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Quantification of confidence in a geological model of Cumbria, UK

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A three-dimensional geological model of Cumbria was constructed by several geologists, applying expert judgment to interpret available data, as both a fence network of cross-sections in GSI3d and surfaces in GOCAD®. Direct statistical measures of uncertainty of the model are not available. Neither is it feasible to undertake post hoc sampling at additional independent boreholes to estimate measures of model uncertainty. The study considered various qualitative and quantitative approaches to assessing the modelled surfaces and volumes.
Modellers make judgments about the relative quality of different types of available data and the extent to which simple trends in the units of interest (e.g. a gentle dip) allow their structure to be extrapolated with confidence away from observations. Confidence decays with increasing distance from a hard observation, such as a field exposure, an interpreted borehole, or a "softer" observation such as a geophysical measurement.
In the study area it is possible to make qualitative assessments of four distinct structural domains, marked by different levels in the confidence of the interpretation of the geological model through factors such as availability of deep borehole data, seismic lines, surface exposure and the complexity of the bedrock geology and an appraisal of the extent, amount and quality of the data used to constrain the boundaries presented within the model.
The study also attempted to provide various quantitative approaches to assess the type and distribution of data. The quantification of a Confidence Index uses expert elicitation to assess the certainty of subsurface interpretations of modelled surfaces and volumes based upon a statistical analysis of the proximity to subsurface data (boreholes and seismic data). Application of this approach is presented as elevation and thickness grids for a principal aquifer in the region. This approach is directly applicable in areas where bedrock strata are poorly exposed and the geologist is reliant upon subsurface data. This situation holds within the Permo-Triassic basins in north and west Cumbria and the offshore area.
However, the Confidence Index approach is less applicable within the Lake District, where bedrock is commonly exposed, the mountainous topography provides a good resolution of the 3D geometry of the bedrock geology, and borehole records and seismic data are scarce or absent. In this domain, three principal sources of uncertainty were recognised: 1) The degree of exposure of surface structure; 2) the heterogeneity of the dip direction (azimuth) observed at the surface, and 3) the heterogeneity of the dip angle (magnitude) itself. The percentage outcrop of bedrock can be determined by aggregating the distribution of all superficial deposits (natural and artificial) and then determining the amount of bedrock which occurs at crop within each cell of a 1 km2 grid. An approach for determining both the direction and magnitude of structural dip are proposed, as is a consistent set of rules to allow the three variables to be integrated into a single uncertainty measure using fuzzy logic to express and apply these rules.