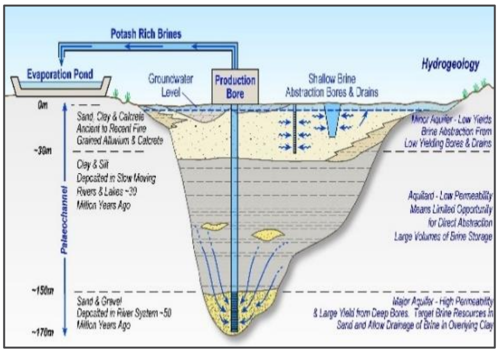
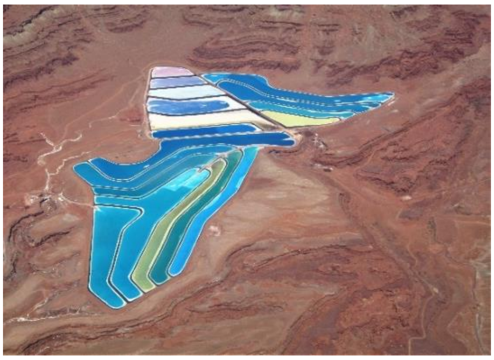
Solution Mining

Need

Solution (brine) mining is the extraction of useful minerals naturally dissolved in brine. Commercial brines include shallow brine beneath saline or dry lakes, and deep brines in sedimentary basins. These brines are pumped to surface and fed into evaporation ponds. Brines are important sources of potash, lithium, copper and other heavier metals and industrial salts. A plentiful lithium supply will be crucial to chartering a future based on automotive and industrial lithium-ion battery energy use as one means of reducing society's carbon footprint, with demand expected to soar fourfold every three years. Potash as a key component of fertilizers, is crucial to feeding an increasing global population.



Hydrogeology plays a critical role in determining the economic viability and shaping development strategy of brine mining operations. In particular, to assess distribution and producibility of groundwater brines, the hydrogeologist must determine vertical and lateral variation in total porosity across the resource, and differentiate the fraction that is occupied by free (mobile) brine, versus the remaining fraction occupied by bound (immobile) brine. To map brine movement the hydrogeologist needs to investigate flow potential, which depends on hydraulic conductivity, the specific yield and specific retention of the rock.

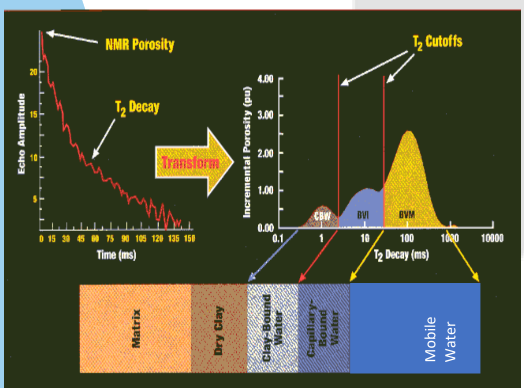


Existing Methods

Total porosity, specific yield, specific retention and permeability can be directly measured **ex-situ** on clean, dried core test plugs. However, accuracy of such tests is influenced by core quality, extent of filtrate invasion, damage to cores during retrieval, poor core preservation, scaling effects, test methods used and quality of the test apparatus.

Total porosity and permeability can also be determined **in-situ**. However, bulk density log-derived porosity values are prone to error if matrix density is not precisely known. Also, as it is not possible to measure permeability directly, complex multi-parameter lithology-dependent correlations are used instead that equate permeability with other measured geophysical characteristics. These correlations are calibrated against **ex-situ** measured permeabilities on cores acquired at disparate, discrete depths, which as mentioned previously can be prone to sizeable errors.

Bulk permeability can also be estimated from monitoring and analysis of **in-situ** pressure transients induced using pipe or wireline conveyed packer tests. However, tests can last hours, even days, to obtain a single measurement.



New In-Situ Method

Total porosity, specific yield and specific retention can all be directly measured **in-situ** using Nuclear Magnetic Resonance (NMR) technology. Borehole NMR is specifically tuned to sense the fluid-filled pores only, so measurement accuracy is completely unaffected by matrix composition, with no special calibrations to formation lithology therefore required. This superior response capability contrasts completely with the lithology-dependent measurement principle of conventional logging tools. Aquifer permeability can also be derived from analysis of NMR responses.

BMR Features and Benefits

While NMR has been used routinely in the oil and gas logging industry for decades, uptake by the brine mining industry has been hindered by NMR tool size and cost of the logging service. NMRSA have addressed this capability gap through development of an advanced miniaturised, slim borehole Magnetic Resonance (BMR) logging tool.

- Advanced NMR pulse sequences and signal processing techniques enable aquifer pore structure and mobile water content to be determined with a high degree of precision and accuracy.
- An appropriate theoretical model is used to also estimate intrinsic permeability.
- Raw data transmission, complemented by a powerful analysis software, enables a detailed log of these geophysical parameters to be generated real-time.
- Despite miniaturisation, the BMR logging tool has impressive signal-to-noise (SNR) characteristics, resulting in a large depth of investigation.
- High SNR, coupled with rapid data acquisition and processing, enables variation in geophysical parameters through the aquifer to be mapped while continuously logging at 1 m/min (~200ft/hr).
- The BMR logging tool can be run centred in open-hole, fiberglass or PVC lined boreholes.

The Right Data for the Best Value

To fit inside the typically small diameter boreholes drilled to explore and delineate new brine aquifers, development of the BMR logging tool necessitated a high degree of hardware miniaturization and implementation of new, advanced NMR excitation and NMR relaxation measurement techniques, posing major technical challenges. These challenges were successfully overcome through pioneering applied research, innovative design and a number of inventive steps. As a consequence of these breakthrough achievements, BMR is able to deliver high quality, high resolution data, on a wide range of geophysical pore-related parameters, providing an in-depth view of aquifer hydrogeology. Furthermore, owing to the simple method of use and minimal support equipment and personnel requirements, the BMR logging service also delivers the best value, as showcased in the comparison table below.

	BMR Logging	Conventional Logging	Packer Testing	Core Retrieval & Testing
In-situ measurement	✓	✓	✓	✗
Measurement accuracy[1]	✓✓✓✓	✓	✓✓✓	✓✓
Total porosity	✓	✓	✗	✓
Free water porosity	✓	✗	✗	✓
Clay-bound porosity	✓	✗	✗	✗
Capillary bound porosity	✓	✗	✗	✓
Permeability	✓	✓	✓	✓
Real time data	✓	✓	✗	✗
Rig-less operation	✓	✓	✗	✗
Continuous depth profile	✓	✓	✗	✗
Crane-free operation	✓	✗	✗	✓
Test speed[1]	✓✓✓✓	✓✓✓	✓✓	✓
Test efficacy[1]	✓✓✓✓	✓✓✓	✓✓	✓
Test cost[2]	$	$$	$$$$	$$$
Cost benefit ranking	1	2	4	3

Notes:

[1] ✓ = worst, ✓✓✓✓ = best

[2] $ = least costly, $$$$ = most costly