one provides a record through to the 1990s (Schneider et al., 1995; Dupont and Wyputta, 2003; Gasse et al., 2008). In areas of the western continental margin where terrestrial inputs from the Orange River combine with highly productive oceanic waters, organic-rich sediment accumulation rates on the Namibian or Namaqualand ‘mud-shelf’ have been reported between 0.25 and 2.4 mm yr^{-1} (Herbert and Compton 2007) or 0.6 – 6 mm yr^{-1} (Meadows et al., 2002) indicating potential for a high-resolution archive. Similarly, off the coast of northwest Madagascar, a high-resolution sediment core provided a detailed record from almost 20,000 yr BP to the present day documenting post-1950 increased soil erosion

(Fontanier et al., 2018) while along the eastern coast of South Africa, Holocene deposits in areas sheltered from the Agulhas Current provide a youngest age of 42 cal yr BP in the upper 1 cm (Hahn et al., 2018). By contrast, a sediment core from the Mozambique Channel (which separates Mozambique from Madagascar), had an average age accumulation of 1,000 years in the uppermost 1 cm (Fallet et al., 2012) and so would be unsuitable for studying recent, high resolution change required for Anthropocene studies.

Speleothems

Speleothems have been identified as a possible target for a GSSP due to their potential to capture atmospheric signals (Waters et al., 2018) and southern Africa contains one of the four largest karst regions identified on the continent. South Africa, in particular, has a long history of research on speleothems as palaeoclimate archives (Braun et al., 2019). In a recent review, 12 of the 49 speleothem records in southern Africa, contained data more recent than 1950: five from South Africa, four from Madagascar, two from Namibia, and one from Botswana (Braun et al., 2019). This included at least three local climate records which specifically focussed on the period between 1950 and 1995-2000 (Holmgren et al., 1999; 2003; Brook et al., 1999), while at least two studies discussed the record in the context of global temperature rise over the last 100 years (Talma and Vogel, 1992; Railsback et al., 2018). However, none of these southern African speleothem records have been analysed specifically for Anthropocene markers, and potential lags between the atmospheric signal and that in the speleothem record could be problematic for accurately identifying the onset of the Anthropocene (Waters et al., 2018).

Corals

Cold water corals dominate on the western coast and southernmost tip of southern Africa, while warm water corals dominate along the eastern coast and around Madagascar (Waters et al., 2018). Like speleothems, corals may be analysed at annual resolution although the growth bands within deep-water corals may have a lower temporal resolution and some stratigraphic markers have displayed a 25-year time-lag when compared to those in shallow waters (Lee et al., 2017; Waters et al., 2018). A 336-year annually resolved record produced from the Ifaty coral south-west of Madagascar, used oxygen isotopes to reconstruct past sea surface temperature (SST) up to 1995 (Zinke et al., 2004), while another coral with seasonal resolution collected from the Mozambique channel, used trace elements to reconstruct SST back to 1970 (although the record potentially extends back to the early-1900s; Zinke et al., 2019). Otherwise, the examination of coral records from the region appears limited and suggested Anthropocene markers have not been examined to date.

Anthrosols

Extensive mining for gold, platinum and coal in South Africa has led to the widespread distribution of anthropogenically modified or created “anthrosols”, especially in mining regions such as Gauteng, North West Province and Mpumalanga, and presumably in neighbouring countries, where few data are available. Six categories of anthropic soils are defined in South Africa: technic, cultic, chemic, hydric, hortic, and urbic (Fey, 2010). Of these, technic soils, created by the rehabilitation of mined land, are most widely distributed, especially in the Mpumalanga coal fields, areas of diamond and gypsum mining in Namaqualand and sand mining areas on both the east and west coasts (Fey, 2010). Weiersbye et al. (2006) summarised other studies showing that the direct footprint of gold mining (contaminated soil and residual slimes) in the Witwatersrand alone covers 400 km^2, with more than 270 storage facilities containing 6 billion tonnes of gold and uranium tailings, 430,000 tonnes of uranium and 30 million tonnes of sulphur. While such deposits are a clear and unambiguous marker of anthropogenic activity through the Anthropocene, questions regarding their asynchronicity or diachronicity and hence usefulness as an archive continue to be debated (Edgeworth et al., 2015).

Tree rings

As with other natural archives, tree rings in southern Africa have been largely used to assess climatic change. Gebrekirstos et al (2014) suggest that the widespread use of dendroclimatology in the region is due to the lack of long-term instrumental climate data and that these records may be used to 'fill the knowledge gap' by reconstructing climate variability and atmospheric circulation patterns. Ring widths of *Pterocarpus angolensis* (also known as teak or bloodwood) have been used to reconstruct rainfall over a 200-year period in Zimbabwe (Therrell et al 2006), while in Namibia, *Dichrostachys cinerea* (Sickle bush) and *Senegalia mellifera* (Blackthorn) have been used to reconstruct rainfall (Shikangalah et al 2021), and those of *P. angolensis* and *Burkea africana* (wild syringa) for El Niño-Southern Oscillation (ENSO) indices over 150 years (Fichtler et al 2004). Tree rings also allow the long-term, high resolution measurement of stable isotopes. February and Stock (1999) showed that $^{13}C/^{12}C$ ratios in *Widdringtonia cedarbergensis* (Clanwilliam cedar) from the Cedarberg Mountains, South Africa correlated with similar data from ice cores and tree rings from both hemispheres, becoming increasingly negative after 1949 thereby demonstrating an increasing industrial influence. Woodborne et al. (2015) reconstructed rainfall over a 1,000-year period using the $\delta^{13}C$ signal from four African baobabs (*Adansonia digitata*) in northeastern South Africa and found that, over most of the record, wetter conditions were predominantly associated with El Niño events although this relationship altered after c.1970 when wetter periods became associated with La Niña.

Beyond climate, dendrochemistry has been used to identify trends in emissions from smelters in both Zambia and Namibia (Mihaljevič et al. 2011; 2015; 2018) using *Pinus latteri* (Tenasserim pine) in Zambia and marula (*Sclerocarya birrea*) in Namibia with a focus on lead and copper from the Copperbelt and Tsumeb smelters, respectively. These records covered 50–70 years and lead ($^{206}Pb/^{207}Pb$) and copper ($^{65}Cu/^{63}Cu$) isotope ratios used to confirm that, close to sources, tree rings reflected above-ground contamination (i.e., atmospheric deposition to leaf surfaces), while at more remote locations, records may be affected by soil chemistry and root uptake (Mihaljevič et al., 2011). In summary, a number of southern African tree species contain datable, annual tree rings and may reach multi-century age (Gebrekirstos et al., 2014; Woodborne et al., 2015). Although reported issues around radial translocation (Hagemeyer, 2000; Chellman et al., 2020) may make interpretation of high-resolution records complex, studies elsewhere on mercury (Schneider et al., 2020), and ^{129}I and ^{14}C from nuclear weapons tests (Turney et al., 2018; Zhao et al., 2019) do suggest potential for Anthropocene records.

Hyrax middens

The use, by some species, of a habitual location for defecation results in an accumulation which may be used as a natural archive. In southern Africa, hyraxes (several species of mammal in the order Hyracoidea) produce middens in sheltered areas such as under rock overhangs. Due to their well-preserved and dateable nature, the analyses of hyrax middens for pollen and insect remains have been used in palaeobotanical and ecological studies

(Quick et al., 2011; Chase et al., 2012) producing records of vegetational and climatic change over millennia (Scott, 1996; Scott et al 2004). Chase et al (2012) summarise the requirements for hyrax midden preservation, as well as their rate of accumulation and temporal resolution. They show that depending on the morphology of the midden and the size of the colony using it, accumulation rates may range between 20 and 2,000 years cm^{-1} and extend back over 40,000 years. Apart from pollen analysis, phytolith, aDNA and lipid biomarkers have been used to provide information on changes in diet while microcharcoal extractions, $\delta^{13}C$ and $\delta^{15}N$ have been used to assess climatic and hydrological change (Chase et al., 2010; 2012). While distribution and conditions appropriate for long-term preservation of hyrax middens are widespread across southern Africa, the low temporal resolution over the most recent period makes them less suitable to measure potential Anthropocene markers.

Discussion

If the Anthropocene Epoch is to be formally recognised, then it will require a GSSP to be established that marks its base in a stratigraphic sequence. Furthermore, if this is to happen in the next few years, then unless a new multi-proxy, high-resolution dataset becomes recognised soon, this GSSP is likely to be selected from one of the records currently under investigation by the AWG. None of these are in Africa. However, the process by which a GSSP is selected may also include “the selection of some auxiliary stratotypes in which the same level is represented by similar or other proxy signals in different parts of the world” (Waters et al., 2018). In order to demonstrate the global synchroneity of a marker that identifies the new epoch it would therefore seem appropriate for at least one auxiliary stratotype to be located in Africa and hence identifying potential archives and sites for future studies is beneficial to this process. If these archives could also be located towards the south of the continent, then they would additionally contribute to the scarcity of data for many of these markers in the southern hemisphere. However, although auxiliary stratotypes can extend the utility of a GSSP, they have no official standing and are not formally approved or ratified by the International Commission on Stratigraphy or by the International Union of Geological Sciences.

There is a long history of palaeoenvironmental studies in southern Africa, but these have been mainly focused around long-term issues on climate change, environmental transformation (e.g., vegetational shifts and fire regimes) and human occupation. Reviews of multiproxy palaeoenvironmental and archaeological studies across southern Africa (Fitchett et al., 2016b; 2017) revealed very few that were likely to provide a suitable temporal resolution to study Anthropocene environmental change, and to date, shorter term, high resolution studies over the last 70 years (i.e., since the start of the proposed Anthropocene) are rather scarce, which is why no GSSPs in southern Africa are currently under consideration. The lack of extensive data on Anthropocene markers is therefore not due to neglect, but rather that the big research questions in the region have not revolved around the Anthropocene or the dramatic changes caused by the Great Acceleration (Syvitski et al, 2020) observed elsewhere. Despite this, as we have shown, considerable potential exists. This includes extant high-resolution archives which may only require additional analyses to be undertaken should sufficient material remain stored in an appropriate way (e.g., high resolution sediment cores taken from Lake Otjikoto in Namibia; Tabares et al., 2020) or, more likely, from new material collected from natural archives in the region.

Although fewer than for some parts of the world (Downing et al., 2006), the number of standing water bodies present across the region and their potential for possessing rates of sediment accumulation suitable for high resolution analysis, initially makes them an attractive prospect as archives of information on the Anthropocene. However, in southern Africa few lentic waters are permanent. Most are ephemeral or seasonal, while many of the artificial pans and dams are not of sufficient age to be useful for an Anthropocene stratigraphy, or they have been disturbed through drawdown or dredging such that their sediment records are unlikely to be uninterrupted and continuously accumulating. However, a small number of permanent lakes, mainly in Mozambique, South Africa and Madagascar, but also less frequently in Botswana and Namibia, are certainly worthy of more detailed palaeolimnological investigation. Possibly more than in most other regions of the world, human pressures on African lakes are recognised to be increasing rapidly (Mammides, 2020) and so anthropogenic markers from both local stressors and the global proxy signals required for a GSSP might be expected to be evident. Beyond lakes, other archive types across the region also possess potential. Marine sediments from the Namibian or Namaqualand 'mud-shelf' (Herbert and Compton, 2007) and off the coast of northwest Madagascar (Fontanier et al., 2018), peats from the Klip River wetland that drains the southern flank of the Witwatersrand watershed and those from the Zululand Coastal Plain, (Thamm et al., 1996), as well as corals from off the south-west coast of Madagascar and from the Mozambique channel (Zinke et al., 2004; 2019) and some long-lived tree species all contain records of sufficient longevity and resolution that, elsewhere, have been used to identify records of the Anthropocene. Although in southern Africa published evidence is, so far, scarce, many of the key markers for the Anthropocene, including the proposed primary one, plutonium, have been identified albeit not always as a well-dated chronological sequence.

Atmospherically transported and globally distributed radioisotopes, mercury, stable nitrogen isotopes and, to a lesser extent microplastics, may all be expected to be recorded and identifiable in natural archives across the region (Figure 2). Furthermore, rapid increases in the regional use of coal since the 1950s whereby consumption in South Africa alone increased from around 6 million tonnes per year in the late-1940s to over 120 million tonnes per year in the early-21st century (Figure 2) might be expected to result in concomitant increases in fly-ash (SCPs) and mercury deposition to, and storage within, archives across the region. Mercury emissions from South African sources reflect this escalation with an increase from around 13 to over 200 tonnes per year over the same period (Figure 2). The use of organochlorine pesticides may also be expected to leave clearly identifiable signals of the compounds themselves, and their metabolites and derivatives, although to our knowledge there have been no published stratigraphies. The use of DDT to control vector-borne disease starting from the mid-decades of the 20th century resulted in an estimated increase in emissions between the latitudes of 18-30 °S from less than 10 tonnes per year in the late-1940s to over 70 tonnes per year in the 1970s (Schenker et al., 2008) (Figure 2) and this might also be expected to be reflected in natural records.

In summary, rapid environmental change in southern Africa, coincident with the Great Acceleration of the second half of the 20th century, has been associated with the emission, deposition and/or production of most of the Anthropocene markers observed in many better studied parts of the world. With careful selection, there is no reason why data from natural archives in the region should not contribute substantially to the debate on the global synchroneity of selected Anthropocene markers and to expanding the utility of a GSSP for the Anthropocene Epoch when it is eventually ratified. This could be through the provision of a robustly, chronologically constrained auxiliary section including a range of the possible proxies associated with the post-1950s period and from a number of possible archives.

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Table 1: Physical, ecological and human markers associated with the Anthropocene.

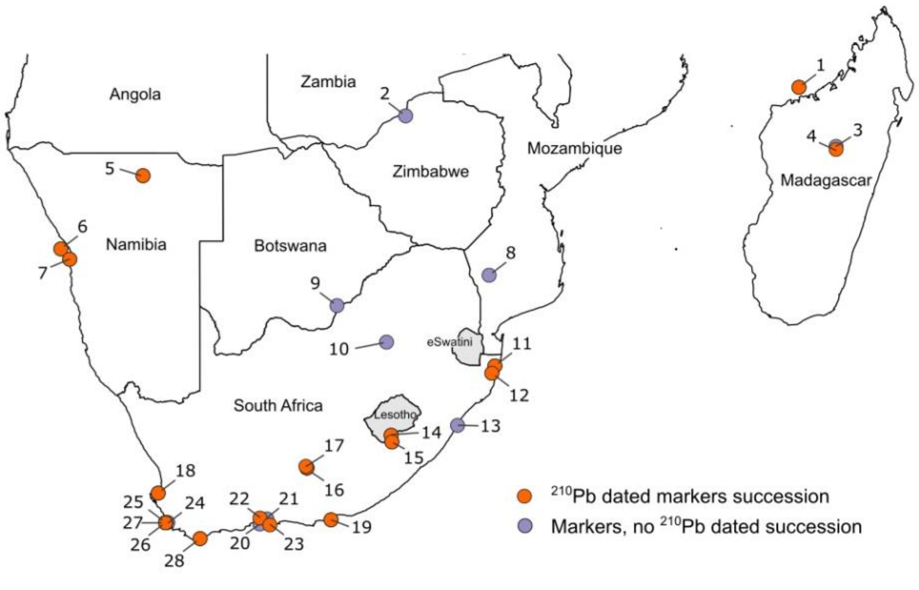
Chronological	**Isotopes**	**Geochemical and particle**	**Ecological Indicators**	**Human Modification**
Annual laminae (varves, growth banding) Radionuclides ^{239}Pu, ^{240}Pu, and ^{241}Pu ^{137}Cs, ^{134}Cs ^{241}Am ^{236}U, ^{90}Sr Radiometric dating ^{210}Pb ^{14}C	δ^{13}C/δ^{15}N ^{206}Pb/^{207}Pb δ^{202}Hg	Heavy metals Organic compounds Fly Ash (SCPs) Black carbon Total Carbon/Nitrogen Microplastics Novel materials	Pollen Diatoms Ostracods Foraminifera Invasive species Domestics Extinctions	Sedimentation and erosion Mines Mine tailings Refuse/Landfill Buildings and infrastructure Urbanisation Agriculture

Note: δ^{18}O, δ^{11}B, NO_3^-, S & SO_4^{2-}, CO_2 & CH_4 have also been used as markers in corals, speleothems and ice cores.

Table 2: Peatland area (Joosten 2009) and the number of large dams (and age of oldest) recorded by country (AQUASTAT 2021). nd = no data

	Peatland area (km²)	**Number of large dams**	**Date of oldest recorded dam**
Botswana	3,000	10	1964
eSwatini	50	9	1966
Lesotho	20	7	1963
Madagascar	1,900	nd	nd
Mozambique	2,000	36	1953
Namibia	100	24	1933
South Africa	300	552	1691
Zimbabwe	nd	198	1901

Figure 1. Locations of published sediment successions containing typical Anthropocene markers (See 'Markers' section); with ^{210}Pb dating (orange dots) and without ^{210}Pb dating or insufficient age/depth to verify mid-twentieth century time (purple dots).



ID	Name	Location	^{210}Pb	^{137}Cs	Pu	1950
1	Fontanier et al. 2018	Mozambique Channel (marine)	Y			Y
2	Kunz et al. 2011	Lake Kariba (Lake sediment)		Y		
3	Chamizo et al. 2020	Madagascar peatlands			Y	Y
4	Rääf et al. 2017	Madagascar peatlands	Y	Y	Y	Y
5	Tabares et al. 2020	Lake Otjikoto (Lake sediment)	Y	Y		Y
6	Emeis et al. 2009	Namibia (Marine)	Y			Y
7	Orani et al. 2019	Namibia (Coastal)	Y	Y		Y
8	Ekblom & Gillson 2010	Limpopo River (Pan)				
9	Franchi et al. 2020	Notwane Reservoir (Dam)				
10	Humphries et al. 2017	Klip River (Wetland)				
11	Stager et al. 2013	Lake Sibaya (Lake sediment)	Y	Y		Y
12	Humphries et al. 2010	Mkuze River (Wetland)	Y	Y		Y
13	Matsugama et al. 2017	Durban Harbour (sediment)				
14	Rose et al. 2020	Letšeng-la Letsie (Lake sediment)	Y	Y		Y
15	Van der Waal et al. 2015	Thina catchment (floodplain)	Y	Y		Y
16	Mighall et al. 2012	Karoo (Dam)	Y	Y		Y
17	Foster et al. 2007	Karoo (Dam)	Y	Y		Y
18	Kading et al. 2009	Berg River (Saltmarsh)	Y			Y
19	García-Rodriguez et al. 2007	North End (Lake sediment)				Y
20	du Plessis et al. 2020	Bo Langvlei (Lake sediment)	Y			Y
21	Reinwarth et al. 2013	Eiland Vlei (Lake sediment)				
22	Haberzettl et al. 2019	Swartvlei (Lake sediment)	Y			Y
23	Wündsch et al. 2016	Groen Vlei (Lake sediment)	Y			Y
24	Neumann et al. 2011	Princess Vlei (Lake sediment)				
25	Das et al. 2008a	Zeekoevlei (Lake sediment)	Y	Y		Y
26	Das et al. 2008b	Zeekoevlei (Lake sediment)	Y	Y		Y
27	Das et al. 2008c	Zeekoevlei (Lake sediment)	Y	Y		Y
28	Gordon et al. 2012	Soetendalsvlei (Lake sediment)	Y			Y

Figure 2. Schematic diagram showing hypothetical historical profiles for selected stratigraphic markers for the Anthropocene in southern Africa (developed after Bancone et al., 2020). Radioisotopes ($^{239+240}$Pu, ^{241}Am, ^{137}Cs) show a coincident peak at 1963; microplastics may be expected to follow that of global production (data from PlasticsEurope 2012; 2016; 2019; 2020) although taphonomic processes may cause anachronistic records (Bancone et al., 2020); DDT emission data are taken from Schenker et al (2008) for southern latitudes 18° - 30°; mercury emission data and coal consumption data for South Africa (to show probable SCP trends) are taken from Rose et al. (2020). Horizontal bar indicates 1950 +/- 5 as the likely start of the proposed Anthropocene Epoch.