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Fusion technology in applied geophysics

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Abstract: The visualization of three dimensional geophysical data is forcing a revolution in the way of working, and allowing the discovery and production of hydrocarbons at much lower costs than previously thought possible. There are many aspects of this revolution that are behind the scenes, such as the database structure, the storage and retrieval of data, and the exchange of data among programs. Also the user had changes where the interpreter (or manager, or processor) actually looks at and somehow interacts with the data. The use of opacity in volume rendering, and how its judicious application can assist in imaging geologic features in three dimensional seismic data. This revolutionary development of new technology is based on the philosophy of synergy of inter-disciplines of the oil industry. Group interaction fostered by large room visualization environments enables the integration of disciplines we strive for, by putting the petrophysicist, geologist, geophysicist, and reservoir engineer in one place, looking at one image together, without jargon or geography separating them. All these tools developed in the oil industry can be applied into the civil engineering industry also such as the prior geological and geophysical survey of the constructions. Many examples will show how three dimensional geophysical technology might make a revolution in the oil business industry now and in future. This change can be considered as a fusion process at data, information, and knowledge levels.

1. Introduction

The concept of fusion is easy to understand, however, in the academic world "Fusion" is a recent terminology and it might be difficult to define clearly. Basically it combines different data, image, information, and even knowledge from various sources or from the same source in many different contexts. It refers to data fusion (Wald, 1999), image fusion (Pohl and Van Genderen, 1998), information fusion (Dasarathy, 2000) and knowledge fusion (Preece et al., 2000). Also fusion is defined as global meaning such as to integrate many different disciplines in science and engineering. These traditional disciplines are fused and a new discipline might appear based upon recent development of information technologies and computer powers.

Wald's (1999) had defined data fusion as "data fusion is a formal framework in which are expressed means and tools for the alliance of data originating from different sources. It aims at obtaining information of greater quality; the exact definition of 'greater quality' will depend upon the application." From this definition, the fusion process requires that the resulting output is more satisfactory for the customers when performing the fusion process than without it.

The object of this paper is to study that the fusion process can be applicable in applied geophysics, especially exploration geophysics. The example adopted here is a recent technical trend in the oil industry since they have the most developed technologies in IT environments and the purpose of geophysical application is clearly defined as finding oil or gas fields. This clear purposes and visible customers make driving forces for creating a new discipline in applied engineering. Geological data fusion called as "geo-informatics" can maximise usefulness of geological and geophysical data of subsurface for finding oil with minimizing the total investments of oil companies.

Usually the life of oil and gas fields is quite long and sometimes it takes more than 30 years shown in Fig. 1. It starts as a pre-field and exploration activates change it into a field. This exploration activity requires more than 5 years or so. Drilling is money-consuming, therefore the role of geological information becomes a key of the exploration investments. Traditionally the flow of geological data and information in an oil company is only one way such as geologists/geophysicists to drilling engineers and then finally to reservoir engineers. Once the production has been started, geophysicists are not required anymore.

Exploration investments will be returned during production phase for the period of about 20 years. However, this is out of match to the modern business such as short investments and quick returns. This financial pressure required changing the structure of exploration works and fusion process of exploration data, information, and knowledge has been occurring last 10 years in oil industry at many technical levels.

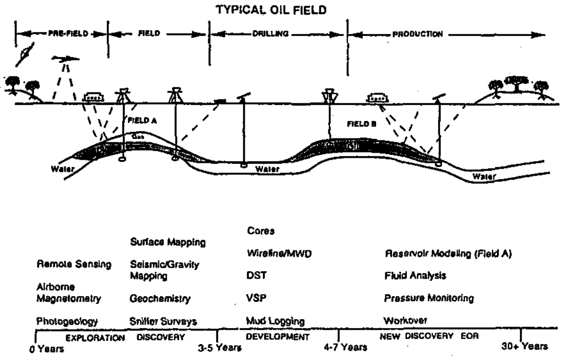

Fig. 1. The typical life of oil and gas field.

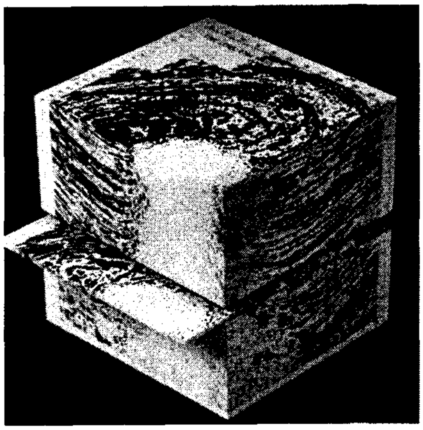

Fig. 2. 3-D data volume showing a Gulf of Mexico salt dome and associated rim syncline. (From Brown, 1991)

2. Three Dimensional Reflection Seismic

Finding an oil field can be considered as hunting. Drilling might correspond to shooting. However, in the case of the oil field hunting, the hunter cannot see or touch the target itself. Only a special hunter can make an image of the oil field from geological and/or geophysical data. Pratt (1952) recognized this and stated that it is our minds where oil is first found. Development of technology had changed this situations and the reflection seismic became eyes of the oil field hunter.

As is well known, the reflection seismic is the most powerful tool to delineate subsurface structures (Gluyas and Swarbrick, 2003). It is a method that allows us to image changes in the subsurface geology by inducing an acoustic wave from near the surface of the earth and listening for the echoes from deeper stratigraphic boundaries (much like ultra-sound is used to create pictures of unborn babies in their mother wombs). Since the subsurface has three dimensional structures, the 2D seismic cannot draw the correct vertical figures of the Earth. To overcome this, the idea of 3D seismic methodology was proposed (Graebner, et al., 2001). Exxon acquired the first 3-D seismic survey over the Friendswood Field near Houston, Texas, in 1967. Even the industry had realized applicability of this approach, however, it took a long time to spread out this technology to the oil industry because of the difficulties for handling large amounts of data.

In the 3D seismic method, we record many lines of receivers across the earth's surface. The area of receivers we record is known as a "patch". Often, we employ lines of source points laid out orthogonally to the receivers. By sequentially recording a group of shots lying between two receiver lines (referred to as a "salvo") and centred within the patch, we obtain uniform, one fold reflection information from a subsurface area that is one quarter of the useful surface area of the patch. Although we usually record a large square or rectangular patch, the useful data at our zone of interest is offset limited by several geophysical factors. Therefore, we often consider the useful area of coverage as a circle with a radius equal to our maximum useful offset. By moving the patch and recording more salvos of source points, we accumulate overlapping subsurface coverage and build statistical repetition over each subsurface reflecting area (bin). One of the most obvious differences between 2D and 3D seismic is that 3D imaging provides information continuously through the subsurface within the bounds of the survey whereas 2D seismic reveals only strips of information (Fig. 2).

Nowadays three dimensional reflection seismic is known as one of the most exciting technology driven developments in oil industries and the earth sciences over the past century. It provides interpreters with the ability to map structures and stratigraphic features in three dimensional detail to a resolution of tens of metres over thousands of square kilometres of sedimentary basins. This incredible imaging capability has already yielded some fascinating (and surprising) insights and will continue to provide a major stimulus for applications not only oil and gas industries but also civil engineering fields using shallow reflection seismic method.

3. Three Dimensional Seismic Interpretation

The problems of organizing and managing large volumes of data fuelled the initial development of interactive interpretation systems. Since the early 1980s, the volume of data to be interpreted has grown at a phenomenal rate.

The growth in the number of 3 D surveys is almost exponential behaviour. The actual volume of data the interpreter has to work has grown much more rapidly than the number of surveys. The volume of data to be interpreted (V) is given by a very simple formula:

$$V = L \times C \times S \times D$$

where : L = the number of lines; C = the number of cross-lines; S = the number of time samples; D = the number of data types. Where the earliest surveys might have had 100 to 200 lines and cross lines, a modern marine survey can easily have 2000 to 3000 of each. The number of samples per trace has doubled or tripled over the last 15 years. The number of data types has also increased (amplitude volumes, discontinuity volumes, velocity volumes, complex attribute volumes, AVO volumes, etc). Taking all of this into account, the amount of raw data to be interpreted per survey has increased by a factor of more than 5000. This has placed a premium on efficiency in the interpretive process.

Workstation-based interactive interpretation systems are absolutely essential to the interpretation of modern 3 D surveys. Initially, interactive systems were computer implementations of methods traditionally used to work on paper (Fig. 3). Later developments allowed the generation of displays that would have been very difficult or impossible to create in a paper-oriented environment. Today, interactive interpretation is no longer constrained to two dimensional displays. Three dimensional data visualization techniques hold vast potential for improving both the quality and efficiency of 3 D seismic interpretation. Volume visualization of the seismic data is a valuable tool for data preview and interpretations. Colored, shaded, 3 D perspective displays allow the integration of information from horizon attributes and structure and interpretation of detailed faulting patterns. These displays are also used to explore the relationship between reservoir horizons and fault surface structure and to integrate reservoir property estimations with structure.

4. Volume Visualization

One of the lessons learned over the last 20 years has been that 3 D seismic interpretation is not just dense 2 D seismic interpretation. Although it is certainly possible to interpret the 3 D seismic volume as a dense 2 D grid (in fact some early interactive interpretation systems actually encouraged this), this is neither an effective nor an efficient approach to the interpretation. The results will be generally of poorer quality and will require significantly more effort than interpreting the data in a 3 D fashion.

Two-dimensional interpretation of a 3 D seismic volume involves limiting your views of the data, and your interpretation, to lines and cross lines. Typically this approach to interpretation has its roots in two things. First, the interpreter is comfortable with seismic sections and it is sliced view of the Earth. Second, the interpreter may simply decide that "there is too much data to possibly look at all of it." Modern interactive systems provide a variety of tools which allows interpreters to perform the interpretation in a more 3 D fashion.

The concept of volume visualization made a revolution of data view and provides a very effective tool for 3D data interpretation. Also this can be used as preview for the data set. This revolution is based on the new idea of data representation called **voxcel** (Kidd, 1999). A voxel means a "volume pixel elements" and, in a 3 D seismic volume the voxcel is a sample itself. Also in this case the opaque becomes other essential tool. Not only you can view animations of opaque slices through the data volume along any orientation, but also control the slicing interactively. You can also adjust the opacity of the volume. By making the data volume partially transparent, it is possible to see the structure of strong reflections prior to doing any interpretation. It may also be possible to isolate elements of depositional systems simply using control of the color and opacity mappings.

Fig. 4 is an opaque volume from a 3 D seismic survey in the southern North Sea Gas Basin. By visualizing the volume with the opacity set so that only the strongest peaks and troughs are opaque, it is possible to see the overall 3 D structure of these horizons prior to interpretation. By using motion (e.g., rotation around the time axis) and stereo displays, the structures, their relationships, and the positions of specific reflections become much more obvious than they are in the still images in Fig.4.

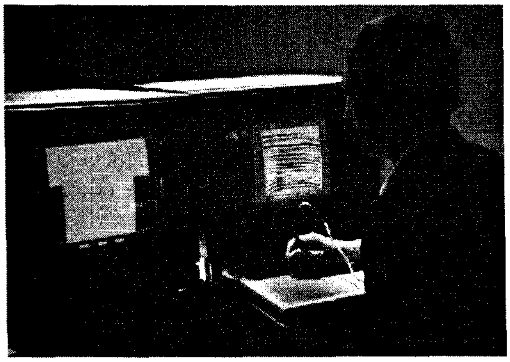

Fig. 3. Seismic Interactive Interpretation System in action ((From Brown, 1991).

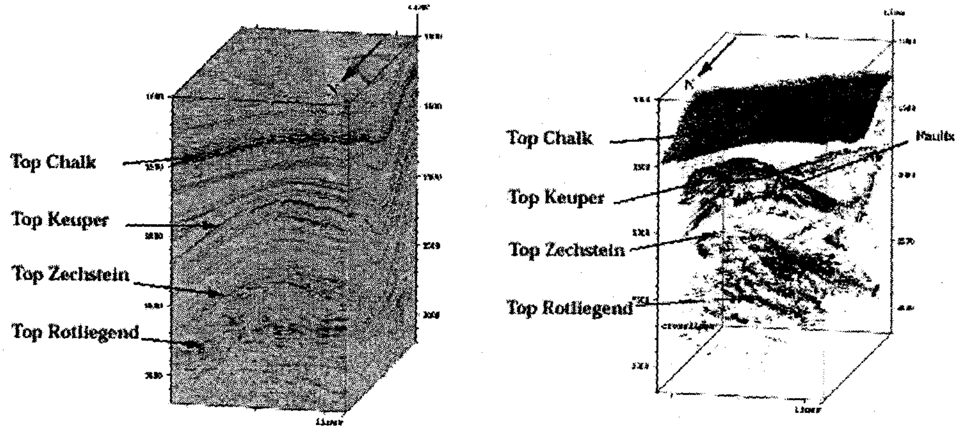

Fig. 4. The left shows the 3D data set by the sliced view and the right shows an opaque cube of seismic data, and its semitransparent counterpart. The 3-D structural details visualized on several horizons before interpretation.

5. Voxcel Picking

Computer assisted interpretation of horizons and fault surfaces is one of the areas where the tools of modern interactive interpretation systems have made most significant impact. There are a number of ways of interpreting horizons in 3 D seismic surveys. These techniques include manual picking, interpolation, autopicking, voxel tracking, and surface slicing.

Manual picking is simply the manual interpretation of horizons on lines, cross lines, time slices, and traverses. This is a technique with which we are all most familiar. It is also, by far, the least efficient horizon interpretation technique in terms of interpreter time and effort. While interpreting manually, the interpreter is looking for some degree of local continuity in the data, and local similarity of character to identify the event to be picked.

Autopicking (or autotracking) has been around in interactive interpretation systems since the early 1980s. The concept behind autopicking is quite simple. The interpreter places seed picks on lines and/or cross lines in the 3 D survey. These seed points are then used as initial control for the autopicking operation. The algorithm will look for a similar feature on a neighboring trace. If it finds such a feature, within specified constraints, it will pick that trace and move on to the next trace. Simple autopickers will allow the user to specify a feature to be tracked, an allow-able amplitude range, and a dip window in which to search. Fig. 5 is a sketch of how such an autopicker works. If any of the search criteria are not met (amplitude out of range, no similar feature in the dip window, etc.) the autotracker stops tracking at that trace. More sophisticated autopickers allow the user to specify additional criteria to control the picking.

A technique called voxel picking has become available with the advent of volume rendering and visualization. Voxel picking is conceptually related to autopicking in the sense that an "event" or feature is tracked through the volume starting from seed control points which are picked by the interpreter. Voxel pickers, however, tend to follow a true three-dimensional path through the data. Starting at the seed voxels, the voxel picker will search for connected voxels that satisfy the search criteria specified by the user. The search is typically conducted in line, cross-line, and time directions.

Fig. 6 is a sketch of a simple voxel picking algorithm and its behavior under two different continuity constraints. Six-way connectivity restricts the search from one voxel to only the neighboring voxels that are connected-to-face. Twenty-six way connectivity allows the search to proceed between neighboring voxels that are connected face-to-face, edge-to-edge, or corner-to-corner. The connectivity constraint that is used affects the outcome of the voxel picking.

Because volume rendering techniques typically place the entire volume being visualized into RAM memory on the workstation and because the tracking algorithm is computationally simpler than most autopickers, voxel picking can be many orders of magnitude faster than autopicking. Generally, voxel picking algorithms are sensitive to poor

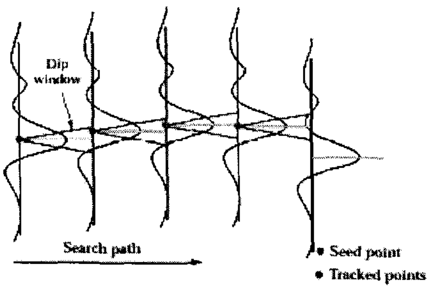

Fig. 5. Sketch of a simple autopicking algorithm.

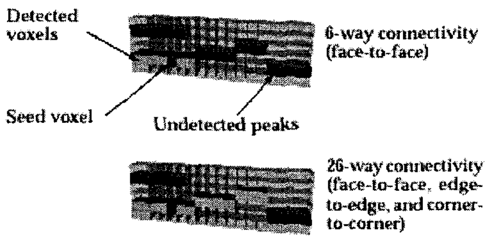

Fig. 6. Sketch of a simple voxel picking algorithm with two connectivity constraints.

signal-to-noise ratio. However, on reflections with a good signal-to-noise ratio, voxel picking will usually be the most efficient approach to picking the horizon. Like autopicking, voxel picking assumes that the data are locally continuous, consistent, and connected or smooth. Both techniques assume that a consistent phase is being interpreted from the data.

6. Virtual Reality of 3-D Seismic Data

The next step in visualization is to engage peripheral vision to become immersed in the data. As humans we have several orders of magnitude more input bandwidth through our eyes than through any of our other senses. When linked to modern computer technology, this innate visual bandwidth proves an underutilized resource. Visualization is especially worthwhile when we wish to increase the quantity, and, because of the pattern-recognition capabilities of our brain, the quality of information entering our mind.

As Wallace Pratt (1952) recognized we must connect the data to our mind and then integrate the new information with our experience in order to identify new hydrocarbon prospects. This creative act is an art form, which is uniquely human. If this process could be replicated by a machine, geophysicists wouldn't be needed.

Geophysicists and/or interpreters are needed to collect data, QC data, process data, extract attributes from data, integrate data, interpret data, present data, and make decisions based on a combination of our experience and data. And at each stage we need to explore and understand the data, to be gaining insights from it, and combining these results to improve our decisions. Traditionally this has been done with maps. Virtual reality models, which combine all available data, are replacing maps as a way to connect data to our minds.

Several oil companies have installed immersive visualization rooms in order to realize the virtual reality world for the subsurface. It based on the CAVE (Computer Aided Visualization Environment) consist of four projection surfaces — three orthogonal flat vertical walls, and the floor (Neff et al., 2000, Midttun, et al. 2000). The images

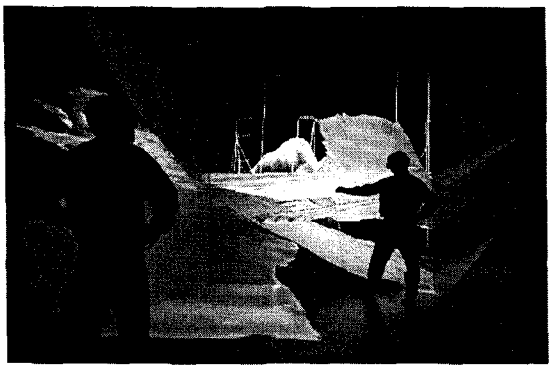

Fig. 7. Visualization and interpretation of data in the Immersive Visualization Environment. The three walls and the floor are all projection surface, and the interpreter is immersed in the data.

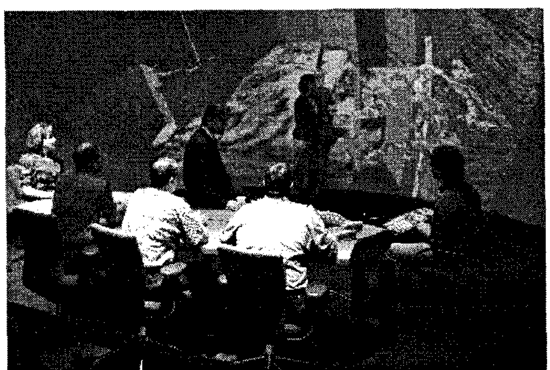

Fig. 8. Immersive visualization technology provides new and better ways of viewing and interpreting data. Geophysicists can now see and think in 3-D world. (From Sheffield et al., 2000)

on the walls are back projected while the image on the floor is projected from the top down. The sense of immersion is achieved by engaging peripheral vision, and by stereo projection of the data. In these environments, the data not only surrounds the interpreter, but it actually appears to fill the room. Fig. 7, and Fig. 8 show interpretive works being performed in the immersive visualization environment.

In this environment the interpreter can walk through the data, along interpreted horizons, between faults to locations where the wells penetrate the target horizons. Since head tracking is used to properly alter the data projections for changes in head position, the view of the data changes very intuitively as the interpreter moves through the data.

7. Summary

3-D reflection seismic is widely used in oil and gas industry since its cost effectiveness of this technology and it changed the working style of exploration geophysics drastically. Virtual reality and immersion interpolation system of 3-D seismic data is routinely used on daily basis at oil companies. Early experience with immersive visualization suggests that significant improvements in efficiency of interpretation can be achieved. An asset team consisting of a geophysicist, geologist, reservoir engineer, and drilling engineer can work together in the environment. It also facilitates the integration of the data from each of these disciplines in three dimensions. By having these specialists working together in the same environment, on the same data, communication and integration through the entire interpretation, development, and drilling planning cycle can be significantly improved.

Based on this kind of an IT platform, the integration of seismic data with gravity data, magnetic data, and borehole data, is considered as a data fusion in geophysical data level. Integration of the geophysical data with geological, geochemical, and production data becomes another data fusion with the different level. These data fusions are integrated into one geological model for considering oil reservoir and we can make an image of it. This whole process based on information technology is called "geo-informatics."

The mentioned above process can be compared with data fusion in human brain. Human sensors acquire information on sight, smell, touch, hearing, and taste. Acquired data integrated and processed within the brain and compared with a priori knowledge and recognised the object. Without the brain, a human cannot recognize the object even he has sensors. This shows that the key issue of fusion technology is that how to prepare an environment of data sharing, information sharing, and knowledge sharing from multiple sources. In the case of oil industry, without the virtual reality and/or immersion environments we cannot share one image of reservoir with many specialists intuitively. Some person cannot image the shape of sand body from contour maps.

In future, oil and gas business is getting more cost game industry. 3D reflection seismology will be consolidated as a main tool in exploration stage and an oil company can win this game by combining with different information and knowledge by using fusion technology.

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