

Institution: Cardiff University		
Unit of Assessment: Earth Systems and Environmental Sciences (7)		
Title of case study: Developing hydrocarbon reservoirs on continental margins offshore Brazil, West Africa and [text redacted]		
Period when the underpinning research was undertaken: January 2009 – March 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
T. M. Alves	Reader	01/01/2007 – present
Period when the claimed impact occurred: 01/08/2013 – 31/12/2020		
Is this case study continued from a case study submitted in 2014? No		
1. Summary of the impact (indicative maximum 100 words)		
<p>Failed exploration boreholes for hydrocarbon reservoirs account for billions of pounds of losses for leading oil and gas companies including Petróleo Brasileiro S.A. (Petrobras), Partex Oil and Gas Group and [text redacted]. Working with these companies, Cardiff University researchers analysed comprehensive geophysical data from a wide range of continental margins; this facilitated enhanced understanding of the structure and evolution of the lithosphere underlying these margins, highlighting economic benefits of drilling 'Breakup Sequences'. The research led to new strategic planning models for the oil and gas industry, which improved decision-making processes, and enhanced staff training. This resulted in economic benefits of over £500M for companies operating in Brazil and West Africa and [text redacted].</p>		
2. Underpinning research (indicative maximum 500 words)		
<p>Deep-water continental margins (500–2,500m below sea level) are promising regions for exploiting oil and gas. High drilling costs and the expense of meeting environmental standards are ever-present problems for deep-water exploration, with failed wells accounting for annual losses of billions of pounds. Research at Cardiff University developed new geological models that explained migration and accumulation of oil and gas on deep-water continental margins, enabling a greater understanding of their economic potential.</p>		
2.1 Fundamental continental rifting research: defining 'Breakup Sequences'		
<p>Alves, Director of the 3D Seismic Laboratory at Cardiff University, led an analysis of the deposition of specific stratigraphic sequences with economic significance. This work was the first acknowledgement of a progressive, diachronous evolution for strata deposited during continental breakup and led to the definition of 'Breakup Sequences' [3.1]. Further analysis investigated stratigraphic correlations between shallow and deeper parts of West Iberia and [text redacted] continental margins. The results led Alves to propose 'Breakup Sequences' as representing the transitional period between the initial phases of lithospheric breakup and the establishment of thermal relaxation as the main process controlling subsidence [3.2].</p>		
<p>A review of field, borehole and geophysical data [3.3] led to a consensus that 'Breakup Sequences' are found on many continental margins, including in regions, at present, experiencing early ocean rifting, as in Baja California (Mexico) and East Africa (Djibouti and Ethiopia). 'Breakup Sequences' have also been systematically documented above older 'syn-rift' strata in the South China Sea [3.4] and [text redacted] [3.2]. 'Breakup Sequences' comprise prolific hydrocarbon reservoirs and source intervals at sub-surface depths in which smaller quantities of carbon dioxide (CO₂), methane (CH₄), and other naturally occurring gases are expected (when compared with older 'syn-rift' strata drilled in previous prospects) [3.4]. Finding smaller volumes of such volatile gases increases the economic viability of hydrocarbon fields.</p>		

2.2 Collaboration with Petrobras, Partex Oil and Gas, and [text redacted]

Cardiff University's identification of 'Breakup Sequences' formed the basis of industry research collaborations across the world, as summarised below:

- **Petrobras:** Cardiff University's collaboration with Petrobras started with work in pre-salt units of the Lula Field, SE Brazil, the third largest offshore oil and gas field in the world. Proprietary data from Petrobras was interpreted [3.5] from 2010 to 2013 using detailed maps of the deep-water Santos Basin to understand the relationship between the pre-salt topology and post-salt deformation, improving the recovery of oil and gas. A second project addressed the inherent variability of 'Breakup Sequences' in Pará-Maranhão Basin, Equatorial Brazil [G3.1] to understand the reservoir potential of prospects deeper than those previously drilled by the company.
- **Partex Oil and Gas:** Between 2013 and 2015, a Cardiff-led consortium (RAFTS), funded by five oil and gas companies and coordinated by Partex Oil and Gas [G3.2], analysed fault families in West Africa and associated reservoir successions deposited during continental breakup. The studied region in Angola, part of the Lower Congo Basin, comprises the most prolific hydrocarbon province of West Africa, and the largest oilfield in this region with 300 million barrels of oil equivalent. As many African countries do not possess the necessary infrastructure to dispose of and utilise natural gases, the region has strict legislation to curtail CO₂ emissions and release of volatiles including sulphur dioxide (SO₂), methane (CH₄) and nitrous oxide (N₂O). As a result, RAFTS' findings, including the volume of gas discovered, remain classified by the Angolan Government.
- [Text redacted]

Through analysis of seismic data, Cardiff University's work shifted the emphasis from deeper 'syn-rift' prospects on continental margins towards younger, shallower strata within 'Breakup Sequences' [3.1-3.6]. The production of hydrocarbons thus became easier, safer, and less costly, while simultaneously avoiding the drilling of areas close to CO₂ conduits from deeper parts of the Earth's crust.

3. References to the research (indicative maximum of six references)

[3.1] **Alves, T.M.**, Moita, C., Cunha, T., Ullnaess, M., Myklebust, R., Monteiro, J.H., Manupella, G. (2009) Diachronous evolution of Late Jurassic–Cretaceous continental rifting in the northeast Atlantic (west Iberian margin). *Tectonics*, 28, TC4003. doi.org/10.1029/2008TC002337

[3.2] [Text redacted]

[3.3] **Alves, T.M.**, Fetter, M., Busby, C., Gontijo, R., Cunha, T.A., Mattos, N.H. (2020) A tectono-stratigraphic review of continental breakup on intraplate continental margins and its impact on resultant hydrocarbon systems. *Marine and Petroleum Geology*, 117, 104341. doi.org/10.1016/j.marpetgeo.2020.104341

[3.4] Zhao, F., **Alves, T.M.**, Wu, S., Li, W., Huuse, M., Mi, L., Sun, Q., Ma, B. (2016) Prolonged post-rift magmatism on highly extended crust of divergent continental margins (Baiyun Sag, South China Sea). *Earth and Planetary Science Letters*, 445, 79–91. doi.org/10.1016/j.epsl.2016.04.001

[3.5] **Alves, T.M.**, Fetter, M., Lima, C., Cartwright, J.A., Cosgrove, J., Gangá, A., Queiróz, C.L., Strugale, M. (2017) An incomplete correlation between pre-salt topography, top reservoir erosion, and salt deformation in deep-water Santos Basin (SE Brazil). *Marine and Petroleum Geology*, 79, 300-320. doi.org/10.1016/j.marpetgeo.2016.10.015

*Note paper based on the 2010-2013 analyses of company data

[3.6] [Text redacted]

Selected grants:

[G3.1] Structural geology studies for reservoir modelling: pre salt carbonate reservoirs in the Santos basin, Petróleo Brasileiro S.A. - Petrobras Project 500876, 01/03/2010 to 30/09/2010, £97,000.

[G3.2] Data transfer and consortium - Total E&P Angola project 504875, 15/09/2012 to 30/11/2014, £301,781.

[Text redacted]

4. Details of the impact (indicative maximum 750 words)

The architecture of offshore hydrocarbon reservoirs is a persistent concern for the oil and gas industry and, without clear geographical mapping, these structures can jeopardise hydrocarbon production and increase drilling costs. Application of Cardiff University's 3D seismic techniques with international industrial partners ensured £500M in savings for the oil and gas industry.

4.1 Petrobras: Brazil

Cardiff University's research delivered impacts for Petrobras, the leading oil and gas company in Brazil, on two major hydrocarbon projects: the Lula Field (Southeast Brazil) and Pará-Maranhão Basin (Equatorial Brazil). The Lula Field is the third largest oil field in the world, while the Pará-Maranhão Basin comprises an exploratory frontier with untapped, deep-water prospects on a poorly defined continental margin. Both areas contain important oil and gas fields in strata deposited during continental breakup.

At the Lula Field, located in the Santos Basin, Cardiff University's 3D seismic modelling identified the full economic potential of pre-salt prospects occurring >5km below the sea floor. Dr Marcos Roberto Fetter Lopes, Manager for Tectonics, Structural Geology and Geomechanics, Petrobras, stated that Cardiff provided *"the first complete assessment of the Lula Oil field"*, a site estimated to contain *"more than 50 billion barrels of oil, being one of the largest petroleum provinces in the world, still to be fully explored and developed"* **[5.1]**.

Cardiff University's assessment of Lula Field was adopted by Petrobras, enabling the company *"to identify four separate sites as a larger system, saving the company considerable time and resources, and allowing more strategic decision-making when exploring the [Lula] oil field"* **[5.1]**. Cardiff's work also provided Petrobras with an assessment of potential new drilling sites in Pará-Maranhão Basin and a wider knowledge of the geology of key prospects in Brazil's deep-offshore basins. This was disseminated through Cardiff-delivered training and field courses, first in 2013 and then 2019, leading to *"Petrobras being able to develop a detailed assessment of the petroleum potential of this [Pará-Maranhão Basin] site, and the decision to explore/not explore... representing a significant financial investment/savings"* **[5.1]**.

Parallel to work on the Lula Field, training courses (informed by Alves' research) were delivered to Petrobras' geologists and engineers; these allowed them to evaluate seismic data using Cardiff's principles. Cardiff University's research and guidance extensively influenced company practices on new exploration strategies, and resulted in substantial savings, with the company stating: *"we estimate gross savings to Petrobras of around \$500M (£402M)"* **[5.1]**.

4.2 Partex Oil and Gas and the RAFTS consortium: West Africa

Between 2013 and 2015 a consortium of five companies, including Partex Oil and Gas, TOTAL, and ACREP, funded a Cardiff-led research project (RAFTS) that analysed fault families in West Africa and associated reservoir successions deposited during continental breakup. Specifically, the work explored the potential of the Lower Congo Basin. As cited by Luís Guerreiro, Exploration and New Ventures Manager for Partex Oil and Gas, Block 17/06 offshore Angola is *"an area of great economic interest to Partex Oil and Gas and concession partners"* with *"an estimated volume of hydrocarbons of 300 million barrels of oil"* **[5.2]**.

As part of RAFTS, Cardiff researchers delivered technical reports, presentations, and field training courses on the petroleum potential of Block 17/06 offshore Angola. After this

integrated analysis of the area, Cardiff University's insights led to widespread changes in exploration strategies for the companies involved: "*Both the RAFTS project and ancillary field course have led to important changes in practice within Partex Oil and Gas and associated partners*" [5.2].

Cardiff University's research "*contributed to a wider, more complete knowledge of key oil and gas prospects in the region*" [5.2]. Development planning for the RAFTS consortium included advising about high-risk areas containing increased levels of natural gas that would need to be disposed or re-injected back into the crust. As a result, Partex Oil and Gas confirmed that Cardiff University's "*project deliverables were key in the decision making process within Partex Oil and Gas, and associated partner companies, leading to a gain of £100M*" [5.2].

[Text redacted]

4.4 Summary

Research at Cardiff University helped global oil and gas companies to more efficiently explore and extract hydrocarbons by analysing off-shore continental 'Breakup Sequences'. [Text redacted].

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] Testimonial from Dr Marcos Roberto Fetter Lopes, Manager for Tectonics, Structural Geology and Geomechanics, Petróleo Brasileiro S. A.

[5.2] Testimonial from Luis Guerreiro, Exploration and New Ventures Manager, Partex Oil and Gas Group.

[Text redacted]