THE AMERICAN OIL & GAS
REPORTER®
JULY 2011

The "Better Business" Publication Serving the Exploration / Drilling / Production Industry

Technology Enhances 3-D Modeling

By Jean-Claude Dulac

HOUSTON–In today's exploration, drilling and production workflows, two worlds try to cohabit: interpretation and modeling. Modelers try as best as possible with the tools at their disposal to use interpretation results to build accurate models. But because of the limitation of the tools, interpreters most of the time do not recognize their interpretations in the final constructed models. Conversely, modelers complain about the lack of consistency of the interpretation in the proximity of faults or around a complex stratigraphic area.

Today, these two activities are separated because the task of converting an interpretation into a consistent 3-D structural model is time consuming and complicated. Nevertheless, the benefits of a geologically consistent 3-D structural and stratigraphic model, compared with a series of independent 2-D maps, are obvious as soon as the maps are put into three-dimensional space.

In addition, when the next step of the workflow consists of creating a 3-D reservoir grid, the existence of a consistent structural and stratigraphic framework based on the original interpretation would greatly facilitate constucting the reservoir grid. This process basically requires that faults form a consistent fault network, that conformable horizons do not cross, and that horizon and fault contacts are geologically coherent.

So how can the two worlds of interpretation and modeling be bridged efficiently when the value of 3-D modeling is not in question, but there are doubts regarding its capacity to honor all the details of an interpretation? Old technologies based on either triangulated surfaces or pillar grids have too many limitations to enable automatic model building while interpreting.

A new mathematical framework is being applied to revolutionize the process of constructing 3-D models directly from the interpretation, greatly reducing the cost of geomodeling. This new framework brings substantial new added value to both interpretation and modeling workflows.

Space/Time Framework

Conventional solutions and technologies are mostly 2-D based. Triangulated surfaces used to represent fault or horizons are difficult to bring in perfect contact with one another. Pillar grids are representing horizons and faults together and do not suffer from the triangulated surface contact issues, but the fault network needs to be fully represented by a coherent set of pillars. This is not possible when fault contacts intersect one another or become horizontal.

A true 3-D approach is necessary to model the 3-D geology, which is composed of a set of chrono-stratigraphic layers deformed by structural events. Using this chrono-stratigraphic concept, it can be postulated that any particle of the subsurface has present coordinates (x, y and z) and paleo-coordinates (u, v and t), where (t) is the geological time of deposition of the particle and (u, v) are its paleo-geographic coordinates at geological time (t).

As defined, the (x, y and z) coordinates and the (u,v and t) paleo-coordinates are intimately linked to one another by the three functions:

- $u = u$ (x, y and z);
- $v = v$ (x, y and z);

FIGURE 1

Faulted Chrono-Stratigraphic Slice Inside UVT Model

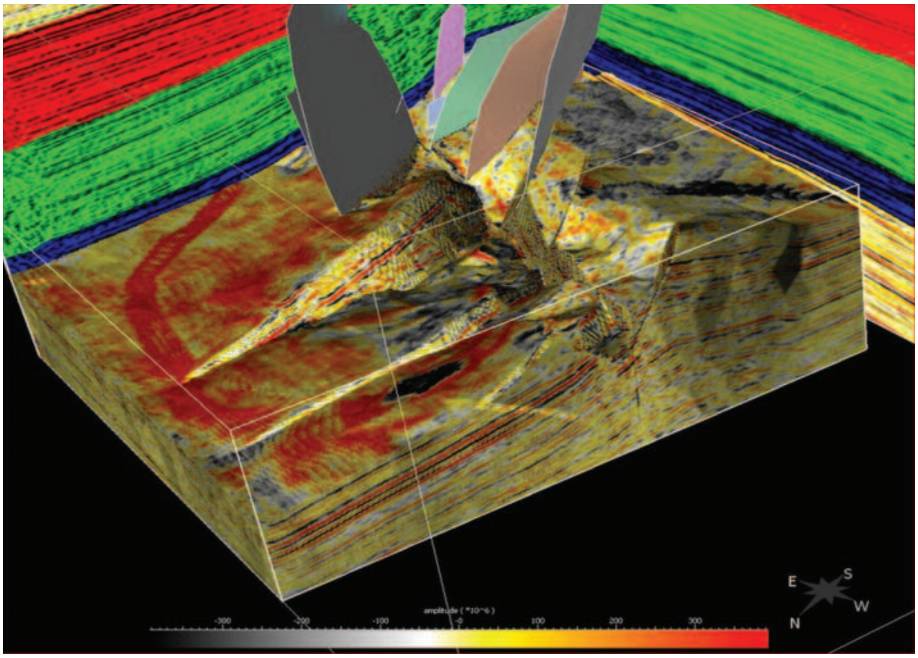
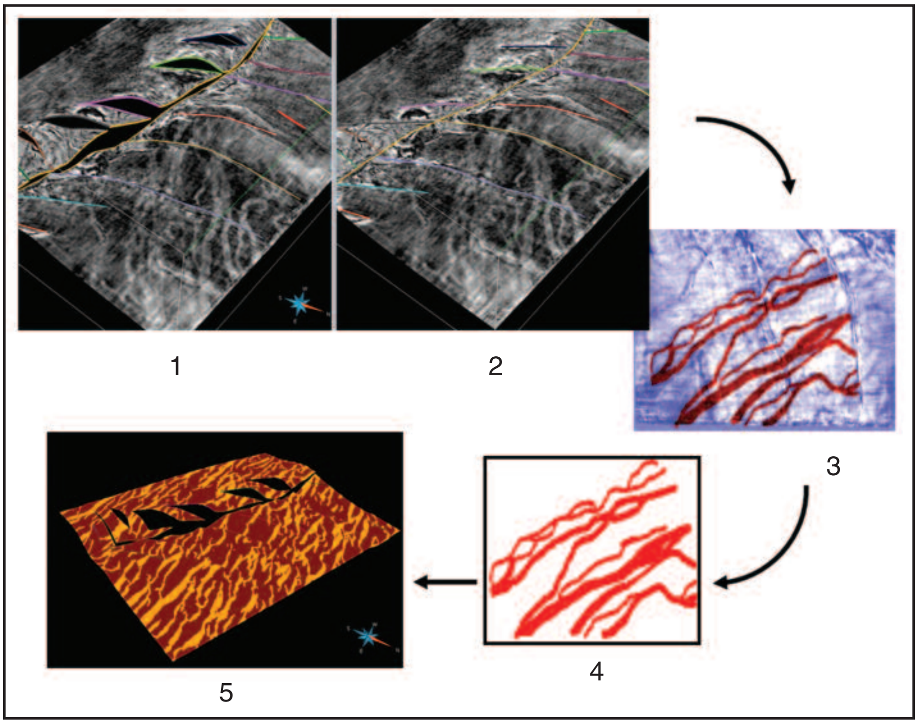


FIGURE 2

Workflow for Integrating Seismic Stratigraphic Features In Reservoir Model



- and t =t (x, y and z).

These three functions allow any location (x, y and z) in the geological domain to be transformed into a location (u, v and t) in the depositional domain. Such a transformation can be called the UVT transform. It is constructed using a very simple observation: A horizon located in the x, y and z space is typically a chrono-stratigraphic surface. All horizon particles have the same t, but each horizon has a different t. Since faults create discontinuous horizons, faults therefore are discontinuities for the functions u, v and t. Given these constraints, horizon and fault interpretations provide all the information needed to construct the UVT transform.

Constructing the UVT transform is automatic, using the sole horizon and fault interpretations as the input. Once the UVT transform is computed, fault surfaces and horizon surfaces can be extracted from it. These surfaces are sealed by construction, and modeled horizons will not cross by definition. This is a first interpretation quality control check.

In addition to these simple rules, additional geologic rules can be enforced while constructing the UVT transform. One example of the additional rules that exist to construct the UVT transform and enforce geological rules is honoring fault type (normal or inverse) information, such as enforcing that the horizon contacts do not cross on the fault plane. Sequential stratigraphic rule and erosion rules also can be honored, such as enforcing that the horizon was not deposited in a particular area.

Another example of the kinds of geologic rules that can be enforced is honoring intraformation chrono-stratigraphy. Similar to dip data, intralayer picks can be used to better control the UVT transform, which in turn, gets the UVT space better aligned with seismic signal–a necessary condition in order to correctly merge well information and seismic information away from the wells.

By using these geological rules, the horizons extracted from the UVT model are going to be coherent with the fault displacement set on the fault, and will be eroded automatically by the eroding layer. These are the second and third automatic interpretation quality control checks.

Chrono-Stratigraphic Slices

As the full UVT model is constructed, every point of the subsurface knows its paleo-geographic coordinates. Multivalued seismic chrono-stratigraphic slices can, therefore, be directly extracted from the UVT transformation. Figure 1 shows a faulted chrono-stratigraphic slice inside a UVT model, highlighting a stratigraphic feature.

The information extracted from these chrono-stratigraphic slices can be used to constrain reservoir models. The subsurface knowledge unified approach UVT transform restores correctly the paleo-stratigraphic continuity across faults, thereby enabling the identification of geobodies across the entire stratigraphic slice. A training image can be extracted from the seismic picture shown in UVT space, which can then be given to a multiple-point statistics simulation executed in that same UVT space to use the seismic-derived geomorphology inside the reservoir model.

The workflow and results of integrating seismic stratigraphic features in the reservoir model are shown in Figure 2. The first image shows the seismic chrono-stratigraphic slice extracted from the UVT model in the x, y and z space. The same seismic chrono-stratigraphic slice is shown in the second image in the UVT space, where all fault displacements have been removed and chrono-stratigraphic slices are plane. The third step is creating the training image inside the UVT space by painting over the seismic image, with

FIGURE 3

Picked Horizons in Regular Space (Left) versus Flattened Space (Right)

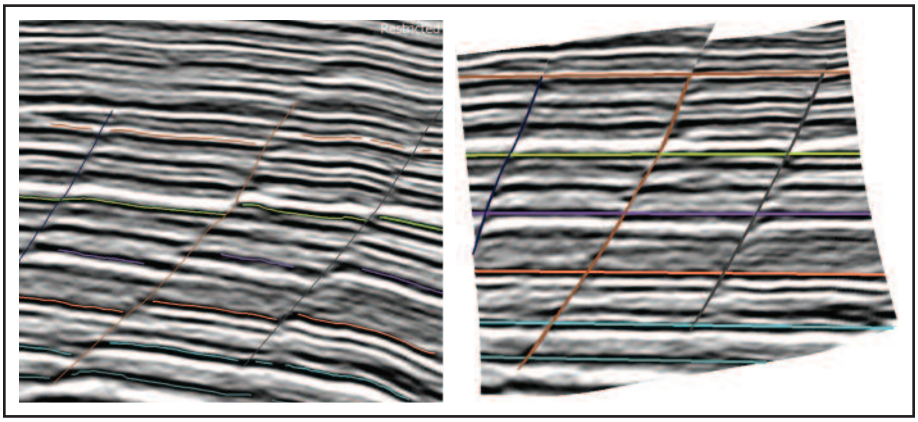
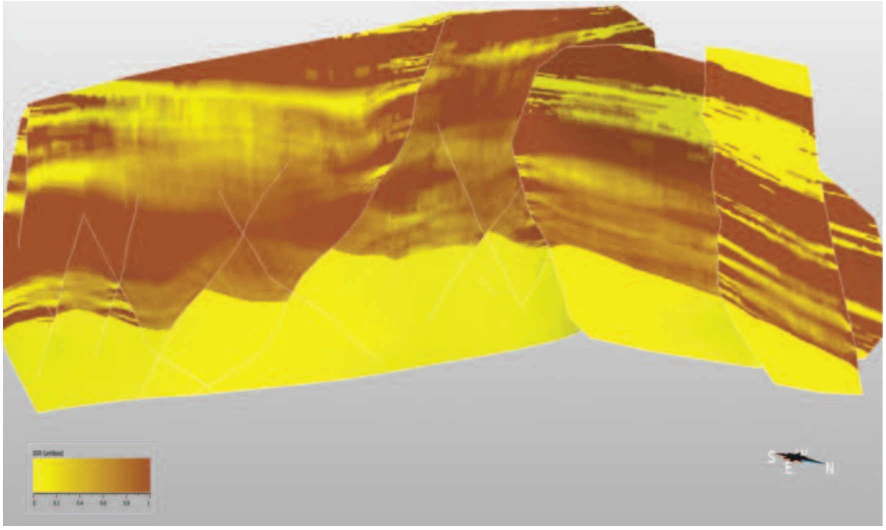


FIGURE 4

Smear Gouge Ratio Computation



the MPS training image shown in the fourth image. The final image shows the multiple-point statistics simulation for a given reservoir slice.

The UVT transform can be used to flatten seismic volumes to perform interpretation quality control. The quality control involves using UV slices. In these slices, we can look at seismic events and see how the seismic chrono-stratigraphic has been captured. If each seismic event is an iso-T event, then all seismic events should be flat and should match perfectly across faults in the UV slices. If events are not flat or do not match across faults, it is possible to interpret in the UVT space to correct the interpretation.

The image on the left in Figure 3 is shown in regular space with picked horizons, contrasted with the flattened space image at right, where interpreted horizons are flat. Seismic chrono-stratigraphic information can be seen in much greater detail than in the x, y and z space.

Model With Many Uses

The UVT transform provides a model with many uses. Additional computations can be performed using the UVT model to validate the interpretation, including computing displacement maps everywhere on the faults surface as well as computing juxtaposition maps.

In addition, shale-gouge ratios and weighted-shale-gouge ratios can be computed on faults. The weighted shale-gouge ratio is computed using an additional parameter, which is the maximum smearing distance of the shale from its origin inside the fault plane. A typical shale-gouge ratio supposes that the shale layer is smeared equally along the fault plane. The clay smear potential is sometimes used as well, but this weighted shale-gouge ratio (Figure 4) combines this information.

Other computations include:

- Computing the deformation of the layers between the x, y and z space and the flattened space, strain and stress;
- Computing the probability of fracturing and the directions of fractures at any location in a reservoir from the deformation and mechanical attributes of the rock type inside the layer; and
- Restoring a UVT-based model sequentially to understand the paleo-basin geometry.

The restoration of the 3-D model is done using the mesh supporting the UVT transform.

A UVT model can have many direct and immediate outputs, optimizing the workflow between interpretation and reservoir modeling and simulation. Geological grids for geostatistical simulation of rock properties are computed directly from the UVT model without any additional user interaction. These grids can be used for velocity modeling or geological modeling. Reservoir grids for reservoir simulation also are extracted directly from the UVT model. The only optional user interaction is defining potential flow simulation grid alignment to faults.

High-quality 2-D prospect maps are constructed automatically from the faulted and sealed horizons defined in the UVT model, and 3-D restoration can be done directly on the UVT model, removing the painful and time consuming step of 3-D mesh generation inside a fully closed structural framework, as is usually necessary using a conventional 3-D restoration workflow.

A UVT model is essentially a 3-D model created in the space/time framework independent of any "grids." Traditional modeling techniques use specialized grids for different applications, such as 2-D grids for mapping, 2-D half-pillar grids for reservoir models, and triangulated surfaces for structural models. Each grid has to be modeled independently, leading to repeated work and inconsistencies between the different "models." In the case of a UVT model, the generated grids all come from the same source; they are not the model, but specialized objects for specialized applications.

The space/time framework has redefined modeling, removing the need for compromises and data simplification, and making geologically-consistent model building accessible to the interpreter while optimizing the interpretation-to-simulation workflow. The UVT model honors all interpretation data, interpretations are geologically consistent, and many additional analyses can be done using the model to further validate prospects or improve predictability. ❐

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Jean-Claude Dulac is chief technology officer, interpretation and modeling, at Paradigm. Dulac was previously founder and chief architect of Earth Decision, a provider of integrated shared earth modeling solutions for asset teams, which Paradigm acquired in 2006. Before founding Earth Decision, Dulac held positions at Unocal, including development manager and senior research geophysicist. Prior to his work at Unocal, Dulac was a developer at Total. He holds an M.S. in geophysics from Stanford University and an M.S. in geology from Ecole Nationale Supérieure de Géologie.