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Geological exploration for a high-temperature aquifer thermal energy storage (HT-ATES) system: a case study from Oman

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A collaborative research programme between the German Research Centre for Geoscience, Potsdam (GFZ) and The Research Council of Oman (TRC) is underway, which aims to develop and implement an innovative concept of a sustainable thermally driven cooling system in combination with a HT-ATES in northern Oman. The system will use an absorption chiller for cold supply, which nominally requires water of around 100°C as energy source. Solar collectors will provide this thermal energy and energy surpluses during daytimes will be stored to ensure a continuous operation of the cooling system. An integral part of this project is, therefore, the development of an efficient HT-ATES (100°C), which is based on temporary storage and recovery of thermal energy through hot water injection in subsurface aquifer horizons. Thus, an accurate thermal and fluid flow characterisation of potential reservoir horizons is essential to ensure optimal efficiency of the cooling system.

The study area is located in the Al Khwad area, approximately 40 km to the west of Muscat. The area is characterised by a thick Cenozoic mixed carbonate-siliciclastic sedimentary succession, containing at least 3 aquifer horizons. We use a multidisciplinary approach for the initial ATES exploration and development phase, including traditional geological fieldwork dovetailed with virtual outcrop geology, thin-section analyses, geological modelling and reservoir fluid flow forecasting analyses. Our first results indicate two potential storage horizons: (1) a Miocene-aged clastic-dominated alluvial fan system and (2) an Eocene carbonate-dominated sequence.

The alluvial fan system is characterised by a more than 300 m thick, coarse-clastic succession of coalesced individual fans. Thermal and hydraulic parameters are favourable for gravel and sandstone intervals but reservoir architecture is complex due to multiple generations of interconnecting fans with highly heterogeneous facies distributions. The Eocene carbonates, as second potential storage horizon, were deposited in a carbonate ramp setting. Individual facies belts extend over kilometres and thus horizontal reservoir connectivity is expected to be good with minor facies variability. Thin-section analyses point to the fossil-rich sections with high porosities and permeabilities and thus good storage qualities.

Fluid flow and thermal modelling indicate that both potential storage horizons show good to very good storage characteristics but also have challenges such as reservoir heterogeneity and connectivity. In particular the tilting of the thermocline, specific to high-temperature systems poses a major challenge. We investigated scenarios to counterbalance the distortion of the subsurface heat-plume, which includes adjustments of the salinity contrast between injected and aquifer fluid to prohibit buoyancy-driven flow. Additionally, geological structures ("HT-ATES traps" e.g.: fault structures) were modelled in detail in order to analyse their suitability as high-temperature storage system. First results show that an effective HT-ATES trap is necessary in the alluvial fan system in order to keep in control of the heat-plume. Salinity adjustments are sufficient in the carbonate-dominated sequences where vertical permeability contrasts are higher and constitute natural vertical flow barriers.