Summary

The structural features of a 3D subsurface velocity model must be defined not only to support seismic modeling, seismic processing and geologic interpretation but also to support the kinematic history of the subsurface structure. A strategy for implementing a 3D velocity model is presented. The key feature of our strategy is that, in addition to being topologically correct, the model is also supported by the principles of structural geology.

Introduction

Since the 1970s the seismic processing industry has been moving away from the traditional definition and use of average or rms velocity towards a detailed subsurface velocity model defined by structural and stratigraphic boundaries. The use of workstations for displaying both the seismic image and the associated structural and stratigraphic information, and the use of networked computer systems for storing that information, makes it much more practical to reuse information in seismic modeling, seismic processing, geologic interpretation and geologic modeling. In this paper, I propose that the structural features of a 3D subsurface velocity model must be defined in a manner that not only supports seismic data analysis and well log data analysis but also supports the kinematic history of the subsurface structure.

Subsurface geology and seismic properties are closely related. Changes in physical properties, such as velocity and density, normally occur at megasequence and sequence boundaries and at fault discontinuities. Interpreters make extensive use of the seismic images of these boundaries in formulating a structural description of the subsurface; this description is ultimately used to define the viability of a trap or prospect. Structural features are also important in defining the kinematic relationship between subsurface units. The ability to model the kinematics of an interpretation provides several critical benefits. Such a process serves to validate an interpreter's concepts regarding the present geometry and the geological development of a region or prospect (Geiser et al., 1988). This validation comprises the demonstration that a given interpretation is "kinematically admissible" and also serves to limit the range of possible interpretations for a set of data constraints (Geiser, 1988). The kinematic model also offers a constraint on deformation variation in a structure. Variations in deformation features such as fractures can affect or control velocity changes which are independent of the primary stratigraphic and structural features.

That the construction of a 3D subsurface velocity model needs to be topologically correct has been recognized in model building systems that have evolved from computer aided geometric design (e.g., Mallet and Nobili (1991) and Wiggins, et al., 1993). However, such systems do not include the requirement that the kinematic history of the structural model developed in that system be supported by the principles of structural geology. The usual technique for validating the subsurface model is through seismic modeling (Fagin, 1991). An exception which demonstrates the use of both kinematic analysis and seismic modeling in the validation of a 2D interpretation is Lingrey (1991).

Requirements

A 3D subsurface velocity model must provide simultaneous support for:

- Seismic modeling
- Seismic data processing
- Geologic interpretation
- Geologic modeling

Each of these disciplines may make use of the information in the subsurface model in a different way. We define the design goals of our subsurface modeling strategy as the ability to support these disciplines.
Seismic Modeling

In seismic modeling there are a number of techniques that require a different view of the subsurface model. For instance, Fagin (1991), describes ray traced seismic modeling that makes use of Snell's law at the interfaces between subsurface regions. Most ray traced based methods of seismic modeling require a representation of the subsurface that contains explicit boundaries between subsurface volumes and some method of interpolating parameters across the subsurface volumes. Other seismic modeling schemes, in particular, those based on numerical modeling, may require gridded representations of the subsurface parameter variation.

Seismic Data Processing

In seismic data processing the primary use of a detailed 3D subsurface interval velocity model is in post-stack and pre-stack depth migration. Even for data with sharp changes in velocity across the subsurface structure, the migration results of Versteeg (1993) suggest that a smoothed representation of the subsurface velocity model may be adequate for migration. The problem then becomes one of delivering a (perhaps smoothed) representation of the subsurface velocity to the migration application. Most frequency domain migration algorithms involve the use of horizontal slices through the subsurface model. Migrations based on the use of finite-difference traveltime calculations require gridded representations of the subsurface velocity.

Geologic Interpretation

In geologic interpretation the sequence boundaries and faults are the important geometrical features, i.e., the same features that comprise the velocity model geometry. In addition, the geologic interpretation process requires integration of data constraints from other disciplines, such as ties to formation tops from wells and maps. Here, the important aspects of the subsurface model are the control points in the subsurface that the user may use to define and manipulate an interpretation. In addition, the importance of the final presentation of the interpretation to users must not be overlooked.

Geologic Modeling

Kinematic modeling of an interpretation is not an end in itself, but an intrinsic element of the interpretation process. As part of the interpretation constraint, it must also use all sources of geological information, including surface data, well logs and seismic images. Currently, most geologic modeling products are limited to the application of restoration and balancing to 2D cross sections through the 3D model. However, 3D versions of these products and the appropriate kinematic algorithms for various structures are under development.

Thus a viable velocity model is based on a sound geologic interpretation, which is itself necessarily constrained by restoration and kinematic modeling. Defining the kinematics of a structure also provides additional information on velocity variation related to deformation features. The velocity model is in turn used for seismic modeling and seismic processing, the results of which form an important element of the geologic interpretation process.

Implementation

Our strategy for providing a subsurface model that supports each of these design goals is to build on proven technology. The industry has adopted various software products by working to reduce the barriers to information exchange between those products. We adopt that technique as a design goal and provide tools, not only for the definition and manipulation of subsurface models but also for the exchange of information from those models with a variety of software products. By providing the tools and definitions that enable the import and export of information from our model, we enable customers to take advantage of products that we do not supply.

In addition, we also realize the importance of the ease of exchange of information across our own product line. To this end we have adopted the strategy of planning for the use of a single subsurface model format. An important aspect of this model is that, in addition to the volume filling representations, that derive from computer aided geometric design, we have chosen to design a model that also supports the analysis of the kinematic history of the subsurface model.

A schematic diagram of the design goals that supports the strategy is shown in Figure 1. The 3D subsurface model is shown supporting each of the disciplines. There are a number of software products that would fit into each of the separate disciplines. Some products may span across disciplines.
The implementation of the actual subsurface model and the associated tools is structured to provide support for the applications in each of the disciplines. The topological elements of the actual model are space filling, bounded volumes. Control points on the boundaries between those surfaces may be defined and edited. Properties of the materials within those volumes are defined in a manner that enables the construction of intuitive editing tools. Where possible, supporting data, either from well logs or from seismic images in 2D (sections) or 3D (cubes) are presented to guide the user in the manipulation of control points. Where those control points need to be linked to form a surface, a constrained triangulation scheme is used that enables the user to guide the surface construction towards a specific interpretation of the data.

To support 3D seismic processing applications we have adopted the use of velocity cubes, similar in structure to the poststack 3D seismic cubes used in interpretation. This cube format is structured to take advantage of 3D visualization toolkits and products.

The 3D subsurface model is designed to support our 2D geologic modeling software now, by automating the task of extracting and modeling on 2D sections through the model. The 3D geologic modeling software, currently under development, will be tightly coupled to the subsurface modeling software. An example of a 3D view of a model constructed from a number of 2D cross sections is shown in Figure 2.

**Conclusions**

A strategy for implementing a 3D subsurface model has been presented. The key feature of our strategy is that, in addition to being topologically correct, the model must also be supported by the principles of structural geology. Ensuring that the subsurface model is supported by seismic modeling, seismic data analysis, geologic data and well information must be supplemented by analysis of the kinematic history of the model.
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References


