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Unified geophysical and geological 3-D Earth models

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At present, 3-D geological Earth models typically comprise triangulated surfaces that represent geological contacts. The geological contacts are known at points from drill-hole intersections and surface mapping, and are interpolated between boreholes and extrapolated outwards to produce a 3-D Earth model. Triangulated surfaces are appropriate for representing the geological contacts as they are sufficiently general and flexible that they can be made to mimic arbitrarily complicated subsurface structure. In contrast, Earth models required for most current 3-D geophysical numerical modelling and inversion approaches comprise a rectilinear grid. This is because the mathematics of the numerical modelling are easier for a rectilinear grid. In such a model, the volume of the Earth's subsurface is discretized into a regular mesh of brick-shaped cells. The relevant physical property or properties is assumed to be uniform within each cell, but possibly different from one cell to the next. In principle, if the discretization is sufficiently fine, this type of Earth model can represent, in a pixellated manner, any spatial variation of physical property in the Earth's subsurface. However, no matter how fine the discretization of the rectilinear grid, such a grid is always incompatible with surface-based geological models, and an intermediary process is required to translate or transform from a geophysical model to a geological one, or vice versa. Also, because the computational resources required by 3-D numerical modelling and inversion procedures increase dramatically as the discretization of a model is refined, it is never really possible to achieve as fine a discretization as one would want. This exacerbates the mismatch between surface-based models and those comprising a rectilinear grid. To address this incompatibility, we are using unstructured tetrahedral grids to specify 3-D geophysical Earth models. These grids can be used to discretize the volumes between general triangulated surfaces while maintaining exactly these triangulated surfaces within the volumetric discretization. It is therefore possible to have geological and geophysical models that are, in essence, the same Earth model. We are developing geophysical forward-modelling and inversion software for unstructured tetrahedral grids, including for seismic travel-time forward modelling and inversion, gravity forward modelling and inversion, joint inversion of seismic travel-time and gravity data, and for electromagnetic forward modelling. We are also developing the tools necessary for creating a volumetric tetrahedral discretization of surface-based geological models.