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SISA Seismically Spotted - Salt Induced Stress Anomalies Causing Depth Conversion Errors Now Detected on Long Cable PSDM

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SUMMARY

Accurate time-to-depth conversion of seismic data is often a critical success factor for wells, particularly in mature HC provinces. Over recent years, a number of wells have been drilled in the Southern North Sea that suffered from incorrect depth conversion. A detailed analysis of variation of overburden rock velocity in well logs showed that velocity variations up to 10% occur within short distances for no apparent reason. By carefully studying the settings where these anomalies occur, a common factor in the overburden geometries was found. Saltwelds appear to act as stress concentrators and give rise to localized rock property changes. A geomechanical model: SISA (Salt Induced Stress Anomaly) has been developed that can explain the observations.
So far these velocity variations were not detectable on the processing velocities from PSDM workflows. The depth and the limited horizontal and vertical dimensions of the anomaly make it difficult to resolve these in conventional reflection seismic. However with the arrival of new high multiplicity, large offset 3D seismic and careful PSDM processing it appears now possible to map out these velocity anomalies.

Introduction

Accurate depth conversion of seismic data is often a critical success factor for wells, particularly in mature HC provinces. Remaining drilling targets are regularly characterized by relatively small HC columns. As a consequence, these targets are very sensitive to depth prediction errors. This certainly applies to the Southern North Sea (SNS) where the Rotliegend payzone is often underneath a strongly deformed Zechstein saltcover. Halokinesis has resulted in areas with increased salt thickness (i.e. saltridges) and areas with full salt withdrawal (i.e. saltwelds). The highly variable overburden poses big challenges for (accurate) time to depth conversion (Fig 1).

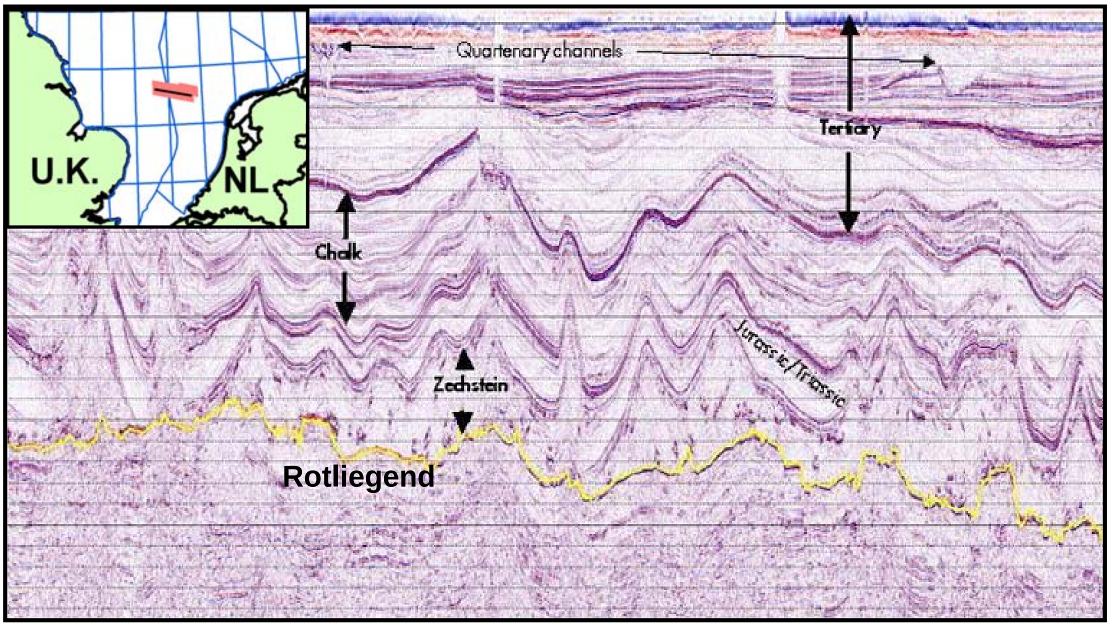

Fig. 1: E-W line over the SNS K7 K8 blocks showing strong salt related deformation. The inset shows the SNS area with the 3D survey in orange and the E-W line in black.

Over recent years, a number of wells have been drilled in the SNS that have suffered from incorrect seismic time to depth conversion. A detailed analysis of Triassic velocities in well logs showed that velocity variations up to 10% do occur within short distances (e.g. ~1 km) for no apparent reason (fig.2). Typically at this depth seismic (processing) velocities are considered not sufficiently sensitive to detect velocity trends and depth conversion velocities are mostly based on (interpolated) well data. Obviously in cases where these anomalies are not being sampled by existing wells, the depth prediction can be significantly off.

Analysis

By carefully studying the settings where these anomalies occur, a common factor in the geometries was found. It appeared that where the Triassic package is residing directly on top of the pre-Zechstein salt substratum (e.g. Rotliegend), the Triassic velocities are higher than in surrounding areas. A geomechanical model has been developed that can explain these observations using the concepts of isostasy and stress arching (fig.3). The vertical stresses resulting from the overburden weight are normally transmitted uniformly and cause laterally uniform compaction in the sediments. However, if the salt layer is able to deform plastically and to redistribute itself under the influence of buoyancy forces, the overburden stress will concentrate itself at the locations of the salt welds. This locally increased stress, together with its related strain (including de-watering of the sediments) will lead to higher seismic velocities in the overburden. The effect of Salt Induced Stress Anomalies (SISA) can explain the velocity variations that were observed in the wells.

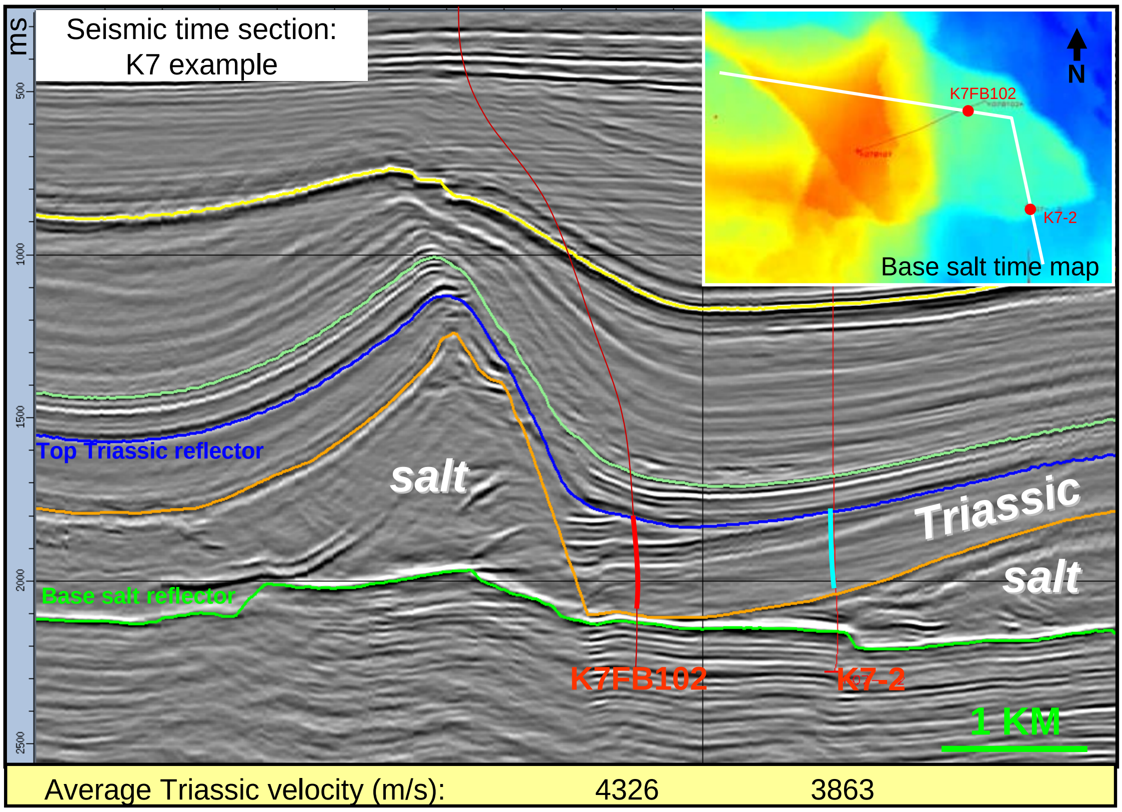

Fig. 2: A seismic cross section showing two wells: K7-2 and the later drilled K7FB102. The latter came in ~100m deep to prognosis. Logging showed that in particular the Triassic package was much faster in K7-FB102 (below saltweld) compared to K7-2

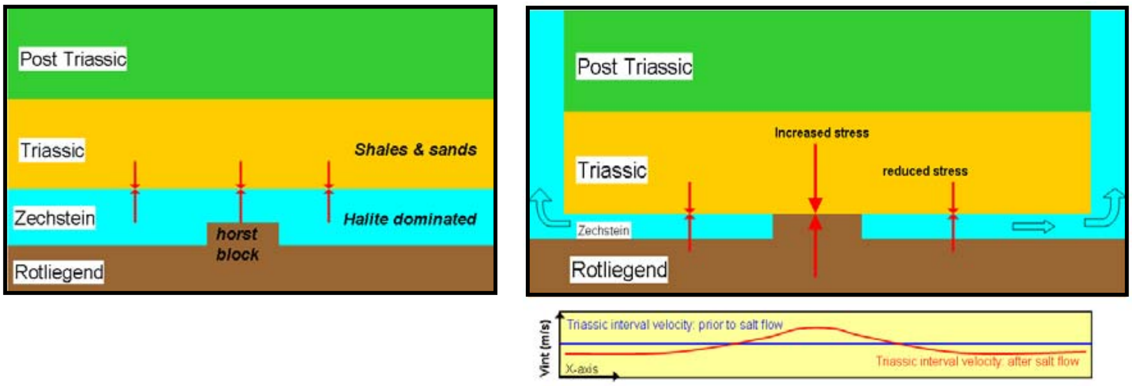

Fig. 3 Simplified mechanical model illustrating how stress concentration can occur when a large rockmass is supported unevenly. Initially (fig. 3 left) the halite layer is sufficiently rigid to support the entire overburden uniformly. Vertical stresses in the Triassic (and velocities) are laterally uniform. Note that the pre-salt topography is not relevant for the post-salt stresses. At a certain stage (e.g. once temperature has risen; fig. 3 right) the halite layer rheology changes from rigid to plastic (fluid). The salt tends to be squeezed out laterally and concentrates in diapirs / domes. As a result, the overburden subsides until an obstacle is encountered (e.g. horst block) and local "grounding" has occurred. The overburden weight will be carried, preferentially, by the horstblock. Above the horstblock the vertical rock stress will be higher than in the adjacent areas. (analogue: brick in bathtub supported on coin)

The same stress concentration phenomena can also explain certain variations in the quality of underlying reservoir rocks. Rotliegend reservoir underneath salt welds shows lower porosities compared to offset wells. Geomechanical Finite Element modeling has been conducted in order to assess the stress distributions semi-quantitatively. An example of the FE modeling result using simplified geometries as described (fig. 3) is given in fig 4.
A data-mining exercise revealed that at least 30 wells in the Netherlands have been drilled in - or close to – salt welds. Around 90% of these wells exhibit velocity variations that are in line with the SISA model.

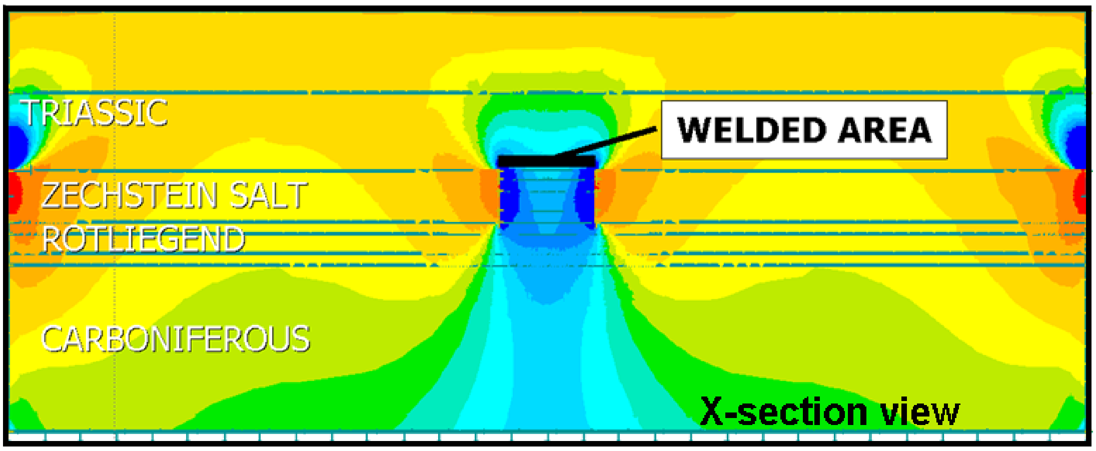

Fig. 4 Crossection showing stress anomalies as a result of the salt weld (SISA). Blue indicates increased vertical stress, red indicates reduced stress.

So far these velocity variations were not detectable on the processing velocities from PreSDM workflows. The depth and the limited horizontal and vertical dimensions of these anomalies make them difficult to resolve in conventional reflection seismic.

In 2006 the area around the well K7FB102 was covered with a state-of-the-art long offset, high multiplicity 3D (fig. 1 inset). This 2300km2 survey was subsequently processed utilizing Pre-Stack Depth Migration technology by the Seismic Processing Team in EPE (Shell Exploration and Production Europe). Special attention was given to the velocity picking process as this would be critical in the subsequent time-depth conversion.
The possibility to accurately pick Residual Move-Out (RMO) on the long cable Image Gathers and the use of the latest Travel Time Inversion techniques allowed the construction of an accurate velocity model.
Whereas earlier data was not able to pickup the velocity anomaly as seen in K7FB102, the new data indeed shows a high velocity zone which is in line with the well results. Depth converting with the new model yields a reservoir depth that matches the well within 10 meters. The areal outline of the high velocity Triassic mimics the saltweld outline; a result that is in line with the SISA model (fig. 5).

Conclusions
Localized velocity anomalies that go unnoticed, can lead to significant depth prediction errors. A geomechanical model has been presented that can explain these velocity anomalies via stress anomalies which in turn are linked to certain salt geometries. In case high quality 3D seismic is available, these anomalies can be picked up by tomographic velocity inversion which is part of the Pre-stack Depth Conversion workflow.

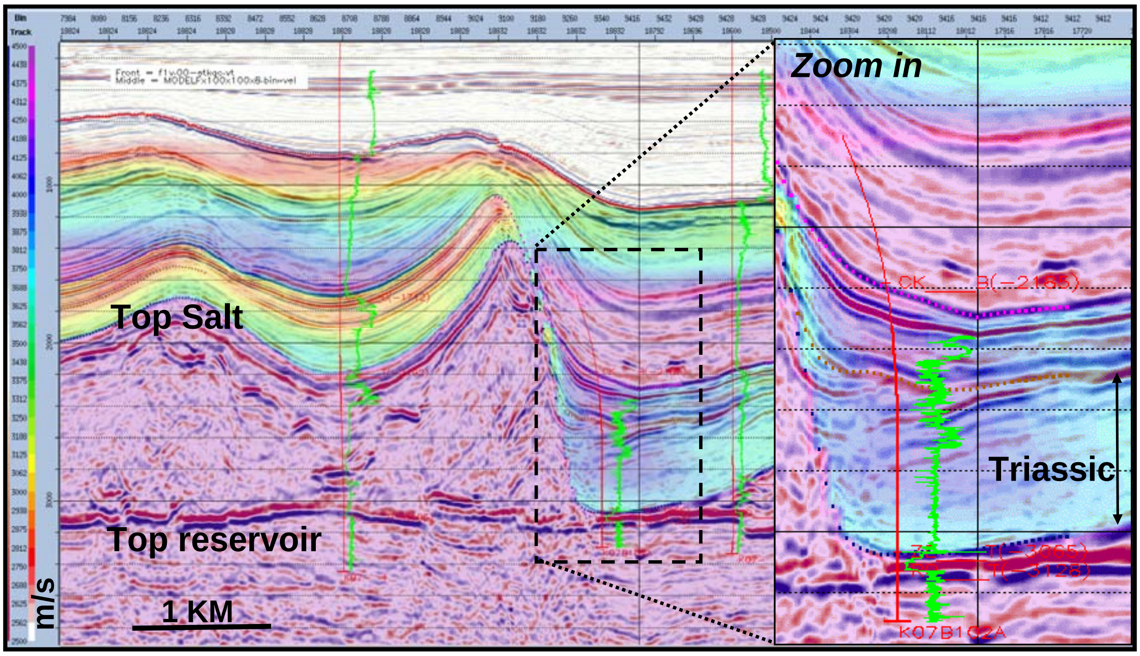

Fig 5. Seismic cross section over the K7 area (displayed in depth). The velocity model used to migrate the data is shown in the background. The SISA effect (10% increase of the Triassic velocities) has been clearly picked up by the inversion in the area of the K07B102A well and the horizons do now match the well markers.

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