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Structural and stochastical modelling of possible contaminant pathways below nuclear installations

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Dounreay Nuclear Power station is situated on the northern coast of Caithness, Scotland on complex normally faulted Devonian sedimentary rocks with a thin, intermittent cover of superficial deposits, predominantly comprising glacial tills of varying provenance.

Bedrock structure, fracture patterns and the relationships between bedrock and the superficial deposits have a considerable impact on the transmissivity of any possible contaminants. Consequently, an understanding of the bedrock-superficial boundary and how fractures and faults influence and control the transport of fluids are a key concern. The principal aims of this work are to gain an understanding of the processes and controls on fluid flow pathways within such complex geological terrains, and develop methods of stochastatically evaluating likely contamination transport within the subsurface.

This work focuses on the near-surface bedrock geology and superficial deposits. The near surface geology of the Dounreay site comprises cyclic sequences of lacustrine rocks; their cyclicity has enabled a reference stratigraphy to be created and correlated across the site. This stratigraphy, the coastal exposures and the extensive amount of borehole data available, provide a unique opportunity to construct and constrain a three-dimensional bedrock model; the interpretive element of which has been robustly test using structural restoration techniques.

In the bedrock of Dounreay, three principal fracture sets have been identified. The first two sets of fractures are approximately orthogonal, trending north-northwest and west-southwest respectively; they represent the regional fracture set. It is proposed that these fractures where produced during loading and burial of the Devonian sediments. The final fracture set is predominantly parallel to bedding of the laminated sediments giving the Caithness Flagstones their ‘flaggy’ nature. This fracture set is the result of the erosion of the Devonian sediments, reducing the overburden pressure.

The regional fracture sets are approximately constant over the site area and vary little with depth, whereas the bedding-parallel fracture set shows a marked decrease in the number of fractures per meter with depth, on a logarithmic trend. This relationship is also visible in the Rock Quality Designation (RQD) values and hydraulic conductivity data from boreholes. It follows that the bedding-parallel fractures are the major controlling factor of flow in the shallow subsurface and that the RQD values can be used as a proxy for fracture density. RQD values are commonly collected during borehole drilling and the relationship between hydraulic conductivity and RQD values offer a method for stochastically populating a 3D geological model with hydraulic conductivity values.

Current geological interpretations of the superficial deposits are based primarily on their genesis. Consequently, subdivisions based on the origin of the sediments do not relate directly to their fluid transmissivity. The superficial deposits generally have a very low hydraulic conductivity, compared to that of the bedrock, impeding the flow of water from the surface to the groundwater system at depth. A combination of driller’s description and comparisons of grain-size distribution enables subdivisions of the Quaternary strata to be established based on their properties instead of their genesis. These properties can then be stochastically interpolated throughout the 3D geological model.

This work provides a framework from which likely contamination scenarios can be modelled, both in the well-constrained subsurface of Dounreay, and at other nuclear installations where the nature of the subsurface is less well constrained.