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A standardized database of MIS 5e sea-level proxies in southern Africa (Angola, Namibia and South Africa)

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Abstract. Evidence for sea-level change during and around Marine Isotopic Stage 5e (ca. 125 ka) in southern Africa derives from a wide variety of geomorphic and sedimentological sea-level indicators, supported in the past 2 decades by absolute chronological control. In addition to these proxies, data provided by both terrestrial (dune sediments and archaeological remains) and marine (lagoonal and nearshore littoral sediments) limiting points provide broad constraints on sea level. Here, we review publications describing these data points. Using the framework of the World Atlas of Last Interglacial Shorelines, we insert in a standardized database all the elements needed to assess former paleo relative sea level, and the chronological constraints associated with them (including uncertainties). Overall, we reviewed 69 studies, from which we extracted 35 sea-level indicators and 25 limiting points.
As far as age attribution is concerned, early dating of molluscs and whole-rock beachrock samples using U-Series allowed ating of several sea-level indicators during the 1980s but the more widespread application of Optically Stimulated Luminescence dating since 2004 has yielded many more (and more accurate) dates from several sites. This has helped resolve the nature and timing of MIS5e shorelines and has the potential to further elucidate the apparent presence of two or more sea-level peaks at several South African sites during this interval. The standardized sea-level database presented in this paper is the first of its kind for this region. Future research should be directed to improve the stratigraphic description of LIG shorelines and to obtain better dating, high-accuracy elevation measurements with better palaeo-RSL interpretation.

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

1 Introduction

This paper aims to describe in detail the background information contained in the southern Africa MIS 5e sea-level database, that was compiled as a contribution to the World Atlas of Last Interglacial Shorelines (WALIS) ESSD Special Issue. The database was created using the WALIS interface, available at this link: https://warmcoasts.eu/world-atlas.html. The WALIS interface has been built following the lessons learned from the PALSEA (a PAGES/INQUA working group) in terms of sea-level databases, summarized in a recent paper by Düsterhus et al. (2016). In brief, the WALIS interface allows a large range of data and metadata on Last Interglacial relative sea-level indicators and associated ages to be inserted into a mySQL database. An export tool allows users to download their datasets as a multi-sheet .xls file. The database for southern Africa described in this study represents the output of the export tool mentioned above, it is open access and is available at this link: https://zenodo.org/record/3960136. Each field in our database is described at the following link: https://doi.org/10.5281/zenodo.3961544. The open access database will facilitate research on the global and regional patterns of sea-level change by the sea-level research community including geophysical modellers, oceanographers, geologists and archaeologists.

To describe our database, and help the reader navigate through our choices in standardizing other author's works, we first give an overview of the published literature in the region of interest (See Section 2). While not all the studies cited in this section contain enough data to be included in the database, they represent the historical background upon which new data were collected and include sites that provide the potential for urther investigation with modern dating techniques. Then, we describe the types of sea level indicators and elevation measurement techniques we encountered while compiling the database (see Sections 3 and 4). In Section 5, we report details for each administrative province/region within the area of interest, where sea level data was reviewed. In the final two sections, we discuss further details on other metadata on paleo sea level indicators that are not included in our database, but that might be useful as research on Quaternary shorelines progresses in southern Africa. We discuss future research directions that may stem from this data compilation.

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

2 Literature overview

Multiple elevated shorelines (some exceeding 100 m above sea level) occur around the coast of Southern African (Angola, Namibia and South Africa). Many of these extend over large distances and they have long been recognised and described in varying levels of detail (e.g. Krige, 1927; Haughton, 1931, Soares do Carvalho, 1961; Davies, 1970, 1972, 1973, 1980). Many early descriptions are rather vague, with imprecise levelling, positioning and a lack of absolute (and even relative) dating control, but they drew attention to the presence of many potential MIS5e deposits. Geomorphological and occasional sedimentological description of these raised shorelines was often scarce or incomplete and their relationship to former sea level was imprecisely defined.

Much early dating of higher than present shorelines in southern Africa came from the study of archaeological material with no fixed relationship to sea level. It could, however, be used to constrain the minimum age of coastal deposits. The presence of Acheulean (approx. 1.5 Ma- 150 ka yrs) tools in littoral deposits or on elevated marine terraces was frequently used to differentiate pre-last interglacial shorelines. Davies (1980) for example, maintained that all elevated beach deposits above 4 m in Namibia were pre-MIS5 because they contained Acheulean tools. The presence of only stone tools of the Sangaon culture (130-10 ka yr BP) was regarded as indicative of Last Interglacial shorelines: for example, on this basis Davies (1970) assigned a probable last Interglacial age to a shoreline at ca. +9 m in KwaZulu-Natal, on the east coast of South Africa (Fig. 1)

Animal macrofossils (e.g. Hendey, 1970, Kensley and Pether 1986; Pether 1986; Le Roux, 1990) established the first absolute controls on some shorelines, particularly in the western Cape, and demonstrated that those higher than ca. 10 m were Early Pleistocene or older (several high shorelines date to the Miocene and Pliocene). Le Roux (1990) used these macrofossils to correlate Neogene units (including shoreline deposits) around the entire Cape coast of South Africa.

Dating and identification of the relationship of potential last interglacial shorelines to former sea levels remained problematic and contentious through the 1970s to the 1990s. Tankard (1975a,b) noted the

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

presence of shoreline deposits (open coast and lagoonal) associated with higher than present sea levels in the western Cape (St Helena bay area) (Fig. 1). By comparison with modern open coast and estuarine deposits, the former sea level was calculated at +6.25 m (Tankard, 1975a) and by comparison with global occurrences of shorelines at this elevation, was assigned a probable MIS 5e age. These deposits contained sub-fossil mollusc shells (in life position and transported) that included a cool water open coast assemblage and a lagoonal assemblage that included species currently confined to the tropics. These thermally anomalous molluscs (Tankard, 1975b) were taken as indicative of warmer waters during the last interglacial. Tankard (1975b) noted several sites between St Helena Bay and Knysna where these assemblages occurred in sediments associated with a former sea level of ca. + 6 m (Fig. 1). In a regional review of "Pleistocene" shorelines Davies (1970, 1971, 1972,1980) presented a gazette of several potential last interglacial sites, both estuarine and open coast, in South African and Namibia where molluscs occur that are currently restricted to warmer waters of west and east Africa. These he termed the Swartkops fauna. Davies (1980) stated (p154) "In estuaries of the South Cape between Coega and Mossel Bay and apparently as far west as Arniston, beds occur with warm water fauna at peak altitudes of +4 to +9 m. Some have probably been eroded, and all would have been laid down under water, so M.S.L. would have been over +9 m". A warm water estuarine fauna from a +6-8 m estuarine terrace at Kosi Bay (Fig. 1) was also assigned to the last interglacial (Cooper et al., 1989). Subsequently, Le Roux (1990) reported that these warm water mollusc species, from estuarine/lagoonal facies were associated with the 6-8 m shoreline and are probably coincident with "the well-documented period of higher temperatures at c. 120 000 B.P. (Kilburn & Tankard, 1975)."

Several sedimentological and geomorphological observations suggested the presence of more than one last interglacial stillstand of sea level at South African sites. Hobday (1976) recognized three "last interglacial
Shorelines" from Lake St. Lucia (+8 m, +3.4-5.3 m, and +4.5 m) and Tankard (1976) found three "last interglacial" shorelines around Saldanha Bay (+ 6.3 m, +2-3.5 m, and 0 m) (Fig. 1). At least the lowest of these three in each case may now be tentatively assigned a late Holocene Age (Cooper et al., 2018). Davies (1971, 1972, 1980) noted the repeated occurrence around the entire South African coast of a +6

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

m terrace incised into a +9 m terrace, implying two highstands separated by a regression. Barwis and Tankard (1983) also recorded two shorelines separated by a regression at Swartklip near Cape Town (Fig. 1). Cooper and Flores (1991) described the sedimentary facies of an outcrop at Isipingo near Durban (Fig. 1) and demonstrated that sediments from two former high sea levels were preserved between +5 and +6 m. Sedimentological work at Nahoon near East London (Jacobs and Roberts 2009) (Fig. 1) also pointed to two sea level highstands during the 5e interglacial, separated by a period of regression and dune building.

From the 1970s until early 2000s, in the absence of direct dating, it was widely accepted that the MIS 5e shoreline/s in South Africa were associated with sea level in the approximate +6-8 m range (e.g. Hobday, 1976; Hobday and Jackson, 1979; Barwis and Tankard, 1983; Cooper and Flores, 1991). The lack of dating control beyond old (contaminated) C14 dates, prohibited further comment on the time of deposition of these units.

Hendey and Cooke (1985) and Hendey and Volman (1986) mounted a challenge to this view after they found (on the basis of vertebrate fossil evidence) that deposits at Saldanha Bay associated with a +6-8 m shoreline (that had previously been correlated with MIS5e), were actually of early Pleistocene (1-1.5 Ma) age. Building on this, they then challenged the admittedly tenuous reported links between sea level and human occupation of important archaeological deposits in a cave at Klasies River mouth (Fig. 1). This evidence, they maintained, supported an early Pleistocene age for formation of the +6-8 m erosional terrace in the cave. They asserted that occupation of the cave (supported by U/Th dates of 98 and 110 ka) was contemporaneous with formation of a lower (supposed MIS5e erosional terrace) associated with a +4 m sea-level. Based on observations at this and and two other cave sites (at De Kelders and Herolds Bay-Fig. 1), they contended that the +6-8 m shoreline in South Africa was early Pleistocene and the MIS5e sea level did not exceed + 4 m. Subsequent OSL dating (see below) shows that their contention, based on universal extrapolation from a few sites, was incorrect.

Apart from several old and contaminated radiocarbon dates, no absolute dates existed for supposed

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

MIS5e shoreline deposits in South Africa until Davies (1980, p162) reported the results of Amino Acid Racemization dating of molluscs from three sites near Port Elizabeth (Fig. 1). The results, although inconclusive, suggested that two shells from a deposit at +6.5 m but "contemporary with the +8 m beds upstream" in the Swartkops Estuary "may be 130 000 B.P. or perhaps in the range 160 000 - 220 000". The first published compilation of late Quaternary to recent sea level data (Ramsay and Cooper, 2002) included only 4 dates from the late Quaternary, all of them based on Uranium Series dating. Since then, detailed studies in the Wilderness and Mossel Bay areas of the Western Cape (Fig. 1) (Carr et al., 2010; Bateman et al., 2008, 2011) and the Maputaland coastal plain in KwaZulu-Natal (Porat and Botha, 2008) applied OSL-dating to aeolianite and occasional littoral facies to investigate the timing of major coastal barrier and dune-building episodes. These were subsequently extended by offshore investigations that applied Optically Stimulated Luminescence (OSL and, in one instance, paired OSL and U-Series) dating to submerged deposits (Bosman, 2012; Cawthra et al., 2018). Data from these studies are reported below in a regional report of data availability.

In southern Namibia, diamond mining provided the impetus for investigation of former shoreline deposits both onshore and offshore (e.g. Spaggiari *et al*., 2006; Spaggiari, 2011; Runds, 2017; Runds et al., 2019; Kirkpatrick et al., 2019). The several higher than present "beaches" of the *Sperrgebiet* or forbidden zone (Fig. 1), rest on erosional terraces and were labelled A-F (with increasing elevation) by Corvinus (1983) (Fig. 2). This terminology has since been widely applied. Shorelines D, E and F range in bedrock platform height from +10 to +30 msl (Fig. 2). They contain a warm-water marine zone fossil *Donax rogersi* and are Tertiary in age (SACS, 1980; Apollus, 1995; Jacob, 2001; Roberts and Brink, 2002). Shorelines A, B and C are characterised by modern cold-water faunas, particularly the infaunal bivalve *Donax serra* (Pickford and Senut, 2000; Pether, 2000; Jacob, 2001; Miller, 2008). These littoral deposits truncate calcreted sandstones and underlying sands bearing the fossil *Equus capensis* and Acheulean artefacts, and are therefore younger than Middle Pleistocene (Pickford and Senut, 2000). Fossil and Middle Stone Age archaeological remains suggest that these lower shorelines (A-C) are younger than 200,000 years. The supposed Mid Pleistocene ('C beach') is located at +8m and the Late Pleistocene (MIS5e) ('B beach') is at +4m (Hallam, 1964; Corvinus, 1983; Pether, 1986; Schneider and

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

Open Access Earth System Science Data Discussions

Miller, 1992; Ward, 2000; Pether et al., 2000). The A beach at +2-3 m is likely of Holocene age but no absolute dating control has been established on shorelines A, B or C.

In Angola, Soares do Carvalho, (1961) first identified several marine terraces at various elevations above present sea level. These had littoral deposits resting upon them and as in Namibia, terraces and overlying deposits were considered to be broadly coeval. Giresse at al. (1984) reported U-Series dates on a number of these terraces at elevations between 0 and 55 m near Benguela and Lobito (Fig. 1). Of these, three dates, deemed by the authors to be acceptable, were in the MIS 5 range. Mollusc samples from a +10-12 m terrace dated to 91 and 136 ka, and from a +20 m terrace to 103 ka. These provided little additional insight into the chronology of the Angolan shorelines which remained enigmatic. Walker et al. (2016) identified a widespread terrace at +25 m elevation that dated to 45 ka (based on 8 OSL dates). This demonstrated late Pleistocene dynamic uplift of the Angolan coast by ca. 300 m (ca. 2 mm/yr) via a mantle done with diameter of ca. 1000 km, centred on Benguela. This finding of substantial tectonic deformation along the Angolan coast, effectively requires a reappraisal of the ages and elevations of all shorelines in Angola, that has yet to be undertaken.

We note that our database contains information on paleo relative sea levels. The "relative" term highlights the fact that every paleo sea level we report is uncorrected for potential post-depositional uplift or subsidence due to, for example, tectonics or glacial isostatic adjustment. Although the South African coast is regarded as tectonically stable during the Quaternary, the potential of tectonics on raised shoreline elevation has also been raised in northwestern South Africa (Namaqualand) and Namibia. Roberts and Brink (2002) reported deformation of Miocene and Pliocene shorelines on the NW coast of South Africa involving ca. 50 m vertical displacement. Raised beaches in the southern Sperrgebiet (southern Namibia, Fig.1) said to be of Plio-Pleistocene age appear to diminish in altitude from south to north (Stocken, 1978; Dingle *et al.*, 1983) and may imply recent deformation. Pickford and Senut (2000) note, however, that some of the Sperrgebeit shorelines may be as old as Miocene and the appearance of tilting could be an artifact.

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

3 Sea level indicators

In reviewing existing studies, we identified several types of last interglacial sea-level indicators (Table 1). All are sedimentological (based on distinctive sedimentary facies that are diagnositic of particular coastal and terrestrial environments) and their indicative meaning (i.e., the relationship between the elevation of the indicator and the paleo relative sea level it represents) can be inferred by comparison with their modern equivalents within certain error limits. The most widespread indicators are marine terraces that sometimes have associated littoral deposits. Although they can be related to former sea levels by comparison with modern equivalents, few of these, however, have been dated. Many estuaries and lagoons contain brackish water back-barrier sediments with distinctive molluscan faunas of which several are known to exist in a quantifiable relationship to sea level (Kilburn and Rippey, 1982). While many supposed MIS5e estuarine deposits have been reported and described in the regional literature, few of these have been studied in detail using modern dating techniques, nor with detailed sedimentological investigations that might provide higher definition relationships to former sea levels.
The most valuable (with best chronological and elevation constraints) Index points from the region are provided by a variety of preserved littoral deposits with a quantifiable relationship to sea level at the time of deposition. These include tidal inlet, foreshore and beachrock facies (Table 1). These can be linked to the sea-level at which they formed by comparison with modern equivalents, however, there is some variability in the vertical range in which each facies occurs. Tidal inlet and foreshore facies can only be constrained within a few metres of former sea-level, whereas beachrock can provide sub-metre constraints. The database also includes some broad indicators that simply record whether sea level was higher or lower than the dated sample. These include terrestrial limiting dates set by aeolianites (now-cemented aeolian dunes that formed by wind action on dry land) or marine limiting dates set by undifferentiated foreshore/shoreface sediments that formed at an unknown depth below sea level in the marine environment.

Table 1: Different types of RSL indicators reviewed in this study.

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

Name of RSL indicator	Description of RSL indicator	Description of relative water level	Description of indicative range	Indicator reference(s)
Tidal Inlet facies	Reversing trough cross-bedded sandstones with gravel lags	Low tide to -2 m	Modal depth of tidal inlet channel in contemporary estuaries	Carr et al., 2010; Cooper, 2002
Beach swash Zone	Planar bedded sands dipping steeply seaward, sometimes with berm to landward.	Low tide to +3 m	Tidal variation plus wave runup.	Cooper, 2013
Foreshore	Loose term applied to areas seaward of beachface by under wave influence- may extend to upper shoreface.	Low tide to ?10 m	Subtidal but under wave influence. Sometimes only a limiting indicator.	Cawthra et al., 2018; Carr et al., 2010.
Beachrock	Intertidal to shallow subtidal cemented beach facies.	Mid-tide to Shallow subtidal	Can be defined more precisely if sub-facies are identified (Mauz et al.,	Ramsay, 1994; Kelly et al., 2015; Mauz et al., 2016

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

			2016).	
Lagoon/estuary	Interbedded sand silt and mud, often with distinctive low energy molluscan assemblage.	Intertidal to subtidal (-3 m)	Tidal variation plus lagoon depth (usually very shallow in South Africa)	Cooper, 2002
Marine Terrace	A near-planar erosional surface in the intertidal zone	Lower intertidal zone	Storm wave swash height - Breaking depth	Smith et al., 2010; Dixon et al., 2014; Cooper and Green 2016)

4 Elevation measurements

The reviewed studies report elevations measured by either barometric altimeter (limited to early studies), levelling, echo-sounding, or do not report the elevation measurement method. As a consequence, the sea level datum to which the data is referred to is usually not reported, and has been assumed to be Mean Sea Level. Spring tidal range around southern Africa is generally less than 2 m but more precise recording and reporting of the relationship of former littoral deposits to contemporary sea-level (and preferably a fixed datum with a known relationship to modern sea level) is desirable in future studies in order to reduce vertical uncertainties.

Table 2: Measurement techniques used to establish the elevation of MIS 5 shorelines in Angola, Namibia and South Africa.

Measurement technique	Description	Typical accuracy
Not reported	The elevation measurement technique was not reported, most probably hand level or metered tape.	20% of the original elevation reported added in root mean square to the sea level datum error
Barometric altimeter	Difference in barometric pressure between a point of known elevation (often sea level) and a point of unknown elevation. Not accurate and used only rarely	Up to ±20% of elevation measurement
Total station	Levelling via optical instrument with elevation tied to fixed land-levelling datum or contemporary tidal frame	Typically ± 5 cm
Echo sounder	Submerged shoreline elevation fixed by acoustic echosounder usually corrected for tidal variation	Typically ± 50 cm

230 ## 5 Overview of datapoints inserted in the database

The sea level information reviewed for South Africa was extracted from sources that are described hereafter, with details reported in the Supplementary file annexed to this paper, as exported from the

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

WALIS data insertion interface (DOI: 10.5281/zenodo.3960136). All site names are the same as those reported in the database.

The database eincludes 60 datapoints, of which 35 are sea-level indicators (i.e. they exist in a quantifiable relationship to the sea level at which they formed) and 25 are limiting points (they show that sea level was some (unquantifiable) elevation above (terrestrial limiting) or below (marine limiting) the material sampled). Chronological control is based on luminesence dating (43 datapoints), luminescence dating (13 datapoints), Amino Acid Racemization (AAR) (1 datapoint) and 3 datapoints rely on stratigraphic control. The highest reported accuracy is associated with the luminescence dates and the AAR datapint is extremely uncertain.

5.1 Western Cape

In the Western province, important work on last interglacial shorelines has been conducted by Carr et al. (2010) who provided a detailed analysis from sites at three locations (Swartvlei, Groot Brak and Cape Agulhas) on the south coast (Fig. 1). This involved several OSL dates for sea-level indicators (tidal inlet, beach berm and foreshore) and several terrestrial limiting data from overlying terrestrial dune (aeolianite) deposits. Collectively, these define a sequence of sea-level indicators recording transgression to a peak of ca. + 8.5 m at ca. 127 ka followed by regression. At Swartvlei and Groot Brak tidal inlet facies overlain by shoreface or aeolian facies indicate a highstand 6.0– 8.5 m above modern sea level. At Cape Agulhas, a gravel beach (ca. 3.8 m amsl) and an overlying sandy shoreface facies (up to 7.5 m amsl) were deposited between 138±7 ka and 118±7 ka. The highstand was followed by accumulation of aeolian dunes (dating to 122±7 ka and 113±6 ka).

Cawthra et al. (2018) broadly confirmed these observations but identified a second sea-level peak from the Great Brak River sequence based on a lower foreshore deposit overlain by aeolianite in a regressive succession, which is in turn overlain by a higher foreshore deposit heralding renewed transgression. The two foreshore units separated by aeolianite suggests two sea-level highstands separated by regression. The second sea-level peak is represented by an ~ 2 m-thick coarse sandy tabular deposit with an

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

orthometric height of 6.8 m amsl. It was not dated but is younger than the underlying foreshore sediments (111.2 ± 7 ka).

At Langebaan several dated samples yielded a largely concordant series of TL, IRSL and U-series ages. The hominid footprints horizon was dated to ~108 ka, (corrected to ~117 ka based on global sea level curves and the conformable contact with the underlying strata) (Roberts, 2008). A discordant (older) TL date was attributed to incomplete bleaching of quartz grains (Roberts and Berger, 1997). The Langebaan footprints were interpreted to date from initial regression from the younger of two MIS 5e highstands identified at Nahoon (see below) at ~120 ka (Roberts, 2008).

Barwis and Tankard (1983) reported similar, but undated observations of two closely spaced probable MIS5e highstands at Swartklip, near Cape Town. The facies relationships reveal beachrock capped by calcrete topped by estuarine sediments and washover fans capped by aeolian dunes. From extant literature, the beachrock was tentatively linked to the 135 ka sea level high. The calcrete crust formed in a subsequent regression to below sea level. The estuarine and barrier washover facies were similarly linked to subsequent sea-level rise around 120+- ka and the washover elevation suggests a sea level at +5.1 to 8 m.

5.2. Eastern Cape

Jacobs and Roberts (2009) undertook a detailed study to clarify apparently conflicting ages of hominid footprint-bearing aeolianite at Nahoon (Fig. 3). They dated aeolianite and associated beachrock, reporting limiting ages for the aeolianite and an index point for the beachrock. The analysis also revealed the presence of two MIS5e beaches, only the younger of which was OSL dated (117 +/-6 ka). Roberts (2008) noted "already fully lithified footprint-bearing [a]eolianites of the Nahoon Formation in the area had been planed off and gullied by a later sea level which rose to ~6 m amsl. This suggested a Marine Isotope Stage 5e (MIS 5e) event. The Nahoon Formation [a]eolianites rest on shallow marine

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

deposits at ~1 m amsl, representing an older sea level highstand. Thus the geological evidence from Nahoon points to two highstands, an older event at ~2 m amsl and a younger counterpart at ~6 m amsl". Although many potential MIS 5 deposits have been reported from the open coast and estuaries of the Eastern Cape, the only other dated evidence comes from a site at Coffee Bay (Fig. 1), where an oyster shell from a beach whose base is at +4.5 m yielded a U/Th age of 104.9 +/- 9 ka (Ramsay and Cooper, 2002).

5.3 KwaZulu-Natal

Porat and Botha (2008), in a comprehensive study of dune development on the Maputaland coastal plain, established a chronology for the many aeolian depositional units. This enabled a reappraisal of the regional stratigraphy (Botha, 2018). They, however, recorded only one MIS5e date, (132710 ka, MP-22) from the crest of a 50 m-high coastal dune at Cape Vidal (Fig. 1), that gave no clear indication of the associated sea level. A cluster of U/Th ages from 95.7 to 117 ka (Ramsay et al., 1993), however, derived from marine shells, beachrock and an elephant tusk associated with a solution pothole on an erosional terrace cut into aeolianite near Durban, identify a sea-level at about +6 m. This is correlated with the second of two supposed (but undated) MIS5 shorelines described at adjacent sites at Isipingo by Cooper and Flores (1991). At Phinda game reserve (Fig.1), an oyster shell in a palaeoshoreline yielded a U/Th age of 95+/- 4 ka (Ramsay and Cooper, 2002). Several beachrock and aeolianite outcrops on the continental shelf (Ramsay, 1994; Bosman, 2012) have yielded sea-level index pints and limiting dates either side of MIS 5e (Table 1).

5.4. Namibia

The geological and sediemntological literature on the Nambian coastal deposits is quite extensive, but none of the literature surveyed meets the minimum database standards for MIS 5e sea-level quantification. The potential 5e sites reported in the literature lack absolute dating control; to our

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

knowledge, and despite the extent of diamond mining from raised shorelines north (downdrift) of the Orange River, no MIS 5e dates have been presented for raised shorelines in Namibia. It has been supposed on molluscan fossil evidence that a shoreline complex at + 8 m (the C Beach of Corvinus, 1983) is mid-Pleistocene and a + 4m (B beach) is of last interglacial age. These deposits require further investigation, especially to establish their ages.

5.5. Angola

Early U-Series dates presented by Giresse et al. (1984) included three potential MS5e ages for raised shorelines at + 12 and + 20 m. These require reappraisal, however, in the light of the subsequent presentation of multiple OSL dates for a +25 m shoreline dating to 45 ka (Walker et al., 2016), that implies large scale Quaternary uplift along the Angolan coast. The Giresse et al. (1984) data are included in the database, but their reliability and actual significance is uncertain.

6 Further details

6.1 Last Interglacial sea level fluctuations

The collated data from South Africa for the period 140-80 ka yr BP are shown in Figure 4 superimposed on global eustatic curves. The South African data are in broad agreement with the global record and include some useful new confirmatory index points for below-present sea levels, in particular. The record, however, also includes two distinct groups of apparently incongruous datapoints. The first (Fig.4, 5) involves OSL dates on submerged aeolianites that overlap with emergent data but which plot well under the inferred sea level. These may be the result of ex-situ sampling of loose boulders on the seabed. The second group includes four U/Th dated sea-level indicators that suggest a higher than present sea level between 80 and 100 ka BP when global records (and other South African index and limiting points, Fig. 4) suggest sea level was below -30 m. These likely indicate delayed uptake or non-closed systems and are probably best regarded as minimum ages.

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

Bateman et al., (2004) presented one dated point for sea level above present ca. 138 ka. Data from Cawthra et al. (2018) suggest a subsequent period of lower than present sea levels around 130 ka. Carr et al. (2006) provide several datapoints for an MIS 5e sea-level highstand of ca. +8 m centred on ca. 125 ka and there is a cluster of dates for a highstand between 115 and 120 ka. Taken together, however, the collated regional data are inconclusive regarding the presence of more than one sea level peak during MIS5e (Fig. 5); the paucity of data points and overlaps in the age ranges preclude a definitive statement. However, several lines of evidence are suggestive of sea-level fluctuations during MIS5e in South Africa (Fig. 5). Notwithstanding the scatter in ages from the collate data, analysis of sedimentary sequences at multiple sites points to two sea-level peaks during MIS 5e. These widely spaced sites include St Lucia (Hobday, 1975), Isipingo (Cooper and Flores, 1991), Nahoon, (Roberts, 2008; Jacobs and Roberts, 2009), Swartklip (Barwis and Tankard, 1983) and Langebaan (Roberts and Berger, 1997). At each of them, the sedimentary sequence (Fig. 6) points to two sea level peaks with an intervening period of lower sea level. While some of these sites contain some chronological control, none has been sampled adequately to more tightly constrain sea level during MIS5e

6.2 Other interglacials

In both the Western Cape and KwaZulu-Natal, coastal dunes of MIS 7 have been dated, but no shoreline indicators have been reported. Ramsay and Cooper (2002) reported a U/Th age of 182+/-18 ka (Pta-U430) from aeolianite from Reunion Rocks near Durban, which overlaps with an OSL date of 203+/- 13 ka (MP-33) from the same location reported by Porat and Botha (2008). Bateman et al. (2004) similarly recorded three OSL dates in the range of 176-283 ka from a landward dune ridge at Wildnerness (Shfd02132, 02133 and 02134). As noted above, early Pleistocene shoreline deposits are widely developed on east and west coasts of South Africa, Namibia and Angola.

6.3 Holocene sea level indicators

Shorelines associated with a Holocene sea-level highstand are well-developed around the coast of South Africa (Ramsay, 1996; Compton, 2001) and Namibia (Compton, 2006). A recent regional review (Cooper et al., 2018) identified a mid-Holocene highstand of +2 to +4 m between 7.3 and 6 ka BP, with

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

potential Late Holocene oscillations of <1 m amplitude around the present sea level in the subsequent interval.

6.4 Controversies

The past controversy around the age of the +6-8 m shoreline, created by Hendey and Volman (1986) was an artefact of limited chronological control and a lack of detailed sedimentological analysis and reporting. OSL dating has since proved that last interglacial shorelines do extend to +6-8 m. Their work, does, however, point to the need for caution in making broad generalisations about the age of shorelines at specific elevations and it is clear that shoreline deposits of various ages can occur at similar levels if the right conditions exist for preservation. The question of potential tectonism in Angola and Namibia is a relatively recent one. The evidence of uplift of Quaternary shorelines presented by Walker et al. (2016) from central Angola is persuasive, but the spatial and temporal extent of tectonic influence on raised shorelines on the coast of Angola, Namibia and possibly Namaqualand in NW South Africa requires further investigation.

6.5 Uncertainties and data quality

The data reported are subject to a variety of uncertainties related to the orginal elevation and associated datum the indicative meaning of the sedimentary facies and the chronological control on the material.

Elevation and datum uncertainties in the sampled material must be considered, especially in pre-2004 studies (the advent of OSL dating). Very many studies do not explicitly report the elevation measurement technique nor the measurement error. In the database, these errors have been estimated via the authors' own experience. In most instances, elevation measurements are not reported to a specified datum, whether Chart Datum (marine) or Ordnance Datum (terrestrial), or a tidal level. This reduces the vertical resolution of most datapoints, which have been referered to MSL in the database.

Paleo RSL calculations from modern analogs rely on detailed knowledge of contemporaray coastal environmenst and associated sedimentary facies. Southern Africa has a high energy, wave-dominated coast within which distinctive sedimentary facies have a large vertical range. Our quantification of modern analogs is based on the global literature on sea-level indicators on high energy coasts (e.g. Cooper 2013; Mauz et al., 2015), reports on the contemporary South African littoral geomorphology and sedimentology (Smith et al., 2010; Bond et al., 2013; Kelly et al., 2014; Dixon et al., 2015; Cooper and Green, 2016; Wiles et al., 2018; Green et al., 2019) and our own experience. More direct measurement (especially in relation to a fixed datum and reporting of the distribution and variability of ranges of open coast sedimentary facies in the region would help constrain comparisons with modern analogues. Tidal inlet-associated units are particularly difficult to constrain because of the marked variability in geomorphology of estuaries and their inlets around the South African Coast (Cooper, 2001) and the paucity of direct measurements of inlet depth. The ranges listed in the database are based on the authors' own experience.

Uncertainties related to dating refer mainly to U-Series dates. These are sometimes at odds with other dating methods and suggest issues with the source material (not from closed systems, for example). OSL dating in contrast, seems to have given more consistent results. The OSL dates, are, however, on sandy sediments from the high energy coast where vertical uncertainties (see above) are comparatively highMany of the U-Series dates are from estuarine sediments where vertical uncertainties on sea-level indicators could potentially be better constrained due to the lower energy conditions in which they accumulate and the specific vertical ranges of certain organisms.

A mandatory evaluation of of data quality is included with each RSL datapoint. This was undertaken following the WALIS guidelines.
(https://walis-help.readthedocs.io/en/latest/Relative%20Sea%20Level/#quality)

7 Future research directions

Our newly compiled database provides a means to investigate the record of sea-level varability around southern Africa and to identify datagaps and precise questions for further investigation. The database provides rather compelling sedimentary evidence for two sea level highstands separated by a regression during MIS5e at several sites around South Africa and into southern Namibia. In this regard, and in

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

light of recent developments in dating, several sites that were reported in earlier studies as likely MIS5e shorelines merit further investigation as they may help refine the detailed pattern of sea-level change during that interval. Sites with particularly well preserved littoral sedimentary facies that suggest more than one sea-level highstand merit fresh investigation. Particularly high-priority sites include Isipingo and Reunion (KwaZulu-Natal) (Cooper and Flores, 1991) Swartkip (Western Cape) (Barwis and Tankard (1983) and Nahoon Point (Eastern Cape)(Roberts, 2008) (Fig. 6). The added potential to date submerged littoral sediments, as has been carried out at several sites in South Africa, holds the potential to elucidate the timing and magnitude of regressions between sea-level highstands.

In addition, the widespread palaeo-lagoonal/estuarine deposits that occur in many estuaries from KwaZulu-Natal to the Western Cape that have been noted (Davies, 1970, 1971, 1972, 1980; Cooper 1996, 1999) but little investigated, remain a valuable resource for detailed sea level reconstruction around the MIS 5e interglacial. In particular, the Listers Point outcrop in Lake St Lucia (KwaZulu-Natal) (Fig. 1), which has been the subject of controversy due to poorly resolved stratigraphy, is worthy of further detailed investigation. Part of the confusion (and unnecessarily strongly-held opinions) that surrounds the site arises from poorly detailed stratigraphical investigations. Cooper et al. (2013) established that at least 5 highstand deposits are preserved, including two separate coral-bearing units, the uppermost of which is probably from the last interglacial. The site is also adjacent to other deposits that have yielded U/Th ages suggestive of MIS5e, although they are somewhat younger (Ramsay and Cooper, 2002).

The thermal preferences of supposed MIS 5e faunas also hold much potential for palaeoclimate reconstruction, especially given the interaction of the Agulhas and Benguela currents and associated upwelling. The broad spread of MIS5e shorelines between east and west coast, subject to summer and winter rainfall regimes respectively, also provides a chance to examine co-eval shifts in climate via the inter continental tropical convergence zone during warm periods such as those predicted for the future.

8 Data availability

The southern Africa database is available open access, and kept updated as necessary, at the following link: https://zenodo.org/record/3960136 (version 2.0). The files at this link were exported from the WALIS database interface on 24/07/2020. Description of each field in the database is contained at this link: https://doi.org/10.5281/zenodo.3961544, that is readily accessible and searchable here: https://walis-help.readthedocs.io/en/latest/. More information on the World Atlas of Last Interglacial Shorelines can be found here: https://warmcoasts.eu/world-atlas.html. Users of our database are encouraged to cite the original sources alongside with our database and this article.

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Preprint. Discussion started: 25 August 2020

655

Figure 1. Locality map of the Angolan, Namibian and South African coasts where various MIS5e sea level indicators occur. KZN = KwaZulu-Natal.

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

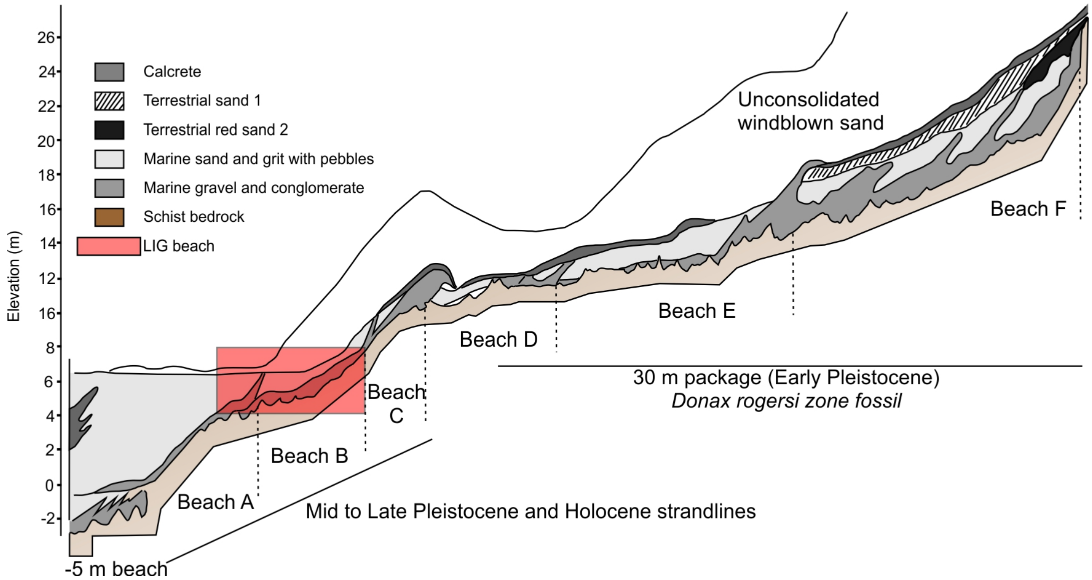

Figure 2. Schematic east-west cross-section through the raised beach deposits of southern Namibia (modified from Runds, 2017). Subtidal to + 10 m elevations represent the A, B and C beaches, and the + 30 m package represents the D, E and F beaches). Data compiled originally from Hallam (1964) and Jacob (2001). Beach 'B" is commonly ascribed to MIS5e, but has not been dated.

https://doi.org/10.5194/essd-2020-166
Preprint. Discussion started: 25 August 2020

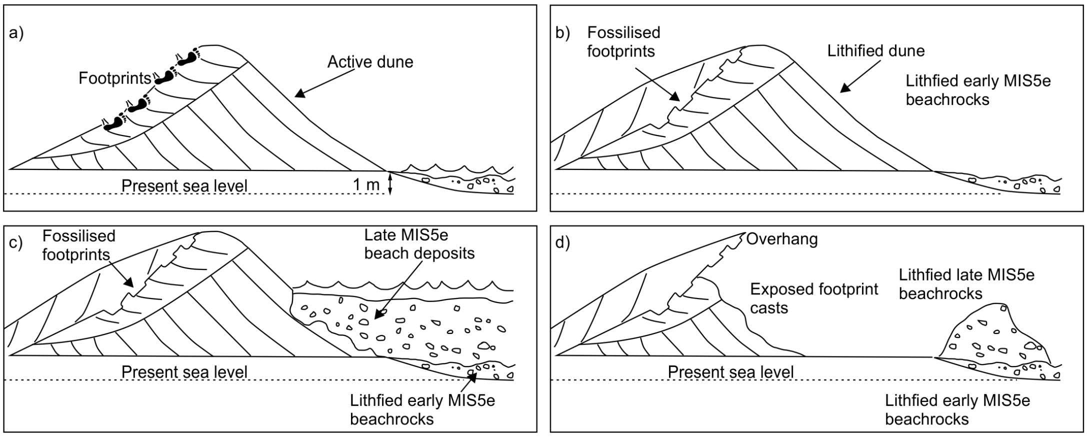

Fig 3. Diagrammatic sequence of depositional events and sea-level change associated with hominid footprints. (a) Human descending seawards down the (unconsolidated) dune face during an initial MIS 5e highstand to +/-1 m. (b) Following burial of the footprints by further aeolian sedimentation, the dune/beach succession is lithified – sea level had fallen by an unknown magnitude below the present level. (c) Later (higher) MIS 5e highstand (to about +/-6 m) partly erodes the earlier MIS 5e marine and aeolian deposits. (d) Further erosion of the MIS 5e dune/beach succession during the Holocene highstand resulted in the development of an overhang, the underside of which bears the (natural) casts of the footprints (adapted from Jacobs and Roberts, 2009)

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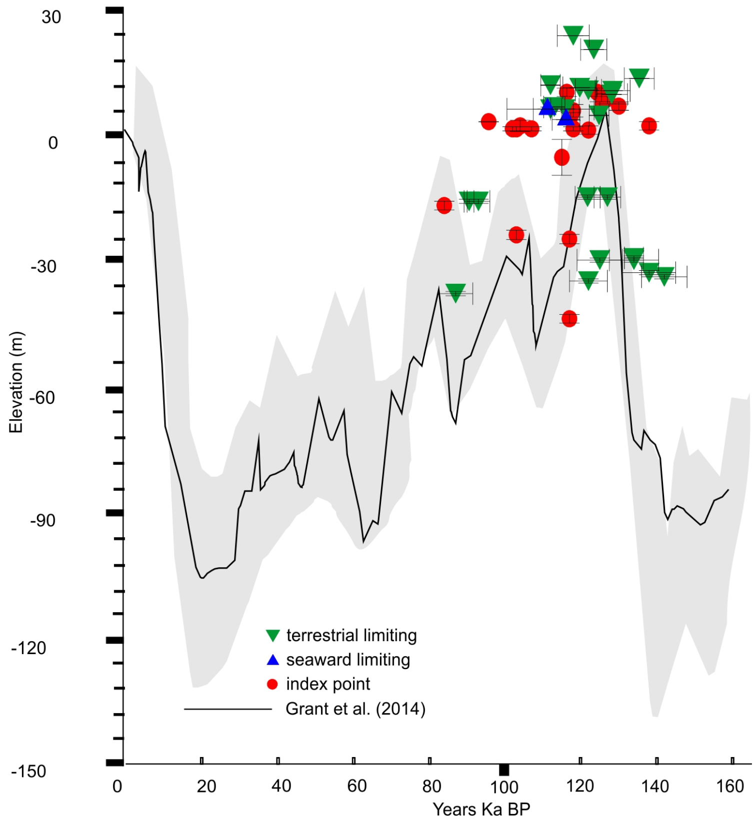

Figure 4. Sea level index points, together with seaward and landward limiting points for all available data from the Angolan, Namibian and South African coasts. Plotted data span MIS 5a to e. The data are compared to a compilation of data sets depicted in the shaded gray curve (Waelbroeck et al., 2002; Bintanja et al., 2005; Kopp et al., 2009; Rohling et al., 2009; Grant et al., 2012; O'Leary et al., 2013), with the curve of Grant et al. (2014) superimposed.

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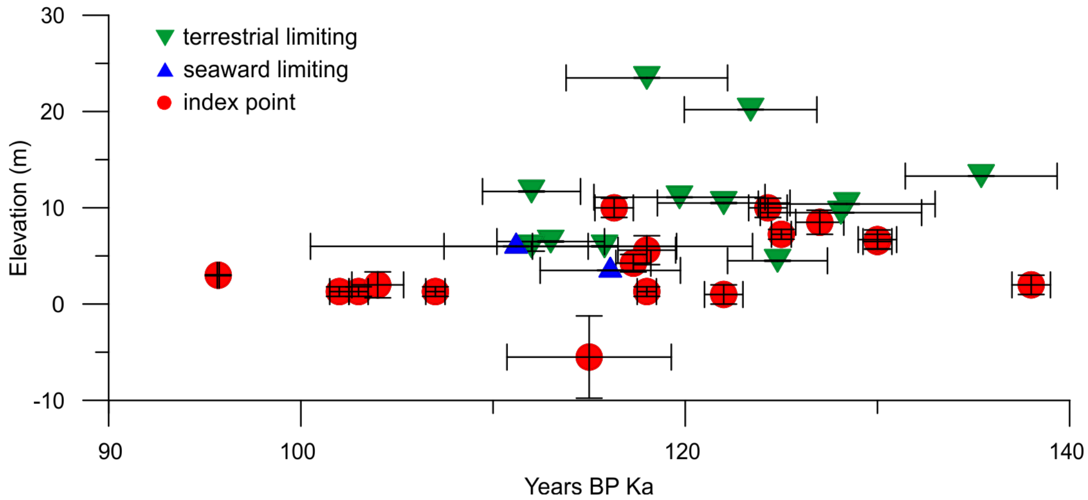

Figure 5. Collated sea level index points, together with seaward and landward limiting points for the South African coast surrounding the last interglacial of MIS5e (Table 1).

690

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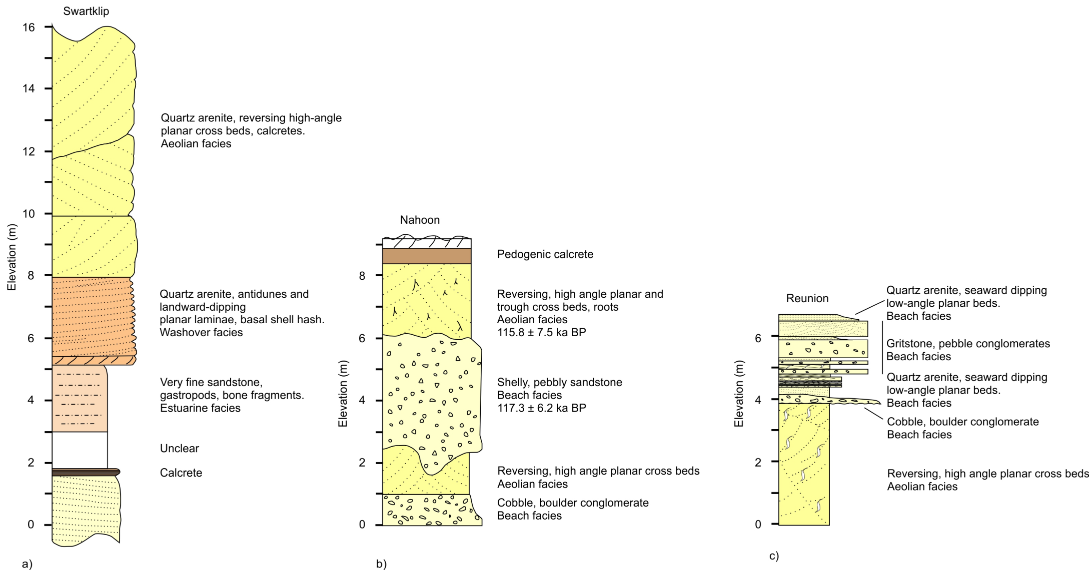

Figure 6. Key sites in South Africa with sedimentary, but not fully dated records suggestive of two sea-level peaks during MIS5e. Locations on Fig. 1. a). Undated sequence exposed at Swartklip, (after Barwis and Tankard, 1983). The lowermost beach sequence represents a possible MIS5e highstand, topped by calcrete formed during subaerial exposure and a lower sea level. The following estuary and barrier washover sequence records a subsequent transgression. b). Sequence at Nahoon (after Jacobs and Roberts, 2008). A similar lowermost beach facies represents a possible MIS5e highstand at ~ +1 m, with a regression represented by the aeolian facies, followed by a second transgression. c). An undated sequence of beachrocks from Reunion, Durban overlying an aeolianite. The lowermost beach facie overlies the platform from which Ramsay et al. (1993) described an elephant tusk found in a solution pothole. The sequence suggests two highstands, the first forming the erosional platform, the second depositing the overlying beachrocks (from Green, unpublished data).