An interpreter has complete freedom to view 3D seismic volumes from any angle using in-line cross-line, time, depth, horizon and stratal slices, and vertical traverse. Each slice or traverse can be interpreted using similar methodology to that used for 2D seismic interpretation. 3D features cannot usually be fully displayed on any single slice so the features have to emerge in maps or models derived from interpreting multiple slices.

The 3D seismic volume provides continuous 3D sampling of the sub-surface. This volume may be further processed using volume operators or volume viewing techniques to disclose 3D features hidden within it, without recourse to mapping or model building. Typically these volume operators or viewing techniques will enhance one attribute of the volume at the expense of another. Fortunately, an interpreter’s understanding of the volume can incorporate insights from all views of the data so there can be gain caused by these techniques.

The reservoirs that we are seeking today are typically more subtle than an anticline or fault bounded trap. Reservoirs in bars, reefs, sand dunes, and channel fan complexes cannot usually be recognized by simple mapping of horizons and looking for amplitude anomalies. These reservoirs are typically found by detecting the depositional system and then seeking the porosity within it. The signature of a turbidite fan might be the absence of a horizon that can be picked or tracked. So conventional horizon picking will not suffice. The feature needs to be recognized in a slice or 3D view and then explored in 3D. There is no magic bullet to accomplish this but there are nearly magic ways to do so and we can suggest methods to follow to help in this task. There is much to be gained by adding 3D techniques to slice-based techniques of seismic interpretation.

**Optical stacking**

This technique was used in the earliest 3D interpretations when in-line displays were printed onto glass panes. More recently, Worral (2001) discussed optical stacking for fault interpretation. The technique is to display a small number, say 10, of vertical sections with opacity of say 50%. This allows the interpreter to see through the entire slab. Faults on seismic sections are typically expressed by a loss of reflection amplitude. When parallel sections are viewed with transparency the reflection amplitudes can be made to reinforce by changing the elevation of the view so that horizons are horizontal in the direction of the view. If the azimuth of the view is rotated so that the view direction is along the strike of the fault, then the loss of amplitude at the fault is reinforced and the fault can be interpreted more easily. A seismic line from a survey offshore Indonesia is shown in Figure 1. An optical stack of 10 lines centred on the line is shown in Figure 2.

The image has been rotated in elevation and azimuth so that reflections of horizons in the central fault block reinforce and the view of the faults is along strike. The image is noticeably washed out elsewhere. In an optical stack there is some ambiguity on where the fault exists in the direction of view while the expression of the fault in the section is enhanced. If the interpreter repeats the fault interpretation in an orthogonal direction, say cross-line, the precision of the fault interpretation can be improved in all directions to the precision of the seismic imaging.

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The benefits of optical stacking are not limited to faults. When horizons are difficult to pick because of their lack of continuity or lack of expression, then optical stacking can reinforce the composite reflection and produce an event that can be manually picked. Horizons that are sub-salt, below volcanic, or complex structures that are impossible to pick by other means may be picked using optical stacking.

Fluid contacts may cause very weak reflections which can be obscured by stronger reflections from structural horizons. Optical stacking can often make fluid contacts clear and is usually very easy since the viewing direction needs to be horizontal and is not sensitive to size since the fluid contact has a simple shape in depth or time. A change in depth of a fluid contact on adjacent traces may be a cue to the interpreter to look for a sealing fault.

**Facies classification**

Unsupervised facies classification needs very little effort from the interpreter. An interval of seismic data (typically 100–200 ms.) has to be defined. In the examples shown in this paper, the interval is below an index horizon that was easy to pick. In this example the facies classification was not innocent. The channel was already known to exist because it had been previously interpreted. The unsupervised classification requires the user to choose the number of classes, typically eight to 12, and then the algorithm examines the trace shape over the interval defined and compares the trace shapes for all traces in the volume. Similar trace shapes are placed in the same classes and assigned colours. The results of such a classification are shown in Figure 3. This classification has automatically exposed the existence of a wide channel in the interval shown as blue and green facies. There is some doubt where the channel goes above wells A and B. There seems to be an indication of over bank deposits shown as blue and green facies in the interior of the meander. Since the algorithm examines an interval or slab of the volume and results in a map, there is no indication of where the channel lies within the interval. However, there is a strong lead on where to look for it by other means. The facies classification would have resulted in the identification of the channel if its existence had not been previously known.

Many oil companies pass every seismic volume collected through stratigraphic analysis as a matter of course. Unsupervised facies analysis is not always part of this process; sometimes it is restricted to reservoir characterization activity where it is invaluable. The example is intended to show that it can be invaluable earlier in the process during exploration and it costs very little other than computer time. This process therefore appears close to magic.

A second classification was run on the same data with the volume to be analyzed restricted to the apparent channel boundary. The results are shown in Figure 4. The intent of this exercise was to see if we could identify sand rich parts of the channel by the shape of the facies and the position within the channel. This hope seems to have delivered limited results. The blue and green facies seem to identify thick parts of the channel. The facies other than the blue seem to change abruptly at faults. This is disconcerting but may be a result of the analysis window including different data on different sides of the fault. The facies in the channel at the top of the image seem to share little similarity with facies at the bottom.
of the image. This casts doubt on whether the two legs of the channel belong together. They are separated by a major fault with lots of strike slip movement so this would not be an impossible scenario.

All these leads and questions arise with almost no effort by the interpreter and it is very comforting to perform the facies analysis so that one knows what a new volume contains. If the two parts of the channel can be determined to belong together by other means and if the channel can be correctly picked above wells A and B, we can derive one data point on the amount of lateral movement there is on the fault.

**3D horizon propagator**

Once a channel is identified, its shape can be extracted from the volume using a trace shape horizon propagator or by voxel picking on the basis of amplitude range. Figure 5 shows a cross-line from a 3D volume with a seed pick placed on a channel in the top right of the image.

The seed pick interval is chosen so that it just contains the top and bottom reflections of the channel. The rest of the parameters for propagation are default. In this case we are lucky and the results of a single propagation are shown in Figure 6.

The propagation has terminated at a fault in the centre of the image and the rest of the channel propagation will require fresh seed points. The colour scale of the channel covers a time interval of about 120 ms. In some cases there is about 60 ms of structural relief in the cross channel direction. The expression of the channel is very easy to discern at the origin seed pick but becomes increasingly difficult to follow. As the propagation continues, the channel lies in a horizon with increasingly steep dip and its amplitudes merge into the amplitudes of its own over bank deposits. If we looked at a volume that was flattened at approximately the channel time we would not be able to easily detect the channel in the over all horizon structure.

In this example we have picked some over bank deposits with the channel. These deposits were originally below the channel but because of structural dip they are now higher. The total complex does not lie on a single plane and can only be seen completely in a 3D view.

**Coherency and automatic fault extraction**

Coherency calculations are another volume operation that can be applied to a 3D seismic volume. Coherency (Bahorich and Farmer, 1995) measures the similarity of traces with their surrounding traces for a set of time gates that cover the trace interval. Marfurt, K.J. et al, 1999 modified the original algorithm in order to calculate coherency in the presence of structural dip. Today we usually use this latter algorithm as an initial choice and in conversation we call it Eigen. The coherency values lie on some interval say [0, 1]. In our example values > 0.5 are white and coherent, values <0.5 are black and indicate discontinuities such as faults or channel boundaries. The time gates used for the calculations were 40 ms so that amount of ambiguity about the depth of any feature. Figure 7 shows a shallow time slice through a channel complex.
Figure 8 shows a composite display of amplitude and coherency which gives greater detail of the channel boundaries. The two attributes agree closely for the main broad channel. The attributes do not agree so well for the channel in the top right corner of the image. This probably means that the coherency is responding to data deeper in the section and that a later composite display will bring both attributes into agreement. Regardless, the display conveys far more information to the interpreter than the amplitude slice by itself.

Coherence volumes are used as input to automatic fault extraction application. The application has many stages but the first stage takes a coherency volume and applies an algorithm to reduce the acquisition footprint that these volumes often display. The second stage processes the coherency data and creates a lineament enhanced volume. This volume tries to turn coherency values on a single time slice to lineament probability values. These are intended to be further processed to determine fault probability volumes to be used in the fault extraction process. The goal of these subsequent processes is to suppress lineaments that are the result of channel boundaries or any other cause that is not a fault by injecting geologic constraints derived from the physical behaviour of known faults. We and others expected to extend this research and develop algorithms to detect reefs, channels, and other sedimentary features using similar methodology.

However, in the mean time, we made a co-rendered display of seismic amplitude and a lineament enhanced volume.

Figure 9 shows a shallow amplitude slice through the Indonesian data volume. Figure 10 shows the same slice with amplitude and lineament enhanced data co-rendered. This allows the interpreter to understand the amplitude variations in terms of the different channels. It also provides a framework that shows which channels cut through other channels. Some channels can be seen to cross the entire data set in the co-rendered image while only a small piece of them can be interpreted in the amplitude data set. This whole sequence in the volume of about 200 ms can be understood much more clearly with this technique.

Figure 11 shows another slice about 50 ms shallower and here the acquisition footprint is strong. In the co-rendered view the amplitude variations due to the footprint can be consolidated with the amplitude variations due to the chan-
Volume rendering
Volume rendering allows interpreters to discard some of the data in the 3D volume in order to view the remaining data in 3D. One tool is to trim the volume to just the interval to be examined. This can be followed with volume sculpting which can remove parts of the volume above and below horizons. The horizons may be picked horizons or phantoms that

els and the brain can filter out the footprint variations to again make sense of the amplitudes. The lineament enhancement process has filtered out some of the noise in the coherency attribute by emphasizing where the coherency forms lines. We don’t see any lineaments along the boundaries in the acquisition footprint while we do in the raw coherency data co-rendered in Figure 8.

Figure 10 Co-rendered amplitude and lineament enhanced time slice.

Figure 11 Co-rendered amplitude and lineament enhanced time slice 50 ms above Figure 10.
Conclusions

This is a long list of 3D operations to apply to 3D data sets. There is nothing special about the data sets we use. When we’ve shown the co-rendering of amplitude and lineament enhanced volumes we’ve been asked where the data comes from. The answer is of course Indonesia but channels and fans exist in all regions of the world. The geology of Indonesia is very interesting but the channels in West of Shetland are equally as interesting and can benefit from the same techniques. There are many seeking magic bullets to view features such as channels on slices of one sort or another. We have an arsenal of tools such as coherency and facies classification that operate in 3D and expose the results on a slice. We have another arsenal of tools such as opacity filtering and volume rendering that allows 3D features to be directly viewed in 3D.

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