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Regional Setting of the Late Jurassic Deep Panuke Field, offshore Nova Scotia, Canada – cuttings-based sequence stratigraphy and depositional facies associations Abenaki Formation carbonate margin – a unique hydrocarbon system and play type

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Summary

Deep Panuke, discovered in 1998, is the only carbonate gas field in the eastern North America continental shelf. Several recently published studies (Weissenberger et al., 2006; Wierzbicki et al., 2005, 2006; EnCana 2006) give details on the hydrothermally-dolomitized reef margin gas field itself. Expanding on those studies using mainly cuttings and core data, Panuke is placed in a larger context between the northeast contemporaneous major Sable Island paleodelta prograding ramp shelf and the southwest thicker cleaner carbonate platform. Wells can be grouped based on geometry and position relative to the shelf margin as follows: prograding ramp margin (only a few of the numerous wells in the Sable Island paleodelta are included), margin slope, margin with full shoaling sequence, margin with paleohighs and encased pinnacles (typical of Deep Panuke area), margin inboard flexure with shoals, interior platform oolitic shoals, interior platform shaly lagoon and 'moat' and near-shore ridge/siliciclastic-rich. The large-scale (second order?) vertical full-shoaling stratigraphic sequence is seen in nearly all margin wells. It comprises a basal transgressive oolite usually, then forereef with microbial mud mounds, then shallow coral-coralline sponge reefs, then oolites and two types of capping beds – either oolites (with or without sandstone interbeds) or lithistid sponge-rich beds. Only Deep Panuke does not show this pattern. Laterally there is a curious pattern to the argillaceous sponge-rich cap beds in being flanked by wells with oolite caps both nearer the delta and south-westward of the Panuke area wells. There is also a regional trend in the color from darker to lighter (and finally even red in the slope beds) away from the Sable Island paleodelta. These facies trends relative to the Sable Island delta and the associated early, deep prodeltaic burial are key factors that contributed to Deep Panuke's possibly unique hydrocarbon system of reservoir, trap, seal and charge properties.

Introduction

Deep Panuke is so far unique in the North American Atlantic offshore for being the only hydrocarbon field in carbonates. Located near Sable Island offshore Nova Scotia, it is near the northeast end of a Late Jurassic gigaplatform that formed the continental shelf edge from the Grand Banks to Florida with a few intervening siliciclastic depocentres (Poag 1991). In 1998-1999 EnCana (Pan-Canadian) discovered gas laterally below an exhausted Cretaceous sandstone oil pool in Panuke PP-3C deepened between the two oldest wells (Demascota G-32 and Cohasset D-42) on the Late Jurassic-earliest Cretaceous carbonate margin in commercial quantities at Deep Panuke (EnCana 2006 - probabilistic mean recoverable $17.8X10^9$ m3 or 632 BCF, perhaps 1TCF in place). This is a much abbreviated presentation of Eliuk (2008a, b, c, d, e and f which totaled some 59 pages with 25 figures, 3 tables of wells & cores and 62 references) on the CD and website of

the 2008 Central Atlantic Conjugate Margin Conference in Halifax and to which the interested reader is directed. Here hydrocarbon system-play type ideas are emphasized over strat sequences-depofacies.

Setting

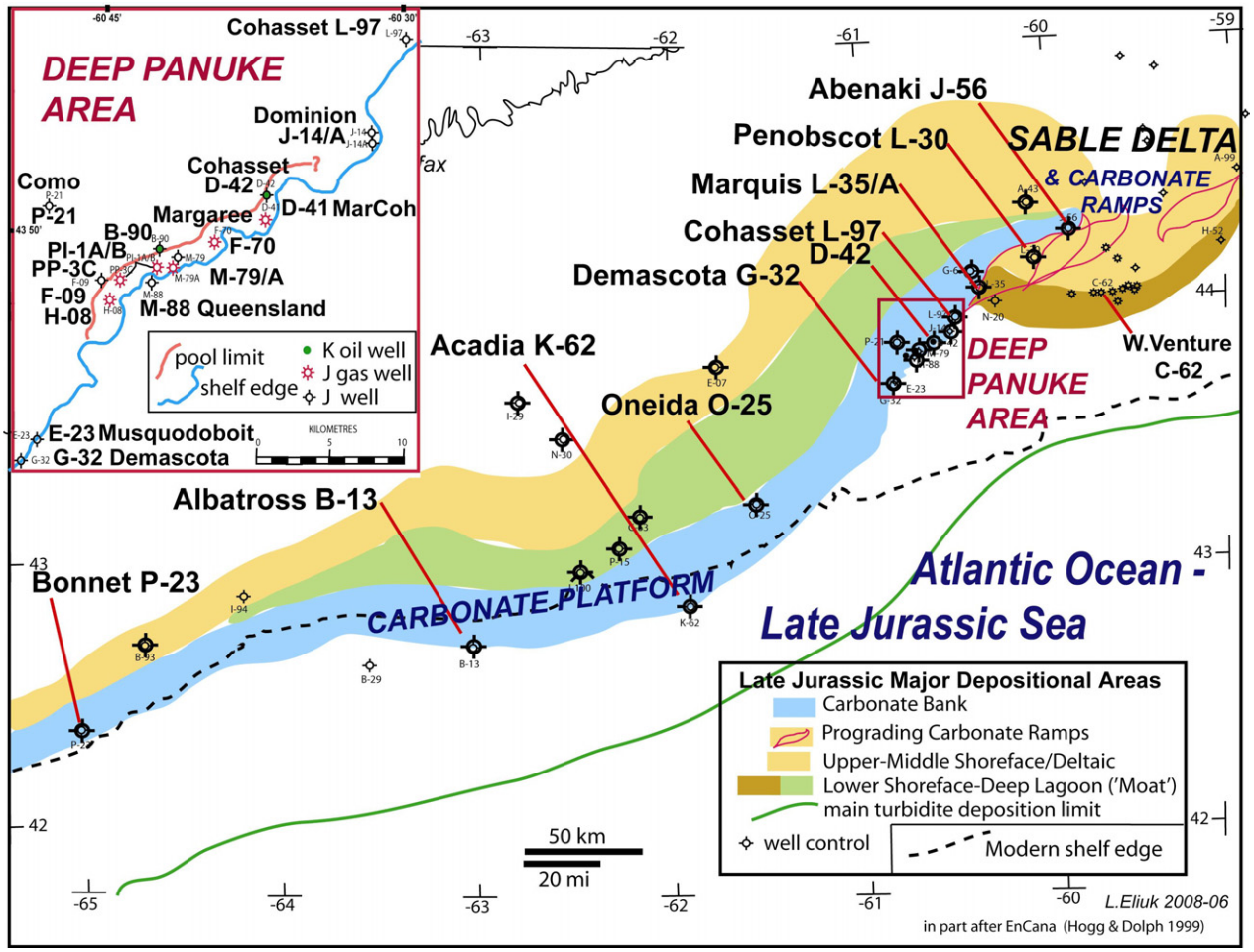

Figure 1. Paleogeographic map for southwest Nova Scotia offshore Late Jurassic showing well control with inset of wells in Deep Panuke area (based in part after Wierzbicki et al. 2006, Wade and MacLean 1990 and Eliuk 1978 with wells labelled by Unique Well Identifier letter-number). Note the two main areas of Sable Island delta and associated carbonate ramps and of Abenaki Formation carbonate platform with nearly-stationary aggrading margin and increasingly siliciclastic-rich shelf interior and near-shore zones of MicMac-Mohawk formations.

Proposed Deep Panuke Hydrocarbon System

Although carbonates and siliciclastics tend to be incompatible due to high sedimentation rates and highly variable environmental stresses associated with fluvial-deltaic sedimentation in particular, the proximity of the Sable Island delta to the Abenaki carbonate bank in combination with the reefal buildup relief is interpreted to have provided all the ingredients for an effective hydrocarbon/petroleum system (see Fig. 2). The Abenaki buildup provided the initial structure-trap (and in fact the low relief anticlinal trap for the overlying Lower Cretaceous oil field) and early reefal debris and reef-derived slope/backreef lime sands that were subsequently burial dolomitized or leached. But the delta provided top and lateral sealing facies due to argillaceous content (sponge-rich limestones) and prodeltaic-basinal shales (Verrill Canyon Formation) and tight clean limestones due to early and deep burial cementation (oolitic limestones on the shelf), source rock from prodeltaic lignitic-humic material, and arguably fracture conduits for diagenetic and reservoir fluids due to loading and failure of the reef margin. As a play type these shelf-margin reefs could be considered analogous to the shelf-margin deltas of Cummings and Arnott (2005) without the growth faults and overpressures

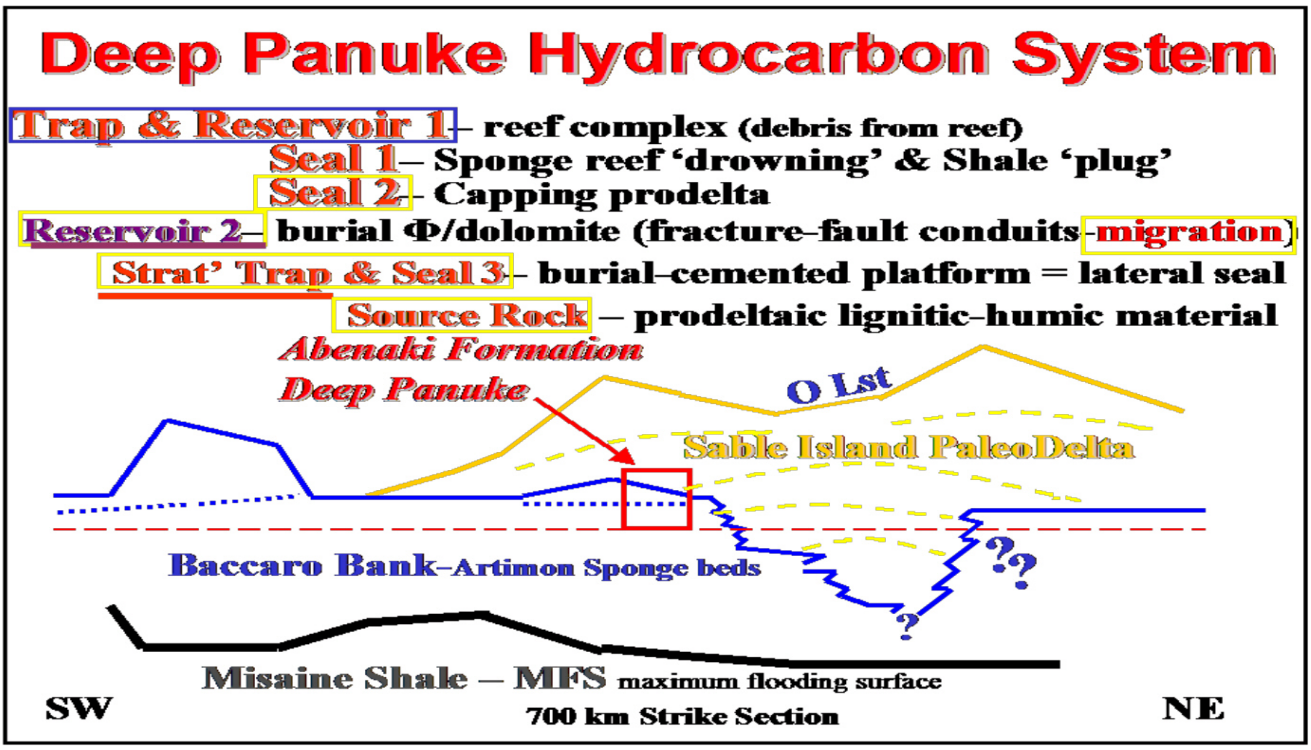

Figure 2. Deep Panuke Hydrocarbon System. - summary of hydrocarbon system components above a schematic line drawing of regional strike section (see Fig. 6 in Eliuk 2008a) to show relation of Deep Panuke on carbonate platform margin to Sable Island siliciclastic depocentre.

Summary Review – a unique reef margin gas field without analogues

Deep Panuke is a gas accumulation in a Late Jurassic platform margin reef complex on the northwestern edge of the then small proto-Atlantic Ocean. Its location near a large delta complex makes it unique or at least very uncommon lacking close analogues in the Recent and possibly even in the geologic record. But considering the great number of Jurassic reefs (Leinfelder et al. 2002) and huge volume of Jurassic hydrocarbon reserves worldwide and particularly in the Middle East; it is surprising to learn that less than 1% of hydrocarbon reserves in carbonate buildups are of Jurassic age. Greenlee and Lehman (1993) list Miocene then Devonian, Paleocene and Pennsylvanian as the ages with the largest reef reserves. The Jurassic does not merit a place on their chart eventhough the Late Jurassic has the second or third greatest number of reef sites for Phanerozoic supersequences after the Late Devonian and before/same as the Miocene (Kiessling 2002, Fig. 2 but reservoir quality is perhaps only 5th Fig. 30). Perhaps that low Jurassic statistic might be slightly under-estimated by the possible exclusion of data on shelf-edge reef hydrocarbon fields in the Carpathian-Caucasus regions of the Ukraine (Izotova and Popadyuk 1993, Lukin 1999, and unfortunately a not easily accessed literature). Nevertheless, it does reflect the fact that most large Jurassic fields are low-relief structures with carbonate shelf interior reservoirs and typically wholly or partly evaporitic top seals (including the Ukrainian reefs). The example of such non-reef fields begins with Ghawar in Saudi Arabia - the world's largest oil field having a Late Jurassic reservoir in the Arab D Formation. In contrast, Deep Panuke platform-margin coral-coralline sponge reef complex adds to a limited collection of circum-Atlantic-Gulf of Mexico Jurassic reef fields that include a coral-microbial reef mound on oolite shoals in a southern England intra-cratonic basin (Sun and Wright 1998), early dolomitized shallow-water microbialite mounds on basement ridges and nearshore microbialite-high energy shoal stratigraphic trap in Smackover Formation restricted embayments in Alabama (Mancini et al 2003, 2008), stacked inner ramp margin coral-microbialite reef complex and outer ramp thrombolite-sponge limestone pinnacles of the Cotton Valley Lime in deep East Texas Basin (Montgomery et al. 1999a & b). It is intriguing that what reef-reef mound reservoir works in one basin does not necessarily

work in another. Deep Panuke differs from all these ramp-associated reefs and most significantly in its much larger estimated reserves and the importance of late burial diagenesis for reservoir porosity because of loss of original depositional porosity with early deep burial near a delta. Deep Panuke is the only carbonate gas field on the North American Atlantic continental shelf. It is the youngest hydrocarbon-bearing reef reservoir in Canada. It is still being developed and hopefully will not continue to be unique but become an analogue for more Jurassic reef fields

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