Integration of Seismic and Non-seismic methods for Hydrocarbon Exploration;- a Bolivian case history

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Summary

The increasing complexity of new exploration targets is the driving force behind the integration of seismic and non-seismic methods into the interpretation process. The increasing availability of high quality digital data, and truly integrated workstation software, has enabled interpreters to simultaneously model seismic and non-seismic data sets. An example is drawn from a prospect in Bolivia, where geochemistry, airborne magnetics, airborne gamma-ray spectrometry and land gravity information was integrated with the seismic data sets to build geological and petroleum system models.

Introduction:

Integration of seismic and non-seismic methods in the exploration for hydrocarbons is not a new concept. Gravity information has, for several decades, been successfully used in the Gulf of Mexico to address the problem of defining the salt/sediment boundary, where even the best quality 3-D seismic data task does not meet the challenges (Nafe & Drake 1957, Gardner 1974, Bain et al 1993). Similarly, the combination of gravity and magnetic information, have complimented seismic data in the interpretation of basin basement character and structure. Data from these two methods have been used in a wide range of tasks; from definition of the tectonic setting of the sedimentary basin, to detailed mapping of the character of thebasement in conjunction with information from seismic data.

Electromagnetic methods, such as MagnetoTellurics and Transient ElectroMagnetics, are less often used, but serve well in situations where overthrusts and younger volcanic flows cover the sediments of interest. In such cases, the ability to test whether an underlying sedimentary section exists, and if so, also have an indication of a possible depth to the top and its thickness, can enable successful reprocessing of the seismic data and achieve a useful interpretation.

Perhaps the least used set of tools are those associated with the geochemical "plume" of altered material that can exist above a hydrocarbon accumulation. These are more correctly considered geochemical anomaly targets, with some physical property change that can be practically measured and mapped using geophysical tools. IP and Gamma-ray spectrometry are probably the most commonly used tools in plume detection and mapping, with magnetics, used on occasions where the area is sufficiently clear of disturbing cultural features (Morse & Zinke 1995, Zinke & Morse 1996, Foote 1995 Schumacher 1996, Donovan 1984).

The rapidly growing momentum in integrating seismic and non-seismic methods in exploration for hydrocarbons would seem to be largely due to:-

- the exploration targets occuring in more complex and difficult settings ,
- both seismic and non-seismic data acquisition and processing are improving, and,
- truly integrated workstation software tools for the various geophysical methods are available.
- Building an earth model from the information brought by all of the various exploration methods, and successfully complying with the constraints imposed, gives greater confidence in the geological interpretation.

An example of a project in southern Bolivia is presented, where multiple non-seismic methods were used to augment the existing seismic information.

Bolivian Project:

The Oil & Gas Concession Block lies in the southern part of Bolivia, and has been the subject of an intense evaluation effort since the early 1970s. The surveys included 2-D and 3-D seismic acquisition and interpretation, detailed airborne magnetic and gamma radiation spectrometry, detailed geochemical surveys, land gravity survey, drilling, well log, reservoir analysis and evaluation for the sub-thrust and footwall plays.

Within the area, the Devonian sequence is one of the important objectives, as the largest fields in the region, produce gas, condensate and oil from this geological interval. The most prominent structural feature in the concession area, is a regional near N-S thrust fault zone, which hosts the prospective areas in the concession, both in the hanging wall and footwall. It is also the major migration route for hydrocarbons into the traps in the region.

The terrain, although not particularly mountainous, is difficult and costly to access with large equipment, and was an added encouragement for the application of non-seismic methods by the current concession holders; particularly the use of airborne methods.

Interpretation of the seismic data, led to mapping of several promising structures along the hanging wall. However, from past experience in the area, not all such structures have hydrocarbon accumulations. Thus a geochemical test survey was carried out over the southern portion of the area and also the adjoining producing areas. The data from the geochemical test survey showed that, if productive, the structures would contain gas rather than liquids. There also would seem to be a correlation between the geochemical anomalies and known hydrocarbon accumulations at depth, and, therefore, a radiometric survey could perhaps discriminate between barren and productive structures.

A detailed, high resolution airborne magnetic and gamma-ray survey was carried out to test whether the known structures hosted any accumulations of hydrocarbons, map any fractures, faults and joints that may add information to the existing geological model, and perhaps also give some estimate of the depth to the crystalline basement.

The radiometric methods are based on the observation that the presence of hydrocarbon microseeps alters the redox equilibrium in the rocks and soils above a hydrocarbon accumulation, and creates an environment which is locally predominantly reducing. This can alter the solubility of minerals which are composed of one or more elements detectable by gamma-ray spectrometry. Minerals of Uranium can have a dramatic change from being readily soluble in the oxidized hexavalent state to being generally insoluble in the reduced tetravalent state (Foote 1995 and Morse & Zinke 1995). Potassium has a similar behavior in the presence of hydrocarbon micro-seeps albeit with a more complex chemistry. The local changes in solubility disturbs the normal (often random) distribution of particularly Potassium (K) and Uranium (U) in the presence of circulating meteoric and ground waters. A geochemical "halo", detectable through detailed mapping of the gamma-ray radiation patterns, can exist over hydrocarbon accumulations (Foote 1995, Morse & Zinke 1995 and Zinke & Morse 1996).

Similarly Iron (Fe) minerals can also be redistributed in a changing geochemical environment and have magnetic minerals formed and accumulated (Donovan et al 1984, Foot 1996 and Machel 1996) that can be detected using the information from high resolution airborne magnetic surveying. These features can be circular features sometimes with anomalies resembling ringfractures with amplitudes of 1 to 5 nT. The Shallow and Near-surface anomalies observed were selected primarily on the gamma-ray radiation pattern- giving preference to a donut shaped low with a central and peripheral high radiation values. Initial selection was based on the TC and K data, and weight added should the anomaly be represented in the K/Th ratio data. Coincident magnetic anomalies were difficult to define, except in one instance.

A detailed high-resolution land gravity survey was carried out over the concession area, which entailed a total of 3,829 stations of data acquired over an area of approximately 1,450 square kilometers, at a station intervals of 500m along survey lines spaced 800 meters apart The area covered by the gravity data generally extended beyond that of the seismic data sets, and offered the opportunity to extend the structures interpreted solely from the seismic data.

The range of densities generally observed in the region, were found to be capable of accounting for the observed gravity field over the structures interpreted from the seismic data. However, there is an indication that interesting structures may exist outside the existing seismic data coverage. It would seem that there is sufficient density contrast across the various stratigraphic sections and that more detailed gravity data should be able to add useful structural information where the seismic method is at a disadvantage, particularly when applied to mapping of the footwall structures.

Conclusions:

The gravity information generally supports the existing geological model and concepts, but indicates the possibility of prospective areas outside the area of currently available seismic data. These feature warrant further attention. The geochemical studies strongly suggest that the most likely accumulation to be found in the structures is gas. If liquids exist they would have to be contained within the discontinuous formation, and at the appropriate depth/thermal regime for the preservation of these hydrocarbons. However, it is concluded that the concession block has good potential for prospective targets, but that structures of four-way closures are necessary due to the high seal risk. Several attractive prospects and leads were developed in the different tectonic environments that are recognized in the blocks. However, the most important point brought by this case, is perhaps that all exploration tools that can decrease exploration risk, should be considered. As each method is sensitive to a particular condition, or set of conditions in the subsurface, each has strength in describing particular properties of the geological model.

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Seismic Node 4C-3D Acquisition System

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Introduction

The methods for marine seismic exploration and reservoir imaging have during the last decades been through several stages of adjustments and improvements. The streamer technologies have gone from 2D seismic to 3D seismic and now in the last decade to 4D seismic. In todays market we see that for frontier exploration 2D seismic is still used. However, for reservoir imaging we find 3D seismic as the most popular choice. Most seismic data that has been acquired is based on pressure (scalar) sensor recording. However, in order to e.g. "see" through/map gas invaded zones, socalled multi-component or 4C (measures P-component + vector response of pressure and shear (S) waves) was commercially introduced in the mid nineties. True 4C-3D measurements (multi-azimuth) result in much better imaging of complex structures (e.g. multi-direction dips and fault planes) and today's advanced directional drilling techniques and well/reservoir engineering can utilise the more accurate spatial picture provided by higher definition 3D. Time lapse-3D – or 4D represents a huge potential for reservoir management but is still immature. A few programs have been carried out or is active, especially in the North Sea region. They have either been based on buried seabed cables or towed hydrophone cables.

The driving force behind the development of the technologies has been the need to find new oil and gas fields to supply the world's increasing demand for fossil energy. As we write 2005, this demand is still increasing and the trend will probably continue in the future. This is not only to the growing demands in existing large consumers like the USA but also to new large consumers with a fast-growing economies like China and India.

It is now a common consensus among the oil companies that most of the large oil fields in the world are discovered. The possibility to find new large field are getting smaller even though a certain small number of such fields could be discovered in immature areas in the world. Based on this it has become a common strategy for the oil companies to focus on how to produce more oil from already producing fields ("Enhanced Oil Recovery"). Big efforts are being put in research and development for technologies that can increase both the producing life and the running hydrocarbon recovery rate of these fields. This includes more efficient and accurate production technologies and also solutions for better reservoir descriptions using seismic, preferably in combination with non-seismic data. World-wide we currently experience a strong interest in 4D and other EOR methods, not only to enhance the performance of established producing fields but also as a way to manage new fields from the very start. This interest stems from an increasing gap between known resources and fossil energy demand - combined with the fact that the projected recovery rate can be disappointingly low. In the North Sea area the estimated recovery rate of clastical reservoirs (high permeability) will typically be around 40%-50% of the theoretical reserves. With full potential of different EOR measures the goal is to recover 50% and 75% of the oil and gas reserves, respectively. For carbonate fields the estimates has increased from a modest 20% to 37%, mainly due to water injection.

Seismic Streamer Cables

Conventional marine seismic is performed by towing a limited number of long hydrophone arrays ("streamers") close to the sea surface, recording pressure wave reflections from the reservoir areas. The source for the pressure wave is usually airguns towed from the same vessel. From a 4D point of view it is a challenge to accurately control the streamer position – both in depth and laterally. Especially at the far offset receivers one can experience lateral skew ("feather") of several hundred meters due to near-surface sea currents. The feather and cable separation change over time due to variation in current speed and heading, cable heading and ship's water speed. In state-of-the-art streamer the feather angle can be reduced to a few degrees by way of active lateral steering systems. Despite the fact that streamer cables are often an efficient way of quickly covering an unobstructed survey area, it is likely that, due to the inherent problems with positioning accuracy and repeatability, the methodology only applies to reservoirs where one can expect to observe strong 4D effects.

Ocean Bottom Seismic (OBS)

An alternative method for recording seismic data is to place the sensors on the seafloor, rather than towing them behind a vessel. Each sensor group or point receiver contains both hydrophones and geophones for recording of both pressure and shear waves. A sensor package usually includes one hydrophone and three mutually orthogonally mounted geophones. The geophones measure either velocity or acceleration and are either fixed to the sensor housing or mounted onto a gimbal. The fixed geophone solution requires determination of the vertical axis and heading to enable all 4C sensors to be numerically rotated into a common coordinate system. The gimballed solution requires only additional heading information to do the vector rotation. However, due to the low gimbal friction geophone signal distortion may be observed. Especially if the sensor package is poorly coupled to the seabed this gimbal effect will be very pronounced. This methodology, called 4C, “multiwave” or OBS, has been in use commercially for about a decade - driven by the desire to record better and more accurate seismic data. In today’s market there are two main 4C technologies available.

Cable Technology

A few contractors are using long cables with the sensor packages incorporated in cables. The sensor packages could be arranged as individual stations (“single sensor”) or in groups, with a typical inter-group/station separation of 25m or 50m. The separation between neighbouring cable strings is typically 400 m. Except for a couple of exceptions, the geophone response from cable-based systems is strongly influenced by the mechanical cable construction in such a way that they will mask anisotropic properties of the reservoir, due to the cable’s much more pronounced, inherent “anisotropy”. If the water depth is not too great, seabed cables are relatively simple to position with good accuracy in the cable’s in-line direction. In the cross-line direction it is much more difficult. Without actively steering the cable’s cross-line movement during deployment one will get a typical deviation between “pre-plot” and “as layed” positions of 25% of the water depth. This is not good news in a 4D context. Hence, all known seabed reservoir monitoring cables have been trenched down into the seabed. The problem with, of course, is that electronics do fail and water intrusions will happen sooner or later. It will be a challenging task to re-install a serviced or new cable into the original position.

Node Technology

The second technology is the Node technology where the 4C sensor packages are deployed and planted into the seafloor, usually in a regular, rectangular grid pattern. However, because each unit is autonomous, inter-Node separation and receiver layout envelope can easily be changed.

Even though Node type technology has been used for scientific studies for over 70 years (e.g. like regional studies at Basin scales), the birth of the commercial scale 4C Node technology happened in the beginning of the 90’s. In today’s market there is only one contractor offering 4C Node services, but a second supplier is expected to arrive the scene late in 2005. The number of 4C cable contractors is presently 4-5.

The first commercial company, Subseaco, was founded in Norway in 1996 by Eivind Berg and Bjørnar Svenning. The first small 4C-3D job was performed in 1997 for Shell at the Guillemot Field in the UKCS. The Nodes utilized in Subseaco was connected to each other and to the surface with cables. In 1998, CGG bought Subseaco and the two founders started the company SeaBed Geophysical AS (SeaBed).

SeaBed has since 1998 done much work on research and development focusing on finding the high quality solution for acquiring 4C data at the seafloor. SeaBed has, through a consortium, ROKVA, done extensive testing of different type of 4C cables and Nodes targeting high quality and Vector Fidelity. The result of this work was materialized in a new Node design based on an autonomous system where there are no cables between the Units or to a surface facility. This system (the CASE System) is based on a small, low-mass sensor package, connected to a control and data acquisition unit, which contains a PC, power supply, high accuracy clock and data storage medium (see figure 1).

Fig.1: Picture showing the SeaBed CASE Unit. In front of the Unit one can see the sensor package, which will be lifted out of the frame when planted

The general idea behind the CASE design is to present a high quality data acquisition system with a high degree of flexibility to be able to acquire data with Vector Fidelity in all kinds of challenging areas. Operating a cable-less system is also advantageous in areas with a lot of infrastructure (obstructions) on the surface and on the seafloor, areas that are environmentally fragile, or in water depths beyond 1000 m - where working with a cable is very challenging.

SeaBed Geophysical, as the only current provider of Node acquisition technology, has performed two 4C-3D surveys with the CASE system. The first survey was conducted at the Volve Field were 128 CASE units were deployed in 2002 (see figure 2). This survey is a part of a consortium, IMPREDO, where the processing of the Node data is finalized in November 2004. The study clearly demonstrated an exceptionally good repeatability in both sensor coupling (vector fidelity) and positioning accuracy. Various configurations used to verify this were :-

- Twin Nodes (1 m node separation – common shots)
- Repeated Node planting without moving the control and data acquisition unit (same location, different plant, different shots)
- Repeated node deployment and planting into same location (pos. accuracy 0.5m @ 100m water depth)

The variation due to positioning and coupling was smaller than the variations caused by the source.

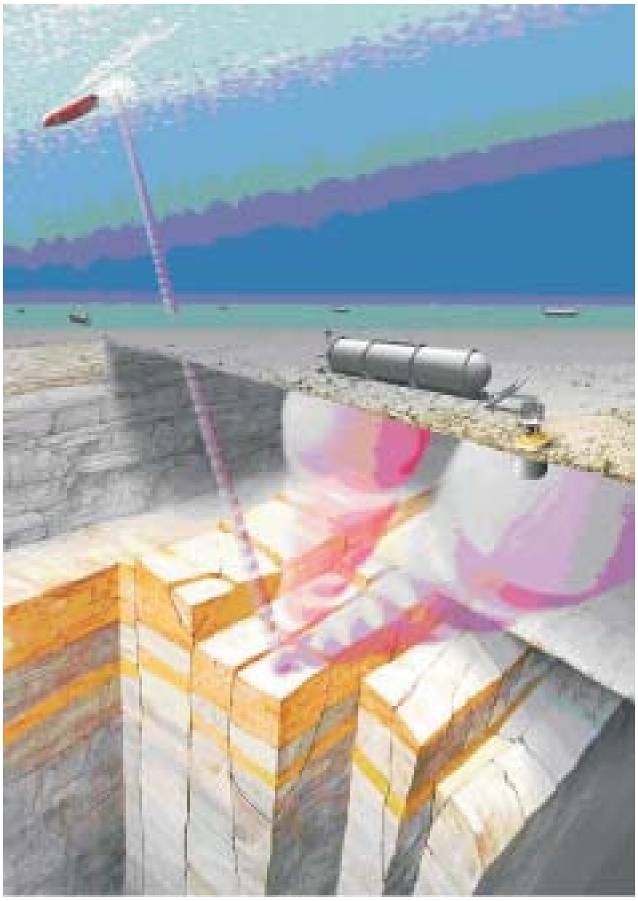

Fig. 2: Drawing showing the principle of Node 4C-3D technology

The second major Node 4C-3D survey was performed by SeaBed Geophysical for Pemex in 2003/2004. This is the world's largest 4C-3D project ever performed (approx. 230 sq.km.). The acquisition was done on the Cantarell field offshore Mexico, which is the world's largest offshore producing field. To be able to cover the requested area, SeaBed utilized 250 CASE Units, which were deployed in 7 patches totalling in approximately 1,400 Node positions. The Cantarell field is densely populated with platforms, subsea structures and pipelines and there is lot of vessel activity in the area. These challenging conditions demonstrated the operational benefits by using a cable-less Node-based system.

Fig. 3: Picture showing the back deck of DP vessel Normand Tonjer during the 4C- 3D operation at the Cantarell Field.

The future of 4C seismic is very much formed by the oil company's strategies in development of the oil fields. An increased demand for high quality data is expected to arise based on the strategy of producing more oil out of existing reservoirs. A second visible trend is to move the 4C systems towards deeper waters (3000m).

SeaBed Geophysical has already performed a successful small pilot at 2,300m using 6 prototype CASE units for BP in the Gulf of Mexico in 2004 and expect to see a developing market on the ultra-deep shelf as well. Finally, there is an increased focus on highly repeatable 4D seismic services, seen in conjunction with other EOR measures. Node-based 4C solutions, like SeaBed Geophysical's CASE technology seem very well suited for this due to its repeatable acoustic coupling, positioning accuracy and because its very easy to service, maintain and upgrade over its 4D service life.

SPG at Madrid 2005

This year two of the SPG, India representatives, namely: Mr. Dhanendra Jain, Treasurer, SPG, India, and Mr. Rahul Samrat Tandon from Jorhat Chapter attended "67th European Association of Geoscientists & Engineers (EAGE) Conference & Exhibition", (MADRID 2005) at Spain during 13-16 June, 2005. SPG, India being the associated society of EAGE, was offered a complementary booth at "Madrid 2005" conference.

Many renowned Geoscientists visited the SPG, India booth at "Madrid 2005" and showed their keen interest in expanding activities of SPG. It provided an opportunity to advertise for KOLKATA 2006, the 6th International Conference and Exposition on Petroleum Geophysics, to be organized by SPG, India from 9-11 January, 2006. Dr. Olivier Dubrule, the then President of EAGE visited the SPG booth and matters of SPG & EAGE cooperation were discussed such as substantial EAGE representation in "Kolkata 2006" and active participation in organizing the event. A meeting was organized by EAGE with its other associated societies to discuss the issue of mutual interests. Many issues related to the joint activities, and how to enhance further relationship between the two societies were discussed.

Distinguished Instructors Short Course (DISC 2005)

In continuation of Society's effort to promote geo scientific education and training, Society of Petroleum Geophysicists, India organized 5th Distinguished Instructor Short Course (DISC 2005) on "*Insights and Methods for 4D Reservoir Monitoring and Characterization*" by Dr. Rodney Calvert, Consultant Reservoir Characterization, Shell, USA on 20th May 2005 at Hotel Madhuban, Dehradun. This course was attended by more than thirty participants which includes the executives from various E&P companies in India. This course added great value to the knowledge base of the participants. The course was well appreciated by all the participants. The course contents which include introduction and motivations, 4D monitoring at works: some introductory examples, 4D monitoring goals, models and measurements, 4D repeatability and the effects of Heterogeneous overburden distortion and noise, seismic acquisition for 4D monitoring, processing for meaningful 4D differences, from monitoring to modeling and what the future holds was of great use to these geoscientists.

SPG executive members with Dr Rodney Calvert during DISC 2005 at Dehradun.