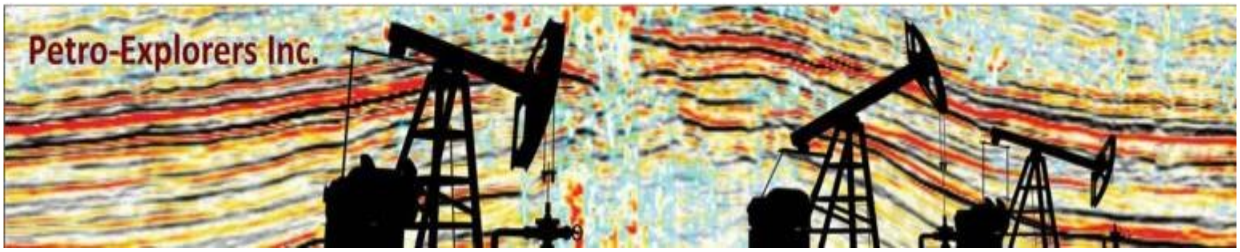


Fluid Migration and Fault Seal Analyses

Fluid Migration and Fault Seal Analyses to detect hydrocarbon migration pathway and its trapping mechanisms

Detection of Vertical Hydrocarbon Migration Pathways

Vertical hydrocarbon migration is recognized in normally processed seismic data as vertically aligned zones of chaotic low -amplitude seismic response called gas chimneys, blowout pipes, gas clouds, mud volcanoes, or hydrocarbon related diagenetic zones based on their morphology, rock properties and flow mechanism. Because of their diffuse character, they often difficult to visualize in three dimensions. Thus, a method has been developed to detect these features using a supervised neural network. (*David Connolly "Visualization of vertical hydrocarbon migration in seismic data: case studies from the Dutch North Sea" In: Interpretation, August 2015*).

Neural Network technology as it is implemented in OpendTect Neural Network plug-in for seismic object detection can illuminate gas chimneys in the seismic data. Statoil and dGB Earth Sciences co-developed this methodology for detecting vertical hydrocarbon migration pathways. It has successfully allowed identification of hydrocarbon migration pathways both at a basin scale (to calibrate source to reservoir migration) and reservoir scale (to perform seismic charge/seal analysis).

The basic workflow of fluid migration identification includes:

Manual Interpretation

In the pre-training phase, two classes are identified: one class of points that are part of a gas chimney, and one class of points that are not part of a gas chimney. On a number of key lines an interpreter selects points that are typical for the chimney and for non-chimney classes, respectively. Once sufficient points are selected (typical 100+), the two classes are stored for later use in Neural Network training

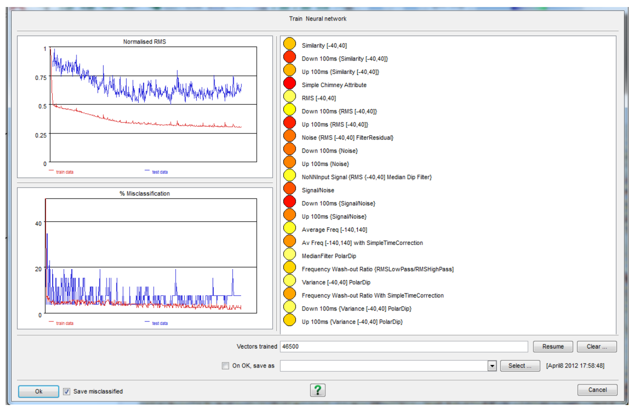
Attribute Analysis

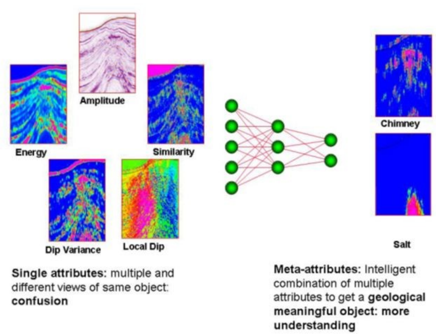
This step begins with the computation of a set of default attributes for chimney analysis. These attributes respond to typical characteristics of chimneys such as low S/N ratio, frequency and amplitude wash-out, verticality and chaotic seismic dips and others. If necessary, these attributes are optimized—or additional attributes are designed—in order to obtain the best response from the seismic dataset under consideration.

Neural Network Training

For the detection of chimneys, the multiple attributes, which were defined in the previous step, are used as input for Neural Network. Using multiple attributes has the advantage of separating chimney and non-chimney locations, based on multiple characteristics of chimney, and extracting seismic objects with true geological meaning. To discriminate between chimney and non-chimney locations, the neural network is trained to correctly recognize the points picked by an interpreter in step 1.

Neural Networks training process with graphical display of progress. Interpreter can stop and start the training process QC and Volume Output.





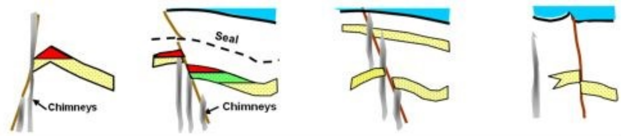
Principle of "meta-attribute": multiple seismic attributes are combined through a neural network to produce geological meaningful objects, such as "gas chimney."

Interpretation of Fluid Migration Data

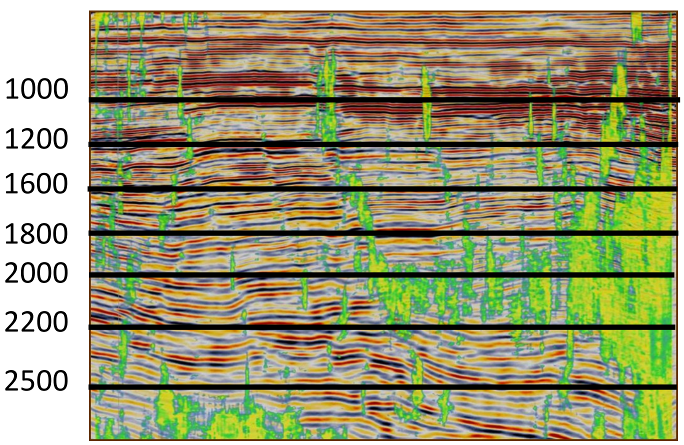
Distinguishing different chimney morphologies on seismic data validates seismic artifacts vs. true hydrocarbon migration in assessing pre-drill prospect risk. If well data are available, we match the chimneys to the production data to check correlations between the (absence of) chimneys and the (absence of) producing wells in order to develop suitable analogs for risking prospects and leads. In addition, we analyze chimney volume for evidence of source rock expulsion, regional hydrocarbon migration and sealing levels, correlations with abnormally pressured areas, and other phenomena of interest.

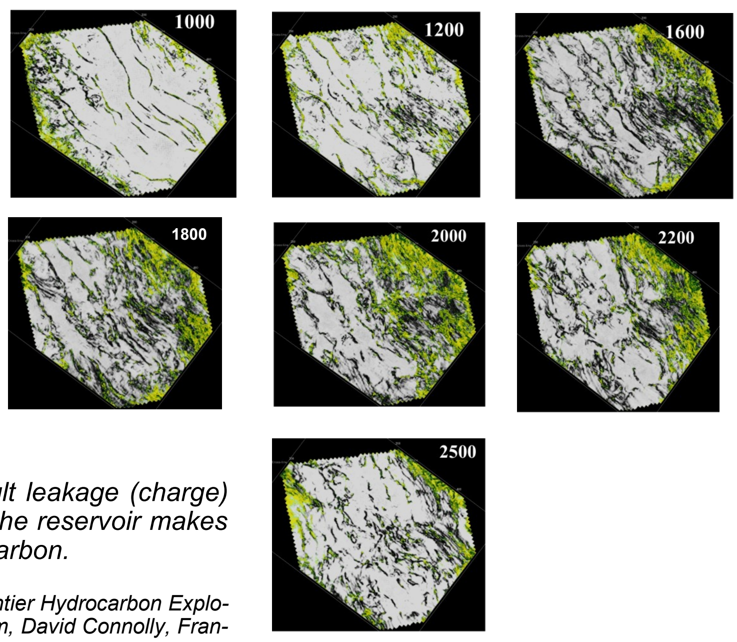
On a detailed level, we use the chimney volume simultaneously with the fault/coherency volume to assess charge of / leakage from individual fields, prospects, and leads. Next to analogs derived from local well data, to ensure quality and consistency in the interpretation, the standard dGB model for prospect risking guides the interpretation. This proprietary model is based on 100+ examples and several peer reviewed scientific papers. Next to the standard model, other considerations such as seal capacity, fault stress history, timing of oil and gas window, healing of leaking faults, and other factors are taken into account before making a final assessment about a prospect or a lead.

Model situations of risking prospect for charge and seal using seismic chimney signatures



Trap Type	Non-fault Seal Trap (HIT)	Fault Seal Trap (HIT)	Fault Leak Trap (MIT-LIT)	Non-chimney Trap
Chimney Character	No chimney over structure	Fault related: With vertical seal; Poss Lateral leak	Fault related: venting to shallow reservoirs or surface	Chimney has no clear link to trap
Mechanism	Vertical fracturing & lateral flow	Fracturing	Fracturing / Sediment Flow	Lateral / Uncertain
Geologic Discoveries	94% N=18	93% N=30	27% N=19	57% N=14





Data example of typical fault-seal trap (HIT). Strong fault leakage (charge) below the reservoir combined with sealing faults above the reservoir makes this a very strong case for charge and trapping of hydrocarbon.

From: Risk Reduction Through Neural Network Chimney Analysis: Frontier Hydrocarbon Exploration in East Africa Rift Basin by Valentina Baranova, Azer Mustaqeem, David Connolly, Francis Karanja and Danson Mburu in AAPG ACE 2013, Pittsburg, USA.

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