Seismic horizon attribute mapping for the Anneveen Gasfield, The Netherlands

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Summary

The Annerveen Gasfield in The Netherlands has been mapped in great detail, utilizing 3D seismic data interpreted on a SIDIS workstation. The combination of automatic horizon tracking and subsequent horizon processing resulted in maps of the following horizon attributes: reflection time, reflection dip, azimuth, shaded relief and amplitude.

Dedicated colour schemes have been designed to display the various attributes. Faults with vertical throw down to 10 m could be made visible, thus allowing high resolution fault mapping. In particular, the combination of a dip map with a shaded relief map turns out to be very powerful in detecting and analysing faults.

The end product of the study, a detailed depth structure map of gas reservoir, will serve as an important aid in future well targetting and field development planning.

Introduction

The Annerveen Gasfield, situated in the northeast of The Netherlands (Fig. 1), was proposed as a candidate for underground gas storage (UGS). The realization of such a UGS scheme would involve the drilling of at least 60 wells into the gas-bearing Rotliegend Sandstone reservoir to fulfil the envisaged capacity requirements.

The identification and correct delineation of faults from seismic data is of primary importance because downhole well locations need to be positioned to avoid intra-reservoir faults. Furthermore, the degree of communication between fault blocks is an important parameter for reservoir modelling, which is necessary for optimum positioning of downhole well locations.

The existing top Rotliegend reservoir structure map (Fig. 1) is based on a 3D seismic survey shot in 1984. Initial interpretation was performed on paper sections in 1986. Horizons were digitized on every tenth line. Subsequently, gridding and contouring were applied to produce maps. An example of a N–S 3D seismic line (Fig. 2) illustrates the overall good data quality, and also indicates the mapped base Zechstein reflection, a strong negative loop immediately above the top reservoir.

With the arrival of interactive interpretation systems in combination with new techniques such as horizon processing (Dalley *et al.* 1989), it was thought that the definition of the subsurface could be improved. In particular, improved structural definition of the reservoir should result in better targetted wells, thus in the case of Annerveen increasing the efficiency of the proposed UGS scheme.

This paper details the impact of interactive interpretation using automatic tracking techniques and the subsequent horizon processing of various attributes. In addition to reflection time and reflection amplitude maps, displays of dip magnitude and azimuth and of shaded relief for the target base Zechstein reflection are presented. The Annerveen project was the first case study in NAM where this combination of techniques has been implemented for field development planning.

Data handling

3D migrated seismic trace data were loaded on to a SIDIS workstation (product of Halliburton Geophysical Services). Interpretation of seven key horizons was performed on every tenth in-line and cross-line. For each horizon separately, these so-called seedlines were input to SPACETRACKER (part of the SIDIS system). This batch-operated program automatically extends the seismic trace interpretation from seedlines by using an amplitude comparision technique. The interpolation is performed in the three dimensions of the seismic data (x,y,t); hence the tool is often referred to as an automatic volume tracker.

The interpolated horizons were inspected on the screen, and in areas where the tracking had appeared to have gone astray extra interpretation was done on intermediate lines. The refined seedline grid was subsequently input to SPACETRACKER again and this procedure was repeated until the result was satisfactory (i.e. no loop skips in the interpolated horizon).

Extensive use has been made of the option to display four basic seismic attributes on the SIDIS screen as colour-coded maps with colour schemes designed to

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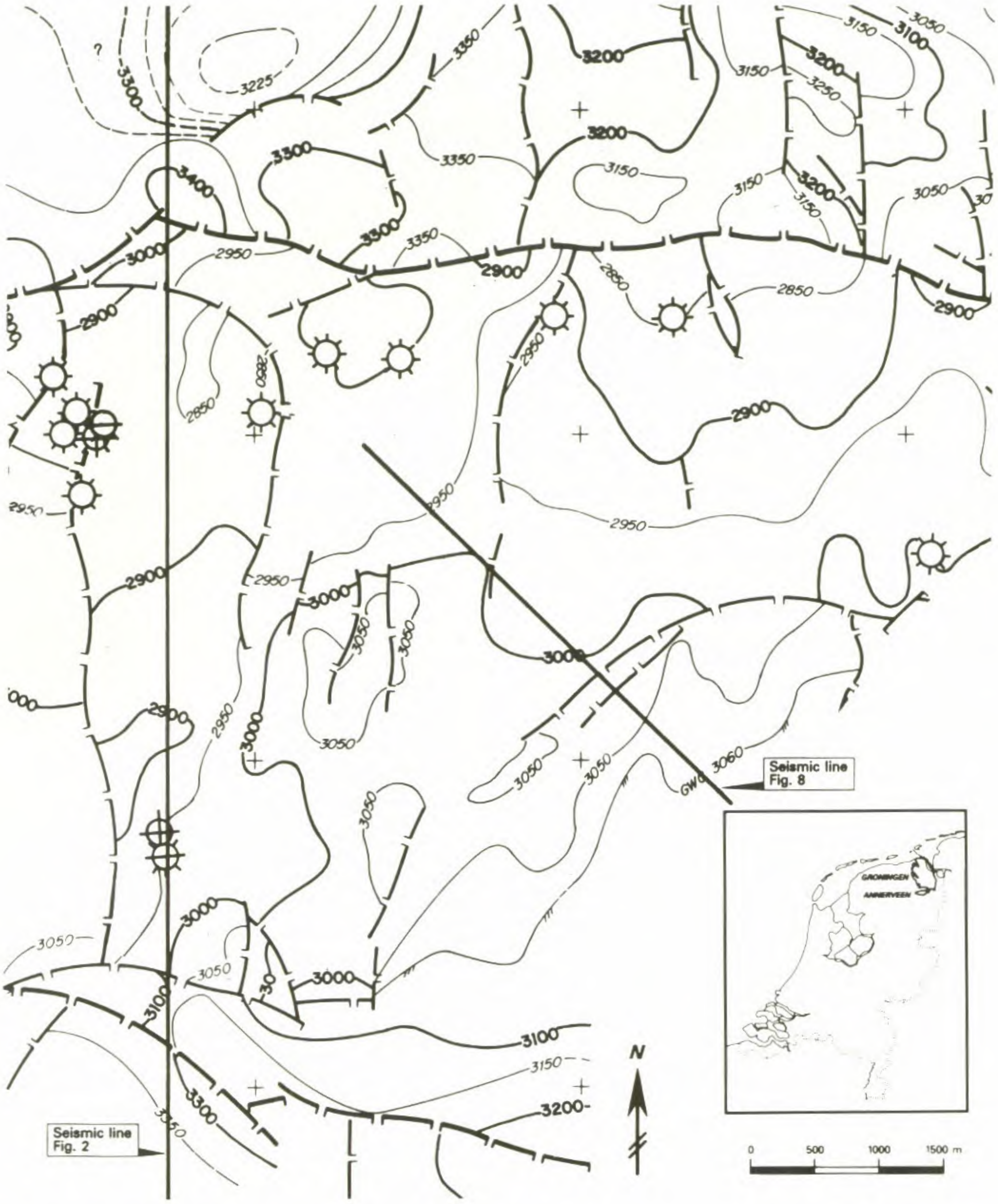

Fig. 1. Depth structure map over the centre of the Annerveen Field for the top Rotliegend reservoir horizon: 1986 interpretation. N.B. All maps (Figs 1, 4–7, 9–11) have the same orientation and cover the same subsurface area as Fig. 1.

display them in the most effective manner. Of these, reflection time and amplitude can be displayed instantaneously while interpreting. However, the running of SPACETRACKER and the resulting dip and azimuth attributes required some overnight batch processing before display on the screen was possible.

Having finalized the time interpretation, an interpolated time and amplitude grid for each key horizon was input to ZYCOR (product of Landmark Graphics Corporation). The Zycor mapping package was chosen for further horizon analysis because of its flexibility in grid manipulations, including time-to-depth conversion, and in display options. Data characteristics of the transformed grids may be summarized as follows:

- Map area: 9.225 km×7.750 km
- Grid/bin size: 25 m×25 m
- Data points: 114390
- Horizons: 7

The attribute mapping dataflow can be represented by Fig. 3. The boxes indicated by thick lines show the attributes which were mapped in this project to assist in the fault interpretation.

Horizon attribute maps

Base Zechstein reflection time map (Fig. 4)

On the reflection time map, reflection time values are colour-coded in the so-called 'mosaic' display, with different colour bands every 50 ms. In addition, each colour is subdivided into ten hues from light to dark. Colour

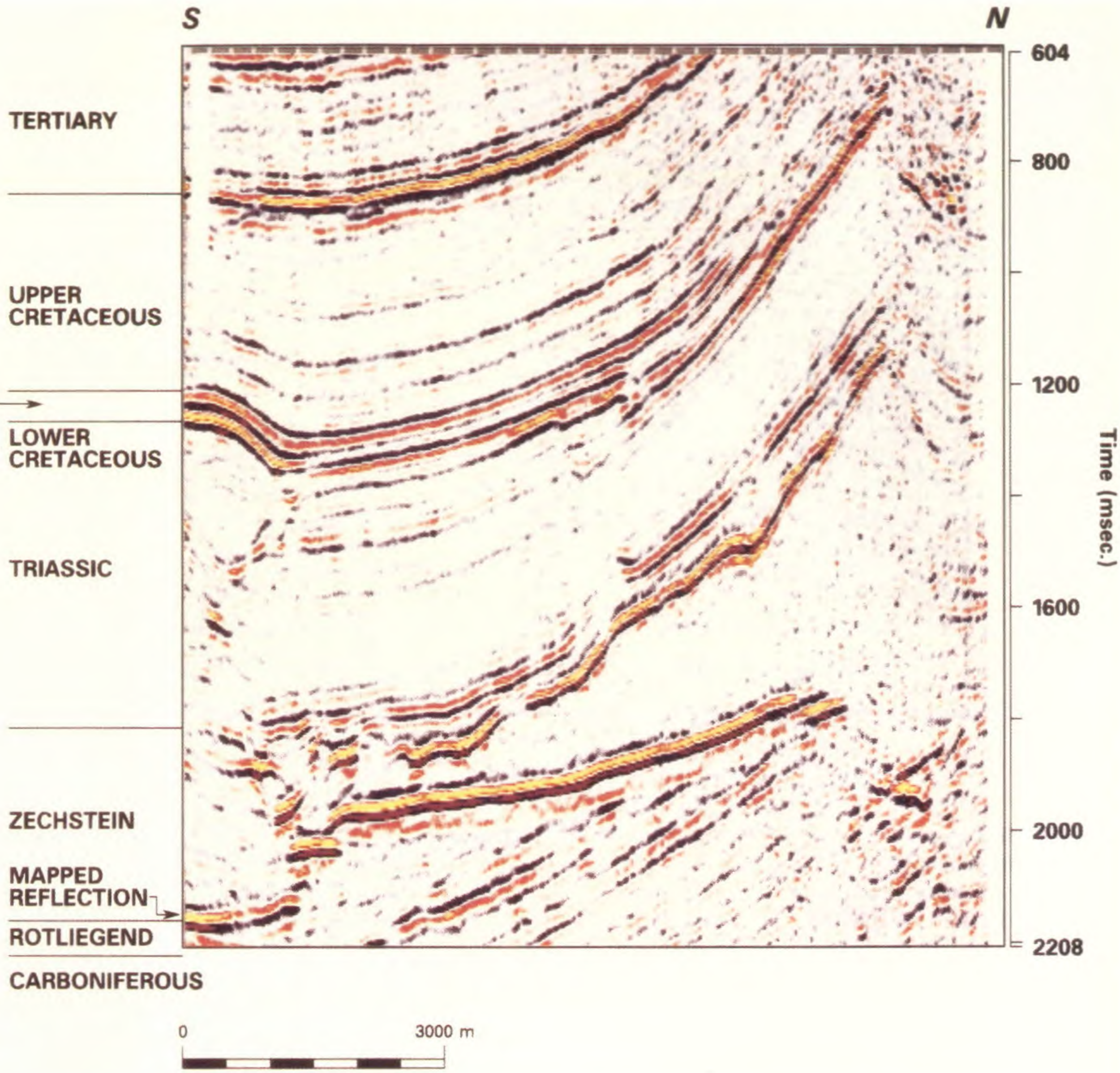

Fig. 2. Typical N–S 3D seismic section showing the top Rotliegend reflection and overburden stratigraphy (see Fig. 1 for location of section).

hue boundaries can therefore be considered as contour lines at 5 ms intervals. The scheme chosen goes from red, representing the shallow values, via yellow and green, to blue, representing the deepest values.

The southeastern part of the map is ill-defined with the poor data zone attributed to the presence of a saltdome overlying the target horizon. The steep dips associated with the dome cause severe ray-bending and related problems with imaging in processing. The same problem applies for the poor data zone in the northwest of the map.

Discontinuities in reflection time, which generally represent faults, show up clearly (e.g. the very clear E–W northern boundary fault and some N–S lineations) unless the fault strike is parallel to the contour. The extent to which the recognized discontinuities represent real faults is discussed in a later section.

Base Zechstein dip magnitude map (Fig. 5)

Reflection dip, expressed as the tangent of the dip angle, is calculated for each gridpoint using the equation

$$D(x,y) = [(dz/dx)^2+(dz/dy)^2]^{\frac{1}{2}}.$$

Dip values are colour-coded in monochrome in 240 steps from dark red, for the flat areas, via red to white, for the steeply dipping areas. On this display, faults correspond to steep dips and show up as light lineaments, (e.g. the E–W northern boundary fault and the N–S lineations

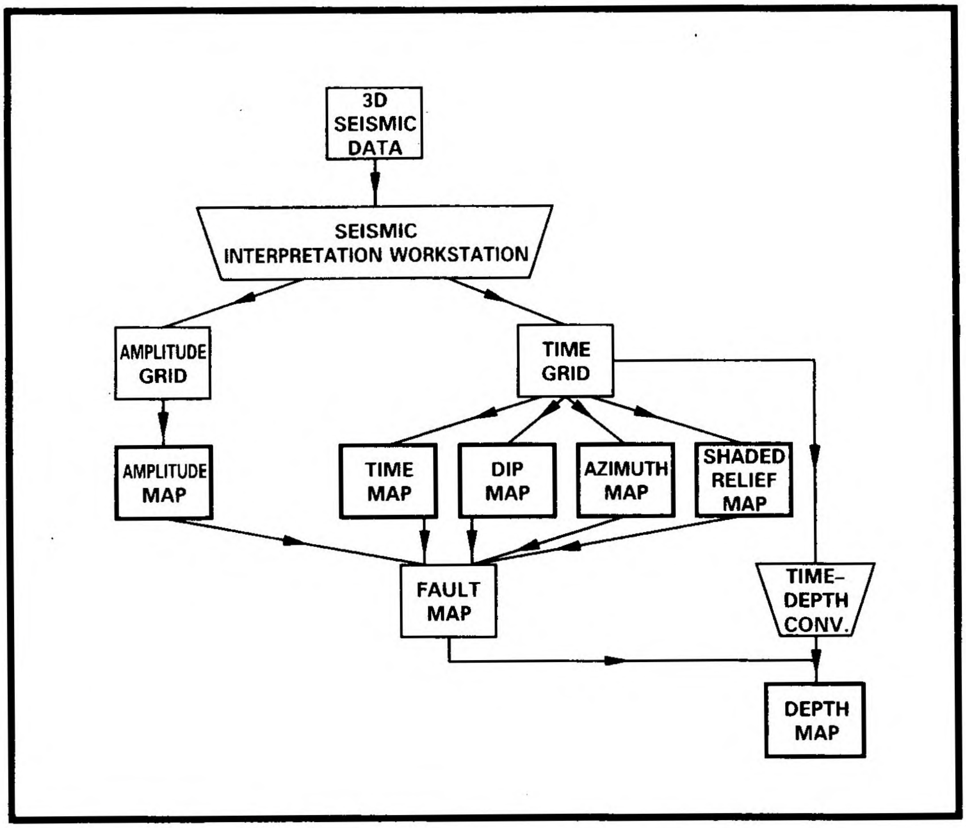

Fig. 3. Horizon attribute mapping: data flow.

previously recognized on Fig. 4). Many other lineations are also now recognizable on this dip display which were not as clear on the reflection time display.

It should be noted that flexures in the surface will also produce lineaments on the dip map. In particular, for small, low-angle features it is generally impossible to discriminate between faults and flexures using a dip map alone.

Base Zechstein azimuth map (Fig. 6)
Reflection azimuth represents the angle between reflection dip direction and geographical north. This angle, expressed in radians, is calculated for each gridpoint using the equation

$$A(x,y) = \tan^{-1}[(dz/dx)/(dz/dy)].$$

The values, which vary from 0 to 2π, are colour-coded using a so-called 'colour wheel' of 120 colour grades, each representing a sector of 3°. The multi-colour scheme consists of different grades of red and blue representing westerly and easterly azimuths, respectively. The applied scheme is therefore best suited for areas emphasizing features with predominantly east and west dip directions such as the N–S trending faults. North and south dipping features, such as E–W trending faults, are less clearly expressed on this display. Note how clearly westerly hading faults (red) are depicted where the predominant reflection times dip to the east (blue). In cases where more azimuth trends need to be highlighted, in principle more colours could be added to the 'colour wheel'. However, the resulting display rapidly becomes messy, and therefore difficult to interpret. A similar weakness, inherent to azimuth displays, becomes very apparent when the surface is nearly flat. Under such circumstances minor changes in the surface orientation may cause drastic changes in colour. The result is a 'noisy picture'.

Base Zechstein shaded relief map (Fig. 7)
The shaded relief option produces a grid in which the values are proportional to the brightness of the reflection surface as if it were 'illuminated by the sun'.

Brightness B can be determined by means of vector calculus. Assume the unit vector **s** points from the surface to the sun. This vector contains the directional information for the sun, which is taken to be constant for the area. Vector **v** represents the normal to the surface and therefore varies from gridpoint to gridpoint. The dot product of **s** and **v** is a measure of brightness: $B = \mathbf{s} \cdot \mathbf{v}$

Brightness values are in this case colour-coded in 240 steps from black via red to white. In this particular shaded relief display, the sun position is to the northwest. Faults having a westerly hade show up as white lineations, whereas those having an easterly hade show up as black. The shaded relief (or artificial illumination)

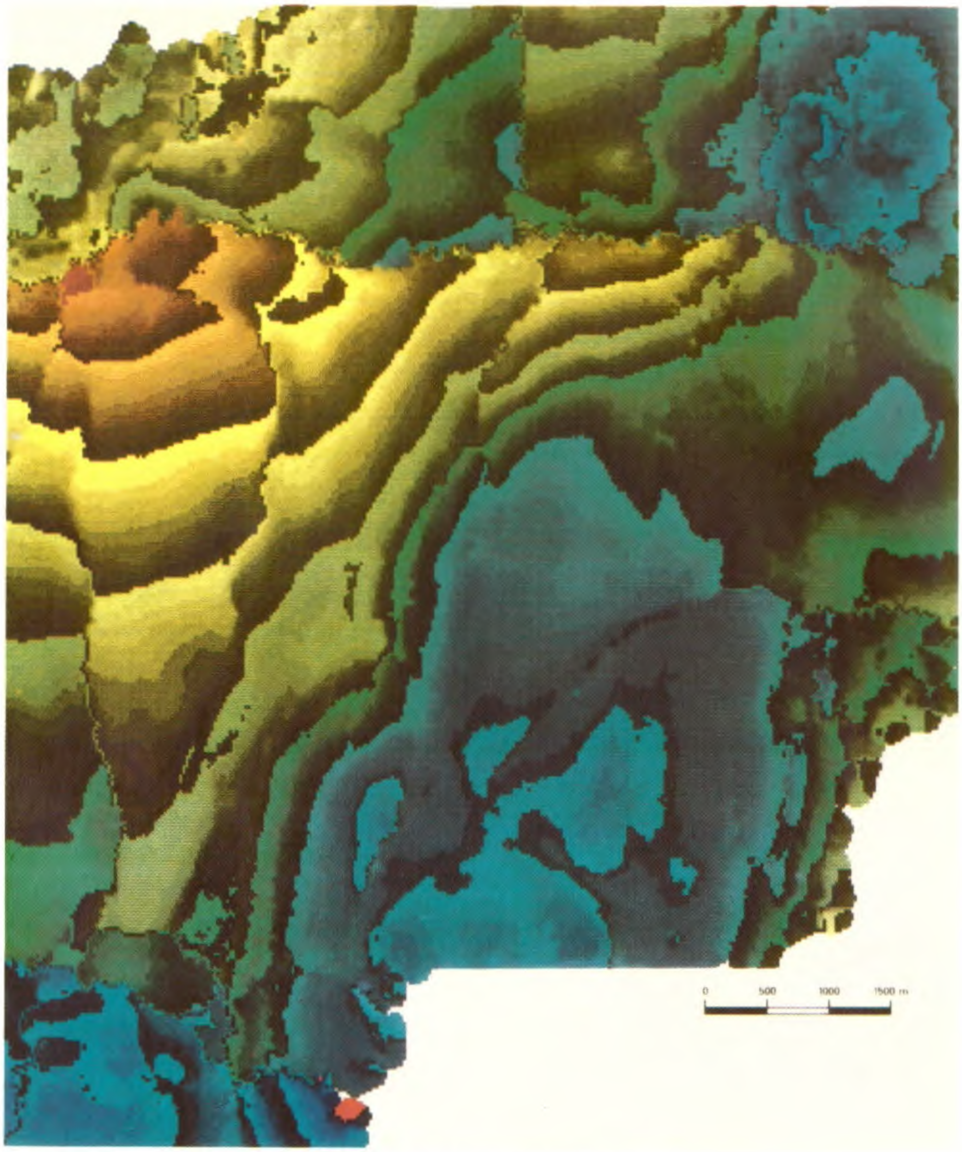

Fig. 4. Base Zechstein reflection time map.

display highlights fine detail in the surface topography. Shaded relief displays have a very natural appearance because of similarities with aerial photographs.

The brightness grid, being a function of reflection dip and azimuth, combines the advantages of both types of display. Although dip maps are powerful aids in fault detection, they do not contain information on throw direction. On the other hand, azimuth maps might contain information on throw direction, but they do not yield information on throw magnitude. In shaded relief displays there is information on fault throw direction as well as fault throw magnitude. One limitation of shaded relief displays is that the choice of the sun azimuth determines which trends are highlighted best. A fault which lines up with the sun's azimuth will not show up on the display. If required, this directional sensitivity can be circumvented by producing shaded relief displays with different sun positions.

The power of this display is shown by the sharp appearance of a small graben feature which runs SW–NE just southeast of the centre of Fig. 7. For comparison, a seismic section selected from the 3D dataset which crosses this graben feature perpendicularly is shown in Fig. 8.

Base Zechstein amplitude map (Fig. 9)

The target base Zechstein reflection is represented by a (white) trough, corresponding to a positive amplitude value. For this display, amplitude values have been colour-coded from red (negative) via purple (zero) and blue (positive) to white (very high positive amplitudes) using some 240 steps. This colour scheme was designed to highlight faults, which are generally characterized by low amplitudes. In addition, possible mis-picks from SPACETRACKER, often characterized by polarity

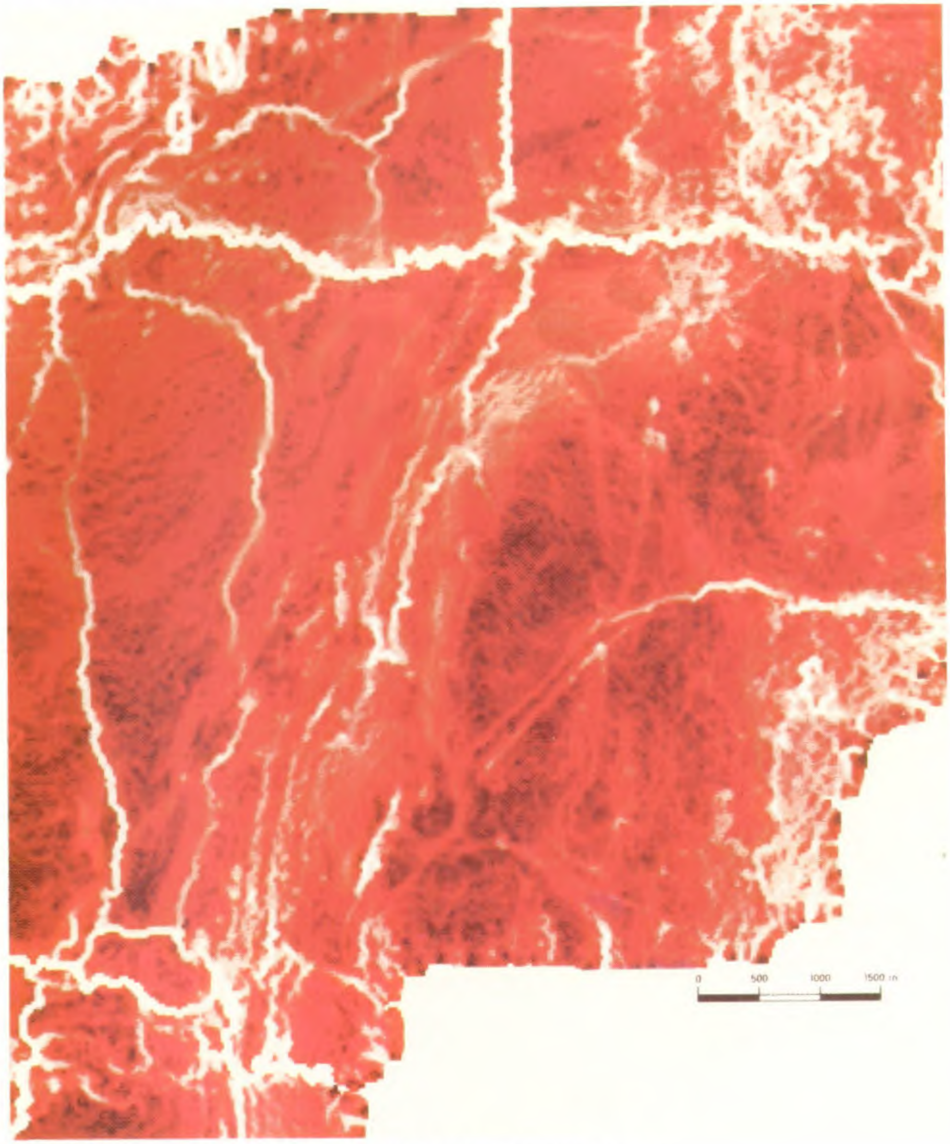

Fig. 5. Base Zechstein dip magnitude map.

flips, show up clearly as red. Some of these can be seen in the northeast of the area (Fig. 9).

Fault resolution on amplitude displays is generally not as good as on dip displays. Amplitude anomalies caused by faults are smeared out over a relatively wide zone, as shown by the E–W northern boundary fault. Compare the smeared out appearance of the small graben feature on the amplitude display (Fig. 9) to that on the shaded relief display (Fig. 7).

Fault interpretation

A detailed fault map for the reservoir has been derived, making use of all the various horizon attribute maps. From all attributes displayed, dip appeared to be the most sensitive for detecting the *location* of faults. By combining the dip map with the shaded relief map, the *direction* of throw could be determined very easily.

Not all identified lineaments on the dip map could be classified as true faults. In particular, several SW–NE lineaments in the centre of the area were interpreted as reflection discontinuities resulting from migration and/or stack errors in seismic processing. These artefacts can be explained by the salt ridge which is overlying that part of the reservoir, a distinctive feature quite separate from the two salt domes previously mentioned.

The top salt reflection is generally very poorly defined in this area. Nevertheless, the shape and extent of the high-velocity salt ridge is well expressed in the shaded relief map of the overlying base Chalk horizon (Fig. 11). This horizon, which has an approximate depth of 1.5 km, reflects the geometry of the underlying salt ridge. The well-imaged crestal faults in the anticlinal structure have throws as small as 10 m.

At target level, faults have also been mapped with a vertical resolution down to the 10–20 m range. All the

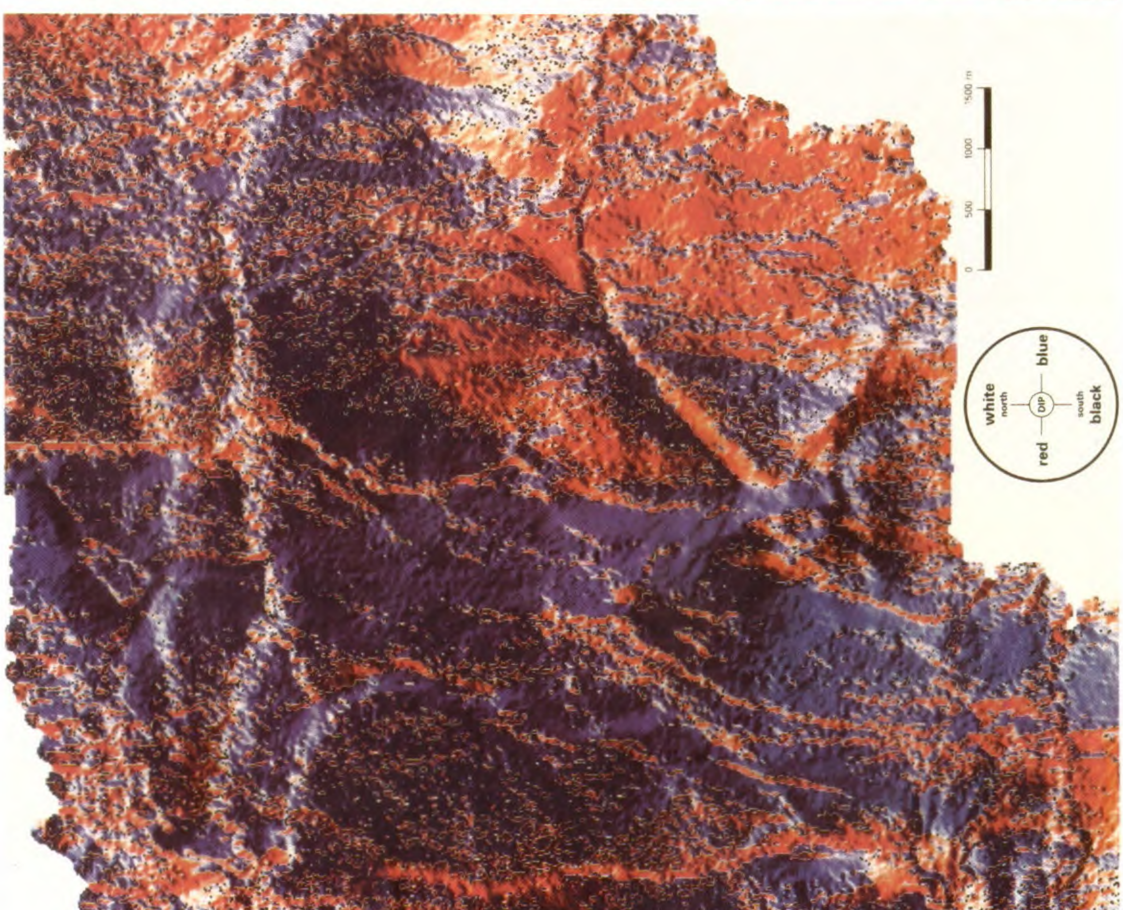

Fig. 6. Base Zechstein azimuth map.

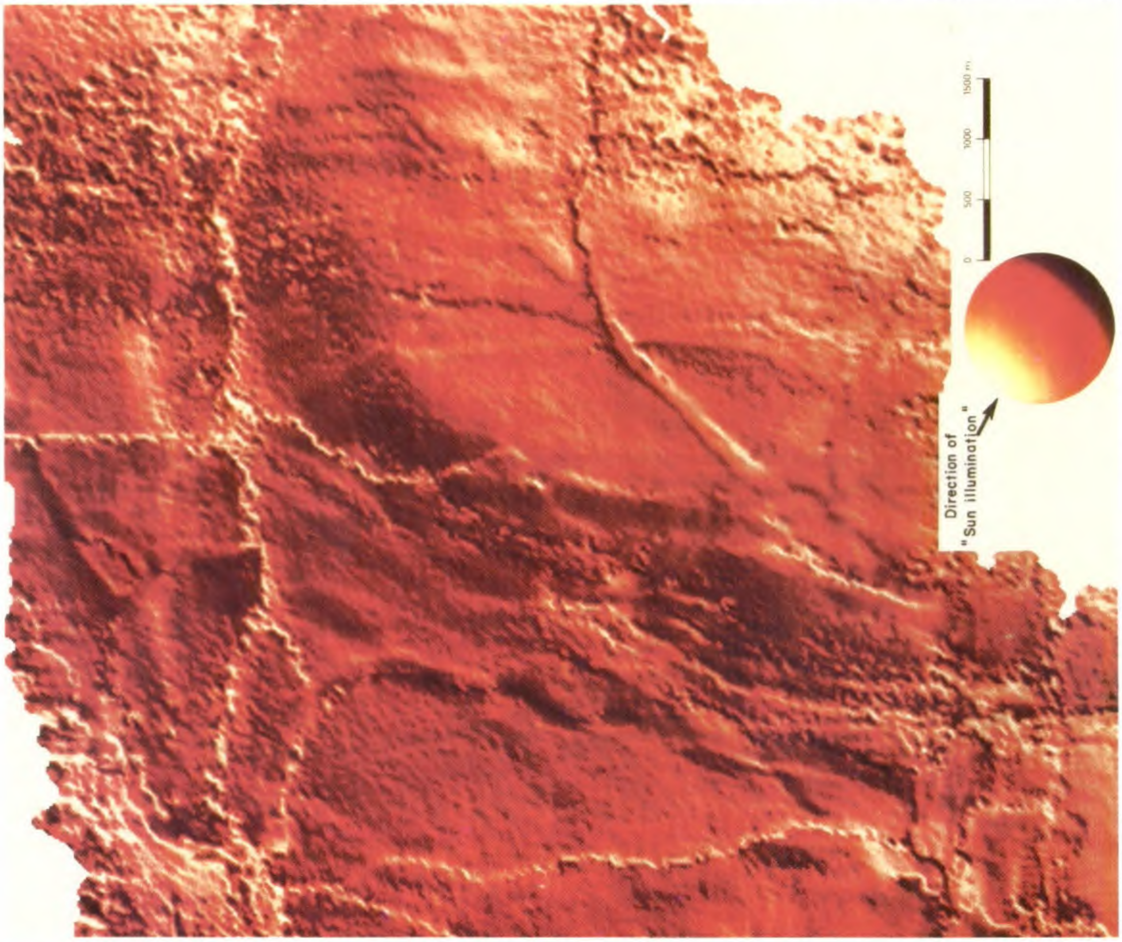

Fig. 7. Base Zechstein shaded relief map.

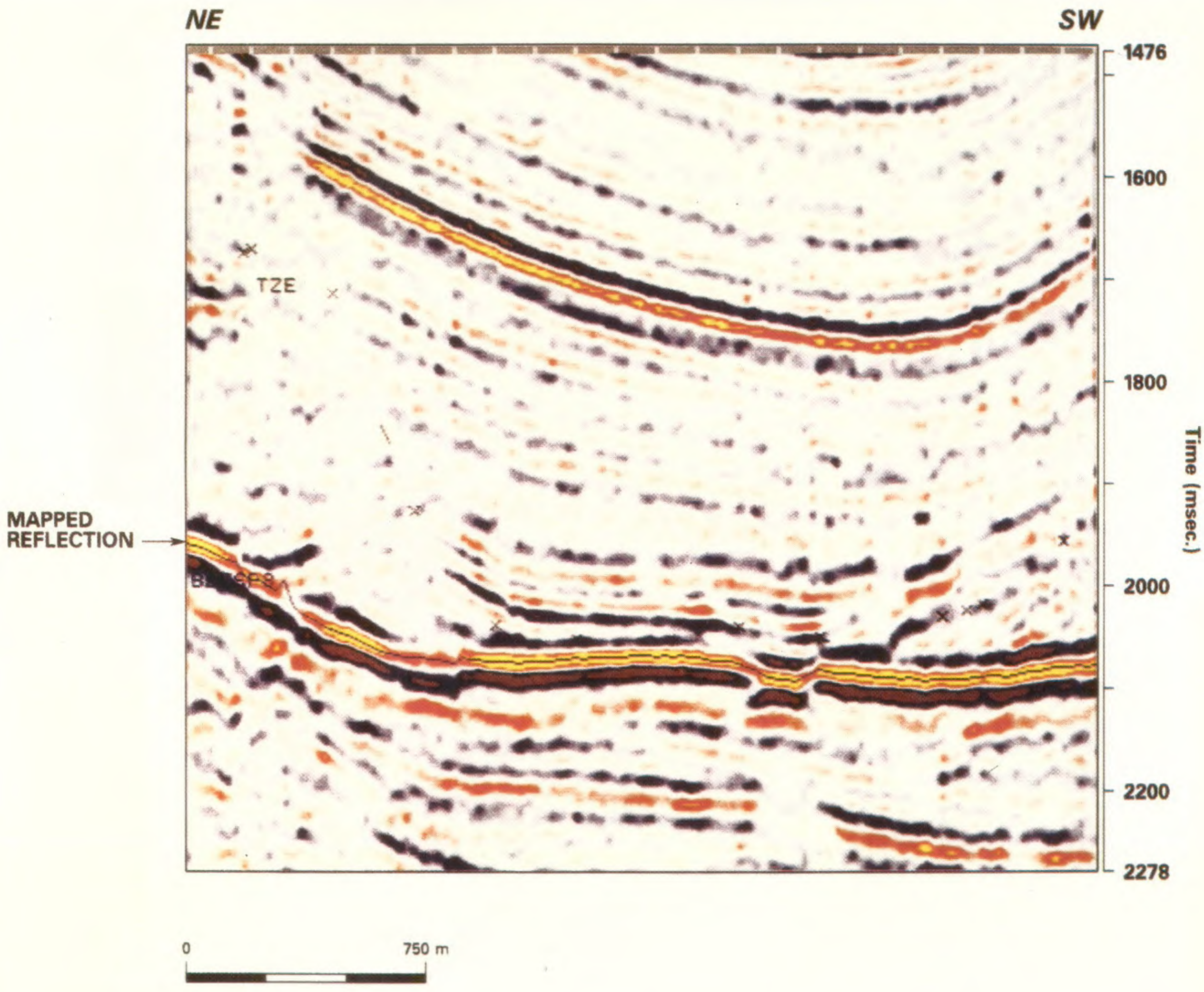

Fig. 8. NW–SE seismic section showing top Rotliegend graben feature (see Fig. 1 for location of section).

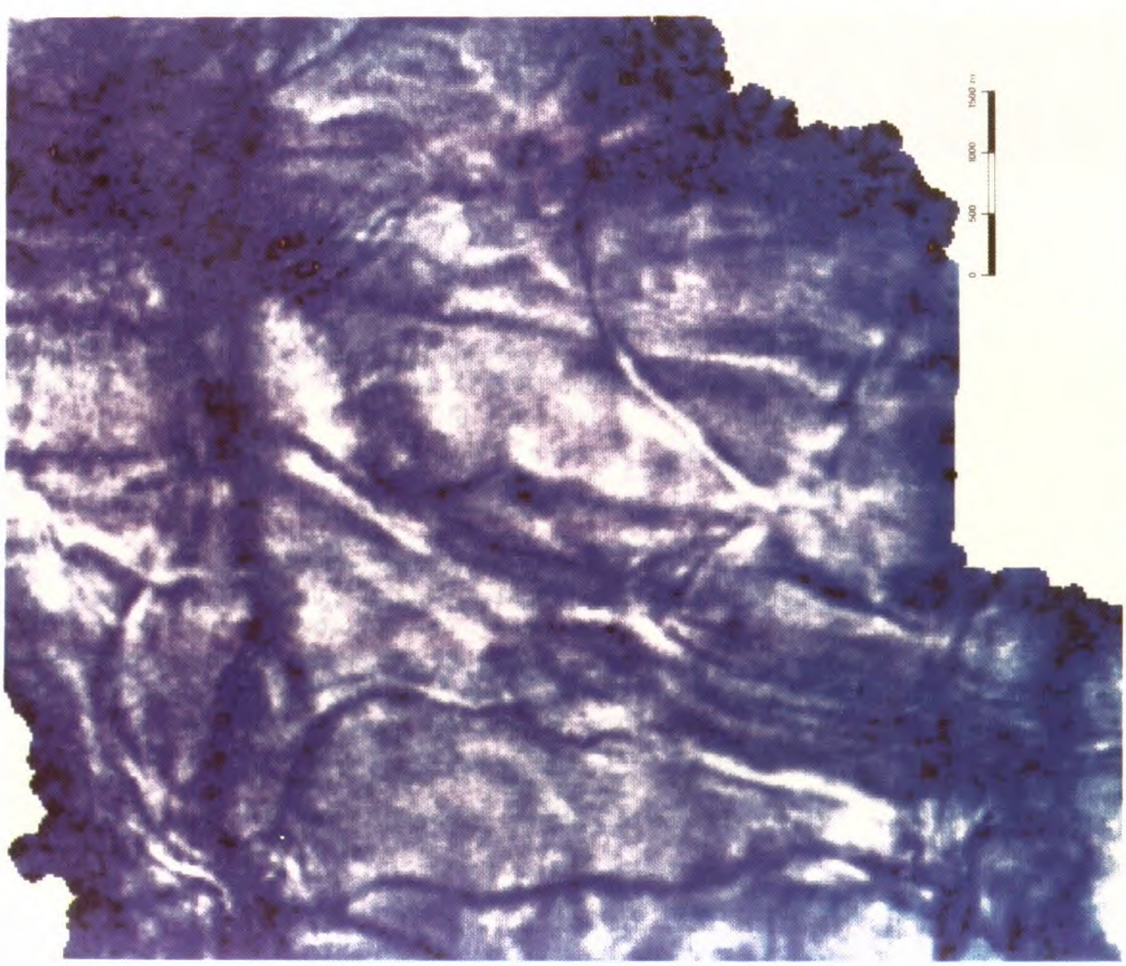

Fig. 9. Base Zechstein amplitude map.

Fig. 10. Depth structure map over the centre of the Annerveen Field for the top Rotliegend reservoir horizon: 1989 interpretation.

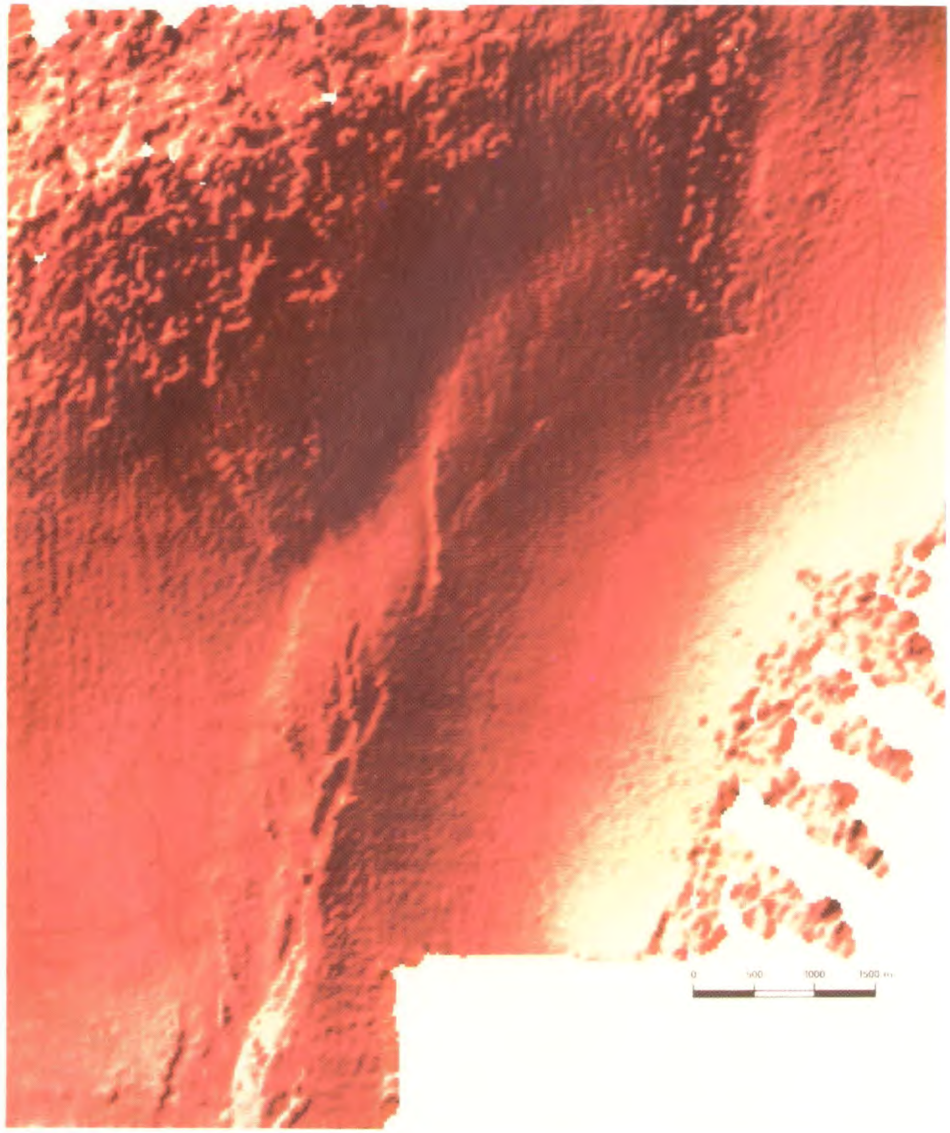

Fig. 11. Base Chalk shaded relief map.

identified faults have been incorporated in a structure map which depicts the resulting fault pattern (Fig. 10) and can be compared with the previous interpretation (Fig. 1). Overall fault geometries are equivalent on both the new and the old interpretations. However, on closer inspection it may be observed that the patterns differ in detail. For illustration, two differences with implications for reservoir modelling are discussed here:

- In the 1986 interpretation the most westerly major N–S fault terminates among a cluster of well positions (Fig. 1), whereas the current interpretation shows that a fault continues to the north and joins up with another major fault (Fig. 10). The fault continuation is clearly visible on the dip map (Fig. 5) and the amplitude map (Fig. 9). Drainage of the area to the northeast of the fault, where no producing wells are located, may be restricted.
- A prominent, arcuate fault to the east of the fault just described continues to the south on the 1986 depth map (Fig. 1). However, the current interpretation shows that this feature should be regarded as two *en echelon* faults with a zone of no throw between the fault segments (Fig. 10). The shaded relief map (Fig. 7) shows this configuration very clearly.

The attribute data also indicate that certain parts of the reservoir are virtually unfaulted, an observation equally important for both well positioning and reservoir modelling. Locally, data quality is very good and one can assume that no faults with vertical throws greater than 10 m are present in that part of the reservoir.

Conclusions

Application of new techniques in seismic interpretation, i.e. automatic tracking and horizon attribute processing, potentially can improve very significantly the quality of a seismic interpretation. In particular, where detailed fault mapping is important for field development planning and/or reservoir modelling, the contribution of these new techniques can be valuable. In the case of the Annerveen Gasfield, fault resolution has improved by at least a factor of 2 compared to the previous interpretation, which was based on paper seismic sections. Faults with vertical throws down to 10 m at a depth of 3 km have been detected and mapped. This high level of detail in fault mapping could be obtained because of the excellent data quality. The availability of good quality seismic data (i.e good enough to allow automatic horizon interpolation) can be regarded as the main prerequisite for a successful horizon attribute project. Dedicated colour schemes to display the various attributes in an optimal way are also considered to be essential.

The additional effort, in terms of manpower required to obtain the presented results is limited. Nowadays, most 3D seismic surveys will be interpreted on workstations. As a consequence, automatic tracking programs, when available, can be quickly accessed and their output can be easily checked. Having established favourable mapping parameters and colour schemes once, the generation of the various attribute maps can be done on a routine basis, making use of computer batch jobs.

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