

## Interpretation of gas chimney in the Maari 3D field of Southern Taranaki Basin, New Zealand.

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### Summary

The interpretation of Maari 3D seismic data of Southern Taranaki Basin, using chimney analysis tool, brings out the vertical gas migration pathways from the source through the reservoir traps all the way to the surface. This correlates well with the available drilling results. The chimney effects also exhibit good correlations with seismic attributes when displayed over the horizon slices mapped over the formation tops. This study provides important inputs in understanding the petroleum system of the study region and acts as a preventive measure for mitigating geo-hazards in future drilling.

### Introduction

The state-of-the-art image processing and visualization techniques have modernized the art of seismic interpretation. This has allowed interpreters to analyze more data with a greater accuracy in less time. Seismic attributes have played a pivotal role in interpreting seismic data. However, their optimal selection to highlight a particular object plays a momentous role, as they may or may not be sensitive to illuminate a particular geological feature (Meldahl et al., 2001). Thus, the advent of seismic-object detection technique (Meldahl et al., 1999; Tingdahl et al., 2001) based on the principle of directionality has been able to successfully address such scenarios. The key aspect of this principle is that attributes are preferably extracted along the events we seek to detect. This principle becomes an appropriate choice and works very well for detecting objects with known dip and azimuth (Tingdahl et al., 2001). Thus, seismic object detection technique for interpretation helps in enhancing the detectability and mapping efficiency of certain geologic objects like faults, reflectors, seismic chimneys, time-lapse differences, stratigraphic features and direct hydrocarbon indicators from seismic data.

Seismic chimneys or gas chimneys are important geologic objects or features to be mapped from the seismic data. Their identification acts as an indicator for the presence of vertical fluid migration containing hydrocarbons. Their mapping also helps in inferring the movement of hydrocarbons between different geological sequences. Several authors have documented different techniques for their detection from the seismic data. Dunbar (1998) used a phased velocity modelling approach for imaging gas clouds. Engelhardt (2001) made use of four component seismic data of south central part of offshore Gulf of Mexico for the interpretation of gas clouds. O' Brien,

(1999) used a detailed velocity model to simulate the seismic effect of gas chimney of the Valhall field.

Apart from the use of these techniques, our study is based on the use of a set of directive multi-trace attributes and a supervised neural network approach for interpreting gas chimneys from seismic data of SW part of offshore Taranaki Basin, New Zealand. This technique has proved to be an effective robust exploration tool for identifying gas chimneys or gas clouds from the seismic data (Meldahl et al., 2001; Ligtenberg, 2003; Heggland, 2004). Mapping of gas chimneys from the entire seismic volume would help us to understand the hydrocarbon migration history from the source rock to the shallower prospects. Beside this, mapping of these geologic objects has a momentous impact on evaluation of pre-drilling shallow gas hazard.

### Seismic chimney cube

A chimney cube is 3D volume of seismic data, which highlights vertical chaotic behavior of seismic characters (Aminzadeh et al., 2002). They generally appear as low-amplitude chaotic events, low trace-to-trace similarity and vertically degraded zones in the seismic image. The major disadvantage of their presence is that these zones completely mask the reflection energy from the sedimentary sequences (Heggland, 1997).

### Geology and Data

The study area (Fig 1) lies in the western part of the Southern Taranaki Basin (STB), offshore New Zealand. The Taranaki Basin demonstrates a very complicated morphology due to several tectonic events and is composed of superimposed subbasins, normal, reverse and over thrust faulting and areas of upliftment. The main structural development of the basin took place during the Late Cretaceous period.

The STB surrounds within the offshore west of New Zealand's North Island and north of the South Island. The basin is a store house of 8 km thick sedimentary strata belonging to the Late Cretaceous to younger sedimentary sequences (Reilly et al., 2015). Stratigraphically, the basin comprises Late Cretaceous syn-rift sequence (the Pakawau Group), Paleocene-Eocene late-rift and post-rift transgressive sequence (Kapuni and Moa groups), Oligocene-Miocene foredeep and distal sediment, starved shelf and slope sequence (Ngatoro Group), Miocene regressive sequence (Wai-iti Group) and the Plio-Pleistocene regressive sequence (Rotokare Group) (King

## Interpretation of gas chimney in the Maari 3D field of Southern Taranaki Basin, New Zealand

and Thrasher, 1996). The most important source rock intervals of the basin includes Cretaceous synrift terrestrial coaly facies, Paleocene organic-rich marine mudstones and Eocene terrestrial /estuarine coaly sequence.

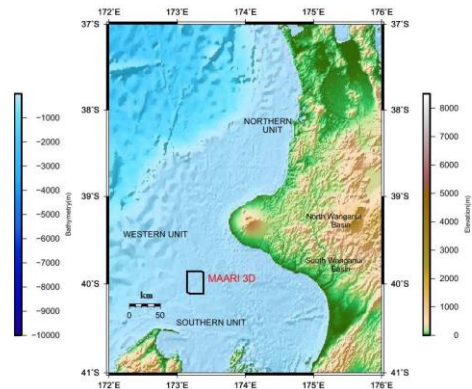


Figure 1: The geological map of the study area showing Maari 3D seismic block marked by a black square.

The data used for this study is a Pre-Stack Time Migrated data volume belonging to the Maari 3D prospect covering an area of 122 sq km and was acquired in 1999. The data length is 3 seconds recorded with sampling interval of 4 ms. The seismic data is 72-fold and the volume comprises 405 inlines and 970 crosslines. The seismic data polarity is SEG normal (increase in acoustic impedance boundary is reflected as peak or positive amplitude). The well data of Moki-1 (total drilled depth 2620 m) is used to validate the chimney results from seismic data.

### Computational Workflow

Seismic objects are generally characterized by a certain seismic response that differs from the surrounding response. These differences in response can be captured by several seismic attributes. Each of the attributes contains information of the object that we wish to detect (Meldahl et al., 2001). Thus, the knowledge of shape and orientation of objects adds up to the process for enhancing the detection strength of the geologic objects. We present a step by step computational workflow that honors this philosophy as follows:

- 1) Targeting for a particular geologic object.
- 2) Selecting a set of potential seismic attributes that could help in enhancing the targeted geologic object.
- 3) Selecting locations or “picks” within the seismic volume that honors the presence or absence of the object.

4) Applying a supervised neural network to train over the selected set of seismic attributes extracted at the object and non-object positions.

5) Training the network over the entire seismic cube to generate a new cube with high values at positions that defines the high probability of the presence of the object.

6) Improving the output by iterating steps 1-5.

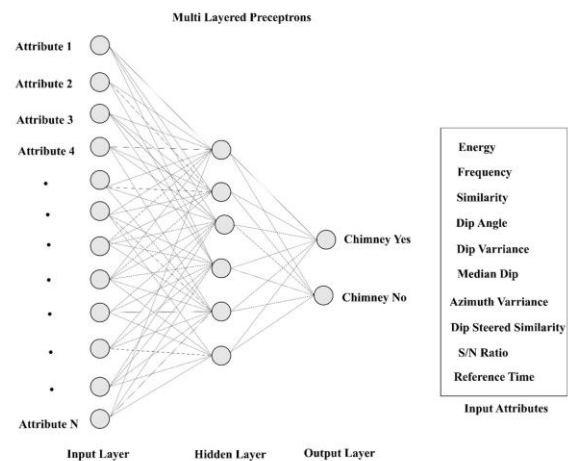


Figure 2: Neural Network topology. The input attributes used for networking are shown in the right hand side box.

The final product of this workflow is a cube in which the chimneys are visible by high sample values (high probability) and the surrounding volume by low sample values (low probability). Thus, the network helps in enhancing the presence of vertical disturbances in the seismic data. Before carrying out the workflow, a steering cube (dip-azimuth volume) is generated from the existing seismic data volume. This steering cube contains the information regarding the local dips of the seismic reflectors and associated discontinuities. This steering cube is then taken as an input for the computation of several dip steered attributes that are used as an input for chimney computation. Different directional attributes like similarity, dip angle, dip steered attributes such as dip steered similarity, dip variance, azimuth variance and other attributes like energy, frequency, reference time, S/N ratio are computed using different step outs and time window. Then a supervised Multi-Layer Perception (MLP) neural network (Fig 2) is used to train these multi trace attributes for distinguishing the chimney and non-chimney zones (initially selected picks) in the seismic data. The use of a pre-computed steering cube gives rise to a successful progress of the workflow as it helps in enhancing the

## Interpretation of gas chimney in the Maari 3D field of Southern Taranaki Basin, New Zealand

discrimination power by using the local dip and azimuth information.

Apart from the chimney processing workflow, other workflows like geologic formation picking is performed. With the help of available geological markers of the well Moki-1, formation tops (Eocene Top, Miocene Top and Seabed) were picked at every 5<sup>th</sup> inline and crossline. Taking into account the fact that horizon picked on the seismic data would get contaminated by the miss-picks which could result in misleading interpretation, the horizon was filtered using median filtering technique using [5x5] step out. All these processes made us to move further for analyzing and interpreting chimneys from the 3D seismic volume of the Maari field.

### Chimney Interpretation

The chimney processing results clearly depicts the origin of the deeper chimney from the Eocene intervals, charging the Miocene intervals and exhibiting an upward migration towards the seabed. It is observed that most of the chimneys tend to have a deeper origin, thereby indicating higher probability of their origin from the base of the Eocene intervals that is the Kapuni group. This fact is better confirmed from the confidence map (Fig 3) of the neural network. The confidence map indicates that, there is high confidence of chimney at the base of the Eocene interval (Kapuni group), while lower confidence of chimney is observed at shallower intervals. These observations were validated with few key criteria (Connolly and Garcia, 2012). The results indicated a good correlation between the observed chimneys and hydrocarbon shows obtained in the Moki-1 well of the region, where gas shows were observed at the Eocene intervals (Kapuni Group), Oligocene intervals and the Miocene intervals. Composite display maps (Fig 4) of time slices from deeper to shallower reservoir indicates the chimney distribution patterns. They also depict a high correlation with the similarity attribute. The gas chimney is observed to propagate through the faults (indicated by blue arrows in Fig. 4) from the reservoir traps all the way to the surface. Pockmark morphology (circular appearance) is observed over the time slice (152ms) at the Seabed. The presence of these features are indicative of gas leakage and may represent shallow gas reservoirs.

Patches of gas clouds are observed at the horizon slices of Eocene top (Fig 5) and Miocene Top (Fig 6) when

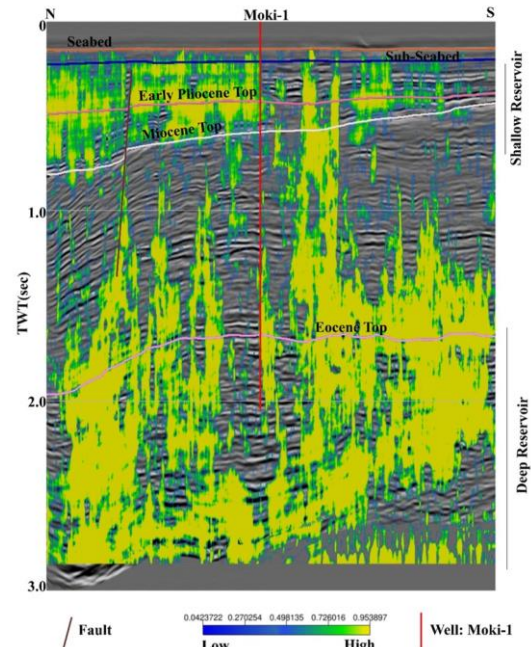


Figure 3: Higher confidence is observed at the deeper part than the shallower part of the reservoir. The shallower reservoirs are cut by fault indicating migration through these structural features.

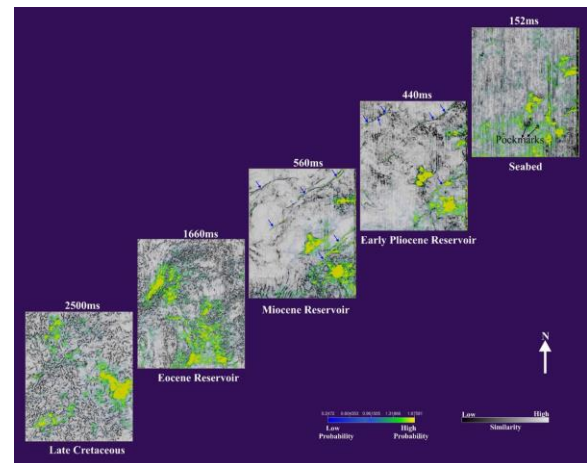


Figure 4: Composite display of chimney and similarity attributes over the time slices of deeper to shallower reservoirs all the way to the seabed. Migration of gas clouds are more prominent at Miocene and Early Pliocene reservoirs.

## Interpretation of gas chimney in the Maari 3D field of Southern Taranaki Basin, New Zealand

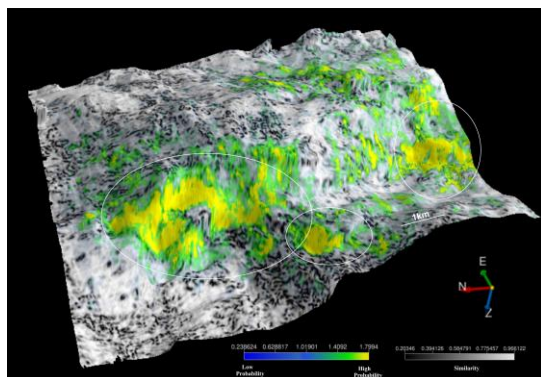


Figure 5: Horizon slice obtained at Eocene Top. The presence of chimney is indicated within white circles. High probability chimneys indicated by yellow color correlates with the low similarity zones.

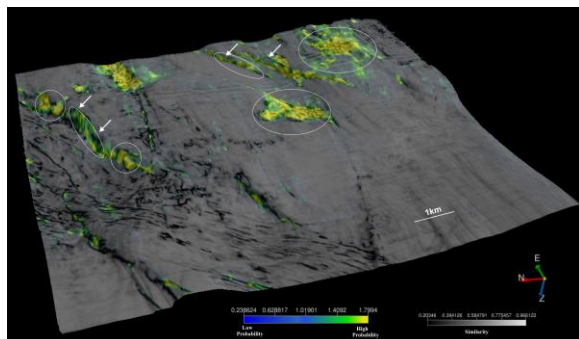


Figure 6: Horizon slice obtained at Miocene Top. The presence of faults is indicated by white arrows. The presence of chimney is indicated within white circles. High probability chimneys indicated by yellow color correlates with the low similarity zones observed near the fault.

corendered with the similarity attribute. These chimneys are inferred to originate from the source rock intervals of the Pakawau Group, which is the primary hydrocarbon source rock of the area and is thermally matured. Faults are also observed to cut the Eocene, Miocene and Early Pliocene intervals (Fig 4, Fig 5 and Fig 6), which suggest the fact for the upward migration of hydrocarbon through these zones. High chimney probability is observed along the fault identified at these intervals which correlates well with the similarity attribute exhibiting low similar values at fault zones.

### Conclusions

The analysis provides important observations with regard

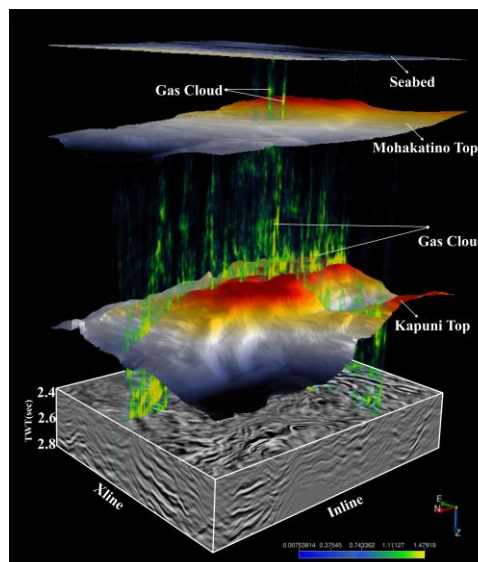


Figure 7: 3D visualization of chimney effect over the Maari prospect. Gas clouds appear to move upward from the base through the Kapuni group and charging into shallow reservoirs.

to understanding the petroleum system of the Maari field of STB off New Zealand. Vertical migration pathways are observed (Fig 7), which are indicative of gas migration from the Pakawau group source rock intervals. These pathways are associated with low amplitude and chaotic seismic characters. Shallower reservoirs are charged with the gas originating from deep reservoirs. This study reveals the fact regarding the hydrocarbon seepages through subsurface structures. This case study brings out the importance of chimney interpretation which acts as a valuable tool in understanding the reservoir architecture of the region thereby revealing the facts related to migration paths, detecting reservoir leakage, spill points, identifying potential over pressure zones and contributing to mitigate drilling risks.

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## EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2016 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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