[PS]3-D Seismic Interpretation of Permian-Carboniferous Carbonates in Offshore Northern Europe: Faulting and Leakage Analysis*

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Abstract

In some areas of northern Europe, the Paleozoic contains potential carbonate reservoirs in the Carboniferous-Permian section. Seismic interpretation focused on both the evaluation of possible compartmentalization, and potential fault-leakage, as the only relevant well had only oil shows.

Mapping of key horizons was made on a 3-D seismic survey. The main objective was the location and reservoir quality of organic buildups normally present at the top of the carbonate sequence. Our interpretation concludes that organic buildups or mounds are not isolated elements, but rather interconnected structures forming a polygonal network with internal depressions. In addition, based on their internal geometry these bodies record different stages of growth, which are not due to vertical stacking, but to shifts and local progradations. These issues complicate volumetric estimates because complete stratigraphic closure is required. Considering all these factors, it was imperative to identify any structural compartmentalization in order to define potential prospects.

In order to support our structural interpretation, several attributes of discontinuity were calculated, being the "structure cube attribute" the one that gave the best results. Unfortunately, horizon slices on top of the carbonate sequence do not yield the expected results, because the stratigraphic features completely mask the structure. However, the combination of several 3-D rendering techniques, such as opacity, transparency, different types of display, etc. permitted the definition of structural compartments within the studied area.

A likely explanation to the dry hole is the existence of leakage due to faulting. In order to document this hypothesis, a series of detection techniques were used, which showed isolated shallow bodies of high amplitude that may represent migrated hydrocarbons. The volume of discontinuity attribute indicates a clear correlation of these anomalies with the direction of fault planes. Additionally,

the seabed was examined for leaks associated with the aforementioned structures, but their impact is minimal. On the other hand, the location of "paleopockmarks" in the Upper Triassic section is very intriguing, and it may provide clues into basin modeling.

Seismic interpretation and attribute analysis permit us to conclude that the polygonal network that comprises the organic buildups can be divided in multiple-sized compartments. This favors the existence of both stratigraphic and structural traps, which facilitates the calculation of volumetrics. The results confirm thus, the presence of leakage in this zone, which is critical to define areas of lower risk.

3D SEISMIC INTERPRETATION OF PERMIAN-CARBONIFEROUS CARBONATES IN OFFSHORE NORTHERN EUROPE: FAULTING AND LEAKAGE ANALYSIS

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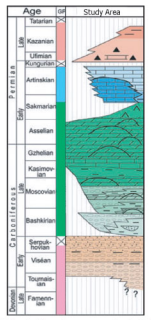
Geological Settings

The Permian-Carboniferous section contains potential carbonate reservoirs along several areas in the world. The region shown here formed part of a vast shelf extending from the developing Uralides westwards through northern Greenland and the Arctic Canada Sverdrup Basin to Alaska.

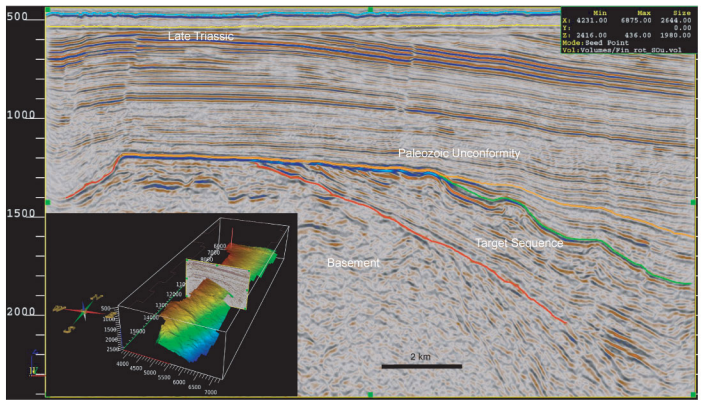
The Upper Paleozoic contains several major sequences. The boundaries between them reflect significant changes in climate, sea-level and tectonic regime.

Our objective is a suite of rocks of mid-Carboniferous to early Permian age, which represent warm water dolomitized carbonates (green colors in the adjacent lithostratigraphic column).

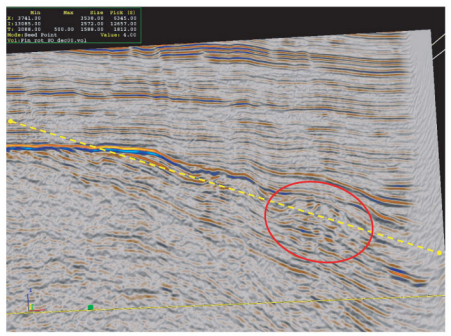
The sequence is represented by three formations. The upper one is dominated by rhythmically bedded limestones and dolomites with *Palaeoaplysina* buildups. The buildups are stacked sequences several hundred meter thick, and are considered the main reservoir in the region.



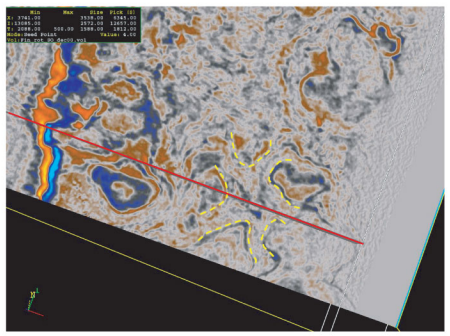
(modified after Larssen et al., 2002)



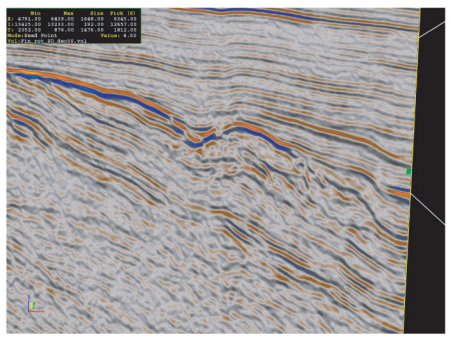
In this representative time seismic section through area of study, can be found a metamorphic basement block with steeply easterly dipping flank and a fault bounded western flank. The basement is overlain by an Upper Paleozoic sedimentary wedge that is also dipping east and thickening eastward. At the crest there is an angular unconformity that truncates the Upper Paleozoic and basement layers, succeeded by Triassic and younger deposits.



Conceptual target, with key facies, chooses to estimate volumetrics (red circle). Dotted line represents the ribbon section display in the next picture.



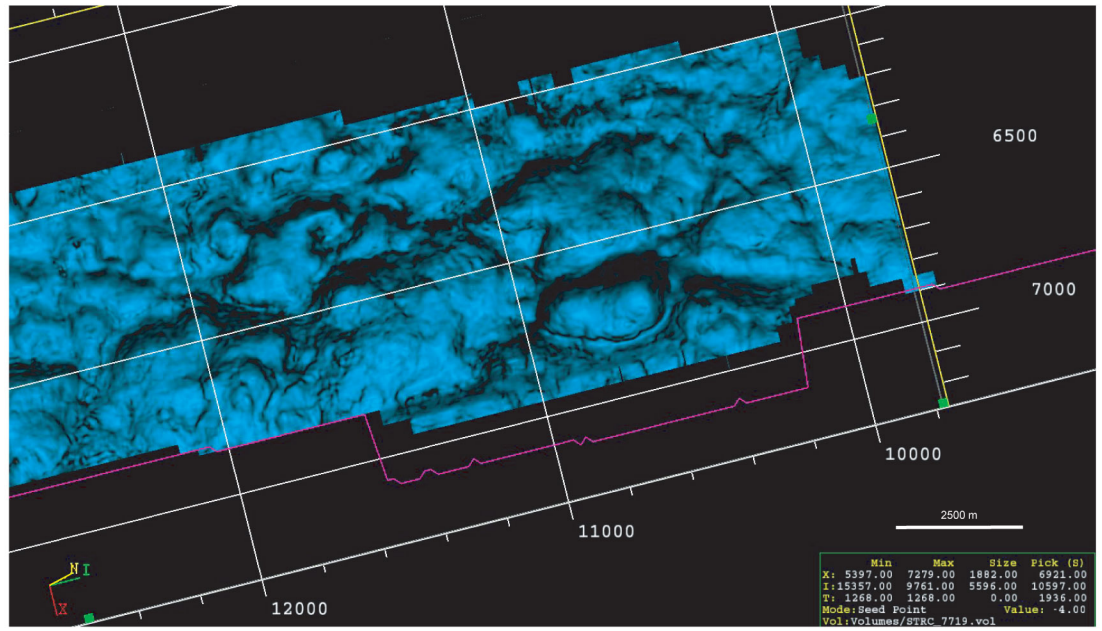
Map view of the ribbon section with previous seismic line location (red line). The yellow lines show the absence of structural closure.



First idea was to review the seismic cube to locate attractive buildups in order to run volumetrics. It is easy to find these bodies along east margin of the structure.

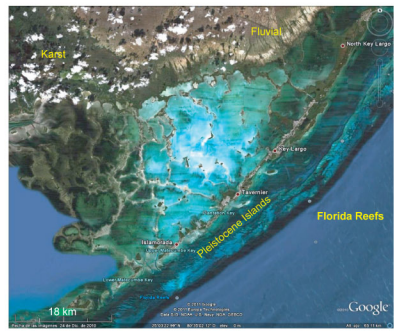
Trying to establish the structural closure for some attractive buildups, for instance, the one in above pictures, we find it is not possible to define the boundaries of this body, the structure is open.

This can be due to the complex internal structure present in the buildups. Although mostly appear to be vertically stacked, there are numerous cases of shifts and local progradations of buildups, expanding the stages of grow to different directions.



From the seismic interpretation it is possible to conclude that organic buildups or mounds are not isolated elements, but rather interconnected structures forming a polygonal network with internal depressions.

This issue complicates volumetric estimates because complete stratigraphic closure is required. Considering this factor, it was imperative to identify any structural compartmentalization in order to define potential prospects.

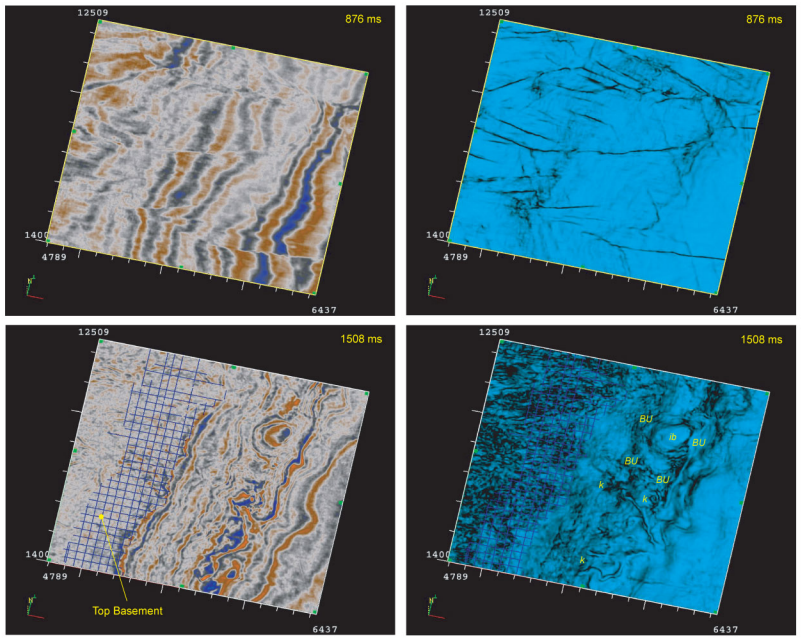


The depositional geometry and size are rather similar to the mud buildups (mounds) in the modern Florida Bay, where the mounds receive different names such as keys or banks, and the inter-mound depression is referred to with misleading terms such as sound, bay or lake. This similarity in geometry does not imply similar origin, paleoenvironment or lithofacies.

Structural Seismic Attributes

Multiple seismic attributes were calculated to improve the image of the faults, such as: dip, azimuth, semblance, etc. The *Structure Cube* attribute is the one that gave the best results.

Structure Cube is a seismic discontinuity volume attribute. Quantify the degree to which neighbouring seismic traces vary from each other. It compares all traces in an analysis window with the average trace of the window to compute seismic discontinuity.



These pictures show the results obtained applying *Structure Cube*.

Top images represent a shallow time slice, where the continuity of the faults, both major and secondary, are perfectly defined.

Lower images correspond to a deeper time slice. The basement interpreted outcrops western. Overlaying to the east, the *Structure Cube* highlights stratigraphic features, such as connected buildups (*BU*), inter-build ups facies (*ib*), or sinkholes and caverns associated with paleokarst (*k*).

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Introduction

This study is part of a potential evaluation project about a carbonated sequence which represents a play known in other geographic areas.

Once located facies of interest, the seismic interpretation focused on both the evaluation of possible compartmentalization, and potential fault-leakage, as the only relevant well had only oil shows.

Due to the short time available during the project, we will see as the different 3D interpretation techniques applied were the key to shed light on the mentioned objectives and obtain results in time.

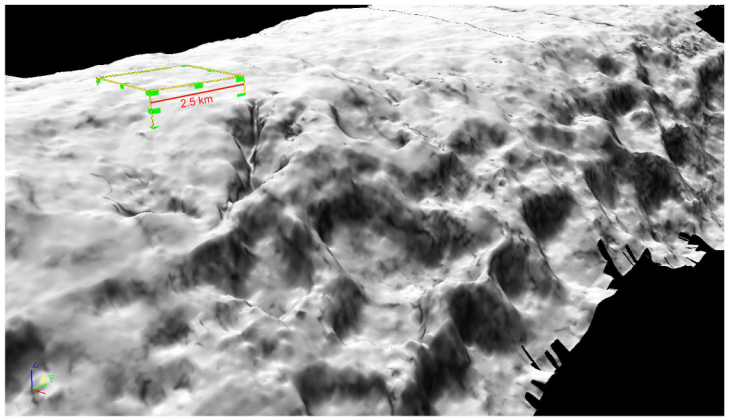
Please, enjoy pretty geology of the area, as well as the displays, so useful and efficient as beautiful !

Key Notes

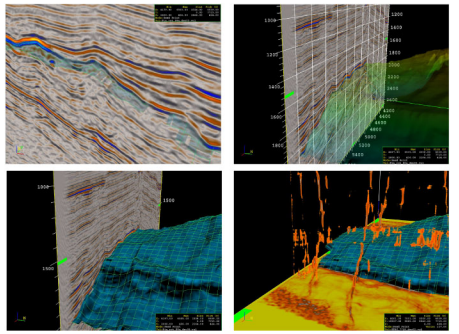
The left panel includes the geological settings. It will be shown both the carbonated sequence of interest and the target facies (buildups). We will find a trouble in order to define possible prospects quickly; the buildups are not isolated bodies. To try to resolve this issue, so as identify potential fault-leakage, structural seismic attributes will be calculated.

Here, in the central panel, it will be seen that using the combination of several 3D rendering techniques, great results will be obtained, in an easy and rapidly way. This allows to add a structural component to the possible traps.

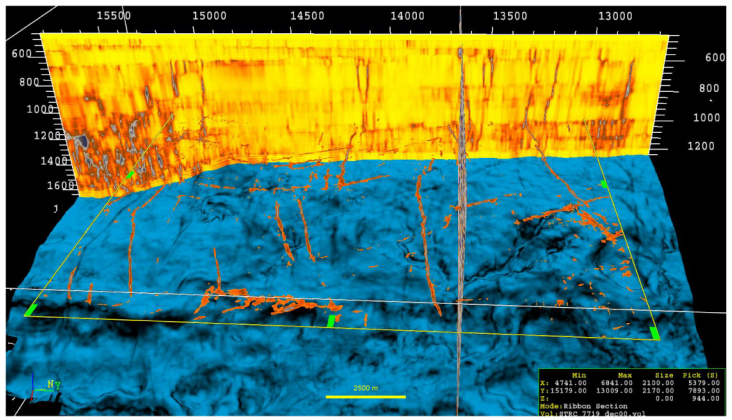
Finally, the right panel displays the first stages of the leakage analysis by combining the shallow high amplitudes distribution and the seabed data.



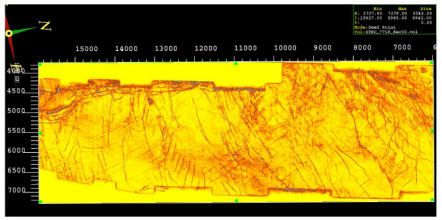
Compartmentalization



Volume interpretation techniques used allow to identify fault lineaments. In this way, the polygonal network that comprises the organic buildups can be divided in multiple-sized compartments. This favors the existence of both stratigraphic and structural traps, and facilitates the calculation of volumetrics.



Fault Interpretation



Discontinuity attribute time slice showing main E-W fault system. A secundary almost perpendicular system can be observed. This is typical of differential compaction depositional mechanism.

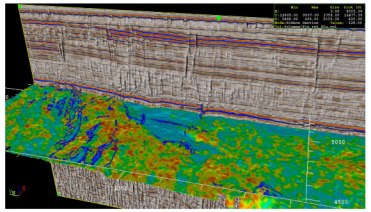
Fault interpretation was supported by (*Structure Cube*) the best discontinuity volume attribute found.

Two main challenges: (i) fault definition in the target sequence, and (ii) leakage analysis.

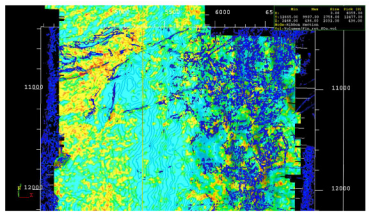
Structure Cube horizon slices on top of the carbonate sequence do not yield the expected results. Stratigraphic features completely mask the structure.

Combinations of volume seismic interpretation techniques were applied.

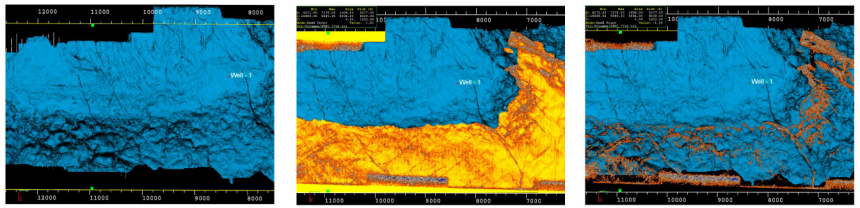
Without drawing a single segment fault, it was possible to deal the problems and achieve the goals, in a fast and efficient manner.



MULTIVOLUME DISPLAYS

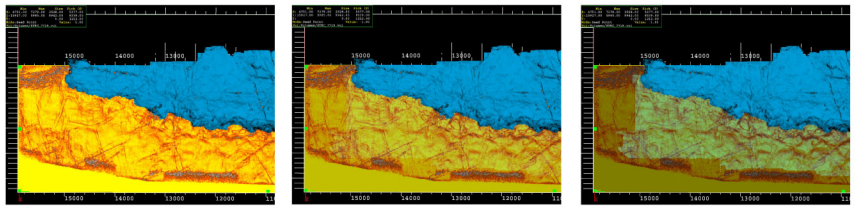


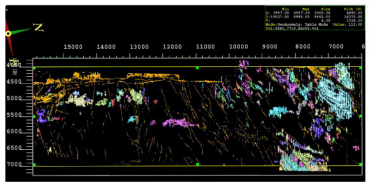
OPACITY



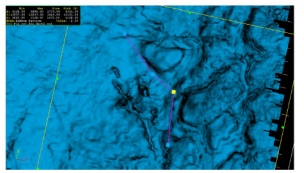
Structure Cube horizon slice. The stratigraphic features completely mask the structure in the buildups area.

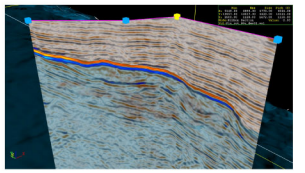
TRANSPARENCY

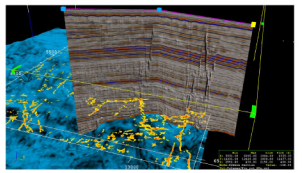


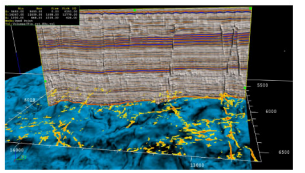


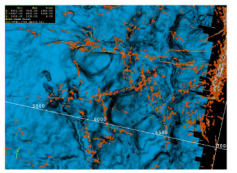
Structure Cube time slice using opacity, in order to try correlate high amplitude anomalies with fault planes.











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Leakage Analysis

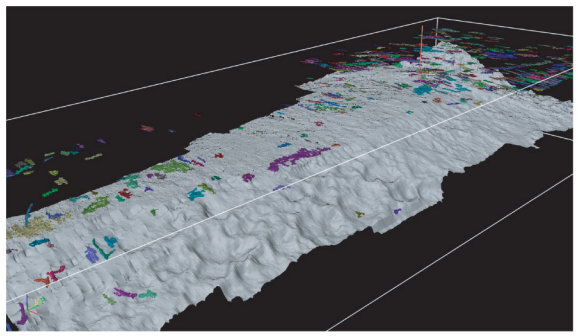
A likely explanation to the dry hole is the existence of leakage due to faulting. In order to document this hypothesis, several interpretation techniques were applied.

Geoanomalies detection technique was tried to rapidly identify and map, high amplitude bodies.

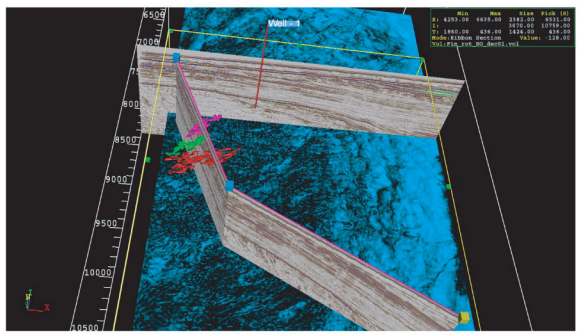
In general, the results show two data sets:

(i) deeper geoanomalies asociated to Paleozoic unconformity, which could represent ancient hydrocarbon migration paths towards the top structure.

(ii) shallow anomalies which could be gas acummulations related to leakage process.

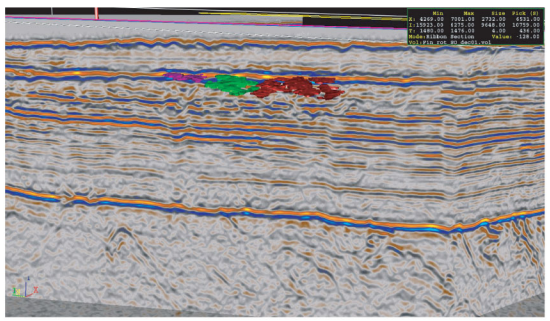


Color bodies represent high amplitude anomalies detected. The surface is the top of the sequence of interest.

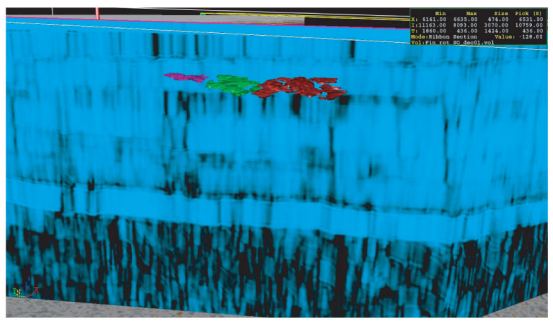


Ribbon section crossing several geoanomalies.

Next step was to try to stablish a relation between the geoanomalies and the fault system. The following images are an example of it.

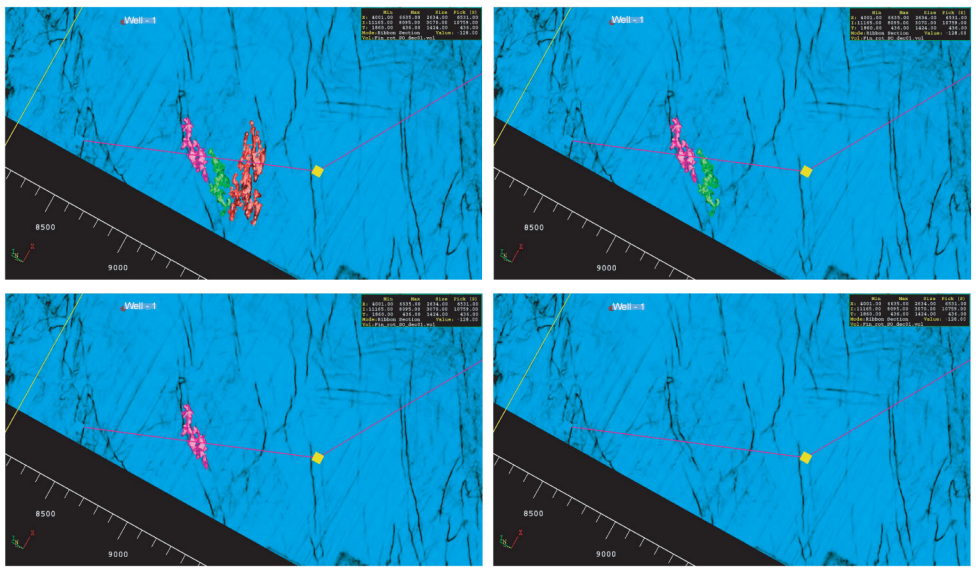


High amplitude anomalies on seismic section.



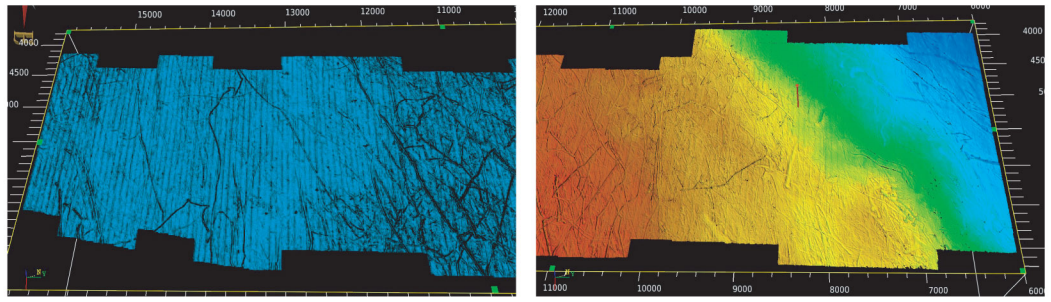
Structure Cube attribute on the same seismic section highlighting the fault system.

High amplitude geoanomalies on discontinuity attribute time slice, showing clearly the relation of these geoanomalies with the fault system. (Please note that a body is hidden in each image).

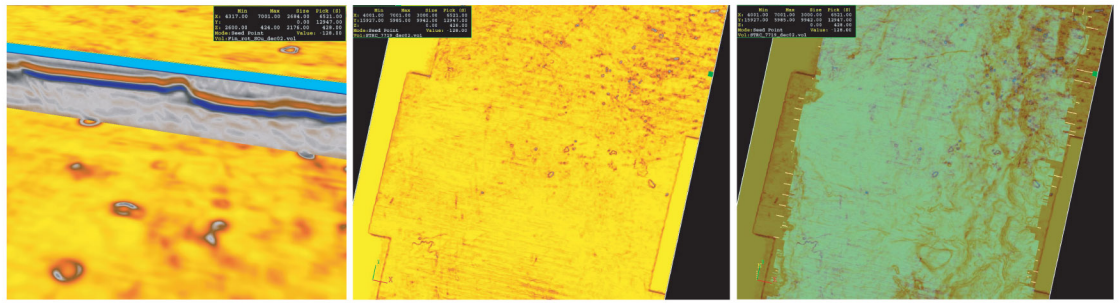


Paleo-pockmarks

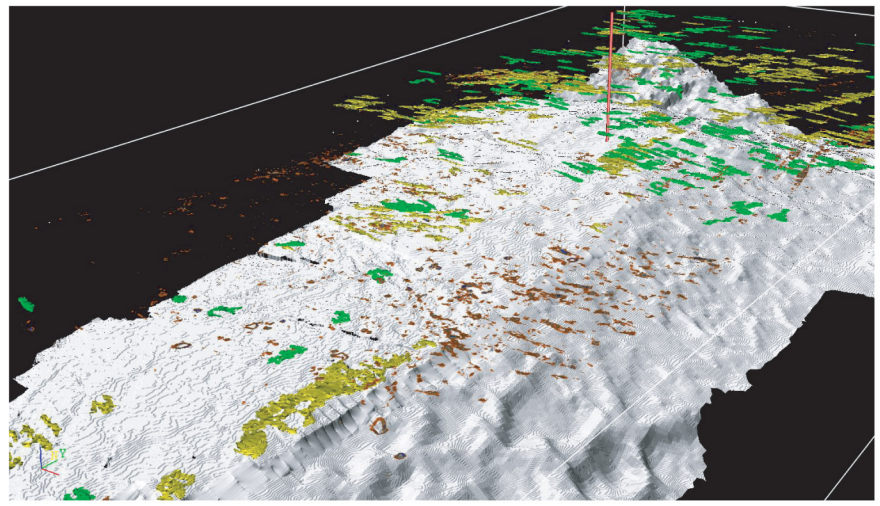
Additionally the seabed surface was examined for leaks structures associated, but their impact is minimal.



(Left) *Structure Cube* overlapping south portion of the seabed. (Right) Time structural bottom sea surface. Note clearly adquisition footprint; lineaments associated to the iceberg ploughmarks not to faults; and minimal presence of knolls or collapses.



On the other hand, the Late Triassic section records many pockmarks. This concentration could indicate a gas migration pulse that occurred in the past. In these figures it is possible to observe: (Left) ring shapes assumed to be created by carbonate precipitation; (Center) *Structure Cube* time slice, showing the pockmark distribution; (Right) A transparency display allows to see just below the possible reservoirs.



Integrating the results, the shallow high amplitude anomalies (yellow & green bodies) are located in the north zone, in the neighborhood of the well. However, the greatest density of pockmarks (orange) is located in the central area.

This valuable information must be present to help in the seal analysis, when it is necessary to propose different scenarios.

Conclusions

Seismic interpretation concludes that organic buildups are not isolated elements, but rather interconnected structures forming a polygonal network with internal depressions.

Based on their internal geometry the buildups record different stages of growth, involving shifts and local progradations. This complicates the prospect definition, since a complete stratigraphic closure is required.

The combination of several volume interpretation techniques allowed, in a very fast and efficient manner, to approach and solve the proposed problems.

Polygonal network that comprises the organic buildups can be divided in multiple-sized compartments. This favors the existence of both stratigraphic and structural traps, which facilitates the prospect definition.

The volume of discontinuity attribute indicates a clear correlation of high amplitude anomalies with the fault planes. It supports the presence of leakage in the area and could explain the well result.

The location of paleo-pockmarks in the Late Triassic section is very intriguing, and it may provide clues into basin modeling.

Acknowledgments

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