HOLOCENE SEDIMENT DYNAMICS ON THE WESTERN MARGIN OF SOUTH AFRICA

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ABSTRACT

The unusually broad, deep shelf on the western continental margin of South Africa is a site of high primary productivity associated with the Benguela Upwelling System and is a repository for Holocene terrigenous sediment delivered by the Orange River. Continental margins represent the interface between the terrestrial and marine environment and provide the key to understanding Holocene interactions of the ocean-atmosphere system. Due to present interglacial sea-level highstand conditions, Holocene margins serve as an analogue for the large continental shelves of the geological past. This study documents Holocene sediment dynamics on the western margin of South Africa, with special reference to the terrigenous mud fraction. The distribution of Holocene terrigenous sediment is used to assess changes in continental and oceanic processes affecting the margin, including oceanic current circulation, sea-level, sediment supply, organic matter cycling and inorganic nutrient flux to the ocean.

The Orange River catchment drains ~45% of South Africa and, upon arrival at the western margin, Orange River sand is transported north by littoral drift. Orange River suspended load mud is deposited temporarily on the prodelta, before being redistributed to the south by a weak poleward undercurrent to form a >500 km long, coast-parallel mudbelt. Since ca. 11 000 years ago (11 ka), Orange River muds have accumulated as the terrigenous prodeltaic mudbelt in a knick point, eroded during previous sea-level lowstands, at the middle to inner shelf transition. The Holocene mudbelt is a clayey silt, consisting of up to 98 weight percent very-fine- to medium silt, deposited at sedimentation rates of 1-2 mm/yr. A depositional model for the Holocene western margin mudbelt is interpreted using seismic profiles and radiocarbon dated sediment cores from off the Holgat, Buffels and Olifants rivers. Mudbelt accumulation is controlled by available accommodation space linked to Holocene relative sea-level and basement topography. The thick northern mudbelt, north of 31°05'S, is lenticular and rests on a well-defined knick point created by the onlap of Upper Cretaceous middle shelf sediment on a steep Precambrian inner shelf. Low accommodation space south of 31°05'S associated with a shallow knick point, which is partially infilled by Neogene sediment, led to the deposition since circa 2 ka of a thin (<3 m) mud drape across the shelf. Northern mudbelt deposition initiated after 11 ka, synchronous with the global meltwater pulse (MWP) 1B sea-level rise, and five internal mudbelt seismic units (H1 to H5) document the shift from early Holocene transgressive (retrogradation) to late Holocene stillstand (aggradational) sea-level conditions. Decreasing accommodation space in the northern mudbelt due to late Holocene (<3 ka) sea-level stabilization led to the southward progradation of the mudbelt and the deposition of units H4 and H5 which blanket the mudbelt.

In contrast to the mudbelt, the middle shelf has a thin (<1 m) Holocene veneer of calcareous foraminiferal sand that extends over the shelf break (300-500 metres water depth) to the slow accumulating continental slope (<0.2 $mm.yr^{-1}$). The terrigenous fraction on the slope constitutes <40 weight percent of the Holocene sediment. The provenance and distribution of the terrigenous clay fraction (<2 μm), transported to the slope in deposition-resuspension cycles in bottom nepheloid layers, is determined using trace elements, strontium ($^{87}Sr/^{86}Sr$) and neodymium ($^{143}Nd/^{144}Nd$) isotopes. The Orange River is a major source of terrigenous sediment on the margin, eroding a variety of lithologies as it traverses South Africa from high rainfall eastern Drakensberg highlands capped by Jurassic basalts, through a semi-arid central plateau of Palaeozoic Karoo Supergroup sedimentary rocks to the arid western margin of Proterozoic crustal rocks. Two geochemically distinct endmembers are identified in clay minerals derived from Orange River catchment soils; a basaltic endmember and a felsic, crustal endmember. The clay fraction of basaltic soil is enriched in heavy rare earth elements, has a non-radiogenic $^{87}Sr/^{86}Sr$ ratio (0.711) and a radiogenic ε_{Nd} ($^{143}Nd/^{144}Nd$ normalized to primitive mantle) value of -4. Soils derived from the weathering of felsic, continental crust have clay fractions with flat rare earth element patterns and radiogenic $^{87}Sr/^{86}Sr$ ratios (0.731-0.746). The composition of Orange River and tributary suspended load clay fractions is determined by eroded source soils and Orange River suspended clay fraction $^{87}Sr/^{86}Sr$ ratios become more radiogenic (from 0.714 to 0.740) as ε_{Nd} values become less radiogenic (from -6 to -9) downstream. Modern Orange River suspended loads delivered to the western margin are dominated by an Upper Karoo Supergroup (felsic) source due to anthropogenic soil erosion. Northern mudbelt clay fractions are similarly indicative of a felsic source, with $^{87}Sr/^{86}Sr$ ratios of 0.728 to 0.740 and non-radiogenic ε_{Nd} values of -9.6 to -10.8, due to particle-size sorting by the poleward undercurrent. Coarse-grained, crustally-derived illitic clays are deposited proximal to the Orange River mouth. Fine smectitic clay, common in Drakensberg basaltic soils, is generally transported either south in suspension by the offshore poleward undercurrent or laterally advects across the shelf via Ekman drift. Radiogenic isotopes and trace element compositions suggest two endmember sources for terrigenous clay fractions on the western margin slope. The Orange River-derived slope clay fraction endmember has heavy rare earth element enrichment, non-radiogenic $^{87}Sr/^{86}Sr$ (0.714) and radiogenic ε_{Nd} (-9.8) values. A second clay fraction endmember, with a negative Eu anomaly and more radiogenic $^{87}Sr/^{86}Sr$ (>0.715) and ε_{Nd} (-11.1) values, is transported south by poleward bottom-water flow from the Namibian slope. Laser grain-size analysis (LGSA) confirms terrigenous grain-size fractionation and sediment sorting on the margin in response to ocean currents. Terrigenous fractions in the shelf mudbelt are coarser grained than on the lower slope (>2500 metres water depth), but upper slope terrigenous sediments (800-1000 metres water depth) can be coarser grained than those in the mudbelt. Off-shelf terrigenous sediment transport and fine fraction winnowing is particularly efficient near the submarine Cape Canyon and areas of steep bathymetry due to turbulent resuspension by internal tide and wave dissipation.

The burial and remineralization of terrestrial and marine organic matter is controlled by across-shelf advection and sedimentation rate of fine-grained (clay) terrigenous sediment. Sites of preferential organic carbon preservation occur in the shelf mudbelt where organic carbon mass accumulation rates can exceed 40 gC/m^2/yr. Variable redox conditions, associated with sediment deposition-resuspension-transport cycles, enhance organic matter degradation and the cycling of redox sensitive trace elements.

The offshore mudbelt records Holocene southern African climate variability through changes in Orange River sediment load. Fluctuations in mudbelt clay content occur in response to catchment precipitation and Holocene mega-flood events, which can be preserved in onshore palaeoflood deposits, are a major source of mud to the offshore mudbelt. Enrichment in the clay fraction bulk organic matter carbon isotope composition ($\delta^{13}C_{org}$) from ca. 8 ka, reaching a pre-anthropogenic steady state at ca. 5 ka, suggests an increase in C_4 vegetation (grasses) in the Orange River catchment over the Holocene. Radiogenic Sr isotope ($^{87}Sr/^{86}Sr$) trends in the mudbelt clay fraction indicate a decrease in basaltic soil input since ca. 5 ka. The proliferation of C_4 grasses since 5 ka may have stabilized basaltic Drakensberg highland slopes and shifted sediment production to the felsic Upper Karoo Supergroup on the lower Drakensberg escarpment. The mid-Holocene change in clay composition and catchment vegetation corresponds to the termination of the southern African altithermal and to increased rainfall in the continental interior, associated with southward migration of the Intertropical Convergence Zone (ITCZ). Since ca. 0.3 ka, anthropogenic land-use changes have significantly increased Orange River suspended loads and a sharp positive shift in mudbelt $\delta^{13}C_{org}$ values may be linked to the replacement of woody C_3 vegetation with C_4 maize crop farming.

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