Multiscale stratigraphic analysis of a structurally confined submarine fan: Carboniferous Ross Sandstone, Ireland: Discussion

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In promoting the Ross Formation (Carboniferous Shannon Basin)[2] as an excellent outcrop analog for Gulf of Mexico, oil-rich, Pliocene–Pleistocene, salt-withdrawal minibasins, Pyles (2008) reaffirmed the popular deep-sea-turbidite model for the Ross Formation (Collinson et al., 1991; Chapin et al., 1994; Elliott, 2000; Martinsen et al., 2000; Lien et al., 2003) without mentioning a detailed published reinterpretation of the Ross Formation as lacustrine, river-fed turbidites (hyperpycnites) and wave-modified turbidites (Higgs, 2004). Oil field development in technologically challenging deep-water settings can have costly economic consequences if based on predictions emanating from inappropriate outcrop analogs. Such consequences include, in order of increasing costliness, (1) selection of nonoptimum perforation intervals, causing lower production flow rates and lower ultimate recovery; (2) nonoptimum placement, spacing, and number of development wells, with the same effects; and (3) inaccurate predictions of reserves volume and production rates, leading to unwarranted declaration of field economic viability (hence major expenditures such as platforms, development drilling programs, and pipelines) or nonviability (Higgs, 2004).

For an outcrop to be considered analogous to any given subsurface example, the two facies associations should be essentially indistinguishable, insofar as this can be judged from the existing core control; in other words, the interpreted depositional processes should be the same, resulting in near-identical sand-body (reservoir) architecture. Given the passive margin context and present deep-water (below storm wavebase) slope setting of the Gulf of Mexico minibasins (e.g., Pyles, 2008), a similar deep-marine setting can be inferred for the Pliocene–Pleistocene. In contrast, the Ross Formation may be neither marine nor of deep-water origin. Sedimentological evidence summarized below suggests (1) lowered salinity, amenable to much greater frequency and duration of hyperpycnal flows than in the sea (Mulder and Syvitski, 1995), and (2) intermittent wave influence, implying deposition in relatively shallow water (above storm wavebase). The waves and sustained hyperpycnal flows are likely to have produced sand-body architectures that differ from those of deep-sea minibasins, perhaps only subtly, but potentially with important implications for predicting fluid flow and reserves.

The Ross Formation contains evidence for less-than-marine salinity (Higgs, 2004), invalidating it as an analog for marine deposits in the Gulf of Mexico or elsewhere. Fossils are confined to a few thin (centimeter–decimeter) goniatiferous bands (in a 500-m [1640-ft] formation) encased in thick (meter) shale units. Trace fossils are exceedingly rare (review by Higgs, 2004); no representatives of the *Nereites* ichnofacies have been reported, unlike truly deep-sea upper Paleozoic formations elsewhere (Seilacher, 1978; Orr, 2001). The combined evidence suggests an open lake (i.e., freshwater inflow exceeded evaporation) near sea level. Large lakes are not

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[2] Editor's note: The name “Ross Formation” (Rider, 1974) is used in this article in preference to “Ross Sandstone” (Pyles, 2008).

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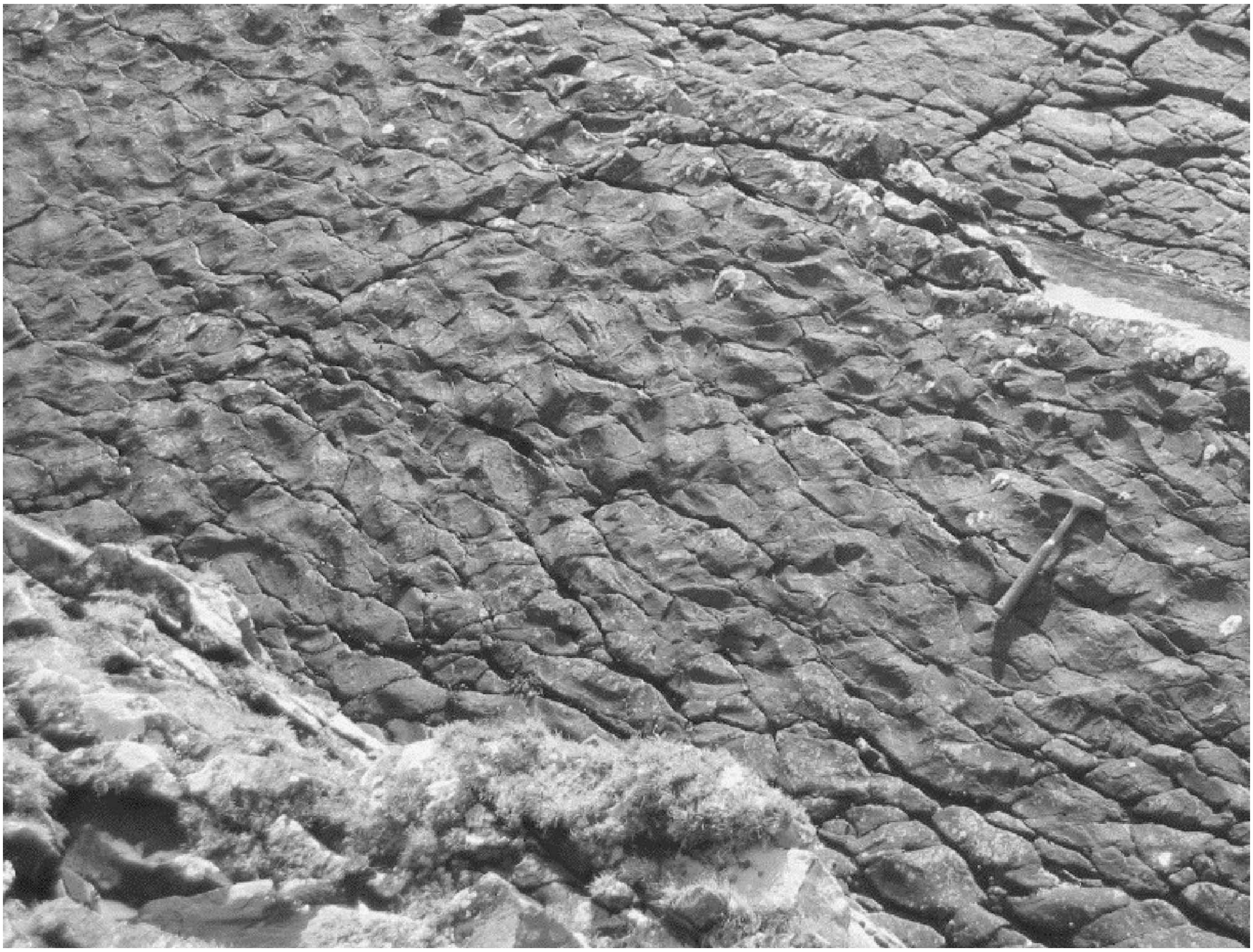

Figure 1. Ross Formation exposure at Rinevella (for the location, see Pyles 2008). A bedding plane shows symmetrical ripples with slightly sinuous crestlines (running top left to bottom right), obscured by two sets of fractures. The hammer is 35 cm (14 in.) long. Because of the predominantly subhorizontal attitude of the Ross Formation at outcrop, such bedding-plane exposures are uncommon.

unexpected in peripheral foreland basins, requiring only that a preceding seaway became isolated, pinched off by advancing mountain-front salients (Higgs, 2004). During extreme eustatic highstands, the lake sill (spill point) was overtopped deeply (tens of meters) by ocean water, forming a marine gulf. At extreme lowstands, the lake was perched at sill level and could potentially turn fresh given enough time ("desalination"; Holdsworth and Collinson, 1988, p. 137). Between these two extremes, the lake salinity was intermediate whenever the sea level was high enough for a salt-water wedge to intrude across the sill (cf. modern Black Sea and Lake Maracaibo).

Quite apart from the salinity problem, careful examination of sedimentary structures in the Ross Formation reveals evidence for deposition above storm wavebase, rendering the Ross Formation inadmissible as an analog for reservoir strata deposited in deep water, whether marine or lacustrine. These structures include hummocky bed forms, hummocky cross-stratification (seldom clearly expressed), and near-symmetrical ripples interpretable as combined wave-current forms (Figures 1, 2) (Higgs, 2004).

In addition, three other aspects of the Ross Formation pointed out by Pyles (2008) highlight its unsuitability as an analog for Gulf of Mexico minibasins in particular.

1. The Carboniferous Shannon Basin is claimed to have been "structurally confined" (Pyles, 2008,

Figure 2. Ross Formation vertical exposure (perpendicular to bedding) at Bridges of Ross (for the location, see Pyles, 2008). A sandstone bed (center) is capped by near-symmetrical ripples. The ripple symmetry index is less than three. The scale is 15 cm (6 in.) long. Note that the vertical exposure surfaces are fracture planes encrusted with oxide and lichen, obscuring internal sedimentary structures.

p. 557) based on multidirectional thinning. However, this thinning is accompanied, or perhaps even caused, by multidirectional shale-out (Pyles, 2008, his figure 5) and may simply reflect differential compaction, for example, around a lake-shelf, river-fed sand tongue (cf. Higgs, 2004). The basin may be an erosional remnant of a much larger basin (Cope et al., 1999, maps C6, C7; Wignall and Best, 2000, their figure 4), interpreted as the Variscan foreland basin by Higgs (2004), instead of a minibasin (Pyles, 2008, his figure 6, dashed line) formed by extension or transtension (Pyles, 2008, following previous authors).

2. The basin subsided much more slowly (during Ross deposition) than the cited minibasins by a factor of about two or three (Pyles, 2008, his table 4, attributes 4 and 5), reflecting the very different tectonic setting, i.e., foreland or extensional basin versus passive-margin-slope salt-withdrawal minibasin. The Ross Formation subsidence rate implied by Pyles (2008, his table 4) is similar to the 300 m (984 ft)/m.y. estimated by Higgs (2004).
3. A list of common attributes between minibasins and the Ross Formation (Pyles, 2008, his table 4) omits grain size. The Ross Formation is notable for nowhere exceeding fine-sand grade (Collinson et al., 1991), possibly a reflection of transportation by relatively slow hyperpycnal flows (Higgs, 2004), as opposed to limited grain-size range in the source area (less likely because medium-grained sandstones occur in the central Clare Group conformably above; Pulham 1989). In

contrast, in the supposedly analogous Brazos-Trinity minibasins (Pyles, 2008), medium sand has been cored even in a distal minibasin (Expedition 308 Scientists, 2006). The coarser grain size may reflect faster (surge-type?) turbidity currents. This difference, combined with the likely shorter duration and longer recurrence time of such flows, and the lack of accompanying storm-wave effect may have resulted in channels and lobes that differ substantially in various respects (e.g., thickness, lateral extent, rate of thinning along and across the sand-transport direction, vertical interconnectedness, and internal bed configuration) from those of the Ross Formation. In addition, the amount of Coriolis deflection depends partly on flow duration (Hill, 1984), therefore lobes built of surge-type turbidites may be straighter than those made of hyperpycnites.

Worldwide, four other formations thoroughly described in the literature closely resemble the Ross Formation in terms of facies association, fineness, and scarcity of trace and body fossils: Brushy Canyon (United States; Beauboeuf et al., 2000), Bude (England; Higgs, 1991), Laingsburg and Skoorsteenberg (South Africa; Johnson et al., 2001; Grecula et al., 2003). Of these, the author has visited the Brushy, Bude, and Skoorsteenberg formations, as well as the Ross. All five are upper Paleozoic turbidite-like successions containing a few, if any, thin (centimeter–decimeter) bands with marine fossils; they can all be interpreted as the deposits of foreland-basin large lakes that briefly approached or attained marine salinity during glacioeustatic highstands (Higgs, 2008). The Ross, Brushy Canyon, and South African formations have been extensively used by oil companies, inappropriately according to Higgs (2008), as outcrop analogs of deep-sea-fan oil reservoirs in the Gulf of Mexico, Brazil, and west Africa continental margins (e.g., numerous articles in Nilsen et al., 2007). Regardless of the salinity and water-depth problems raised above, the questionability of comparing these passive-margin reservoirs with foreland-basin outcrops is underscored by the fact that passive-margin-slope or -rise strata can only achieve outcrop in a metamorphosed and/or intensely deformed state (orogenic collision belt), yet the supposed outcrop analogs are mostly subhorizontal, except where overrun by the foreland-basin deformation front (e.g., Bude and Laingsburg).

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