A vision for 3D seismic technology and visualization

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Abstract: Three-dimensional seismic data and visualization are the key elements of a rapid technological evolution in the remote sensing of the subsurface that has resulted in geoscientists moving from being data poor to data rich. The proliferation in subsurface data has profoundly affected the oil exploration and production industry in the last two decades. Most notably it has radically improved our ability to predict what lies beneath the Earth's surface and, hence, reduce risk in exploration and production.

One-dimensional data (wells) were supplemented by 2D data (seismic sections and maps) in the 1950s and by 3D seismic data from the 1970s onwards. However, the evolution up to this point essentially dealt with a static Earth without the fourth dimension – time. More recently came the advent of recording changes in the subsurface due to hydrocarbon extraction over time, with the use of time-lapse 4D surveying.

There are also now more refined imaging techniques such as multi-component (4C) and single sensor recording. The resulting explosion of information has led to challenging questions as to how geoscientists can interact with the data to collaborate and communicate more effectively in this new data-rich world.

The breadth of influence of 3D seismic data and visualization in earth sciences is likely to be far wider than the oil and gas industry. Collaborative Visualization Environments (CVEs) are already being used in universities and 3D seismic data are also being used as a research tool in many unrelated earth science disciplines. The next step will be the establishment of CVEs at schools and colleges for teaching the next generation of earth scientists.

Keywords: visualization, 3D seismic, immersion, geovisualization

DVD: Movie 2 is relevant to this chapter and can be viewed on the accompanying DVD.

Since the advent of 3D seismic data in the 1970s, earth scientists have set out on a fast-moving technological journey, predominantly fuelled by the constant demand to find and economically produce hydrocarbons from mature provinces or challenging new exploration frontiers. This has been paralleled by a proliferation in subsurface data. In decades to come, when researchers look back on this journey, it will become evident that 3D seismic technology and visualization revolutionized scientific endeavour across a broad range of earth science disciplines. It will also have impacted how earth scientists are taught at schools and universities world-wide. More immediately, it is already changing the way teams work and the role and skill sets of modern seismic interpreters within the oil and gas industry. Although many industry earth scientists may take these advances for granted, being exposed to them on a day-to-day basis this should not make one underestimate the breadth of influence that these technologies will have in the future.

The 3D Visions section of this volume is a diverse selection of papers that show how seismic and visualization technology is being applied in the fields of reservoir petrography (i.e. at micron scale), depositional system analysis and the exploration and production of hydrocarbons. This contribution is tailored to introduce the papers in this section and present one selective vision of what lies ahead from an industry and academic perspective.

A view of the past

Although the acquisition of 2D data actually started in the 1930s, the 3D seismic technology revolution has its roots in the 1960s, when the oil and gas industry developed digital recording and processing techniques. Outcrop-based geological information integrated with boreholes and later limited 2D seismic data allowed simple subsurface maps to be generated (Fig. 1). 2D subsurface imaging was followed in the 1970s by 3D imaging. It quickly led to paradigm shifts such as the 'stratigraphy revolution' of the late 1970s and 1980s. Data at this time were interpreted on 2D paper copies and digitized to produce contour maps of subsurface structures. The first commercial 3D survey was recorded in 1975 in the North Sea, UK and was interpreted in the same year.

The present

Evolving computer technology has facilitated the proliferation of 3D seismic data, with an overall trend of decreasing cost and increasing data quality (Table 1). It has allowed industry and academic groups to develop increasingly sophisticated acquisition equipment and processing algorithms, leading to advances in image quality along with the acquisition and processing of increasingly large 3D datasets. Now 3D seismic surveys cover thousands of square kilometres, enabling basin-scale processes to be investigated. The vast majority of the 3D seismic surveys have been acquired by the hydrocarbon industry, due to the key role this technology now plays throughout the life cycle of oil and gas exploration, development and production (e.g. Fig. 2). It is commonly accepted that 3D seismic data and technology can often reduce exploration risk, increase the accuracy of structural and reservoir models (**Dooley *et al.***, this volume; **McClay *et al.***, this volume) and, at its best, enable development and production wells to be positioned within complex hydrocarbon reservoirs (**Colleran *et al.***, this volume; **Dart *et al.***, this volume). Today, exploration involves the extraction of more geological information from the seismic signal than ever before (**Leadholm *et al.***, this volume). The interpreter's tool box is now becoming increasingly

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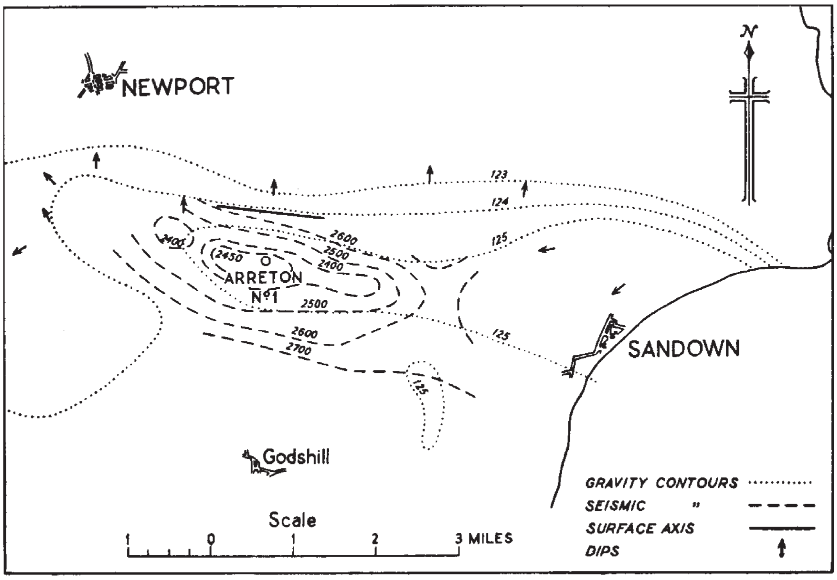

Fig. 1. Early mapping using 2D seismic data: map of the subsurface of near Sandown, on the Isle of Wight, UK (data vintage 1950s) – source unknown.

comprehensive, allowing subtle stratigraphic and structural features to be resolved (**Posamentier**, this volume; **Huuse *et al.***, this volume).

It is also becoming evident that there are several important changes in the way industry geoscientists and related disciplines work together. The modern mature oil field has turned into a mountain of multidisciplinary data that no single individual can any longer fully comprehend in all of its complexity. The task of the interpreter is also evolving, with geophysical and geological roles becoming increasingly merged. Communication and collaboration across disciplines, such as drilling, site surveying and exploration and production geology and geophysics, have become paramount. In development and production settings there is a vast quantity of reservoir models, static as well as dynamic. Decision-making involves being able to compare and contrast the geological and geophysical data with these reservoir models. Displaying the diverse data sources (e.g. **Kayser *et al.***, this volume) in a single canvas, or better, in an immersive Collaborative Visualization Environment (CVE), now provides a very effective means of communication provided that the entire team can interact with these data in front of a large display system. This is termed ‘geovisualization’, which is defined as the collaborative analysis and interpretation of geological and related engineering data using visualization environments. CVEs are graphically intensive stereo-enabled settings that allow exploitation of the powerful capabilities of volume interpretation systems.

Table 1. Cost versus year of acquisition for 3D seismic data in the North Sea, UK

North Sea 3D cost over time	
Year	k USD km^{-2}
1982	70–100
1986	30
1990	12–15
1993	8–9
1999	4
2002	10–20

USD, US dollars.
From Davies *et al.* (2004).

A vision of the future

The advent of CVEs represents one of the most exciting developments in the industry since the advent of 3D seismic data, and most energy companies have embraced this new immersive and collaborative setting. Economic success may well depend on the full utilization of data to reduce and understand risk in order to make the right decisions, in some cases ahead of the competition. In the future there may be increasing usage of these facilities in favour of traditional 2D-based forums. The number of new interpretation tools for CVEs and conventional workstation settings will also continue to increase. This automation will reduce interpretation time (e.g. **Carrillat *et al.***, this volume; **Gibson *et al.***, this volume). There will be an increasing emphasis on how interpreters interact, understanding perception, using immersion and using motion when displaying data volumes. These themes are discussed briefly in the following sections.

Collaboration and integration

Traditional meetings may produce an insufficient level of collaboration, as language and 2D images often lead to a superficial communication of complex geology and geophysics. Therefore, it can be difficult to forge a true shared understanding among the diverse operational and technical professionals involved in solving complex problems. Using CVEs, team members can more readily

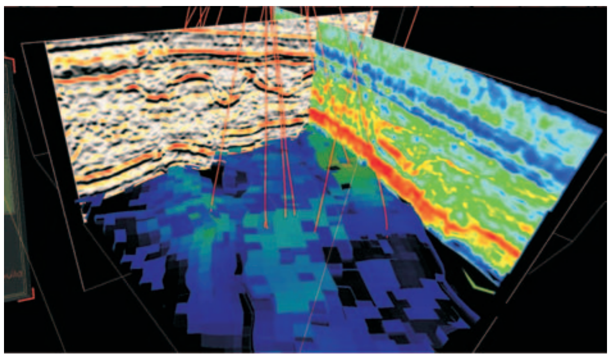

Fig. 2. Subsurface data vintage 2002: simultaneous visualization of multiple seismic and reservoir engineering data. Example taken from a gas field within the North Sea, UK.

communicate comments, concerns, issues and discoveries to each other and reduce risk in subsurface decision making. However, what is seen in a CVE fundamentally depends upon one's perception of complex datasets and more emphasis will probably be placed on this in the future.

Human perception and vision

Perception is the neurological process, based chiefly on memory, by which people detect and interpret information from the external world, by means of sensory receptors. Visual perception is one example that most people assume is unbiased, but is, in fact, dependent on knowledge, experience, cultural and social backgrounds. In reality, all perceptual stimuli are combined through intelligence which synthesizes and interprets them as a whole, depending on the memory of experience and on the knowledge transmitted by colleagues. The visual system is, therefore, an image-processing device that transforms a mosaic of light energy on the retina into informative perceptual representations of form, colour, depth and motion.

Immersion

Immersive visualization is the saturation of the visual sense with meaningful computer-generated images. This is achieved by filling the field-of-view with information relevant to the task at hand. Field-of-view is important, as a narrow field-of-view degrades spatial awareness. Therefore, immersion is important, as the audience is wholly engaged and focused. The system monopolizes the visual sense and gives the feeling of 'being there'. The immersion essentially improves the focus of the user on the information being displayed.

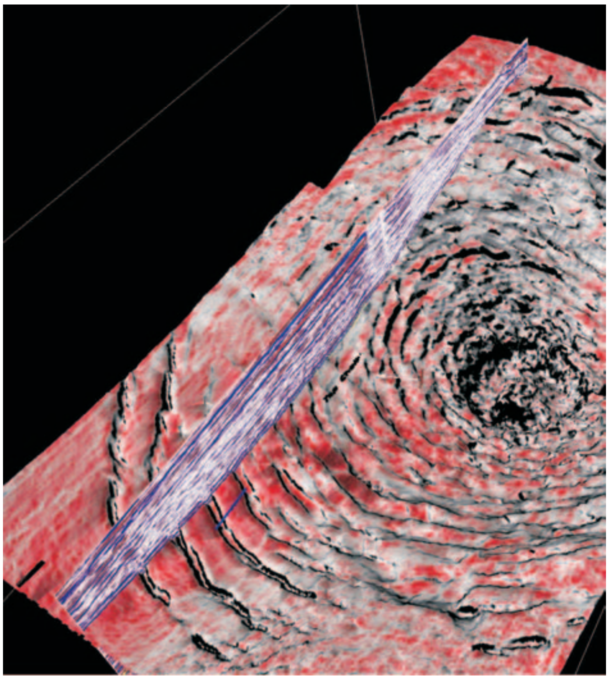

Fig. 3. Illuminated image from Movie 2 of the Silverpit meteorite impact crater. Movie 2: 0–20 s: comparison with images of different terrestrial and extraterrestrial impact craters; 21–24 s: location of the Silverpit crater; 25–38 s: top and base Cretaceous Chalk surfaces. The view is from the southeast; 39–56 s: central uplift in the centre of the Silverpit Crater, view from southeast. 57–60 s: east–west seismic line showing extensional faults on the western rim of the crater; 61–84 s: top Cretaceous Chalk surface showing extensional fault blocks on the western rim. View from south, below and above this surface; 85–93 s: top Cretaceous Chalk surface with flight over central high from west rim to east rim of the crater; 94–108 s: top Cretaceous Chalk surface showing compressional faults on the eastern rim. Comparison with the expression of faults on east–west seismic line; 109–123 s: east–west seismic line showing central high. Animation through the seismic volume; 124–143 s: top Cretaceous Chalk surface: view of the crater and central high from above; 144–153 s: top Cretaceous Chalk surface, view of the crater and central high from above. Example of the multiple ring features; 154–157 s: image of Tyre Crater on Europa; 158–162 s: summary of key points; 163–168 s: summary of seismic data owners.

Motion

As motion and dynamic behaviour are a fundamental part of efficient visualization, new interpretation techniques should use interaction and animation extensively. Data analysis will continue to evolve from static to dynamic. Animation provides one of the most powerful means for communicating ideas, as well as clarifying spatial complexity.

Future advances in earth sciences

Every new map, whether it be in two-way travel time or a seismic attribute map, has the potential to reveal features that are yet to be appreciated fully in the field. Therefore, at geoscience conferences there is likely to be an increasing number of examples of new geological structures or structures revealed in more detail than ever before on 3D seismic data (e.g. Silverpit Crater – Fig. 3). The scale and detail of some geological structures will increase because they will be recognized for the first time on 3D data (e.g. Cartwright 1994; Stewart 1999; Cole *et al.* 2000; Molyneux *et al.* 2002; Stewart & Allen 2002; Davies 2003; **Huuse *et al.***, this volume). The discovery of new phenomena is not simply the result of a blinkered hunt for geological curiosities. It will ultimately lead to a better understanding of sedimentary basin processes, whether they be structural, sedimentological or even related to poorly understood subjects such as fluid flow. Three-dimensional seismic data will also become a tool used by other well-established earth science disciplines, such as geomorphology. Researchers will now be able to do what they once may have only dreamed of: see how the morphology of the earth has changed through time, rather than only seeing its present-day surface manifestation. The diversity of disciplines using the data will increase; it has already reached 'hard rock' subjects such as igneous geology (Davies *et al.* 2002; Trude 2004; Hansen *et al.* 2004; **Thomsen**, this volume).

In the oil and gas industry seamless integration across disciplines in CVEs is already becoming routine (**Samuel *et al.***, this volume). Advances in seismic resolution such as multi-component seismic and single sensor technology, together with advanced 3D visualization, allow more complex and subtle migration and reservoir systems to be imaged, recognized and interpreted for the first time (**Huuse**, this volume). Time-lapse seismic data (e.g. **Scorer *et al.***, this volume) will lead to true 4D seismic imaging, providing observation over time. A permanent installation of sensors on the seabed, coupled with instruments in wells, also provides the opportunity for further monitoring of the subsurface: for example, of dynamic subsidence in the overburden, and micro-earthquake events from sub-seismic faulting in the reservoir – the 'electric oil field' vision of dynamic earth monitoring (e.g. Davies *et al.* 2004).

Pitfalls that lie ahead

We met the enemy and he is us
(quote by American cartoonist, Walt Kelly (1970)).

Technology is only as good as the people that use it. As our understanding of the complexity in the oil fields grows, so the modern geologist needs to be a super-geoscientist, part-time geophysicist, reservoir engineer and drilling engineer in order to communicate efficiently within asset teams. Oil companies are

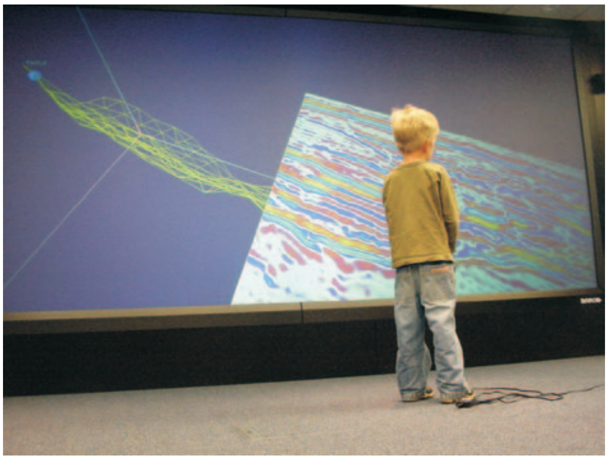

Fig. 4. A child in a virtual reality environment. Today, immersive visionariums are already being established at universities in the developed world. As hardware and software costs are reduced, such facilities may become commonplace teaching tools for the next generation of earth scientists.

increasingly realizing that advanced technical skills need to be matched by 'soft skills', such as communication and team work skills in order to optimize decision making. Furthermore, the new generation of earth scientists that is required to replace the ageing petroleum geoscience population needs to be well versed in the latest technologies, including CVEs (Fig. 4).

While interpretation tools have become increasingly accessible, it is likely that data acquisition and processing will become more advanced and complex. An understanding of the assumptions made in the processing of 3D seismic data requires an ever-deeper understanding of geophysics. Interpreters will need to widen their skill set to encompass the range of geological architectures that are revealed on higher quality data. The modern interpreter must truly be a multidisciplinarian, well versed in subjects as diverse as petrophysics and sequence stratigraphy. Continued professional training is, thus, a priority in such a demanding environment.

Conclusions

The communication of new ideas at geological meetings throughout the nineteenth and twentieth centuries has been facilitated through the use of 2D images, such as geological cross-sections, maps and photographs augmented by careful and precise verbal description. The 3D Visions session at the 6th Petroleum Geology Conference was more than a series of presentations on visualization and the innovative use of 3D seismic data. It attempted to test the viability of a CVE as a way for geoscientists to communicate, not just within the conference medium but also within large multidisciplinary teams. The authors predict that 3D seismic technology and visualization will influence many other disciplines within the broader geological community and that advances made so far are dwarfed by the future potential.

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