3-D modeling of complex geological structures

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Abstract

In areas of the subsurface the presence of complex geological structures reduces the seismic imaging quality. This difficult the success of finding oil and recovering greater amounts from existing wells. New technologies (e.g. modeling and visualization) are being more and more used as a tool to increase the ability to find new prospects of hydrocarbons and improves the efficiency of oil and gas exploration. In the oil and gas industry 3-D earth models are crucial for decision making and other purposes. In this paper we present modeled 3-D complex geological structures that can be part of sedimentary basins and areas appropriate for accumulation of hydrocarbons. These models can be used to test the efficiency of methodologies of seismic processing in 3-D media.

Introduction

Petroleum geophysical methods are used in a logical sequence of several steps that goes as follows: data acquisition, data processing, geologic and petroleum interpretation, the aim of which is to define the appropriate petroleum structures (prospects) and the future well locations.

In areas of the subsurface the presence of complex geological structures (faults, recumbent folds, dikes, diabase sills, salt domes, etc), reduces the seismic imaging quality (due to false structures). This difficult the success of finding oil and recovering greater amounts from existing wells.

With the seismic surveys and geophysical studies complete, geologists build a digital 3-D geomodel of the subsurface to help decide whether to develop an oil or gas field. Geomodeling is a vital risk-minimizing tool (Andréini et al., 2008).

In the oil and gas industry 3-D earth models are crucial for decision making and other purposes: a) to check the consistency between geological objects, b) to plan the path of non-vertical wells, c) to monitor the reservoir (4-D seismic), d) for the reservoir model construction, e)seismic inversion and f)velocity analysis (Euler et al., 1998, 1999).

3-D visualization greatly facilitates many phases of the interpretation process, including fault interpretation, structural horizon interpretation and stratigraphic feature interpretation (Jansen, 2003).

Building faults for a 3-D depth model can become a very difficult task because of the little data one can get concerning this very special geological object. From the acquisition to the depth modeling, data are transformed by different processes (Lecour et al., 2000). The main problem comes from the fact that each step is done by different teams and that all strategic choices are not necessarily given from one step to the others (Basire, 1998).

Euler et al. (1998) presented a new method to build a sealed, topologically and geologically consistent model. They built a model consisting of four horizons and three faults (Overthurust model SEG-EAGE 1994).

Euler et al. (1999) presented three tools indispensable to the editing and updating of the 3-D Earth Model components (horizon, fault, salt body, etc).

Lecour et al. (2000) proposed a new approach to incorporate uncertainty estimations in the modeling of faults and faults networks.

Kidd and Montilla (2003) developed 3-D volume visualization methods to address complex structural interpretation problems in the Eastern Venezuela Fold and Thrust Belt.

Frank et al. (2005) introduced a new adaptive method for the implicit reconstruction of discontinuous surfaces (ex. a salt dome) from scattered, unorganized points as extracted from seismic data.

Chira et al (2008) modeled the structural geology, the stratigraphic and the velocities of an interest area of Amazonas sedimentary basin (Brazil). These results contribute for the resolution and understanding of the problems due to the presence of diabase sills in this region.

In this work were modeled 3-D complex geological structures by using synthetic data that can be part of sedimentary basins and areas with appropriate structures for accumulation of hydrocarbons. Additionally sections or slices had been generated to visualize the internal structure of the studied geological objects. That is very important for the study of the petrophysical properties and the fluid flow in the interior of one determined reservoir.

Theory

Geomodeling is defined as all the mathematical methods use to produce an unified model of the topology (their interconnectivity), geometry (their shapes) and physical properties of the geological objects under study, while taking into account all the types of data relating to these objects (Andréini ei al, 2008).

The 3-D model synthesizes all the available data: a) digital data derived from seismic interpretation and concerning faults and horizons, b) digital data from exploration wells, particularly the position and dip of the main horizons intersected by the wells and c) non-digital data based on the geologist's know-how. It evaluates the geometric uncertainties and the properties of the geological structures. These properties may be seismic velocity, geological facies, formation pressures, porosity, and permeability or formation temperature, among others. They are either constant or vary gradually (laterally and with t he depth).

The 3-D Earth Model divides 3-D space into closed volumes called regions. Each region is a volume sealed off by intersecting surfaces. A region may be a layer or a fault block (Euler et al., 1998).

The 3-D modeling helps us in the geologic and seismic interpretation to identify possible reservoirs or areas of capture of hydrocarbons in one determined sedimentary basin.

The 3-D modeling of complex geological situations contributes to understand and quantify the risk associated with hydrocarbon exploration and production due the presence of these structures.

Method

3-D Geological model

The geological model is represented by two models: structural and stratigraphic.

3-D Structural model

To construct the structural model of the interest area was used the *Structural Modeling Workflow* of the GOCAD software (GOCAD consortium, France). This workflow builds a structural framework that includes faults, horizons, fault-to-fault contacts, and horizon-to-fault contacts, fitting the faults to well markers, and fitting the horizons to well markers (Gocad, 2008).

A Structural Model is constituted by a collection of horizons and fault networks. When combined, these horizons and fault networks produce a structurally coherent model of the geometric relationships and geologic boundaries of a reservoir, where all contacts between the horizon and faults are sealed. The structural model can also include information about the source data for a horizon or fault, the termination of a fault, and the continuity of a horizon before it was faulted (Gocad, 2008).

The data types and geologic information in a structural model are:

-Horizon: points, interpretation lines, outline, well markers, surface, fault polygons, isopach/isochore.

-Faults: points, stick, outline, well markers, polygons, trace (dip, extrusion), surface.

The general steps for the model construction are (GOCAD, 2008):

1. To import files with data of the components of the structural model: horizons and faults.
2. Data managing.
3. To define a volume of interest.
4. Fault modeling.
5. Fault contact modeling.
6. Horizon modeling.
7. Horizon-fault contact modeling.
8. Structural modeling.

3-D Stratigraphic model

To construct the stratigraphic model of the interest area was used the 3D *Reservoir Grid Builder workflow*. This workflow facilitates the construction of stratigraphic models, also called *stratigraphic grids* or *3-D reservoir grids,* for modeling simple or complex geological depositional environments. Overturned beds, listric faults, inverse or Y-faults, faults terminating in the middle of the layer can all be handled (GOCAD, 2008)..

Stratigraphic grids (SGrid) are controlled by the top and bottom structures, fault network and wells, and are easily updated as new data becomes available. Within a structural unit, stratigraphic layer boundaries are computed using well marker information, accounting 100% for horizontal well constraints.

These grids are constructed for the purpose of distributing reservoir and performing fluid flow simulation. The grids are constructed from interpreted horizons, or from structural models with multi-z horizons, inverse faults, etc.

From surfaces of the geological model is constructed the 3-D stratigraphic model. The general steps for this construction are (GOCAD, 2008):

1. Select the reservoir grid creation method.
2. Select the horizons.
3. Select a gridding computation mode.
4. Compute a gridding computation mode.
5. Define Intermediate stratigraphic units.
6. Construct the Reservoir Grid.

3-D Geophysical model

The geophysical model is represented in this case by the velocity model in this case.

3-D velocity model

The velocity modeling module used provides 2-D or 3-D grid construction and time-to-depth conversions by modeling the entire geologic column, accurately locating reservoirs and mapping potential drilling hazards in the overburden. Verify and correct horizon picks and adjust time-to-depth converted horizon in 3-D, along side seismic data, well picks, check shot data and regional data

There are two forms to build 3-D velocity models: a) *Voxet model* and b) *3Dmodel*. A *Voxet model* is the gridded volume confined with the cage of the Voxet. We used the Voxet model. In a *Voxet Model*, the *Voxet* should be smaller than all the surfaces that will to cut the Voxet walls, creating layers.

The steps to construct the velocity model are (GOCAD, 2008):

1. To assign a geological feature for each horizon and fault.
2. Create a Voxet from Corner points or vectors.
3. Add or to specify the surfaces to be included in a Voxet Model.
4. To build a Voxet model.

5. Create a property model.
6. Define the property (velocity).
7. Determine the values of the velocity for every layer of the model.

Results

We modeled 3-D complex geological structures by using synthetic data that can be part of sedimentary basins and areas with appropriate structures for accumulation of hydrocarbons. Additionally sections had been generated to visualize the internal structure of the studied geological objects.

Model 1

We consider a 3-D synthetic model constituted by nine reflectors and ten layers separated by smooth and curved interfaces (Figure 1). In this model the layers are interrupted by two normal faults. This model is associated with graben and horst structures. The right fault has a dip of 60^o and the left fault has a dip of 55^o. These faults are classified as high angle fault.

From surfaces of the structural model (Figures 1), was constructed the 3-D stratigraphic model (Figures 2).

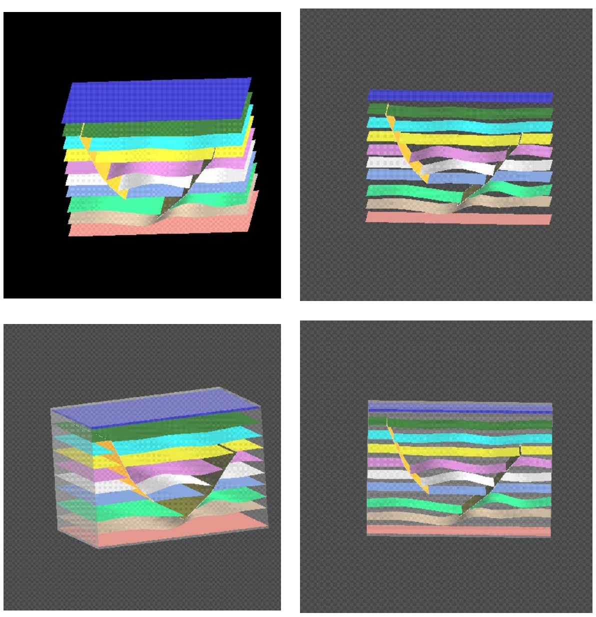

Figure 1. Different visualizations of the 3-D structural model 1.

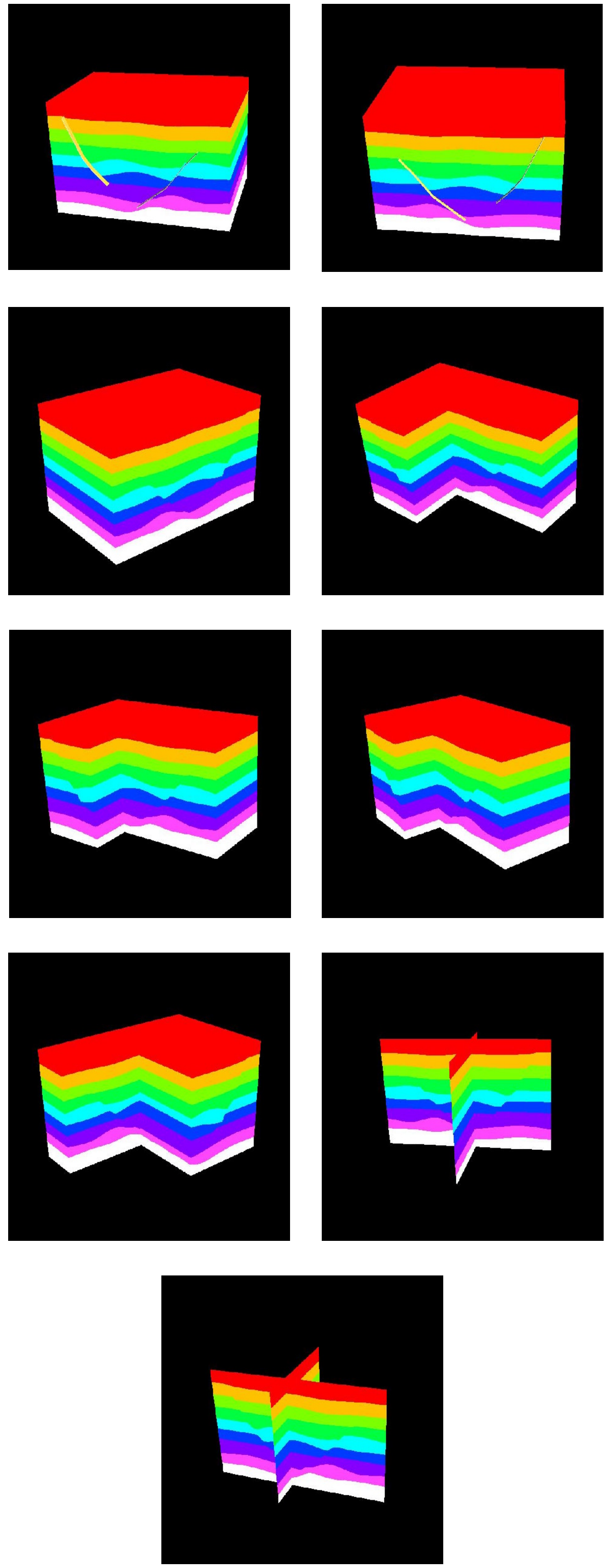

Figure 2. Different visualizations (cubic and slice type forms) of the 3-D stratigraphic model of Figure 1.

Finally, we built the 3-D velocity model based in the intervals velocities and the geological model. The velocities cube has a 3-D rectangular grid. The velocity value is constant along the layer. The velocity values from top to base are: 1.5 km/s, 2.0 km/s, 2.5 km/s, 3.0 km/s, 3.5 km/s, 4.0 km/s, 4.5 km/s, 5.0 km/s, 5.5 km/s and 6.0 km/s for the half-space (Figures 3).

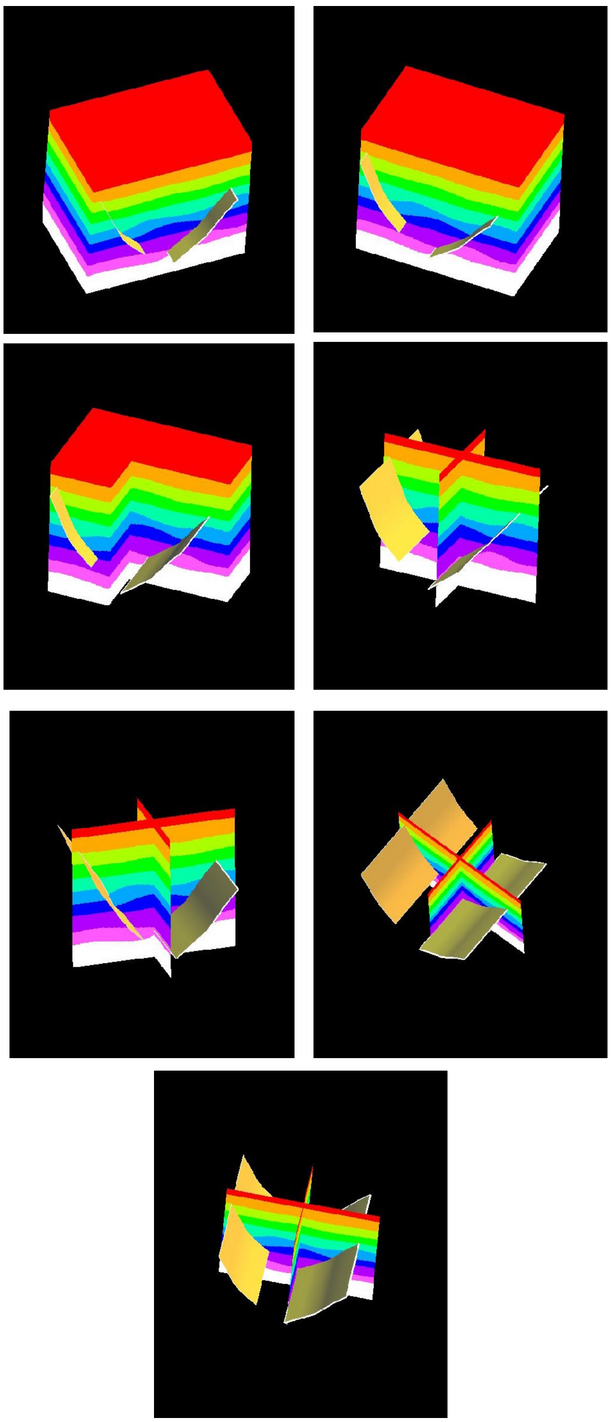

Figure 3. Different visualizations (cubic and slice type forms) of the 3-D velocity model of Figure 1.

Model 2

Other propitious structures to accumulate hydro-carbons are the folds. So that this happens must exist a petroliferous system. In this system, the petroleum reservoirs are generally made up of sedimentary rocks: sands (unconsolidated), sandstones (consolidated, i.e. compacted) or porous carbonates. We simulate a 3-D model with the characteristics of a petroleum system. The reservoir rock is the sandstone and for the seal rock was considered the shale.

We consider a 3-D synthetic model constituted by six reflectors and seven layers separated by smooth and curved interfaces. This model is associated with one anticline and one synclinal (Figure 4). From surfaces of the structural model (Figures 4), was constructed the 3-D stratigraphic model (Figures 5). The lithology from top to bottom is the following: sandstone, siltstone, limestone, shale (seal rock), sandstone (reservoir rock), evaporate and the basement.

We built the 3-D velocity model based in the intervals velocities and the geological model. The velocity value is constant along the layer. The P-wave velocity values from top to base are: 2.0 km/s, 2.8 km/s, 3.6 km/s, 4.3 km/s, 4.5 km/s, 5.0 km/s and 5.3 km/s for the half-space (Figures 6).

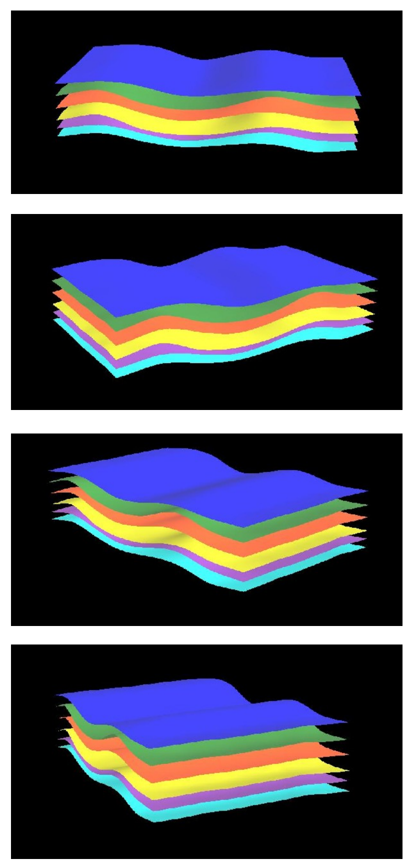

Figure 4. Different visualizations of the 3-D structural model 2.

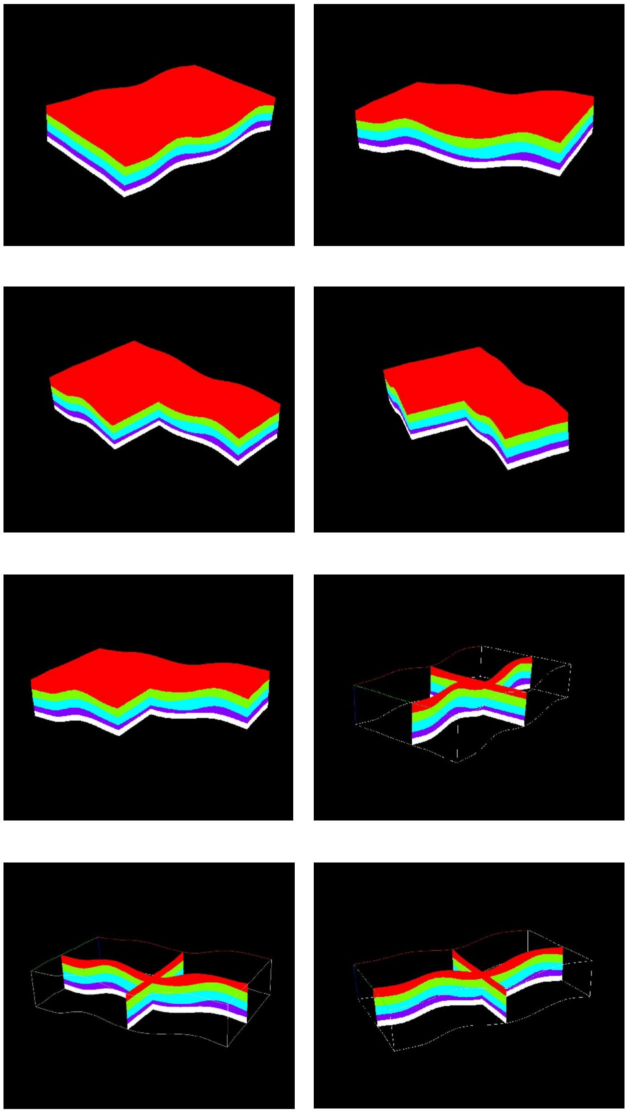

Figure 5. Different visualizations (cubic and slice type forms) of the 3-D stratigraphic model of Figure 4.

Conclusions

We present diverse 3-D models (structural, stratigraphic and velocity) in subsurface with the presence of complex geological structures (e.g. faults and folds).

The 3-D modeling helps us in the study, understanding and quantifies the risk associated with hydrocarbon exploration and production due the presence of these structures. Especially, the normal faults are the principal structural components of basins and rifts and are very significant for the oil exploration.

Accurate velocity models enhance imaging quality and improve drilling results in challenging environments under guidance of sharper 3-D models.

The velocity model can generate other velocity models (e.g. RMS velocity, interval velocity or average velocity model) or converted into rock properties.

These models can be used to generate seismic data and to test the efficiency of methodologies of seismic processing (seismic stacking, seismic migration, seismic inversion, etc) in 3-D media with complex geological structures.

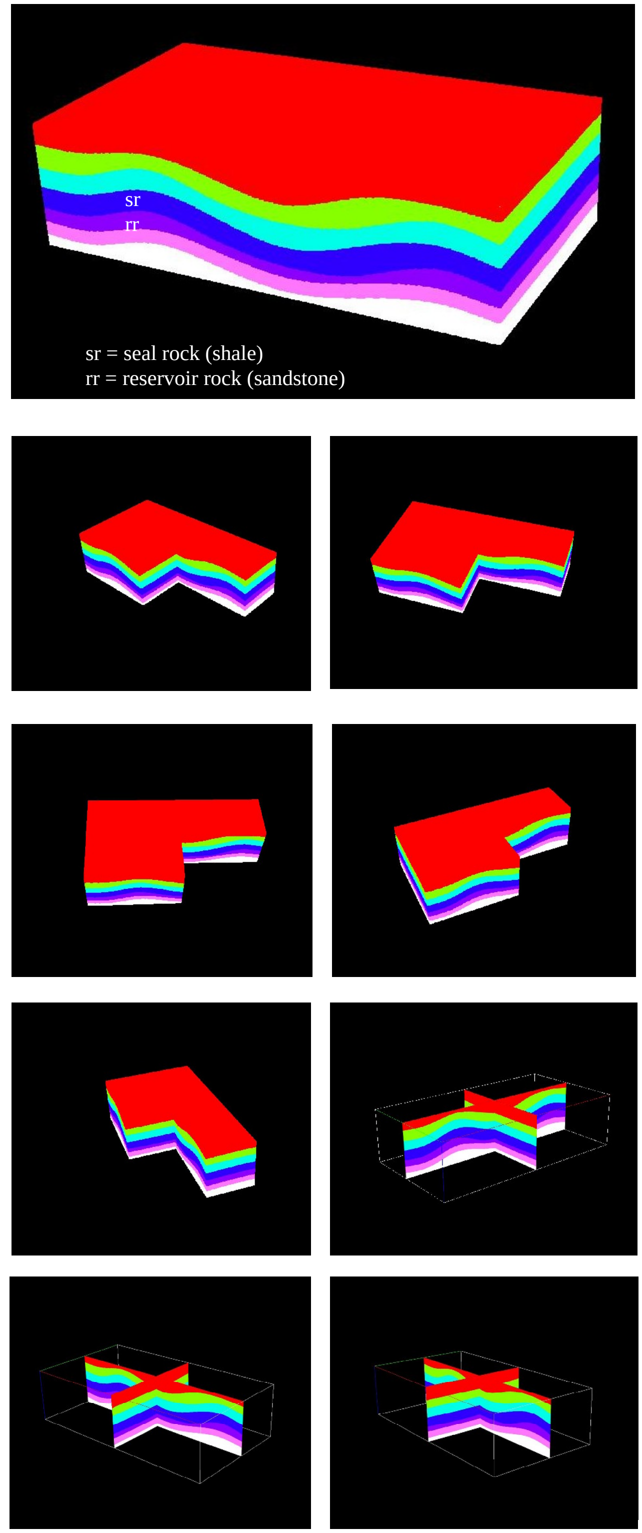

Figure 6. Different visualizations (cubic and slice type forms) of the 3-D velocity model of Figure 4.

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