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Types of permeability development in limestone aquifers in Britain

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Advances over the last forty years have resulted in a clear understanding of how dissolution processes in limestone rocks enhance aquifer permeability. Laboratory experiments on dissolution rates of calcite and dolomite have established that there is a precipitous drop in dissolution rates as chemical equilibrium is approached. These results have been incorporated into numerical models, simulating the effects of dissolution over time and showing that it occurs along the entire length of pathways through limestone aquifers. The pathways become enlarged and integrated over time, forming self-organized networks of channels (or solutionally-enlarged fractures or fissures) that typically have apertures in the millimetre to centimetre range. The networks discharge at point-located springs.

Numerical models that simulate dissolutional enlargement of fractures in limestone aquifers have given many insights into the conditions that favour different styles of permeability enhancement. Two end-member channel network types may be distinguished, one with many channels of similar size and one where a small number of large channels conduct most of the flow. In the latter case the larger channels may be metres in diameter (i.e. caves). Numerical modelling has shown that the former type are favoured where there is densely fractured rock, high hydraulic gradients, and recharge water close to chemical saturation (c/ceq close to 1). The latter type are favoured where there is sparsely fractured rock, low hydraulic gradients, and low values of c/ceq.

These two contrasting types of aquifer have no distinguishing names in the literature. It seems reasonable to define a karst aquifer as an aquifer with self-organized, high-permeability channel networks formed by positive feedback between dissolution and flow. In this case both these aquifer types are karst aquifers. Perhaps it would be appropriate to call the former "microkarstic" aquifers and the latter "macrokarstic" aquifers.

The range of karst aquifers types is well demonstrated by examples from England. The Chalk aquifer is an example of the microkarstic type. It has few caves but wells are characterised by high productivity, with a geometric mean transmissivity from pumping tests in 1257 wells of 440 m2/day, with a standard deviation of 0.76 log units. Well logs show that most production is from a few solutionally-enlarged fractures in each well. The Carboniferous Limestone aquifer provides a strong contrast. The geometric mean transmissivity from pumping tests in 59 wells is only 22 m2/day, with a standard deviation of 1.31 log units. Its wide range in well productivity and the presence of large cave streams are both indicators that it is a macrokarstic aquifer.

These two contrasting aquifers share a number of common properties. Both have convergent flow to springs and channel networks with rapid flow (typically > 100 m/day). Furthermore, in both cases the matrix of the rock has relatively high porosity and low hydraulic conductivity, whereas the fractures and channels have low porosity and high hydraulic conductivity. Consequently, the flux of water through these aquifers occurs mainly through the channel networks although the matrix provides substantial storage. Other well-documented limestone aquifers in England such as the Magnesian Limestone and Jurassic limestones have transmissivity properties that are intermediate in value between the Chalk and the Carboniferous Limestone and have generally also been considered as being intermediate in karstic characteristics. The above conceptual model that karst aquifer type depends upon the size and frequency of channels provides a good explanation of the range of aquifer properties found in British limestone aquifers.