Accurate reservoir surveillance is a critical component of successful oilfield planning and management. Asset teams are constantly challenged to collaboratively visualise and interpret diverse datasets originating from a multi-vendor software portfolio. While much of this information is often static subsurface data, temporal monitoring of oil and gas fields is becoming increasingly commonplace. The ability to incorporate time varying data adds a significant level of complexity to successful data visualisation. Finding a single, flexible visualisation environment that can display such diverse data can be a considerable barrier to efficiency in the workflow.

The solution discussed in this article addresses many of these challenges, and offers a dynamic, temporal visualisation environment for data fusion and integrated reservoir surveillance. Two field examples are highlighted, demonstrating the valuable insights gained through integrated subsurface data analysis. With such a collaborative visualisation tool in hand, asset teams can make better, faster and more accurate reservoir management decisions.

Introduction

As producing oil and gas fields mature, and new discoveries push the limits of existing technology, it is becoming increasingly important to fully understand the reservoir environment in the context of all available data, so that better development and management decisions can be made. Accurate reservoir characterisation, surveillance and management is an extremely challenging task, and mistakes can be costly. While new discoveries and younger fields often have a lower diversity of data to analyse (which presents its own difficulties), producing and mature fields usually have vast amounts of subsurface data to integrate and interpret. Asset teams composed of geologists, geophysicists, and reservoir and production engineers, face an extremely tough challenge as they try to integrate and understand their multidisciplinary data. Faced with this challenge, some development teams have relied on makeshift solutions (such as slide show presentations and static images) to achieve data integration during collaborative planning and surveillance meetings, limiting the efficacy of these interactions and the resulting asset management decisions.

Recognising the existence of this critical visualisation gap in the oil and gas industry, Dynamic Graphics has developed a software solution that provides a vendor-neutral collaborative visualisation environment. The software consists of a fully georeferenced 4D viewer, capable of simultaneously displaying time lapse seismic volumes and attributes, geologic models, well data, instantaneous and cumulative production data, reservoir properties, 4D reservoir simulations, drilling hazards, as well as many other surface and subsurface data types (Figure 1). In addition to providing advanced graphics rendering and temporal animation, the software offers direct links to a variety of data sources with options for automatically keeping the necessary data ‘evergreen’.

The software aims to offer an integrated, dynamic environment that facilitates multidisciplinary analysis and interpretation of the diverse subsurface data typical of today’s asset teams. The layout of the visualisation environment and data interface allows for quick and seamless integration of the software into the daily workflow.

Data entry and management

A key feature of the software is the ‘Data Registry’ that works in direct conjunction with the visualisation environment. This data catalogue is organised by data type and is designed to be built and used in a team setting, with each discipline expert managing the relevant data types. In this manner, the entire asset team has quick access to all the necessary data; each individual does not need to know which application generated a particular file or in what disk/directory to find it. Direct imports from many commonly used applications are available, making populating,
maintaining and updating the data catalogue a straightforward task. Once a data pointer is established, it can be refreshed automatically by loading the file into the viewer, instantly and transparently keeping all of the visualised data up to date.

In addition to georeferenced 2D, 3D and 4D data, non-spatial data can also be included within the data catalogue for consideration in the larger context; this includes reports, well review documents, schematics, photographs, etc.

Many data types are supported by the software, including but not limited to:

- Seismic data, in both time and depth including 2D, 3D and 4D seismic data, and attributes. Also passive microseismic monitoring surveys.
- Seismic based interpretation of horizons and faults, both as point data and grids.
- Well locations, survey information and logs. Also mechanical data, casing details, perforations, drilling targets and change of status events.
- Geologic models, both structural and property models. Also geocellular models.
- Reservoir simulation models, including history matching and predictions, with multiple static and temporal attributes.
- Fluid production/injection/pressure data, both instantaneous and cumulative values.
- Cultural data such as lease boundaries, facility/pipeline information, aerial photographs, satellite images and geologic maps, including temporal instances showing changing conditions over time.

**Collaborative visualisation**

The visualisation environment as described here is capable of simultaneously displaying large volumes of diverse spatial and temporal data, including multiple geologic models, property grids, seismic volumes, along with well events, logs and fluid production information. Once a link has been established to a particular file, the file is easily loaded to the visualisation environment, where it can be manipulated, analysed and queried within the context of other available data. Flexible viewer scaling permits data from a wide range of spatial scales to be loaded at the same time, and it is possible to move quickly and seamlessly from a broad, regional view, down to the level of a single well log within a reservoir (Figures 2a - c).

This flexible viewing environment offers many advanced features for detailed data interrogation, interpretation and analysis, including:

- Statistical analysis, with real time interaction between the statistical interface and the viewer.
- Fast, interactive volumetric calculations.
- Instantaneous cross sections along arbitrary traverses.
- Data clipping, filtering and scaling options.
- Multiple ‘model spaces’ to simultaneously render datasets with different vertical units.

Perhaps the most important feature of any reservoir management visualisation environment is the ability to display time varying data. Understanding and integrating these 4D data is essential to the effective development, management and surveillance of a reservoir, and software should be able to efficiently and rapidly display a wide range of temporal data types, over varying temporal and spatial scales, and with diverse temporal resolution (sampling frequency). All data with temporal information are fully integrated into a ‘global timeline’ that spans the full range and resolution of dates in the files loaded into the viewer. Functionality is included to restrict the animation over specific date ranges and to use custom time increments, allowing for precise control of the data files as they change over time. The 4D component of the visualisation environment enables a deeper understanding of the oil and gas reservoir setting; interrelationships between events and the resulting changes they have on areas of the reservoir can be observed and understood, and in this manner, the impacts of management decisions on the reservoir can be assessed.
Case histories
A number of examples point to dramatic end user benefits of incorporating collaborative visualisation software into the typical oil and gas workflow. The examples discussed below clearly demonstrate the fundamental importance of fully understanding the reservoir environment. A dynamic visualisation environment makes it possible to see the effect that management decisions have on the success of an oil and gas field.

Case 1
In an offshore North Sea field, a discrepancy between the predicted response from a reservoir simulation model and the actual seismic response was discovered when several subsurface datasets - especially time lapse geophysical data and reservoir simulation data - were integrated and examined over time. The ability of the team to integrate and visualise multiple, time varying datasets enabled them to uncover the source of the problem and develop a strategy to correct it. Several instantaneous ‘snap shots’ from this North Sea field, taken from a continuous temporal animation sequence spanning 14 years, are shown in Figures 3a - d; subsurface data includes a series of seismic surveys, a reservoir simulation prediction model, seismic amplitude extractions/amplitude differences for the reservoir sands, and well event information.

Figure 3a represents the initial conditions in the field, and the earliest time point in the series of figures. In 1993, a large gas cap is interpreted in the upper sand (later confirmed by drilling), indicated by the low impedance values (red) in the seismic amplitude extraction. As the field was produced, an injector well was emplaced to assist with production from the lower sands. In 2002, shortly after the injection well was drilled, a second seismic survey was conducted. After processing the 2002 seismic survey, and comparing it to the baseline 1993 response (Figure 3a), a large anomaly (blue) is observed in the seismic attribute difference map near the location of the injector well (Figure 3b). This anomaly - an increase in seismic impedance - is suggestive of high pressure and/or significant water injection in the upper sand, a condition that was not forecast by the reservoir prediction model (Figure 3c). At the same time, in the deeper reservoir sand, gas breakout due to a pressure drop was interpreted from the time lapse seismic response, and temporal visualisation quickly showed that the pressure drop coincided with a nearby producing well coming online. Using this combined evidence, the team concluded that the water injector perforations to the lower sand were blocked, causing a failure of water injection in this reservoir zone and anomalously high injection rates to the upper sand. Adjustments were made to the field, and pressure monitoring indicated efficacy of the operation. Figure 3d shows the results from comparing the 2002 survey with a third seismic survey acquired in 2004. The differences in the seismic response indicate that the high pressure anomaly had been reduced, and the actual conditions in the reservoir were in closer agreement with the reservoir prediction model.

The ability of the North Sea field’s team to observe the interaction between different areas of the reservoir over
time was essential in discovering the source of a critical mismatch between the actual and predicted behaviour in the reservoir. These subtleties may have been missed if the data were not simultaneously displayed and animated in a collaborative visualisation environment.

**Case 2**

During the drilling of a production well in an offshore field, a gas kick occurred and led to a well control incident. Multiple subsurface datasets were examined to help uncover the source of the gas kick. Data from this offshore field are shown in Figures 4a - c, including a geologic model, seismic amplitude survey, a Gamma Ray curve and lathe (radius) plot of normalised gas data along the production wellpath.

The 3D visualisation in Figure 4a shows low GR values (yellow) associated with high gas values (red), against the geologic model, in the area of the reservoir where the gas kick occurred. In this section, however, the team had expected to encounter a low porosity, low permeability shale cap rock. Following the incident, a 4D seismic grid, representing the difference between the original baseline survey and one acquired after production began, was examined to determine the potential source of the gas kick. By selectively filtering the difference grid, the brightest amplitudes become isolated (Figure 4b). In this grid, the bright, positive amplitudes (increased impedance) are likely to indicate areas of increased pressure. A bright anomaly was observed in close proximity to a water injector well that had been drilled a couple of years earlier, and the team proposed that this anomaly was related to the gas kick. By decreasing the level of filtering, and displaying more of the medium amplitude values (Figure 4c), the team searched for a direct pathway, such as a sand stringer, between the anomaly near the water injector and the production well that took the kick. Unfortunately, the resolution of the seismic data was too low to see such a path connecting the two wells.

By examining the seismic difference grid, together with wellpaths and well logs in a 4D visualisation environment, the team became critically aware that important pressure changes had taken place in the reservoir as it was produced. They could begin to see the relationship between these anomalies, and were made aware of the urgent need to acquire a new, higher resolution survey, so that potentially hazardous areas within the shale cap rock could be identified, thus avoiding future well control incidents.

**Conclusions**

The integration of a flexible, dynamic 4D visualisation environment into the oil and gas workflow can significantly improve an asset team’s ability to accurately analyse, interpret and understand a broad range of static and time varying subsurface datasets. This article has discussed a visualisation solution that fits into a multi-vendor software portfolio, and offers improvements over current integrative visualisation options.

When multiple datasets, over varying spatial and temporal extents, can be simultaneously visualised and interrogated, the complex and often subtle interrelationships within the reservoir become apparent. In the two field cases cited, the importance of visualising 3D and 4D datasets from multiple disciplines is clearly demonstrated. In both cases, the source of unexpected changes in reservoir conditions after production began, became evident only after fully integrating the subsurface data within a single visualisation environment. A deeper understanding of reservoir behaviour enables better, faster and more accurate development and management decisions.