

Determining Migration Pathway in Marco Polo Field Using Chimney Technology

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D. WALRAVEN¹, D L. CONNOLLY², F. AMINZADEH¹

Address
¹Anadarko, 1201 Lake Robins Dr, The Woodlands, TX 77380USA
²dGB-USA

Abstract

Chimney volumes derived from 3-D seismic data are used to determine fluid migration pathways in the vicinity of the Marco Polo field in the deepwater Gulf of Mexico. The results obtained have three main objectives: a) to characterize the chimney signature associated with the main field pay zones; b) to understand the deep hydrocarbon migration pathways in relation to the mobile salt canopy; c) to predict seeping and non-seeping surface faults to improve positioning of shallow piston cores.. Results of the chimney processing showed clear chimneys adjacent to and immediately below the main pay reservoir intervals. These chimneys did not extend significantly above the reservoir interval. This indicates clear vertical hydrocarbon migration into the reservoir interval and an effective seal. These results can be used to assess charge and seal risk on similar plays pre-drill. Chimney pathways were identified from the sub-salt interval through the salt canopy and into the Marco Polo reservoirs. These results indicate that favorable positions for supra-salt plays can be predicted pre-drill. There was a good correlation between shallow chimneys and piston cores with geothermal oil signatures. Seeping and non-seeping faults can be distinguished to optimize piston core positioning..

The results of the Marco Polo chimney study have been integrated with previous studies in the deepwater GOM to develop criteria to quantify the seal and charge risk. Such criteria can then be applied to predict seal integrity on un-drilled prospects. The emphasis is on how chimney processing and interpretation can be used in an integrated workflow to constrain uncertainty on both seal and charge for hydrocarbon exploration and to rank prospects.

Introduction

Usually, the main focus of interpreters of seismic data is to delineate structure and predict reservoir and its quality. Although determining fluid migration pathway and predicting presence of a good charging mechanism and an effective seal are most critical components of exploration, seismic data are not used for these purposes routinely. As it has been demonstrated in Heggland et al (1999), Aminzadeh et al (2002), Alvarado et al, (2003) Ligtenberg (2003) Walraven et al (2004), and Heggland (2004), gas chimneys could be an effective tool to address these issues. Through integration of gas chimney probability data, basin modeling information and pressure data, we can often determine fluid migration pathways, seal integrity, source rock expulsion and ultimately assess the charge and seal risk.

Purpose of Study

The primary objective of the chimney processing in the Marco Polo area was to contribute to a catalog of the chimney signatures for a number of discoveries and breached traps in the GOM slope. These studies will provide analogs for exploration, and criteria for assessing charge and seal risk regionally. Other discoveries which have been investigated for their chimney character include the Tanzanite discovery, in Eugene Island South Addition Block 346, the Sazerac sub-salt breached trap in Green Canyon 99 & 143, the Raptor discovery in Ship Shoal Block 296, and the Auger Field in Garden Banks 426 (Walraven, 2004). The second objective of the study was to understand the hydrocarbon migration pathways through the salt canopy to determine if certain traps receive preferential charging. The third objective was to relate these chimneys to shallow piston cores to determine if chimney processing could be used to distinguish seeping versus non-seeping faults.

Marco Polo Field

Marco Polo is a producing field in the deepwater slope of the Gulf of Mexico. The location map is shown in Figure 1. The trap is a down-thrown fault closure on the flank of a northwest – southeast trending salt ridge. The key strike line is shown A-A'.

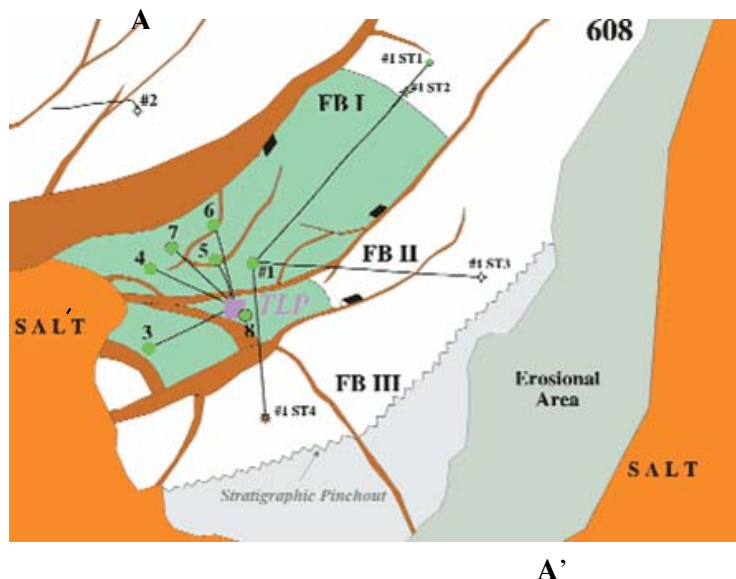


Figure 1- Marco Polo Field

Chimney Processing

Chimney processing was undertaken to highlight vertical fluid migration pathways in the seismic data and relate them to seal integrity. For details of chimney processing procedure see Heggland et al (1999) and Aminzadeh et al (2002). Among attributes used for training, Similarity (lateral along bedding planes and Cube Similarity (lateral and vertical) were most critical for neural network

training. A key step in this procedure is that most of the attributes were extracted in three separate time windows: one above, one centered around and one below the point of investigation. In this way we utilize the fact that chimneys are vertical bodies with a certain dimension. The reliability depends on a number of factors, including: the availability of good training data, the accuracy with which the interpreters can detect suspected gas chimneys as input to the training data set, and the quality of seismic data. The type of attributes and neural network used are also critical. In a similar way a faultcube was created over the project area. Known or suspected faults were picked in the data. A set of attributes were calculated at the pick locations, and the results were run through a neural network. The resultant output is a fault probability volume.

Observations

Chimney signatures at Marco Polo reservoir interval: A strike line through the Marco Polo field (Figure 2) shows high probability chimneys (shown in gray scales) and high probability faults (shown in blue shades) overlain on the normal seismic. The line shows a number of high probability vertical chimneys immediately adjacent to and below the main reservoir interval of the field (strong amplitudes shown with arrow). These chimneys seem to be associated with the main Northeast to Southwest trapping fault. Figure 3 (left) is a time slice through the main reservoir interval and , showing high probability chimneys (blue to red) overlain on high probability faults (gray shades). Most chimneys are associated with salt ridge which runs Northwest to Southeast along the western side of the survey. However there are significant chimneys related to the Northeast trending trapping fault of the Marco Polo Field (arrow). Figure 3 (right) is a similar display of a time-slice well above the main reservoir interval. In this interval chimneys are limited to the crestal areas of the large salt ridge. The Northeast trending fault system and its associated chimneys are absent. The Northwest trending faults on the eastern side of the study area do not have associated chimneys.

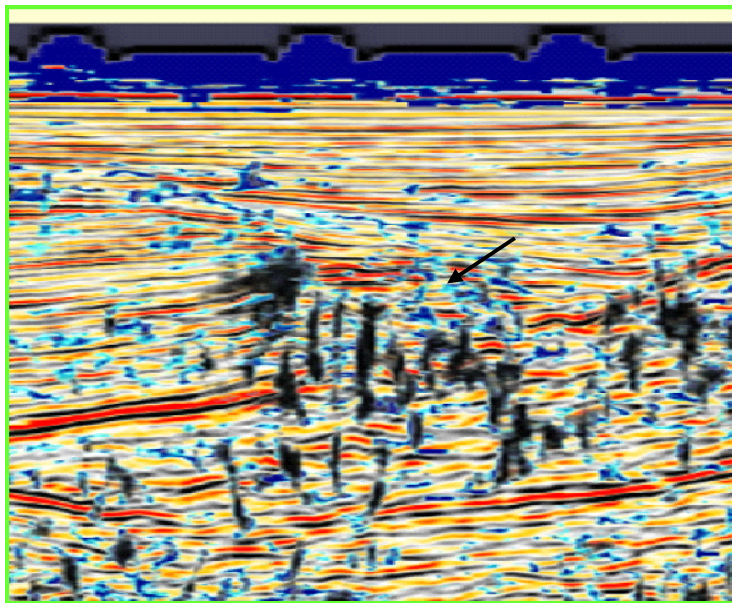


Figure 2, Strike line through Marco Polo field. Seismic data is overlain by fault probability data (blue shades) which in turn is overlain by chimney probability data (gray shades). Main reservoir interval for field is denoted by arrow.

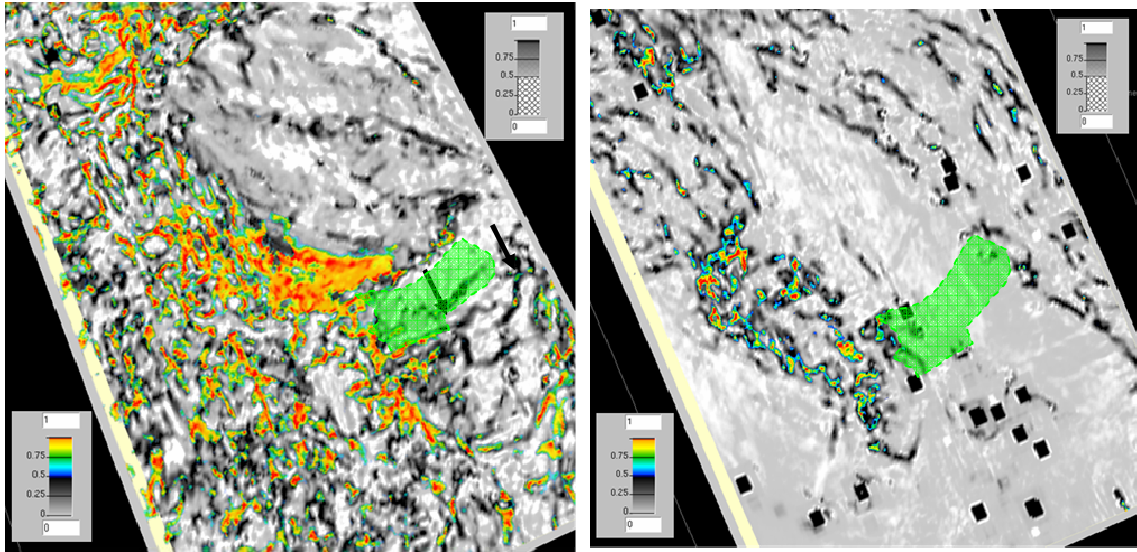


Figure 3, Time-slice of fault probability volume overlain by chimney probability volume through main reservoir interval (left) – above main reservoir (right)

Indications of chimneys through salt canopy: A display of high probability chimneys 1000 ft below the mapped top of salt horizon (Figure 4) demonstrates possible zones of weakness in the salt canopy through which hydrocarbon migration can occur (and must occur to charge supra-salt oil fields such as Marco Polo). Significantly the high probability chimneys (shown in gray) are related to major flexures in the salt. But most significantly, a major ENE trending chimney system is immediately below the Marco Polo Field. The circular character of these chimneys supports that they are related to fluid flow.

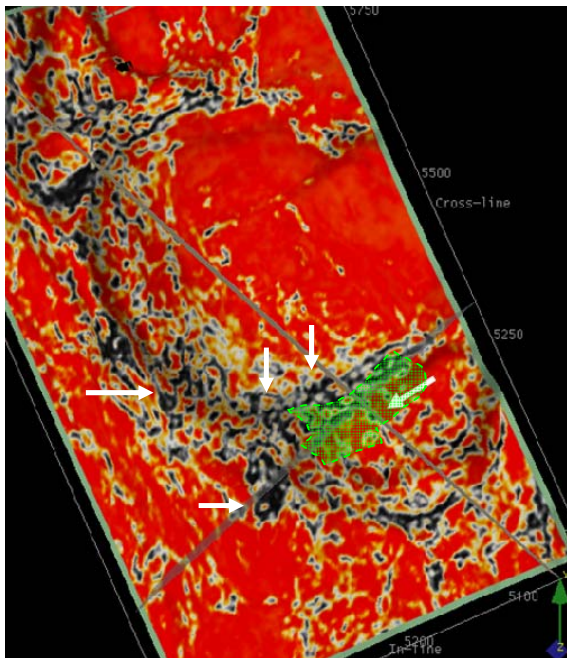


Figure 4, Horizon slice of chimney probability volume, 1000 ft below top of salt horizon. High probability chimneys in black.

Relationship of shallow chimneys to piston core results: Figure 6 shows a shallow fault probability time-slice with chimneys overlain to an interval near the sea floor. The location of the piston cores taken at the sea bottom is overlain on this time-slice. Piston cores with positive indications of oil seepage are shown in green triangles, while negative indications are shown in red. There is a relatively good correlation between the positive oil indications and the strong probabilities for chimneys. Significantly the chimney probability data seems to be able to distinguish faults with circular features (such as at core 12) from true seeps (such as at cores 6 & 7).

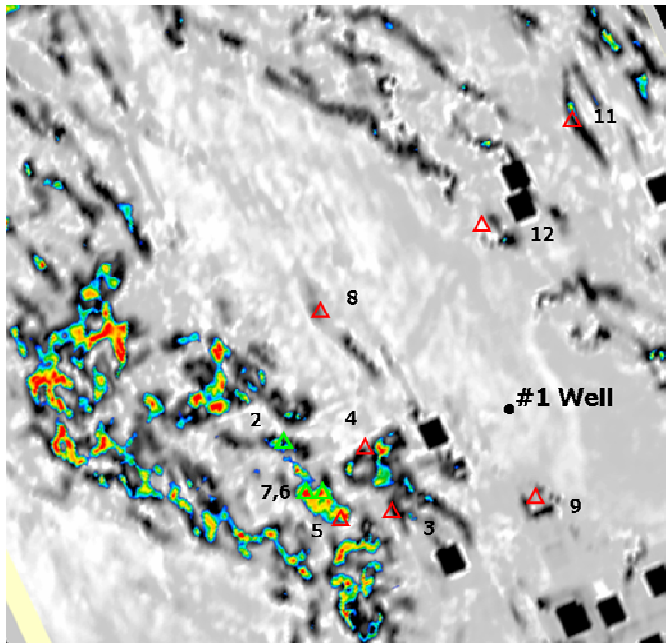


Figure 6, Time-slice of shallow fault & chimney volume with piston core data overlain. Positive indications of oil seepage shown in green triangles, negative indications in red.

Conclusions

Chimney signature at Marco Polo Field: Chimney processing shows clear vertical hydrocarbon charge into the reservoir interval of the field, primarily related to shear along the ENE trending fault on the north flank of the field. Fluid flow along this fault is suggested by the large circular pockmarks which are often located at the juncture of two fault trends. Hydrocarbon flow into the reservoirs was facilitated by a pressure differential between the high pressure chimneys and the lower pressured reservoir sands. Studies of modern fault systems, which are leaking oil, show a similar pattern (Ligtenberg, 2003). The chimneys related to this fault terminate immediately above the reservoir interval, due to the termination of the fault by an overlying unconformity. This termination provided the vertical seal for the field. All the fields which we have investigated, to date in the GOM shelf and slope, show similar sealing character. All breached accumulations (as yet a small number) have shown shallow chimneys which may leak hydrocarbons to the surface. Additional studies of both breached traps and producing fields are necessary to substantiate these findings.

Detecting hydrocarbon migration pathways through the salt canopy: Chimney processing is useful in delineating hydrocarbon migration pathways through the salt canopy. The study in the Marco Polo area suggests that these pathways are related to major flexures in the salt. Movement of hydrocarbons appears to be in possible rubble zones related to salt suturing or in areas where the salt is thin to absent. In the Marco Polo area ENE trending fracture zones may be important migration pathways, but conduits along the flank of the major salt bodies are also important.

Distinguishing seeping and non-seeping faults: Based on piston core data, chimney processing can distinguish faults which are seeping oil. This is useful to optimize piston core surveys. Both surface and subsurface data confirm, the chimneys highlighted through this seismic processing approach are related to vertical hydrocarbon migration.

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