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Vulnerability of geoheritage sites in South Africa to climate change: Examples from the Eastern Cape Province

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ABSTRACT

Climate change and variability have potential to impact on all types of heritage sites globally, through increasing weathering and erosion of geological and built heritage, changes in biome and ecosystem viability, sea-level rise and coastal flooding, and increased climate hazard events. This study examines the most likely impacts of climate change on different heritage sites in South Africa, with a particular regional focus on sites of potential geoheritage interest in the Eastern Cape Province of the country. The diverse examples described in this study are: (1) Klasies River cave, which is a Middle Stone Age archaeological site; (2) different localities along the coast where faunal footprints are preserved within aeolianite that dates mainly to the last interglacial period; (3) different localities inland where rock art panels are present within caves or rock shelters; and (4) Cape St Francis, which is a coastal foreland where different phases of late Quaternary coastal dunes with archaeological interest are preserved. Results show that many of these very varied sites of geoheritage interest are not protected as National or Provincial Heritage Sites under current legislation, which is weak and inconsistently applied across the country. This means that no specific management plans, under national policy guidelines, are in place for mitigating against the impacts of present and future climate change and variability, either regionally or nationally. These climate changes include: sea-level rise and increased coastal storminess and wave attack; and changes in weathering and erosion regimes as a result of increased temperatures and likely decreased rainfall or higher rainfall variability. A better appreciation of the interconnections that exist between geology and natural and cultural heritage may lead to valuing landscape and site geoheritage more highly at the local, national and international level.

1. Introduction

Many heritage sites of all kinds globally, including those of natural, geological and cultural heritage value, are currently under threat as a result of ongoing climate change and direct human activity, in combination (e.g., Scheermeyer, 2005; Chirikure, 2013; Brooks et al., 2020; Sesana et al., 2021; Vousdoukas et al., 2022). For natural and geological heritage sites, climate change can impact on land surface geomorphic and ecological processes and these in turn can alter site properties. This may potentially include the very properties for which the heritage site was protected, such as the presence of rare species. For cultural heritage sites, climate change and extreme weather conditions can threaten the fabric of built structures by rainfall or weathering, and ground stability through erosion or undercutting of these structures (Carroll and Aarrevaara, 2018; Saha et al., 2021). Heritage sites of different types that are designated or inscribed internationally, such as UNESCO World Heritage Sites (WHS), Ramsar sites, Biosphere Reserves or Global Geoparks, are also threatened by climate change (Marzeion and Levermann, 2014; Kapsomenakis et al., 2022; Vousdoukas et al., 2022) although in many cases the most likely impacts of future climate change upon individual sites are not known. Such impacts are not well known for heritage sites in Africa, where the continent is already water scarce and where there are both climatic and societal stressors on environmental resources that have potential to negatively impact on heritage sites (Knight et al., 2015; Knight and Merlo, 2024). These international heritage site designations are relatively under-represented in Africa compared to other areas of the world (Table 1). For example, only 13 % of WHS are found in Africa whereas of those WHS that are categorised as 'in danger', 38 % ($n = 21$) are in Africa. Thus, African sites have higher vulnerability to 'endangerment' in particular where governance and management frameworks are insufficient to mitigate against climate and other risks (Matshusa and Leonard, 2023a, 2023b).

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Table 1
Internationally identified sites of (geological, natural or cultural) heritage values, and those that are under threat because of climate change (data correct as of 16 October 2023).

Conservation scheme	Number of sites identified (number in Africa)	Those threatened by climate change	Source	Number of sites in South Africa
UNESCO World Heritage Sites	1199 (154, 13 %)	56 (4.7 %) listed as 'in danger' although climate change is not mentioned explicitly as a reason.	https://whc.unesco.org/en/list/	10 (including transfrontier sites)
Ramsar sites	2494 (424, 17 %)	613 (24.5 %) due to climate change and severe weather.	https://rsis.ramsar.org/	29
UNESCO Biosphere Reserves	748 (93, 12 %)	Not clear, but 45 sites withdrawn from the World Network of Biosphere Reserves (as of 2018). Site management plans and annual updates are not provided.	https://en.unesco.org/biosphere/wnbr	10
UNESCO Global Geoparks	195 (2, 1 %)	Not clear. Site management plans and annual updates are not provided.	https://www.unesco.org/en/iggp/geoparks#full-list-of-unesco-global-geoparks	None
IUGS Geological Heritage Sites	100 (15, 15 %)	Not described	https://iugs-geoheritage.org/designations/	1

Despite the acknowledgement of the role of climate change as a threat to heritage sites at an international scale, there is much less known about the threats to heritage sites that are protected through national or regional scale legislation and policies in South Africa (van der Merwe, 2019; Neto and Henriques, 2022). This is despite such sites being far more common than WHS and, by virtue of their smaller scale and the landscape, ecological or geological or heritage properties that are contained within them, are more vital and valued by local communities for their environmental and ecosystem services (Knight et al., 2015; van der Merwe, 2019). It is therefore likely that, at a global scale, such local sites have been overlooked in an assessment of potential threats, and that there is insufficient audit at a national or regional scale that evaluates these threats systematically in terms of heritage site vulnerability. These sites may also be influenced by more local-scale factors including threats from urbanisation, mining or agriculture; and extreme weather events (Sayama et al., 2022). For example, heritage sites along the coast of southeast Brazil are reported to be exposed to the effects of sea-level rise and tidal flooding and this is amplified by aquaculture, salt production, urban development and groundwater extraction (Mazzucato et al., 2022; Rabelo et al., 2023). In Scotland, climate change represents a significant threat to many heritage sites, largely as a result of coastal erosion triggered by sea-level rise and increased storminess (Wignall et al., 2018; O'Neill et al., 2022). Changes in rainfall and river erosion, and destabilisation of mountain rock slopes, give rise to increasing geohazard risk to certain Scottish sites (Gordon et al., 2022). Although climate change can be considered as a regional to global driver, its impacts on individual sites will depend on site type (geological, natural, cultural) and site properties. This means that potential impacts of climate change on heritage may be highly variable.

The aim of this study is to examine the challenges posed by climate change on heritage sites in South Africa and with implications for conserving heritage site properties and values. This aim is achieved by (i) first examining the number and distribution of heritage sites of different types across the country from a national heritage database, and (ii) then considering the specific site-scale issues associated with climate and environmental changes at selected geoheritage sites in one of South Africa's nine provinces, namely Eastern Cape Province. (iii) This study then identifies and discusses the global-scale challenges posed by climate change on the viability of different types of heritage sites in the Anthropocene, with specific reference to South Africa where climate change impacts are predicted to be significant for the environment and for human communities. This work is important and novel because it highlights the limitations of existing heritage management strategies and the challenges posed by climate change to heritage sites. It also proposes some solutions to these problems.

For convenience, this study employs the following terms to describe the focus of conservation of particular heritage sites: *geoheritage sites* are those where geological or geomorphological features or structures are the focus; *natural heritage sites* are those where plants, animals or ecosystems are the focus; and *cultural heritage sites* are those where tangible elements of the built environment (rather than non-material cultural artefacts) are the focus. These definitions broadly follow those used by UNESCO for the adoption of WHS, although in reality most heritage sites contain several of these elements in combination (e.g., Saha et al., 2021; Kapsomenakis et al., 2022).

2. Research approach

This study assembles and analyses information from previous studies and publicly-available databases on different types of heritage sites in South Africa, and provides new insight on the vulnerability of some specific geoheritage sites to climate change. Heritage in the country is administered through the South African Heritage Resources Agency (SAHRA), which is a statutory body established by the National Heritage Resources Act and tasked with declaring, monitoring and managing heritage sites and assets of different types, with a dominant focus on cultural heritage sites. Sites identified by SAHRA are recorded on the South African Heritage Resources Information System (SAHRIS) database (available at https://sahris.sahra.org.za/, accessed 16 October 2023) (Smuts et al., 2016; Mlungwana and Jackson, 2017). All catalogued data are downloadable as a single Excel spreadsheet and it was in this format that the data were then analysed. Results of this analysis are presented below and discussed at the national and then the provincial scale. This analysis is then supported by observations and site descriptions from specific sites of geoheritage interest in the Eastern Cape Province of South Africa. Site properties are discussed with respect to present and future predicted patterns of climate and environmental change in the region. This then helps to derive an understanding of site vulnerability and resilience to ongoing climate forcing.

3. Heritage sites and conservation in South Africa

At a national scale, heritage assets of different types in South Africa are protected under several different national policies and statutory instruments, dealing with built heritage, cultural heritage, and natural heritage. An overview of the legislative and policy context of heritage conservation in South Africa has been recently provided by van der Merwe (2019). The relevant legislation includes the National Heritage Resources Act, No. 25, 1999; World Heritage Convention Action, No. 49, 1999; and the Tourism Act, No. 3 of 2014, as well as provincial-scale legislative instruments that mirror national legislation and policies (Knight et al., 2015; van der Merwe, 2019). Limitations of the scope and implementation of these instruments have also been identified, with particular reference to their coverage of geoheritage (including palaeontology) (e.g., van der Merwe, 2003; Cairncross, 2011; Deacon, 2015). Indeed, of the 15 categories of 'heritage' identified by SAHRIS, 13 are cultural and only two are geological (meteorites, palaeontological sites). Landscape geomorphology, and ecosystems or species (i.e., of '*natural*' heritage) are not specifically mentioned.

The SAHRIS database (as of 16 October 2023) was interrogated. The database comprises 3840 items in total and in this analysis all items were used, even though there are some problems with this database, described below. Here, 2664 sites (69.4 %) are declared as National Monuments and 89 (2.3 %) as Provincial Monuments. Twenty four sites (0.6 %) fall within or are part of a Conservation Area. Other sites have "registered" status (605, 15.7 %), although it is not clear exactly what this means, or have information missing in the database (325, 8.5 %). The major classifications of National Heritage Sites (4.5 %) and Provincial Heritage Sites (74.3 %) are the most significant conservation sites listed in terms of legal robustness (Table 2). The detailed classification of 'site type' appears rather arbitrary, inconsistently applied and geographically biased (Table 3). For example, archaeological and palaeontological sites are a relatively small proportion of the total (12.6 %) but there are two shipwreck sites and three rock art sites that are not classified as archaeological, and an internationally-significant cave site at Sibudu (KwaZulu-Natal Province) with Middle Stone Age lithic technocomplexes (Wadley, 2005) that is classified as neither archaeological nor palaeontological but is termed 'Artefact, Deposit'. Geological sites are relatively common at the national scale (24 % of the total), but these exclusively refer to geotrails and are all located at four nearby sites in Mpumalanga Province. No National Heritage Sites of geological interest are noted anywhere else in the country, despite locations such as Table Mountain and Vredefort meteorite site being of global renown (Anhaeusser et al., 2016). Of the Provincial Heritage Sites, site type classification appears to be somewhat more inclusive. By far the most common sites are 'buildings' (87.1 %, Table 4) but these correspond to individual buildings only, and are often adjacent buildings along the same street. Archaeological sites are more common at the provincial (n = 40) than the national level (n = 17). However, there are other site types that could be usefully classified as archaeological but which are not, including two rock shelter sites, two shell midden sites, and nine prehistoric stone wall sites. The National Heritage Resources Act also grants statutory protection to all rock art sites, whether these are reported or not. This may account for the relatively low proportion of sites in which rock art is specifically mentioned (Table 4). Sites classified as 'natural' at the provincial level include waterfalls or stands of trees. Geological and palaeontological sites are a very minor component of Provincial Heritage Sites overall (0.8 %) and mainly refer to specific outcrops where certain features (glacial pavements, dinosaur tracks) can be seen.

Each of South Africa's nine provinces has a provincial heritage authority, established under the National Heritage Resources Act, that is required to consider and inscribe Provincial Heritage Sites (Mlungwana and Jackson, 2017; Jackson et al., 2019). The regional allocations of National and Provincial Heritage Sites are shown in Table 5. Some provinces have a higher proportion of National rather than Provincial Heritage Sites (Gauteng and Mpumalanga), whereas in other provinces it is the opposite (Eastern Cape, Western Cape). Such inconsistencies highlight inherent problems with the identification and the subsequent listing of these sites. This is done by local field recorders working within individual provinces, and thus the numbers and types of sites identified at provincial and then national level (Tables 3, 4) depend very much on the interests, expertise and motivation of individual recorders. This can explain why there are thematic and geographic 'biases' in the database. In addition, some provinces actively engage in heritage issues (including

Table 2
Classification of heritage sites in South Africa from the SAHRIS database (accessed 16 October 2023). Please note that KZN refers to sites classified under provincial legislation in KwaZulu-Natal Province. Similar legislation exists in other provinces but no other examples are listed in the SAHRIS database.

Site status	Number
Deproclaimed	7
Heritage Area	26
Heritage Landmark (KZN)	2
Heritage register sites	610
Heritage register sites (KZN Heritage Act)	45
National Heritage Sites	175
Protected Areas	1
Provincial Heritage Sites	2853
Provincial Landmarks (KZN)	1
Provisional protection	120
TOTAL	3840

Table 3
Site types of those that are identified as National Heritage Sites on the SAHRIS database (accessed 16 October 2023) (n = 175).

Site type name	Number
Archaeological	17
Buildings	39
Burial grounds and graves	31
Cultural landscapes	4
Geological	42
Palaeontological	5
(Other site types)	37
TOTAL	175

Table 4
Site types of those that are identified as Provincial Heritage Sites on the SAHRIS database (accessed 16 October 2023) (n = 2853).

Site type name	Number
Archaeological	40
Battlefields	20
Bridges	12
Buildings	2486
Burial grounds and graves	51
Geological	12
'Natural'	53
Rock art	15
Palaeontological	12
(Other site types)	37
TOTAL	2853

Table 5
The distribution by province of National and Provincial Heritage Sites in South Africa, from the SAHRIS database (accessed 16 October 2023). Symbols for province names are used on Fig. 1.

Province name	National Heritage Sites		Provincial Heritage Sites	
	Number	%	Number	%
Eastern Cape (EC)	13	7.4	589	20.9
Free State (FS)	3	2.8	159	5.6
Gauteng (GT)	34	19.4	174	6.2
KwaZulu-Natal (KZN)	8	4.6	250	8.9
Limpopo (LIM)	3	1.7	37	1.3
Mpumalanga (PM)	44	25.1	53	1.9
North West (NW)	6	3.4	52	1.8
Northern Cape (NC)	2	1.1	178	6.3
Western Cape (WC)	59	33.7	1328	47.0
(Overseas territories)	1	0.6	0	0
TOTAL	175	99.8	2820	99.9

heritage tourism, conservation and management) whereas others have very few personnel and little expertise in this area (van der Merwe, 2019). It can also explain situations where existing sites are neglected despite the statutory requirement for compliance by provinces under the National Heritage Resources Act 1999 (Jackson et al., 2019; Motlanthe, 2021).

Other problems with the SAHRIS database are also identified. There are many duplicates within the record. Different 'sites' may actually be several elements within the same overall site; for example different graves within the same cemetery that fall under the same gazette number in the database. The database also includes 'heritage objects' such as artefacts or specimens that may be conserved ex situ in museums or archives, thus these items do not have a geographical context.

Sites are also conserved nationally through the South African National Parks (SANParks) network. Across the country, there are 19 National Parks (including transfrontier parks) that cover over 37.5 million km^2 or 3 % of the country's area. These historically tend to focus on plant and animal conservation although they indirectly include wider landscape and thus elements of archaeological and geological heritage. Examples are the mid-19th century Albasini Ruins and Masorini Iron Age smelting site in Kruger National Park in northeastern South Africa. Other protected areas in South Africa under national-scale legislation include Marine Protected Areas, Forest Reserves and botanical gardens. There are also many private game reserves which likely host sites of archaeological and geological heritage.

4. Heritage conservation sites at a provincial scale in South Africa: Eastern Cape Province

The national-scale context of heritage conservation in South Africa, especially with respect to geoheritage, can be examined in detail using the case study of Eastern Cape Province, one of nine provinces in South Africa (Fig. 1). This province represents 13.9 % of the total area of the country, 11.0 % of the national population (in 2022) and 7.9 % of national GDP (in 2022) (data from https://ecprov.gov.za/). It also contains 7.4 % of National and 20.9 % of Provincial Heritage Sites (Table 5). The classification of all heritage sites in the province is shown in Table 6. This shows, relative to the national total on the SAHRIS database, that the Eastern Cape Province is over-represented in terms of heritage sites including buildings, monuments and memorials, and palaeontology. It is under-represented in archaeological and 'natural' sites. Cultural landscapes, geological and rock art sites are not listed as being present at all.

Although the properties of the physical environment and their attributed heritage values depend upon underlying geology, geomorphology, ecology and human history, some of the disparities between national- and provincial-level records are striking. The meaning of 'natural' heritage in the database is not always clear as in the Eastern Cape one of the 'natural' sites listed includes a botanic garden, which is clearly human-made. Of the five palaeontological sites listed for Eastern Cape, three cover the same broad stratigraphic interval and marine faunas of the Lower Campanian (Upper Cretaceous) (also ascribed to the Eocene) but at two different sites. At Needs Camp near East London, foraminifera assemblages have been described from marine sandstones and clayey limestones (Cooper and Liu, 1999; McMillan, 2009); at several coastal locations such as south of Port Edward (Fig. 1), foraminifera and molluscan faunas have been described from the Mzamba Formation (Cooper and Greyling, 1996). In terms of archaeological sites, three are listed within the Eastern Cape (Table 6). One of these sites, White Lady Cave at Kalkoenkrans, is very poorly described: the SAHRIS website simply states that 'this cave contains very rare and important rock paintings' but does not describe these panels further or given any attribution. The 'White Lady' of the title refers to the rock art figures of these panels, although their gender and meaning is uncertain and very little research has been done to investigate them (Baard, 1970; Green, 2020). However, several rock art traditions have been identified in the Eastern Cape (Henry, 2010). The other two archaeological sites listed are actually a single site, Klasies River cave, but listed separately as a National Heritage Site, and as a Provincial Heritage Site and National Monument. The justification for its designation as a National Heritage Site, as given on the SAHRIS database, is as follows: 'The Klasies River Cave Complex has yielded some of the earliest and most extensive evidence for anatomically modern humans in southern Africa, and some of the oldest behavioural evidence for a coastal economy through the extensive use of marine resources in Africa. The site also preserves the most extensive record on stone artefact technology, food gathering and settlement organisation in the Middle Stone Age in sub-Saharan Africa.' There is no information on areal coverage of the site designation, the nature of elements at the site that are protected, or any other

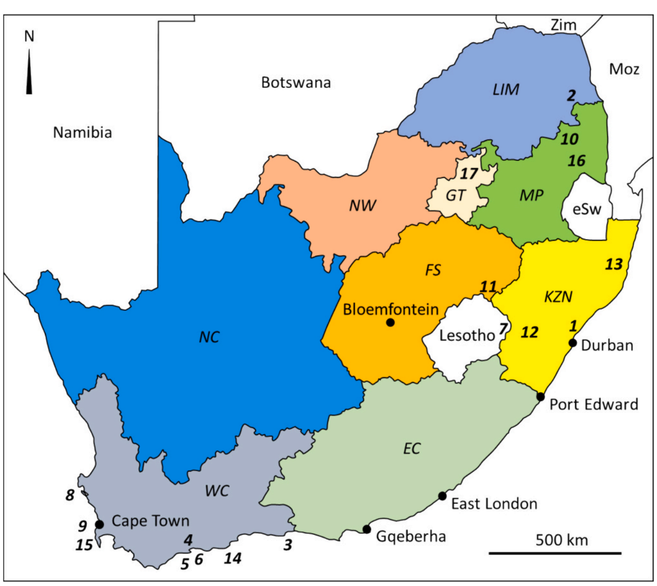

Fig. 1. Location of the Eastern Cape (EC) Province of South Africa and locations of sites named in the text. Full province names from their abbreviations are given in Table 5. Zim = Zimbabwe, Moz = Mozambique, eSW = eSwatini. A more detailed map of Eastern Cape Province is shown in Fig. 2. Sites mentioned in the text are: 1-Sibudi cave, 2-Masorini Iron Age site, Kruger National Park, 3-Robberg, 4-Still Bay, 5-Blombos cave, 6-Pinnacle Point, 7-Drakensberg mountains, 8-Saldanah Bay, 9-Robben Island, 10-Blyde River Canyon, 11-Golden Gate Highlands National Park, 12-Kamberg, 13-iSimangelio Wetland Park, 14-Wilderness lakes, 15-Chapman's Peak, 16-Sabie River, 17-Sterkfontein caves.

Table 6

Heritage site type in Eastern Cape (EC) Province, South Africa (accessed 16 October 2023) and their proportionality with respect to national totals of such sites.

Site type name	Number in EC (%)	Number of all such site types present in the SAHRIS database (% of such sites in the EC)
Archaeological	3 (0.5)	57 (5.2)
Bridge	1 (0.2)	12 (8.3)
Buildings	593 (94.1)	3277 (18.0)
Burial grounds and graves	8 (1.3)	82 (9.7)
Conservation area	1 (0.2)	26 (3.8)
Cultural landscapes	0	16 (0)
Geological	0	56 (0)
Monuments and memorials	8 (1.3)	57 (14.0)
'Natural'	3 (0.5)	59 (5.0)
Palaeontological	5 (0.8)	17 (29.4)
Rock art	0	19 (0)
(Other site types)	8 (1.3)	162 (4.9)
TOTAL	630	3840

information about site properties or its history of investigation. This site is explained in more detail below.

Apart from the SAHRA sites, other heritage designations also cover areas of the Eastern Cape. This includes three SANParks National Parks (Addo Elephant National Park, Camdeboo National Park, Mountain Zebra National Park) (Fig. 2) that are mainly conserved for their ecology but also include elements of geological interest. There are no Ramsar sites present. At Addo Elephant National Park, some work has examined the role of rivers and soils in landscape formation (Roux et al., 2002). At Camdeboo National Park, dolerite and sandstone weathering forms are common landscape elements enjoyed by visitors, especially at a site called the Valley of Desolation where dolerite columns are present. This is a designated Provincial Heritage Site. Within the Mountain Zebra National Park, some previous work has been concerned with ecosystems and grazing patterns (Novellie and Bezuidenhout, 1994; Bezuidenhout and Brown, 2021). There are a number of rock shelter and open-air archaeological sites within the park (Brooker, 1977) but this is not mentioned by SANParks on their website (https://www.sanparks.org/parks/mountain_zebra/).

In order to examine these issues in more detail, specific examples of geoheritage sites in the Eastern Cape are now presented, including consideration of the role of climate change in impacting upon their physical properties (locations shown on Fig. 2). The majority of these are not even mentioned on the SAHRIS database, and their absence may mean that any unprotected site is vulnerable to destruction.

5. Heritage sites in the Eastern Cape and potential climate change impacts

5.1. Klasies River cave

This is one of the most important archaeological sites in southern Africa because of its long record of lithic technology and human cultural evolution from at least Marine Isotope Stage (MIS) 5 onwards (Villa et al., 2010; Stratford et al., 2021; Brenner et al., 2022). Klasies River Main Site comprises a complex of two main caves (caves 1, 2) and adjacent rock shelters (caves 1 A, 1B). The site is approximately 25 m inland from the present-day shoreline and coastal storm beach and is located between 6 m (floor of cave 1) and 18 m asl (floor of cave 2) (Fig. 3). These caves were developed by weathering and erosion in an undulating cliffline of quartz arenite bedrock. With reference to the geologic and landscape setting of the site, several studies have examined how prehistoric peoples made use of environmental resources in the surrounding environment (Lombard and van Aardt, 2023), including on the continental shelf of the Agulhas Plain that was periodically exposed during global sea-level lowstands (Loftus et al., 2019; Wurz et al., 2022). Evidence for human occupation and site use at Klasies River comes from charcoal, pollen and other biochemical markers and remains, and from cave earth stratigraphy constrained by radiometric ages. This evidence reflects variations in climatic conditions over glacial–interglacial timescales. It also reflects the development of human activity and occupation styles, evidenced by different lithic technocomplexes during the Middle Stone Age period (Lombard et al., 2022). A summary of the cave floor stratigraphy, age constraints and evolution, is given by Morrissey et al. (2022).

Although presently located not far above sea level, the long evolutionary history of the site means that its relationship with climate variability has also changed. For example, during the last interglacial which corresponds to the earliest dating evidence at the site, regional sea levels were 6–8 m higher than present (Marker, 1987), meaning that cave 1 was routinely wave-washed and storm wave effects would have been experienced at all the other sites. During glacials and sea-level lowstands, rivers and wetlands would have been a common feature of the surrounding environment, with more common megafauna in the region, and the coastline would have been more distant, maybe by some tens of km (Marean et al., 2020). Thus, the relationship between the site and surrounding environments and conditions has changed significantly over the lifespan of the preserved site today.

The major climate change threats to Klasies River caves are:

- Future sea-level rise. The present calculated rate of sea-level rise (at Gqeberha) based on CMIP5 reanalysis data for the period 1993–2018

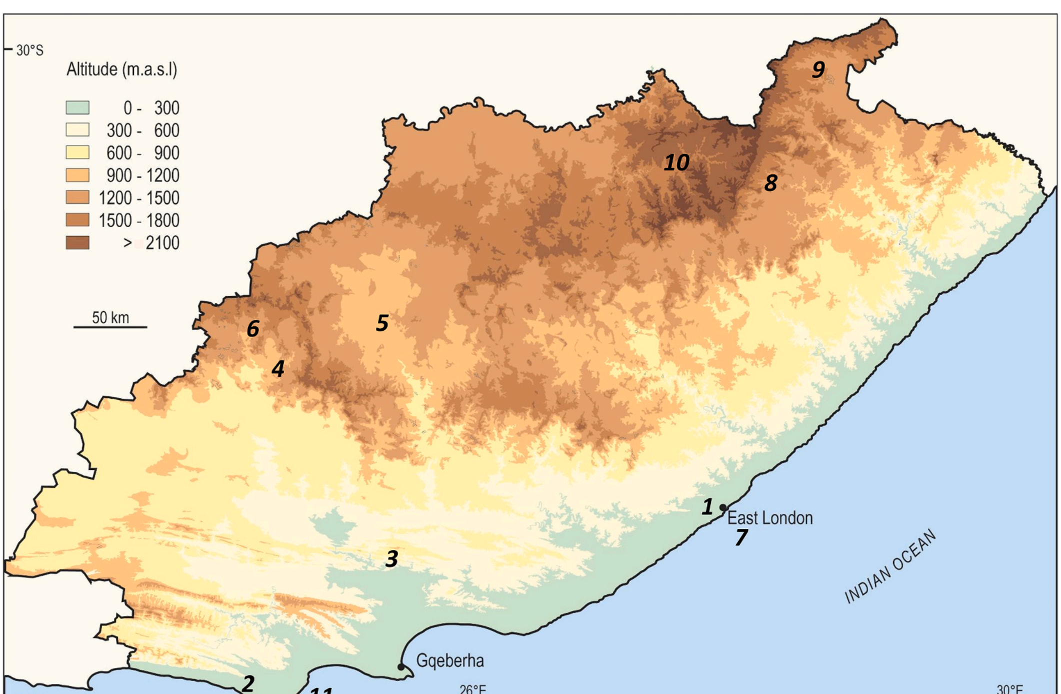

Fig. 2. Topographic context of the Eastern Cape Province, South Africa, and the locations of sites named in the text. 1-Needs Camp, 2-Klasies River caves, 3-Addo Elephant National Park, 4-Camdeboo National Park, 5-Mountain Zebra National Park, 6-Valley of Desolation, 7-Nahoon Point, 8-Maclear, 9-Matatiele, 10-Barkly East, 11-St Francis Bay.

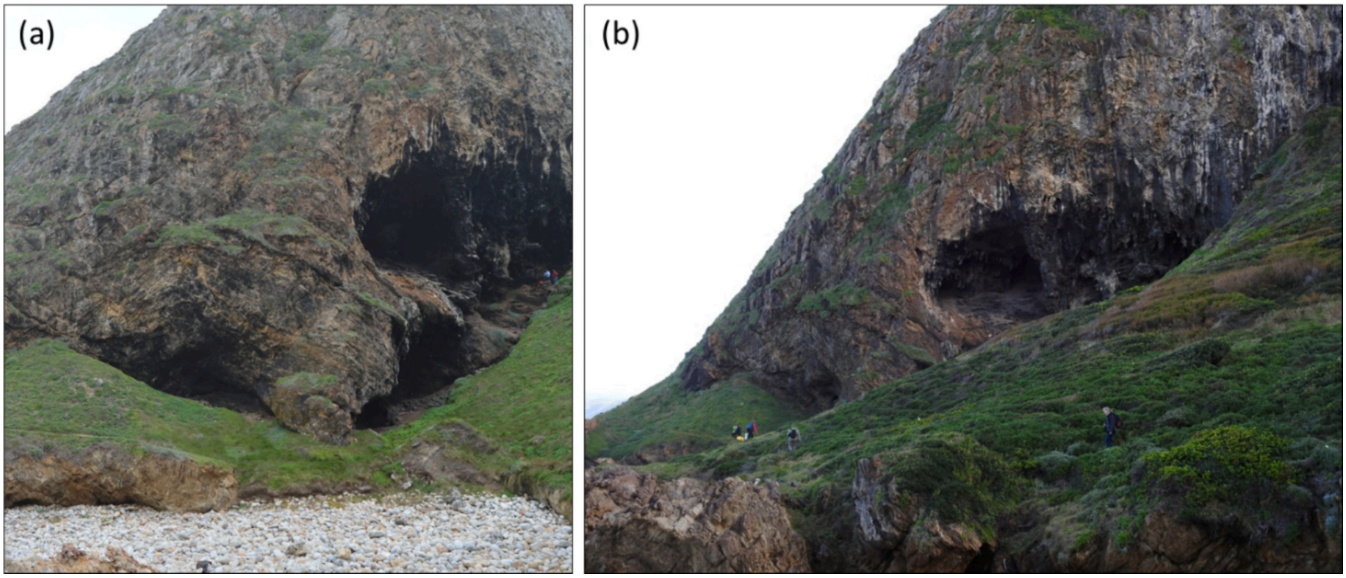

Fig. 3. Photos of Klasies River cave site, Eastern Cape coast, from different viewpoints, showing the main cave and rock shelter systems within which archaeological evidence is found (reproduced under Creative Commons license).

varies between +2.99 and + 3.95 mm yr^{-1}, based on different climate models (Allison et al., 2022). Based on different future emissions scenarios, future sea-level rise for Gqeberha is projected to be between 0.5 and 0.85 m by 2100 (Allison et al., 2022). Rising sea levels can lead to increased coastal erosion and undercutting of the cliff-face, and therefore destabilisation of the cave support structure. A more proximal coastline will also lead to higher energy conditions, the landward migration of the present storm beach (Fig. 3a), or stripping away of the beach landform and allowing bigger waves to approach the cave mouth.

- Increased coastal storminess and waves. Changes in storm tracks and synoptic circulation conditions, associated with warmer seawater surface temperatures, can lead to increased frequency of coastal storms, such as cut-off lows which are particularly common in this sector of the South African coast (Molekwa et al., 2014; Xulu et al., 2023), resulting in larger waves and thus more energetic coastal environments. The outcomes of this are increased nearshore wave height, higher coastal erosion, and increased likelihood of coastal flooding, and this trend has already been noted along the South African coast (Dube et al., 2022).
- Rockfalls and cliff stability. In coastal locations this arises mainly as a result of coastal erosion and cliff-face undercutting. A further factor contributing to instability in these locations is high rainfall, decreasing internal rock shear strength and increasing the likelihood of rockfall and other mass movements.
- Changes in cave environments. Increased temperature, moisture and humidity levels within caves and rock shelters can lead to increased weathering, plant or algae growth and deterioration of conditions suitable for site and artefact preservation (Patania et al., 2022).
- Changes in plants and ecosystems. This environment currently has grassy vegetation species typical of the regional Greater Cape Floristic Region (Lombard and van Aardt, 2023). Coastal squeeze as a result of sea-level rise and wave splash will increase soil salinity in this zone and this is more likely to favour both salt-tolerant coastal species and the spread of invasive species (Bessinger et al., 2022). Along rocky coastlines, this may also cause changes in tidal-elevation-dependent rates of marine notch development associated with increased wetting and drying cycles, and salt weathering (Trenhaile, 2014). Increased storminess and sea spray may also contribute to this.

5.2. Footprint and trace fossil sites

Much recent work along the south coast of South Africa has identified faunal footprints and a range of other trace fossil types of broadly Pleistocene ages (e.g., Helm et al., 2019, 2021; Lockley et al., 2022). These are found as imprints on the depositional surfaces of ancient sand dunes, now preserved in aeolianites, and in some instances are attributed to human activity (trackways) through a coastal sand dune environment (Helm et al., 2020, 2023a). Luminescence dating of the stratigraphic units of the aeolianites in which the footprints are found has yielded ages in the range 40–153 ka (Roberts et al., 2008; Helm et al., 2023b). These ages are therefore contemporary with the dated occupation of Klasies River caves and other sites along the south coast of South Africa, such as Robberg, Still Bay and Blombos (Helm et al., 2021). At Nahoon Point (East London, Eastern Cape), similar footprints have also been observed within aeolianite of MIS 5 age, and these footprints are also uniquely associated stratigraphically with occasional lithic artefacts of Middle Stone Age typology (Morrissey et al., 2020) (Fig. 4). This evidence is the first to specifically tie these track fossil imprints to human activity along the MIS 5 coastline in South Africa. It is also likely that aeolianite elsewhere along the coast contains more such evidence, as yet unknown.

Aeolianite is a common element along the South African coast, forming the cliffline at the back of sandy beaches (especially along the Western Cape coast) or on top of an upper intertidal or supratidal bedrock platform (where present along the Eastern Cape and KwaZulu-Natal coasts) (Bateman et al., 2004; Carr et al., 2019; Knight, 2021). Sand grain cementation by $CaCO_3$ is highly variable both within and along individual aeolianite beds. This results in a variable drusy to sucrose texture of aeolianite beds as a whole. Cemented elongate rhizoliths are also present, developed along former dune vegetation roots. Such variable cementation then gives rise to differential wetting/drying, thermal and salt (occasional biological) weathering, forming hollows excavated into the aeolianite (tafoni) that have case-hardened outer margins. Aeolianite erosion takes place as a result of structural collapse of individual blocks, often as a result of prior sand grain compaction during lithification, and affected by wave undercutting. Despite the importance of the evidence for faunal footprints and other trace fossils across the south coast, only a couple of sites in the Western Cape where footprints have been identified (Pinnacle Point, Blombos Cave; Helm et al., 2019, 2020) are listed as Provincial Heritage Sites. Nahoon Point

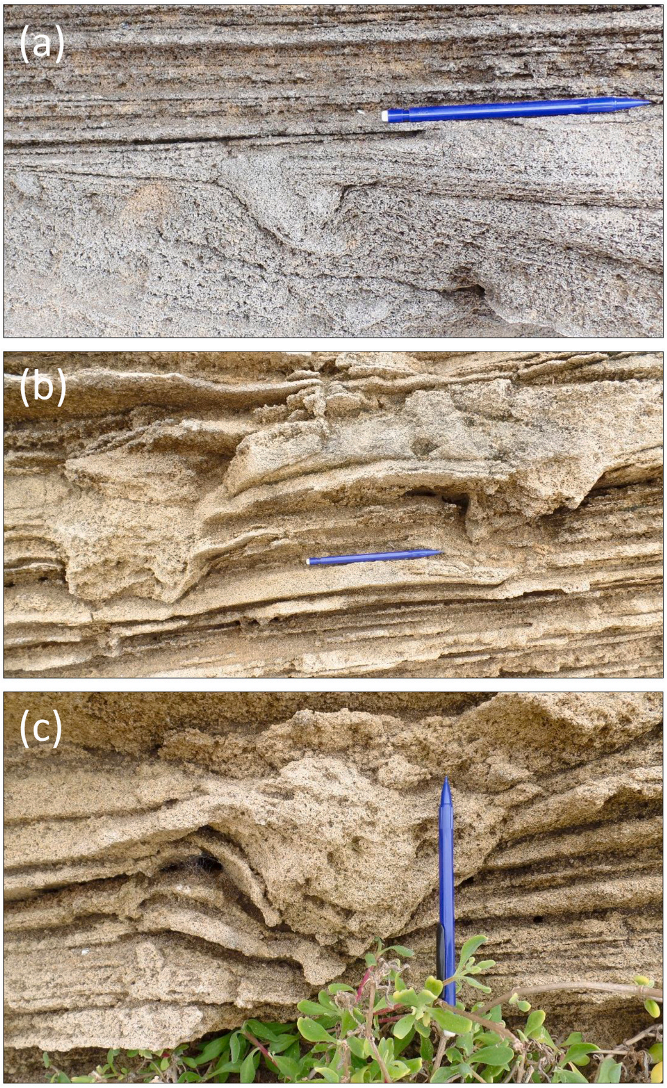

Fig. 4. Examples of trace fossil imprints (likely faunal footprints) within aeolianite at Nahoon Point, East London, Eastern Cape.

is protected as a Nature Reserve but does not appear on the SAHRIS database as a heritage site. Although footprints may be considered as ephemerally-exposed features and cannot in themselves be easily protected or conserved, the aeolianite coasts along which they are commonly found can be protected, and this may be a better and more inclusive conservation approach.

The major climate change threats to coastal sites where footprints and trace fossils in aeolianite are present include:

- Future sea-level rise and coastal erosion. Aeolianite sites commonly form natural coastal cliffs and as such are sensitive to the same present and future sea-level forcing as for Klasies River cave, described above. Future sea-level rise and increased coastal storminess (and associated increased wave heights) will likely increase the rate of wave undercutting, cliff collapse and thus erosion. Where presently exposed in the cliff-face, trace fossil imprints will be lost (although others may be exposed).
- Aeolianite weathering. Aeolianite generally has a friable sucrose texture that is sensitive to changes in environmental conditions (heating/cooling, wave splash, increased humidity within tafoni, the presence of marine and intertidal organisms) that can lead to increased weathering rates (e.g., McLaren, 2001; Erginal et al., 2013; Knight, 2021). The outcome of weathering is the development of deeper tafoni and other surface depressions, and granular disintegration of the aeolianite face. Biologically-induced weathering may also be increased by surface vegetation growth.
- Rockfalls and cliff stability. Wave undercutting, vegetation growth and destabilisation of individual aeolianite blocks can lead to rockfall and cliff collapse (summarised globally and also with reference to the South African coast by Emery and Kuhn, 1982). This is particularly the case on Western Cape aeolianite where these cliffs are near vertical and up to 30 m high (Knight, 2021).

5.3. Rock art sites

Many rock art sites are present throughout the Eastern Cape, especially in inland and rural locations, encompassing thousands of panels at dozens of sites, many of which are poorly documented or as yet undiscovered (Laue, 2017; Green, 2020). Rock art is particularly common at rock shelter sites around Maclear and Matatiele where mixing and conflict between prehistoric tribal groups took place, resulting in complex rock art scenes and images (Pearce, 2010; Pinto et al., 2018) (Fig. 5). Despite its significant cultural and archaeological importance, only one rock art site in Eastern Cape (White Lady Cave) is listed as a Heritage Site in the SAHRIS database (Table 6) and this is not actually a site that has been the focus of most recent research.

The major climate change threats to rock art sites include:

- Changes in cave microclimates. Increased temperatures, humidity and CO_2 values, associated with both climate change and when there is present-day human activity and tourism within the cave, have significant impacts on the stability of the cave environment, including the formation on condensation on cave walls, air circulation patterns and temporal (diurnal, seasonal) and spatial temperature gradients (Prelovšek et al., 2018; Salmon et al., 2024). This may also have implications for water availability within the cave (including $CaCO_3$ reprecipitation), and biological activity.
- Weathering and erosion processes and rates. Cave environments generally experience fairly constant environmental conditions, but if they change as a result of climate change or human exposure, then weathering and erosion processes and their rates would also likely change in response (Wang et al., 2014; Killing-Heinze et al., 2017). Physical weathering is commonly associated with the spalling of loose flakes or granular disintegration, especially on sedimentary rocks. Chemical weathering is facilitated by high moisture availability and atmospheric chemistry, in particular CO_2 levels (Wang et al., 2014). Predicted climate change trends in southern Africa to 2100 suggest increasing temperatures and declining rainfall, but that these trends are spatially variable across the region (Jury, 2013). In KwaZulu-Natal Province, higher fluctuations in seasonal rainfall to 2100 are predicted which, in combination with higher temperatures, leads to a statistically-significant increase in potential evapotranspiration ($r^2 = 0.41$) (Jury, 2022). It is very likely that the adjacent Eastern Cape will also follow this trend. However, the precise trajectories of change in cave microclimates are unknown and there are few studies globally that have considered these issues. Changes in cave humidity and liquid water availability are the most likely outcomes. Studies of rock art panels in the Drakensberg of eastern Lesotho, north of the Eastern Cape, suggest that rock moisture variability (wetting/drying) is the most important control on panel deterioration, rather than thermal stress (Hall et al., 2007; Meiklejohn et al., 2009). This suggests that a lower meteoric water flux into cave systems under climate change may potentially reduce these weathering rates.
- Pigment loss. Deterioration of painted rock art panels takes place through chemical and biological processes affecting the pigments (Arocena et al., 2008), or through changes in the integrity of host rock itself through granular disintegration. In addition, different pigments may also exhibit different responses to changes in thermal

Fig. 5. Example of a rock art panel (approximately 60 cm wide) from the Barkly East district of Eastern Cape Province. (Image reproduced with permission from SARADA/Rock Art Research Institute, image reference RARI RSA BUL1 164D.)

and humidity regime (Hall et al., 2007, 2010). Surface flaking is the major mechanism of rock art deterioration, where the pigment and attached rock mineral grains are detached together (Hoerlé, 2005). Changes in wetting/drying regimes is a likely climate change trigger for this process. Algal growth across organic pigments is another important flaking mechanism.

- Cave water movement. Rainwater and groundwater seepage onto cave floors, down cave walls, or through ceiling drips can also take place. Water flow down cave walls can lead to the precipitation of dissolved solutes, as speleothem growth or discoloration, that can potentially affect rock art panels. Future drier conditions may reduce this phenomenon.
- Physical instability. Collapse or destabilisation of caves or rock shelters can take place as a result of weathering or – in upland areas inland where most rock art sites are located in the Eastern Cape (Green, 2020) – mass movements associated with landslides, fluvial erosion, or slope processes. Climate change and more importantly climate instability is likely to increase the frequency of such events (Knight and Grab, 2021). Drier conditions in the interior may also promote decreased vegetation cover and thus increased likelihood of slope activity.

5.4. Cape St Francis palaeo-dune system

Immediately west of the town of St Francis Bay is the foreland of Cape St Francis (Fig. 6). This area (up to 17 km wide, extending up to 6 km inland, ~66 km^2) has been affected by repeated cycles of Quaternary sea-level change with palaeo- (fossil or relict) dunes <40 m high located on top of a basement of progradational gravel beach ridges (Marker, 1984). Collectively, these belong to the late Cenozoic Algoa Group (Le Roux, 1990; Claassen, 2014). This area therefore reflects the interplay between coastal processes and sea-level change during the Quaternary (Butzer and Helgren, 1972). The fossil dunes at Cape St Francis vary from parabolic dunes 10–15 m high at the landward margin of the system, to parallel, east-west-aligned, linear and laterally extensive (km-scale in length) relict foredunes. The present fossil dunefield at its western end is contiguous with active and progradational transverse and parabolic dunes at Oyster Bay (Knight and Abd Elbasit, 2022). There are also active transverse dunefields inland (Fig. 6a), triggered by deflation of the underlying fossil dunes that is likely related to vegetation disturbance.

To examine the progressive development of the dune system in more detail, in this study ridge crestlines were mapped and classified into contiguous geomorphic units on the basis of nested sets of ridges that can be considered to reflect single episodes of development (Fig. 7). These sets are separated by zones in which there is a significant difference in ridge alignment and where older ridges have been eroded out. Four phases of dune ridge formation are identified in this study (1–4 from oldest to youngest, marked in different colours in Fig. 7). Although the age and depositional environment of each phase is not known at this stage, Illenberger and Burkinshaw (2008) stated that Early Stone Age lithics recovered from the most landward dunes of the Cape St Francis system (stage 1 dunes, Fig. 7) suggest a dune system age of at least 200,000 years. It is likely that these different dune phases developed in response to different episodes of coastal environmental forcing, driven by changes in sea level that either expose the coastal plain as a site for dune progradation (during sea-level regression) or erode out and rework older dunes (during sea-level transgression) (Marker, 1984).

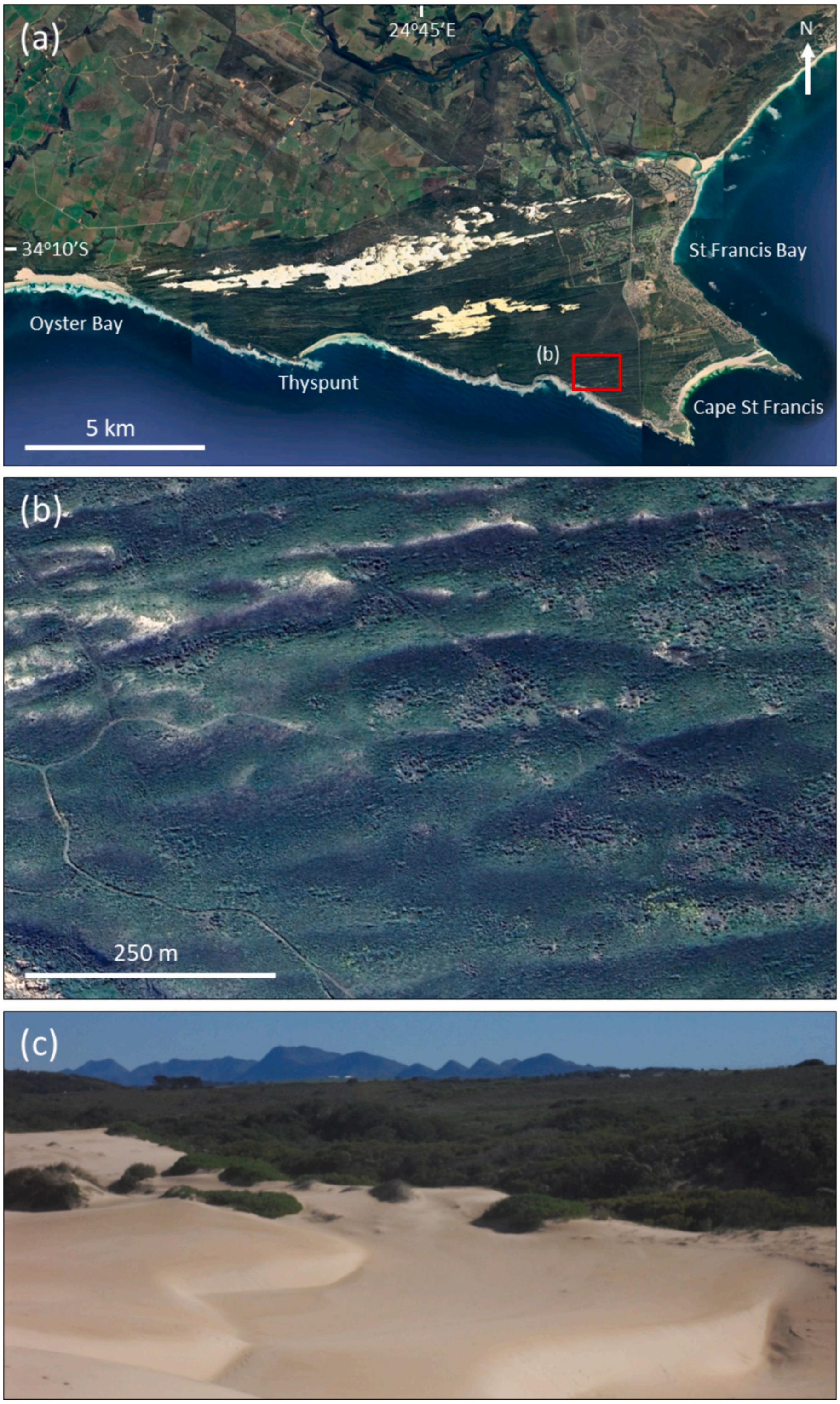

Fig. 6. (a) Map of the Cape St Francis area (location marked in Fig. 2) (background image from Google Earth, image date 8-11-2023), (b) detail of dune ridge morphology, location boxed in (a), (c) photo looking north from Oyster Bay, showing the vegetated palaeo-dunes inland.

Throughout, it is also important to note that the regional trend of the underlying geology is northwest–southeast (Claassen, 2014), therefore the orientation of the mapped dune ridges (Fig. 7) is not geologically controlled.

The major climate change threats to the Cape St Francis system include:

- Future sea-level rise. Increased coastal erosion associated with regional sea-level rise, previously described, will likely start to erode back into the present sand dune fringe, especially at the back of the sandy embayments at Oyster Bay, Thyspunt and Cape St Francis. This is very unlikely to influence windblown sediment supply inland, because of the dense vegetation on the adjacent dunes, but will have impacts on longshore sediment transport and sediment systems

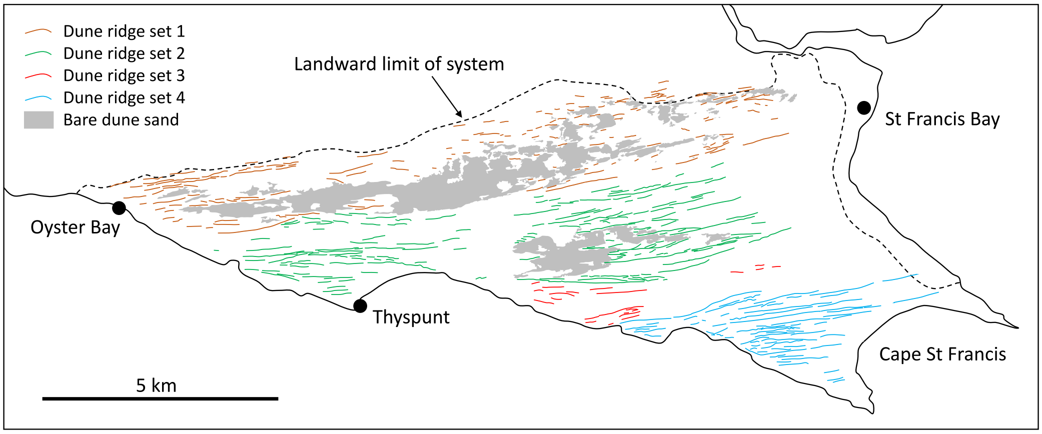

Fig. 7. Mapped crestlines of dune ridges in the Cape St Francis system, classified into four phases (1–4) from oldest to youngest.

Table 7
Potential changes in future climatic conditions and their likely impacts on different heritage types in South Africa.

Climatic driver	Environmental outcomes	Locations most affected	Types of heritage sites most affected and their impacts	Specific potential examples in South Africa (marked on Figs. 1, 2)
Sea-level rise	Enhanced coastal erosion, flooding, salinization of lagoon and estuary sites	Coastal/beach/cliff locations, estuaries, wetlands	Geoheritage: coastal sites, both rocky and sedimentary settings; increased erosion Natural heritage: intertidal and coastal ecosystems and habitats through coastal squeeze, increased erosion and salinization Cultural heritage: coastal built structures	Klasies River cave, Blombos cave, Pinnacle Point cave; estuary and mangrove sites, Saldanha Bay; Robben Island WHS
Increased mean temperatures	Higher potential evapotranspiration, reduced surface and soil water content	Regionally, especially in inland locations where future temperature increases are predicted to be higher than in coastal areas; increased temperatures/salinity and stratification of water bodies	Geoheritage: thermal stress weathering of rock surfaces, surface desiccation and deflation, impacts on lakes, rivers, rock surface landforms Natural heritage: decreased surface and soil water affecting different vegetation types, drought Cultural heritage: deterioration of stone built structures and rock art sites	Blyde-River Canyon tufa deposits (palaeo- and still actively forming); Golden Gate Highlands National Park historic cemetery (sandstone); Kamberg Rock art site; iSimangeliso Wetland Park; Saldanha Bay; Wilderness lakes
Change in precipitation (higher or lower annual totals, event precipitation, seasonality)	Increased river flooding and associated erosion, increased land surface instability and mass movements	Regionally, especially in inland locations, in valleys and in upland areas	Geoheritage: land surface erosion on slopes, river valleys, coasts; slope destabilisation and different types of mass movement hazards Natural heritage: flooding of low elevation/relief areas, impacts on ecosystems and animal species; impacts of prolonged dryness on plant species; impacts on food chains of prolonged droughts or longer dry seasons Cultural heritage: erosional undercutting of built structures especially along rivers and coasts; ground surface dryness may cause subsidence	Recent closures of the infamous Chapman's Peak Drive, Western Cape, due to heavy rains and rockfalls; Sabie River flood of 2000 in Kruger National Park caused centennial scale riparian landscape change
Increased extreme events (floods, heatwaves)	Increased landslides and other mass movements, increased flood events, fire hazards	Regionally, the areas affected will depend on the extreme event type. Heatwaves, thunder storms and lightning are more likely to take place inland, cyclonic storms and intense rainfall are more like to take place around the coast	Geoheritage: marginal environments at the top/bottoms of slopes, on steep, bare, or unconsolidated slopes, along river valleys or coasts will be particularly affected by land surface instability Natural heritage: land surface instability and extreme events can stress ecosystems and marginal species Cultural heritage: land surface instability and extreme events can deteriorate the structure of buildings or can lead to physical destruction	Historic 70 yr old Durban Vishnu Temple completely destroyed in the April 2022 flood; Closure of the Sterkfontein Caves (Cradle of Humankind) due to flooding and rock instability

adjacent to the bedrock headlands. These issues have been previously discussed along the Eastern Cape coastline (Knight and Burningham, 2021, 2022).
- Invasive species and other ecosystem changes. Regionally dryer conditions will influence fire state at Cape St Francis, where fire events have impacts on ecosystem composition and dynamics in this area (Strydom et al., 2021). Destabilised land surfaces as a result of fire can lead to increased soil erosion, deflation, and can favour the spread of invasive species and scrub.
- Groundwater level changes. Areas between sand dune ridges commonly intersect the groundwater table, forming wetter areas (ponds or small wetlands), termed slacks. These are generally areas of much higher biodiversity within sand dune environments, particularly for invertebrates, and have been described from Eastern Cape dunefields (van der Merwe and McLachlan, 1991; Avis and Lubke, 1996). A regional aridity trend, previously described, and a decrease in groundwater table elevation will contribute to drying out of slacks with associated negative impacts on biodiversity. It is also likely to increase deflation and dune activity in these areas.

Other future challenges at Cape St Francis, not related to climate change, include development and urbanisation, sand mining, and overall land degradation and environmental deterioration.

6. Discussion

This study shows that the concept of geoheritage covers a wide range of landscape-scale processes and properties that, both directly and indirectly, are of value for not just geology and geomorphology, but also for their natural and cultural heritage, as well as for today's use of environmental and ecosystem resources and services. These reasons mean that sites of geoheritage importance should be set in their wider landscape context that provides a more integrated justification for their protection (Knight et al., 2015; Neto and Henriques, 2022). Overarching issues related to the impacts of climate change on geoheritage sites in South Africa are listed in Table 7. These show that all types of climatic and weather events have potential to negatively impact upon all heritage types, and may give rise to changes in their properties (such as ecosystem composition) and their physical integrity and intactness. This integrated approach to evaluating impacts of climate change on heritage sites has not been always widely adopted (Saha et al., 2021; Selmi et al., 2022; Kapsomenakis et al., 2022); most work hitherto has focused on coastal sites subject to changes in sea level and coastal erosion (Marzeion and Levermann, 2014; Sabour et al., 2020; Ciski and Rząsa, 2021; Vousdoukas et al., 2022). There is therefore a need for an integrated landscape-scale approach to integrated heritage conservation and management.

6.1. *Limitations of the SAHRIS database and the identification of geoheritage sites in South Africa*

The SAHRIS database reflects the listing of National and Provincial Heritage Sites in South Africa. Thus, the limitations of the database reflect the inadequacies of the site designation process when enacting the requirements of the National Heritage Resources Act. This process seems very haphazard and uncoordinated, with many sites recorded on the SAHRIS database being originally identified as far back as 1936 (thus predating the National Heritage Resources Act) and not seemingly revisited since. This is clear from the limited documentation provided on SAHRIS for each individual site. It also suggests that some sites in the database may be now redundant or duplicated, may no longer exist, or the reasons for their original designation are no longer applicable. The overall structure of the database has multiple and overlapping heritage categories (termed 'types') that are in some instances illogical and there has been hitherto a greater emphasis on built heritage rather than other types of heritage (Table 4). It is also notable that 'geological' and rock art sites are not mentioned at the provincial scale in the Eastern Cape, despite these being important expressions of regional geoheritage (as described in this study), and the latter of which being statutorily protected under the National Heritage Resources Act in the first place. All these points highlight that the sites listed on the SAHRIS database reflect a reactive process (in response to potential sites being brought to SAHRA's attention by individuals) rather than as part of a proactive and national-scale mapping and inventorizing strategy. As indicated in this study, the examples presented from the Eastern Cape show that many sites with significant geoheritage interest are not mentioned or acknowledged at the provincial level. There is very little correspondence between the scientific investigation of these sites and how that translates to the valuing and protection of sites, and this is an element that is missing in the SAHRIS database documentation. This absence makes it more difficult for planners and managers to understand any recent work on individual sites, and thus the potential scientific importance of those sites.

SAHRA itself states that "SAHRIS represents a world first in terms of proactive, integrated heritage management tools" (Smuts et al., 2016, p.138). This evaluation by SAHRA of its own work is incorrect and misleading. SAHRIS, as a national inventory of heritage sites, is out of date, incomplete, not linked to present knowledge or research, and is thus insufficient as an evaluative or a site management tool. This is also shown by the lack of capacity and engagement with heritage management issues at the provincial level (Jackson et al., 2019; Motlanthe, 2021). The absence of geoheritage throughout is of concern because geology and geomorphology provide the context for all other heritage types, thus one cannot protect the latter without being aware of and appreciating the former. A key example is battlefield sites (Table 4) that are of historical and cultural significance but which are strongly influenced by their physical and geological setting (Passmore et al., 2015). It also means that any unlisted sites are more likely to be neglected, polluted or destroyed. The general lack of public and community participation in heritage management also means that the different values ascribed to sites by local people are not considered (Sethaba and Scholes, 2021; Matshusa and Leonard, 2023a).

6.2. *Future geoheritage site management under climate change*

The Natural Resources Management Act does not specifically discuss the role of management strategies under climate change or other drivers. However, the Declaration of Antananarivo (dated 2019), put together by PanAfGeo (Organisation of African Geological Surveys Partnership) amongst other stakeholders, provides a framework for promoting geoheritage and geoconservation in Africa, and mentions climate change as an important site management challenge. A limitation is the extent to which these principles are being applied at the national level or at different sites in South Africa (e.g., Neto and Henriques, 2022; Matshusa and Leonard, 2023b). As the impacts of climate change may vary from one site to another (Table 7), it is important to consider the needs of individual sites separately as this will inform on the most appropriate heritage management plan for that situation.

Climate change is already known to be leading to significant deterioration of African heritage sites and their intrinsic properties (Berred and Berred, 2021; Vousdoukas et al., 2022; Knight, 2023; Matshusa and Leonard, 2023a). This is in addition to an increasing continental-wide population and increasing need for environmental and ecosystem resources and services. Thus, heritage management is also part of the wider context of environmental and socioeconomic sustainability. A better understanding of the relationships between landscape geology and different heritage types may lead to a higher appreciation of the value of landscapes and their geoheritage.

6.3. Recommendations for heritage managers, practitioners and researchers

This study highlights that there is a disconnect between the sites that are listed on the SAHRIS database and the site descriptions that accompany them, and the scientific and heritage values ascribed to these and other unlisted heritage sites by researchers and local communities, respectively. This is particularly the case for geoheritage sites. Thus, the SAHRIS database needs to be updated to reflect the most recent research, and other important geoheritage sites added to it. This should be done by active and systematic engagement between geoscientists, governmental heritage officers at the provincial and national level, and heritage practitioners who deal with site management and community engagement on the ground. At present, there does not seem to be a forum in which such interactions can take place, and this is a limitation in ensuring that SAHRA has the most up-to-date information. There is also a need for a clearer process for site identification, valuing and listing through SAHRA, such as an online web form where individuals can propose different categories of heritage sites, and a mechanism by which these proposed sites can be checked or investigated by provincial or national heritage officers. There is also a need for SAHRA to systematically undertake (possibly annual) site visits for all sites in the database, to check their condition, identify threats, and to gather information from relevant stakeholders including heritage officers, site managers and local communities. Sites noted as under threat should be flagged and a corrective management plan put in place. There also needs to be clear criteria and a mechanism for site delisting and/or downgrading (e.g., from a national to a provincial site) or upgrading (e.g., from a provincial to a national site). Greater alignment is also needed between national and appropriate international heritage categories and conservation schemes. Such actions as these will enable the SAHRIS database to be more complete, reflect present knowledge, needs and values of heritage sites, facilitate community engagement throughout, and will lead to better management decision-making.

These recommendations, although founded in the specific regional and national context of South Africa, are applicable throughout Africa and globally, not least because the same threats to heritage such as climate change, environmental pollution and infrastructure development are of global concern (Table 7). The recommendations also highlight the critical need to engage with all relevant stakeholders, and to seek links between heritage conservation and sustainable tourism, which is seen as key for socioeconomic development in natural, rural landscapes (Brooks et al., 2020; Matshusa and Leonard, 2023a; Knight and Merlo, 2024).

7. Conclusions

This study highlights the issues and limitations associated with geoheritage conservation in South Africa, especially in the context of ongoing climate change. The Natural Resources Management Act is the national legislation that applies to heritage conservation and management in the country, but the SAHRIS database that reports protected sites has limited information on the properties of individual sites and thus is of limited use for informing on heritage management. In addition, it is notable that geological and palaeontological sites hardly feature in this database. Nonetheless, examples from the Eastern Cape Province illustrate the wide range of sites of geoheritage interest, many of which are not protected as a designated Heritage Site and do not feature in any way in the SAHRIS database. This suggests a situation of:

- Lack of awareness of the importance of geological sites as features of heritage interest at the provincial level;
- Lack of motivation and engagement with geological heritage at the national level;
- Under-reporting of significant geological sites; and
- Inconsistencies in interest in geoheritage from one province to another.

Geological sites are sensitive to ongoing climate change, in particular through changes in temperature/precipitation that influence geomorphological processes, and sea-level rise. These challenges and their possible impacts are not considered in the context of geoheritage site management, which is a weakness of the existing legislation and how it is applied through SAHRA and reported in the SAHRIS database. At present, there is limited appreciation of geological heritage and its protection under the Natural Resources Management Act despite the significant role that geology and geomorphology plays in landscape development and in natural and cultural heritage sites.

CRediT authorship contribution statement

Jasper Knight: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Stefan W. Grab:** Writing – review & editing, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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