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Permian "deep-sea-fan" turbidites, Karoo Basin, South Africa, reinterpreted as lake-shelf hyperpycnites

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Most of the major oil companies have intensely studied the coeval Skoorsteenberg and Laingsburg Formations (Permian, Karoo Basin) as supposed analogs of Cenozoic passive-margin deep-sea-fan reservoirs (Gulf of Mexico, Brazil, West Africa, etc). The analogy is inappropriate (with profound economic implications), because published descriptions and comparisons with lookalike Carboniferous formations (Bude, England; Ross, Ireland) show the Karoo outcrops to be: (A) foreland basin, not passive-margin deposits; (B) up to an order of magnitude thinner (Skoorsteenberg Fm 300 m) than typical passive-margin-fan deposits; (C) essentially lacustrine (no reported fossils), as was previously interpreted for underlying strata. An intra-Permian glacioeustatic low would have favored development of a fresh-water lake ("Lake Karoo" proposed here), rather than a seaway, given the existence of a structural saddle (lake sill) and a humid climate. Similar facies in the Malvinas/Falkland islands, deposited alongstrike in the same foreland basin prior to Gondwana breakup, have likewise been interpreted as lacustrine turbidites (influenced by waves). Some Skoorsteenberg intervals with reported (but not illustrated) marine ichnofossils may reflect brief marine incursions over the lake sill, caused by short-term glacioeustatic highs. As lakes are susceptible to river-fed underflow, the Karoo turbidites are interpreted here as mainly hyperpycnites; (D) shallow-water deposits, based on wave-influenced features such as sharp sand-bed tops, pinch-and-swell beds (mud-draped scours), and many thin (cm-dm) beds with rounded, near-symmetrical, sub-vertically climbing ripples. Significantly, this "sinusoidal ripple lamination" was originally defined from shallow-water (< 10 m) glaciolacustrine deposits (Pleistocene), and can be attributed in the Karoo to a combined flow that was nearly symmetrical (hence the steep climb), comprising storm waves and a comparatively weak hyperpycnal current, i.e. these are wave-dominated hyperpycnites; and (E) overlain, only 150 m above, by nearshore facies with symmetrical ripples, limiting the space for any intervening deep-water-slope deposits above the supposed "deep-sea fan". Clinoforms are reported in the overlying Kookfontein Formation, downlapping onto the Skoorsteenberg, suggesting drowning of the Lake Karoo shelf (see below), followed by construction of a new prograding shelf-and-slope equilibrium profile, perched on the old drowned shelf. The drowning may reflect long-term eustatic rise over the sill, probably turning the lake brackish (still no marine fossils; cf. modern Black Sea).

Given that sand-transporting hyperpycnal flows are much more frequent and sustained (weeks?) in lakes than in the sea, plus the evidence for waves, Karoo sand bodies probably differ substantially from deep-sea fans in dimensions, relative proportion and internal bed configuration; they would also deviate more from downslope alignment, because sustained flows have time to respond more fully to Coriolis deflection. Moreover, in base-of-slope fans, hyperpycnal flows might be outweighed by slump-generated turbidity currents, whose brevity and possibly higher velocity both diminish the Coriolis effect. Karoo sand bodies are interpreted here as (1) amalgamated-hyperpycnite tongues (10s km long; km wide; m thick), incised by (2) small, sinuous, non-leveed channels (100s m wide, 3-20 m deep), carved by infrequent, strong combined flows (storm waves plus hyperpycnal), and filled passively with hyperpycnites. Stratigraphically between tongues, distal heterolithic intervals contain thin (cm-dm) hyperpycnites and wave-modified hyperpycnites.

The Karoo hyperpycnites accumulated at shelf depths in two orthogonal sub-basins, the Tanqua (N-S, overfilled) and Laingsburg (E-W, underfilled). The sub-basins met at a SW-NE subaqueous(?) high formed by right-angle mergence (interference) of the two forebulges. Hyperpycnal flows from the Cape Fold Belt (CFB) western branch underwent leftward Coriolis deflection (high southern latitude), and therefore swung axially northward along the Tanqua "enclosed shelf" (ramp; cf. modern Taiwan Foreland Basin). In contrast, the Laingsburg "open shelf" was flanked by a "missing" southern deep-water flysch trough (now eroded), which trapped flows from the CFB southern branch. Orogen-derived hyperpycnal flows from the SW traveled E along the Laingsburg shelf, the leftward Coriolis influence balanced by the southward shelf gradient. On both shelves, syndepositional differential subsidence (generally increasing orogenward) controlled Skoorsteenberg and Laingsburg thickness variations, rather than supposed "fan" surface or basal topography. In both sub-basins, published sand petrology indicates a metamorphic and plutonic provenance, interpreted here as a now-eroded nappe atop the CFB (weakly metamorphosing it), rather than a previously proposed source situated anomalously far away (200-500 km, i.e. wider than most foreland basins) in South America. The inferred presence of a deep-water trough (Laingsburg) calls into question whether the foreland basin was of the retroarc type, as generally believed, or the peripheral type (commonly underfilled initially), perhaps recording collision with a microcontinent involving Patagonia and/or Antarctica.

The aforementioned Karoo-lookalike Bude and Ross Formations, both lacustrine except for rare goniatite bands (glacioeustatic highs), and likewise used erroneously as deep-sea-fan analogs, show similar evidence for wave action, including numerous beds (though volumetrically minor) with hummocky cross stratification. A fourth Upper Paleozoic foreland-basin shallow-lake hyperpycnal succession widely misinterpreted as submarine fans is the Brushy Canyon Formation (Permian), USA. The author's studies of the Bude and Ross suggest that, in fresh-water lakes, direct offshore sediment supply by hyperpycnal flows enhances vertical aggradation, at the expense of delta progradation.