Geo-Marine Letters (2021) 41: 40
https://doi.org/10.1007/s00367-021-00701-y

ORIGINAL

Bathymetry of the South African continental shelf

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Received: 15 January 2021 / Accepted: 13 May 2021 / Published online: 16 August 2021

Abstract
Detailed knowledge of shelf bathymetry is essential for understanding the long-term geological evolution of continental margins, the extent of the coastal plain as the shoreline moved in response to Pleistocene sea-level fluctuations, and for ecosystems management, resource exploration, and navigation. Although some areas have been mapped in detail, most South African shelf bathymetry is poorly resolved. This paper presents a bathymetric map of the South African continental shelf derived from digital single-beam echo-sounding data collected by the Department of Agriculture, Forestry and Fisheries (DAFF) that is at a significantly higher resolution than was previously available as presented by Dingle et al. (Annals of the South African Museum 98:1–27, 1987). The bathymetric dataset consists of approximately 7 million data sonar points collected by the Fisheries Division of DAFF over the last two decades, covering the entire South African continental shelf area of 541,000 km^2 between the Orange River mouth on the West Coast and Kosi Bay on the East Coast. The new map not only resolves known shelf bathymetric features in greater detail but also reveals new features. The origin of some bathymetric features remains unknown, but many appear to relate to bedrock geology, sediment deposition (river drainage systems and ocean currents), and sea-level fluctuations.

Keywords South Africa · Continental shelf · Continental margin · Bathymetry · Sea level

Introduction

Shelf bathymetry forms a critical interface between the continents and the oceans but remains poorly resolved in many parts of the world, including South Africa. Although there have been recent advances in the use of satellite altimetry to derive seafloor bathymetry of the deep ocean, it has had limited application to shelf regions bordering the continents (0–500-m water depths). South Africa has an extensive shelf area that is narrow on its eastern margin, broad on its southern margin, and unusually broad and deep on its western margin (Fig. 1). Some areas of the South African continental shelf have high-resolution bathymetry from multi-beam and side-scan sonar surveys capable of resolving centimeter-scale features of the seabed (e.g., Bosman et al. 2005; Green et al. 2007, 2012; Cawthra 2010; Cawthra et al. 2014, 2015; Pretorius et al. 2019; Palan et al. 2020). However, these are limited to relatively small areas of the shelf and many are held privately by the offshore diamond mining, and oil and gas companies. Besides these small pockets of high-resolution bathymetric datasets, the shelf bathymetry has to date been known from the compilation of Dingle et al. (1987) and navigational charts available from the South African Navy Hydrographic Office. The Dingle et al. (1987) bathymetric map is based on a number of surveys carried out during the 1970s and 1980s; i.e., before modern high-resolution sonar systems and more precise ocean positioning systems were available (such as the satellite global positioning system (GPS) and differential GPS).

There has been an increased interest in developing a better resolved, more detailed bathymetry of the South African continental shelf, especially because bathymetry is a key component to navigation, marine geological mapping and research (Glass 1980; Ramsay 1996; Bosman et al. 2005; Cawthra et al. 2012; Green et al. 2012), modelling coastal processes (such as tsunami inundation, storm surge, ocean currents, contaminant dispersal, etc.), ecosystems

This article is part of the Topical Collection on *Coastal and marine geology in Southern Africa: alluvial to abyssal and everything in between.*

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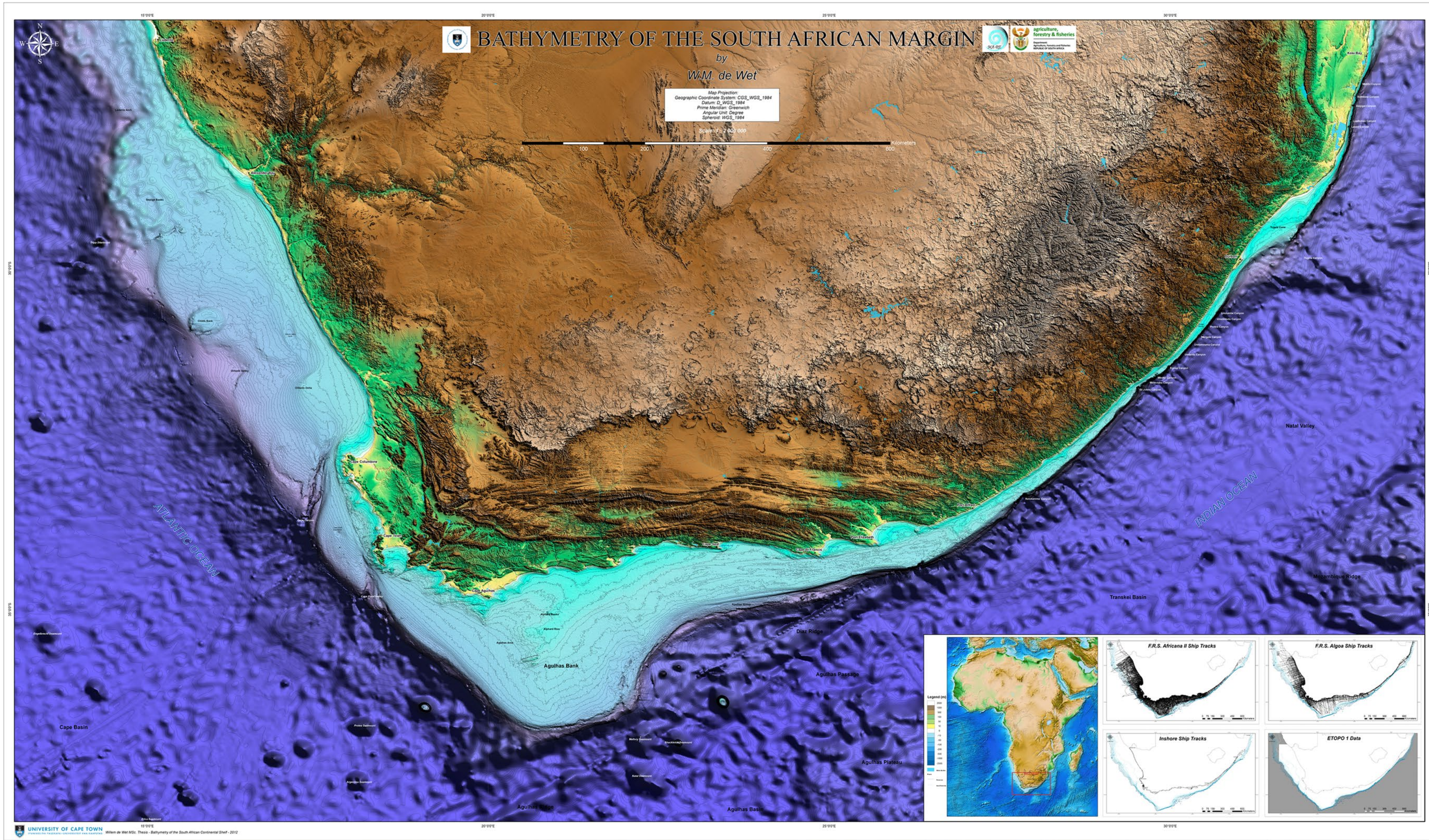

Fig. 1 A 1:2,000,000 scale shaded relief bathymetric map of the South African continental margin, along with deep ocean bathymetry (ETOPO1, cf. Amante and Eakins 2009) and on land topography (SRTM 30—1 ARC Second map downloaded from https://www.usgs.gov/). Bathymetric isobaths are spaced at 10-m intervals for water depths ranging between 0 and 500 m, at 20-m intervals for water depths ranging between 500 and 1000 m, and at 100-m intervals for water depths greater than 1000 m (De Wet 2013). The rivers and water bodies are courtesy of the Department of Water Affairs and Forestry (DWAF)

management and marine habitat research (Sink et al. 2011; Shabangu et al. 2014; Pfaff et al. 2019), as well as coastal and marine spatial planning. Of recent interest has been the nature of the landscape exposed during major glacial lowstands of the Pleistocene and evidence of early modern human settlement in these regions (e.g., Marean 2010, 2011; Compton 2011; Jacobs et al. 2019). This paper presents a better resolved and more complete single-beam bathymetric map of the South African continental shelf and discusses the major new bathymetric features that it reveals along its western, southern, and eastern margins.

Geological setting

The continental margin of South Africa covers a total area of roughly 165,000 km^2 up to the 200-m isobath and 400,000 km^2 up to the 2000-m isobath (Broad et al. 2006). It has had a complex geological history that can be linked to the tectonic cycles of supercontinent assembly and break-up, especially since the break-up of Western Gondwana (180 to 135 Ma). Numerous episodes of rifting and continental drifting during the Early Cretaceous (127 to 117 Ma) resulted in the present morphology of the South African continental margin (Fig. 1) (Tankard et al. 1982; Dingle et al. 1983; Partridge and Maud 1987; Séranne and Anke 2005; Broad et al. 2006; Watkeys 2006). Two distinct continental margins were produced during Cretaceous break-up: the divergent western and north-eastern continental margins that formed due to tensional rift faulting (Dingle and Scrutton 1974), and the translational southern and south-eastern continental margins that formed due to shearing along the Agulhas-Falkland Fracture Zone (AFFZ) (Fig. 1) (Tankard et al. 1982).

Although the entire margin of southern Africa is tectonically passive, the Atlantic Ocean (West Coast), Southern Ocean (South Coast), and Indian Ocean (East Coast) margins differ markedly. The shelf on the West Coast is wide and relatively deep, being characterized by several stacked shelf breaks, whereas the South Coast shelf is broad and shallow (Agulhas Bank) and the East Coast shelf is extremely narrow (Siesser et al. 1974; Dingle et al. 1983; Emery et al. 1992). These large morphological differences are the result of divergent plate movement during the formation of the Atlantic Ocean margin and translational plate movement during the formation of the Indian Ocean margin, throughout the break-up of Western Gondwana (Dingle et al. 1983; Emery et al. 1992; Francheteau and Le Pichon 1972; LaBrecque and Hayes 1979; Tankard et al. 1982). These margins have also experienced vastly different Late Cenozoic uplift, climate and sediment supply linked to morphology, sea-level fluctuations, ocean currents, and drainage systems (Partridge and Maud 2000; Tinker et al. 2008; Brown et al. 2014; Wildman et al. 2015; Knight and Grab 2016).

Post-Gondwana erosion cycles during the mid and Late Cretaceous had considerable effects on sediment dispersal, causing massive amounts of terrigenous sediments to amass in the major offshore sedimentary basins (King 1967; Scrutton and Dingle 1976; Partridge and Maud 1987; Tinker et al. 2008), resulting in the expansion of the Southern African continental shelf. Multiple episodes of epeirogenic uplift and erosion during the Paleogene (65 to 55 Ma), known as the "Great African Cycle of Erosion" (King 1967; Scrutton and Dingle 1976; Partridge and Maud 1987, 2000; Wildman et al. 2015), contributed to the formation of the Great Escarpment, a massive erosional escarpment that encircles the entire southern African subcontinent. Two separate erosional surfaces developed: the southern African plateau, a large block of uplifted continent above the Great Escarpment that has been eroded by ancient and present river systems but remains relatively level, and the coastal plain below the Great Escarpment that experienced several Neogene uplift and erosional events (Partridge and Maud 1987, 2000; Moore and Larkin 2001; Moore et al. 2012), along with fluctuating sea levels throughout the Cenozoic that resulted in its present-day morphology (Dingle and Scrutton 1974; Siesser and Dingle 1981; Tankard et al. 1982; Dingle et al. 1983; Partridge and Maud 1987; Ramsay and Cooper 2002; Compton 2011).

The present-day South African continental margin consists of a pre-Cretaceous basement, the bulk of which crops out as a narrow, coast-parallel rocky nearshore platform along the South African continental shelf (Dingle 1973a; Dingle et al. 1983). A thick succession of mid to Upper Cretaceous fluvial, marine and alluvial sediments, and a relatively thin cover of Cenozoic deposits overlie these basement rocks. Sediment cover is absent on structural highs, but it is over 10 km thick within the numerous Mesozoic rift basins and offshore sediment deltas along the margin (Dingle 1973a; Dingle et al. 1983; Brown et al. 1995; Broad et al. 2006).

Methods

Data source

The source of the sonar data used in this study is from 20 years of digital single-beam echo-sounding profiles collected by the Fisheries Division of the Department of Agriculture, Forestry and Fisheries (DAFF) during routine cruises assessing demersal fish stocks along the South African continental margin. The dataset was assembled from 127 surveys of the F.R.S. Africana II (1991–2011), 102 surveys of the F.R.S. Algoa (1993–2005), and additional nearshore surveys, using a semi-rigid inflatable in shallower water (Fig. 1). The sonar data were collected using SIMRAD EKS-38, EK 400, EK 500, and EK 60 single-beam echo-sounders, along with the SIMRAD ES38B split-beam transducer operating at 38 kHz. During each cruise, a SIMRAD EK60 echo-sounder was operated continuously by a scientific team while the ship steamed between stations or transects at a constant survey speed of ~ 8 to 10 knots. The echo-sounder was interfaced to sonar data Echolog and Echoview software, which were continuously monitored to determine the position and extent of fish schools for trawling and sampling. The single-beam bathymetric data were collected continuously using all available frequencies (18, 38, 120, and 200 kHz) at a standard pulse duration of 1 ms, with positioning of the data provided via a shipboard differentially corrected global positioning system (DGPS, such as the Leica MX-412), having a positional accuracy of less than 2 m. Additional data used in the bathymetric map include ETOPO1—1 arc-minute global relief model dataset (Amante and Eakins 2009) for the shelf area north of the Orange River mouth (Fig. 1), as well as the deep ocean areas adjacent to the continental shelf. Onshore topography is from the SRTM 30 dataset (Becker et al. 2009).

Data processing

The bathymetric data made available by DAFF were in digital format, with soundings spaced at 1-min intervals for each specific ship survey/track. The retrieval, correction, gridding, plotting, and displaying of the bathymetric dataset was done manually using the following processing steps:

(1) DDS Export Wizard (developed internally by DAFF) was used to extract the raw digital single-beam bathymetry data into*.csv* files; (2) Microsoft Office Excel was used for erasing error values of individual ship track files; (3) Grapher 8 (Golden Software Ltd.) was used to plot individual ship track files on a two-dimensional graph in order to pinpoint and remove any spurious bathymetric data points; (4) ArcGIS 9.3 (ESRI Inc.) was used to plot individual soundings in order to remove any irregularities regarding their latitude and longitude positions (7% of the single-beam data were removed during steps 3 and 4); (5) Surfer 9 (Golden Software Ltd.) was used to produce the final corrected bathymetric dataset using the Kriging gridding method and to produce the final DTM as well as the bathymetric contours; (6) Global Mapper (v. 12.02) was used to produce a shaded relief bathymetric map of the gridded dataset; (7) ArcGIS 9.3 (ESRI Inc.) was used to produce the various bathymetric maps displayed throughout this paper (for a more detailed description of the processing steps, see De Wet (2013)).

Results

Overview

The 1:2,000,000 scale bathymetric map of the South African continental margin produced by this study can be subdivided into the West Coast (from Alexander Bay to Cape Town), South Coast (Cape Town to Port Alfred), southern East Coast (Port Alfred to Scottburgh), and northern East Coast (Scottburgh to Kosi Bay) (Fig. 1). The bathymetric map is consistent with most of the major, low-resolution features of the Dingle et al. (1987) map, with the major differences being in the resolution of the shelf and its known features, such as Cape Canyon, Cape Point Valley Canyon, Child’s Bank, and the Agulhas Bank. The bathymetric map shows nearly identical seafloor morphology when compared to the South African Navy’s Hydrographical charts and known datasets (e.g., Glass 1980), as well as more detailed bathymetric surveys such as Green and Uken (2008).

West Coast (Alexander Bay to Cape Agulhas)

The West Coast can be divided into an inner, middle, and outer shelf area (Rogers 1971). The rocky inner shelf extends as a narrow, coast-parallel band from the present coastline out to approximately 130-m water depth. It varies in width from 35 km near Cape Agulhas, 16 km off Cape Point, 40 km off Table Bay, and St. Helena Bay to less than 8 km along the entire West Coast margin north of Cape Columbine (Fig. 2). The middle shelf is relatively featureless except for three submarine canyons (the Olifants Valley, Cape Canyon, and Cape Point Valley) that cut across it. The Cape Canyon has a total longitudinal extent of nearly 200 km, a maximum local relief of around 900 m, and can be traced to a water depth of 3600 m (Dingle 1970a). South of the Cape Canyon the middle and outer shelves are generally smooth, featureless, and narrow until cut by the Cape Point Valley submarine canyon, which starts within 15 km of the present coastline to the west of Hout Bay. The total extent of the Cape Point Valley is 84 km and widens from less than 2 km at its canyon head at 200 m water depth, until it reaches a maximum width of 50 km at its southernmost extent at the edge of the continental shelf. It gradually deepens southward until reaching a maximum water depth of 1360 m.

The middle shelf has a gentle average gradient of 0.1° that steepens to define the outer shelf area that extends to a generally well-defined shelf break (Dingle et al. 1983). The shelf break is generally parallel to the general SE-NW trend of the coastline, with the shelf widening from 50 km

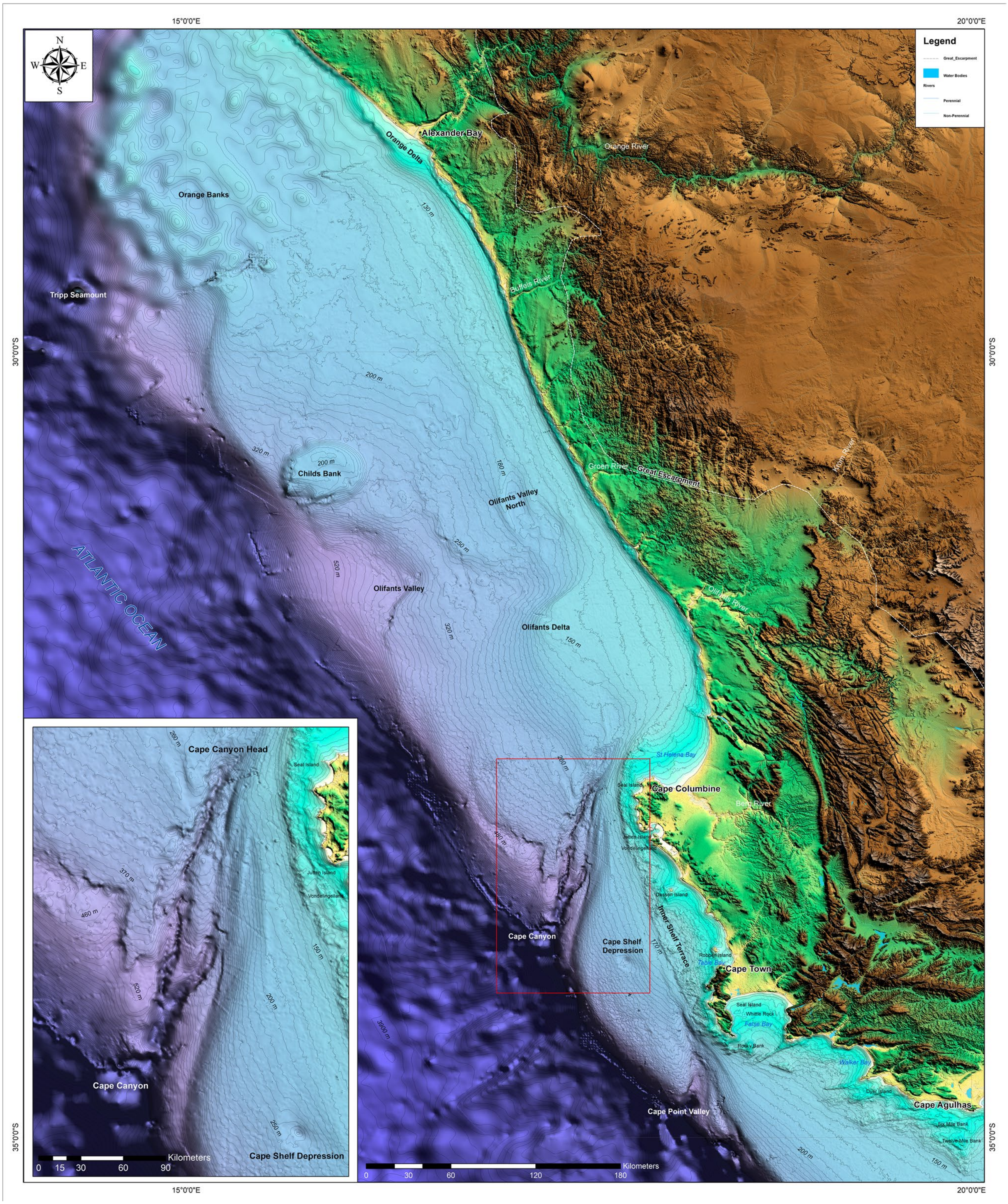

Fig. 2 Bathymetry of the West Coast continental margin of South Africa and adjacent deep ocean area with a detailed insert of the Cape Canyon area, "Cape Shelf Depression" and Inner Shelf Terrace offshore of Cape Town. Bathymetric isobaths are spaced at 10-m intervals for water depths ranging between 0 and 500 m, at 20-m intervals for water depths ranging between 500 and 1000 m, and at 100-m intervals for water depths greater than 1000 m

off the Cape Peninsula to a maximum of 240 km off the Orange River mouth where it has a clearly defined double shelf break (Fig. 2). At water depths ranging between 196 and 600 m, it is one of the deepest shelf breaks in the world (Shepard 1963). The shelf break is an erosional/non-depositional environment due to the workings of internal tides (Monteiro et al. 2005) and poleward-flowing bottom currents (Shannon and Nelson 1996), and consists mainly of a thin Quaternary veneer or exhumed Neogene deposits (Wigley and Compton 2006; Compton and Wiltshire 2009). The average upper slope gradient is roughly 3.3° and the continental slope and rise gently dip offshore for approximately 400 to 600 km into the Cape Basin abyssal plain.

South Coast (Cape Agulhas to Port Alfred)

The distinct, triangular-shaped continental shelf area of the South Coast, with the broad Agulhas Bank that narrows significantly eastwards across the Outeniqua Basin reflects the translational shearing and separation between the African and South American plates along the AFFZ during the Early Cretaceous break-up of Western Gondwana (Ben-Avraham et al. 1997) (Fig. 3). Its widest point of 260 km lies due south of Cape Infanta, from where it progressively narrows in a north-northeast direction towards Cape Seal. South of Cape Seal the trend of the shelf break changes to east northeast up to Algoa Bay, where the NE-trending east coast shelf commences (Fig. 3). Previous publications on the bathymetry and morphology of the South Coast margin include Dingle (1970a, b, 1971, 1973c), Rogers (1971), Birch (1971, 1980), Siesser (1970, 1971), Dingle and Gentle (1972); Dingle and Rogers (1972), Gentle (1987), and Cawthra et al. (2014, 2015, 2018).

Similar to the West Coast, the South Coast margin can be subdivided into an inner, middle, and outer shelf area. The inner shelf consists of a narrow, coast-parallel rocky nearshore platform that extends from the present coastline to the middle shelf. It is 20 km wide and rocky off Cape Agulhas and Arniston but becomes less rocky and narrow (< 5 km) off Cape Infanta, with its seaward limit generally between 60 and 70 m water depth. East of Cape Infanta, the width of the rocky nearshore platform rarely exceeds 2 km and its seaward limit parallels the coast at a water depth of 50 m. The inner shelf remains narrow (< 5 km) along the Outeniqua shelf area until Cape St. Francis where it widens to 12 km Widening of the rocky inner shelf platform off Cape St. Francis and Cape Recife is the result of the Cape Fold Belt swinging south-eastward where it forms highly resistant Table Mountain Group headlands that continue offshore to a water depth of 110 m. Two major nick points along the rocky inner shelf correspond to Pleistocene lowstands at water depths of 45 and 75 m (Compton 2011). Lowering of sea level to 130 m water depth during past glacial periods greatly expanded the coastal plain that lined the entire subcontinent and may have facilitated the movement of animals and humans between the West and South coasts and the interior (Marean 2010, 2011; Compton 2011).

The middle shelf is relatively featureless, with an average gradient of 0.06° that steepens slightly across the outer shelf towards the shelf break. The shelf break is generally well defined, with a steep continental slope along the Agulhas Bank, but a double shelf break is evident along the entire Outeniqua shelf area known as the Agulhas Slump (Fig. 3 insert) (Dingle 1977; Dingle et al. 1983). The average upper slope gradient is roughly 7.3° off the Agulhas Bank and 6.0° off the Outeniqua shelf area, both relatively steep compared to the world average of 4.4° (Shepard 1963).

A clearly defined double shelf break is evident along the Outeniqua Shelf area between Cape St. Blaize and Cape Recife (Fig. 3), with an upper slope nick point situated on the outer shelf at a water depth of 180 m between Cape Seal and Cape St. Francis. The inner shelf break is situated at 150 m water depth roughly 80 km to the south of Cape Seal, and at 130 m water depth roughly 38 km to the south of Cape Recife. The continental shelf narrows considerably between Cape Seal and Cape Recife, where the double shelf break pinches out to form a well-defined, single shelf break, which extends eastwards along the Outeniqua Shelf and continues along the East Coast. The outer shelf break and adjacent upper and middle slope between Cape St. Blaize and Cape Recife consist of multiple slope "terraces" (at water depths of 240 to 260 m and 360 to 390 m) stepping towards the lower slope. The main slope "terrace" deepens from 360 m water depth south of Cape Seal to over 700 m water depth south of Cape Recife. East of Cape Recife, the shelf break is again well defined, with upper slope gradients of between 5° and 11° before it shallows from a water depth of 160 m to less than 120 m off Port Alfred. These slope "terraces" may be the result of large-scale post-Pliocene slumping along a region called the Agulhas Slump (Fig. 3) (Dingle and Robson 1985; Dingle et al. 1987). The Agulhas Slump stretches 750 km from the eastern margin of the Agulhas Bank east into the Transkei Basin (off East London), and is bounded by the Agulhas Marginal Fracture Ridge, which forms part of the AFFZ along its seaward margin (Dingle 1977).

East Coast (Port Alfred to Kosi Bay)

The East Coast continental margin of South Africa (Figs. 4 and 5) consists of an extremely narrow, coast-parallel continental shelf, ranging between 1.3 and 45 km in width. In general, the resolution of East Coast shelf bathymetry is low compared to that of the West and South coasts, largely due to

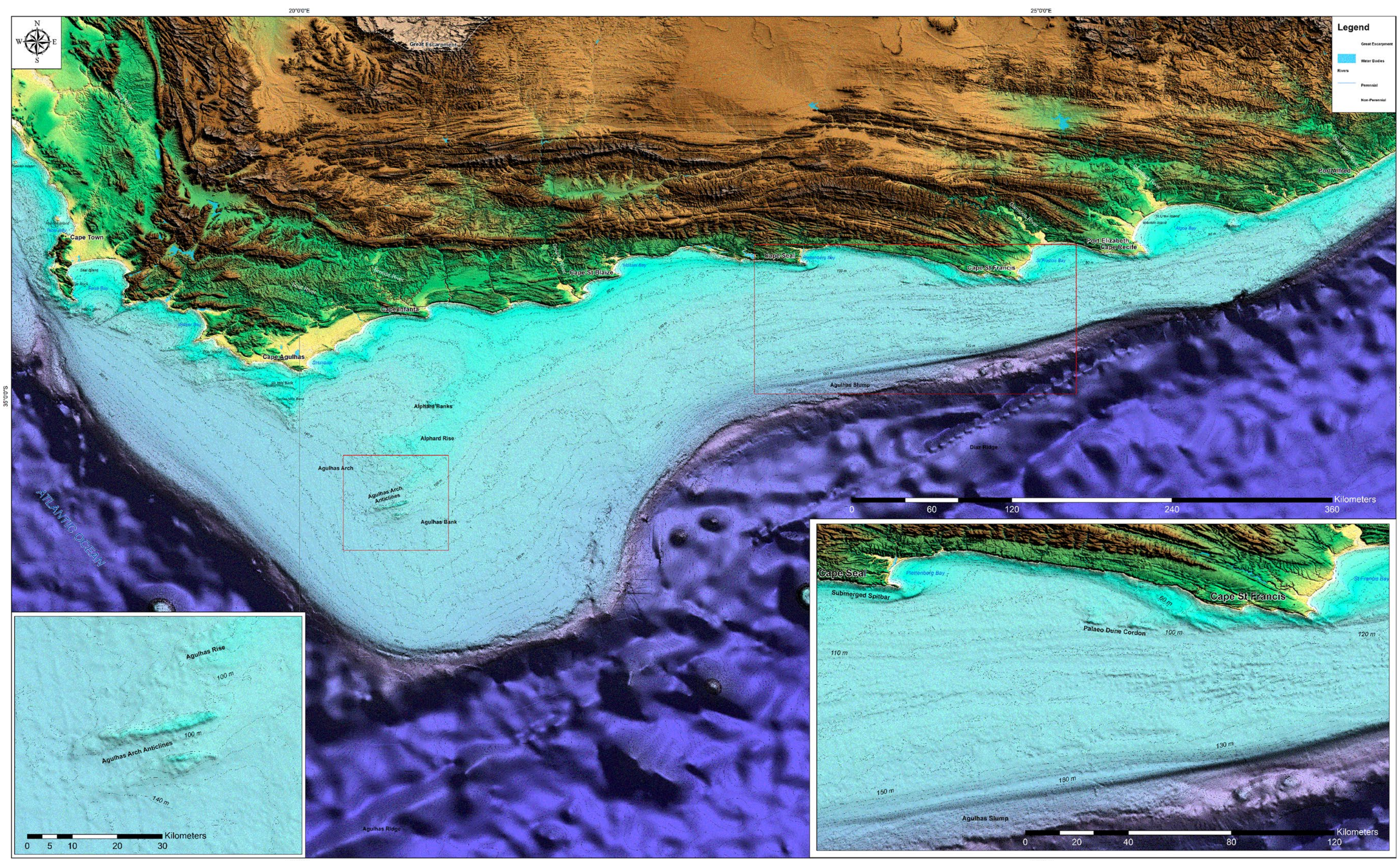

Fig. 3 Bathymetry of the South Coast continental margin of South Africa with a detailed insert of the Cape Seal spit-bar, Agulhas Slump, wave-cut platforms and palaeodune cordons off Cape St Francis. Bathymetric isobaths are spaced at 10-m intervals for water depths ranging between 0 and 500 m, at 20-m intervals for water depths ranging between 500 and 1000 m, and at 100-m intervals for water depths greater than 1000 m

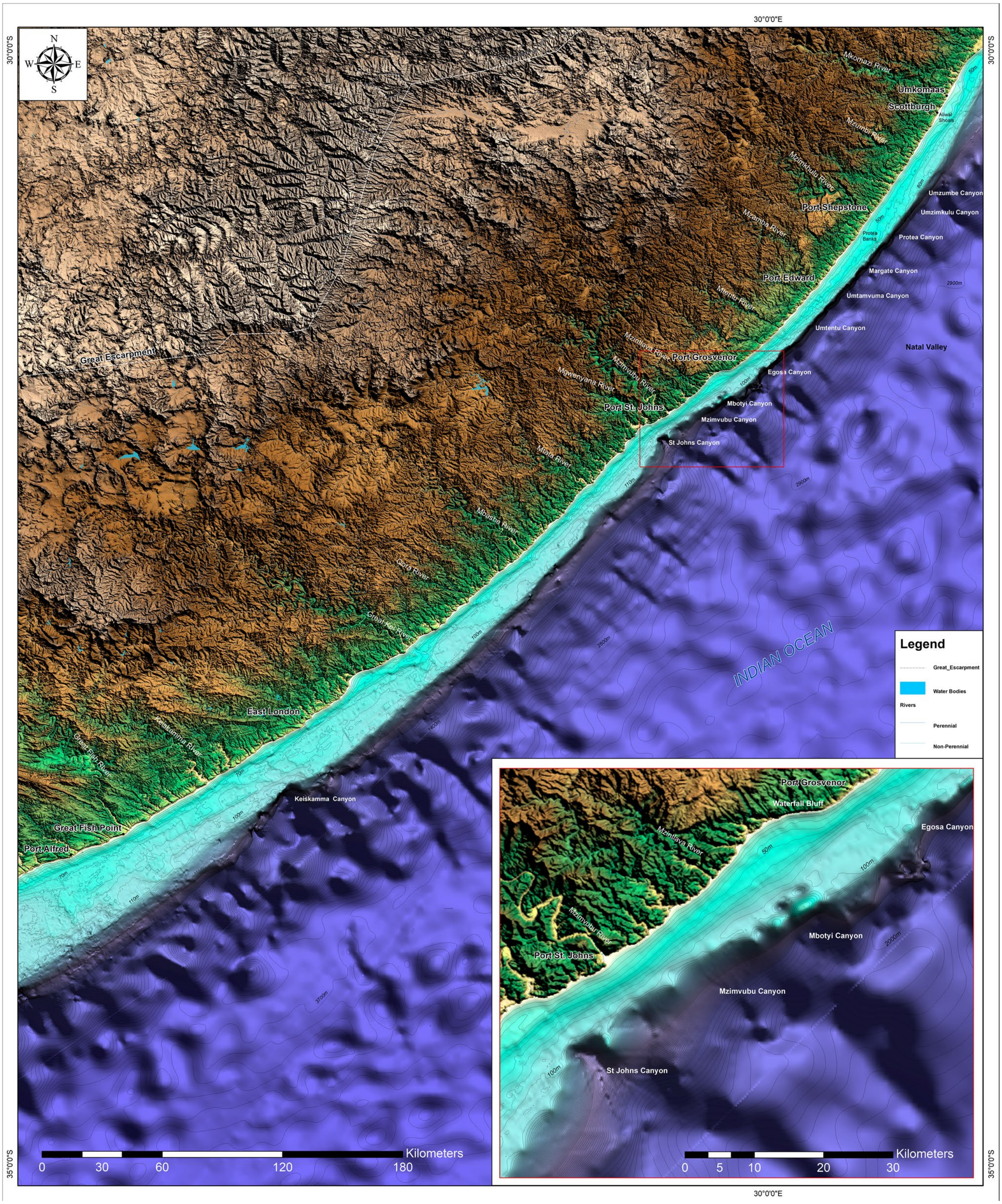

Fig. 4 Bathymetry of the East Coast continental margin of South Africa and adjacent deep ocean area between Port Alfred and Scottburgh with a detailed insert of the St Johns, Mzimvubu, Mbotyi, and Egosa canyon areas. Bathymetric isobaths are spaced at 10-m intervals for water depths ranging between 0 and 500 m, at 20-m intervals for water depths ranging between 500 and 1000 m, and at 100-m intervals for water depths greater than 1000 m

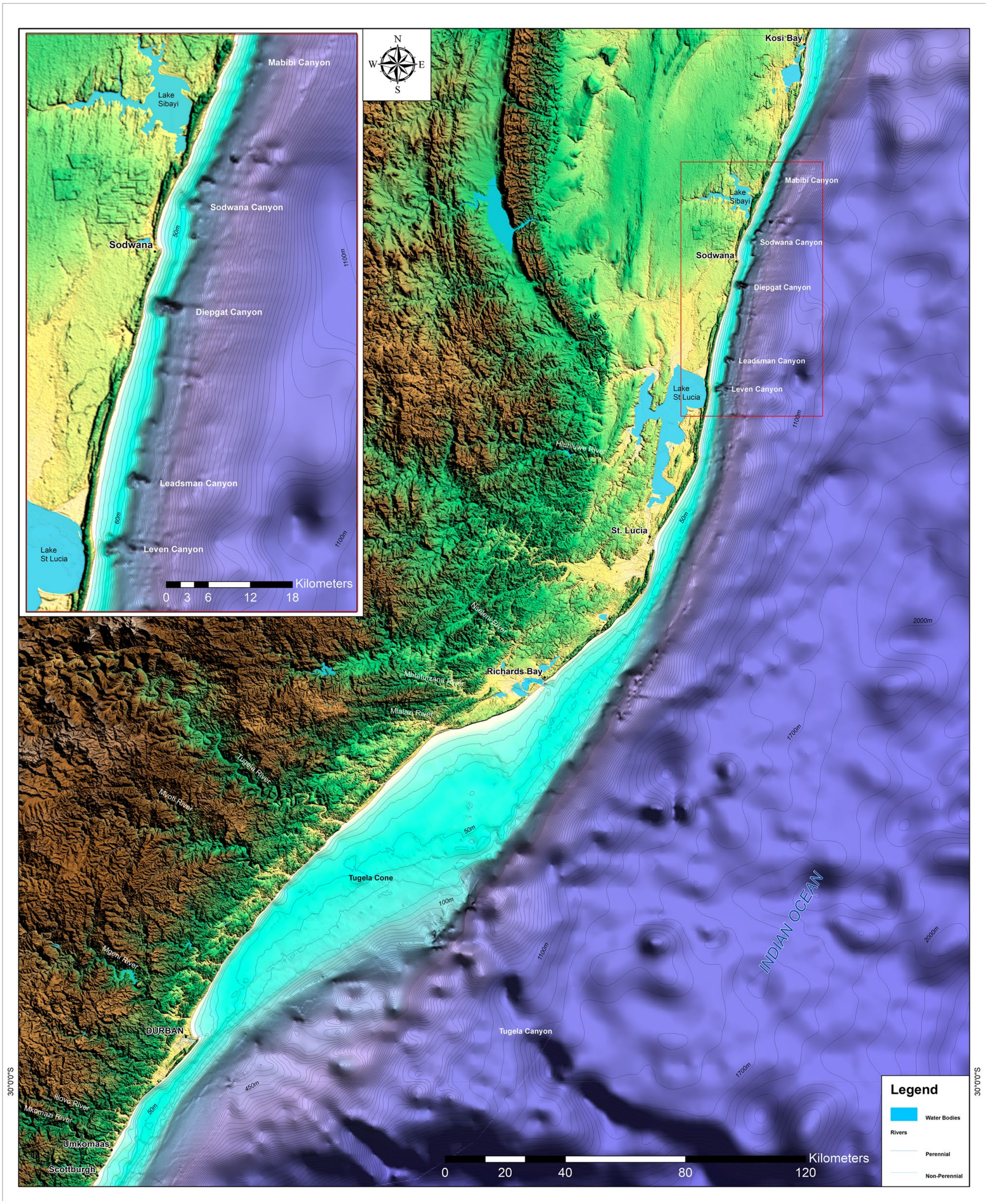

Fig. 5 Bathymetry of the East Coast continental margin of South Africa and adjacent deep ocean area between Scottburgh and Kosi Bay with a detailed insert of the Leven, Leadsman, Diepgat, Sodwana, and Mabibi canyon areas. Bathymetric isobaths are spaced at 10-m intervals for water depths ranging between 0 and 500 m, at 20-m intervals for water depths ranging between 500 and 1000 m, and at 100-m intervals for water depths greater than 1000 m

much less dense ship track coverage of the East Coast (Fig. 1 insert). The inner, middle, and outer shelf areas on the East Coast margin are less well defined in comparison to the West and South Coast margins. Major bathymetric features on the East Coast include the Protea Banks, Aliwal Shoals, and Tugela Cone, as well as several shelf-indenting submarine canyons. The shelf break is situated at water depths of 110 m between Port Alfred and Port St. Johns, 100 m between Port St. Johns and Scottburgh (East Coast South), and ranges from 61- to 100-m water depth between Scottburgh and Kosi Bay (East Coast North) (Flemming 1981; Goodlad 1986). The adjacent continental slope is steep, having an average gradient of between 4.5° and 16°, and reaches a maximum of 25° off the Port Shepstone area.

Discussion

West Coast (Alexander Bay to Cape Agulhas)

The morphology of the West Coast continental margin has undergone a complex history of sedimentation, erosion, and differential warping (Simpson 1971; Rogers 1971; Dingle 1973a; Dingle et al. 1983; Wigley and Compton 2006; Wildman et al. 2015). The inner shelf is narrow between the Orange River and Cape Columbine, with a wide, gently sloping middle to outer shelf that defines two large, relatively featureless areas, the Orange and Olifants shelves, which are separated by an expansive Olifants Valley (Fig. 2). Between Lüderitz and the Olifants River mouth, the inner shelf has a rocky nearshore platform that consists of the Precambrian Namaqua Belt (Dingle 1973a; Dingle et al. 1983). As a result of the high wave energy and low sediment supply, the basement rock is exposed to storm wave base at water depths between 40 and 80 m (De Decker 1987), with only thin patches of coarse sand and gravel outside of the 80-km-long and 10- to 20-km-wide Orange River delta sediment wedge. South of the Olifants River mouth, the inner shelf basement consists of seaward dipping Cretaceous strata (Fig. 2).

From storm wave base depths to the inner part of the middle shelf is a narrow, coast-parallel Holocene mudbelt that extends from the Orange River prodelta to Cape Columbine (Birch 1977; Rogers 1977; Birch et al. 1991; Rogers and Bremner 1991; Herbert and Compton 2007; Lodewyks 2010). River sand and gravel fractions are transported northwards by longshore drift, while the mud fraction is transported southwards by poleward bottom currents (Shannon and Nelson 1996). The mudbelt forms a sediment wedge up to 15 m thick centered on the basement nick point cut during sea-level lowstands (Herbert and Compton 2007; Lodewyks 2010). It expands from a narrow ribbon north of the Olifants River mouth into a thick, expansive sediment cover associated with the Olifants River delta, formed from terrigenous sediment discharged by the Olifants and Berg rivers into St. Helena Bay. Beyond the mudbelt, the middle and outer shelf area is covered in a thin veneer of Quaternary sediment.

Features on an otherwise homogeneous middle to outer shelf include the Orange Banks/Shoals and Child's Bank (Fig. 2). These are elevated, remnant Neogene limestone features, which shoal gradually up to water depths of less than 180 m from the middle to the outer shelf area and are bounded at their outer edges by sheer cliffs more than 150 m high (Birch and Rogers 1973). The Orange Banks are erosional outliers formed during a major post-Pliocene sea-level regression and erosional event (Dingle 1973a; Siesser et al. 1974). Childs Bank is a rounded, flat-topped plateau with gentle northern, eastern, and southern margins but a steep, slump-generated outer face at the edge of the continental shelf (Birch and Rogers 1973; Dingle et al. 1983). Childs Bank is revealed here (Fig. 2) to have a much less angular and elongated shape than depicted by Dingle et al. (1987) and does not taper to a sharp point towards its western edge.

The Olifants Shelf is dominated by the extensive Olifants River delta and Olifants Valley, a wide, shallow submarine depression that extends across the entire middle and outer shelf area to the north of the Olifants River delta (Fig. 2). It consists of a gentle sloping (0.2° to 0.4°), east–west trending valley, roughly 150 km in length that forms a distinct V-shaped double shelf break on the outer shelf. The valley head is most likely situated underneath the thick sediments of the Olifants River delta. A narrow, north–south orientated valley, Olifants Valley North, connects to the main east–west striking Olifants Valley on the middle shelf 40 km offshore. The North Olifants Valley reaches a maximum water depth of 206 m in surrounding water depths of less than 195 m and does not appear on the Dingle et al. (1987) map. It may be part of the Cretaceous drainage network linking the "palaeo" Orange (present-day Krom River) and Olifants rivers.

The deeply incised, prominent Cape Canyon defines the boundary between the Olifants shelf and the Cape Columbine to Cape Agulhas shelf to the south. The head of the Cape Canyon, located 25 km off Cape Columbine, runs parallel to the rocky inner shelf terrace and continues as a shallow, indistinct feature for nearly 27 km to the southwest before deepening rapidly and forming the northern segment of the Cape Canyon (Fig. 2) (Wigley 2004; Wigley and Compton 2006). The canyon head is likely buried beneath the thick Quaternary sediments of the Olifants Delta (Dingle 1971, 1973a). The northern segment of the Cape Canyon is roughly 100 m deep and 10 km wide, becoming progressively deeper and wider towards the middle segment, which has two distinct channels that continue southwest for ± 80 km (Simpson and Forder 1968; Dingle 1986;

Wigley 2004). At the Cape Canyon's middle segment, these two channels reach water depths of up to 600 m in surrounding water depths of 400 to 550 m, as well as a maximum width of nearly 30 km. The southern segment of the Cape Canyon is a single, 15-km-wide, and deeply incised channel that exposes Paleogene deposits (Wigley 2004; Wigley and Compton 2006).

The origin of the Cape Canyon is uncertain (Dingle 1971, 1973c; Dingle et al. 1983; Siesser et al. 1974; Dingle and Hendey 1984; Wigley 2004; Wigley and Compton 2006). It may represent an erosional conduit for sediment eroded from the continent after break-up, a narrower canyon than the Olifants Valley canyon to the north, but both converging on the Olifants and Berg river mouths and the Krom River valley that cuts into the Great Escarpment. Formation of the Cape Canyon may also relate to faults along the northern boundary of the major structural high, the Columbine-Agulhas arch that defines the prominent Saldania Belt headland at the southwest tip of Africa (Wigley and Compton 2006).

The inner shelf between Cape Columbine and Cape Agulhas is relatively wide and rocky, forming a prominent erosional scarp distinct from the middle and outer shelves, which are broad and smooth, having a gentle 0.1° average gradient. The morphology of the shelf and shoreline mainly reflects the underlying geology. Rocky headlands and inner shelves are associated with granite outcrops and irregular ridges of resistant Table Mountain Group sandstone, whereas embayments and relatively smooth valleys are associated with Malmesbury and Bokkeveld Group shales. For example, the contact zone between the Malmesbury Group metasediments and the Cape Peninsula granite pluton is well delineated directly west of Cape Town (Fig. 2). Large embayments, such as False and Walker bays, occur between more resistant rocky headlands composed of the highly resistant Table Mountain Group sandstone extending offshore of Cape Hangklip and Danger Point. Some sandstone rocky ridges extend further offshore, such as the Six and Twelve Mile banks immediately offshore Cape Agulhas and the "Agulhas Arch Anticlines" further offshore to the southeast (Fig. 2) (Dingle et al. 1975; Birch et al. 1986). The thin cover of reworked sand and gravel on the rocky inner shelf is interpreted to have been repeatedly reworked during Pleistocene glacial to interglacial cycles, particularly since 0.9 Ma, as the strandline migrated from near its present-day position to water depths of 130 m—the depth of the sharp contact between rocky and smooth, sediment-draped seafloor. Unlike off the Orange and Olifants rivers to the north, the lack of major rivers has resulted in a rocky, sediment-starved inner shelf.

A prominent new feature revealed on the middle to outer shelf (termed the "Cape Shelf Depression") is a dimple-like depression situated on the center of the gentle, westward-sloping middle shelf directly west of Robben Island (± 60 km offshore). The depression is 5 km wide, semi-circular, and reaches a water depth of 273 m surrounded by areas at 250-m water depth on its western margin, and 230 m on its eastern margin (it is situated at the foot of a 0.4° seaward slope). The origin of this large, pockmark-like feature is uncertain and awaits further seismic investigation. It may relate to natural gas chimneys, which have been documented on the outer Olifants Shelf (Kuhlman et al. 2011; Palan et al. 2020).

South Coast (Cape Agulhas to Port Alfred)

The numerous headlands and their associated east-facing log-spiral bays along the South Coast reflect the underlying geology (Fig. 3). The rocky nearshore platform consists almost entirely of folded Cape Supergroup rocks that form part of the onshore east–west striking Cape Fold Belt. The coastal headlands (and their offshore extensions) are formed by the highly resistant Table Mountain Group sandstone while the log-spiral embayments are formed by Holocene sands overlying less-resistant shales of the Bokkeveld Group and the Cretaceous Uitenhage Group. The greater number of headlands and embayments east of Cape Agulhas is due to the fact that the basement structures of the Cape Fold Belt run roughly parallel (east to west) to the overstep of Cenozoic and Cretaceous beds to the west of Cape Agulhas, while to the east they are almost normal to the overstep and generate more tight folds, the anticlines of which tend to form the headlands and the synclines the log-spiral embayments (Birch 1973; Gentle 1987).

Large, elongated, Holocene submarine spit-bars extend eastwards beyond the South Coast headlands across their adjacent bays (Martin and Flemming 1986). These submerged spit-bars create eastward extensions of the inner shelf area off Cape Infanta, Cape St. Blaize and Cape Seal. For example, the Robberg submerged spit-bar off the Cape Seal headland is a flat and shallow Holocene sediment wedge 5 km wide and up to 60 m thick that formed by easterly littoral sediment transport from the predominant southwest swell (Fig. 3 insert) (Martin and Flemming 1986). A 25-km-wide terrigenous Holocene mudbelt runs along the seaward edge of the rocky nearshore platform between Cape Seal and False Bay (Dingle et al. 1983). This mudbelt consists of sandy mud delivered by South Coast rivers that is carried to the west by bottom currents. The remainder of the Agulhas Bank seafloor is either erosional (non-depositional) or has only a thin veneer of Holocene sediment cover (Rogers 1971).

At the southernmost edge of the Alphard Rise is a prominent, east–west striking, elongated double ridge. These ridges were originally mapped as northwest-southeast trending features and were thought to reflect the strike of the Columbine-Agulhas Arch (Dingle 1970b, 1971, 1973b;

Gentle 1987; Dingle et al. 1975, 1987). However, this study reveals a more or less east–west orientation for these ridges. Because of their similar orientation to the Cape Fold Belt onshore, these ridges (termed the “Agulhas Arch Anticlines”) are suggested here to be a pair of anticlines that represent distal outliers of the Cape Fold Belt (Fig. 3). On the north-eastern flank of these two anticlinal ridges, the bathymetric isobaths swing towards the northeast reflecting a large Quaternary sediment wedge that has transgressed over the Cretaceous and pre-Cretaceous basement rocks forming an elongate and shallow shoal known as the Alphard Rise (Dingle 1970b; Gentle 1987).

The Alphard Rise covers an area that is nearly 160 km long and 60 km wide, trending in a northeast-southwest direction, the crestline meeting the coast at Cape Barracouta. The south-western boundary of the Alphard Rise primarily consists of uplifted pre-Cretaceous basement rocks along a northeast-southwest striking ridge that forms part of the Agulhas Arch. Although much of the Alphard Rise lies beneath the younger Cretaceous strata of the Alphard Group, outcrops of Table Mountain Group and Bokkeveld Group sediments are found at the southern section of the Alphard Rise (Dingle 1970b; Gentle 1987). A cluster of slender pinnacles, situated 64 km south of Cape Infanta, known as the Alphard Banks, occur on the edge of the Alphard Rise. The Alphard Banks are Cenozoic volcanic intrusive plugs that protrude above the seafloor up to depths of less than 20 m below sea level (Dingle 1970b; Gentle 1987). The area lacks bathymetric detail because of the hazard they present to survey vessels. The Alphard Rise defines the eastern margin of a large valley that appears to be the drainage valley of the Breede River when the Agulhas Bank was exposed during sea-level lowstands. This Breede River drainage valley reaches a maximum width of more than 50 km and runs parallel to the Alphard Rise for 125 km from the Breede River mouth towards the southern extent of the Twelve Mile Bank located directly south of Cape Agulhas (Fig. 3).

The middle to outer shelf along the eastern Agulhas Bank is more or less uniform except for an area 90 km south of Cape St. Blaize, where a slight rise (less pronounced than the Alphard Rise) occurs on the eastern edge of the Agulhas Bank between the middle shelf and the shelf break (Fig. 3). This feature may be associated with the shallow Gouritz River drainage valley lying directly to the west. The Gouritz River drainage valley stretches a total distance of 190 km, from the Gouritz River area (southwest of Cape St. Blaize at the – 100 m isobath) to the south past the shelf break (Birch and Rogers 1973; Gentle 1987) where it appears to have formed a small, relict submarine canyon on the upper slope. The shoreward margin of the middle shelf consists of Upper Jurassic to Lower Cretaceous Uitenhage Group deposits. They overlie the Upper Cretaceous Alphard Group which extend offshore to water depths of 90 m before disappearing underneath Paleogene and Neogene deposits that blanket the remaining middle to outer shelf area.

Between Mossel Bay (Cape St. Blaize) and Cape St Francis, numerous low, east–west trending ridges occur along the inner to middle shelf area. These have been interpreted as wave-cut platforms caused by various Pleistocene sea-level lowstands at water depths of 40 to 45 m, 50 m, 75 to 80 m, 100 to 105 m, and 110 to 115 m (Dingle 1970b; Dingle et al. 1983; Flemming et al. 1983; Martin and Flemming 1986; Cawthra et al. 2015, 2018). Parallel to these wave-cut platforms are up to 14 relict, Pleistocene coast-parallel dune cordons, similar in dimension to those exposed onshore along the Wilderness and Knysna coastline (Fig. 3) (Flemming et al. 1983; Martin and Flemming 1986; Bateman et al. 2004; Cawthra et al. 2014). These ridges represent palaeodune cordon systems that developed on the landward side of past sea-level lowstands, which were then rapidly flooded and preserved on the middle shelf as sea level rose (Martin and Flemming 1986). An up to 30-km-wide mudbelt covers some of these Pleistocene dune cordons. Off Cape St. Francis where these wave-cut terraces are best developed, typical “saw-tooth” bottom topography occurs along the middle and outer shelf due to smaller, parallel ridges to the wave-cut platforms (Fig. 3) (Dingle 1970b). These ridges are relict calcareous dune cordons (or cemented aeolianite limestone ridges) that originated parallel to Pleistocene lowstand strandlines, similar to those found off the Wilderness/Knysna area. East of Cape St. Francis, these ridges become progressively more deeply buried and only rarely protrude above the Holocene sediment drape. These ridges most likely formed in the course of Pleistocene glacial to interglacial climate cycles, with wave-cut nick points at water depths of 40 m, 50 to 55 m, and at 65 to 75 m formed by previous lowstand shorelines (Tankard 1976; Siesser and Dingle 1981; Martin and Flemming 1986; Cawthra et al. 2015, 2018).

The Outeniqua shelf extends 340 km between Cape Seal and Port Alfred and is relatively narrow, with relict aeolianite dune cordons and marine terraces on the middle shelf. The inner section of the middle shelf is dominated by the Lower Cretaceous Uitenhage Group, which crops out between Cape St. Blaize and Cape Padrone as the rocky nearshore platform. The Uitenhage Group is overlain by the Upper Cretaceous Alphard Group, which only crop out in small areas on the middle shelf to the west of Cape Seal and to the east of Cape St. Francis, as well as on the continental slope in the region of the Agulhas Slump (Dingle 1977; Dingle et al. 1983).

Overlying the Cretaceous deposits is the Paleogene Cape St. Blaize Group, the thick deposits of which are situated mainly to the west of Cape St. Francis along the middle shelf to the Alphard Rise, as well as to the east of Cape Recife to Port Alfred, extending to the outer shelf in places. A thin Neogene succession covers these Paleogene deposits along the outer shelf that extend onto the middle shelf between Cape St. Francis and Cape Recife and beyond the shelf onto the slope. A thin, coast-parallel Holocene sediment wedge is situated along the middle shelf of the Outeniqua Shelf area adjacent to the rocky nearshore platform, up to 30 km offshore of Algoa Bay (Flemming et al. 1983; Martin and Flemming 1986; Flemming and Hay 1988). The irregular bathymetry and lack of sediment cover on the middle and outer shelf east of Cape St. Francis reflect the erosive influence of the Agulhas Current upon this region. The St. Francis Bay and Algoa Bay embayments are underlain by the relatively easily eroded shale of the Uitenhage and Bokkeveld groups. The terrigenous sediment drape in these embayments originates from the discharge of the Gamtoos and Sundays rivers, but no obvious river valleys or channel structures extend offshore (Dingle et al. 1983). The Uitenhage Group also overlies the Bokkeveld Group in the major embayments that form onshore extensions of the Pletmos, Gamtoos, and Algoa sub-basins of the main Outeniqua Basin.

East Coast - Port Alfred to Scottburgh

The East Coast does not display typical passive continental margin morphology, such as a wide, gentle sloping continental shelf and slope adjacent to a deep ocean basin (Martin and Flemming 1988). The narrow continental shelf to the south of Durban is the result of translational shearing along the prominent AFFZ, in which the Falklands micro-plate moved south-westwards past the Agulhas Bank and west towards the tip of South America during Gondwana breakup, which also marks its seaward extent (Figs. 4 and 5).

The shelf can be subdivided into an inner shelf up to a water depth of 50 m, a middle shelf between 50 and 70 m water depth, and an outer shelf from 70 m up to the shelf break (Birch 1981; Flemming 1981; Hay 1984; Martin and Flemming 1986, 1988). Flemming (1981) divided the shelf platform into a nearshore and offshore zone, separated by a "drowned and partly reworked Pleistocene sediment ridge" that lies at water depths ranging between 40 and 80 m. This sediment ridge is the remains of a flooded coastal dune cordon that extends along a major part of the shelf area and is almost continuous between Port Grosvenor and Durban, covering nearly 195 km. It includes major bathymetric features, such as the Aliwal Shoals and Protea Banks (Figs. 4 and 5) (Birch 1981, 1996; Flemming 1981; Hay 1984; Bosman et al. 2005). This ridge not only forms an effective barrier to cross-shelf sediment dispersal, it also limits the influence of the Agulhas Current on its shoreward side, giving rise to a smooth, gentle sloping, Holocene sediment cover on the inshore area (Birch 1981; Flemming 1981; Hay 1984; Martin and Flemming 1986, 1988).

Numerous submerged, Late Pleistocene linear aeolianite dune cordons along the East Coast at water depths between 40 and 80 m represent shoreward margins of sea-level lowstands, similar to the coastal dune cordons along the northern KwaZulu-Natal coastline (Flemming 1981; Birch 1982; Flemming et al. 1983; Hay 1984; Martin and Flemming 1986). Wave-cut nick points in the bedrock at water depths of 40 m, 50 to 55 m, 75 to 80 m, and 100 to 105 m correspond to sea-level lowstands throughout the Late Pleistocene, similar to those found along the South Coast (Martin and Flemming 1986).

Holocene sediment is restricted to a highstand progradational sedimentary prism on the inner shelf that stretches along the entire shoreward margin of a Late Pleistocene linear, coast-parallel aeolianite ridge (Flemming 1981). This nearshore sediment wedge varies in thickness, with its width and shape depending on the source of terrigenous sediment, as well as the influence of the Agulhas Current and cyclonic eddy systems. The nearshore zone (up to 60 m water depth) is dominated by a high-energy swell regime with an underlying sandy sediment wedge (Flemming 1980, 1981; Flemming and Hay 1988). The lack of sediment deposition elsewhere on the shelf reflects the erosional force of the fast (2 m/s), poleward-flowing Agulhas Current along the shelf break (Lutjeharms 1996, 2006). It is only where the coastline and adjacent shelf are offset to the west that cyclonic eddies are induced, causing an accumulation of Holocene sediments within coastal bights (Pearce et al. 1978). These eddies also play a major role in Quaternary sediment dispersal and the morphology of the middle and inner shelves.

For example, a submerged and nearly buried Pleistocene aeolianite ridge off the Port St. Johns Bight shelters the shoreward shelf area against the Agulhas Current (Flemming 1981; Martin and Flemming 1986). The formation of the associated expansive sediment wedge is due to a cyclonic eddy situated between the Port St. Johns Bight and the Waterfall Bluff structural offset to the north. The core of the Agulhas Current overshoots the shelf at the Mbotyi Canyon and causes a north-flowing inshore counter-current and littoral drift that result in a northerly sediment transport (Flemming 1981; Martin and Flemming 1986). This, together with the damming action of the aeolianite dune ridges along the Port St. Johns Bight, results in the deposition of a thick sedimentary wedge along this sheltered shelf area, with the bulk of its terrigenous sediment from the Mngazana, Mngazi/Mgwenyana, Mzimvubu, and Mzintlava rivers.

Between Port St. Johns and the Mzintlava River mouth, the inner and middle shelves are dominated by an up to 32-m-thick nearshore sediment wedge that extends across to the head of the Mzimvubu Canyon (Martin and Flemming 1986). North of the Mzintlava River mouth, the shelf narrows (<2 km) and steepens (1.6°) up to a relatively flat (0.3°) nearshore sediment wedge situated to the south of the Waterfall Bluff structural offset (Martin and Flemming 1986). North of the Mzintlava River, the sediment wedge widens, forming a 3.5-km-wide and flat sedimentary terrace before narrowing again off the Waterfall Bluff offset. A sequence of small, sub-parallel palaeodune ridges exists on this flat sediment terrace on the southern margin of the Waterfall Bluff structural offset (Martin and Flemming 1986). This Cenozoic sediment wedge lies to the south of the Egosa Fault and formed as a result of the protection that this structural offset provided against the strong, southward flowing Agulhas Current (Flemming 1980; Hay 1984). The presence of a cyclonic eddy on the leeward side of the Waterfall Bluff structural offset greatly influences the deposition of this thick sediment wedge due to northern littoral drift of sediments delivered by major rivers such as the Mzimvubu and Mzintlava (Harris 1978; Flemming 1980, 1981; Martin and Flemming 1986). The core of the Agulhas Current overshoots the outer shelf edge off the Mbotyi Canyon head and transports the bedload sediment "off" shelf into the adjacent Natal Valley (Flemming 1980, 1981; Martin and Flemming 1986).

The middle shelf is dominated by an immense, linear, coast-parallel relict Pleistocene dune ridge, roughly 7 km offshore off Port Shepstone at water depths of 50 m and 60 m (Flemming 1981; Birch 1981; Hay 1984; Martin and Flemming 1986). Forming part of this relict, Pleistocene dune ridge southeast of Port Shepstone at 40- to 50-m water depth is a large shoal, the Protea Banks, which rises 15 to 25 m above the surrounding seabed (Fig. 4) (Birch 1981; Flemming 1981; Hay 1984). Northwards, towards Scottburgh, two parallel Pleistocene dune ridges form the seaward extent of the inner and middle shelf areas of an up to 34-m-thick nearshore sediment wedge protected from the Agulhas Current (Flemming 1981; Martin and Flemming 1986).

Between Port Alfred and the Great Fish River, a wide, shallow valley cuts across the middle and outer shelf, possibly incised by the Great Fish River during lowstands. A second incised cross-shelf valley is situated at the south-eastern margin of the prominent inshore sediment wedge. This valley cuts across the middle and outer shelf and continues onto the continental slope as a small submarine canyon (termed the "Keiskamma" Canyon) roughly 32 km south of East London (Fig. 5) (De Wet 2013). This valley may link to the Keiskamma River, since it trends in an east–west direction towards this area, although concealed by the thick Quaternary nearshore sediment wedge along the inner shelf. The outer shelf area at the foot of this valley has been indented slightly by the "Unknown" submarine Canyon. North of this valley, the middle and outer shelves extend seaward as a large, flat ($<0.1°$) terrace that continues northwards past East London.

Subaerial exposure of the East Coast continental shelf during the Last Glacial Maximum and its overall narrowness resulted in the formation of numerous shelf-incised (and later infilled) river channels and valleys and the further incising of the numerous submarine canyons, such as the "Keiskamma," St Johns, Mbotyi, Mzimvubu, Egosa, Protea, and Umzumbe (Figs. 4 and 5) (Flemming 1981; Dingle et al. 1983; Hay 1984; Martin and Flemming 1986; Green et al. 2007, 2013; Green and Uken 2008; Green 2009a, b; Green and Garlick 2011). Numerous slump scars are also visible along the continental slope, especially along the steeply dipping southern margin between Port Alfred and Durban.

East Coast - Scottburgh to Kosi Bay

Between Scottburgh and Umkomaas, the inner shelf gradually widens north of the Mtwalume River, forming an extensive, nearshore sediment wedge (Flemming 1981; Hay 1984). North of Umkomaas, this sediment wedge narrows abruptly to less than 2 km off the Illovo River, where it gives way to a wide, flat middle shelf terrace (Fig. 5). This gentle sloping ($<0.4°$), nearshore sediment wedge, known as the Illovu submerged spit-bar, extends a maximum of 7.8 km offshore between water depths of 40 and 60 m. It represents a massive, up to 34-m-thick, north-eastward prograding sand body fed by the terrigenous sediment flux of the Illovu, Mkomazi, and Mpambanyoni rivers (Birch 1981; Flemming 1981; Hay 1984; Flemming and Hay 1988; Martin and Flemming 1988).

Close to the center of the Illovu submerged spit-bar is a 3-km-long, 380-m-wide, northeast-southwest trending aeolianite ridge known as the Aliwal Shoals (Fig. 5) (Flemming 1981; Hay 1984; Bosman et al. 2005). Rising from water depths of 24 and 30 m to just 6 m below mean sea level, the Aliwal Shoals is a major shipping hazard. Thought to form part of a series of large, reworked Late Pleistocene palaeodune ridges on the inner shelf between Port Shepstone and Durban (Flemming 1981; Bosman et al. 2005), the Aliwal Shoals consist of two parallel, linear palaeodune ridges on the seaward margin, with the shoreward ridge marking the extent of the nearshore sediment wedge.

The strong north to south geostrophic flows induced by the Agulhas Current limits sediment to a thin veneer, mantling relict, outer shelf gravels (Flemming 1978, 1981; Ramsay et al. 2006). A bedload parting zone exists along the southern margin of Lake St. Lucia (Flemming 1981; Flemming and Hay 1988) as a result of a large cyclonic eddy that is caused by the significant structural offset along the southern margin of the extensive Mozambique Coastal Plain. Most shelf sediment north of Lake St. Lucia is transported by a northern littoral drift and is deposited into the Northern Natal Valley via the Leven, Leadsman, and Diepgat canyons (Fig. 5). Several linear bedforms, such as northward-migrating dune fields and sand streamers, exist along the outer shelf as a result of the northern bedload transport conveyor belt (Flemming 1980, 1981; Green and Uken 2008). Similar to the St. Lucia Shelf, the Sodwana Shelf is influenced by a large cyclonic eddy on the leeward side of the extensive Mozambique coastal plain. This counter-current to the south-flowing Agulhas Current results in a northward littoral drift that transports sediment northwards, as well as "off" shelf via canyons cutting the outer shelf. Current-related features include large, northward-migrating dune fields on the middle and outer shelf to the south of the North and South Mabibi canyon heads (Green et al. 2007; Green and Uken 2008).

Significant sediment accumulation on the East Coast shelf is mostly restricted to the Tugela and Limpopo cones, with the majority of the sediment deposited on the adjacent continental slope and deep ocean basins (Dingle 1973d; Dingle et al. 1983). Neogene sediments are relatively thin to non-existent due to a major Neogene uplift and erosion cycle (Partridge and Maud 1987). The Tugela Cone is a triangular-shaped marginal plateau of terrigenous sediment delivered by the Tugela River since the Early Cretaceous (Hobday 1982; Goodlad 1986; Martin and Flemming 1988). The cone is cut by numerous terraces and valleys, with the Tugela Canyon being the most prominent, cutting obliquely across the southern part of the Tugela Cone, starting at ~ 1000 m and reaching a maximum water depth of 2800 m (Dingle and Siesser 1977; Martin 1984; Martin and Flemming 1988). Off-shelf, the Tugela Cone extends up to 220 km to the south-east of the Tugela River onto the northern margin of the Natal Valley (Goodlad 1986; Martin and Flemming 1988) (Fig. 5).

The Richards Bay structural offset resulted in a seaward extension of the shoreline to the north of the Mlalazi River towards Richards Bay, creating a southward-facing embayment that shelters the large inshore sediment wedge of the Tugela Cone to the south of it from the Agulhas Current. This structural offset causes a large semi-permanent cyclonic eddy on its leeward margin. An extensive, nearshore Quaternary sediment wedge formed by sediment transported north by littoral drift lies between the Tugela River mouth and the eastern margin of the structural offset (Harris 1978; Flemming 1980, 1981; Martin and Flemming 1988). The inner shelf is dominated by a nearshore sand prism while the outer shelf consists of a gravel pavement due to the erosional nature of the fast-flowing Agulhas Current (Flemming 1980, 1981). Excess sediment is transported along shelf by an Agulhas Current-dominated sand stream (situated along the middle shelf) until it is dispersed off-shelf at one of three major structural offsets along the East Coast margin off Durban, Port St. Johns, and Port Elizabeth (Flemming 1980, 1981; Flemming and Hay 1988).

Numerous submarine canyons indent the narrow shelf between Lake St Lucia and Kosi Bay, namely the Leven, North and South Leadsman, Diepgat, Sodwana Canyon Complex (Wright and Wright Sands canyons), and Mabibi Canyon Complex (South Mabibi, Mabibi, South Island Rock, and Island Rock canyons) (Green et al. 2007; Green and Uken 2008; Green 2009a, b, 2011). Other smaller, less distinct submarine canyons are also situated along the St. Lucia Shelf, but are mainly confined to the continental slope and rise and do not disrupt the continental shelf and shelf break.

Conclusions

The newly derived single-beam, echo-sounding bathymetric maps significantly improve the resolution of shelf bathymetry from what was previously available (Dingle et al. 1987). They not only resolve the major bathymetric features in much greater detail and accuracy but reveal numerous new features on the western and southern continental margins of South Africa. Better resolved features include Childs Bank, Cape Canyon, Cape Point Valley, the Inner Shelf Terrace between Cape Columbine and Cape Point on the West Coast, the Rocky Nearshore Platform between Cape Point and Cape Infanta on the South Coast, numerous headland extensions, the Agulhas Arch, Alphard Banks, the Robberg submerged spit-bar off the Cape Seal headland, as well as the numerous canyons along the East Coast.

One of the newly identified features is the northern extension of the Olifants Valley submarine canyon ("Olifants Valley North"), which is proposed to represent a drainage valley for either the palaeo-Orange River or the palaeo-Olifants River during past sea-level lowstands. Other new or better-defined shelf features include the inner shelf platform between Cape Columbine and the Cape Peninsula, the basement anticlinal ridges situated at the southernmost extent of the Agulhas Arch ("Agulhas Arch Anticlines") and the coast-parallel wave-cut terraces and palaeodune ridges (aeolianites) on the middle shelf between Cape Seal and Cape Recife. Another new feature is the pockmark-like depression ("Cape Shelf Depression") situated at the center of the gentle, westward-sloping middle shelf 60 km west of Cape Town. One prominent submarine canyon ("Keiskamma Canyon") was also identified south of East London. Little is known of these features and further studies are necessary to provide a better understanding as to how they formed.

The bathymetric dataset derived from this study will provide a solid basis for the planning of future scientific studies, such as geological mapping and research, modelling of coastal processes, ecosystems management, and habitat research, as well as coastal and marine spatial planning. It will greatly help to aid future bathymetric research expeditions, which will hopefully add to its spatial extent, improving the resolution and accuracy of the dataset.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00367-021-00701-y.

Acknowledgements The single-beam bathymetric data were collected by the Department of Agriculture, Forestry and Fisheries (DAFF) during the last two decades, on board the vessels F.R.S. Africana II and F.R.S. Algoa, and we gratefully acknowledge their entire staff and crew for their skill, hard work, and dedication. We would especially like to thank Janet Coetzee and Dagmar Merkle from DAFF, as well as Rochelle Wigley, Hayley Cawthra, Michael MacHutchon, and Wilhelm Van Zyl of the Council for Geoscience Marine Geoscience Unit for their various contributions in the form of software licenses, datasets, professional help, and expertise. We thank the editor (Andrew Green) and the two reviewers for their valuable input and suggestions that significantly improved this paper.

Funding This research project was funded by the Marine Research Institute (MARE) at the University of Cape Town in the form of a MARE Basics Bursary.

References

Amante C, Eakins B (2009) ETOPO1 - 1 arc-minute global relief model: procedures, data sources and analysis. NOAA Technical Memorandum, NESDIS NGDC 24:19 pp

Bateman MD, Holmes PJ, Carr AS, Horton BP, Jaiswal MK (2004) Aeolianite and barrier-dune construction during the last two glacial-interglacial cycles from the Southern Cape coast, South Africa. Quatern Sci Rev 23:1681–1698

Becker JJ, Sandwell DT, Smith WHF, Braud J, Binder B, Depner J, Fabre D, Factor J, Ingalls S, Kim S-H, Ladner R, Marks K, Nelson S, Pharaoh A, Trimmer R, Von Rosenberg J, Wallace G, Weatherall P (2009) Global bathymetry and elevation data at 30 arc seconds resolution: SRTM30_PLUS. Mar Geodesy 32:355–371

Ben-Avraham Z, Hartnady CJN, Kitchin KA (1997) Structure and tectonics of the Agulhas-Falkland fracture zone. Tectonophysics 282:83–98

Birch GF (1971) The glauconite deposits on the Agulhas Bank, South Africa. Bulletin of the Joint Geological Survey/University of Cape Town Marine Geoscience Group 4:1–134

Birch GF (1973) Unconsolidated sediments off the Cape west coast. Technical Report of the Joint Geological Survey/university of Cape Town Marine Geoscience Group 5:48–66

Birch GF (1977) Surficial sediments on the continental margin off the west coast of South Africa. Mar Geol 23:305–337

Birch GF (1980) Nearshore Quaternary sedimentation off the coast of South Africa (Cape Town to Port Elizabeth). Bulletin of the Geological Survey of South Africa 67:20

Birch GF (1981) The bathymetry and geomorphology of the continental shelf and upper slope between Durban and Port St Johns. Annals of the Geological Survey of South Africa 15:55–62

Birch GF (1982) Sedimentological and Geophysical investigations of a major sediment exit point on the south-east African continental margin (vicinity of Port St Johns). Transactions of the Geological Society of South Africa 85:91–103

Birch GF (1996) Quaternary Sedimentation off the East Coast of Southern Africa (Cape Padrone to Cape Vidal). Bulletin of the Geological Survey of South Africa, Council for Geoscience 118:55 pp

Birch GF, Rogers J (1973) Nature of the sea floor between Lüderitz and Port Elizabeth. South African Shipping News and Fishing Industry Review 28:7 pp

Birch GF, Rogers J, Bremner JM (1986) Texture and composition of sediments of the continental margin of the Republics of South Africa, Transkei and Ciskei Map. Geological Survey of South Africa Marine Geoscience Series: 3 Sheets

Birch GF, Day RW, Du Plessis A (1991) Nearshore Quaternary sediments on the west coast of Southern Africa. Department of Mineral and Energy Affairs, Geological Survey Bulletin 101:1–14

Bosman C, Uken R, Smith AM (2005) The bathymetry of Aliwal Shoal, Scottburg, South Africa. S Afr J Sci 101:255–257

Broad DS, Jungslager EHA, McLachlan IR, Roux J (2006) Offshore Mesozoic Basins. In: Johnson MR, Anhaeusser CR, Thomas RJ (eds) The geology of South Africa. Geological Society of South Africa, Johannesburg/Council for Geoscience, Pretoria, pp 553–571

Brown LF, Benson JM, Brink GJ, Doherty S, Jollands A, Jungslager EHA, Keenan JHG, Muntingh A, van Wyk NJS (1995) Sequence stratigraphy in offshore South African divergent basins: an atlas on exploration for Cretaceous lowstand traps by SOEKOR (Pty) Ltd. American Association for Petroleum Geologists: Studies in Geology 41:1–184

Brown R, Summerfield M, Gleadow A, Gallagher K, Carter A, Beucher R, Wildman M (2014) Intracontinental deformation in southern Africa during the Late Cretaceous. J Afr Earth Sc 100:20–41

Cawthra HC (2010) The Cretaceous to Cenozoic evolution of the Durban Bluff and adjacent continental shelf. MSc thesis (unpublished), University of KwaZulu-Natal, Durban, South Africa 257 pp

Cawthra HC, Uken R, Oveckhina M (2012) New insights into the geological evolution of the Bluff ridge and adjacent Blood reef, Durban, South Africa. S Afr J Geol 115:291–308

Cawthra HC, Bateman MD, Carr AS, Compton JS, Holmes PJ (2014) Understanding Late Quaternary change at the land-ocean interface: a synthesis of the evolution of the wilderness coastline, South Africa. Quatern Sci Rev 99:210–223

Cawthra HC, Compton JS, Fisher EC, MacHutchon MR, Marean CW (2015) Submerged shorelines and landscape features offshore of Mossel Bay, South Africa. In: Harff J, Bailey G, Lüth F (eds) Geology and archaeology: submerged landscapes of the continental shelf. Geological Society, London, Special Publications 411:15 pp

Cawthra HC, Jacobs Z, Compton JS, Fisher EC, Karkanas P, Marean CW (2018) Depositional and sea-level history from MIS 6 (Termination II) to MIS3 on the southern continental shelf of South Africa. Quatern Sci Rev 181:156–172

Compton JS (2011) Pleistocene sea-level fluctuations and human evolution on the southern coastal plain of South Africa. Quatern Sci Rev 30:506–526

Compton JS, Wiltshire JG (2009) Terrigenous sediment export from the western margin of South Africa on glacial to interglacial cycles. Mar Geol 226:212–222

De Wet WM (2013) Bathymetry of the South African continental shelf. MSc thesis (unpublished), University of Cape Town, Cape Town, South Africa 309 pp

De Decker RH (1987) The geological setting of diamondiferous deposits on the inner shelf between the Orange River and Wreck Point, Namaqualand. PhD thesis (unpublished), University of Cape Town, Cape Town, South Africa 99 pp

Dingle RV (1970a) Bathymetry. Technical Report of the Joint Geological Survey/university of Cape Town Marine Geology Program 3:11–12

Dingle RV (1970b) Preliminary geological map of part of the Agulhas Bank, South African continental margin. Proc Geol Soc Lond 1663:137–142
Dingle RV (1971) Tertiary sedimentary history of the continental shelf off southern Cape Province, South Africa. Transactions of the Geological Society of South Africa 74:173–186
Dingle RV (1973a) The geology of the continental shelf between Luderitz and Cape Town (Southwest Africa), with special reference to Tertiary strata. J Geol Soc London 129:337–363
Dingle RV (1973b) Post-Palaeozoic stratigraphy of the eastern Agulhas Bank, South African continental margin. Mar Geol 15:1–23
Dingle RV (1973c) Mesozoic palaeogeography of the southern Cape, South Africa. Palaeogeogr Palaeoclimatol Palaeoecol 13:203–213
Dingle RV (1973d) Regional distribution and thickness of post-Palaeozoic sediments on the continental margin of southern Africa. Geol Mag 110:97–102
Dingle RV (1977) The anatomy of a large submarine slump on a sheared continental margin (South East Africa). J Geol Soc London 134:293–310
Dingle RV (1986) Revised bathymetric map of the Cape Canyon. Technical Report of the Joint Geological Survey/university of Cape Town Marine Geoscience Unit 16:20–33
Dingle RV, Gerrard I, Gentle RI, Simpson ESW (1971) The continental shelf between Cape Town and Cape Agulhas. In: Delany FM (ed) The geology of the east Atlantic continental margin. ICSU/SCOR Working Party 31 Symposium, Cambridge 1971, Report of the Institution of Geological Sciences of London 70:199–209
Dingle RV, Rogers J (1972) Pleistocene Palaeography of the Agulhas Bank. Transactions of the Royal Society of South Africa 40:155–165
Dingle RV, Gentle RI (1972) Early Tertiary volcanic rocks on the Agulhas Bank, South African continental shelf. Geology Magazine 109:127–136
Dingle RV, Scrutton RW (1974) Continental breakup and the development of post-Palaeozoic sedimentary basins around southern Africa. Bulletin of the Geological Society of America 85:1467–1474
Dingle RV, Moir GJ, Bremner JM, Rogers J (1975) Bathymetry of the continental shelf off the Republic of South Africa and South West Africa, Scale 1:125000 at Lat 30° Map. Geological Survey of South Africa Marine Geoscience Series: 1 Sheet
Dingle RV, Siesser WG (1977) Geology of the continental margin between Walvis Bay and Ponto do Ouro Map. Geological Survey of South Africa Marine Geoscience Series: 2 Sheets
Dingle RV, Siesser WG, Newton AR (1983) Mesozoic and tertiary geology of Southern Africa. AA Balkema, Rotterdam, Netherlands, 375 pp
Dingle RV, Hendey QB (1984) Late Mesozoic and Tertiary sediment supply to the eastern Cape Basin (SE Atlantic) and palaeo-drainage systems in southwestern Africa. Mar Geol 56:13–26
Dingle RV, Robson S (1985) Slumps, canyons and related features on the continental shelf off East London, SE Africa (SW Indian Ocean). Mar Geol 67:37–54
Dingle RV, Birch GF, Bremner JM, De Decker RH, Du Plessis A, Engelbrecht JC, Fincham MJ, Fitton T, Flemming BW, Gentle RI, Goodlad SW, Martin AK, Mills EG, Moir GJ, Parker RJ, Robson SH, Rogers J, Salmon DA, Siesser WG, Simpson ESW, Summerhayes CP, Westall F, Winter A, Woodborne MW (1987) Deep-sea sedimentary environments around Southern Africa (South-East Atlantic and South-West Indian Oceans). Annals of the South African Museum 98:1–27
Emery KO, Bremner JM, Rogers J (1992) Hypsometry of divergent and translational continental margins of southern Africa. Mar Geol 106:89–105
Flemming BW (1978) Underwater sand dunes along the southeast African continental margin — Observations and implications. Mar Geol 26:177–198
Flemming BW (1980) Sand transport and bedform patterns on the continental shelf between Durban and Port Elizabeth (southeast African continental margin). Sed Geol 26:179–205
Flemming BW (1981) Factors controlling shelf sediment dispersal along the southeast African continental margin. Mar Geol 42:259–277
Flemming BW, Eagle GA, Fricke AH, Hunter IT, Marin AK, Schumann EH, Swart VP, Zoutendyk P (1983) Agulhas Bank Studies, Report II. Memo of the Stellenbosch National Research Institute for Oceanology 8319:78 pp
Flemming BW, Hay R (1988) Sediment distribution and dynamics on the Natal continental shelf. In: Schumann EH (ed) Coastal ocean studies off Natal, South Africa Lecture notes on Coastal and Estuarine Studies. Springer, Berlin, 26:47–80
Francheteau J, LePichon X (1972) Marginal fracture zones as structural framework of continental margins in the South Atlantic Ocean. Bulletin of the American Association of Petrological Geology 56:991–1007
Gentle RI (1987) The Geology of the inner continental shelf and Agulhas Arch: Cape Town to Port Elizabeth. Bulletin of the Joint Geological Survey/University of Cape Town Marine Geoscience Unit 20:129 pp
Glass G (1980) Geology, morphology, sediment cover and movement. In: Gasson B (ed) The future management of False Bay. False Bay Conservation Society, Cape Town, South Africa, pp 15–25
Goodlad SW (1986) A tectonic and sedimentary history of the mid-Natal Valley (SW Indian Ocean). Bulletin of the Joint Geological Survey/University of Cape Town Marine Geology Program15:415 pp
Green AN (2009a) Palaeo-drainage, incised valley fills and transgressive systems tract sedimentation of the northern Kwazulu-Natal continental shelf, South Africa, SW Indian Ocean. Mar Geol 263:46–63
Green AN (2009b) Sediment dynamics on the narrow, canyon-incised and current-swept shelf of the northern KwaZulu-Natal continental shelf, South Africa. Geo-Mar Lett 29:201–219
Green AN (2011) Submarine canyons associated with alternating sediment starvation and shelf-edge wedge development: Northern KwaZulu-Natal continental margin, South Africa. Mar Geol 284:114–126
Green AN, Goff JA, Uken R (2007) Geomorphological evidence for upslope canyon-forming processes on the northern KwaZulu-Natal shelf, South Africa, SW Indian Ocean. Geo-Mar Lett 27:399–409
Green AN, Uken R (2008) Submarine land sliding and canyon evolution on the northern KwaZulu-Natal continental shelf, South Africa, SW Indian Ocean. Mar Geol 254:152–170
Green AN, Garlick GL (2011) A sequence stratigraphic framework for the narrow, current-swept continental shelf: the Durban Bight, central KwaZulu-Natal, South Africa. J Afr Earth Sc 60:303–314
Green AN, Leuci R, Thackeray Z, Vella G (2012) Number One Reef: an overstepped segmented lagoon complex on the KwaZulu–Natal continental shelf. S Afr J Sci 108(7–8):113–118
Green AN, Dladla N, Garlick GL (2013) Spatial and temporal variations in incised valley systems from the Durban continental shelf, KwaZulu-Natal, South Africa. Mar Geol 335:148–161
Harris TFW (1978) Review of the coastal currents in southern African waters. Report of the South African National Scientific Programmes 30:103 pp
Hay ER (1984) Sediment dynamics on the continental shelf between Durban and Port St Johns (southeast African continental margin). Bulletin of the Joint Geological Survey/University of Cape Town Marine Geology Program 13:238 pp

Herbert CT, Compton JS (2007) Geochronology of Holocene sediments on the western margin of South Africa. S Afr J Geol 110:327–338
Hobday DK (1982) The Southeast African margin. In: Nairn AEM, Stehli FG (eds) The ocean basins and margins, Chapter 6: The Indian Ocean. pp 149–183
Jacobs Z, Jones BG, Cawthra HC, Henshilwood CS, Rob RG (2019) The chronological, sedimentary and environmental context for the archaeological deposits at Blombos Cave, South Africa. Quaternary Science Reviews 22 pp
King LC (1967) Scenery of South Africa. Oliver and Boyd, Edinburgh, 308 pp
Knight J, Grab S (2016) Quaternary environmental change in Southern Africa: physical and human dimensions. Journal of African Archaeology 15(1):129–131
Kuhlman G, Adams S, Anka Z, Campher C, Di Primio R, Horsfield B (2011) 3D petroleum systems modelling within a passive margin setting, Orange Basin blocks 3/4, offshore South Africa – implications for gas generation, migration and leakage. S Afr J Geol 114:321–348
LaBrecque JL, Hayes DE (1979) Seafloor spreading history of the Agulhas Basin. Earth Planetary and Science Letters 45:411–428
Lodewyks T (2010) Seismic stratigraphy of the Upper Pleistocene gravel and Holocene mudbelt deposits between Wreck Point and the Kamma River on the western shelf of South Africa. MSc thesis (unpublished), University of Cape Town, Cape Town, South Africa
Lutjeharms JRE (1996) The exchange of water between the South Indian and South Atlantic Oceans. In: Wefer G, Berger WH, Siedler G, Webb DJ (eds) The South Atlantic: past and present circulation. Springer-Verlag, Berlin, pp 125–162
Lutjeharms JRE (2006) The Agulhas Current. Springer-Verlag, Berlin, p 329
Marean CW (2010) Pinnacle Point Cave 13B (Western Cape Province, South Africa) in context: The Cape Floral kingdom, shellfish, and modern human origins. J Hum Evol 59:425–443
Marean CW (2011) Coastal South Africa and the coevolution of the modern human lineage and coastal adaptations. In: Bicho N, Haws JA, Davis LG (eds) Trekking the shore: changing coastlines and the antiquity of Coastal Settlement. Springer, New York, pp 421–440
Martin AK (1984) Plate tectonic status and sedimentary basin in-fill of the Natal Valley (SW Indian Ocean). Bulletin of the Joint Geological Survey/university of Cape Town Marine Geology Program 14:1–102
Martin AK, Flemming BW (1986) The Holocene shelf sediment wedge off the south and east coast of South Africa. In: Knight RJ, McLean JR (eds) Shelf sands and sandstones. Memoir of the Canadian Society for Petroleum Geology 2:24–44
Martin AK, Flemming BW (1988) Physiography, structure and geological evolution of the Natal Continental Shelf. In: Schumann EH (ed) Coastal ocean studies off Natal, South Africa Lecture Notes on Coastal and Estuarine Studies. Springer, Berlin, 26:11–46
Monteiro PMS, Nelson G, van der Plas A, Mabille E, Bailey GW, Klingelhoeffer E (2005) Internal tide – shelf topography interactions as a forcing factor governing the large-scale distribution and burial fluxes of particulate organic matter (POM) in the Benguela upwelling system. Cont Shelf Res 25(15):1864–1876
Moore AE, Larkin PA (2001) Drainage evolution in south-central Africa since the breakup of Gondwana. S Afr J Geol 104:47–68
Moore AE, Cotterill FPD, Eckardt FD (2012) The evolution and ages of Makgadikgadi palaeo-lakes: consilient evidence from Kalahari drainage evolution, south-central Africa. S Afr J Geol 115:385–413
Palan K, Green AN, Andrew B, Sink K, Wiles EA (2020) A morphometric analysis of the fluid flow features of the southern Orange Basin, South Africa. Marine Geology 423:14 pp
Partridge TC, Maud RR (1987) Geomorphic evolution of southern Africa since the Mesozoic. S Afr J Geol 90:179–208
Partridge TC, Maud RR (2000) Macro-scale geomorphic evolution of southern Africa. In: Partridge TC, Maud RR (eds) The Cenozoic of Southern Africa. Oxford University Press, New York, pp 3–18
Pearce AF, Schumnn EH, Lundie GSH (1978) Features of the shelf circulation off the Natal coast. S Afr J Sci 74:328–331
Pfaff MC, Logston RC, Raemaekers SJPN, Hermes JC, Blamey LK, Cawthra HC, Colenbrander DR, Crawford RJM, Day E, du Plessis N, Elwen SH, Fawcett SE, Jury MR, Karenyi N, Kerwath SE, Kock AA, Krug M, Lamberth SJ, Omardien A, Pitcher GC, Rautenbach C, Robinson TB, Rouault M, Ryan PG, Shillington FA, Sowman M, Sparks CC, Turpie JK, van Niekerk L, Waldron HN, Yeld EM, Kirkman SP (2019) A synthesis of three decades of socio-ecological change in False Bay, South Africa: setting the scene for multidisciplinary research and management. Elementa: Science of the Anthropocene 7:32
Pretorius L, Green AN, Cooper JAG, Hahn A, Zabel M (2019) Outer- to inner-shelf response to stepped sea-level rise: insights from incised valleys and submerged shorelines. Marine Geology 416:14 pp
Ramsay PJ (1996) Quaternary marine geology of the Sodwana Bay continental shelf, northern KwaZulu–Natal. Council for Geoscience Bulletin 117:86 pp
Ramsay PJ, Cooper JAG (2002) Late Quaternary sea-level change in South Africa. Quatern Res 57:82–90
Ramsay PJ, Schleyer MH, Leuci R, Muller GA, Celliers L, Harris JM (2006) The development of an expert marine geographical information system to provide an environmental and economic decision support system for proposed tourism developments within and around the Greater St Lucia Wetland Park World Heritage Site. Innovation Fund Project 24401:92 pp
Rogers J (1971) Sedimentology of Quaternary deposits on the Agulhas Bank. Department of Geology, Bulletin of the University of Cape Town, SANCOR Marine Geological Program 1:1–117
Rogers J (1977) Sedimentation on the continental margin off the Orange River and the Namib Desert. Bulletin of the Joint Geological Survey/University of Cape Town, Marine Geoscience Group 7:1–162
Rogers J, Bremner JM (1991) The Benguela ecosystem, Part VII Marine-geological aspects. Oceanogr Mar Biol Annu Rev 29:1–85
Scrutton RA, Dingle RV (1976) Observations on the process of sedimentary basin formation at the margins of Southern Africa. Tectonophysics 36:143–156
Séranne M, Anke Z (2005) South Atlantic continental margins of Africa: a comparison of the tectonic vs climate interplay on the evolution of equatorial West Africa and SW Africa margins. J Afr Earth Sc 43:283–300
Shabangu FW, Coetzee JC, Hampton I, Kerwath SE, De Wet WM, Lezama-Ochoa A (2014) Hydro-acoustic technology and its application to marine science in South Africa. In: Funke N, Claassen M, Meissner R, Nortje K (eds) Reflections on the state of research and technology in South Africa's marine and maritime sectors, pp 120–151
Shannon LV, Nelson G (1996) The Benguela: large scale features and processes and system variability. In: Wefer G et al (eds) The South Atlantic: past and present circulation. Springer, Berlin, pp 211–217
Shepard FP (1963) Submarine geology. Harper and Row, New York, p 551

Siesser WG (1970) Carbonate components and mineralogy of the South African coastal limestones and limestones of the Agulhas Bank. Transactions of the Geology Society of South Africa 73:49–63

Siesser WG (1971) Petrology of some South African coastal and offshore carbonate rocks and sediments. PhD thesis (unpublished), University of Cape Town, Cape Town, South Africa, 232 pp

Siesser WG, Dingle RV (1981) Tertiary sea-level movements around southern Africa. J Geol 89:83–96

Siesser WG, Scrutton RA, Simpson ESW (1974) Atlantic and Indian Ocean margins of southern Africa. In: Burk CA, Drake CL (eds) The geology of continental margins. Springer-Verlag, New York, pp 641–654

Simpson ESW (1971) The geology of the southwest African continental margin: a review. In: Delanny FM (ed) The geology of the east Atlantic continental margin. SCOR Symposium, Cambridge, 1970, Inst. of Geo. Sci., Rep. 70/16:153–170

Simpson ESW, Forder E (1968) The Cape Submarine Canyon. Fisheries Bulletin, South Africa 5:35–38

Sink K, Holness S, Harris L, Majiedt P, Atkinson L, Robinson T, Kirkman S, Hutchings L, Leslie R, Lambeth S, Kerwath S, von der Hayden S, Lombard A, Attwood C, Branch G, Fairweather T, Taljaard S, Weerts S, Cowley P, Awad A, Halpern B, Grantham H, Wolf T (2011) National biodiversity assessment 2011: technical report Vol 4: marine and coastal component. South African National Biodiversity Institute, Pretoria, pp 325

Tankard AJ (1976) Cenozoic sea-level changes – a discussion. Annals of the South African Museum 71:1–17

Tankard AJ, Jackson MPA, Eriksson KA, Hobday DK, Hunter DR, Minter WEL (1982) Chapter 12: fragmentation and Mesozoic Palaeogeography. Crustal Evolution of Southern Africa. Springer-Verlag, New-York, pp 407–454

Tinker J, de Wit M, Brown R (2008) Mesozoic exhumation of the southern Cape, South Africa, quantified using apatite fission track thermochronology. Tectonophysics 455:77–93

Watkeys MK (2006) Gondwana break-up: a South African perspective. In: Johnson MR, Anhaeusser CR, Thomas RJ (eds) The geology of South Africa. Geological Society of South Africa, Johannesburg/Council for Geoscience, Pretoria, pp 531–539

Wigley RA (2004) Sedimentary facies from the head of the Cape Canyon: insights into the Cenozoic evolution of the western margin of South Africa. PhD thesis (unpublished), University of Cape Town, Cape Town, South Africa, 310 pp

Wigley RA, Compton JS (2006) Late Cenozoic evolution of the outer continental shelf at the Head of the Cape Canyon, South Africa. Mar Geol 226:1–23

Wildman M, Brown R, Watkins R, Carter A, Gleadow A, Summerfield M (2015) Post break-up tectonic inversion across the southwestern cape of South Africa: new insights from apatite and zircon fission track thermochronometry. Tectonophysics 654:30–55