New modelling technology delivers consistency

Jean-Laurent Mallet, Stanislas Jayr* and Philip Neri of Paradigm consider the problem that a unique mathematical representation of the subsurface cannot cater for all the disciplines of geoscience and engineering. The authors believe that the newly introduced uvt-transform is a major step forward in that it supports multiple representations while linking them through a rigorous process

The subsurface model is the final deliverable of all the contributions of earth scientists and engineers starting from field data and going through all the motions of processing, interpreting, analyzing, and refining the information. The model in its final form is an assembly of contiguous layers and geobodies all populated with rock and fluid properties.

Modelling software has been available for over 20 years, and it is now a pivotal part of exploration and production workflows, not the least because it is the bridge between the geology, geophysics, petrophysics, and rock mechanics of geoscience and the development planning and simulation activity of reservoir engineering.

Despite the ubiquitous usage of modelling at many stages in the life cycle of an E&P asset, from prospect to producing field, the geoscientists have been struggling to perform a variety of tasks using a single reference system and a single mathematical representation of the subsurface that is ready for geocellular upscaling and inclusive of all the detail and knowledge acquired since project inception. Whichever modelling process is chosen, it is ideally suited for many tasks, acceptable for others, and unsuitable for a number of uses.

To adapt to these limitations, modellers wishing to use a single system for the whole workflow have needed to compromise on one or more of the following criteria when building or manipulating models of the subsurface: limit the complexity of the model, reduce the number of faults, simplify fault topology, eliminate certain hierarchical relationships between faults (e.g., antithetics, fault displacing a fault, etc..), smooth model properties, and build geocellular grids with non-orthogonal faces, to name but the most frequent occurrences.

The alternative is to use different modelling processes at different stages of the workflow, each one best adapted to the particularities of a specific stage of the process. This reduces the number of compromises, but introduces a disconnect between the different representations of the subsurface model that are going to coexist while not being constrained by each other. Updates to one representation will require the export of the modifications to the other representation or representations in order to achieve project uniformity.

To illustrate this, let us look at a typical and simple workflow on structural interpretation and property modelling. In a classical software context, this would be decomposed into two phases:

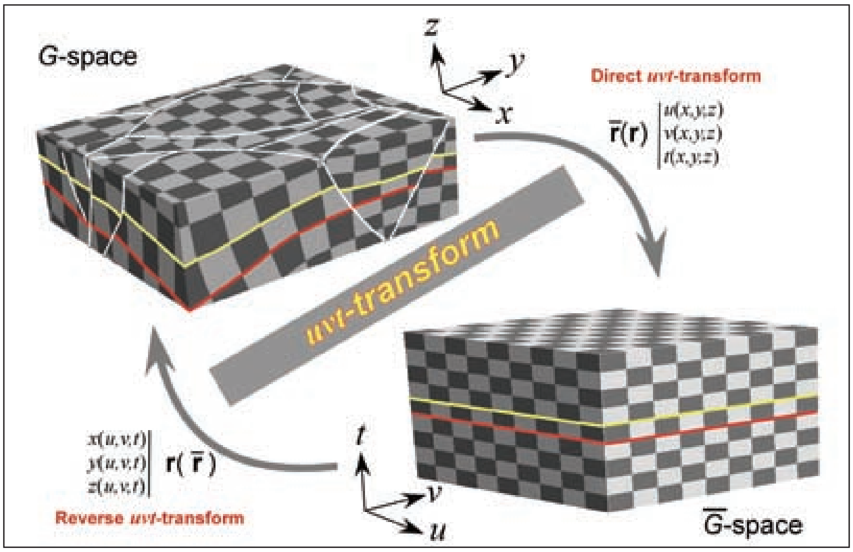

***Figure 1** uvt-transform of the geological domain G into a depositional domain G* (after Mallet, 2008)*

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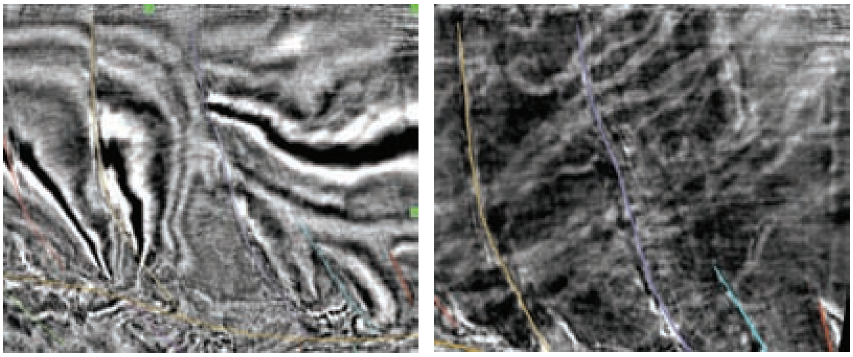

***Figure 2** Comparing a seismic time slice (left) with a geological time slice (right).*

- Building a structural model consisting of a set of parametric or triangulated surfaces (horizons and faults) which can be built without limitations.
- Mapping out the properties model (permeability, porosity, rock-type, ...) consisting of a stratigraphic grid construction of which often requires severe simplifications of the fault network.

As a consequence of such heterogeneous geological models, the property model and the structural model in this classical geomodelling software will be more often than not inconsistent.

GeoChron

In the frame of the recently introduced GeoChron model, we introduce the uvt-transform, the primary purpose of which is to unify the structural and the property models and to remove the need for any simplification of the fault network (Mallet, 2004, 2008, 2007).

The uvt-transform impacts practically all the branches of geomodelling, well beyond the scope of this particular model. The following is a non-exhaustive list of the model's applications and the uvt-transform:

- Applying geostatistical algorithms without the 'traditional' bias induced by pillar-based stratigraphic grids (Mallet, 2008).
- Upscaling reservoir properties whatever the type of flow grid used (structured or unstructured) and whatever the shape of the flow-cells (hexahedral or polyhedral).
- Assessing geometrical uncertainties in a mathematically proven coherent way.
- Computing displacement maps everywhere on the fault plane in a precise and well defined mathematical way.
- Computing shale-gouge ratio and weighted-shale-gouge ratio on faults in a precise and well defined mathematical way.
- Honouring dip/azimuth information anywhere in the volume.
- Honoring well path information for non-intersection.
- Honoring fault type displacement information (normal fault, reverse fault).
- Computing the probability of fracturing and the directions of fractures at any location in a reservoir.
- Construction of 4D basin models.
- Building and populating flow-grids, automatically.
- Building seismic velocity models.
- Flattening of seismic volumes.

These clearly show that this mathematical model and the UVT-transform are unifying the modelling of the subsurface. As a consequence, in place of the former generation of geomodellers consisting of series of independent models, it is now possible to build a new generation of geomeodellers built around one unique consistent mathematical model.

GeoChron model and uvt-transform (in a nutshell)

Any particle of sediment observed today in the geological domain G holds a series of properties such as:

- Coordinates (x,y,z) where (x,y) are the geographical coordinates and (z) is the altitude as observed today.
- Coordinates (u,v,t) where (t) is the geological-time of deposition of the particle and (u,v) are its paleo-geographic coordinates at geological-time (t).
- Geological and seismically-derived properties attached to the particle such as, but not limited to, the porosity, the permeability, and the seismic attributes at location (x,y,z).

The (x,y,z) coordinates and the (u,v,t) paleo-coordinates so defined are intimately linked to each other's by the three following functions:

$$u = u(x,y,z) \; ; \; v = v(x,y,z) \; ; \; t = t(x,y,z)$$

In (Mallet, 2004), the mathematical model based on these three functions was called GeoChron where 'Geo' refers to the paleo-geographic coordinates (u,v) whilst 'Chron refers to the geological-time (t). The functions u(x,y,z), v(x,y,z), and t(x,y,z) allow any location (x,y,z) in the geological domain G to be transformed into a location (u,v,t) in the depositional domain G*: such a transformation is called the 'uvt-transform'.

Computing the UVT-transform

Consider an horizon H(t) located in the geological space and its image H*(t) in the depositional space. In the frame of the

GeoChron model, it has been mathematically established (Mallet, 2002) that, if we want the distortions of H*(t) to be minimized whatever the location (u,v,t) in the depositional domain G*, then u(x,y,z), v(x,y,z), and t(x,y,z) must honour a specific system of non-linear coupled partial differential equations. In the general case, solving this system is extremely difficult. However, taking into account the shape of the horizons, it has recently been shown that a simple and robust solution exists which can be numerically obtained in a very efficient and optimal way (Mallet, 2007).

One can see in Figure 1 an illustration of the result of the uvt-transform applied to a geological structure affected by a complex fault network (X-faults, Y-faults, λ-faults). One can notice that, in spite of the presence of these complex faults and of a strong lateral variation of the layers' thickness, the images of the horizons in the G* depositional domain are flat and unfaulted and there is no gap or overlap in G*.

Application example

In the frame of this article, there is not enough room to demonstrate the many applications of the uvt-transform. For this reason, in the following we will focus on only one of these applications: the flattening of a seismic volume, which is one of the most straightforward applications.

Whatever the geological time (t), there is a strong interest in visualizing the seismic attributes on the flattened image H*(t) of an horizon H(t). Several attempts to solve this problem have been proposed in the literature (e.g., see Stark (2005), de Groot and Hemstra (2006) and Monsen et al. (2007)): whatever their implementation details, all of these 'classical' methods consist in defining H*(t) as the vertical projection H(t) onto a horizontal plane. As a consequence, all of these classical methods harbour the following drawbacks:

- In the presence of a normal fault, gaps are generated on H*(t).
- In the presence of a reverse fault, overlaps are generated on H*(t).

In the presence of non-horizontal or folded horizons, the image H*(t) is distorted. As Figure 1suggests, the minimization of the distortions between a horizon H(t) and its flattened image H*(t) obtained in the G* depositional domain thanks to the uvt-transform allows these drawback to be avoided. In other words, the uvt-transform clears the way for a robust and reliable visualization/interpretation of the seismic attributes in the G* depositional domain. As an illustration of the power and efficiency of such an approach, one can refer to Figure 2 where a seismic time slice and a geological time slice taken (approximately) at the same location of a seismic cube are displayed in top view:

- On the left hand side of Figure 2, one can see that the seismic time slice does not reveal any structure except the presence of faults: this is because the horizontal seismic time slice plane cuts the non-planar horizon H(t) where channels were deposited
- On right hand side of figure 2 corresponding to the flatten image H*(t) of H(t), one can see a set of anastomosed channels which were put in place at geological time (t). In spite of the presence of normal faults, it can be noticed that there is no gap in image H*(t).

Figure 3 shows the power of that transformation, this time in a cross-section and compares it with the result obtained with a standard 2D flattening technique (just based on a pure vertical shift of the traces).

Summary of benefits

The uvt-transform is a very powerful tool introducing mathematical rigour into the modelling and interpretation of the subsurface. Once the system of geologically driven partial differential equations used to compute the functions u(x,y,z), v(x,y,z), and t(x,y,z) are solved, the uvt-transform allows the property and structural model to be unified. Not only does the user have only one model to create (simplifying greatly the modelling workflow), but because the model is volumic and unique the uvt-transform contains much more information than the surfacic or gridded models. Many applications already exist and more are to be developed.

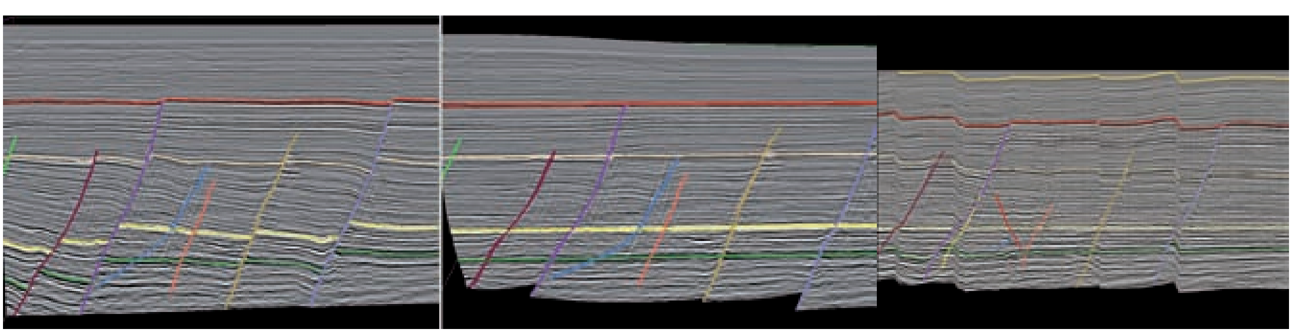

Figure 3 Vertical seismic section shown in the (x,y,z) geological space (left), its image in the (u,v,t) depositional space G (centre) and the same section in a standard (x,y, shifted z) flattened view (right). One can observe that as soon as the density of fault is important, just shifting seismic traces leads to unusable results whereas the centre picture using the uvt-transform gives crystal clear images.*

Impact on modelling activities

As we discussed in the introduction, it is a common understanding that a unique mathematical representation of the subsurface would not be able to cater for all the diverse requirements and constraints of the many disciplines of geoscience and engineering. The uvt-transform is therefore a major step forward in that it supports multiple representations while linking them through a rigorous process. This solution elegantly circumvents the limitations of multiple disconnected models, and makes it possible for many different disciplines to share a unique model while working on the representation adapted to the nature of their data and to their different requirements.

This yields two critical benefits. First, it delivers a better integration of the activity of the different disciplines across the organization. People are working on a single intrinsic model, they must reach agreement on any editing or improvement to the model. Secondly, it does away with the compromises and approximations, as each discipline can fully populate the model and represent the complexity of the data in their domain. The result will be a significantly more accurate model that embodies all the knowledge and information about the subsurface contributed by the many actors in the organization.

Acknowledgements

The authors would like to thanks Paradigm for permission to publish this article and specifically all the members of the Paradigm SKUA team who made the applications of the uvt-transform a reality.

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