FRED AMINZADEH, dGB-USA, Sugar Land, Texas, **,** DAVID CONNOLLY, dGB-USA, Sugar Land, Texas, & HERALD LIGTENBERG, dGB Earth Sciences, Enschede, The Netherlands.

Hydrocarbon Phase Detection and Other Applications of Chimney Technology

Abstract

Large scale vertical fluid migration**,** dominating the Gulf of Mexico and other basins, has been known for years from geochemical maturity data. This vertical migration often occurs via gas clouds or chimneys related to fault zones or fractures. Detecting and confirming the origin of such chimneys has been very difficult. Gas chimney processing and interpretation offers the opportunity to highlight these vertical disturbances in the seismic record, map fluid migration pathways, and thus predict favorable traps for gas or oil accumulation. Gas chimney technology can also be used to distinguish oil-prone from gas-prone traps in basins, such as the Gulf of Mexico, which produce both oil and gas. This is accomplished by careful investigation of different types of chimneys and interpreting their different characters, in conjunction with geochemical and other geological data, to predict hydrocarbon phase.

Gas chimney processing is a new concept which uses multi-dimensional attribute sets along with an artificial neural network to focus on vertical chaotic seismic disturbance in 3-D data. This leads to creation of a new volume highlighting fluid migration pathways. Gas chimney interpretation is a key exploration tool in an integrated workflow. Seal and charge risk can be significantly reduced when this migration path data is combined with other independent indications of hydrocarbon migration and entrapment. These include basin modeling, piston coring, pressure prediction, and direct hydrocarbon detection through spectral analysis and AVO. Selected examples from GOM and other basins will be shown to demonstrate hydrocarbon phase detection and other applications of chimney technology.

Background

There are four major controls on any hydrocarbon accumulation: structural geometry, reservoir extent and quality, seal effectiveness, and charge effectiveness. With the advent of 3D seismic and sophisticated reservoir characterization approaches from multi-attributes and pre-stack inversion (Berge et al, 2002) fewer dry holes are being drilled because of a lack of structural geometry or reservoir presence. In a typical exploration portfolio, charge and seal integrity issues contribute to the majority of dry holes. Through interpretation of chimney data both charge and seal risk can be assessed more accurately.

Gas clouds and gas chimneys have often been considered as a source of seismic noise that degrades the quality of seismic reflection events. Many efforts have been devoted to deal with this problem and filter out the impact of gas clouds and provide interpretable sections by imaging through them. In contrast, our approach is designed to create a 3D volume of seismic data which highlights this vertical chaotic behavior in the seismic data.

These disturbances are often associated with gas chimneys. The new era Chimney prediction scheme using seismic data was developed by (Meldahl et al, 1998). This was originally motivated by the abundant presence of gas chimneys in the North Sea and their impact on drilling hazards.

The chimney 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 generated, 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. 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), Aminzadeh et al (2001), Aminzadeh et al (2002) and Connolly et al (2002).

Methodology

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. The procedure involves:

a) Calculating and identifying a set of single-trace and multi-trace seismic attributes that distinguishes between chimneys and non chimneys;
b) b) Designing and training a neural network with known chimney and non chimney areas;
c) 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;
d) Visualizing and interpreting the chimney volume. Integrating chimney cube data with other structural, stratigraphic and geophysical interpretations (velocity or pore pressure, acoustic impedance, AVO, fluid factor etc.) allows us to understand chimneys as the spatial link between source rock, reservoir trap, spill-point and shallow-gas anomalies. Not all chimneys are related to hydrocarbon migration. Shallow chimneys may represent de-watering of poorly consolidated mudstones.

Other details of chimney detection using neural networks can be found in Aminzadeh et al (2001).

Chimney Cube Interpretation

Chimney cube data must be integrated with other geologic information, both on the regional and prospect specific level, to use it as an effective exploration tool. On a regional scale, piston core or SAR data provide information on the occurrence, maturity, intensity, and phase of present day seeps. 2 ½ D or 3D basin modeling indicates the location of the source kitchens. Ligtenberg & Thomsen (2003) discuss how chimney data can be integrated with basin modeling. On a prospect scale, chimney data can influence the input parameters into the 2D basin models and impact the fault seal analysis. Often there is also a strong relationship between elevated pore pressures and chimneys. The strain history of the structure can also shed light on both the location and the intensity of vertical migration. Regional well information is very important to calibrate the impact of chimney occurrence on seal and charge effectiveness. Borehole Imaging Logs can indicate the current day stress field. Fluid inclusion technology (FIT) and apatite fission track analysis (AFTA) can provide significant clues into the intensity and timing of fluid migration. Shale capillary pressure measurements, pore pressure measurements, and leak-off tests can constrain hydrocarbon column heights and define pressure compartments and seal. Oil and gas geochemistry gives clues to the maturity and source type of the migrated hydrocarbons.. In the following sections we will show a number of case histories demonstrating the use of chimney cubes in the exploration for oil and gas.

Gulf of Mexico: Distinguishing Sealing Versus Leaking Faults

Many basins, such as the Gulf of Mexico, are essentially undercharged, and migration of hydrocarbons via faults is dominant. Understanding which faults are the major hydrocarbon conduits is critical to high-grading the fault blocks as drilling prospects. This is especially critical in off structure stratigraphic plays which may not be optimally located in the major zone of vertical hydrocarbon migration. Gas chimney processing can assist us in determining if there is evidence of charge into these more subtle plays. In this example form the northern Gulf of Mexico shelf (Figure 1), time slices of chimney data through the section above the main reservoir units in this gas field do not show high probabilities of chimney presence. Moderate to above background probabilities for chimney, in this case, help distinguish the fault trends. However there is no evidence of the pockmarked character associated with gas migration. In contrast, the time slice of chimney data below the main reservoir units shows clearly high probability chimneys and a pock-marked character to the chimneys oriented along the main fault trends. More discussion of using chimney technology to detect fluid migration along faults is in Ligtenberg (2003).

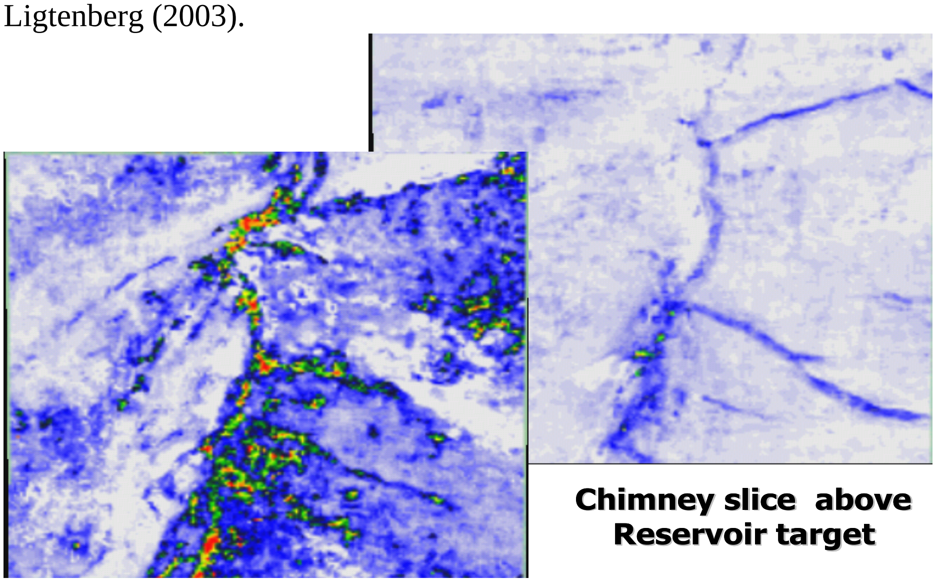

Figure 1 – Gulf of Mexico: Chimney probability time slice above and below gas reservoir.

Deep-water Gulf of Mexico: Seal Prediction

The ability to predict seal effectiveness is especially critical in the deep water Gulf of Mexico. While 3-D has been mostly successful to determine structure, seals with limited capacity and small hydrocarbon column heights, incapable of holding sizable hydrocarbons, are often the reason for failure. In a recent seminar on GOM deepwater dry holes (McVey, 2000) ten of the eleven dry holes were due in part to seal failure. This is often due to higher pore pressures in the shallow section in the deepwater environment and the resultant small differential between pore pressure and fracture gradient. Gas chimneys are usually caused by significant pressure gradients in the sub-surface and are characterized by low velocity and higher pressure.

By combining gas chimney probability data and pressure data, we can often determine areas of optimal seal.The figure below shows chimney results overlaid on a seismic section from Akalan filed in the Gulf of Mexico. A three dimensional visualizations the chimneys in relation to the key horizons displaying the acoustic impedance, near the Malah number 1 well is shown in Figure 2. The chimneys show leakage from shallow reservoir objectives which do not have effective seals

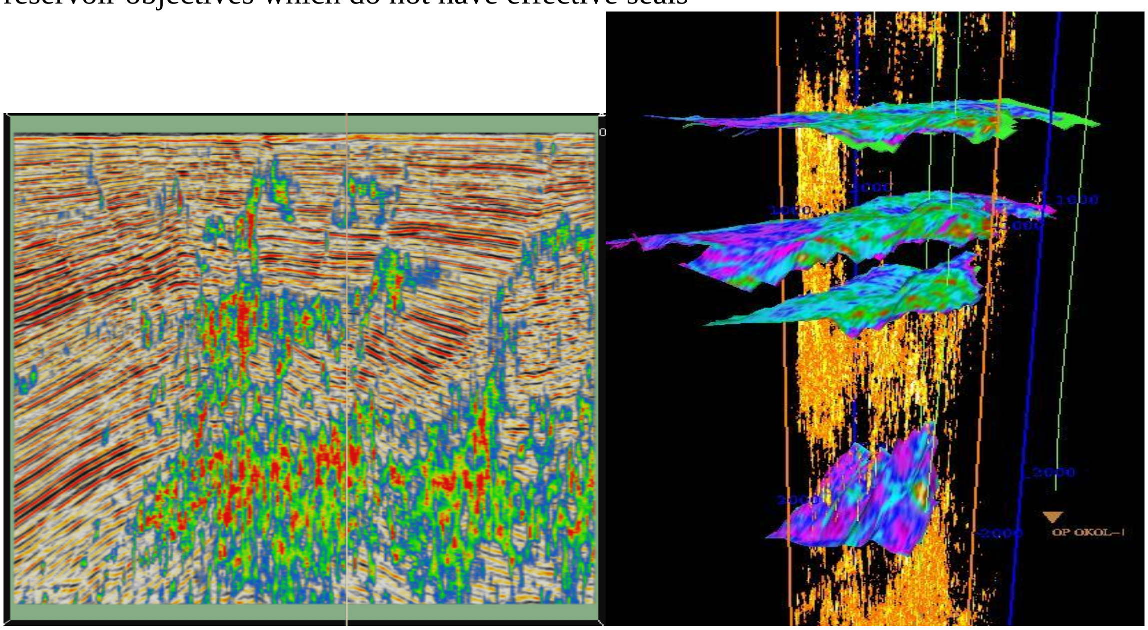

Figure 2: Akalan area: Chimney probability overlain on seismic (left) and 3d view of chimneys (right) show leakage from shallow reservoir objectives (Aminzadeh, et.al. 2003).

Distinguishing Oil-prone vs. Gas-prone Prospects

In multi-phase petroleum systems, where both oil and gas are migrating into a trap, the structures which vent the gas (either through faulting or fractures) will be more oil-prone. Processing can detect the weak signal associated with venting. This approach has been used to successfully predict hydrocarbon phase in a number of basins in West Africa, the North Sea and the Gulf of Mexico.

Integrating Chimney Data and Surface Geochemical Data

Chimney data can be used in a number of ways to improve the analysis of the piston core information:

1) Chimney data can be used to position piston cores optimally. Chimney data can demonstrate where the highest probability of surface seeps which are linked to deep geothermal migration pathways may occur.
2) Chimney data can be used to link to the results of piston core data to the sub-surface. In this example from the Lamprea area (Figure 3) the chimney data demonstrates that the geothermal character of the piston core is related to hydrocarbon migration along a deep fault. It also indicates the associated gas seep indicated by the side scan sonar data is due to deep gas generation rather than shallow biogenic gas. A time slice near the sea floor (300 msec) through the chimney probability cube (below upper left) shows the pock marked character associated with gas migration. Significantly the location of the piston core with good evidence of geothermal gas is near the intersection of the two fault trends. This is a preferential zone for fluid migration due to a higher fracture density and reduced fault gouge production.

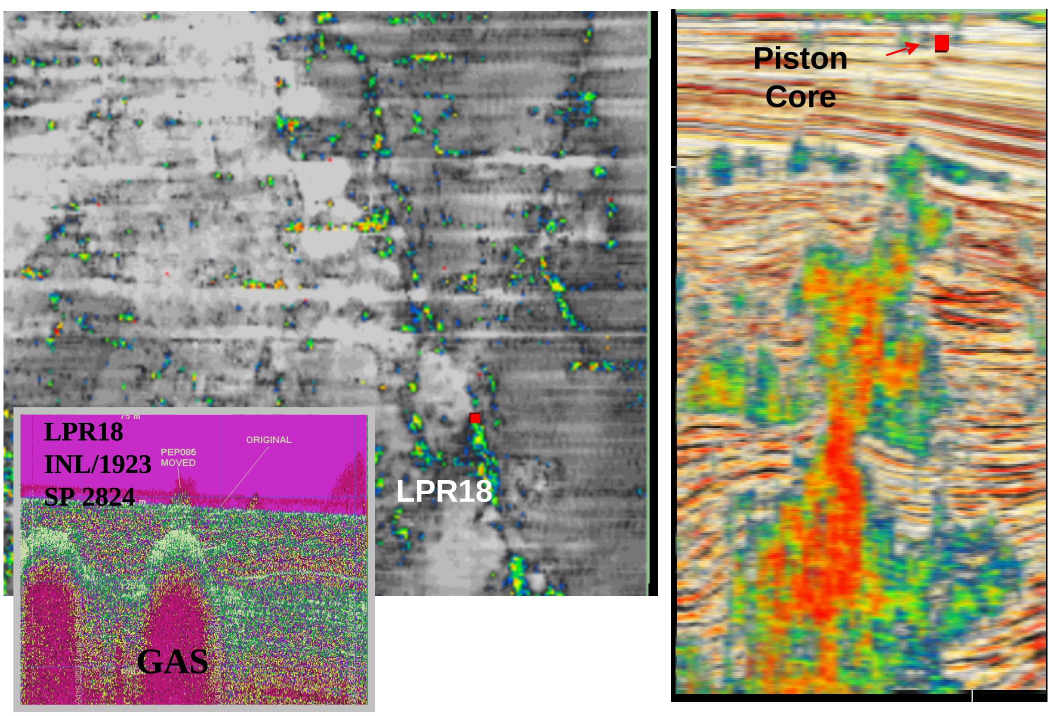

Figure 3 –Lamprea Area: Relationship of gas chimneys to piston core data (Alvarado, et. al. 2003).

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Key Words

Gas chimney, seeps, seismic attributes, seal,