

Semi-automated object detection in 3-D seismic data

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About: Herald Ligtenberg is working as a geoscientist for dGB and is predominantly involved in seismic object detection studies. Part of this work includes attribute analysis for detection and interpretation of gas chimneys, faults, flat spots and other objects. Furthermore, he is involved in seismic inversion projects and seismic interpretation projects. Herald worked three years for Halliburton as a wellsite geologist and pressure engineer at drilling locations on- and offshore. He holds an MSc in Structural Geology and Tectonics from the university of Utrecht, the Netherlands. Since

1999 he has been actively involved in the "geoscience professional's affairs" committee of the Royal dutch geological society KNGMG.

Introduction

Interpretation of 3-D seismic data is a time-consuming task that requires advanced interpretation workstations and trained and experienced personnel. In the last decade, numerous advanced tools have been developed to assist the interpreter who has to cope with ever increasing data volumes. Improved visualisation methods such as 3D stereo vision and immersive techniques as well as seismic attributes and image processing techniques have emerged as important tools to produce more accurate interpretations in less time.

The number of seismic attributes available on standard interpretation systems is constantly growing. Although this is considered a positive development in itself, we do identify problems with the *interpretation* of the ever-growing amount of attributes. One of these is that only few experts know what the attributes mean in geological / geophysical terms. Another problem is that many attributes are non-unique, i.e. different geological features have similar attribute responses. It is therefore not sufficient to only look at one attribute. Instead one has to use many attributes simultaneously. The obvious questions that arise are which attributes to use, and how to combine them. Today, many interpreters display and compare multiple attribute cubes, while others try to combine these using some kind of mathematical expression. In the first case, the interpreter must have a workstation capable of handling multiple volumes of attribute data and displaying them simultaneously. In the latter case, the interpreter must find a mathematical expression to combine the attributes effectively. Since seismic surveys of different vintage usually exhibit different characteristics, a mathematical expression between various attributes will only be valid for the vintage it was developed. Instead of having a static mathematical expression between attributes, we use artificial neural networks to find relationships between the attributes and desired objects in the seismic data.

Methodology

Artificial neural networks are computing techniques that aim to emulate some desired properties of the human brain. One of these properties is learning from experience. Given a number of examples an artificial neural network can be trained to learn the relationship between the inputs, e.g. a set of attributes and the desired output, e.g. is this a fault or is it not a fault.

The usage of the artificial neural network based object detection is straightforward and intuitive. The interpreter focuses on one geological object at the time. This can be seismic chimneys, faults, reflectors, stratigraphic features, hydrocarbon anomalies, and so on.

Basically any object that is relevant for seismic interpretation. The first objective of our method is to enhance the contrast between objects and their background. The output is an “object probability” cube. With the help of modern visualisation techniques it is then possible to study the spatial relationship between different objects enhanced in this way. A second objective, which is beyond the scope of the current paper, is to extract objects (3D bodies and planes) from the enhanced cubes to facilitate geological model building. The workflow for the generation of “object probability” cubes is as follows:

1. The interpreter scans the seismic data for the object of his/her choice. Let us assume that the objective is to map faults. Clicking on seismic sections and time-slices at recognised fault and non-fault positions then creates the required training set for the neural network.
2. Attributes with the potential to increase the contrast between object and background are selected. The selection process is based on common sense and visual inspection supported by statistical measurements such as correlation matrices and color-coding of neural network weighting functions. The latter is a simple and effective technique that assigns a color from a given color bar to the input nodes of the neural network. Higher

weights mean that the network relies more heavily on the input node to predict the target value. The important attributes are thus easily identifiable. Default attribute sets exist for a range of geological objects to facilitate non-expert users.

3. The artificial neural network is trained to give an output of one at object locations and zero at non-object locations. The performance of the classification is measured by dividing the locations into two groups, one for training and one for testing the neural network. The quality of the result is expressed in a classification matrix.
4. The trained network is applied to all sample locations in the seismic data. The network gives an output value ranging between approx. zero and one. The output can thus be considered to represent the probability of the object of interest to be present at each location.

The technique described above has been applied successfully to detect such object-types as gas chimneys, faults and salt-bodies.

Examples

1) Chimneys and salt

The first example presented in this paper is from a prospect evaluation study. The data is from the deep-water slope of Green Canyon in the Gulf of Mexico at about 2000m water-depth.

The 3D seismic cube covers an area of approximately 5 x 10 km². Seismic chimneys, a salt dome, amplitude anomalies and mapped horizons are the objects of interest. Horizons were mapped using conventional techniques. The amplitude anomalies are shown as single-attributes. The neural network, multi-attribute object detection technique, enhanced chimneys and salt. These objects have similar characteristics and therefore cannot be separated effectively by single attributes. For example chimneys and salt are both characterised by low energy, low trace-to-trace similarity (or coherency) and a chaotic behaviour of the seismic response. The latter feature is captured by an attribute we call “dip variance”. In a small cube

around the extraction point the statistical variance of the local dips and azimuths are calculated to derive the “dip variance”. To distinguish salt from chimneys we use the so-called “directivity principle” when we create attribute sets for chimneys and salt. Geometrical aspects of the bodies, such as size, shape and notably directions are used to increase the contrasting power of the attributes. Attribute sets are made directive by specifying attribute windows and by using multiple windows aligned in the direction of the object. With chimneys this is simply done by extracting the same attributes in three vertically aligned windows around the evaluation point. The network can thus learn that we are looking for a vertical disturbance of the seismic response. For salt we use only one extraction window but we also give the in-line, cross-line and 2WT location of the evaluation position to reflect the fact that salt does not occur anywhere in 3D space but is confined to a particular corner around the example locations.

Massive oil and gas seepage is taking place over the entire northern slope of the Gulf of Mexico. This is evident from geological, biological and satellite data. The most pervasive seepage seems to occur in the deeper water slope areas rather than on the shelf (Jean K. Whelan, *Sea Technology*, Sep. 1997, pp. 10-18). Seafloor features that have been associated with hydrocarbon seepage in the Gulf of Mexico include carbonate mounds, mud volcanoes and seabed depressions. Seismic chimneys are commonly correlated with hydrocarbon seeps. By enhancing seismic chimneys through the method described above it becomes feasible to interpret hydrocarbon migration paths and unravel the hydrocarbon system. Detailed studies help to identify where hydrocarbons originate in the geological sequence, how these hydrocarbons migrate upwards and become trapped and spill to reach the surface. Chimney interpretation is therefore a useful tool in the exploration phase, but it also can provide

valuable information at later phases of a field's life cycle e.g. regarding fault sealing and compartmentalization.

Fig. 1 shows a 3D visualization of the chimney cube, the salt cube, the standard seismic cube and three mapped surfaces. The three mapped surfaces are displayed as time maps in blue, green and brown. The upper one represents the seabed. The second one is mapped at approx. 200m sub-seabed and the third at 400m sub-seabed. From the standard seismic cube, only the highest amplitudes are displayed in red. Lower amplitudes are made transparent in this display. Chimneys from the chimney cube are displayed in yellow. These correspond to the high values in the cube (i.e. high chimney probability). Lower values are made transparent. The salt is displayed in bluish-white. The shallow cloud of high amplitudes (red) is interpreted to represent a hydrocarbon charged reservoir. Chimneys surrounding the salt dome are interpreted to indicate upward fluid migration from a deeper reservoir. High density of shallower chimneys indicates charging of the shallow reservoir. The sub-seabed surfaces (green and brown) exhibit a radial fault pattern caused by the upward movement of the salt dome. Chimneys are visible up to the seabed. A small mound is present at the seabed close to the top of the shallowest chimney on the right-hand side. This may be a small mud volcano generated by transport of sediments, fluid and/or gas to the seabed (Fig. 2).

2) Faults

Mapping faults is usually one of the most difficult and time-consuming tasks in seismic interpretation. In a typical workflow the initial goal is to establish a structural framework by mapping the larger faults first. This is followed by detailed mapping of smaller scale faults at the reservoir interval. The example shown here is from an area offshore Africa. The same method used to enhance chimneys was used here to detect faults. Similar attributes were used but attribute parameters and window settings were tuned to faults rather than chimneys. Fig. 2 (left) shows a time-slice from the resulting fault cube. The figure on the right is a single

attribute similarity display at the same time level. The multi-attribute, neural network-based approach shows better fault continuity and a higher signal/noise ratio.

3) Salt

Mapping the exact outline of a salt dome is important for structural mapping and accurate time-depth conversion. In pre-stack depth migration exercises a geological model must be updated repeatedly and it pays to incorporate a fast, accurate mapping procedure. The example from onshore Western Europe shows a Zechstein salt pillow. The boundary between salt and overlying / underlying formations is quite sharp. At various positions along the top of the salt small domes can be observed where salt has moved upwards and possibly squeezed into the overlying strata. The "proto-" salt domes seem to coincide with weaker zones in the overburden where faults are observed.

Conclusions

The method of seismic object detection has proved to reduce interpretation cycle times drastically. In the first example shown the presence and distribution of chimneys that have been mapped in the area, make the presence of a deep and a shallow hydrocarbon charged reservoir more likely. A manual mapping of chimneys would have been difficult, less precise and more time consuming. The second example showed that faults can be mapped more accurately by the method than by conventional, single attribute techniques. The last example showed that salt bodies can be delineated in great detail.