SoleGeo

Reservoir Characterization - Geoscience studies

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SoleGeo staff and associates have successfully completed Exploration and Reservoir Studies for the following clients:

Construction of a Worldwide Analogues Database for Naturally Fractured Basement Reservoirs

Seismic Attribute Applications and Merits for Exploration and Education

P. Th. R. De Beukelaar and O. Medina

The **main objective** of this work was to **facilitate** the otherwise tedious **selection and compilation** of essential literature and reading needed for exploration in a focused area. This work is illustrated with a Northern North Sea play under study. Our project was resulting into an overview and the creation of a first prototype or **file system of major Worldwide Analogues of NFR**, Naturally Fractured Basement Reservoirs and/or for Reservoirs of overlaying sediments in fluid communication with basement rock. Much work had been done since in extending this database for more general purpose and access to also other parties getting finally extremely useful in **exploration projects and educational programs** worldwide.

New aspects covered
A rather simple PC-tool was made that consisted of a hierarchical linked Word, Excel and Powerpoint file system with a structure based on regrouped mostly pdf files sorted as countries, fields and specific NFR reservoir properties. In this system special attention was given to the compilation and review of successful and most recent borehole log interpretation techniques that in an expected next step, or in a similar exploration project, serve as calibration for mapping and prediction of Mesozoic-Palaeozoic to basement rock properties derived from seismic data. The latter would be possible by analysis of recently acquired 3D high resolution, wide azimuth and long offset seismic data. Authors are now searching a wider audience because the work has:

- *Allowed the development of a new and successful training course that made and still makes this work very useful for education of oil-and-gas company staff.*
- *Contributed to recent exploration successes in Norway.*
- *Directed a way forward in seismic reservoir characterisation if relative low porosity by the use of novel seismic attribute techniques in applications on high quality 3D wide azimuth seismic data.*

Introduction

The trend of **deeper exploration targets** and the ever **improving quality of imaged seismic data** has led to a renewed interest in Pre-Tertiary deposits and petroleum systems connected to or associated with **fractured, altered, eroded and weathered basement**. Basement type of reservoirs are dominantly characterized by a **lack of porosity and often at rather large depths** that penalize even exclude many now widely used seismic reservoir characterization methods using AVO and/or Inversion, see e.g. De Beukelaar et al. (2001). Techniques measuring acoustic or elastic parameters for mapping lithology and fluid fill, less sensitive for underlying **low and weak porosity variations** can best be approached with additional mapping of appropriate geometric attributes. Fractured reservoir porosity further divides into a definition of a pseudo matrix consisting of micro porosity and dual porosity (Figure 1). Moreover many of deeper Pre-Tertiary prospects are thermally over-mature for oil preservation as also the role of severe tectonism, deformations, **faulting and folding associated to several rifting phases** are often still poorly understood.
We constructed a collection of **analogues for major fields** in terms of production from about 25 countries e.g. Vietnam, India, Indonesia, Korea and Thailand as only to mention those major basement reservoirs known in Asia. Although often considered as marginal in continental Europe, much had been documented and published for CIS, Russia, Middle East, Oceania, North-and South America. Examples of published reviews are Koning (2003) and Batchelor and Gutmanis (2010).
Various approaches of **fracture prediction from seismic data** use knowledge of aperture type, dominant fracture direction etc. using local calibrations from borehole logs: quantitative image analysis, dipmeter and analyses from acoustical measurements. Cores and Formation Tests together with guided geological interpretation deliver details at the smallest possible scale (Serra and Serra, 2003). A geo-mechanical approach was applied by e.g. Nieuwland (2011) for a basement type of reservoir. In our work we carried out both the **construction of a worldwide analogues PC based database** of naturally fractured reservoirs integrating previous experience of numerous scientists as well several months later we focused in particular on **prediction methods and mapping of fracture patterns from seismic data** that might relate to permeability and stress orientations not depending primarily on classic measurements of porosity.

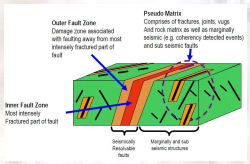

Figure 1: *Pseudo matrix of micro and dual porosity.*

Figure 2: *Fragment of a NFR Property list as linked entries in a PowerPoint file.*

Procedure and Methods

Our work consists in **making a useful catalogue of world-wide analogues of basement type of reservoirs**, metamorphic or igneous, regardless of age together with those type of reservoirs of sedimentary origin with little matrix porosity or just considerable fracture porosity due to deformation, erosion, alteration or weathering (or a combination of them) and in many cases overlain by a sedimentary HC bearing containing sequence of interest. Numerous **technical papers were reviewed and selected** for major fields and basins together with the collection of papers related to certain properties and exploration aspects and further added to our data base hierarchical file structure. Main entries in respectively PowerPoint and Excel files were ***Property*** (Figure 2) and ***Country*** (Figure 3). Some detailed well reports and well tests taught us how possibly to interpret and to apply **previous production experience** to similar prospects in several areas of interest in the Northern North Sea (e.g. Figures 4 and 5a). Relevant information was made public in literature, to be found in the large IFP and IPGP libraries in Paris and on the internet and also more difficult to access from archived reports if made available for free access to these libraries, originating from databases of oil-and gas companies.

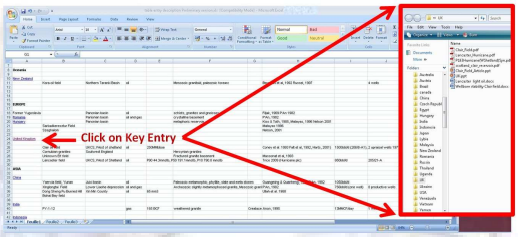

Figure 3: *Excel Spreadsheet Entries. Clicking on hypertext links lead to display of e.g. related file lists in country folders.*

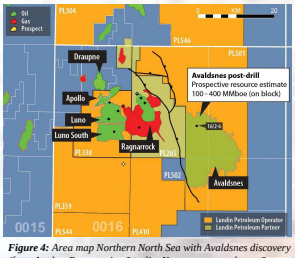

Figure 4: *Area map Northern North Sea with Avaldsnes discovery (from Analyst Presentation Lundin, Norway, press release, 2 December 2010).*

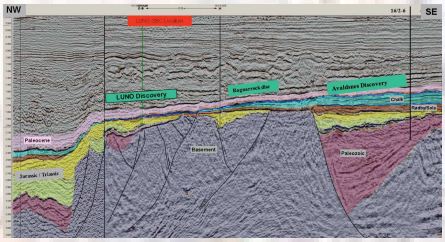

Figure 5a: *Interpreted Seismic Profile (from Analyst Presentation Lundin, Norway, press release, 2 December 2010) Mesozoic-Palaeozoic sediments draped on weathered and fractured basement.*

Examples

From the large database we highlight e.g. the following fields with respect to their exploration and production history: Clair and Lancaster, Western Shetlands, Mangala and PY-1, India, Lake Albert, Victoria Nile Delta plays, Uganda, Nafura-Awjilah, Libya, White Tiger, Vietnam, Zeit Bay, Egypt.

Successful discovery in Northern North Sea, Norway

The Norwegian Petroleum Directorate applies a 2-year cycle in releasing data to the public domain that makes it rather easy to re-use recent interpretations, initiate new play types and gain insight in the exploration of blocks for licenses in the APA, Awards of Predefined Areas and open licence rounds. We show the case of **licence PL501 in Blocks 16/2 and 16/3, Northern North Sea**, with several prospects we had worked previously on from October 2008 until recently in preliminary mapping for different parties that cannot be disclosed for reasons of confidentiality. The license example shown here is that of J.V. partners Lundin (operator), Maerskoil and Statoil. **Exploration Success** was achieved with interpretation of **high quality 3D seismic data** newly acquired in 2009 and 2010, the use of **innovative software** and the efforts of several **exploration staff, contractor contributions and management**. All this had been freely published in great detail in formal press releases. Lundin (2010). See also Rønnevik (2011). The public was informed about the **Avaldsnes discovery in Autumn 2010** consisting of mainly Draupne Jurassic reservoir sands with estimated reserves of **100-400 MMboe** directly draped or still with underlying Mesozoic-Palaeozoic sediments on weathered and fractured basement of the Haugaland and along the flanks of the well known but so far underexplored Utsira High. An interesting exploration concept is that Atlantic Mid Ocean Ridge **transform boundaries** can be traced across oceanic crust towards the coastline forming **Basement Structural Highs**. Parry (2011).These Highs (Figure 5b) are related to volcanic activity along strike of these "leaky" fracture zones in the oceanic crust. Such structures set up the initial structural framework of the continental margin basins. Syn-rift and post-rift deepwater sedimentation on-lap these basement highs and the influence of the transfer zones continues to propagate into younger strata by differential compaction. Faults created by this process both act as a **hydrocarbon migration pathway** from deep seated source rocks to shallower reservoirs, as well as influencing **deepwater sediment delivery systems**. Zones of long-lived crustal weakness can be **subsequently reactivated during later tectonic episodes**, giving rise to inversion structures and complex compressive and transpressive/transtensional features.

Stress orientations and fracture prediction derived from seismic data

Several seismic attributes were selected and mapped. Multitrace edge-type attributes as coherence, variance, semblance or correlation etc. are today routinely applied. These attributes however are less sensitive in detecting fracture systems if lacking apparent throw in macro and/or micro faulting. Reflection volumetric curvature and its derivatives like **most positive and most negative, dip-and strike curvature** in addition enable delineation of fracture orientation and density. Chopra and Marfurt (2007). More recently developed approaches are the many applications of **azimuthal anisotropy of P-wave velocity** e.g. using offset vector tiles: Stein et al. (2010) and **duplex wave migration**: Khromova et al. (2011). **Rose diagrams** expressing major stress orientations directly derived by lineament patterns from seismic measurements finally need careful calibration with similar diagrams **directly read from borehole image logs** and indirectly measured from e.g. Naturally Gamma Radioactivity **(GR) logs**. Both combine in delineation, spatial estimation and mapping of e.g. density, aperture, length, open or healed etc. characterization of **typical fracture parameters**. Authors gained extensive experience in using also an **Ant tracking algorithm**, a Petrel plugin (Schlumberger) on Oseberg seismic data (Statoil). Figure 6 further shows an example of a **Dual Azimuth Attribute algorithm** as applied to data acquired in the Norwegian Sea (courtesy GDF-Suez) that highlights the dominant fracture system for two different parameters. Similar attributes demand intensive **pre-scan dip-and azimuth computations**. Well calibrations were providing highly accurate 3D fracture characterisation maps. The latter technique was also successfully combined with a **3-D anisotropic diffusion filter** with normalized gradient to replace the gradient in the computation of the diffusion coefficients. This reduced the speckle effectively while preserving the edges. Evaluation of the **in situ stress tensor from log and core measurements** formed the basis of equivalent measurements of **anisotropy and fracture patterns from seismic** data relating to stress orientation and permeability.

Conclusions

The work described in this project had been of help in acquiring extended knowledge and insight in exploration and the interpretation of seismic and well bore data covering Jurassic-Triassic-Palaeozoic to-basement for **relatively low porosity naturally fractured basement reservoirs in the Northern North Sea in Norway**. Initial well-and-seismic interpretation in 2008 until late 2009 served in 2010 as basis for further extending this Naturally Fractured Reservoir analogues database with newly published material to tailor made **regional training courses with detailed borehole and seismic interpretation** methods useful for geoscientists working in particular NFR basins in countries as UAE, Malaysia, Yemen, Vietnam and Venezuela. For these experts getting often into lively discussions of various related topics, it appeared to be surprisingly useful to get **precious information about previous exploration-to-production** in e.g. The Western Shetlands (offshore), India (offshore and onshore), Libya and Uganda (both onshore) and often getting direct answers to remaining questions in their own specific local or regional work situation. Finally in the more detailed interpretation and estimation of **fractures for newly acquired wide azimuth 3D data**, it was attempted by several of these companies to apply a workflow of several most recent **quantitative seismic measurements and attributes**, combined with the insight of **rock physics-stress related patterns** and **calibrated borehole data** for mapping fracture character through a 3D seismic volume.

Advanced attributes like **Structurally Oriented Semblance** and **Spectral Decomposition**, attribute combinations and visualisation techniques (Opacity Blending) were applied with focus on improving definition and delineation of stratigraphic targets including channels in the Jurassic and landforms and channels in the Triassic as published in Norton et al. (2010). Further investigation of several wells on the flanks of the Utsira High and adjacent acreage showed in equal depth detail that the underlying weathered, altered and **fractured basement in addition to the Jurassic-Triassic stratigraphic structural features** could all together be considered as a single petroleum system. With the newly available high resolution, 3D, long offset, wide azimuth seismic data this would naturally ask for further mapping also **the sub-seismic structural detail and stress regimes** with even more recent and **advanced seismic attributes, imaging techniques** and **application workflows** as described in the following paragraph "**Stress orientations and fracture prediction derived from seismic data**".

Acknowledgements

Although all of our above statements and findings were sole those of the authors as experienced with the intention to make this paper useful and informative, we respected and still respect all possible known and unknown data property holders and issues of confidentiality. In this publication we have used or own data or data freely published on the internet. This is meant as a disclaimer against any legal action in the free expression of our ideas solely to the benefit of scientific integrity. We are grateful having had the opportunity in agreement, sometimes disagreement, at least fruitful discussions with e.g. **Hans C. Rønnevik, Bernt Erik Reed** and several other company staff not mentioned here. Special thanks go to **Tako Koning**, retired and based in Luanda, Angola with at least 25 years of experience in basement reservoirs in Indonesia, Venezuela and most recently contributed substantially in the very promising outlook for Uganda. Our gratitude goes also to **Bruce Finlayson**, who contributed to the success of the major billion barrel Mangala field oil discovery in January 2004 in faulted/ fractured basement in a Tertiary rift system making part of the Barmer basin, Rajasthan, India. Thanks goes also to **Dick Nieuwland**, regarding his recent geomechanical work, not making use of seismic, but borehole break outs in fracture estimation in a project for another North Sea operator company and last but not least we express our gratitude to **all of the hundreds of enthusiastic company staff, participants** of several NFR, QI Seismic and Open & Cased Borehole training classes organised in 2010 for their numerous good questions, lively discussions and constructive feedback.

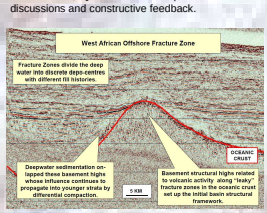

Figure 5b: *Basement Structural High, from Parry (2011)*

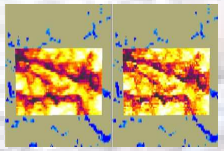

Figure 6: *Example of a Dual Azimuth Attribute algorithm as authors applied to a Norwegian Sea seismic data set (courtesy GDF-Suez). Left and Right Figures show two different parameters selected.*

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