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Seismic inversion for acoustic impedance and porosity of Cenozoic cool-water carbonates on the upper continental slope of the Great Australian Bight

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Abstract

Seismic inversion is used to estimate detailed seismic and rock properties, such as acoustic impedance and porosity, from seismic data. The method is widely used and proven successful by the petroleum industry, but has hitherto not been widely adopted for academic studies. This paper outlines a workflow and reports the application of model-based seismic inversion to a Cenozoic cool-water carbonate succession on the upper continental slope of the Great Australian Bight that was cored during Ocean Drilling Program Leg 182. Acoustic impedance data and the derived porosity distribution facilitate detailed studies of lithology, compaction and fluid flow in the shallow subsurface (0–500 m). A comparison of reflection and impedance data support the notion that seismic reflection events arise from bed boundaries rather than from lateral changes in impedance, even where these are significant. The uppermost continental slope of SW Australia is swept by a strong (>0.5 m/s) geostrophic current, the Leeuwin Current, and seismic profiles across the upper slope show geometrical similarities with contourite drifts. Cores taken through a conspicuous mounded seismic facies at ODP Site 1131 suggest that bryozoan build-ups nucleated on top of contourite mounds on the uppermost slope. Core recovery at three sites on a transect across the uppermost continental slope systematically decreased with increasing acoustic impedance and depth of the drilled section regardless of age. Because of the enhanced interpretability afforded by acoustic impedance and porosity data, and the possibility of predicting core recovery, the workflow outlined here should be of use in a broad spectrum of continental margin studies.

Keywords: seismic inversion; acoustic impedance; carbonate; contourite; Great Australian Bight; ODP Leg 182

1. Introduction

Seismic reflection profiles provide images of relative subsurface variations of acoustic impedance,

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i.e., they show the distribution of interfaces between layers with different acoustic properties. Acoustic impedance is the product of rock density and compressional (P-wave) velocity. It is thus a measure of physical properties that are commonly measured in boreholes, such as bulk density and sonic velocity, as well as being qualitatively observed in core and outcrop as the 'hardness' of the rock. Seismic inversion is a method of deriving seismic parameters, such as acoustic impedance, from reflection seismic data constrained by borehole data (e.g., Sheriff and Geldart, 1995; Veeken and Da Silva, 2004). This information may be used to derive the detailed porosity and lithology structure of the subsurface, provided there is a link between porosity (or lithology) and acoustic impedance (Anselmetti and Eberli, 1997; Marion and Jizba, 1997).

Seismic inversion for acoustic impedance is widely used for subsurface interpretation by the petroleum industry, particularly in settings where a unique relation between acoustic impedance and porosity can be established (e.g., Marion and Jizba, 1997). A suite of inversion methods has been developed in response to the need for detailed subsurface mapping of porosity and pore-fluid variations as part of the petroleum industry's hunt for increasingly subtle oil and gas reservoirs (Maver and Rasmussen, 1995; Buiting and Bacon, 1999; van Riel, 2000; Story et al., 2000; Veeken and Da Silva, 2004). The increasing number of oil discoveries that have been made using inverted seismic data has confirmed that inversion is indeed a powerful means for enhancing the interpretability of seismic data (e.g., Buiting and Bacon, 1999; Vejbæk and Kristensen, 2000). Apart from their use for standard reservoir interpretation, rock property data and their derivatives (such as porosity) are useful for a range of other studies that include fluid flow and continental slope stability (e.g., Dugan and Flemings, 2000; Bünz and Mienert, 2004). Consequently, there has been a recent shift in emphasis from inversion focused at petroleum reservoir levels to also include the overburden to prospective intervals in the inversion. Such studies have proven particularly useful for inferring drilling hazards caused by shallow gas or overpressured intervals (e.g., Dutta, 2002; Dai et al., 2004; Salisbury et al., 2004). However, despite the advantages of impedance data for shallow hazard detection and for seismic facies and lithology interpretation, inversion methods have so far not been widely adopted for non-petroleum research, such as, e.g., the majority of the ocean drilling (DSDP, ODP, iODP) activities. This is despite the fact that boreholes are tied to detailed site surveys and regional seismic surveys using synthetic seismic and seismic modelling as an integral part of both academic and industrial drilling programs (e.g., Lorenzo and Hesselbo, 1996). When well-to-seismic ties have been made, and a wavelet has been extracted, the final step of inverting the data is comparatively straightforward.

This paper presents the workflow and application of model-driven seismic inversion to estimate the acoustic impedance and porosity of Cenozoic cool-water carbonates in the Great Australian Bight, using seismic data collected during site surveys (Feary, 1997) as well as core and borehole log data acquired during Ocean Drilling Program (ODP) Leg 182 (Feary et al., 2000, 2004). After outlining the method for deriving the acoustic impedance section and estimating porosity, we discuss the enhanced interpretability afforded by the impedance data by looking at the internal structure of carbonate mounds and discussing the origin and significance of reflections within the Pleistocene slope succession. The advantages for interpretation and the relationship between core recovery and acoustic impedance makes seismic inversion a powerful tool that could be useful for most integrated studies of borehole and seismic data.

2. Geological setting: the Great Australian Bight

The Great Australian Bight is a siliciclastic-starved, passive continental margin bordering the Southern Ocean. The uppermost continental slope along SW Australia is swept by a strong geostrophic current, the Leeuwin Current, and associated counter-flow and eddies, the intensities of which vary on multiple time scales (Cresswell and Peterson, 1993; Creswell and Griffin, 2004). The target of the ODP Leg 182 drilling campaign was an improved understanding of the factors that controlled cool-water carbonate deposition of Eocene to Quaternary sequences on the continental shelf, slope and basin (Feary and James, 1998; Feary et al., 2000, 2004). The shelf edge to upper slope in the Great Australian Bight consists of a spectacular succession