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Determining Migration Path from Seismically Derived Gas Chimney*

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Abstract

The paper describes how seismically derived gas chimneys can be used to determine migration path and relate them to surface seeps and mud volcanoes. It shows a new processing and analysis method of seismic data. We demonstrate how chimney cubes reveal vertical hydrocarbon migration paths that can be interpreted from their source into reservoir traps all the way to near surface (shallow gas) and the surface (seeps). Among many applications of chimney cubes are the following:

- They unravel the hydrocarbon history model and the migration path
- The can be used to rank prospects
- They help detect reservoir leakage, spill points & sealing versus non-sealing faults
- They can assist Identifying potential over-pressured zones & drilling (shallow gas) hazards
- They reveal areas of sea bottom instability

The methodology used here is based on an approach called the principle of directional attributes. Aside from the conventional single trace attributes such as amplitude, frequency and energy our directional attributes such Dip Angle Variance with different step outs, similarity measures, and dip-azimuth based contrast enhancement. Similar ideas are used to detect not only chimneys but also other objects and interfaces such as: faults, stratigraphic bodies, direct hydrocarbon indicators and time-lapse objects.

Chimney cubes are produced though running a selected and appropriately weighted set of attributes through a supervised Multi-Layer-Perceptron (MLP) neural network. The weights are determined by training the network from multitude of available information and geologic interpretation. Several examples from recent successful case histories including those in South Africa demonstrate benefits of chimney processing for different structural and reservoir problems.

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Background

Different hydrocarbon-rich areas of the world have been associated with seepage of hydrocarbon long before the birth of oil industry in the middle of 19th century. Temples of fire worshippers with their "eternal flames" began to canvass many population centers long times ago. Fire raged from "Atashkadeh"s of Zorostarians of ancient Persia to those of Aztecs in South America. Those fires, for the most part, were fueled by the natural gases that were seeping from different sub-surface accumulations through "gas chimneys". Some of these sites, such as the one just outside Baku, continue to be in operation.

Several thousand years later, likes of Drake in the US, Darcy in Iran and Nobel in Azerbaijan used surface seepage information in conjunction with other geologic data to drill successful oil wells and opening a new chapter in industrial revolution. Most major oil fields discovered in the first 60 years of oil industry were close to known were seepage. It is no accident that many smaller fields pre-dated discovery of the largest oil field in the world, Ghawar. Indeed, absence of such seepage in the deserts of Saudi Arabia was what prompted the English explorer's proclamation: "I would drink all the oil find in this land to the last drop. This is when chimneys don't come all the way to the surface due to strong sub-surface seals.

Chimney prediction scheme was developed in Europe, Given the abundant presence of gas chimneys in the North Sea, Meldahl et al, (1998). A chimney cube is a 3D volume of seismic data, which highlights vertical chaotic behavior of seismic characters. These disturbances are often associated with gas chimneys. The cube facilitates the difficult task of manual interpretation of gas chimneys. It reveals information on the hydrocarbon history, migration path and fluid flow models. Practically, chimney cubes can reveal where hydrocarbons were originated, how they migrated into a prospect and how they spilled from this prospect and or created shallow gas, mud volcanoes or pock marks at the sea bottom. As such a chimney cube can be seen as a new exploration tool. Examples of such applications can be found in Heggland et al, (2000), Meldahl et al, (2001), Berge et al (2001) and Aminzadeh et al (2001).

Procedure and Attribute Selection

Through chimney processing, a volume of 3-D seismic data is provided as an input to a specially designed a neural network. This volume is transformed to a chimney probability cube volume as the output of the properly trained neural network, Figure 1.The procedure involves:

1) Calculating and identifying a set of single-trace and multi-race seismic attributes that distinguishes between chimneys and non chimneys,

2) Designing and training a neural network with known chimneys and non chimneys

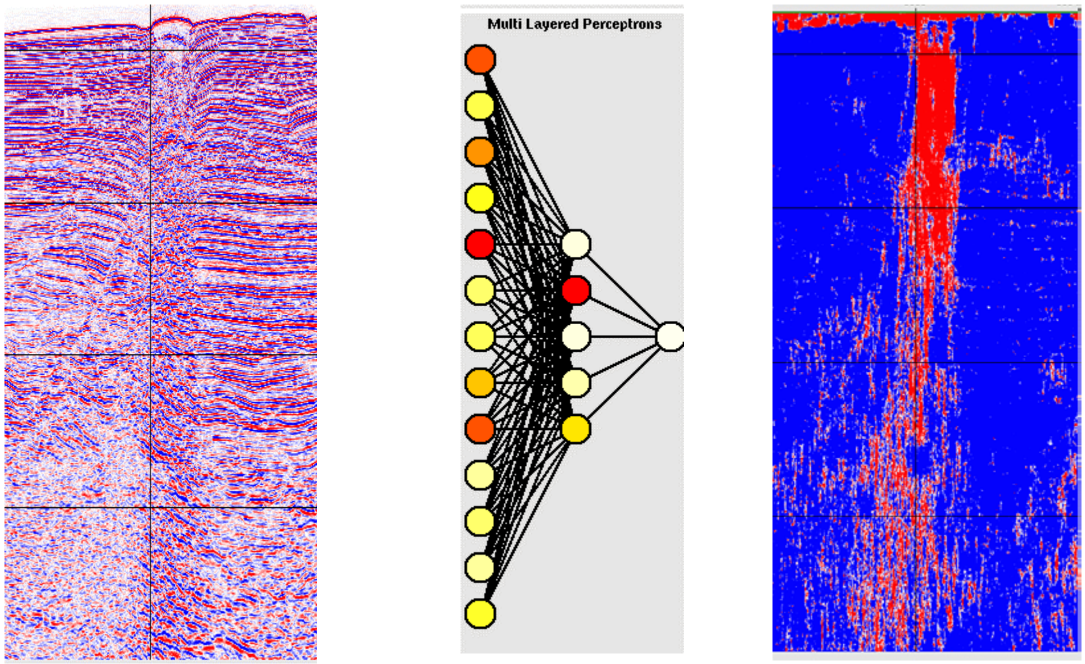


Figure 1- Slices of input 3-D volume of Seismic and the output chimney cube.

3) Creating a "chimney cube" volume from multi-attribute transformation of the 3D seismic volume highlighting vertical disturbances as the output of the trained neural network,

4) Visualizing and interpreting the chimney volume. Using the chimney cube in conjunction with other structural, stratigraphic and geophysical interpretation acoustic impedance, AVO, fluid factor) allows us to study chimneys as the spatial link between source rock, reservoir trap, spill-point and shallow-gas anomalies.

Neural networks

After the selected attributes have been extracted at a representative set of data points we will recombine these into a new set of attributes to facilitate the detection process. In this step we use supervised and unsupervised neural networks. We identify locations in the seismic cube where examples of chimneys to be detected are present. Seismic attributes described in the last section are calculated at these positions as well as at control points outside the objects. The neural network is then trained to classify the input location as falling inside or outside the object. Application of the trained network yields the desired texture enhanced volume in which the desired objects can be detected more easily.

Figure 2 shows the structure of a MLP neural networks with different attributes calculated from the seismic data at different time gates as its input and a measure of the combined chimney like behavior of theses attributes as an output. At the training stage appropriate weights for the input parameters and the hidden layers (the layers of neural network involving the nodes between the input and the output) are calculated.

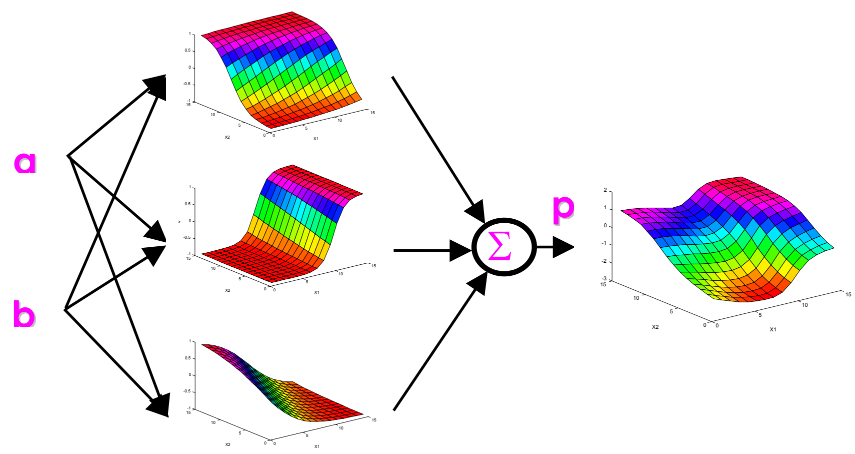


Figure 2- Structure of the multi-layer perceptron demonstrating nonlinear transformation of the input data

The two inputs (a and b) to the neural network in Figure 2 can be two of the attributes (e.g. energy and similarity measure in a vertical window). The output is the chimney probability function, p. With a properly defined threshold level one can distinguish chimneys from non-chimneys.

Chimney interpretation

Gas clouds or chimneys appear as low quality seismic response with vertical bodies of varying dimensions. Also shape and distribution may vary, although cigar-shapes and a distribution along faulted zones are common. The internal texture shows a chaotic reflection pattern of low energy. The exact outline of a chimney is very difficult to determine on conventional seismic displays. Only large chimneys can be recognized. To also detect more subtle disturbances we will transform the data into a new cube that highlights vertical disturbances. A neural network does this by classifying the data in two classes: chimney versus non-chimney. Example locations are chosen inside interpreted chimneys as well as outside.

Chimneys, in most cases, also demonstrate radial patterns on time slices of chimney cubes, Figure 3. This is caused by the friction generated from vertical migration of hydrocarbons and possible fracturing of near by rocks. These fractured rocks are subsequently filled with hydrocarbons. Once the chimneys are identified, they can be displayed in conjunction with the structural model or other reservoir property information. This helps validating certain geological interpretation such as the origination

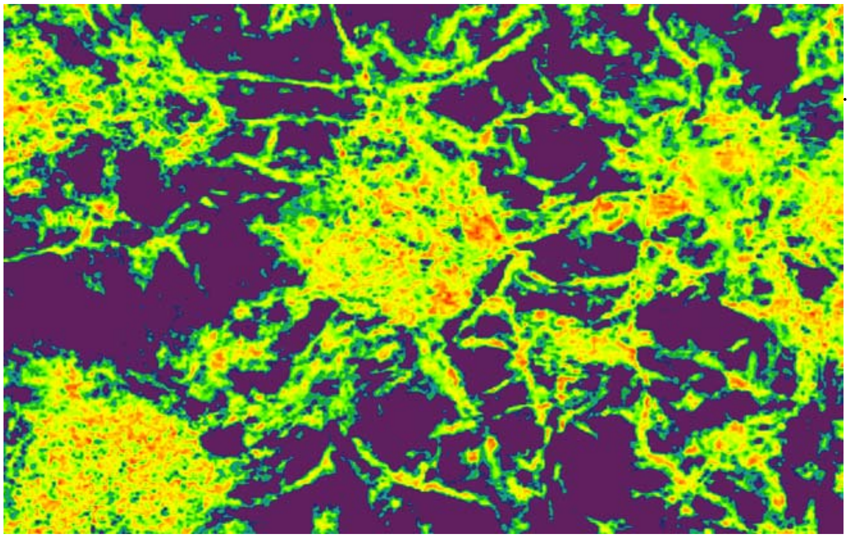


Figure 3- Radial patterns in a chimney slice

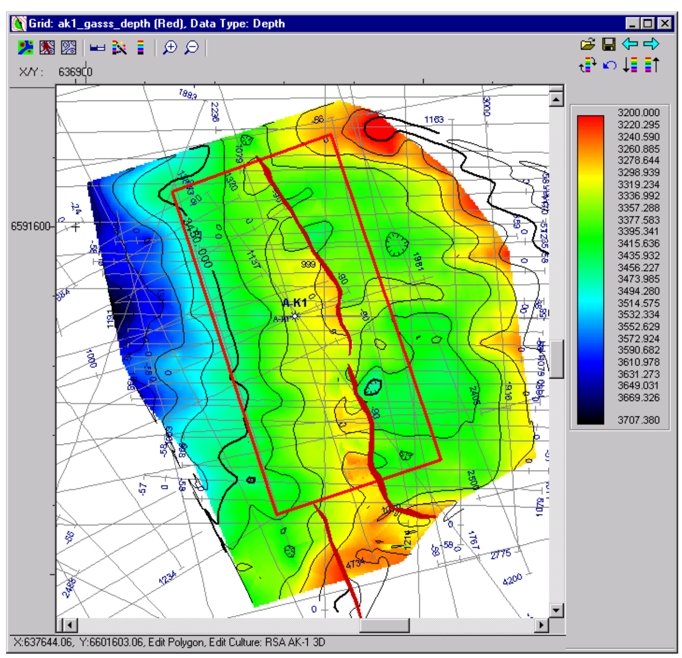
points of hydrocarbons, spill points, reservoir accumulation and gas seepage to the surface.

South Africa Case History

In this section, we will focus on chimney analysis in Block 2A around the AK-1 gas discovery in South Africa . The original discovery well was plugged and abandoned as it was thought to be a small non-commercial structural trap. This field, now designated as the Ibhubesi Field, is a giant stratigraphic trap. The 3D area covers a small part of the southern extent, which may eventually produce as much as 15Tcf of gas. Attribute processing and gradient analyses with the chimney volume clearly show individual gas accumulations in meandering fluvial channels and other component facies of fluvial-deltaic system. Fluvial channels, meander belts, crevasse splays and overbank deposits, distributary systems and deltas can all be identified. Figure 4 shows a structure map.

A 4-well drilling program was undertaken to evaluate the field and prove-up a core development area with enough reserves to be economically developed. 3 different anomalies were targeted and each well woul test individual compartments for a total base project of 3.1 Tcfg. The A-K2 well tested 30 Mcfg and over 600 bbls of condensate per

Figure 4, Structure Map



day from a 20 meter thick pay sand on a ¾" choke with a flowing tubing pressure of 2200 psi. The reservoir characteristics were better than expected: clean and well sorted with average porosity of 22% and almost no water saturation.

The Chimney analysis made a significant contribution to the interpretation and validation of earlier work. This was done through integration of chimney analysis and the conventional seismic processing. Figure 5a is the display of original seismic while Figure 5b is the chimney output on the inline 2800. These results were obtained after training the

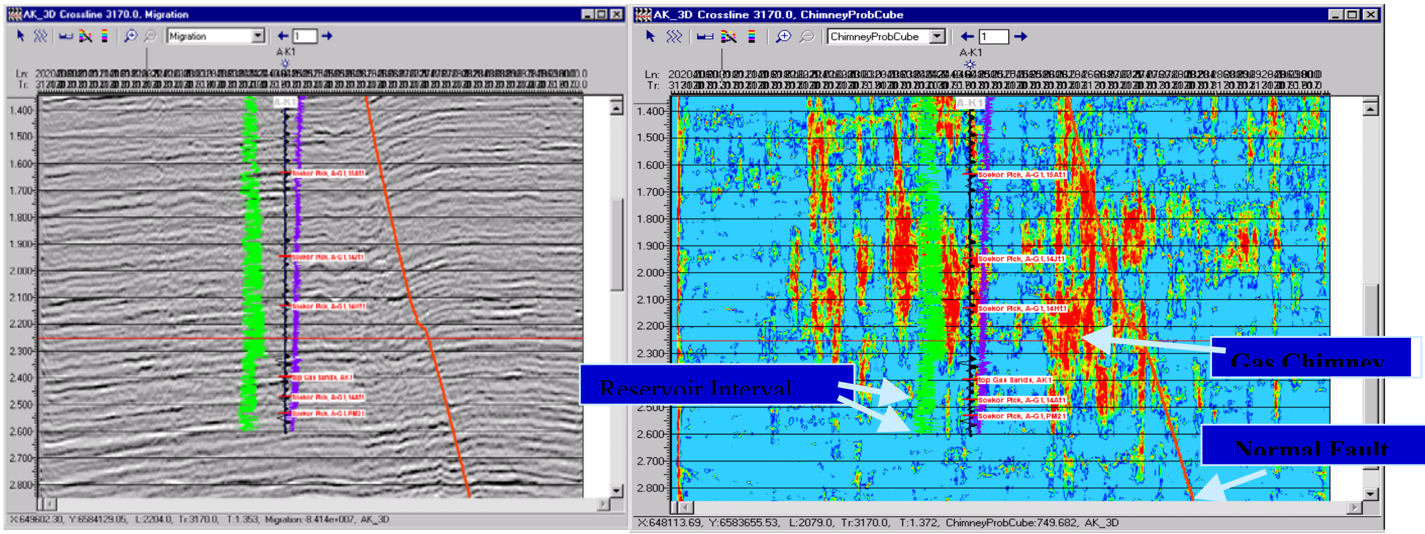


Figure 5- A- Original Seismic, **Figure 5B- Chimney Results**

Neural network on suspected chimneys picked by interpreters. Figures 6 shows a time slice, highlighting the major chimney s or chimney like phenomena near the major fault.

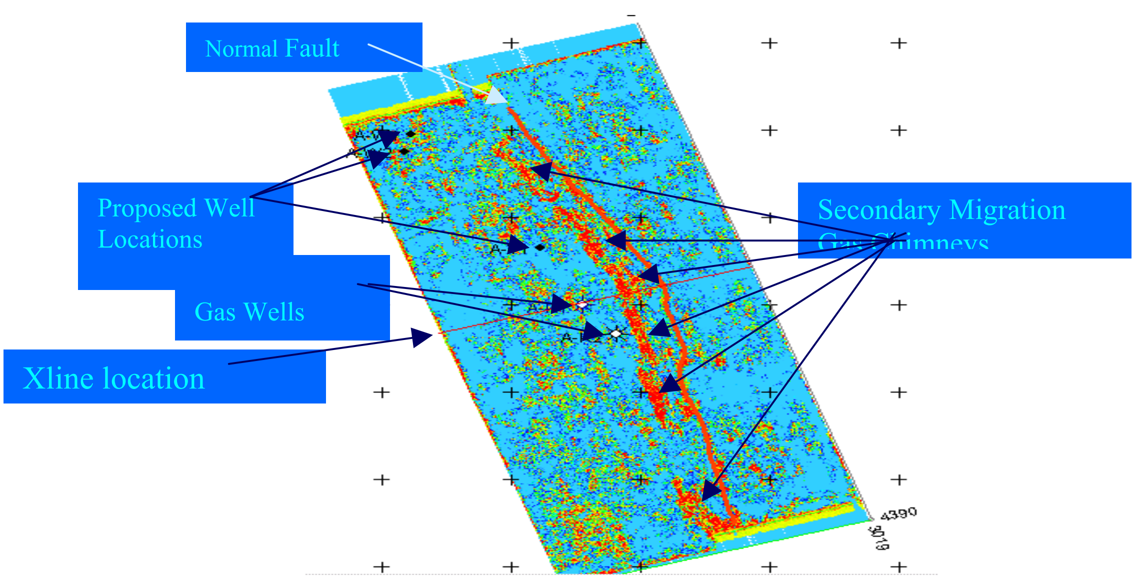


Figure 6 A time slice of chimney cube output

DISCUSSIONS AND CONCLUSIONS

Based on many case histories some of which are shown in references 1, 2 and 4 we are convinced that this methodology has proven to be useful in many areas. Among those are: relating the surface seeps to subsurface structures and reservoirs, understanding the hydrocarbon history model and the migration path, ranking prospects, detecting reservoir leakage, spill points & sealing versus non-sealing faults, assisting in identifying potential over-pressured zones & drilling (shallow gas) hazards, and assessing the sea floor stability for platform design and drilling. Figure 7 shows an example of evolution of chimneys from deep faults through reservoir units and to shallow gas accumulations.

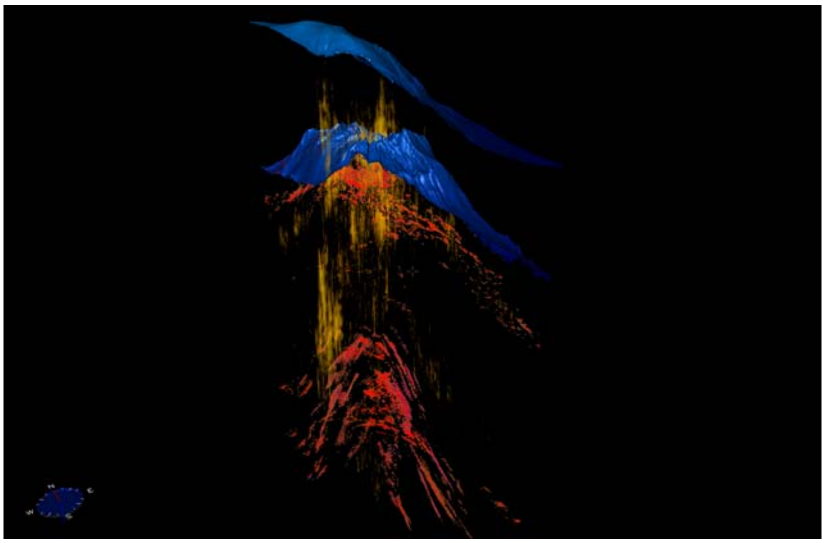


Figure 7- chimneys (yellow) overlaid on structure (red &blue)

References

1- Aminzadeh, F., Berge, T., B., de Groot, P. and Valenti, G., 2001, Using Gas Chimneys as an Exploration Tool, Part 1, and Part 2 World Oil May and June Issuee, pp 50-56 and pp 69-72.

2- Aminzadeh, F. and de Groot, P., 2001, Gas Chimney Processing and Analysis, Proceedings of SEG-GSH Spring Symposium, Reservoir Resolution through Comprehensive Use of Seismic Data Attributes, Houston, Paper 2.6.

3- Berge, T., B., Aminzadeh, F., and Oldenziel, T., 2001, The Application of Neural Network to Predict Reservoir, Gas Content and Secondary Migration Routes, A Case History from Ibhubesi Field, Orange Basin, South Africa, Proceedings of SEG-GSH Spring Symposium, Resrvoir Resolution through Comprehensive Use of Seismic Data Attributes, Houston, Paper 2.4.

4- Heggland, R., Meldahl, P., de Groot, P. and Aminzadeh, F., 2000. Seismic chimney interpretation examples from the North Sea and the Gulf of Mexico. American Oil and Gas Reporter, February issue, pp 78-83.

5- Meldahl, P, Heggland, R., de Groot, P. and Bril, A. 1998. Seismic Body Recognition. Patent Application GB. 9819910.2.

6- Meldahl, P., Heggland, R., Bril, B., and de Groot, P., 2001. Identifying Fault and Gas Chimneys Using Multi- Attributes and Neural Networks, The Leading Edge of Geophysics, pp. 474-482.