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Research paper

Interpretation of the Penobscot 3D seismic volume using constrained sparse spike inversion, Sable sub-Basin, offshore Nova Scotia

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ABSTRACT

In this study we investigate the utility of constrained sparse spike inversion (CSSI) applied to a small (87 km^2), public domain, 3D seismic volume at Penobscot in the Sable sub-Basin, offshore Nova Scotia. The objective is to establish the effectiveness of this technique at Sable, in mapping absolute acoustic impedance that can be directly and quantitatively related to lithology. The intent is to subsequently apply the workflow to large 3D seismic volumes sub-regionally, with the goal of identifying and mapping, source, seal, reservoir, and overpressured intervals either not known, or partially known, from well control. *Absolute* acoustic impedance is an incremental parameter that is not explicit in the reflection amplitude cube and is the primary driver for undertaking this inversion. It has quantitative advantages over *relative* acoustic impedance that can be derived using 'fast-track' inversion techniques. CSSI at Penobscot has been completed and provides a valid geological model in the upper Jurassic to lower Cenozoic interval that is constrained by wireline logs at two well penetrations (one of which has 12 m net pay). This acoustic impedance volume facilitates interpretation of: (1) low impedance Cretaceous reservoir sandstones, in both complex confined channel systems and extensive unconstrained marginal marine systems; (2) polygonal fault systems (PFS) in a high impedance, late Cretaceous, chalk; (3) interfingering of low impedance shales and high impedance carbonates at the margin of the Jurassic Abenaki Carbonate Bank.

Three other inversion studies have been reported at Penobscot: Ahmad, 2013; Sayers 2013; Qayyum et al., 2014. Relative acoustic impedance is derived in each study, using 'recursive', 'spectral' and 'coloured' inversion algorithms respectively. None of these studies documented the PFS and Cretaceous channel systems described here and there are significant interpretation differences in the Jurassic section, which is only partly penetrated by wells at Penobscot.

Based on this work at Penobscot, CSSI is the optimum technique for progressively building large sub-regional scale inversions at Sable where we need to balance work-effort, signal-to-noise ratio (spectral inversion results are very broadband but appear very noisy), reliable quantitative mapping of absolute acoustic impedance, and the identification of stratigraphic features on horizon-slices (for which 'fast track' inversions are also be suitable).

1. Introduction

Since 1959, when exploration licences were awarded near Sable Island, over 200 wells have been drilled on the Scotian margin (Fig. 1). Approximately 400,000 km of 2D seismic data and 29,000 square kilometres of 3D seismic data have been acquired (Catuneanu, 2006). On this, passive margin of the Atlantic Ocean, there have been twenty-three significant hydrocarbon discoveries since 1967. Eight discoveries were commercial. Two commercial projects are currently producing hydrocarbons: gas from the Cretaceous and Jurassic clastic reservoirs in the five fields of the Sable Offshore Energy Project (since 1999); and gas from Jurassic carbonate reservoirs in the Deep Panuke Project (since 2013). The Cohasset-Panuke Project produced 44.5 MBO between 1992 and 1999 from Cretaceous clastic reservoirs (of similar age to thin, <5 m, hydrocarbon bearing zones at Penobscot).

The hydrocarbon system at Sable is gas prone, sourced from

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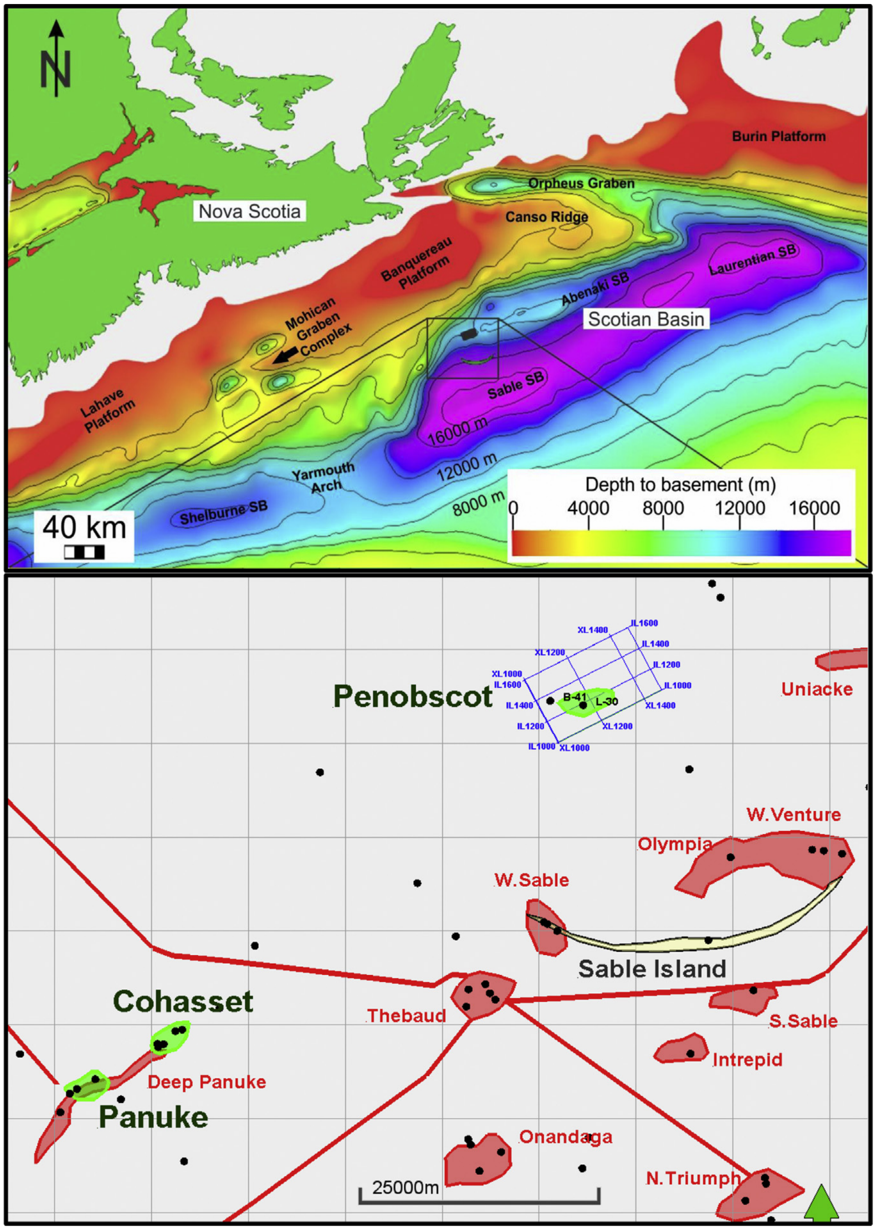

Fig. 1. Scotian shelf sub-basins and location of the Penobscot 3D, wells and nearby fields and pipelines.

marginal marine shales that contain lean, but pervasive, terrestrially derived Type III organic matter (Wade and MacLean, 1990). With two exceptions, commercial hydrocarbons at Sable are trapped in Cretaceous and late Jurassic, marginal-marine, clastic reservoirs in rollover anticlines associated with down-to-basin listric faults, some of which have salt movement in the footwall. Multiple non-commercial accumulations are similarly trapped. Where these traps are fault dependent (or become fault dependent at the limit of independent, four-way dip closure) hydrocarbon column heights are controlled by cross-fault reservoir connections, which allow upward leak of hydrocarbons to levels above trap closure (Richards et al., 2008). At Deep Panuke, hydrocarbons are in Jurassic carbonate reservoirs, in a complex structural, stratigraphic, diagenetic trap (Wierzbicki et al., 2005; Weissenberger et al., 2006; Eliuk, 2010). At Cohasset-Panuke clastic reservoirs are draped over the carbonate bank margin. At Penobscot the proven hydrocarbon trap is a four-way dip closure in the hanging wall of a listric fault (that occurs above the carbonate bank margin).

The seismic, well and production data based on the Scotian margin has been systematically archived and studied by the Canada Nova Scotia Offshore Petroleum Board (CNSOPB) and the Geological Survey of Canada (GSC). It is almost entirely in the public domain and is available through the CNSOPB's Data Management Centre and the GSC's online 'BASIN' database. Seismic data are available in 'hardcopy' format, which includes digital images but not SEGY files. One exception is the 87 km^2 Penobscot 3D seismic cube (location, Fig. 1), which is owned by the province and is available to the public through the CNSOPB at no charge.

The Penobscot 3D seismic cube is of very good quality in the Cretaceous and Cenozoic section and is structurally simple. The cube provides an excellent opportunity (outside energy companies or government agencies) to interpret, manipulate and publish digital seismic data from the Sable sub-Basin in a workstation environment where modern techniques such as attribute analysis