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Seismic guided Well Placement in Karstified Carbonate Reservoir: A case study

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Summary

Well Planning and placement in carbonate reservoirs is always challenging due to the inherent nature of carbonates. Carbonate reservoirs can be extremely heterogeneous in pore space and permeability. Karstification in carbonate cause additional heterogeneity. Hydrocarbon production from such heterogeneous formation is often influenced by the presence of faults & fractures. Knowledge of the distribution of the karst bodies, faults and fractures in carbonates is helpful for well planning and placement in a mature field. In many fields, existing seismic data is found to be inadequate to map karst bodies requiring acquisition of new high resolution seismic data and new processing workflows and interpretation techniques.

The case described here is from one of the offshore field of India viz. Neelam, which is highly karstified and well placement was challenging. Instead of acquiring new seismic data, a less expensive method like interpretative image processing technique for data conditioning and extraction of advanced seismic attributes was tried to understand the geometry of karst and fault network in 3D, which helped in successful planning and placement of development wells.

Introduction

Carbonate reservoirs differ a lot from sandstone reservoirs. Unlike sandstone reservoirs they can show extreme variations in pore space and permeability due to digenesis, the post depositional chemical and physical changes that transform the sediments into solid rocks. Carbonate rocks are also susceptible to dissolution, leading to development of sinkholes, caves and intricate drainage patterns like disappearing streams etc. This process is known as karstification of carbonates, and it causes additional heterogeneity. The extreme nature of carbonate makes well planning and placement very challenging.

Given the heterogeneity of the carbonate rocks, it is not surprising that hydrocarbon production from these formations often is influenced by the presence of faults, fractures and karst. Karst can be either a problem or an opportunity in development of the reservoir. During drilling it can result catastrophic bit drops, mud losses, but at the same time it can also result in extremely high porosity and permeability.

Since, the karst bodies have different porosity from the adjacent matrix; their acoustic behavior will be slightly different from the adjacent matrix. Due to this their seismic response will be different from that of the matrix and it will be emphasized in some of the attribute volumes. However, karst may not be identifiable during conventional seismic interpretation due to small difference in seismic signature and also due to presence of noise in the data.

In many cases it is not possible to extract 3D geometry of the karst bodies, fault and fractures from existing seismic due to presence of various noises and other factors. This makes it necessary to acquire high resolution seismic data and subsequently process and interpret them under an integrated scheme [1-2]. However, with advancement of interactive interpretative processing for image enhancement and faster computer availability it makes sense to attempt extraction and interpretation of such subtle feature from seismic data.

Methodology

Advanced techniques of data conditioning for noise reduction and extraction of suitable edge preservation attributes help in identifying the geometry of the karst bodies. The internal characteristic of the karst bodies may be obtained by frequency decomposition and RGB

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blending, which is supposed to highlight frequency variations inside and outside the karst bodies. Combining the information of the karst geometry and its internal characteristics, 3D geometries of the karst bodies can be delineated in the form of geobodies. The size, extent and connectivity of the features can be analyzed and information on the surrounding rock can be ascertained from the extent of the dissolution. The methodology described above is used to understand the 3D geometry of the karst bodies and the fault network in one of the offshore field of India, so that well planning and placement can be done optimally.

Case History

The Neelam field is producing oil from limestone reservoir of mid Eocene, known as Bassein Fm. The top part of the reservoir is marked by an unconformity and it was subjected to severe digenetic effects due to sub aerial exposure. The formation has Karst topographic features like vugs, solution channels etc, that have been identified from various core and well log studies. Additionally, the limestone is also fractured, especially in the northern part, which has caused both drilling and production difficulties. The degree of Karstification and effect of fractures, are of varying degree in different parts of the field. This has been experienced from the well data of many wells, which have encountered moderate to heavy mud loss while drilling. Although the effect of karsts on the flow behavior etc has been studied from the well data [(3)], no attempt was made to find out distribution of karst in 3D. The present work aims to fill up this gap by extracting 3D distribution of karst bodies from existing seismic data by using the methodology described above.

The primary input was 3D Seismic data of 1999 vintage in depth domain (380 sq km Approx). The interpreted horizon was used to limit the processing volume. Data processing workflow is given in Fig 1.The major steps in the workflow consist of Data conditioning (Fig 2), Structural Imaging, Karst investigation (Fig 3) and Fault Imaging (Fig 4).Karst investigation includes Frequency decomposition, RGB Blending, karst attribute generation and extraction of geobodies. SVI Pro, a seismic image processing and volume interpretation software was used in association with M/S Foster Findlay and Associates of UK during the study.

One of the output volumes of this study provide karst and fault geometry in 3D (Fig 4), which we have labeled karst volume. The visualization of this karst volume together with well trajectories and slices through this volume was used to understand three dimensional dispositions of the karst bodies along with well path (Fig 5).

Mud loss in the karst and fault zone being the main problem in Neelam field, the mud loss at the reported depth was calibrated with the karst and fault signatures at 12 well locations. Good match was observed between them. Trajectory of one of the earlier drilled well (well 1) through this karst volume, shown in (Fig: 6) indicates the penetration of karst body at reported mud loss depth. New well trajectories were designed successfully to avoid karst and fault zone (Fig. 7& Fig 8). Karst volume was also calibrated with log data, which also indicated the karstified zone in the reported mod loss area (Fig 9).The distribution of karst bodies will also be used to make revised reservoir model.

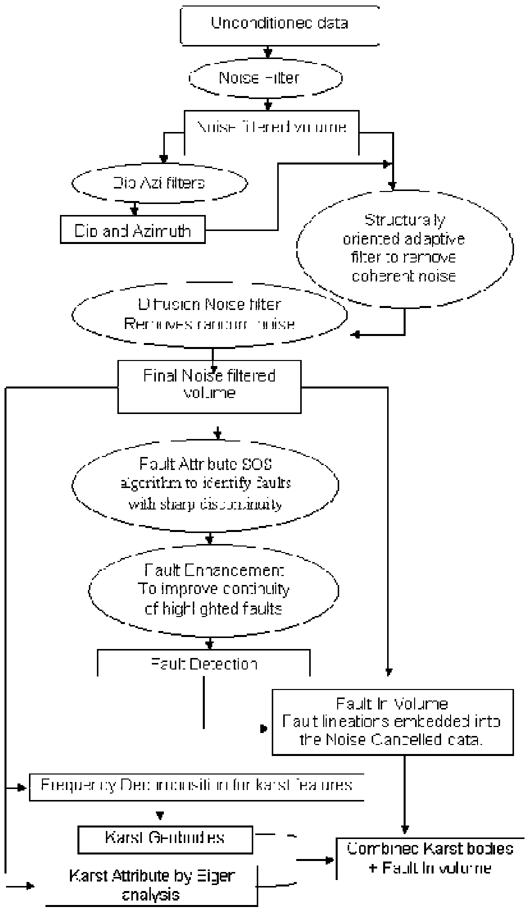

Fig. 1: Data Processing workflow

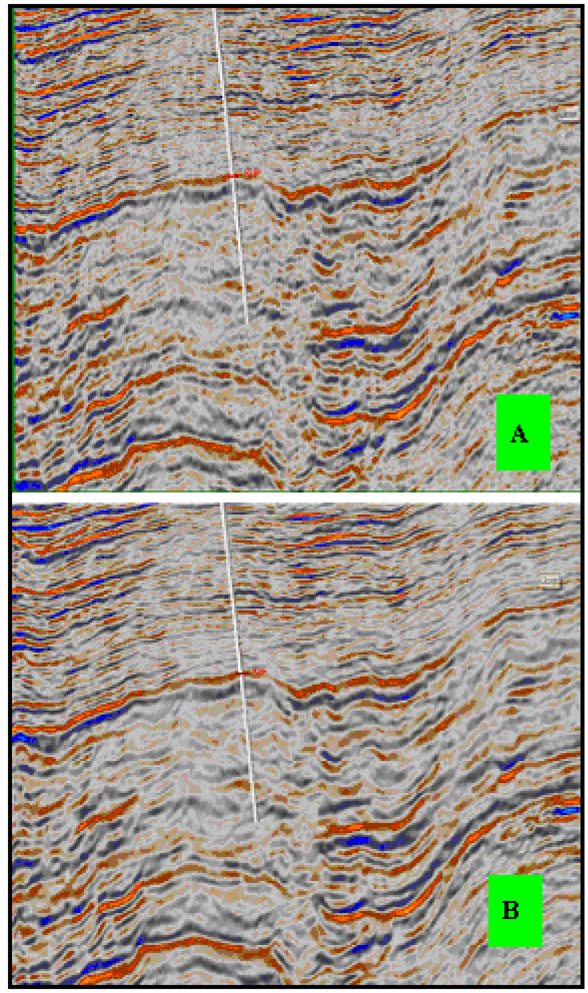

Fig. 2: Data conditioning showing improvement of seismic reflector continuity and faults before (A) and after noise cancellation (B)

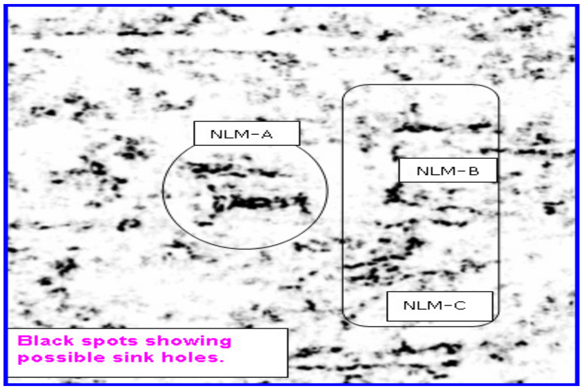

Fig.3: Eigen processed data showing Karst attribute at Bassien zone

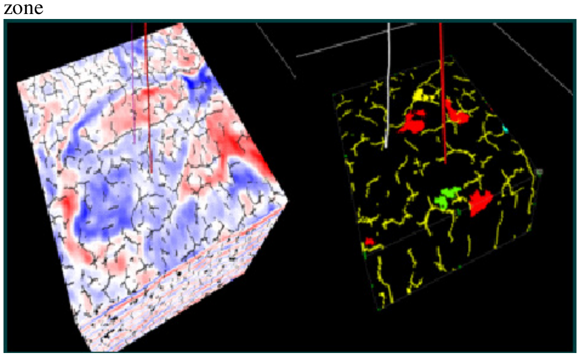

Fig.4: Fault embedded in data and karst volume

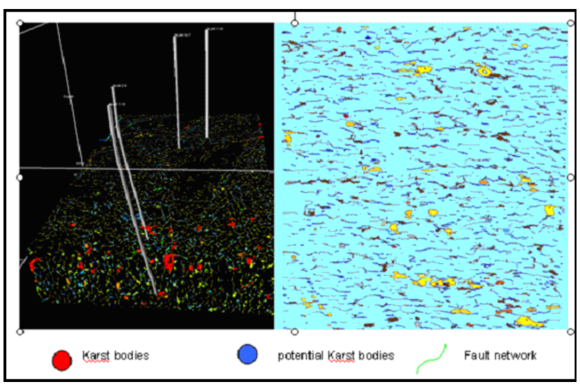

Fig.5: Well trajectories through karst volume and slices

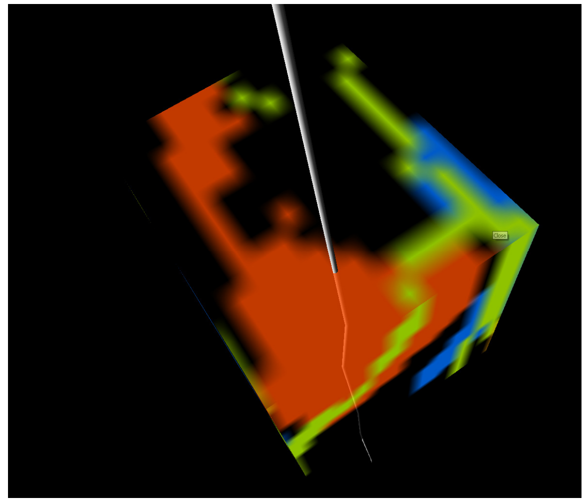

Fig.6 3D Picture through one of the drilled well 1.The well penetrates through karst body at 1792 m. The reported mud loss depth

Well trajectory of NLM-Well 2 shown on depth slice at 1453 m, which was designed successfully to avoid karst and fault zone. No mud loss was reported in the well while drilling. Well is currently producing more than > 450 BOPD.

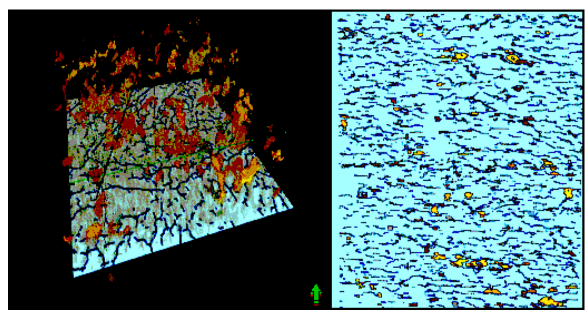

Fig.7 A: Well trajectory of NLM-Well 2 on karst volume B: Depth slice at 1453 m

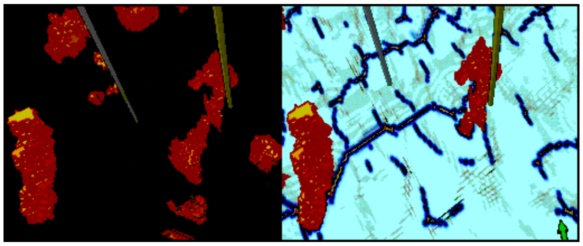

Fig.8 A: Well trajectory of NLM-Well 3 on karst volume B: Depth slice at -1393 m

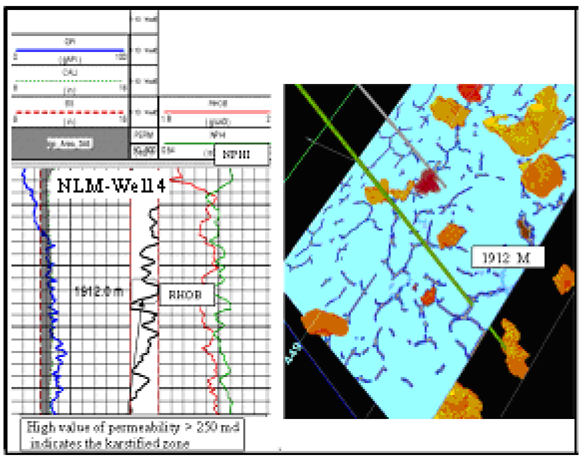

Fig.9: NLM-Well 4 Calibration with log data

NLM-Well-4 reported heavy mud loss in at 1912 m MD depth. The well penetrates a fault at 1912 m as shown in the karst volume. The permeability computed using effective porosity & irreducible water saturation derived from processing shows > 250 md, which indicates presence of karstified zone.

Conclusions

This study shows that with appropriate data conditioning and interpretative processing tool, extraction of advanced seismic attribute volumes like karst volume is possible even from old data, which can improve seismic data quality, increase the rate of success and helps to address operational problem in well placement for enhancement of oil production in mature field.

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