[PS]Seismic Stratigraphy and Hydrocarbon Prospectivity in the Northern Sector of the North Falkland Basin, South Atlantic*

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Abstract

Analysis of 2D seismic reflection data north of the Falkland Islands, has delineated a series of discrete basins to the north of the prolific North Falkland Basin, which are termed here as the Northern sector of the North Falkland Basin (NNFB). Six regionally significant seismic reflectors have been interpreted within this data set, dividing the sedimentary fill into six tectono-stratigraphical packages, including: early syn-rift, late syn-rift, transitional phase, early post-rift, middle to late post-rift, and an undifferentiated sag phase. Structural interpretation has led to the definition of four north-south orientated depocentres: (1) Eastern Graben, (2) Eastern Graben Splay (3) Western Graben splay, and (4) the newly defined Phyllis Graben. A network of NW-SE and NE-SW trending faults controlled the development of these grabens through the syn-rift and into the late post-rift. Hydrocarbon discoveries to the south of this study area (e.g. Sea Lion, Isobel Deep, and Liz) confirm a nearby working petroleum system. This study has identified various Direct Hydrocarbon Indicators, such as shallow amplitude brightening events; these may correspond to an extension of this petroleum system and active migration pathways. The main interval of hydrocarbon interest in the northern sector is likely to be vertically amalgamated stratigraphically trapped turbidite fans within the early post-rift interval. This paper also proposes a secondary fluvial structural syn-rift play, which has yet to be tested in this region.

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Introduction

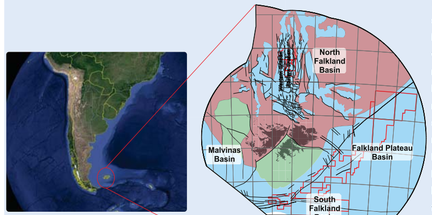


Fig. 1 Geological map of the offshore areas around the Falklands Islands. Red blocks show extent of the current hydrocarbon exploration licences[1]. The NFB consists of several subsidiary depocentres illustrated by N-S orientated Mesozoic-Cenozoic basins. Inset (top left) image shows the location of the Falkland Islands with respect to South America (Google Earth, 2019).

The Falkland Islands offshore designated area covers approximately 460,000 km^2 and consists of four main sedimentary basins of Mesozoic to Cenozoic age, including; the North Falkland Basin, Falkland Plateau Basin, South Falkland Basin and Malvinas Basin, which lie north, east, south and south-west of the islands respectively (Fig. 1). So far, the most successful in terms of hydrocarbon prospectivity has been the Eastern Graben of the North Falkland Basin (NFB). The Eastern Graben lies beneath 150-500 m of water, 150 km north of the Falkland Islands. An exploration campaign in 2010-11 discovered commercial quantities of hydrocarbons in early post-rift sandstones derived from the eastern basin margin, within a succession of deep laustrine fan systems[1]. The major success of the Sea Lion discovery in 2010, along with other discoveries such as Casper, Beverley, Zebedee, Isobel Deep and Liz, highlighted the hydrocarbon potential in the basin[4]. One area which has remained under explored is the Northern Sector of the North Falkland Basin (NNFB), this basin is essentially an extension of the main NFB and likely contains a succession of early post-rift lacustrine sediments, similar to the hydrocarbon bearing sandstones and oil bearing claystones in the NFB.

This research addresses the following questions:

(1) What is the structural configuration of the NNFB?
(2) What are the main structural controls, i.e. timing and style of faulting?
(3) How does basin fill compare with the Eastern Graben towards the south?
(4) What is the nature of tectonostratigraphy?
(5) What are the likely petroleum systems and plays in the NNFB?

Geological Background

The NFB is a failed rift system, composed of a series of depocentres following two dominant structural trends: N-S orientated faulting predominately in the northern area and WNW-ESE orientated faults within the Southern North Falkland Basin (Fig. 1). Initial east-west rifting of the NFB is likely to have began in late Jurassic and lasted until the early Cretaceous as a result of the break up of Gondwana[3]. This rifting phase was followed by a thermal sag phase that began in the Berriasian-Valanginian (Fig. 2). The environment of deposition throughout this sag phase is thought to be predominantly continental and deep lacustrine until Albian-Cenomanian times, when the basin began to develop increasingly marine conditions.

The main depocentre of the NFB is orientated N-S, is approximately 30 km wide by 250 km long, and is referred to as the Eastern Graben. A shallower depocentre, present towards the west, is referred to as Western Graben, which is separated from the Eastern Graben by an intra-graben high, named the Orca Ridge. The Eastern Graben displays an asymmetric half-graben profile, downthrown to the east.

These grabens are bounded to the east and west by basin margins, named the Western and Eastern Flanks, possibly composed of Devonian-Permian sediments and defined by N-S trending basin bounding faults. Furthermore, there are a number of subsidiary depocentres immediately east of the Eastern Graben, all which follow a similar N-S trend (Fig. 3).

The basin fill can be sub-divided into a set of tectonostratigraphic intervals, including : early syn-rift; late syn-rift; transitional/sag; early post-rift; middle post-rift; late post-rift and post uplift sag (Fig. 2). The post-rift succession is further divided into a number of sub-units: LC2, LC3 and LC4 in the early post-rift; LC5, LC6 and LC7 in the middle post-rift; and L/UC1 and UC1 in the late post-rift, where "LC" is Lower Cretaceous and "UC" is Upper Cretaceous[5]. The LC3 package has been the main focus of hydrocarbon exploration, which is typically comprised of a series of amalgamated turbidite fans and fluvio-deltaic sediments, deposited in a lacustrine setting[3].

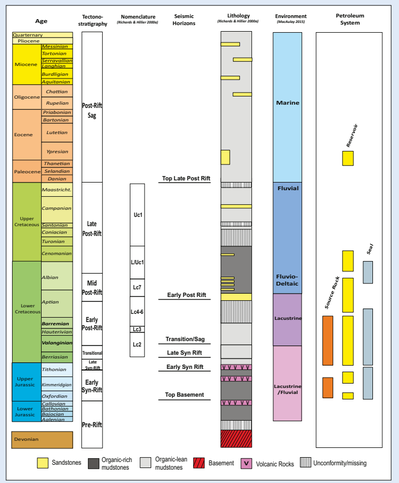


Fig. 2 Geological summary chart for the North Falkland Basin from Devonian to Quaternary. (Seismic horizons are correlated with established nomenclature[3], lithological interpretations and environment of deposition)[3].

Data and Methodology

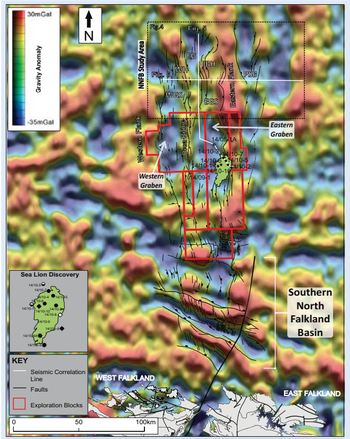


Fig. 3 Structural framework underlain by Bouguer gravity data of the North Falkland Basin. The study area is highlighted with a dashed box. Grabens includes: WGS - Western Graben Splay; WH - Western High; EG - Eastern Graben; EGS - Eastern Graben Splay; IBH - Intra-Basin High; PSB - Phyllis Graben[2,3].

This study used 1,250 km of 2D seismic reflection data ("FALK2000" survey) collected and processed by Veritas in 2000. The data is post stack time migrated, displays a positive polarity and is zero-phased. The seismic data is widely spaced with a N-S separation of 2.5-5 km and 2.5-10 km E-W (Fig. 4). Overall the data quality is good down to 3-3.5 seconds two way travel time (TWTT), beyond this the signal to noise ratio increases significantly and amplitude reflections become chaotic. In addition to the seismic data, major structures and overall basin-geometries were identified using Bouguer gravity data from global satellite data[7] (Fig. 3).

No wells have been drilled in the NNFB, however a seismic correlation has been made southwards along strike from the Eastern Graben, from the "FALK2000" 2D seismic, into the "Company Composite" 3D seismic survey to intersect the nearest well (14/05-1A), along with other wells close to the Sea Lion Discovery (14/10-2, 14/10-3, 14/10-5 and 14/10-7; Fig. 5). The stratigraphy is better constrained in the main NFB and this tie-line has helped to cross correlate the known seismic stratigraphy and basin fill into the NNFB (Fig. 6).

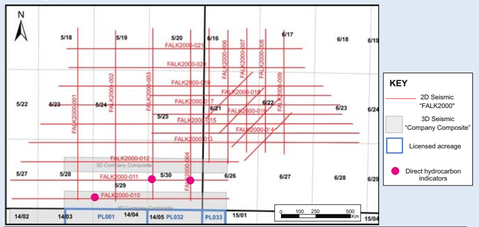


Fig. 4 Orientation of 2D seismic data interpreted during this study, along with 3D seismic data used to correlate the tectonostratigraphic packages[2]

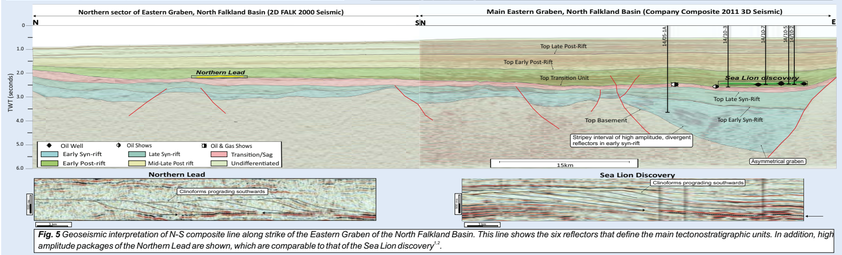


Fig. 5 Geoseismic interpretation of N-S composite line along strike of the Eastern Graben of the North Falkland Basin. This line shows the six reflectors that define the main tectonostratigraphic units. In addition, high amplitude packages of the Northern Lead are shown, which are comparable to that of the Sea Lion discovery[1,2].

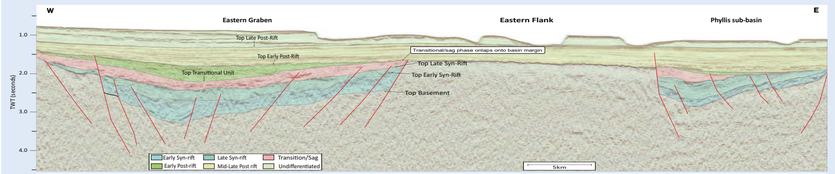
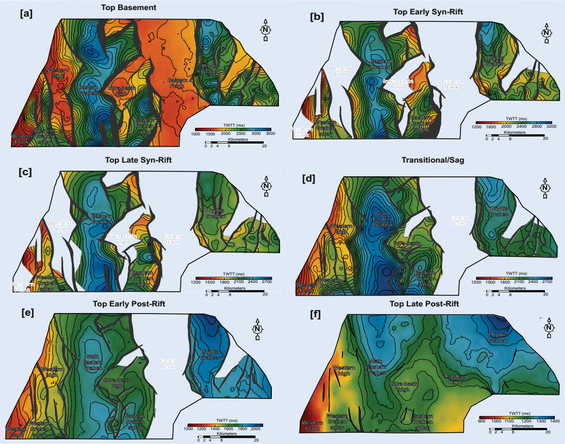


Fig. 6 Geoseismic interpretation of 2D seismic line FALK2000-020, showing a typical cross-section of the NNFB, displaying the Eastern and Phyllis Graben separated by the Eastern Flank[2].

Structural Configuration of NNFB



A number of TWTT structural maps were produced from the interpretation of the 2D seismic data in order to understand the structural evolution of the NNFB (Fig. 7). The NNFB shows four N-S orientated depocentres, defined from west to east as: (1) Western Graben Splay - an extension of the existing Western Graben; (2) Eastern Graben - an extension of the main hydrocarbon proven Eastern Graben; (3) Eastern Graben Splay - a spur of the main Eastern Graben; (4) Phyllis Graben - a previously unnamed sub-basin.

The NW-SE faults observed here represent the reactivation of NW-SE Paleozoic thrust faults. NE-SW faults probably formed contemporaneously with the central part of the NNFB to the south, possibly as a result of east-west rifting during opening of the South Atlantic.

Structural highs seem to have remained active throughout the syn-rift, continuing to separate the Eastern Graben from the Phyllis Graben until the late post-rift.

Fig. 7 A series of TWTT structural intepretation maps showing different seismic reflectors that define the top of the tectonostratigraphic units, at various stages of basin evolution. Dashed black lines represent sub-cropping of the units. (a) Top Basement (b) Top Early Syn-Rift (c) Top Late Syn-Rift (d) Transitional/Sag Phase (e) Top Early Post-Rift (f) Top Late Post-Rift[2].

Petroleum System and Plays

Hydrocarbon discoveries, located to the south of this study area confirm a working petroleum system adjacent to the NNFB. Basin modelling studies[6] indicate the syn-rift to early post-rift units of the NNFB are currently within the oil window at 2.5-3 km. This study has identified potential direct hydrocarbon indicators (DHIs), which may suggest an extension of this petroleum system (Fig. 8). The main targets in the NNFB are probably early post-rift stratigraphically trapped hydrocarbon accumulations, contained within vertically-amalgamated turbidite fan sandstone reservoirs. A second, yet to be tested, syn-rift play has also been identified within fluvial sandstones contained within hanging wall structures (Fig. 9).

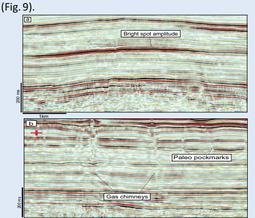


Fig. 8 DHIs observed on the 2D seismic dataset in the study area. (a) Bright spot amplitudes and potential fault trap. (b) Gas chimneys and visible paleo-pockmarks. [2]

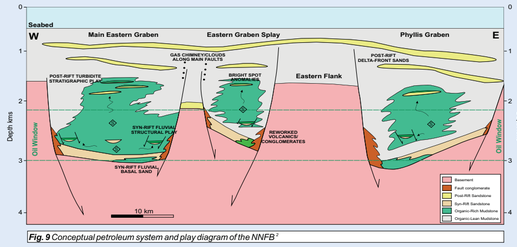


Fig. 9 Conceptual petroleum system and play diagram of the NNFB[2]

Conclusions

- The NNFB consists of two main depocentres: (i) one consisting of both the Western Graben and a nothern continuation of the Eastern Graben of the NFB. (ii) a newly-defined depocentre, named the Phyllis Graben.
- NW-SE and NE-SW trending faults have controlled the development of the grabens throughout the syn-rift until the late post-rift.
- Seismic mapping from this study has defined six tectonostratigraphic units across the NNFB; early syn-rift; late syn-rift; transitional/sag; middle post-rift; late post-rift and overlying sag.
- Two hydrocarbon plays are identified for NNFB: (i) early post-rift combined structural-stratigraphic traps, with turbidite fan sandstone reservoirs, analogous to the Sea Lion Main Complex. (ii) syn-rift fluvial sandstones contained within two or three-way dip hanging wall closures.
- The NNFB remains a virtually un-explored area with great hydrocarbon potential. The geological knowledge of this area has been correlated from the Eastern Graben of the NFB.

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