

# From Black Magic to Swarms: Hydrocarbon Exploration using Non-Seismic Technologies

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## Summary

“Why don’t hydrocarbon detection methods always work?” Only one third of recent exploration new venture opportunities used surface hydrocarbon detection methods to calibrate the presence of charge in the system. There are distinct differences between the manifestation of hydrocarbons at surface in these environments, which drive the methods applied and ultimately the way in which we interpret these data. Most commercially available onshore ground-based techniques are restricted in their application to prospect-scale assessment, primarily because of logistics and costs. Unfortunately, prospect-scale application often results in ambiguous or misleading results. Offshore applications of surface hydrocarbon methods are better calibrated and practiced. Airborne and satellite systems are commonly used in basin-scale applications. Non-seismic geophysical exploration techniques are important strategic components of the exploration toolkit when properly calibrated and applied. In this paper we review non-seismic exploration technologies including gravity, magnetics, marine electromagnetics, airborne EM, magnetotellurics, remote sensing, LightTouch, and others, indicate recent advances and developments that have enhanced their value, and present real examples and case histories that illustrate the benefits in using combinations of these tools for large scale exploration activities.

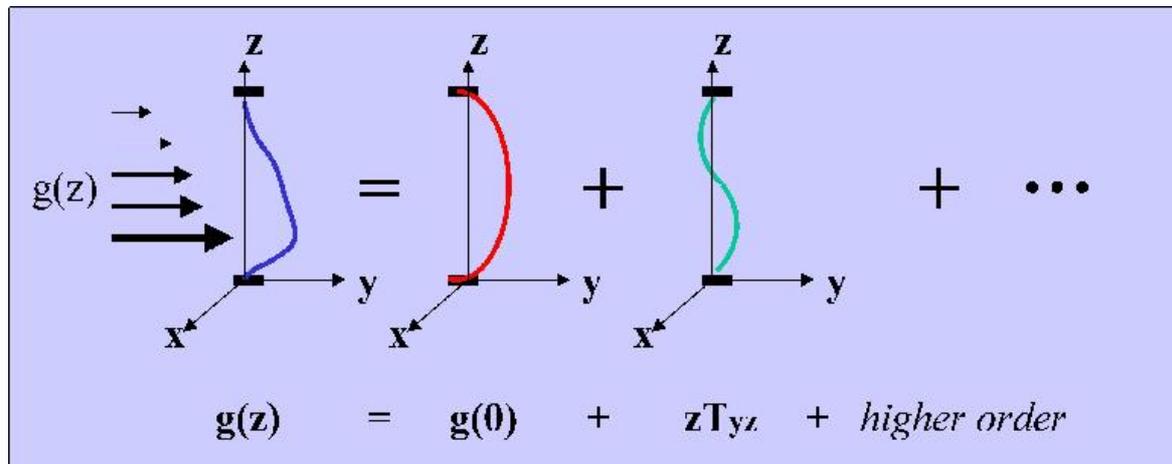
## Methodology

Subsurface de-risking is presently almost exclusively done by methods using seismic data. Indeed all other data collected at the surface is referred to as 'non-seismic' data expressing this fact. However, there are emerging gravity measurement technologies that could fundamentally change the game of subsurface risk management. Recently we have discussed how gravity gradiometer data have been fully integrated in the cycle of iterative prestack depth migration (PSDM) anisotropic model updating to arrive at a high-fidelity subsurface model which can be used both for improved seismic imaging as well as seismic amplitude related studies. Based on results so far we conclude that the potential of this technology could fundamentally change the role of gravity field measurements in the process of subsurface de-risking as in some cases the resolution of subsurface structures is comparable to seismic resolution. Applications range from 4-D reservoir monitoring, to structural definition, to borehole applications using gradiometer data acquired on the land and from marine and airborne moving platforms.

Recently, Veryaskin (2000) reported a breakthrough in the design and manufacturing of an absolute instrument for measuring gravity and magnetic gradients. His proposal is to use a mechanical string or ribbon whose deflection under the influence of an inhomogeneous gravity field can be measured very accurately. In particular he shows how the different harmonics of the string are coupled to the different components of the gravity field: the even or symmetric harmonics of the string couple directly to the gradient (and odd numbered) higher order derivatives of the gravity field. By applying suitable boundary conditions (e.g. by constraining the mid-point of the string) one can (at least in principle) project out mechanically the lowest odd-mode that couples to linear accelerations (the common mode or C-mode deflection), and isolate the lowest symmetric harmonic the S-mode that couples directly to the gradient. Note that this is very similar to the historical torsion balance, of which the single degree



of freedom, the rotational angle, directly couples to the gradient field. However, unlike the torsion balance a constraint string sensor operates very fast and should allow for very accurate gradient measurements. Since it is an absolute instrument the calibration and stabilization is much simpler than a differential accelerometer system, hence its deployment may turn out to be more economical.



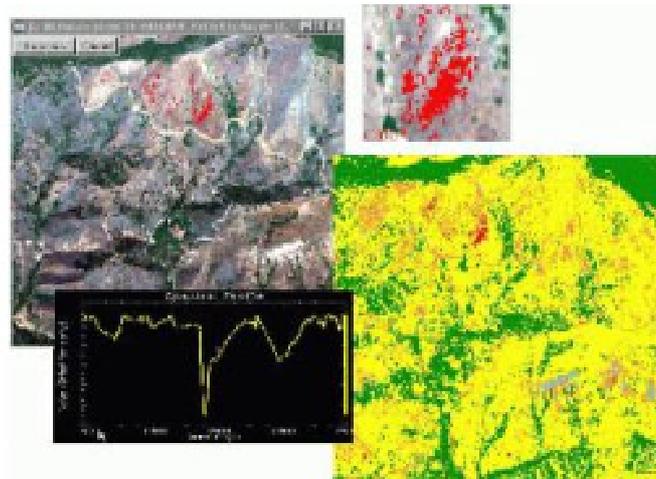
**Figure 1.** Concept of a string gravity gradiometer (c.f. Veryaskin 2000). The various components of an in-homogenous force field, e.g. provided by an inhomogeneous gravity field couple differently to the string excitations. By providing a (mechanical) boundary condition constraining the string to deflect at its midpoint the common mode factor can be eliminated thus isolating the signal corresponding to the gradient field.

Gas-Fluid contacts within reservoirs have the potential to create large density contrasts that may produce gravity anomalies detectable by suitable sensitive gravimeters and gradiometers. In a time-lapse, or 4-D mode, these sensors may act either directly as monitors of reservoir performance or can be used as “triggers” to aid in choosing when an expensive 4-D seismic “snapshot” might be required. As discussed by Biegert and Witte (2001), gravity has been used to detect and measure fluid level changes for both hydrothermal and hydrocarbon reservoirs. Land surface gravity measurements have been used to monitor gas/liquid movement at Prudhoe Bay, Alaska and have attained repeatability of 5-10  $\mu\text{Gal}$  with measured changes of up to 250  $\mu\text{Gal}$ . Vertical resolution of the GWC is on the order of meters with the field at 2500 m depth. Borehole gravity can also be used to address the “coning” problem in wells. Manik Talwani of Rice University, Lockheed-Martin, and several oil companies tested a land-based gravity gradiometer in a torsion-balance configuration to monitor steam-front development in shallow reservoirs at Belridge, California. Field tests suggest a sensitivity of 0.5 E with steam front anomalies of 1-5 E. Time-lapse gravity has also been used in Shell. Van Popta successfully used three time-lapse borehole gravity surveys to monitor the gas-oil-contact (GOC) in Gabon’s Rabi Field. More recently, we evaluated the 4-D gravity and gravity gradient response to gas cap development and OWC movement for a reservoir simulation analysis of the deepwater Gulf of Mexico Mars reservoirs and analyzed surface, seafloor, and borehole configurations.

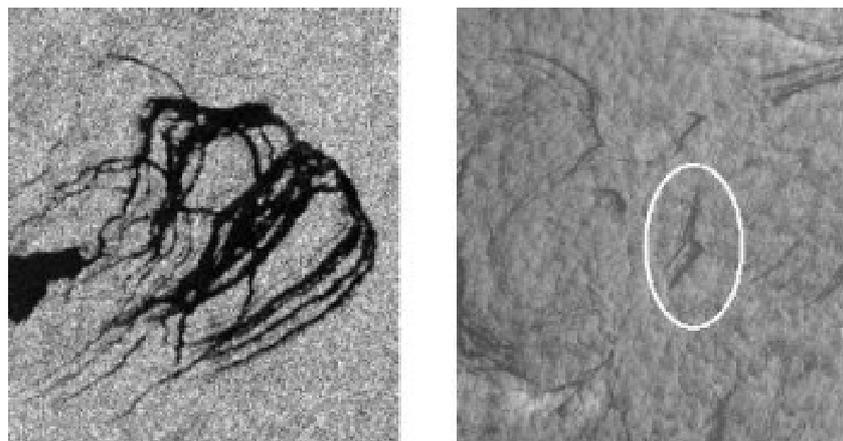
Our industry is changing rapidly, but not as rapidly as the remote sensing technologies that support so many of our business decisions. A new generation of satellites is changing the way we look at the world – and the way we conduct our business. Remotely sensed data from new airborne and marine geophysical systems, especially gravity and magnetics, are increasingly being used to reduce risk and improve profitably in our industry. Although they have historically been used primarily for reconnaissance in the exploration, or upstream, side of our business, remotely sensed data can and do play an important role in the downstream side, even all the way down to the gasoline pump. Remotely sensed data are modern, digital data sets. Satellite data provide global coverage, available on-demand from on-line web-browsable digital archives or in real-time by tasking the satellite to obtain imagery for targets of opportunity. Easily georeferenced and made into maps, the data offer synoptic views of large areas or detailed images of a small region. Numerous space borne sensors offer panchromatic, multispectral, hyperspectral, radar, and multitemporal views of the earth, and new sensors will have



spatial resolutions ranging down to one meter. We have more channels of data with higher resolution than we have ever had before, and hyperspectral sensors can identify different surface materials based solely on reflectance spectra characteristics.



**Figure 2.** Hyperspectral sensors Dibblee oil seeps (Ellis, 2001).



**Figure 3.** Direct detection of hydrocarbon seeps using radar imagery.

A new, low-cost oil and gas prospecting technology from Shell Global Solutions is helping to find oil and gas reserves by measuring ethane gas escaping from the ground. LightTouch was developed by Shell working in co-operation with scientists from the Optics Applications Group at the University of Glasgow. Using what is probably the world's most sensitive ethane gas sensor, equipment that measures wind speed and direction, and a wireless local area network to download data in real time to computers, information can be analyzed while the survey is being conducted. Sources of hydrocarbons can be detected at a range of several kilometers from the sensor. Ethane gas is a good indicator of oil and gas reserves because it is formed through the cracking of larger hydrocarbon molecules. Unlike methane, it is not produced by biological decay, and the atmospheric background concentration is a thousand times lower, meaning that seepages of ethane show up far more clearly.

Active source marine and airborne electromagnetic systems can reliably map the subsurface resistivity structure of the earth. Archie's law indicates that the method is more sensitive to high saturation hydrocarbon pore fill and due to the low frequency nature only relatively large accumulations of high saturation will be detectable, and mineral alteration zones that may be indirect hydrocarbon indicators can also be identified.



Figure 4. LightTouch exploration in the Oman desert.

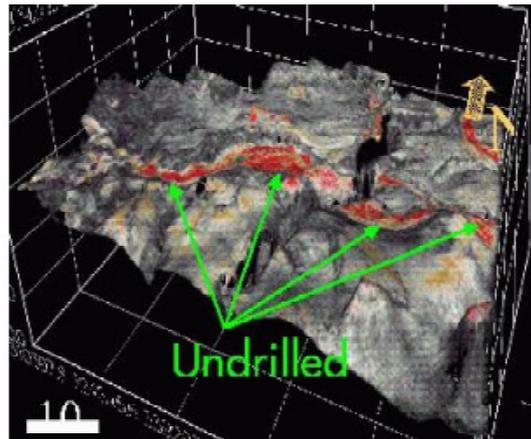
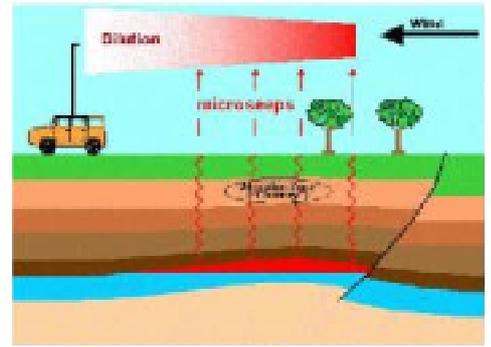


Figure 5. Marine CSEM results from a Shell survey.

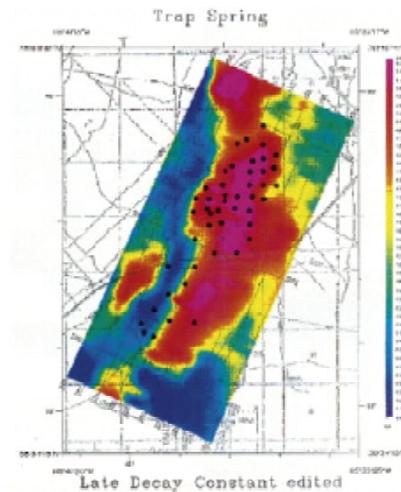


Figure 6. Fugro airborne EM mapping alteration zones.

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