Provenance of Permian sediments in the Moatize–Minjova Basin (Lower Karoo, Mozambique): Insights from geochemistry and Sr–Nd isotopes

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Palabras Clave: Karoo, Subcuenca Moatize–Minjova, Paleogeografía, Condiciones paleoclimáticas. **Key Words:** Karoo, Moatize-Minjova Sub-Basin, Palaeogeography, Palaeoclimatic conditions.

INTRODUCTION

During the Late Carboniferous–Early Jurassic, Africa lay at the heart of Gondwana and recorded the transition from Late Palaeozoic glaciation to Triassic aridity. These environmental and tectonic changes are preserved in the Karoo basins, including the coal-bearing Moatize–Minjova Sub-Basin (MMSB) of the Zambezi Karoo Basin in Mozambique (KZBM). This study examines the whole-rock geochemistry and Sr–Nd isotopic composition of Permian mudrocks from the Moatize and Matinde formations to constrain sediment provenance, weathering history, palaeoclimatic conditions, and the palaeogeographic evolution of the Moatize–Minjova Sub-Basin.

GEOLOGICAL BACKGROUND

The Lower Karoo Group in the KZBM (Tete Province) was deposited in a system of intracratonic graben and half-graben basins that developed along the strike of pre-existing high-strain geological sutures formed during the Pan-African Orogeny (620–530 Ma). In the MMSB, the succession comprises three clastic formations: Vúzi, Moatize, and Matinde.

The Vúzi Formation (Kungurian–early Roadian) rests unconformably on the Precambrian basement and records fluvioglacial to lacustrine environments. The overlying Moatize Formation occurs either conformably on the Vúzi Formation or, locally, unconformably on the basement. It represents fluvial–lacustrine deposition with extensive coal development; its base is early Roadian, and its top is diachronous, ranging from early Capitanian to late Wuchiapingian. The Matinde Formation overlies the Moatize Formation and consists predominantly of fluvial deposits, up to ~2 km thick, recording tectonically controlled sedimentation and a transition to braided river systems. Its base is also diachronous, and its upper part may approach the Permian–Triassic boundary (Fernandes et al., 2024).

RESULTS AND DISCUSSION

X-ray diffraction analysis shows that the Moatize and Matinde formations have similar mineralogical assemblages. Their clay fractions are dominated by kaolinite, with minor muscovite and subordinate mixed-layer illite/mica. In both formations, the non-clay fraction is predominantly composed of quartz. Mudrocks from the Moatize and Matinde formations display similar major element compositions, dominated by SiO_2 (55–57%), Al_2O_3 (~23%), Fe_2O_3 (< 3.0%) and K_2O (< 1.50%), with low, MnO, MgO, CaO, and Na_2O values. The K_2O/Al_2O_3 and

Na_2O/K_2O ratios are below the Upper Continental Crust (UCC) and Post-Archean Australian Shales (PAAS), and the Index of Compositional Variability (ICV; Cox et al., 1995) is low (Moatize: 0.09–0.73; Matinde: 0.08–1.05), indicating high clay content.

The Moatize and Matinde mudrocks exhibit comparable trace element patterns. Mudrocks from both formations have average V, Cr, Co, and Ni contents similar to PAAS despite a wide range of transition trace elements contents, which is most pronounced in the Matinde samples. Compared to the UCC, mudrocks from both formations exhibit similar Nb and Ta contents, but show variable enrichment in Zr, Y, and Th. The chondrite-normalized patterns of the Moatize and Matinde mudrocks are similar to those of the UCC, with distinctive light rare earth element enrichment, nearly flat heavy rare earth element patterns, and a variable negative Eu/Eu* anomaly.

The mudrocks of the Moatize and Matinde formations also exhibit similar isotopic signatures, with εNd (t) values of -9.32 ± 0.74 and -7.99 ± 1.10, and Nd T_{DM} model ages of 1.68 ± 0.08 and 1.51 ± 0.12 Ga, respectively. The initial $^{86}Sr/^{87}Sr$ (t) ratios of the Moatize and Matinde formations vary from 0.7082 to 0.7125 and from 0.7117 to 0.7196 respectively. The Sr-isotopic signatures suggest a predominance of sediments derived from UCC.

Overall, the geochemical signatures of both formations suggest minimal sediment recycling and a low degree of sorting, possibly due to high sedimentation rates in an actively subsiding extensional setting. Trace element systematics and key provenance ratios (Th/Sc, La/Sc, Cr/Th, La_N/Sm_N, Eu/Eu*) indicate heterogeneous source areas dominated by felsic rocks with a minor mafic contribution. In addition, the Sm-Nd isotopic data reveal that both formations were derived from mixed sources, including late Mesoproterozoic and Neoproterozoic rocks from southern Malawi, the Nampula Block (a subdomain of southernmost Malawi), the Guro Suite and the Macossa-Chimoio Nappe.

Both Moatize and Matinde mudrocks exhibit high Chemical Index of Alteration (Nesbitt & Young, 1990; CIA; >85) and Chemical Index of Weathering CIW; (>90) values, along with low Index of Compositional Variability and low K/Cs ratios. The Al_2O_3–(CaO + Na_2O)–K_2O (A–CN–K) relationships indicate that the Moatize and Matinde mudrocks have not undergone post-depositional K-metasomatism. Collectively, the data suggest intense palaeoweathering in the source regions. Furthermore, the weathering indices are consistent with a warm and humid palaeoclimate during deposition of the Moatize and Matinde formations.

Post-glacial paleoclimatic reconstructions indicate warm-humid conditions in the Main Karoo Basin (MKB) of South Africa since the Early Permian, with increasing aridity from the Middle Permian to the Triassic, as evidenced by decreasing CIA values (*e.g.*, Scheffler et al., 2006). Similar trends are observed in the Kalahari Basin. In contrast, high CIA and CIW values in the Moatize and Matinde formations suggest distinct palaeoclimatic conditions in the MMSB during the Mid to Late Permian, relative to the Main Karoo and Kalahari basins. These differences likely reflect the influence of a paleotopographic barrier that may have isolated the MMSB and preserved local climatic conditions. Palaeogeographic reconstructions indicate that a mountain chain, the Cargonian Highlands, lay between the MKB and the Karoo rift basins to the north (e.g., Scheffler et al., 2006). This barrier may have favoured warm and humid conditions in the Karoo rift basins and in the MMSB, where thick coal deposits accumulated during the same interval.

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