Fault seal analysis: A method for De-Risking of prospects in Upper Assam North Shelf in Assam & Assam Arakan Basin, India

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Abstract
Faults commonly trap and impact the flow of fluids such as hydrocarbons (HC) and therefore are of economic significance. During HC-exploration, analysis of the sealing capacity of faults can impact both the assessment of the probability of finding hydrocarbons and also the estimate of the likely resource range. The present study primarily aims to ascertain the role of faults in entrapment of HC based on fault seal analysis (FSA) in a mature brown field of Upper Assam Shelf North (UAN) of Assam-Arakan Basin. Faults are identified and its architecture, throw, heave and orientation are analyzed based on 3D seismic data. Primarily, two sets of faults viz. NE-SW trending longitudinal faults have been offset by NW-SE or N-S transverse faults in the study area. 3D Geo-cellular model has been prepared, incorporating drilled well data, geological information, petro-physical & seismic interpretation data to capture the vertical as well as lateral heterogeneities and to analyze structural disposition across faults and fault sealing properties. Sealing nature of faults has been analyzed using properties such as Facies Juxtaposition (FJ) and Shale Gouge Ratio (SGR). The study brought out the sealing potentiality of entrapment faults at different pay levels, which helped in de-risking the prospects of the study area.

Introduction

Faults play an important role in creating hydrocarbon traps. Evaluating fault seals forms an important aspect of HC-exploration, production, and reservoir management (Knipe,1992b). Sealing behaviour of faults is important in defining the vertical and lateral distribution of HC that provides conduits to migrate into traps. In the HC-industry, faults can bound two- or three-way closures which pose exploration risk than the simpler four-way closures owing to the inherent uncertainties associated with predicting fault seal. Fault seal behaviour can be analysed based on hydrocarbon contacts, fault dependent leak points & Pressure data.

Fault seal can be developed from reservoir/non-reservoir juxtaposition. A first-order seal analysis involves identifying reservoir juxtaposition by using the mapped horizons and a refined reservoir stratigraphy defined at the fault surface. Juxtaposition analysis is the traditional method to evaluate the Fault Seal in which either fault-plane maps or Allan diagrams (Allan, 1989) is used. The basic assumption of the model is that a fault is neither a seal nor a conduit. Later, Knipe et al. (1997) developed a juxtaposition diagram which is used for 1D fault seal analysis, which shows all possible juxtapositions of a faulted sequence from no displacement to a throw of varying range. Juxtaposition measures the degree to which facies (sand/shale) are juxtaposed across the fault. The structural disposition across faults and fault sealing properties can be better analysed by using 3D Geological models. In 3D juxtaposition analysis, a juxtaposition value is assigned to each grid cell based upon the facies and it is juxtaposed against the fault. The juxtaposition map along the fault plane displays different colors with each color attribute define different juxtaposition scenario.

The second-order phase of analysis assesses whether the sand/sand contacts are likely to support lithology-dependent attributes shale gouge ratio and shale smear factor. Several algorithms are available to estimate fault-seal potential. Yielding et al. (1997) introduced the SGR, which is the ratio of the sum of shale bed thicknesses, divided by the throw and is expressed in percentage. The simpler case assumes one or more layers of clay or shale being offset by a fault with a given throw. The SGR algorithm takes the average clay content of those beds that have slipped during faulting and treat this as an estimate of fault zone composition. If SGR is high (>40%), the

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fault rock is assumed to be dominated by clay smears whereas the fault rock is likely to be disaggregation zone if SGR is low (<15%) (Yielding et al. 2010). The objective of the present study is to de-risk the prospects for Barail play in Laiplingaon field and Banamali field in view of the Fault seal analysis.

Geological setting:

Assam geologic province is the first known hydrocarbon province in India. The Upper Assam shelf, a SE-dipping shelf is the foreland part of Assam-Arakan Basin. It is bounded by Mishmi hills along its NE-boundary and the shield of Mikir hills towards its west. Upper Assam shelf contains about 07km thick sediments of mostly Tertiary and Quaternary age. The study area forms part of the lease area of ONGC (Figure.1). It is a typical poly-history basin having more than one phase of tectonics and sedimentation. The evolution of the basin is essentially influenced by the Northward movement of the Indian plate towards the Eurasian and Burmese plates. Extensional tectonics prevailed till Oligocene when the tectonic regime changed to compressional environment during the major phase of Himalayan orogeny. Many basement faults reactivated due to compressional tectonics with evolvement of flower structures in the basin until this time. This resulted in reactivation along faults, resulting in reverse faults and inverted structures. The oldest fault trend in the area is NE-SW which is transected by the younger E-W to NW-SE trend creating a number of fault blocks.

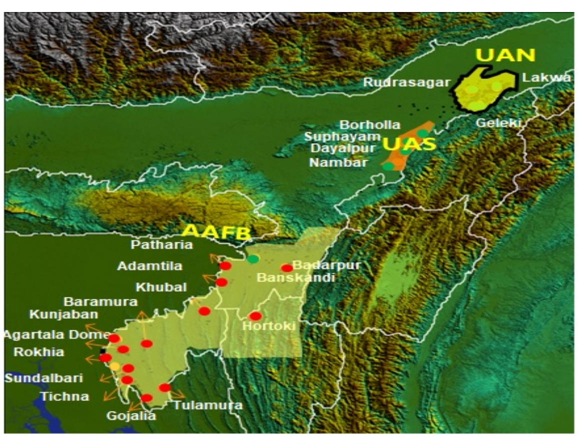

Figure.1: Regional Digital Elevation map showing physiographic division & fields of A & AA Basin

The onset of sedimentation in the UAN part of the basin started during Paleocene to Early Eocene time in a fluvial to marginal marine to shallow marine environment where Tura formation was deposited over Basement in a passive margin set-up. End of Tura sedimentation, witnessed a widespread transgression during which carbonate dominated Sylhet Formation and marine pro-delta Kopili Formation were deposited. Regression was observed after deposition of Kopili Formation which is overlained by delta front sandstone of Demulgaon Formation or BMS (Barail Main Sand) succeeded by delta plain interbedded shale and sandstone with thin layers of coal of Rudrasagar Formation or BCS (Barail Coal Shale). These delta plain BCS deposits are unconformably overlained by a thick sequence of high energy (braided) fluvial sandstone of Tipam Group.

Methodology:

An area of 178Km^2 covering Laiplingaon-Mahakuti field and Banamali field in UAN has been taken for the FSA study. Seismic studies have been carried out by utilizing the re-processed 3D-PSTM data for the area. Based on well to seismic tie, BCS, LBS-5, LBS-2, LCM and Tipam horizons have been mapped. Fault mapping was carried out using vertical seismic sections, fault-likelihood volume-based attribute time slices and relief maps close to top of Barail sands (LBS-5 & LBS-2). Most of the faults trend NE-SW & E-W and some NW-SE & N-S trending cross faults were also observed at places dissecting the older trend. Using interpreted horizons and faults framework, Time & Depth maps were prepared close to top of LBS-2 & LBS-5 pay sands of Barail Formation.

The structural disposition across faults and fault sealing properties can be better analyzed in 3D domain with better visualization. A total number of 30 wells were selected for the study. Well log correlation and Facies log have been prepared for all the wells in the study area. 3D Geo-cellular model of the study area has been prepared, incorporating drilled well data, geological information, petro-physical & seismic interpretation data to capture the vertical as well as lateral heterogeneities and to analyze structural disposition across faults and fault sealing properties. The Geo-Cellular model consist of 06 no. of surfaces (LBS-1, LBS-2, LBS-3/4, LBS-5, LBS-6 & BCS), 18 no. of faults, 07 no. of Zones, 330 no of layers and has 2,34,63000 no of Grid Cells. The detailed work-flow (Figure.2) is enumerated in the following sections.

Structural framework:

A total of 18 number of faults were incorporated in FSA study (Figure.3). In the study area, faults are broadly trending in NE-SW & E-W direction. The prospect EP-1 lies in the hanging wall (HW) block w.r.t. the HC-bearing footwall (FW) block of prolific Laiplingaon field. EP-1 falls on a three-side fault bounded structural closure where F2, F3 and F4 are structure bounding entrapment faults. The fault F3 is E-W trending while F2 & F4 are trending in N-S direction. Fault F3 is the major fault against which the structural closure of EP-1 is formed. It is having a throw ranging from 40-50m which hade towards north. F2 is the bounding fault which lies towards west of EP-1 having a throw ranging from 15-20m while F4 is the bounding fault which lies towards east of EP-1 having throw ranging from 15-20m and hade towards NE. The prospect EP-2 falls within a fault bounded structure, formed against the NE-SW trending normal fault. It is a footwall prospect formed against the NE-SW trending normal fault F9 having throw ranging from 10-20m hading toward N-NW. F10 is also a structure bounding fault which lies to the east of the prospect (Figure.3). This fault is trending in NW-SE direction and has a throw ranging from 10-20m, which hade towards SW. Fault modelling was done to generate a robust 3D Structural grid (Figure.4).

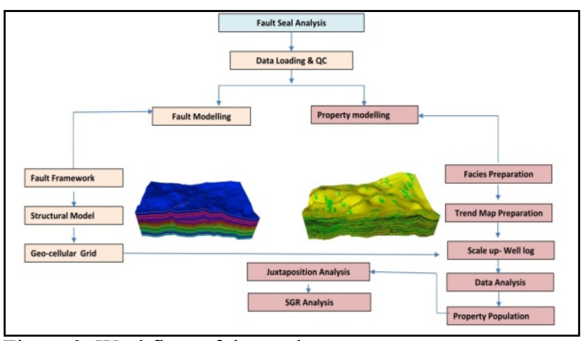

Figure 2. Workflow of the study

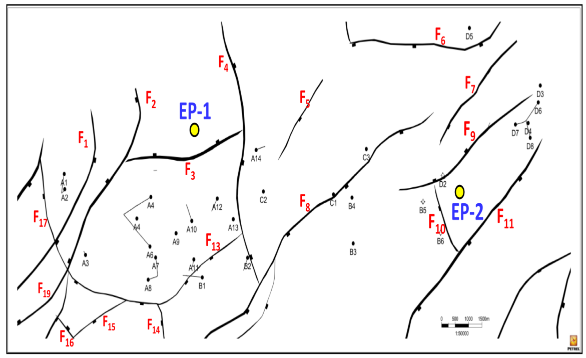

Figure.3: Base map of the study area showing faults

Facies Modeling:

The facies are interpreted based on the log signatures in individual wells with Vclay logs & well data and cross-plots have been generated to understand the relation between them (Figure.5). Facies variations within LBS sands depict multi-layered heterogeneity in Banamali and Laiplingaon fields of UAN. Data analysis was carried out for all the four facies i.e. Sandstone, Siltstone, Shale and Coal. For all the seven zones, the facies logs were upscaled and data analysis was applied to the upscaled facies logs. Subsequently, upscaled well logs are used to populate discrete properties in the grid. The spatial distribution results were analysed. The trend maps of sand distribution were prepared for the Barail sands and trend was given during facies population for better geological control.

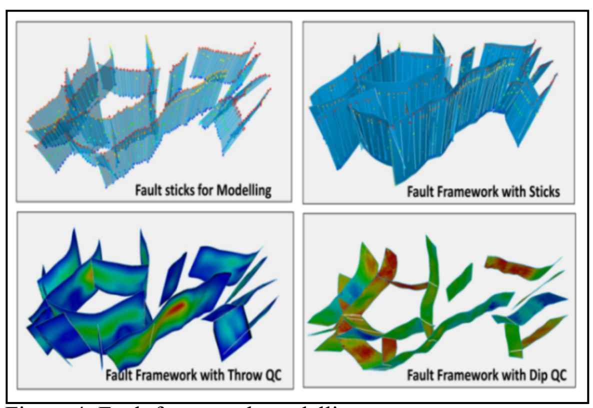

Figure.4: Fault framework modelling

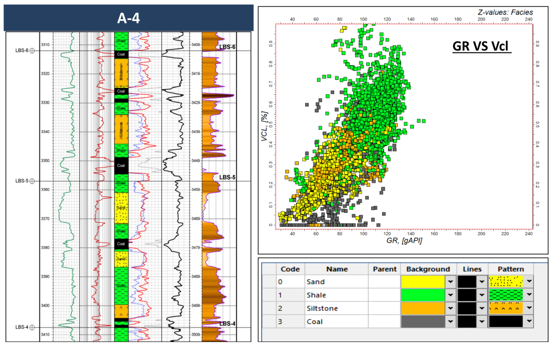

Figure.5: Facies log generation

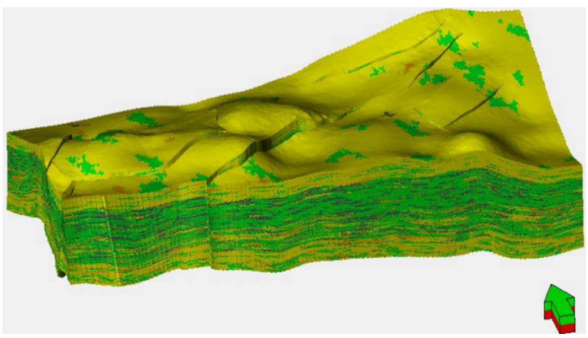
Figure.6: 3D Facies Model

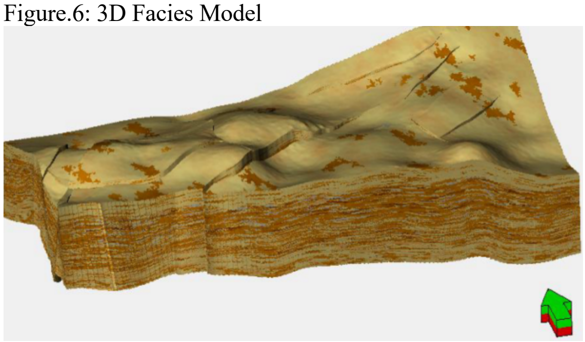
Figure.7: 3D Vclay Model

Petrophysical Modeling:

In this process, data analysis was carried out on the up scaled Vclay logs. Subsequently, the Variogram model was used to fix-up the appropriate range in major, minor and vertical direction. Vclay data population was performed using "Gaussian Random Function Simulation" (GRFS) to generate the 3D Vclay Model (Figure.7).

Results and Discussion:

Fault Seal properties have been computed along every fault, where in few major faults presented entrapment scenarios thereby indicating that sealing behaviour of faults might have played a major role in hydrocarbon entrapment in the closures formed by them. In the current study, two properties namely FJ and SGR have been utilized for characterizing the sealing/ non-sealing behaviour of the faults.

FJ & SGR have been computed along all the entrapment faults for the prospects EP-1 & EP-2 (Figure.8 & 9). Pay wise analysis have been carried out for all the wells against its entrapment providing faults.

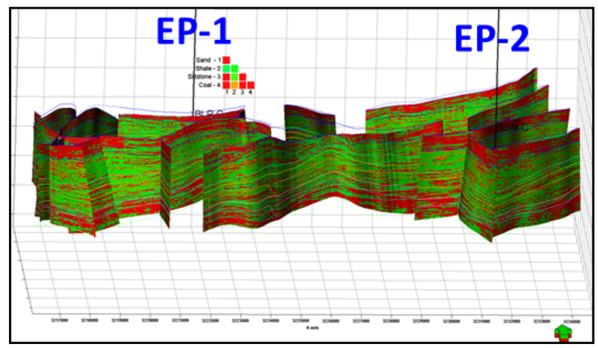

Figure.8: Facies Juxtaposition along fault plane

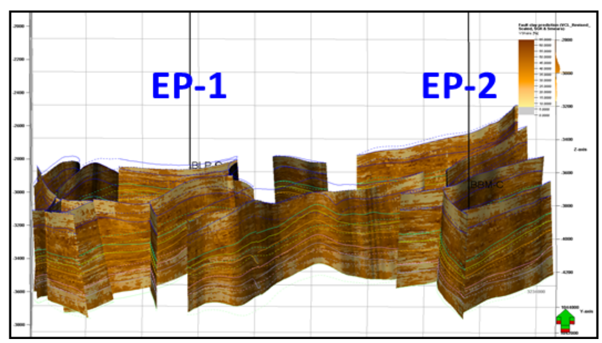

Figure.9: SGR along fault plane

In the Laiplingaon field, for Prospect EP-1, a N-S section has been taken to analyse the juxtaposition across the entrapment fault F3 (Figure.10). In the 3D-FSA, LBS-5 & LBS-3 pay sands are found favorably juxtaposed against the shaly layers developed in LBS-4 & LBS-3 Formation respectively in the FW block of main Laiplingaon field. In LBS-2 Formation, the top part of reservoir sand is found to be juxtaposed against the shaly layers developed in the bottom part of LBS-2 Formation in the FW block defining the probable lateral sealing across the fault.

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In LBS-1 Formation, the top part of reservoir sand is found to be juxtaposed against the sandy layers in the FW block. In the case of LBS-6 sand in the block of EP-1, lateral seal is provided by shale sequences developed within the LBS-6 Formation due to lateral facies variation. SGR values along fault plane for F3 fault (Figure.9) in respect of pay units (LBS-6, 5 & 3) are found to be more than 40%, indicating the good sealing potential of the fault. Similarly, for pay units LBS-2 & LBS-1, SGR in the range of 20-30% suggest the fair to partial sealing potential respectively (Figure.11).

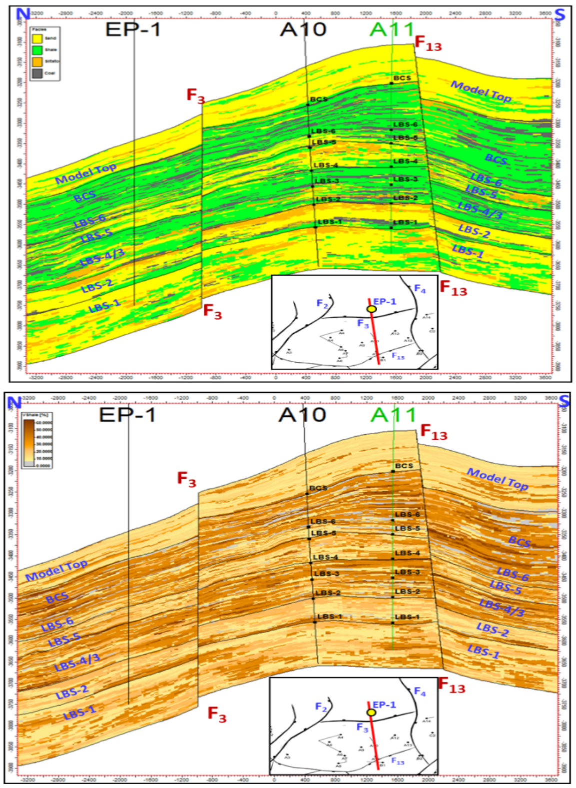

Figure.10: N-S Section passing through prospect EP-1 showing juxtaposition of Facies & Vclay

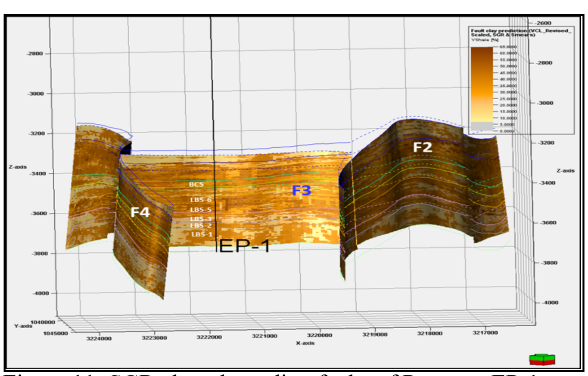

Figure.11: SGR along bounding faults of Prospect EP-1

In the Banamali field, for Prospect EP-2, a NW-SE section has been taken to analyse the juxtaposition across the entrapment fault F9 (Figure.12). In the 3D-FSA, the top part of reservoir sand of LBS-2 is found to be juxtaposed against the shaly layers developed in the bottom part of LBS-4/3 Formation in the HW block. In LBS-1 Formation, the top part of reservoir sand is found to be juxtaposed against the sandy layers in the HW block. SGR values for LBS-2 pay unit is 30-40% attributed to the fair sealing potential while it is found to be in the range of 20-30% for LBS-1 pay suggesting a fair to partial sealing potential of the fault (Figure.13). In addition to FSA, prospect EP-2 falls in the footwall block which make a separate fault closure against the main entrapment F9 fault which likely favours entrapment potential.

In the Laiplingaon-Lakwa-Lakhmani-Banamali field, it has been found that the same pay sands in different HC-bearing blocks are having different contacts (OWC) suggesting separate hydrodynamic system for each block attesting the sealing nature of faults defining the entrapment with reservoir compartmentalization.

Conclusion:

In the 3D-FSA for the prospect EP-1, juxtaposition & SGR study reveals that pay units in LBS-6, LBS-5 & LBS-3 has good sealing potential of entrapment faults. For LBS-2 & LBS-1 pay units, FSA results indicates fair sealing & fair to partial sealing potential respectively for the faults. Additionally, the lateral heterogeneity within the LBS pays also supports the lateral sealing potentiality. Similarly for prospect EP-2, juxtaposition & SGR study reveals that objective LBS-2 pay unit may have fair sealing potential while it is fair to partial sealing for LBS-1 pay unit of Barail Formation. In the study area, the same pay sands in different HC-bearing blocks are having different contacts suggesting separate hydrodynamic system for each block attesting the sealing nature of faults. This validates the FSA results of prospects EP-1 & EP-2. The study brought out the sealing potentiality of entrapment faults at different pay levels, which helped in de-risking the prospects of the study area.

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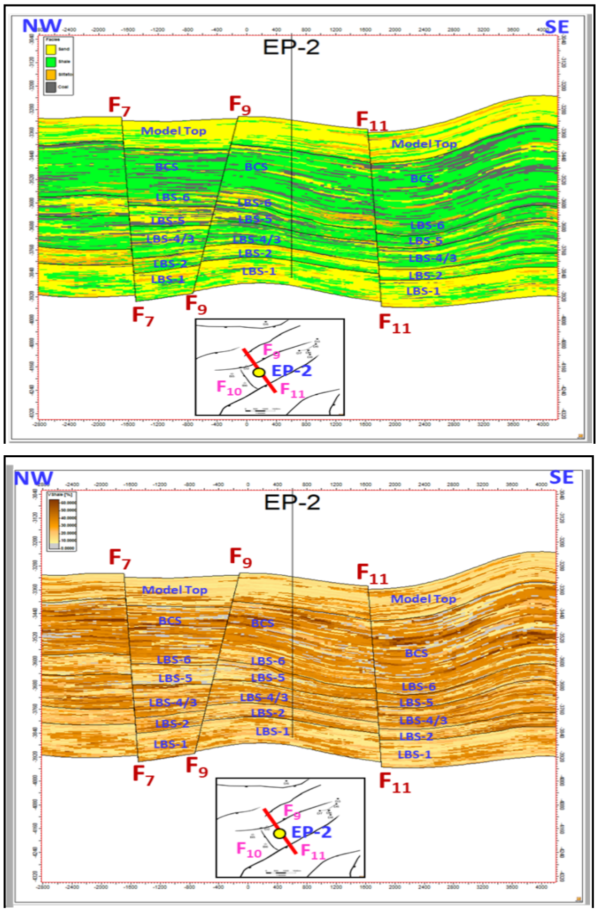

Figure.12: N-S Section passing through prospect EP-2 showing juxtaposition of Facies & Vclay

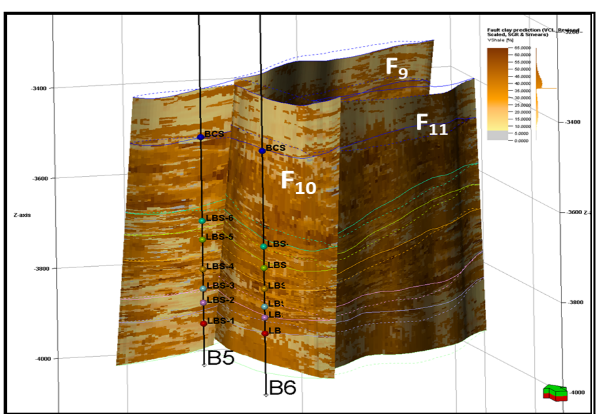

Figure.13: SGR along bounding faults of Prospect EP-2

References:

Allan, U.S., 1989, Model for Hydrocarbon Migration and Entrapment within Faulted Structures. American Association of Petroleum Geologists Bulletin, Vol.73 (7), pp.803-811.

Knipe, R.J., 1992b, Faulting processes, seal evolution, and reservoir discontinuities: An integrated analysis of the ULA Field, Central Graben, North Sea, Abstracts of the Petroleum Group meeting on collaborative research programme in petroleum geoscience between UK Higher Education Institutes and the Petroleum Industry, Geological Society, London.

Yielding, G., Freeman, B., and Needham, D.T., 1997, Quantitative Fault Seal Prediction, AAPG Bull., Vol. 81, pp.897–917.

Yielding, G., Bretan, P. and Freeman, B. 2010, Fault seal calibration: a brief review: Jolley, S.J., Fisher, Q.J., Ainsworth, R.B., Vrolijk, P.J. & Delisle, S (eds.). Reservoir Compartmentalization, Geological Society, London, Special Publications, Vol.347, pp.243–255.

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