Approach Couples Fluid Flow, Geomechanical Simulations In 3-D Reservoir Modeling

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HOUSTON–As the industry targets a growing roster of unconventional formations and more challenging geologic settings, reservoir modeling is playing an increasingly important role in developing and producing oil and gas reserves.

To understand the geomechanical stability of an oil and gas reservoir, the effects of induced fracturing, the possibility of fault seepage during exploitation or even carbon dioxide storage, the importance of coupled fluid flow, and geomechanical simulations are becoming more and more relevant to understand future production and associated development risks.

Stated simply, reservoir flow and geomechanical simulations divide the reservoir into blocks that represent the reservoir volume with a mesh of points or grid blocks. Typically, coupled fluid flow and geomechanical simulations are done using different meshes that result from complex gridding processes, and lead to many rock and fluid property transfer and rescaling issues. A new approach brings the two worlds of reservoir flow simulation and geomechanical simulation closer together, saves time on mesh construction, and removes rescaling problems.

Coupled fluid flow and geomechanical simulations are crucial to give the reservoir engineer an understanding of whether hydraulic fracturing, high-pressure injection or hydrocarbon depletion is going to modify the stress regime of a reservoir and "reactivate" sealing faults that could lead to potential oil or gas seepage to the surface or to a drinking water aquifer.

Similarly, these simulations are required to evaluate the capacity and containment potential of prospective carbon dioxide storage sites. Coupled simulations also are very important to assess formation and well bore stability during reservoir production to predict, for example, areas of potential permeability collapse.

Very Different Meshes

Today, flow simulation grids and geomechanical meshes are very different, with little in common. A flow simulation grid is typically a corner-point grid in which cells tend to be as "cubic" as possible. The grid cells can be aligned aerially and/or vertically to the faults, but the faults often will be represented by a "zigzag" both aerially and in depth to enable the representation of complex fault networks. However, because of gridding limitations, constructing a flow simulation grid generally is restricted to the reservoir interval. This is not sufficient for a full geomechanical study in which the over, under and side burdens must all be modeled.

On the other hand, geomechanical grids typically are fully unstructured meshes composed of tetrahedrons, or polyhedrons composed of four triangular faces, three of which meet at each vertex. The process of constructing these tetrahedrons can be very complex since all fault and horizon intersections must be explicitly represented, and tetrahedrons must respect the triangulated mesh that results from these intersections.

Three-dimensional tessellation (with no overlaps and no gaps) problems arise when the triangles on the fault surfaces become very small, as is the case, for example, with fault tips, horizons terminating against erosion, or when small displacements put horizons on both sides of the fault in the vicinity of each other (Figure 1). This process can be so difficult that fault and horizon surfaces need to be resampled. Consequently, the geometry often has to be simplified.

Furthermore, tetrahedral meshes cannot honor the internal stratigraphy of a reservoir layer, which is obviously a problem since rock properties typically are distributed following the stratigraphy. Introducing such constraints on the mesh greatly adds to the complexity of the mesh creation process.

To perform coupled fluid flow and geomechanical simulations, the reservoir engineer must use two meshes with very different samplings. During the simulations, he needs to transfer properties from one mesh to the other while honoring stratigraphy and fault block information as accurately as possible. This problem is considerably more difficult than classical

FIGURE 1

Difficult Areas to Tessellate in 3-D on a Fault Plane
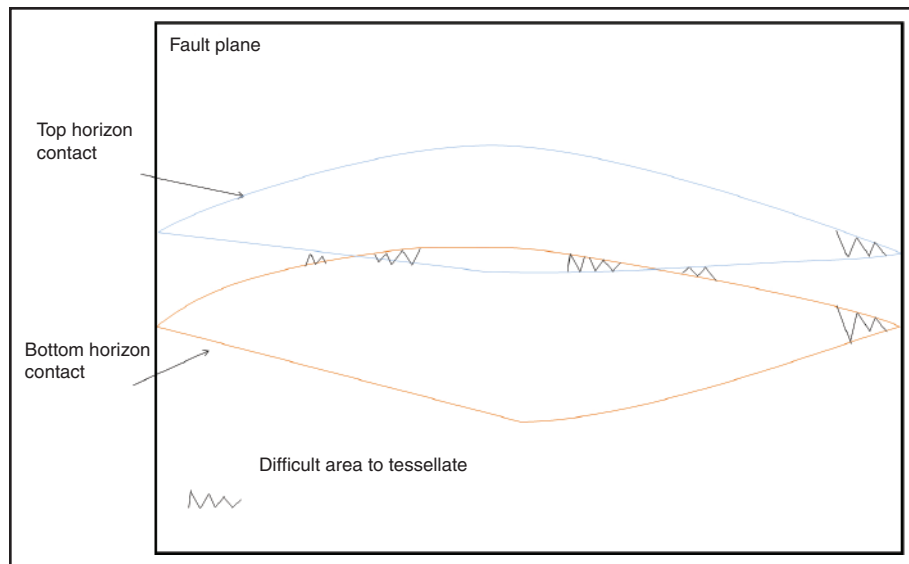
upscaling between a fine geological grid and a coarse reservoir grid, where both are "regular" and the former is often a subdivision of the latter.

New Solution

The bottom line is that the industry faces two challenges: meshing the reservoir and its surrounding rock formations, and then passing properties between two meshes. To simultaneously solve both problems, a new common space/time referential framework (UVT space) and a new type of mesh have been introduced.

UVT transform technology is based on the observation that horizons represent geochronological surfaces. Working with a paleo-geographically correct mesh, geobodies, reservoir properties and other attributes can be correctly modeled in their depositional state in 3-D space.

Any particle of sediment observed in the geological domain (G) holds a series of properties, such as the coordinates X, Y and Z

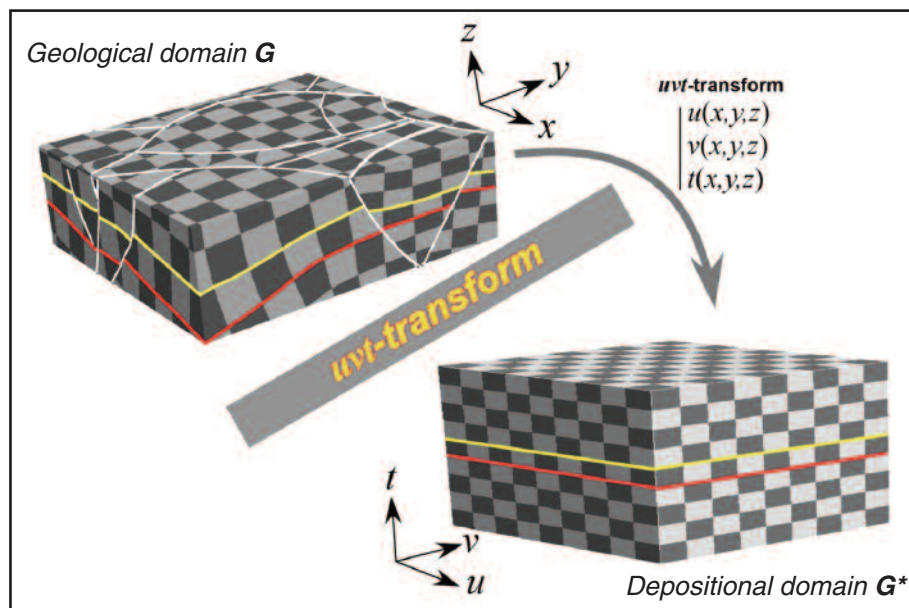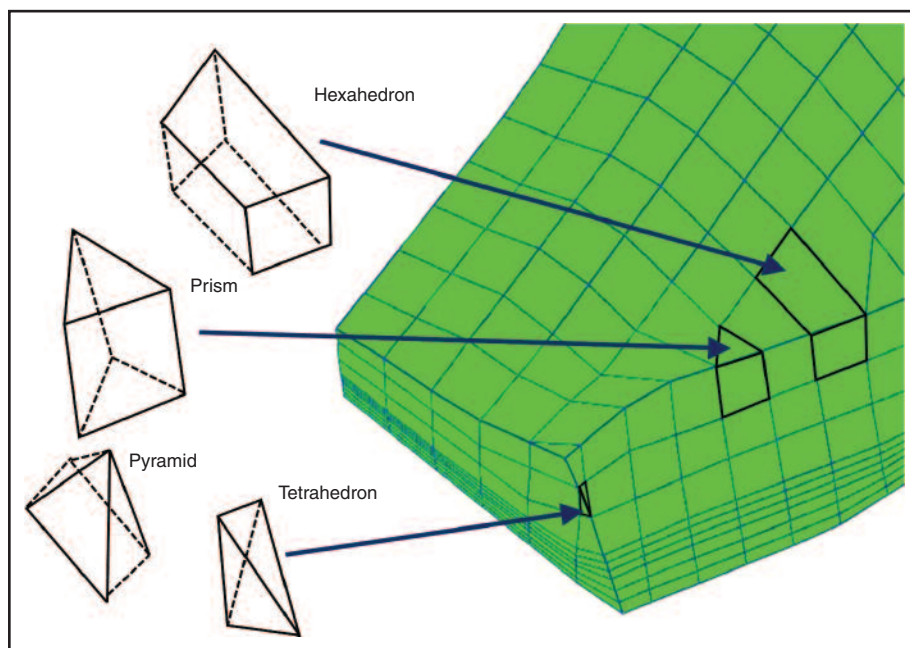## FIGURE 2

Illustration of UVT Transform

FIGURE 3

Unstructured Geomechanical Grid Honoring Faulting and Stratigraphy

(where X and Y are the geographical coordinates and Z is the altitude as observed today), and the coordinates U, V and T (where T is the geological time of the deposition of the particle and U an V are its paleo-geographic coordinates at geological time).

The X, Y and Z coordinates and the U, V and T paleo-coordinates so defined are intimately linked to one another by three functions: U = U (X, Y, Z); V = V (X, Y, Z); and T = T (X, Y, Z). All three of these 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 (G*). This transformation is the UVT transform.

Figure 2 illustrates the result of the UVT transform applied to a geological structure affected by a complex fault network (X-faults, Y-faults and λ faults). In spite of the presence of these complex faults and of a strong lateral variation of the layers' thicknesses, one can notice that the images of the horizons in the deposi-

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tional domain are flat and unfaulted, and there is no gap or overlap in the depositional domain.

The advantages of the UVT transform for the coupled-simulation workflow are numerous. First, the transform is computed on top of an unstructured mesh, which honors exactly the fault network. Second, it is rather straightforward to sample the UVT space with any kind of mesh and have that mesh be stratigraphically coherent in the X, Y and Z space.

Most importantly for this workflow, however, all of these meshes have the same referential when creating a different mesh topology in the UVT space, which allows properties honoring both the faults and the stratigraphy to be properly transferred and rescaled.

Hybrid Grid

Geomechanical simulation software and other similar simulation engines require meshes that coincide with stratigraphic layers that are made up of tetrahedral to hexahedral cells, and have cell faces parallel to the fault surfaces.

From the UVT model, a hybrid grid is created that contains noncubic cells at the fault locations to honor both faults and stratigraphy. Figure 3 shows an unstructured grid for geomechanics that honors fault planes as well as stratigraphy. These hybrid meshes are very efficient numerically compared with pure tetrahedral or hexahedral meshes because the "nonhexahedral" elements are in topological continuity with their nonfaulted hexahedral neighbors.

Figure 4 shows a geomechanical grid that includes both the reservoir and the overburden to surface. The reservoir zone is a heavily faulted area, with a large strike-slip fault in the middle of the model and oppositely dipping faults on either side of the strike-slip fault (faults are shown in transparency). The UVT space is constructed using chronostratigraphic information given by the horizons inside a faulted unstructured mesh. The construction of the UVT space and of the geomechanical grid is done automatically from the input fault and horizon interpretations.

The top image in Figure 4 represents the entire grid composed of three layers. In the middle image, the top layer has been removed. In the bottom image, only the last layer is shown, and the alignment of the grid cells along the fault plane can be observed. It is apparent that neither the presence of oppositely dipping faults against the main strike-dip fault nor the presence

FIGURE 4

Geomechanical Grid from Reservoir to Surface
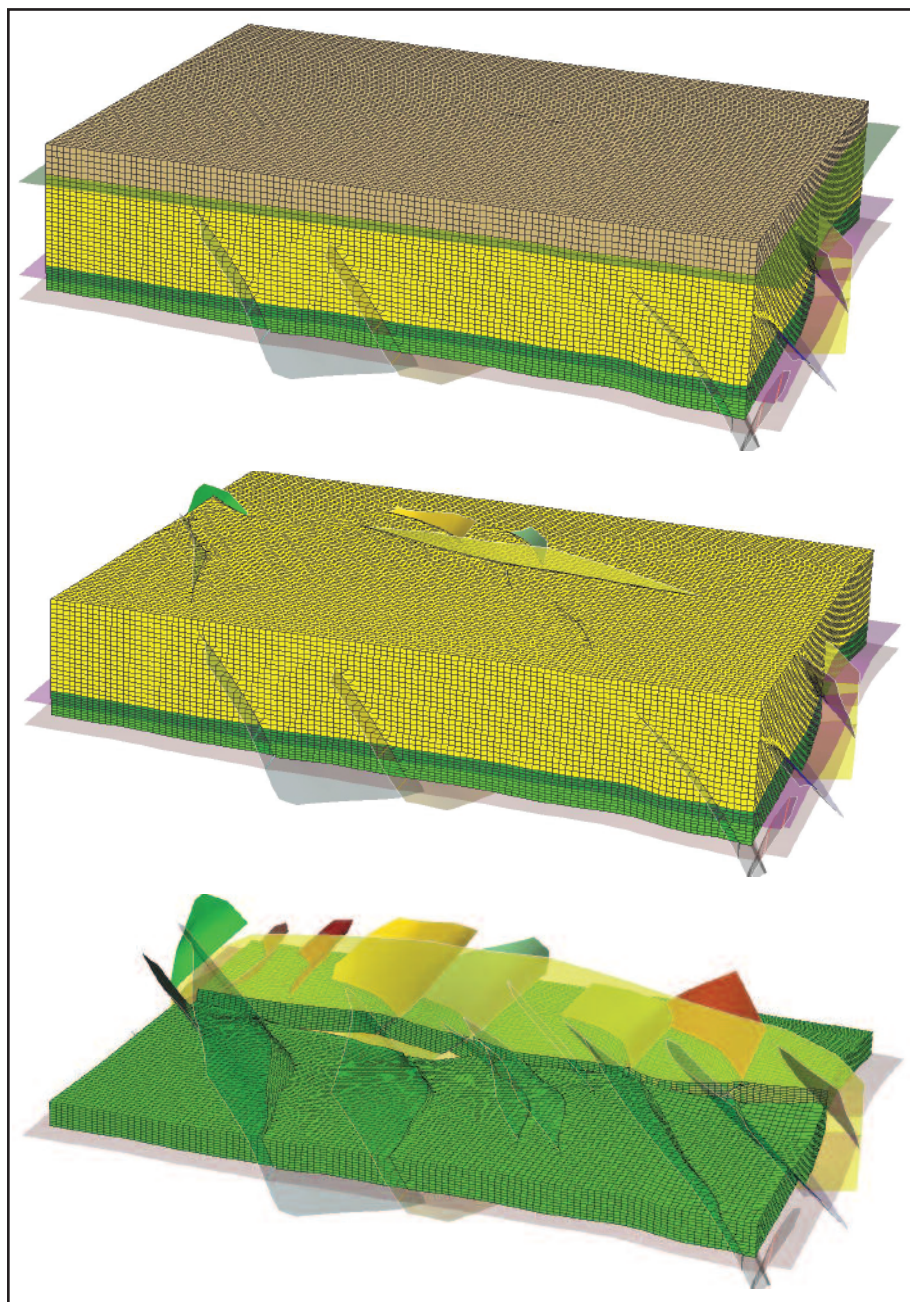
of "floating" faults in the middle of the model prevent the construction of both geomechanical or flow simulation grids.

The construction of the UVT space is not only essential for constructing different grids (i.e., geological, flow simulation and geomechanical grids), but it also enables a consistent property transfer between these different grids in terms of both stratigraphy and fault blocks. Once the chronostratigraphic model is constructed, the generation of different grids is immediate. The geomechanical grids created from the UVT space honor the requirements of geomechanical simulation codes just as the flow simulation grids created

from the UVT space honor the requirements of flow simulators, and the geological grids honor the requirements of geostatistical modeling. The UVT space provides the glue between these grids.

The geomechanical grids and the very simple method of constructing them are a dramatic step forward in coupled geomechanical and fluid flow simulation for many applications in the oil and gas industry. Using the UVT transform reduces gridding or meshing time by large factors without the limitations of previous simulation workflows. ❏