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Insights from a Low-Porosity Hydrothermal Aquifer Tracer Study

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An added Sulphur Hexaflouride (SF_6) push-pull tracer experiment in sub-seafloor hydrothermal fluid circulating in the eastern flank of the Juan de Fuca plate was conducted from 2010-2014. Experiment planning and initial data analyses assumed a point-source instantaneous tracer injection, analogous to a high porosity terrestrial groundwater system. This conceptual model was used to plan the extensive and costly engineering required to execute this sub-seafloor experiment. When preliminary results were obtained, the model was used to calculate the local formation fluid background linear velocity and perform mass-balance calculations, providing estimates of aquifer properties.

Additional tracer breakthrough data from adjacent boreholes has given reason to reevaluate this conceptual model, potentially replacing the original terrestrial analog model with one taking into account extremely limited effective porosity and 10-100x lateral anisotropy, controlled by ridge-parallel faulting orienting the connectedness of fractures and pore in the basalt basement aquifer.

A near-instantaneous breakthrough at a borehole 311m downgradient of the injection site suggests that effective porosity is so limited that the injectate volume alone was sufficient to displace fluid 200-300 meters. Contrasting with the immediate detection, the breakthrough at a farther downgradient borehole occurred hundreds of days later, conveyed by the natural average linear velocity of 1-2 meters per day. Furthermore, a Cesium tracer was injected in two pulses hours apart and intended to thoroughly mix in the vicinity of the borehole, effectively producing one signal. Instead, it produced two distinct breakthroughs, supporting the ultra-low porosity hypothesis.

Continuous autonomous sampling systems have provided high-resolution data in this fractured rock aquifer and provided opportunities to refine tracer study planning in low porosity systems and analytical techniques for dissolved gas tracers. The methods, results, and interpretations of these data have the potential to guide future sub-seafloor aquifer studies and may be useful in terrestrial fractured-rock aquifer settings for potable use studies, contaminant transport, and geothermal reservoir applications.