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South Malvinas/Falkland Basin: Hydrocarbon migration and petroleum system

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ABSTRACT

We report a detailed seismic interpretational study of direct hydrocarbon indicators (DHIs) using 2D multichannel seismic reflection data. The study includes analyses of four distinctive types of DHI: (1) a bottom simulating reflection (BSR), (2) enhanced reflections (ERs), (3) pipes and vertical anomaly clusters, which indicate focused migration of hydrocarbon fluids, and (4) flat spots which indicate a deeper source for the shallower hydrocarbon occurrences. The interpretation of these DHIs included analysis of spatial distribution, amplitude variation with offset (AVO) and instantaneous spectral decomposition. These analyses are set in a tectono–stratigraphic context in order to evaluate the relationship between intra–basinal structures, hydrocarbon occurrences and migration pathways. The recent discovery of a gas condensate accumulation in the study area (Darwin well, ca.190MMbbl) confirms the presence of a mature source rock in the basin and supports a model whereby the observed DHIs are connected via an active hydrocarbon plumbing system.

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1. Introduction

Hydrocarbon plumbing systems (HPSs) are assemblages of permeable pathways that allow hydrocarbons to ascend from the deeper kitchen area of a basin where they are generated to shallower reservoirs where they can become trapped in sufficient quantities to form commercial accumulations (Andresen, 2012). The pathways involved in any given HPS are highly variable, depending on geological context, but generally involve a combination of stratal (along bedding) and cross–stratal hydrocarbon migration (England et al., 1987). One of the most enigmatic aspects of secondary hydrocarbon migration is the common observation that shallow accumulations often occur directly above the kitchen, but are separated by several thousand metres of low permeability sediments (Aplin et al., 1999). This observation led Cartwright et al. (2007) to suggest that highly focused vertical hydrocarbon migration may move mainly through a diverse set of geological features that they termed seal bypass systems, and which can be subdivided into three main classes: (1) faults, (2) intrusions, (3) pipes. Berndt (2005), Imbert (2009), Andresen and Huuse (2011) and Andresen (2012), among others, developed similar ideas to account for the array of observations stemming from multi–attribute 3D seismic interpretation in areas of active vertical fluid and hydrocarbon flow. Andresen (2012) in particular showed how it is possible to group a set of seemingly disparate fluid flow phenomena observed on seismic data, such as a bottom simulating reflection (BSR), pipes, and pockmarks, and link them together explicitly as part of a single connected flow system. Where hydrocarbons are proven to be part of the flow, then this can in turn be described as an HPS. Subsequently, Anka et al. (2012) and Ostanin et al. (2013) have taken the analysis of HPSs to a more advanced level using a similar approach, but by introducing additional data such as geochemistry of surface hydrocarbon seeps and numerical modelling of source rock maturation and hydrocarbon migration into their analytical framework.

In this paper, we focus on the challenges confronting those interested in analysing HPS in frontier basins, where there may be few or no wells available, no geochemical data, and only 2D, rather than 3D seismic data. We focus on a geophysical approach to augment classical observations of direct hydrocarbon indicators (DHIs). The central aim of this paper is to develop an integrated geophysical interpretation using quantitative techniques such as amplitude versus offset (AVO) and frequency analysis to document either in situ hydrocarbons or features that indicate the passage of

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hydrocarbons through the sediment column. Then, following the approach developed by Andresen (2012), by collating and analysing the distribution of DHIs and fluid flow features, to examine whether their spatial relationships suggest a causal association such that the assemblage could reasonably be grouped into a HPS. A secondary aim is to discuss the likely origin of hydrocarbons, and discuss whether thermogenenic, biogenic or some mixture of the two best accounts for the observed distributions and the geometry of the HPS.

The study area is the South Malvinas/Falkland Basin (SMFB; Fig. 1), a region that has received only limited research attention (e.g. Ludwig, 1983; Platt and Philip, 1995; Bry et al., 2004). Petroleum exploration in this frontier exploration area is also relatively recent, with few wells drilled to date but potential for working petroleum systems to match those identified with drilling further North-East on the Malvinas/Falklands Plateau Basin (Richards et al., 1996; Fish, 2005). The primary geophysical data available to interpret the HPS in this area are 2D reflection seismic, and as such this is an ideal case study area in which to adopt a more quantitative geophysical approach to analysing an HPS.

2. Data and methods

2.1. Seismic and well data

The entire South Malvinas/Falkland Basin (SMFB) has been imaged by a number hydrocarbon exploration and scientific multichannel reflection seismic surveys (Ludwig, 1893; Richards et al., 1996; Platt and Philip, 1995; Fish, 2005). The seismic dataset used in this work is composed of two 2D seismic surveys (Fig. 1B) provided by Falkland Oil and Gas Limited (FOGL) and Geophysical Service Incorporated (GSI).

The FOGL dataset was acquired using multiple airguns and streamers with 480 channels and a sampling interval of 2 ms. The nominal fold was of 120 traces per common mid−point (CMP) and a trace length of 8 s TWT. The survey was processed using a work−flow focused on multiple removal, which included surface related multiple elimination (SRME) and demultiple Radon transform. Full Kirchhoff pre−stack time migration has been applied to restore the position of the reflections in time domain. The GSI dataset acquisition parameters were not provided. The processing applied to the GSI dataset is similar to the one applied to the FOGL dataset. However the GSI processing flow included anisotropic time migration and F−X deconvolution. These differences on the processing flow provided a larger frequency bandwidth of the final migrated dataset and a clearer definition of the seismic image. Both seismic surveys are composed of two angle−stack and full−stack seismic sections. This allowed computing analysis in pre−stack domain (near and far domain). The FOGL dataset included also velocity stack data in time domain which have been used to perform time-to-depth conversion of some key lines. This process has been performed by using Halliburton-Landmark ProMAX (see

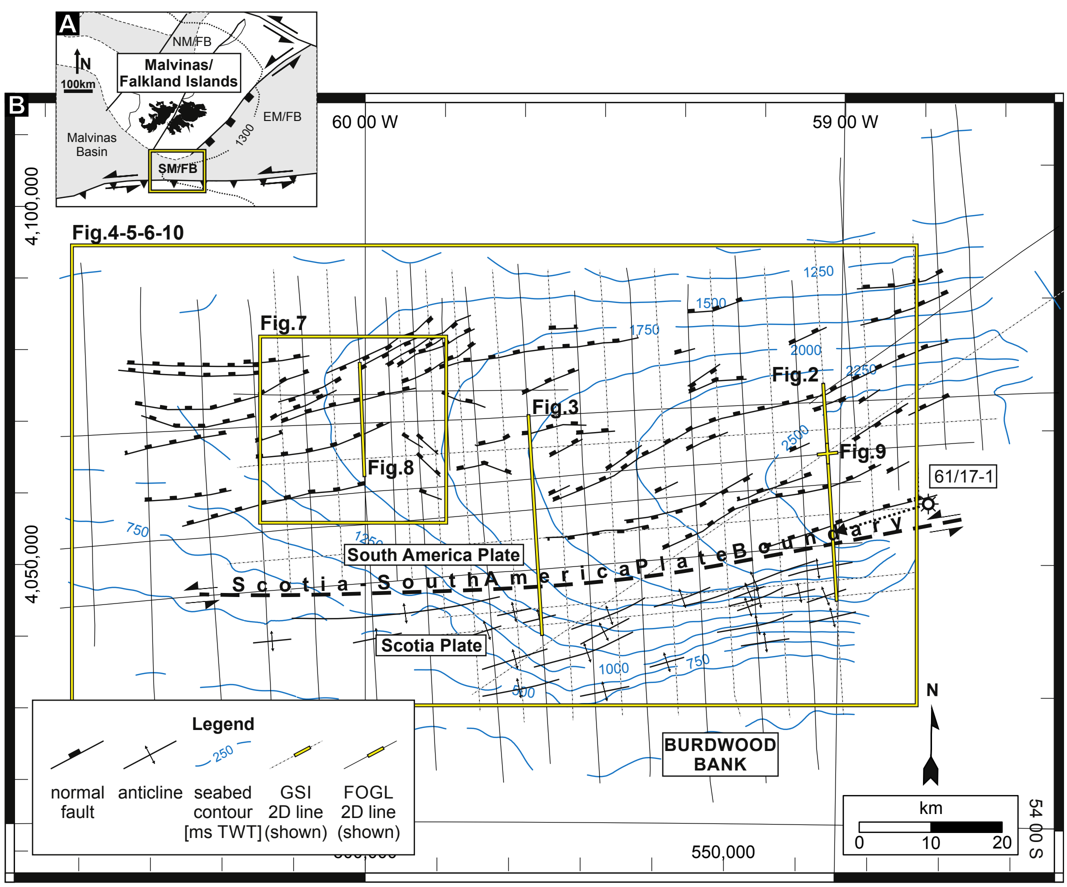

Fig. 1. Location map of the Malvinas/Falkland Islands and surrounding basins with main tectonic elements, distribution of the Mesozoic−Cenozoic sedimentary coverage (grey shade, dashed lines) and contouring of the bathymetry @ 1300 ms TWT (dotted line; A; from Platt and Philip, 1995 (mod.)). The South Malvinas/Falkland Basin (SM/FB) is located approximately 200 km south of the Malvinas/Falkland Islands. NM/FB = North Malvinas/Falkland Basin, EM/FB = East Malvinas/Falkland Basin. Detailed bathymetric map of the seabed (derived from seismic interpretation), 2D seismic grid, well site 61/17−1 location, and main structural elements of the SM/FB (B). The SM/FB runs along the Scotia− South America Plate Boundary which divides the South America Plate and the Scotia Plate (B). The seabed plunges eastward with a maximum depth of c.2000 m close to the position of the well site 61/17−1 and a minimum depth of 140 m above the Burdwood Bank (B).

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