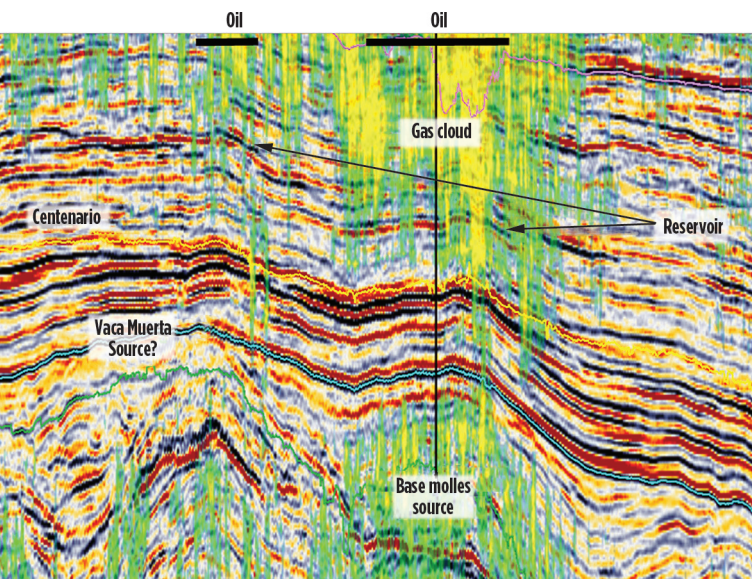


Tracking hydrocarbon seepage in Argentina's Neuquén basin



The integration of surface microbial surveys and gas chimney probability volumes is useful for detecting overlooked pay and unconventional resources in mature basins, such as the Neuquén basin.

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Surface indications of hydrocarbon seepage have been influential in the discovery of oil and gas fields since the beginning of petroleum exploration. To this end, detailed geochemical and microbial surveys are an important means of detecting overlooked oil and gas reservoirs. The technique involves analyzing shallow, surface soil samples for hydrocarbon oxidizing microbes. As depleted reservoirs quickly lose their associated microbial anomalies, such surveys can subsequently detect non-depleted reservoirs.

While microbial surveys are an effective means of measuring hydrocarbon micro-seepage, they have several limitations. First, hydrocarbon micro-seepage is predominantly vertical, but it can be influenced by shallow faulting. Thus, the geochemical anomaly may be offset from the source of the anomaly. Sec-

ondly, we cannot tell from the microbial anomaly, the depth of the hydrocarbon reservoir. To provide a link from reservoir to surface, and to tie the surface expression of seepage to the suspected hydrocarbon trap, it is important to delineate the hydrocarbon migration pathways in the 3D seismic data. Such vertical hydrocarbon migration paths are generally recognized as vertically aligned zones of chaotic, often low amplitude reflectivity, described variously as blowout pipes, gas clouds or in the case of this article, gas chimneys (Cartwright et al., 2007). These chimneys may be vertical or sub-vertical of the related faults.

In this article, we will look at how the creation of a chimney probability volume in 3D can help determine where the hydrocarbons originated, and where they migrated within the field. This is achieved through the generation of a neural network from which multiple seismic attributes are extracted as examples of gas chimneys. In this way, the chimney probability volume acts as an important complement to the microbial survey and helps the interpreter gain a better understanding of the prospective interval from which the hydrocarbons are originating.

NEUQUÉN BASIN FIELDS

The fields used to test this new approach were the Agua Del Cajón and El Salitral fields in the Neuquén basin of Argentina. We chose the fields for a number of reasons: the surface geology was suitable for geochemical surveys, such as microbial surveys; a recent microbial survey had taken place over much of the area; the two fields produced oil and gas from multiple reservoirs; the petroleum system in the area was well understood; and drilling had taken place prior to the geochemical survey. Hydrocarbon micro-seepage is a dynamic process, with seepage patterns often changing rapidly in response to production-induced changes (Schumacher, 1996).

The Neuquén basin is a foreland basin on the eastern flank of the Andean Cordillera (Fig. 1) and has undergone multiple rifting episodes (Vergani et al., 1995) from the late Triassic period. The Agua Del Cajón area contains the El Salitral and Agua Del Cajón fields, which have been covered by a recent 3D survey, Fig. 2. The primary producing zones in the area are the Lower Jurassic Molles gas sands, Middle Jurassic Lajas gas sands, and Upper Jurassic Tordillo gas sands. Oil-producing Quintuco fractured carbonates were encountered in a number of Agua Del Cajón field wells, and Centenario oil sands are producing in the El Salitral field.

The initial goal was to highlight overlooked oil reserves in the Quintuco fractured carbonates using surface geochemical sampling. Surface geochemical samples were acquired in the fields to determine the location and presence of geochemical anomalies, and the composition of migrated hydrocarbons as well as target areas for exploration drilling. Analysis was performed on 1,534 microbe samples and 178 sorbed gas samples.

Gas clouds observed over the Centenario oil reservoirs in Argentina's Neuquén basin.

Fig. 1. The Neuquén is a foreland basin on the eastern flank of the Andean Cordillera.

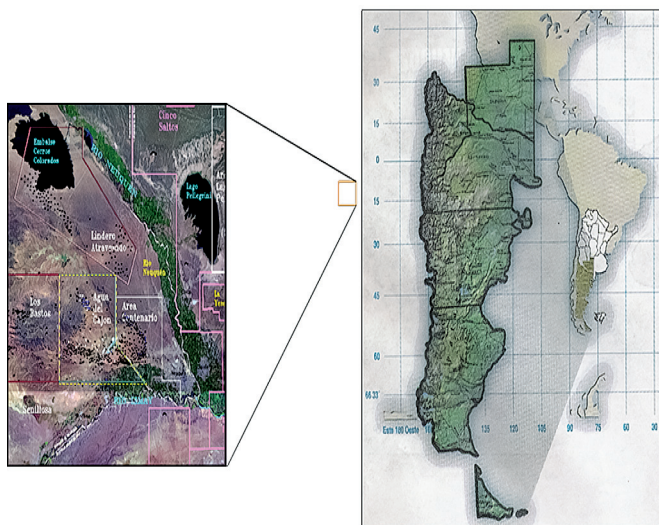
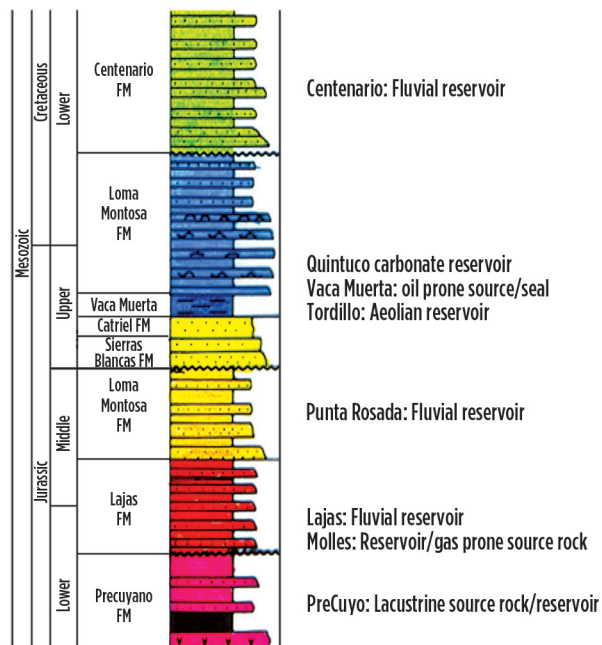


Fig. 2. Agua Del Cajón area contains the El Salitral and Agua Del Cajón fields, which have been covered by a recent 3D seismic survey.

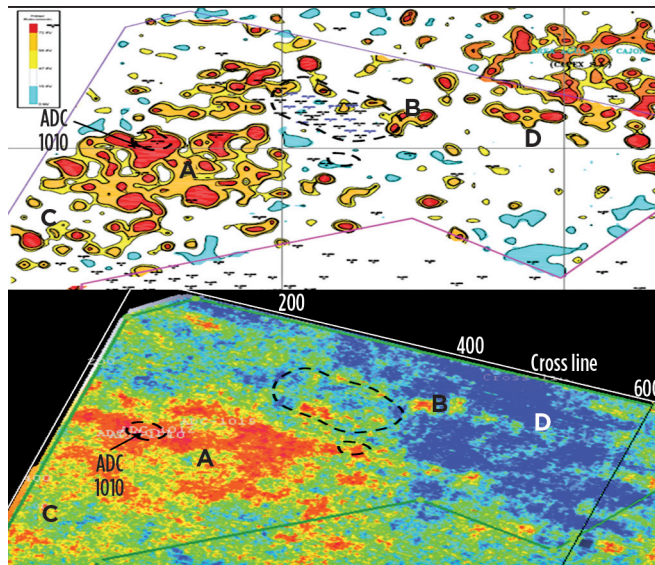


The results of the microbial analysis documented the presence of a large micro seepage anomaly (A) in the southwest sector of the survey, **Fig. 3**. Other anomalies were also noted in the area (B, C, & D). **Figure 3** also illustrates how the ADC 1010 well was drilled on a strong microbial anomaly. The well is producing from fractured Quintuco limestone. As expected, microbial values over the Agua Del Cajón field, itself, showed medium-to-low values due to pressure depletion from production. The geochemical data also suggest a correlation to Centenario or Quintuco oil-producing formations.

CHIMNEY DETECTION METHODOLOGY

A chimney probability volume was generated to help map the gas chimneys in 3D seismic data, a particularly challenging

Fig. 3. The results of the microbial analysis documented the presence of a large micro seepage anomaly (A) in the southwest sector of the survey. This anomaly correlates closely with the chimney results in the shallow section above Top Centenario (red values indicate high-probability chimneys).



task, due to the diffuse nature of the chimneys. By generating a neural network from multiple seismic attributes extracted as examples of gas chimneys picked by the interpreter, the volume can then be visualized in 3D.

Whereas single attributes, such as similarity or other coherency type attributes, can potentially highlight gas chimneys, using multiple seismic attributes allows the interpreter to show the location of chimneys on horizons and time slices, visualize the migration pathway in 3D, and determine the origin of the hydrocarbons and where they terminate. As part of the chimney detection methodology, the interpreter finds good examples of chimneys within the 3D seismic data. He or she selects example locations, or “picks,” both in the chimneys, and in low- amplitude or discontinuous zones, which are not suspected to be chimneys. A set of attributes are then chosen, which show the chimneys most clearly on key seismic lines.

Since chimneys are generally low-amplitude chaotic events, attributes, such as similarity, dip variance and energy (amplitude), are often used. Attributes that measure signal-to-noise ratio are also useful, and gas chimneys may also cause a high-frequency attenuation, due to scattering of the seismic signal. Thus a ratio of high pass (>36 Hz) energy to low pass (<12 Hz) energy may show subtle chimneys.

Once a set of attributes is chosen, the attributes are calculated at the picked chimney and non-chimney sites. This information is fed into a neural network, and a chimney probability ‘meta-attribute’ is created. The neural network results are then applied to selected seismic sections and time slices to determine if the observed chimneys are being detected correctly.

Once a chimney probability volume is processed, it can be displayed as overlays on seismic lines, horizon slices, time slices, or fault surfaces. Horizon slices, for example, show the morphology of the chimneys, which can give clues as to their validity. By displaying the chimneys on a horizon showing faulting, we can determine if the migration is related to faults.

Not every vertically aligned, low-amplitude discontinuity in seismic data is related to hydrocarbon migration, however. Thus, the chimney probability volume results must be validated through a series of key questions:

- Do we observe gas shows in wells drilled in the detected chimneys?
- Do we observe a correlation between observed chimneys and surface geochemical anomalies?
- Do the chimneys have characteristic pockmark morphology on horizon slices or time slices? Chimneys frequently have a round circular morphology and occur at fault intersections.
- Do the chimneys originate from known or suspected thermally mature source rock intervals? This is especially critical in distinguishing true hydrocarbon migration from de-watering of shaly intervals, which results in polygonal faulting that may resemble gas clouds.
- Are chimneys linked to hydrocarbon-filled reservoirs, shallow DHIs, amplitude anomalies, or chemosynthetic build-ups?
- Are the chimney results supported by basin modelling? Either 2D or 3D basin models will often indicate zones for preferential vertical hydrocarbon migration, based on fluid pressures and rock physics.

CHIMNEY PROCESSING RESULTS

In the Agua Del Cajón 3D seismic data set, chimney picks were made on a few key lines, primarily between the Base Molles and Grupo Neuquén horizons, Fig. 4 (top). No picks were made above the Grupo Neuquén, since the quality of the seismic data was much poorer, due to surface statics and low fold. Picks at the PreCuyano interval were also considered less reliable as the shallow picks were in an interval with little structuring and no obvious surface irregularities. At all these locations, a selection of seismic attributes was extracted and fed to the neural network, together with the user-interpreted chimney and non-chimney picks.

The neural network was then applied to the complete seismic survey, and a 3D map of gas-chimneys was created. Figure 4 (bottom) shows the results overlain on the seismic data, with high-probability chimneys displayed in yellow and probable chimneys shown in green to blue. The chimney processing shows deep chimneys, roughly originating from the Molles interval and charging Molles and Tordillo objective intervals. It also shows shallow chimneys, which originate from the Centenario interval.

To determine the validity of these chimneys, we applied the six criteria discussed previously. The results included a good correlation between observed chimneys and the hydrocarbon shows in the wells in this study; a fair correlation with the surface geochemistry (as shown in Fig. 3); the chimneys tending to have a circular morphology; most of the deep, highly probable chimneys originate near the Base Molles interval (the primary gas-prone source rock in this area and thermally mature); the deep chimneys are closely associated with pay intervals in Agua Del Cajón and El Salitral fields; and finally, that most of the shallow chimneys have at least an indirect correlation to similar amplitude anomalies.

The neural network map of the gas chimneys is likely to have high confidence between the Base Molles and Grupo Neuquén horizon, while having lower confidence at shallow intervals. Figure 5, for example, shows a chimney probability horizon

Fig. 4. In the Agua Del Cajón 3D seismic data set, chimney picks were made on a few key lines, primarily between the Base Molles and Grupo Neuquén horizons (top). The neural network was then applied to the complete seismic survey and a 3D map of gas-chimneys was created. The image at the bottom shows the results overlain on the seismic data with high-probability chimneys displayed in yellow and probable chimneys shown in green to blue.

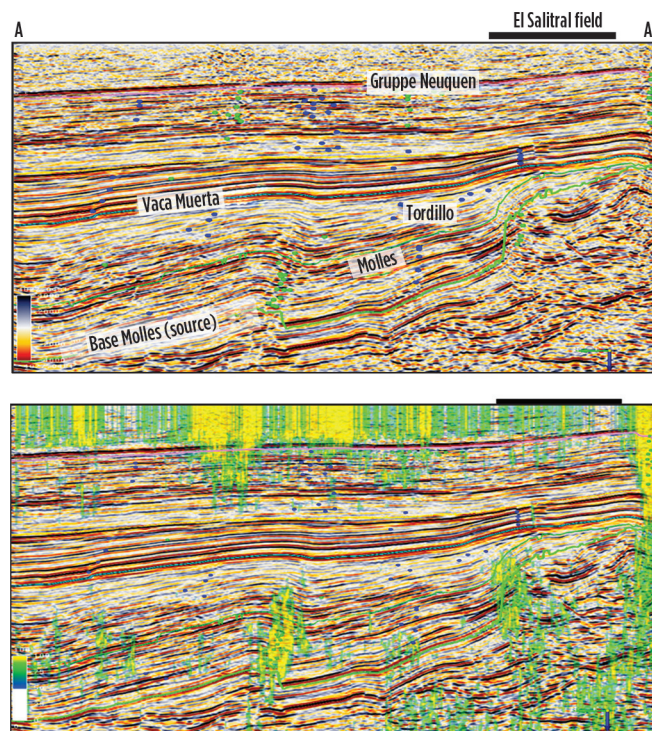
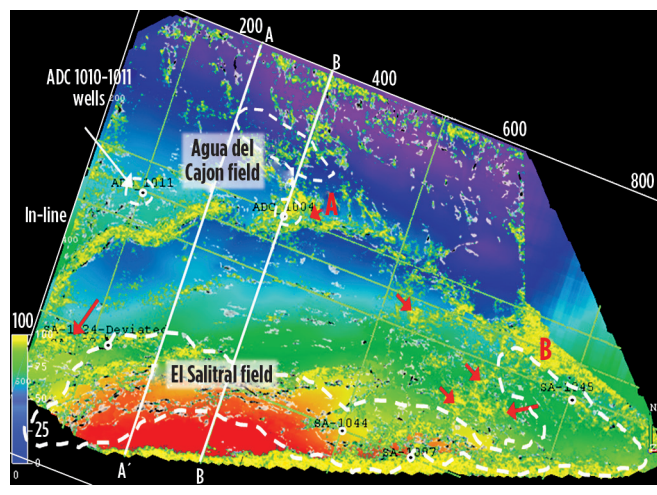
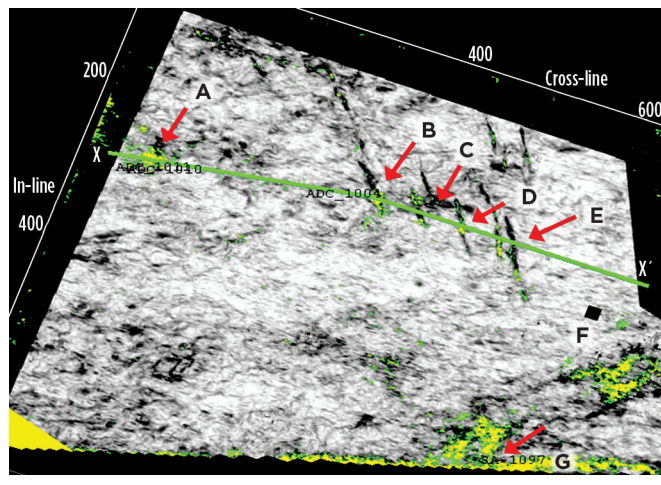


Fig. 5. A chimney probability horizon slice 80 ms above the Base Molles horizon, which has been created to show hydrocarbon migration pathways originating from the Molles source rock interval and charging the Molles reservoirs approximately 300 m above the source rock interval.



slice 80 ms above the Base Molles horizon, which has been created to show hydrocarbon migration pathways originating from the Molles source rock interval and charging the Molles reservoirs approximately 300 m above the source rock interval. Thermally mature source rock has also been identified in the section near the Base Molles horizon. Fault-related high-probability chimneys can also be identified in this interval, and they

Fig. 6. An arbitrary horizon slice 180 ms above the Base Centenario, which shows the fault attribute with chimney probability results overlain.



directly underlie the Molles reservoirs in El Salitral and Agua Del Cajón fields (white dashed lines). The chimneys noted with red arrows also have characteristic pock mark morphology and can be considered highly reliable.

CORRELATION OF SHALLOW CHIMNEYS

The primary purpose of this study was to determine if we could correlate shallow surface geochemical anomalies to subsurface hydrocarbon accumulations using gas chimney detection. The first consideration is to identify how well the shallow microbial anomalies tie to the shallow chimneys. If we go back to Fig. 3 (bottom), for example, the horizon slice shows the maximum chimney probability 20-100 ms above the Grupo Neuquén horizon. If we overlay the major microbial anomalies on this display, we observe a rough correlation between the major anomalies—A, B, and C, and the shallow chimneys. Although some of the anomalies are slightly offset from the chimneys, this can be explained easily by non-vertical migration (fault-related) migration in the shallow subsurface, or an offset between shallow gas sands, and the chimneys which are charging them.

The second consideration is to assess how well the shallow chimneys tie to subsurface hydrocarbon accumulations. If we look at typical seismic lines over the Agua Del Cajón structure in Fig. 4, we can see that the chimneys generally originate slightly above the Base Centenario horizon. Figure 6 takes this further by illustrating an arbitrary horizon slice 180 ms above the Base Centenario, showing the fault attribute with chimney probability results overlain. The figure shows that the chimneys are associated with NNW trending shear faults (A, B, C, D, and E).

Significantly, the only places where we have penetrated Quintuco or Centenario oil are areas overlain by shallow gas clouds. These gas clouds originate from the Base Molles source rock interval. These chimneys are not well-imaged in the strongly reflective Vaca Muerta to Quintuco interval. However, frequency attenuation and signal deterioration in the interval between the deep chimneys and shallow chimneys in the figure on page 101, suggest that the chimney goes through the formations. This indicates that gas generated

from the Base Molles source rock migrates through the relatively low maturity Vaca Muerta oil prone source, causing an expulsion of oil. This oil migrates into the Quintuco and Centenario reservoirs.

CONCLUSIONS

From these observations, we can make several conclusions regarding the petroleum system in Agua Del Cajón and El Salitral fields, which can be used further to guide exploration efforts. First, we can detect vertical migration pathways, which represent expulsion of primarily gas from the Molles source rock interval. These pathways are generally associated with a chaotic, low-amplitude seismic character. The hydrocarbon migration pathways are often related to thrust faults that penetrate the Molles source rock interval but may also be related to shear faults, and especially fault intersections or bends. These deep-migration pathways provide hydrocarbon charge to the deep Molles, Lajas and Tordillo reservoirs in the Agua Del Cajón and El Salitral fields.

Secondly, we can detect areas where hydrocarbon migration is occurring through the relatively impermeable, Vaca Muerta marine, oil-prone source rock. These pathways are related to the major bounding thrust fault and to minor NNW trending shear faults. This vertical migration releases hydrocarbons from the Vaca Muerta source rock (primarily oil), which charges adjacent Quintuco carbonate reservoirs and overlying Centenario or Neuquén fluvial and deltaic reservoirs.

This article has shown how useful the integration of surface microbial surveys and gas chimney detection is for the detection of overlooked pay and unconventional resources in very mature basins, such as the Neuquén basin of Argentina. Microbial surveys can indicate areas of possible, undepleted hydrocarbon reservoirs. Gas chimney processing can then provide clues as to the subsurface location of overlooked reservoirs and origin of the hydrocarbons. [WO](#)

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