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# Detecting Fault-Related Hydrocarbon Migration Pathways in Seismic Data: Implications for Fault-Seal, Pressure, and Charge Prediction

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## ABSTRACT

A method is demonstrated to highlight hydrocarbon migration related to faulting in seismic data. The method uses multiple seismic attributes and neural networks to highlight the vertically aligned low-energy chaotic seismic data described as gas chimneys, gas clouds, or seepage pipes. The result is a gas chimney probability volume. Methods are also described for highlighting faults in seismic data using directional attributes. When the gas chimney probability data are overlain on the fault data, obvious vertical gas chimneys can be distinguished. However subtler fault-related hydrocarbon migration can also be seen. This hydrocarbon migration is often associated with fault intersections or splinter faults related to shear along the fault. Overlaying the chimney information on fault planes can often indicate which parts of the fault have been migration pathways and which parts of the fault have not. More than 125 chimney analyses have been performed on drilled structural closures with effective reservoir. Approximately one quarter of the wells are dry holes. Thus, the dry holes failed because of either ineffective charge or seal. These structures were classified, based on the character of the chimneys below and above the reservoir, into eight classes. We will demonstrate how this information can be used to risk vertical seal and charge prior to drilling.

Gas chimneys are a means by which deep pressures can be transmitted into the shallow subsurface. This partly explains why producing reservoirs are often near the top of abnormal pressure. We will demonstrate the correlation of rock property data (fracture pressure and pore pressure), gas chimneys, and hydrocarbon column height. Case studies are shown from the Gulf of Mexico onshore, shelf, and slope.

## INTRODUCTION

It has long been recognized that many of the Tertiary, Mesozoic, and Paleozoic basins are dominated by vertical hydrocarbon migration from deep thermally mature source rocks encased in fine-grained, low-permeability mudstones. This vertical migration is generally recognized in seismic data as vertically aligned zones of chaotic, often low-amplitude, reflectivity described variously as gas chimneys, seepage pipes, blowout pipes, mud volcanoes, gas clouds, or acoustic turbidity zones. Associated features are fault-related pockmarks, direct hydrocarbon indicators (DHIs), and hydrocarbon-related diagenetic zones (HRDZs). Furthermore, it has been recognized frequently that hydrocarbon discoveries are often poorly imaged and often associated with overlying gas clouds.

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This vertical hydrocarbon migration and its seismic expression have been extensively studied in the near surface in Minerals Management Service funded studies in the Gulf of Mexico (Roberts, 2001), and the 2001 AAPG Hedberg Research Conference. Vertical hydrocarbon migration related to mud volcanoes has also been studied in conferences such as the 2006 Hedberg Conference on “Mobile Shale Basins—Genesis, Evolution, and Hydrocarbon Systems.” These surface seeps have also been related to hydrocarbon accumulations in the Green Canyon and Ewing Bank areas, northern Gulf of Mexico (Bolchert et al., 2000). These studies have discussed how this vertical migration is often fault related.

The seismic expression of this fault-related hydrocarbon migration in the subsurface has also been documented and classified into trap-forming faults and supra-trap faults in assessing vertical seal integrity (Cartwright et al., 2007). Gas chimneys have also been related to seal integrity (Heggland, 2005; Ligtenberg, 2005).

A number of case studies show the relationship of vertical hydrocarbon migration mechanisms to known fields and dry holes that were drilled on valid structures with effective reservoir. Case studies include the Eugene Island 346 Tanzanite discovery and Green Canyon 99 Sazerac dry hole (Walraven et al., 2004), Marco Polo Field (Walraven et al., 2005), and Gullfaks South Field, North Sea (Løseth et al., 2002). There is also an excellent internet database on the Northwest Shelf of Australia oil and gas fields (Cowley and O’Brien, 2000) that developed criteria for distinguishing low, moderate, and high integrity traps based on the intensity (often expressed as velocity pull up) and aerial extent of the HRDZs. These studies identify both linear (fault-related) and circular (gas clouds, blowout pipes, seepage pipes, and mud volcanoes) anomalies, which often occur at fault intersections or structural crests. Heggland et al. (2000) found empirically that linear fault-related chimneys are more likely to be breached than the non-fault related chimneys or gas clouds. Cowley and O’Brien (2000) reached similar conclusions from their data in the Northwest Shelf of Australia. They have further found that long (1.5-5 km [0.9-3 mi] in length) fault-controlled HRDZs indicate that the trap has leaked considerably and may be completely breached while small effectively point-source anomalies (0.2-1.5 km [0.1-0.9 mi] in length) will have low amounts of leakage.

## METHODOLOGY FOR HIGHLIGHTING VERTICAL MIGRATION IN SEISMIC DATA

Many gas chimneys and HRDZs are very obvious in the seismic record. However, subtle gas clouds above hydrocarbon reservoirs, deep chimneys related to expulsion from source rocks, and fault-related hydrocarbon migration pathways are often difficult to distinguish on normally processed seismic data. The diffuse character and weak expression of gas chimneys in seismic data make them difficult to map. Often they are most obvious on vertical seismic sections, but not clear on 3D seismic time slices. Thus a method for detection of gas chimneys in post-stack 3D data is needed to improve the identification of gas chimneys in seismic data, to map their distribution, and to allow them to be visualized in three dimensions.

A method making use of multi-attribute calculations and neural networks was developed (Heggland et al., 2000; Meldahl et al., 2001). Chimneys are recognized as vertically-aligned low-amplitude chaotic zones in normally processed seismic data and will often cause a frequency washout or attenuation of high frequencies (Brouwer et al., 2008). Thus individual trace-to-trace attributes such as similarity (a type of coherency attribute) and dip variance will often highlight chimneys. Also, single trace attributes such as instantaneous amplitude, energy, and frequency will show chimneys. However, individual attributes will also highlight features not related to chimneys. As example, low similarity will also result from faults or mass transport deposits. Thus it is useful to use a multiple attribute set, which are combined through neural network training to isolate gas chimneys against all other features.

The procedure involves initially reviewing the seismic cube to select lines or cross lines, which display the suspected vertical hydrocarbon migration pathways or gas chimneys most clearly. Gas chimneys are often associated with shallow amplitude or amplitude versus offset (AVO) anomalies. These anomalies can be used to guide identification of chimneys. Surface seeps either from synthetic aperture radar or shallow geo-hazard surveys can also guide finding locations of shallow chimneys. Next, chimney picks are made in the most obvious chimneys. Also non-chimney picks are made in chaotic or low amplitude areas, which are suspected not to be chimneys. Non-chimney picks are also made along faults which show no evidence of hydrocarbon migration. A set of attributes, which have been shown on numerous datasets to highlight chimneys, are then evaluated on the key seismic lines. Attributes that show the chimneys most clearly are chosen as input to a neural network. The type of neural network used in this methodology is a supervised neural network that learns from the provided

representative samples (Meldahl et al., 1999). Once the interpreter is satisfied with the resultant neural network training, based on a reconnaissance of key lines, the neural network can be applied to the entire seismic volume. The resulting chimney probability volume or ChimneyCube® will have values ranging between zero and one, based on their similarity to the chimney picks. This volume can then be overlain on seismic sections or visualized in three dimensions.

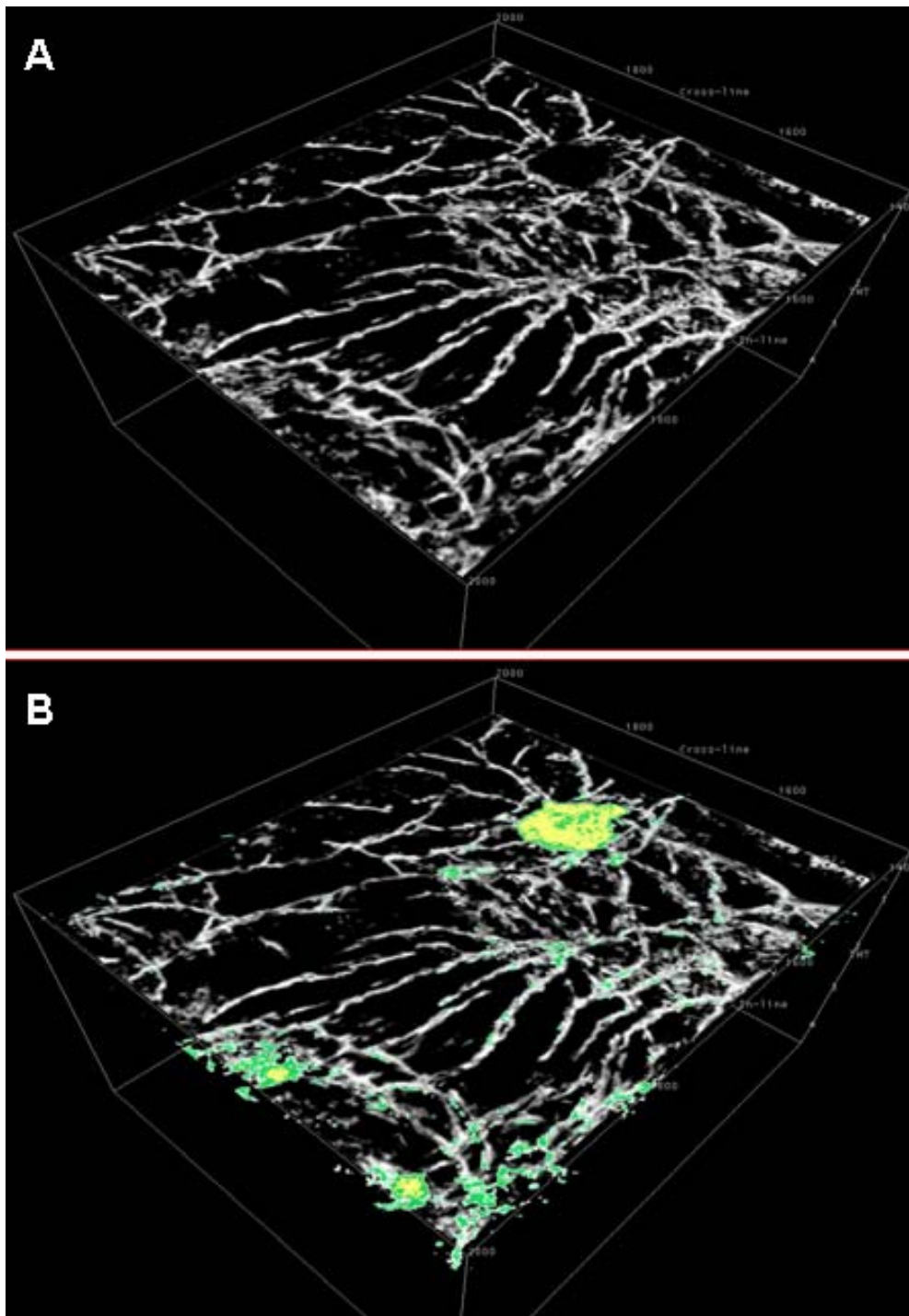
Following the creation of a chimney probability volume, the results must be interpreted to validate them as true vertical hydrocarbon migration. Vertically-aligned chaotic data can occur for other reasons than gas chimneys. Geologic features such as diapiric shale and salt, mass movement complexes, and volcanic pipes can look similar to chimneys. De-watering of mudstones related to burial compaction can result in polygonal faulting, which can look chaotic on seismic section views. Poor seismic imaging related to surface statics, fault shadows, complex structuring (imbricate thrusts), subsalt, or subthrust intervals can also be misleading. True hydrocarbon migration pathways can be substantiated in a number of ways: (1) Presence of drilled fields, or seismic evidence of hydrocarbon presence, such as DHIs (amplitude, AVO, or frequency attenuation anomalies), and chemosynthetic carbonate build-ups associated with the chimney; (2) linking the gas chimney to shallow sea-bottom indications of hydrocarbon seepage detected through piston core data, side scan sonar, and other scanning methods; (3) matching of the chimneys with basin modeling which can predict vertical hydrocarbon migration based on independent inputs; and (4) linking the chimneys within deep thermally mature sediments that contain source rock intervals. The chimney morphology should express a circular pockmark pattern, which is characteristic of fault related hydrocarbon migration. This is best evaluated on time and horizon slices. Wells drilled through gas chimneys in the North Sea often encounter elevated pore pressure, gas shows, and gas wetness (Løseth et al., 2002).

## DETECTING HYDROCARBON MIGRATION RELATED TO FAULTING

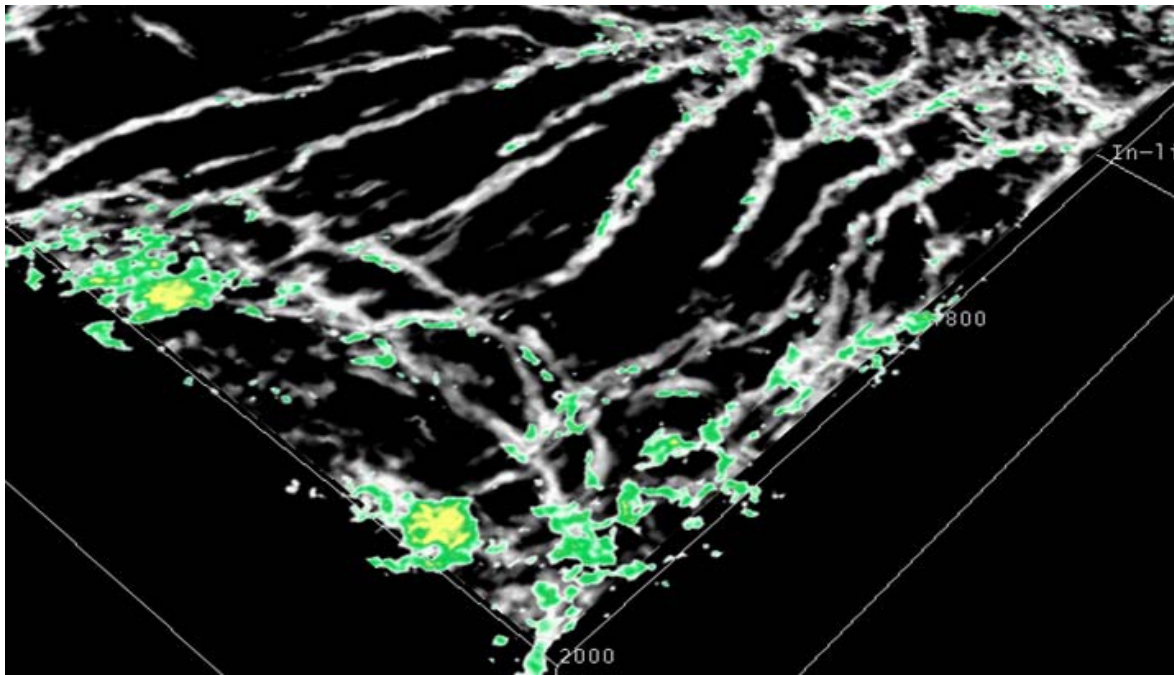
Gas chimney detection methods were originally used to highlight subtle vertical seepage pipes, mud volcanoes, and gas clouds. However it was soon recognized that the methodology could be used to highlight more subtle hydrocarbon migration related to faulting, and thus be used in assessing fault seal risk (Ligtenberg, 2003, 2005; Ligtenberg and Connolly, 2003; Heggland, 2005; Connolly and Aminzadeh, 2006). The method consists of combining chimney and fault detection volumes to determine which faults or portions have had active hydrocarbon migration associated with them. Faults can be highlighted using a number of approaches. Single multi-trace attributes such as coherency or similarity can be utilized. A fault attribute can be created using a workflow based on dip steered enhancement of discontinuities in the seismic data. Faults can also be enhanced using a neural network supervised training approach, similar to ChimneyCube® processing. Examples of faults and non-faults are picked on representative lines. A set of multi-trace attributes are chosen which highlight picked faults most clearly. These attributes are calculated at the picked locations and the results are fed into a neural network. The resultant output algorithm is applied to the entire seismic volume to create a probability of fault volume.

If the chimney probability results are displayed on the fault probability results, we can get an indication of which faults have been migration pathways for hydrocarbons, and which faults have not (Fig. 1). In this case from the Niger Delta, the upper display shows a time slice of the fault cube by itself. In the lower diagram the chimney cube data is displayed on top of the fault data. Only the high probability chimneys in yellow (most likely) to green (probable) are shown. The low probable chimneys are transparent. Large circular chimneys can be recognized on these time slices. However these chimneys can often be recognized easily on normally processed seismic data. Chimney processing allows us to image more subtle hydrocarbon migration, which occurs at fault intersections, or along faults. If we look at this time slice in more detail (Fig. 2), we can observe that in fault related cases the high probability chimneys (shown here in green-yellow) occur at the fault intersections. These intersections can occur at the junction of major faults, or at the intersection of a major fault with splinter faults. These splinter faults are inferred to be related to shear along that fault. Gartrell et al. (2004) suggested that these fault intersections may be one of the most important pathways for hydrocarbon migration in a basin. They studied the mechanical behavior of fault intersections using numerical modeling. Based on their work at fault intersections, a dilation zone is formed, which has a high concentration of open faults and fractures. The shear strain at these intersections is very low resulting in reduced fault gauge and thus prone to higher fluid flux.

If the chimney data is displayed on the mapped fault surface we can actually observe which parts of the fault are migrating hydrocarbons. In this case, it is observed that high-probability chimneys occur primarily at bends



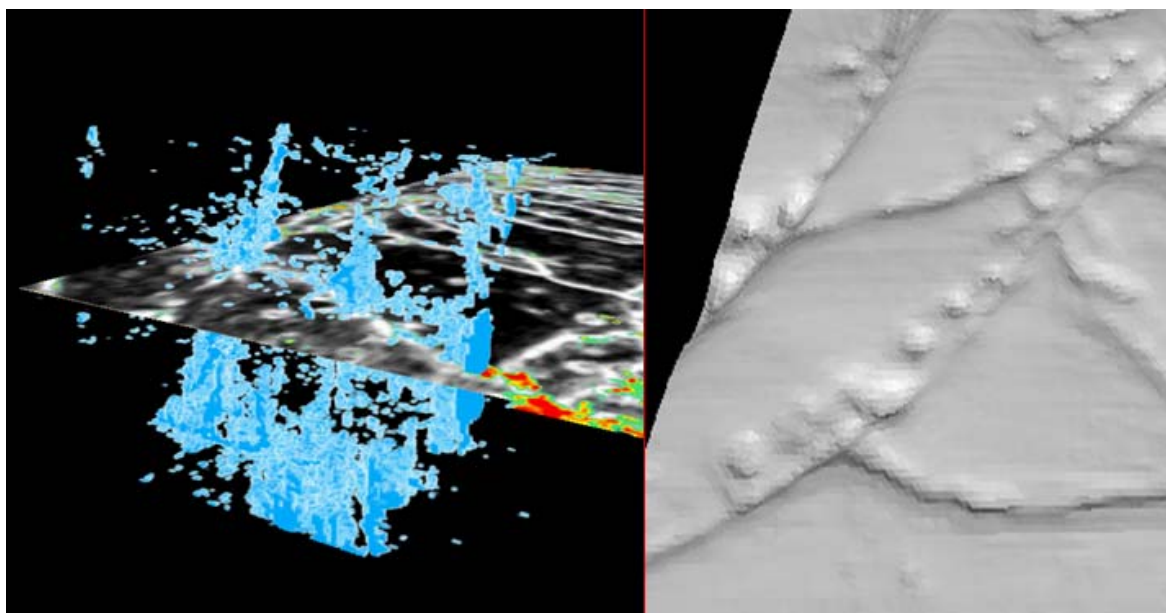
**Figure 1.** The upper image (A) shows on a time slice the neural network based extraction of the fault system, the faults indicated by the white color. The lower image (B) shows the neural network extraction of vertical HC migration (gas chimneys) which is overlain on the same time slice displaying the faults. The locations with vertical HC migration are indicated by the green and yellow colors. The display highlights the relation between faulting and vertical HC migration.



**Figure 2.** This is a detail from [Figure 1B](#). It shows the vertical fluid flow to take place preferentially at small splinter faults and at intersections of faults.

or kinks in the fault. These variations in plane orientation in relationship are very common in faults and can be defined as the roughness of the fault zone (van der Zee, 2002). When there is a strike-slip component to the movement of the fault, these bends can create the dilation and or the splinter faults that are observed in the time slices and are preferential migration pathways for hydrocarbons. If these high probability chimneys ([Fig. 3](#)) are observed in three dimensions, they occur as regularly spaced pockmarks. Ligtenberg (2005) related these regularly spaced pockmarks to diapiric fluid flow, whereby minor weaknesses in the fault are concentrated and propagated in a vertical direction. These regularly spaced pockmarks are observed at the sea floor. Piston core data confirms the presence of both oil and gas in similar pockmarks in the Niger delta (Cameron et al., 1999).

It is important to note that the detection of hydrocarbon-migrations pathways related to faulting does not tell us when that fault was leaking. The residual gas saturations and vertical fracturing related to the hydrocarbon migration will leave an imprint on the seismic data. Thus we can infer that the fault has leaked, but may not be leaking today. Timing of fault leakage can be inferred from basin modeling, which gives us an idea of when hydrocarbons were being actively generated in the basin. Timing can also be inferred from fault-stress analysis, which is an important tool to assess the failure potential of a fault. Shear fractures will often leak. If a fault is critically stressed with respect to the present-day stress field, it is likely to slip. Fault slip, in turn, elevates fault zone permeability, enabling hydrocarbons to leak. This can also occur in faults that have sufficient smear gauge ratios to suggest they should be sealing. Hillis (1998), comparing the Central North Sea and the Timor Sea, indicated that the type of stress-induced failure varies from basin to basin. Based on pressure versus depth relationships in the North Sea, the vertical stress is greater than horizontal stress, indicating a normal fault regime. In contrast, in the Timor Sea the horizontal stress is greater than the vertical stress, indicating a strike-slip fault regime. Regional stress fields can vary during geologic time, thus there may be particular times in which a fault is likely to be critically stressed. To understand when a fault is likely to be critically stressed, we need accurate regional stress information and accurate fault mapping. Therefore unbiased mapping based on fault attribute, neural network fault volumes, or coherency data is important. Faults in different geologic periods or stress regimes should be expected to show decoupling, which is critical for fault seal. De Ruig et al. (2000) showed from



**Figure 3.** The three dimensional display (left image) of the vertical migration pathways (in blue) along a fault plane shows a discreet columnar behavior. Similar pockmark patterns can be observed at the sea floor (right image).

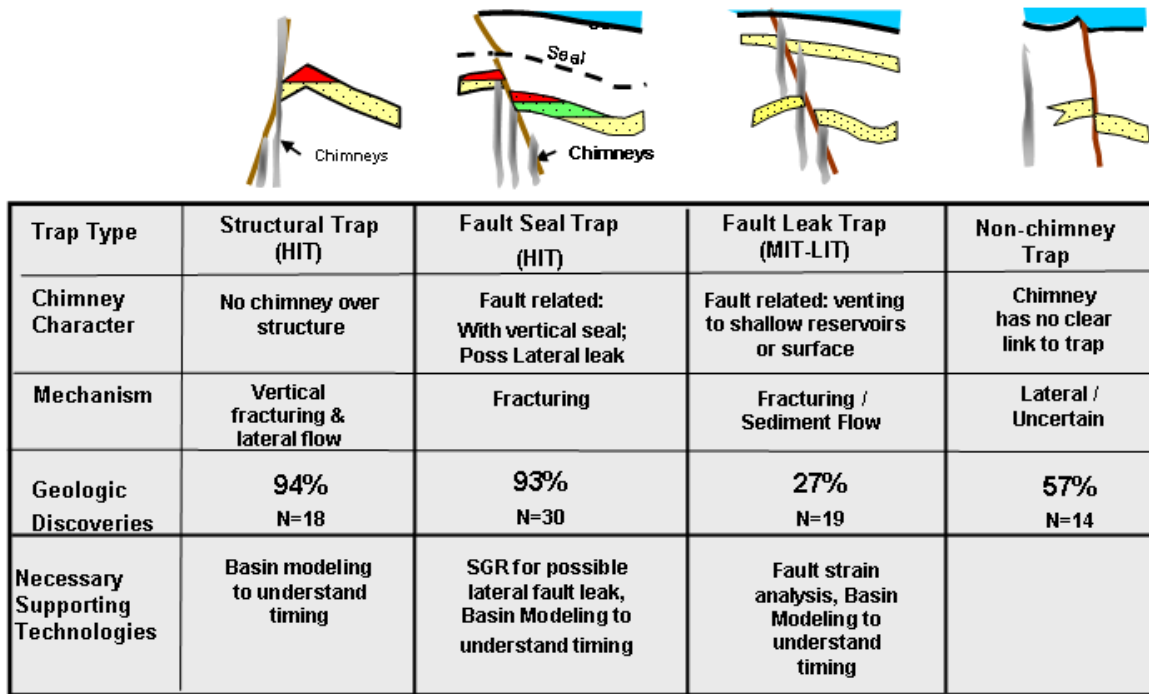
detailed fault mapping and fault displacement ratios that the Jurassic and Tertiary fault systems in the Timor Sea are essentially decoupled. Such a decoupling often provides a sealing interval between two fault systems, and just below such a sealing interval we expect an increased probability to encounter hydrocarbon-filled reservoirs.

### PREDICTING VERTICAL SEAL AND CHARGE RISK

The main purpose of delineating gas chimneys is to predict vertical seal and hydrocarbon charge risk for prospects prior to drilling. Hegglund (2005) has evaluated the character of gas chimneys above structural traps to predict seal integrity. His findings show that traps with chimneys on the flank of structures (as would be expected) have effective seals. Traps with non-fault related gas clouds over them generally have effective seals. Traps, however, with fault-related chimneys generally have breached seals.

This classification has been expanded to include the character of gas chimneys above and below the oil or gas field or dry hole (Fig. 4). Case studies were acquired over oil and gas fields or discoveries. Examples were also evaluated for dry holes, which were drilled on valid structures with effective reservoir. Thus the well failed because of a lack of charge or seal. Dry holes, which had suspected lateral fault leakage, were excluded so that only top seal risk is being evaluated. The classification has also been expanded to include both fault-related traps and top seal traps, using the nomenclature suggested by Cartwright et al. (2007) dividing fault-bypass systems into two families based on whether the faults define the trap (trap-defining fault) or whether they are embedded in the sealing sequence (supratrap faults).

Fault-related traps have been divided into four classes. The first class is a “structural trap” where the fault is involved in charging the trap, but not forming the actual trap. These traps are generally rollover structures, and as would be expected are low risk. One possible risk with this type of trap is the risk that the reservoir is of limited extent and highly pressured. Thus the reservoir would be bypassed in favor of shallower low-pressure sands, or expelled to the surface. These traps are high integrity traps (HIT) and are generally filled to spill or to their intersection with the charging fault. The second class is a “fault-seal trap.” These structures show clear evidence of



**Figure 4.** The classification system based on the different geometries of gas chimney, reservoir, and seal. The models are derived from actual case studies with known drilling results. Using the drilling results a probability for the presence of a significant hydrocarbon column is calculated for each model. All the case studies are done on valid structural traps with good reservoir quality, thus charge and risk are the primary risk factors.

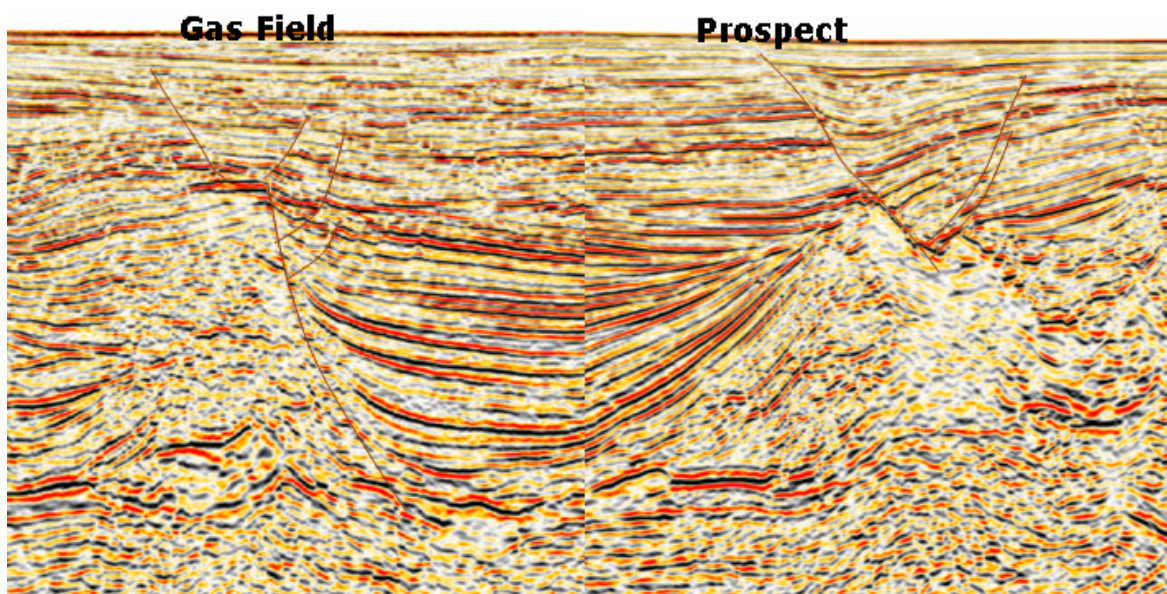
vertical charging from deep-seated faulting often related to basement structure, salt, or shale movement. These faults terminate at the reservoir interval or in the sealing interval above the reservoir. These traps are very low risk HITs, and often filled to spill. This type of trap is very common in the Gulf of Mexico. Because the chimneys are located in the more poorly imaged section below the reservoirs, they are often not recognized. The chimneys are often related to fracturing and provide a conduit for deep pressures to be transferred into the shallow section. Thus the productive reservoirs often occur near the top of abnormal pressure. The third class is a “fault-leak trap.” These traps show fault related leakage above the objective reservoir interval. They are low integrity (LIT) to moderate integrity (MIT) traps, and represent higher risk for vertical seal integrity. The fourth class is a “non-chimney trap,” where the trap has no direct connection through a permeable pathway to any chimneys. For producing fields, the lack of vertical chimneys may indicate that the basin is dominated by lateral migration. Alternatively the seismic data quality may not be adequate to delineate vertical migration pathways.

Fault traps can exist in a continuum between fault leak traps and fault seal traps. Faults can leak along a single point of weakness, often at an intersection of two faults and resemble more of a blowout pipe. Cowley and O’Brien (2000) have investigated the character of fault leakage over a number of faulted traps in the Northwest Shelf of Australia. They have determined that the majority of oil fields in the Timor Sea are MITs, with fault leakage from 500-1500 m (1640-4921 ft) in length. LITs (breached traps) generally have faults with greater than 1500 m (4921 ft) of fault leakage. For fault-leak traps the intensity of the leakage will also have an important control on the trap integrity. Cowley and O’Brien (2000) provide a table that provides a likely interpretation of trap integrity based solely on HRDZ intensity (as measured by velocity pull-up) and aerial extent. A trap with a high-intensity, but aerially-limited HRDZ represent a robust petroleum system and an effective trap. In contrast a high-intensity aerially-extensive HRDZ is a breached trap. Measuring intensity of leakage associated with gas chimneys is more subjective.

## GULF OF MEXICO SLOPE: FAULT-SEAL AND FAULT-LEAK TRAP

Obviously, distinguishing fault-seal traps from fault-leak traps is critical for risking fault seal. While, the soft linkage between the overlying supratrap faults and the underlying trap forming faults should be expected in fault-seal traps, often the seismic does not have the resolution to distinguish the type of linkage. In this case study from the Green Canyon area, Gulf of Mexico slope, two adjacent structures are evaluated (Fig. 5). The structure on the left is the King Kong gas field characterized by AVO and frequency attenuation anomalies. The Lisa Anne structure on the right was drilled as a dry hole. The structure had similar AVO and frequency attenuation anomalies to the King Kong field at the same objective interval. The Lisa Anne well encountered effective reservoir sands in the objective interval, with low saturation “fizz gas,” indicating a breached trap. A fault was recognized over the prospect, which extends to the seafloor. However, the risk of leakage through that fault was difficult to quantify pre-drill. Chimney processing was done on the 3D seismic volume, which goes through the two structures to determine if vertical fault leakage could be detected. In Figure 6, a seismic line with the high probability chimneys (in gray to black) shows clear charging of both traps through gaps in the salt canopy. It also shows a lack of chimneys above the King Kong Field, and possible leakage above the Lisa Anne trap. However, the amount of leakage is not clear. A 3D image of the chimney results shows the leakage aligned along the southeast trapping fault more clearly (Fig. 7). The vertical leakage shows the same pockmarked (columnar) character as described by Ligtenberg (2005); please also see Figure 3.

There is no vertical leakage above the King Kong Field, while above the Lisa Anne dry hole leakage is along the full extent of the trapping fault. Using the classification scheme described in the previous section (Fig. 4), the King Kong Gas Field is classified as a fault-seal trap. The Lisa Anne dry hole is classified as a fault-leak trap. These two examples are the end members in a range from no vertical fault leakage to fault leakage along the full length of the trapping fault. Many practical cases fall in between these extremes. Among other factors, the lateral length of leakage along a fault is indicative for expected hydrocarbon column height. Larger leakage length indicates lower expected hydrocarbon column heights, or in dual phase systems a tendency to retain only an oil column. Thus mapping extend of vertical leakage along fault systems can aid pre-drill economical analysis of prospects. This is studied and described in more detail by Cowley and O’Brien (2000).



**Figure 5.** The structure on the left is the King Kong Gas Field characterized by AVO and frequency attenuation anomalies. The structure on the right is the Lisa Anne trap with similar AVO and frequency attenuation anomalies at the same objective interval. Seismic data courtesy of WesternGeco.



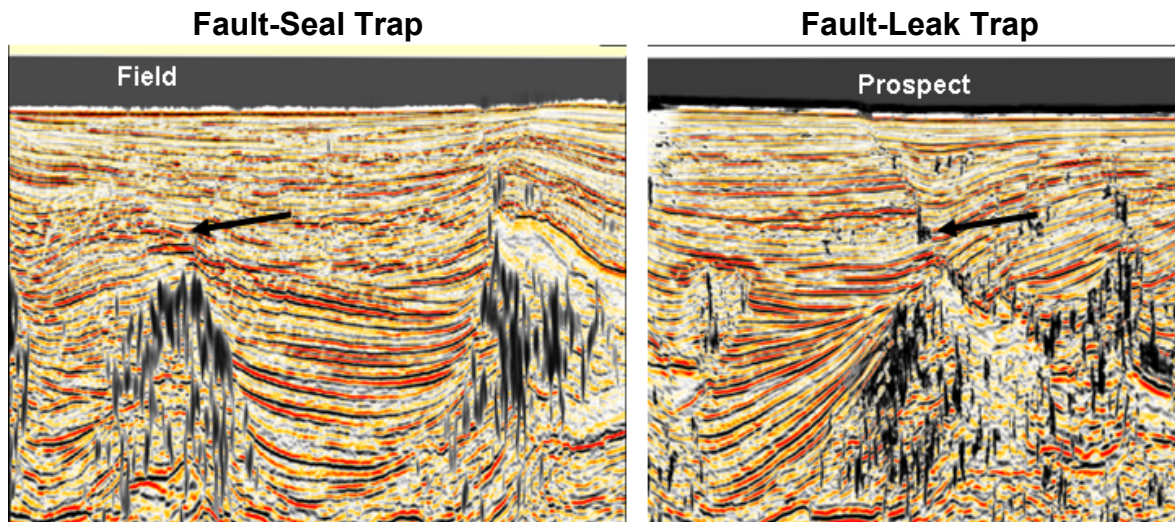


Figure 6. The same sections as shown in Figure 5 with the high probability chimneys (in gray to black) superimposed. It shows that both field and prospect have vertical hydrocarbon migration below the trap, indicating good hydrocarbon charge. However, the prospect shows signs of vertical hydrocarbon migration (fault leakage) above the reservoir, indicating a vertical fault-seal risk. Seismic data courtesy of WesternGeco.

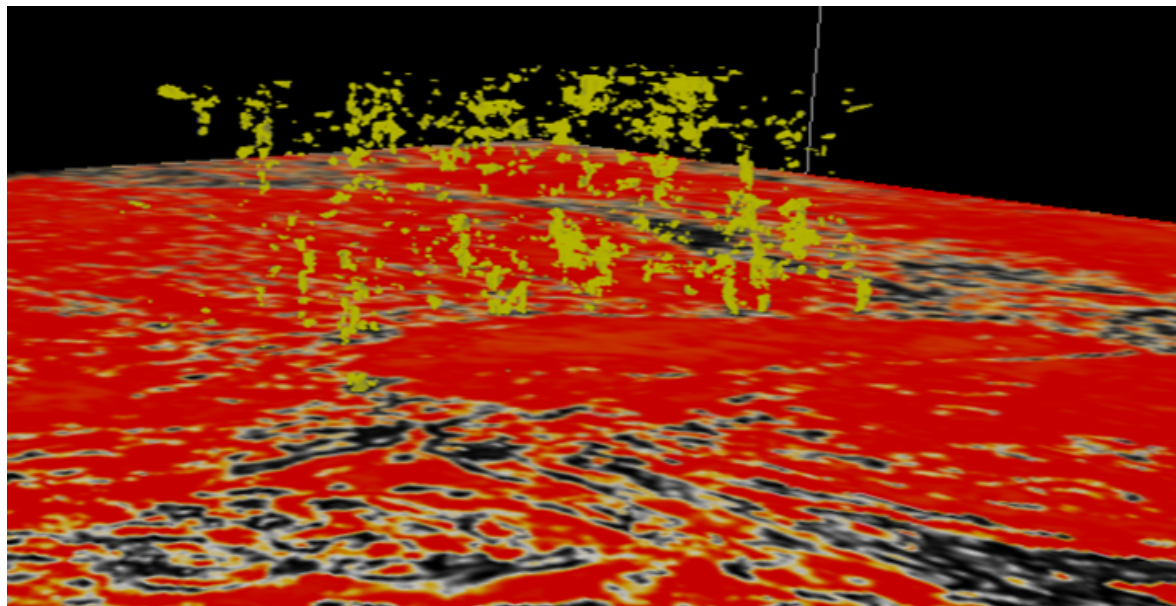


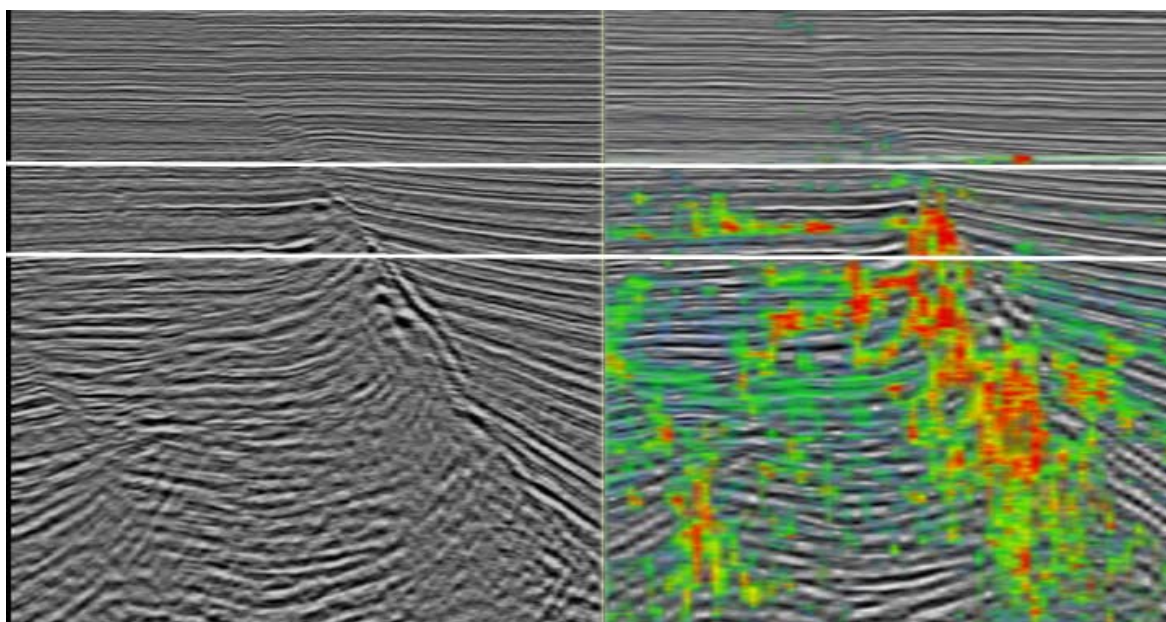
Figure 7. 3D display of gas chimneys (in yellow) along the fault surface above the Lisa Anne prospect displayed in the right frames of Figures 5 and 6. It is evident that the supra-trap fault is very leaky and presents a significant top seal risk. These results confirm the results of the Lisa Anne well, which indicate low saturation gas sands in the objective interval.

## GULF OF MEXICO SHELF: FAULT-SEAL TRAP

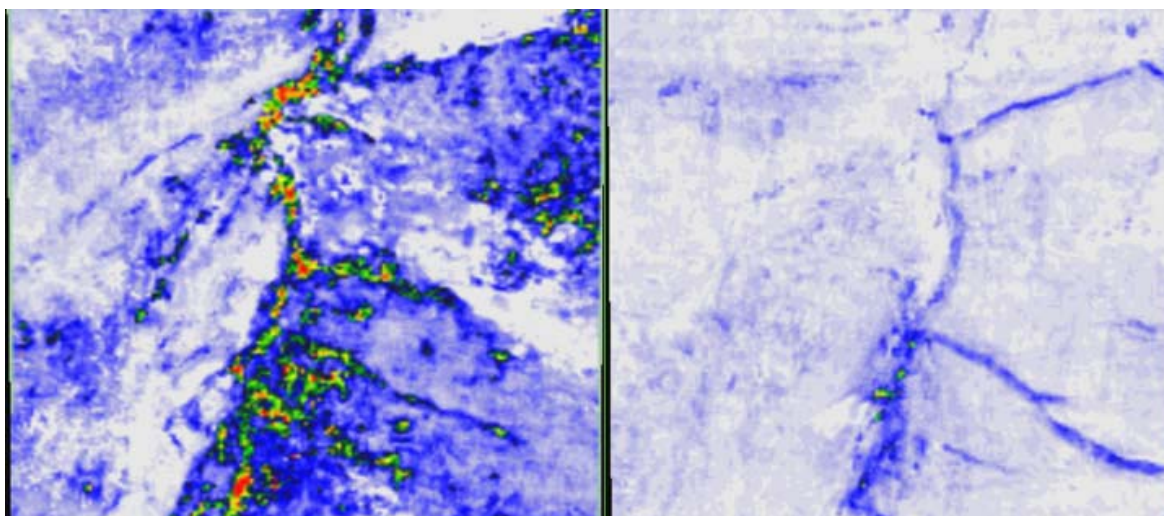
Another example from the Gulf of Mexico shows two stacked reservoirs with a fault-dependent trap. In section view (Fig. 8), it is seen that the fault is leaking in the deeper part approximately up to the level of the reservoirs (the increased amplitudes left of the fault plane, between the two white lines). Above the reservoirs the fault is sealing. This is a typical example of a fault-seal trap, where the deeper part of the fault provides a charge pathway and the shallower part of the fault is effectively sealing. Obviously the level where the fault behavior is changing is prone to accumulate hydrocarbons, provided a three-way closure is present. Also, the top of the fault related chimneys coincides with the top of overpressure, an observation that is repeated in many Gulf of Mexico case studies. In this study, there is some concern that the observed chimney may in fact be a fault shadow rather than true hydrocarbon migration. However the presence of two confirmed reservoirs exactly at the top of the gas chimney already directs us towards a geological cause for the zone of low seismic data quality. Evaluating fault and chimney attributes just below and just above the reservoir (Fig. 9) confirms that the chimney has the typical pockmarked character associated with vertical hydrocarbon migration along faults. Fault-seal traps are very common in the Gulf of Mexico and have a high chance to retain a significant hydrocarbon column.

## CONCLUSIONS

Numerous studies in the Gulf of Mexico and basins worldwide has shown that fault related hydrocarbon migration pathways can be distinguished in seismic data using a gas chimney processing. The methodology uses a set of directional attributes and neural networks to highlight these pathways in normally processed seismic data. The results of this processing can be validated by linking the chimneys to shallow DHIs and chemosynthetic build-ups, deep hydrocarbon kitchens, and distinctive pockmark morphology. When gas chimney results are



**Figure 8.** A seismic section showing a drilled stacked pay in a typical fault seal trap configuration. The reservoirs are the higher amplitude reflection on the right side of the fault between the white lines. In the right image, the gas chimney detection is overlain on the seismic, with probable vertical fluid migration pathways in yellow and red. The two white lines indicated the level of the below and above reservoir extraction of vertical fluid migration pathways in Figure 9.



**Figure 9. Display of timeslices below (left) and above (right) the reservoirs seen in Figure 8. The more intense blue tones provide an indication of the fault system. The yellow and red overlay show the most probable vertical fluid migration pathways. In the left image, we see the typical pockmarked pattern associated with vertical fluid flow with the most intense pathways at fault intersections. The right image shows, that in the next time slice (a few 100 msec upward), all evidence for vertical fluid flow has disappeared. From this we can infer the presence of excellent seal, possibly due to decoupling of the fault systems, in between the time slices.**

overlay on time slices and fault surfaces, we can often distinguish which faults have been conduits for hydrocarbon migration. Many times these migration pathways occur at fault intersections or bends in the fault surface which may be zones of weakness for vertical fluid flow.

Structural traps with effective reservoir have been divided into eight classes, based on the character of the chimneys below and above the reservoir interval. This classification provides a means of assessing vertical charge and vertical seal risk prior to drilling. Over 125 case studies of fields, dry holes, and sub-commercial discoveries have been studied in a number of petroleum producing basins worldwide. The number of dry holes evaluated is relatively under sampled, and examples of mud volcanoes, seepage pipes, and blow out pipes are currently limited. However, preliminary conclusions indicate that structures classified as non-fault-seal traps, fault-seal traps, and gas-cloud traps are at a low risk for vertical charge and seal. In contrast, structures classified as fault-leak traps are at a higher risk for seal failure. Fault-seal stress analysis is a critical technology in this type of trap environment to assess timing of fault leakage.

The case studies presented shows how fault-leak traps can be distinguished from fault-seal traps. This is especially critical to distinguish fully saturated gas reservoirs from low saturation “fizz gas,” because traditional geophysical tools such as AVO and frequency attenuation cannot do this effectively.

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