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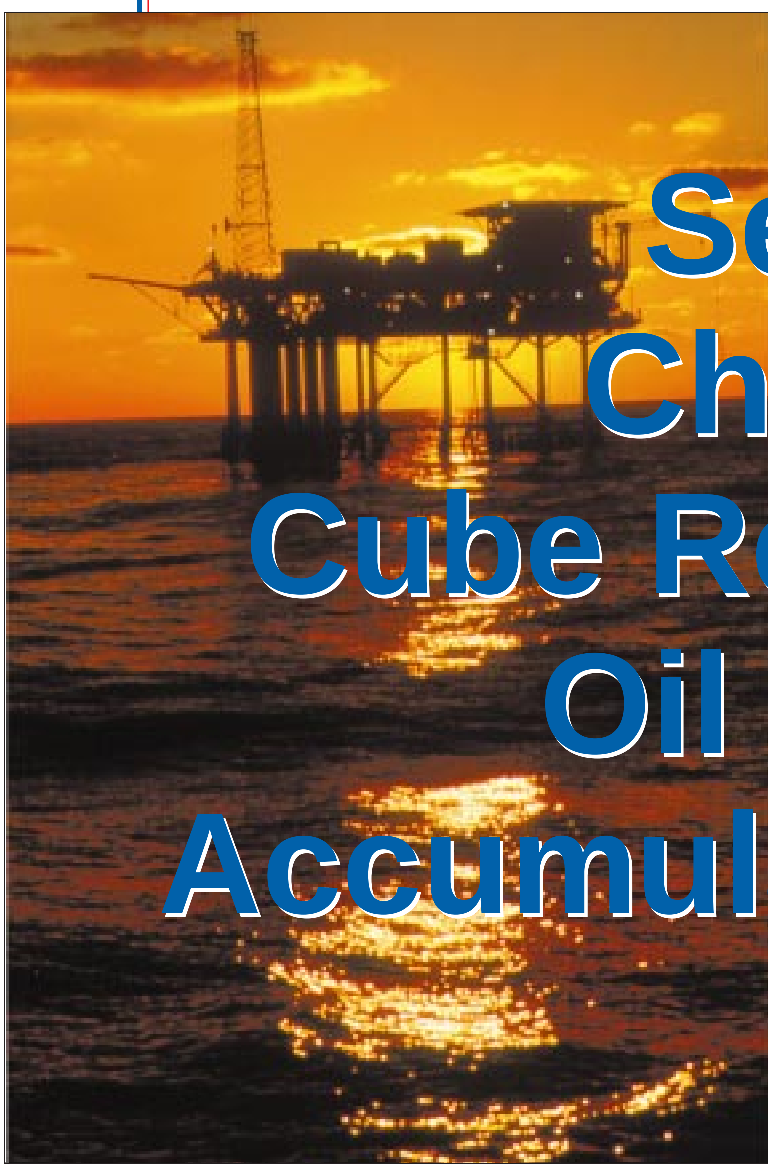
The Gulf of Mexico



Seismic Chimney Cube Reveals Oil & Gas Accumulations

cusses the time scale of oil and gas migration into reservoirs at Eugene Island Block 330 along the OCS slope offshore Louisiana–including one of the most productive oil and gas fields in the world.

Sea floor features that have been associated with hydrocarbon seepages in the Gulf of Mexico include carbonate mounds, mud volcanoes and seabed depressions. In the same area, hydrocarbon seeps are commonly correlated with seismic chimneys. The chimneys may have variable seismic amplitude responses that are related to gas-charged sediments, gas-hydrates, and reflective authigenic carbonates (described by H.H. Roberts, et. al., in "Hydrocarbon Seeps of the Louisiana Continental Slope: Seismic Amplitude Signature and Sea Floor Response," Gulf Coast Association of Geological Societies, Vol. XLII, 1992).

Hydrocarbon seeps in the Gulf of Mexico that have been seen in association with geo hazards like mud flows, over-pressured water and gas sands were described by Exxon Exploration Company's J. E. Corthay II at the 1998 Offshore Technology Conference (OTC 8594, "Delineation of a Massive Seafloor Hydrocarbon Seep, Overpressured Aquifer Sands, and Shallow Gas Reservoirs, Louisiana Continental Slope").

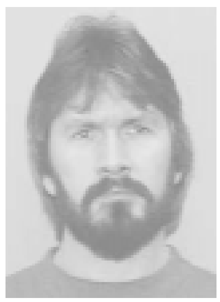
The area of study for the application of the chimney cube in the Gulf of Mexico was the deepwater slope of Green Canyon in a water depth of about 6,600 feet. A 3-D seismic cube covering an area approximately three-by-six miles squared was used to generate a chimney cube. The standard seismic cube and the chimney cube were used in combination, along with mapped horizons to evaluate possible hydrocarbon migration.

Gulf of Mexico Example

Figure 3 shows a comparison between a standard seismic section from the area of study and the corresponding section from the chimney cube. Figure 4 shows a 3-D visualization of the chimney cube, the standard seismic cube, and two mapped surfaces. The two mapped surfaces are displayed as time maps in blue color, with the upper one representing the seabed and the lower one mapped at approximately 1,320 feet subseabed. From the standard seismic cube, only the highest amplitudes are displayed in red. Lower amplitudes are made transparent in this display. Chimneys from the chimney cube are displayed in yellow. These correspond to the high values in the cube (i.e. high chimney probability). Lower values are made transparent.

The deeper cloud of high amplitudes corresponds to the outline of a salt dome, while the shallow cloud of high amplitudes is interpreted to represent a hydrocarbon-charged reservoir. Chimneys surrounding the salt dome indicate upward fluid migration from a deeper reservoir. The high density of shallower chimneys indicates charging of the shallow reservoir. The subseabed surface exhibits a radial fault pattern caused by the upward movement of the salt dome. Chimneys are visible up to the seabed, and a small mound is present at the seabed close to the top of the shallowest chimney on the right-hand side. This may be a small mud volcano generated by the transport of sediments, fluid and/or gas to the seabed.

The presence and distribution of the chimneys that have been mapped in this area make the presence of a deep and a shallow hydrocarbon-charged reservoir more likely. A manual mapping of chimneys would have been difficult, less precise, and more time consuming. The chimney cube helped to visualize and efficiently evaluate the possible hydrocarbon migration. ❐



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Roar Heggland is a staff geophysicist for Statoil in Stavanger, Norway. He has served at Statoil since 1984, working on geo-hazards interpretation and research and development, based on 2-D high-resolution and 3-D seismic data. For the past eight years, his research has been focused on applying 3-D seismic to hydrocarbon migration. He earned a degree in particle physics from the University of Bergen.

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Paul de Groot is co-founder and director of de Groot-Bril (dGB) Earth Sciences B.V., which conducts seismic reservoir characterization studies and offers consultancy services and software products. He began his career in 1981, and served in a variety of geophysical-related positions for Shell, Petroleum Development Oman, and Shell Petroleum Development Company of Nigeria. He then became director of Quest Geophysical Services B.V., and subsequently served as senior geophysicist for TNO Institute of Applied Geoscience before co-founding dGB-BV in 1995. He holds a Ph.D. in geophysics from the University of Delft.

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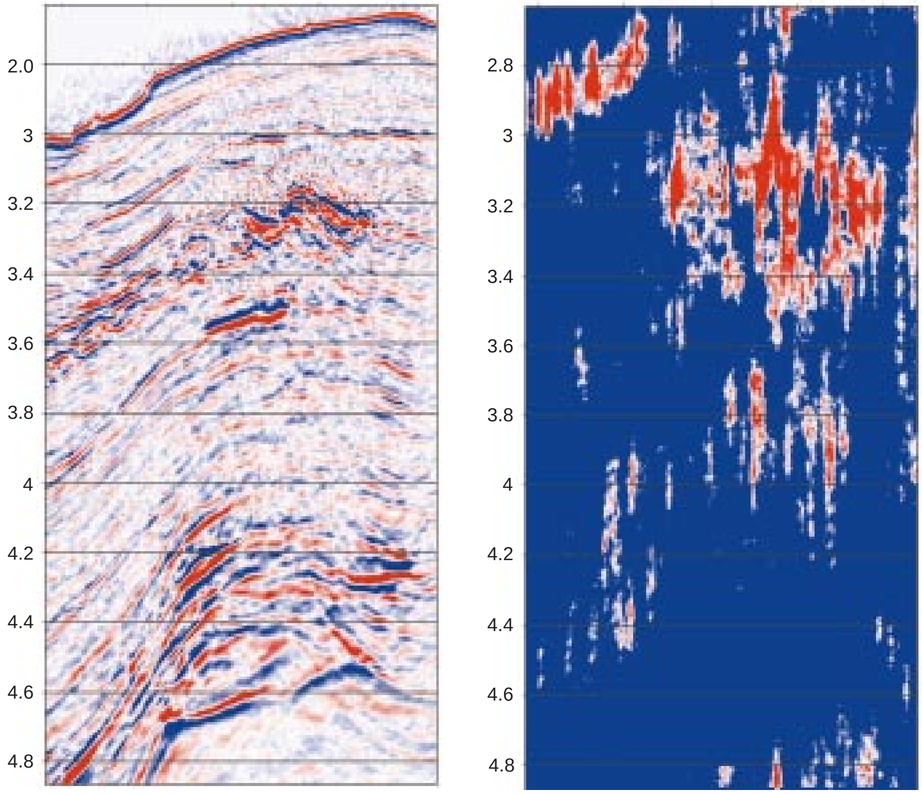
Fred Aminzadeh is president of FACT Inc., a geophysical consulting, training and service company in Sugar Land, Tx. He is also president and chief executive officer of dGB-USA, a joint venture between dGB-BV of the Netherlands and FACT Inc. that offers services and software for quantitative seismic interpretation, stratigraphic analysis, seismic inversion, neural networks-based reservoir characterization and gas chimney/fracture detection. Aminzadeh previously worked for Unocal with both technical and management responsibilities. He is a member of the National Research Council's Committee on Seismology and a former chairman of the Society of Exploration Geophysicists' Research Committee.

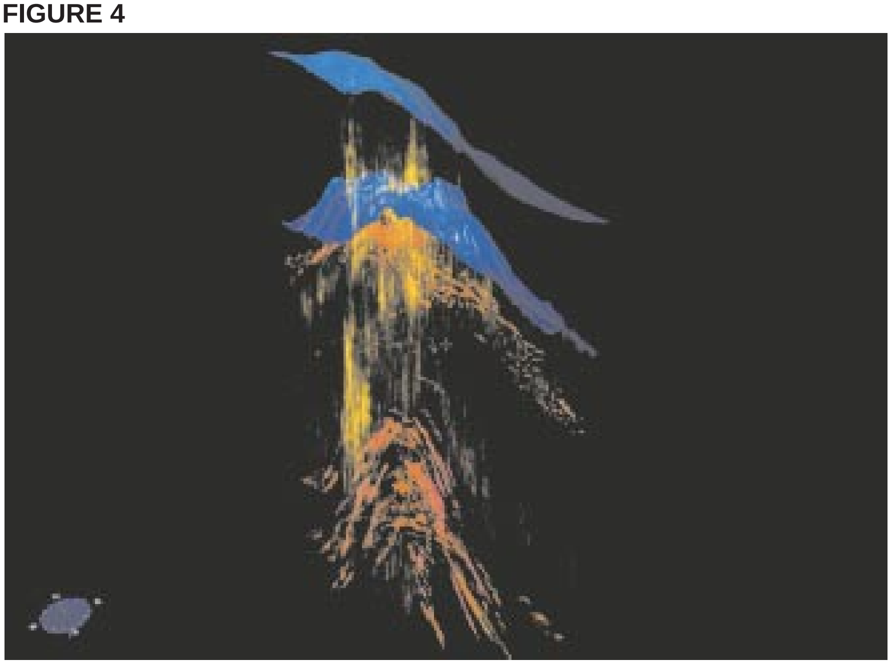
FIGURE 3



Shown here are the seismic line and corresponding chimney probability from the Gulf of Mexico data set.

chimney. Example locations are chosen inside interpreted chimneys as well as outside. At these locations, various attributes such as energy and trace-to-trace similarity are computed in several vertically aligned windows.

FIGURE 4



This 3-D image of chimneys, amplitude anomalies and mapped surfaces was generated from the Gulf of Mexico data. Chimneys indicate leakage from a reservoir trap against the flank of a salt dome (deep red cloud), feeding other reservoirs with associated amplitude anomalies above the salt dome (deep blue surface and shallow red cloud). From there, they spill to the surface, forming a mud volcano at the sea bottom (upper blue surface).

This enables the network to detect that the body has a certain vertical extent. The trained network is subsequently applied to the entire seismic cube on a trace-by-trace and sample-by-sample basis. Because the output nodes "chimney" and "non-chimney" are each other's mirror images, it is sufficient to pass only the value for the chimney node to produce the desired output cube. A high value for this node indicates a high chimney probability at that location.

North Sea Example

Figure 2 shows an example from the North Sea where a chimney cube is displayed along with mapped surfaces and shallow amplitude anomalies from a standard seismic cube. The chimneys are displayed in yellow. Only the highest values in the cube (high probability) are shown. Lower values are transparent. Similarly, maximum amplitudes from the standard cube are displayed in red, while lower amplitudes are transparent. The blue surface is the interpreted base Cretaceous horizon in time. Seismic chimneys have their starting point at the top of Jurassic faults visible on this surface. The red/green surface within the cluster of chimneys is a time map corresponding to the top of an Eocene oil and gas reservoir.

Chimneys are interpreted to represent the migration of hydrocarbons from Jurassic faults, charging the Eocene reservoir. The shallower parts of the chimneys represent hydrocarbons bypassing, or spilling from, the reservoir up to the seabed. The shallow high amplitudes (red) on top of the chimneys may represent shallow gas accumulations at approximately 330 feet below seabed caused by hydrocarbon migration from deeper sediments. Alternatively, they may correspond to carbonate formations generated above hydrocarbon seeps at this ancient seabed. The two wells located within the chimney cluster were drilled through the Eocene reservoir, and hydrocarbons were present in both wells. The well located in the right-hand corner, where no chimneys are present, was dry. Similar observations have been made in other parts of the North Sea.

Massive Seepage

Massive oil and gas seepage is taking place over the entire northern slope of the Gulf of Mexico, and is evident from geological, biological and satellite data. The most pervasive seepage seems to occur in the deeper water slope areas rather than on the Outer Continental Shelf. In an article in the September 1997 issue of *Sea Technology*, author Jean K. Whelan dis-

Chimney Cube Unravels Subsurface

By Roar Heggland,
Paul Meldahl,
Paul de Groot
and Fred Aminzadeh

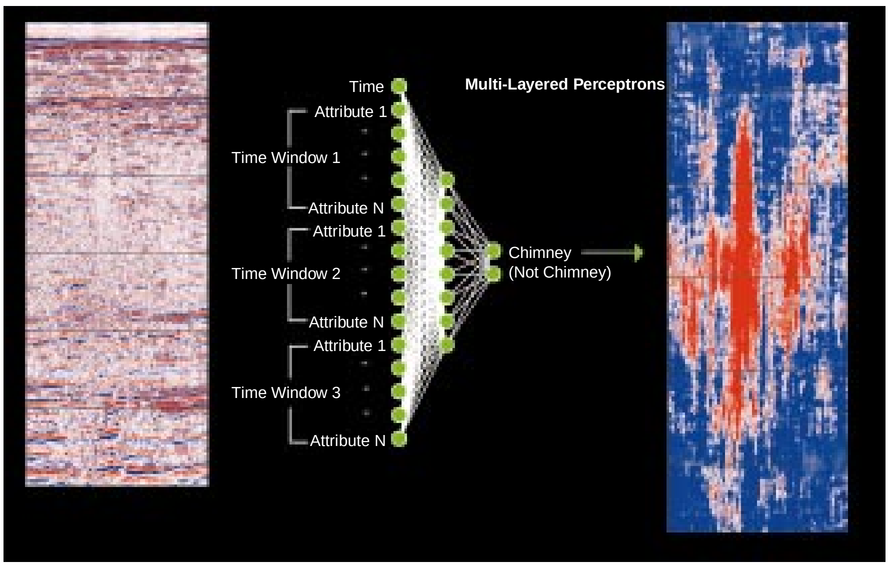
STAVANGER, NORWAY–Ever since Colonel Drake drilled the first successful oil well in 1859 in Pennsylvania, it has been known that natural hydrocarbon seepages are linked to subsurface accumulations. In fact, all major oil provinces found in the 19th century were discovered because wells were drilled near seepages. So-called "sniffing" methods developed in the last decade are exploiting this phenomenon by measuring concentrations of natural gas in the air or from soil samples.

Direct and indirect evidence of seepage is also often seen in seismic data. Examples of indirect evidence are distinct features such as pockmarks and mud-volcanoes. Hydrocarbon seepage-related features have been recognized in many basins around the world at the sea bottom and deeper reflections.

Direct evidence of seepage is a so-called "chimney," a vertical disturbance of the seismic response. Recent studies in the North Sea have revealed a high correlation between chimneys and known oil and gas accumulations. These studies make use of a chimney cube–a neural network-based multi-attribute transformation of the three-dimensional seismic volume into a volume that highlights vertical disturbances (Figure 1). This transformation allows chimneys to be studied as the spatial link between source rock, reservoir trap, spill point and shallow gas anomalies (Figure 2).

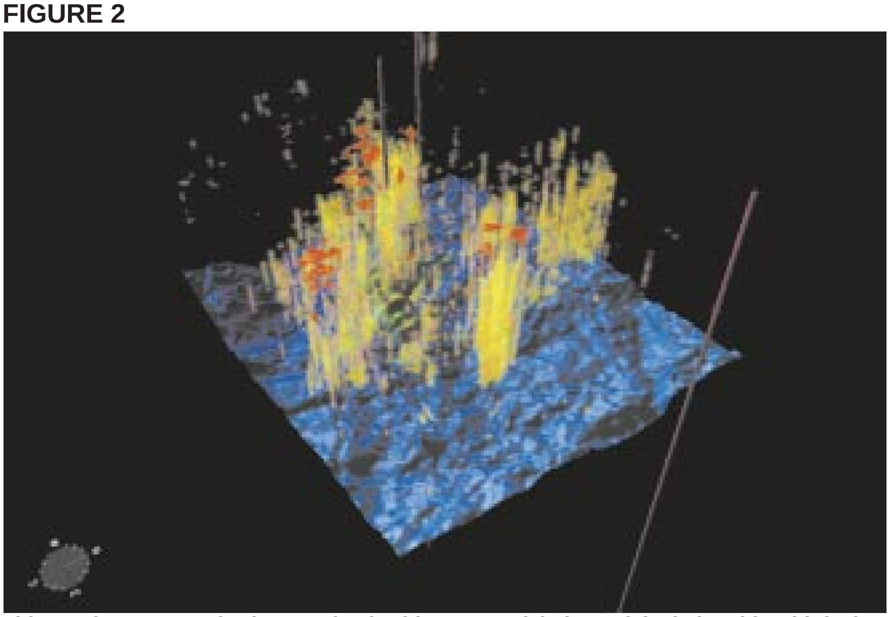
The interpretation helps unravel a basin's hydrocarbon history, distinguish between charged and non-charged prospects, identify geo-hazards. The technology was presented at the 1999 Society of Exploration Geophysicists' annual meeting by authors Meldahl and Heggland, et. al., in a two-part paper, "The Chimney Cube: An Example of Semi-Automated Detection of Seismic Objects by Directive Attributes and Neural Networks." After initial applications in the North Sea, the patent-pending technology has been applied for the first time to data from the Gulf of Mexico.

FIGURE 1



The seismic line and chimney probability, as predicted by the supervised neural network, are displayed here.

FIGURE 2



This North Sea example shows seismic chimneys and their spatial relationship with faults, hydrocarbon accumulations and amplitude anomalies.

Seismic Chimneys

Seismic chimneys are caused by saturated fluids and/or free gas migrating through porous rocks. As the fluids move up toward the surface, the pressure drops and solution gas is released. Some gas stays in the pores, changing the acoustic properties of the rock. This connate gas especially affects compressional (P-wave) velocity. Alternatively, over-pressured fluids may have cracked the rocks, causing the scattering of seismic waves.

On seismic data, chimneys appear as vertical bodies of varying dimensions. Shape and distribution may also 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, and only large chimneys can be recognized.

To detect more subtle disturbances, the data are transformed into a new cube that highlights vertical disturbances. A neural network does this by classifying the data in one of two classes: chimney or non-