



Noble Gas Tracers: Improving the Understanding of Groundwater Recharge and Flow Systems in Australia

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Australia has several large groundwater basins, including the Great Artesian Basin (GAB), one of the largest aquifer systems in the world, which has a long history of groundwater extraction for stock, agriculture and urban water supplies. Recently there was an increase in exploration and development for coal bed methane and shale gas and the extension of existing and approval of new mining operations. There is a need to characterise recharge processes and flow dynamics in these complex aquifer systems to assess cumulative impacts, develop policy for groundwater use and underpin the social licence to operate for extractive industries.

Case 1: Eastern Recharge of the Great Artesian Basin (New South Wales)

⁸¹Kr improves reliability of flow velocity results from other tracers.

³⁶Cl results highlighted the existence of two different flow areas with very different recharge mechanisms. Although these isotope systems yielded the qualitative results in a relatively straightforward manner, the isotopes ⁸⁵Kr and ⁸¹Kr provided much more reliable results than ³⁶Cl (and ¹⁴C), for which detailed geochemical corrections were needed. The application of noble gases therefore helped to reduce the conceptual uncertainties associated with previous tracer studies.

- ³⁶Cl/Cl: affected by increasing Cl along flow path 4×10^{-4} mg/(L m) dilutes ³⁶Cl/Cl, distortion up to 300,000 years towards "too old", southern flow path velocity 0.85 ± 0.65 m/y
- ⁸¹Kr: southern flow path velocity 0.47 ± 0.14 m/y. Northern flow path 'real' 3-5% values indicate 4.5-11 cm/y, whereas if there is underground production of 4% ⁸¹Kr after radioactive decay of the original air input, 5 mm/y possible
- He vs. ³⁶Cl/Cl: He ingrowth rate of 3×10^{-11} cc/(g y), whereas expected in-situ production is $7-12 \times 10^{-12}$ cc/(g y) [2], hence there is possibly contributions of an external flux of He

Case 2: Cambrian Limestone (Northern Territory)

Noble gases elucidate the recharge mechanisms that lead to heterogeneous and contradictory results of other tracers across a study region of extreme environments

The Beetaloo Sub-Basin, located in the Northern Territory, contains aquifer systems that cover thousands of square kilometres. The karstic and heterogeneous structure of the shallow aquifers, and associated recharge characteristics that are variable in season, latitude and local structures, pose many challenges for the characterisation of groundwater flow and recharge. Conventional tracers demonstrate apparent contradictions (see below). The noble gases provided insights into the recharge mechanisms, elucidating the challenges within the rest of the dataset, and suggest that ³⁹Ar might be very useful as it covers a unique age range that is important for better understanding the system.

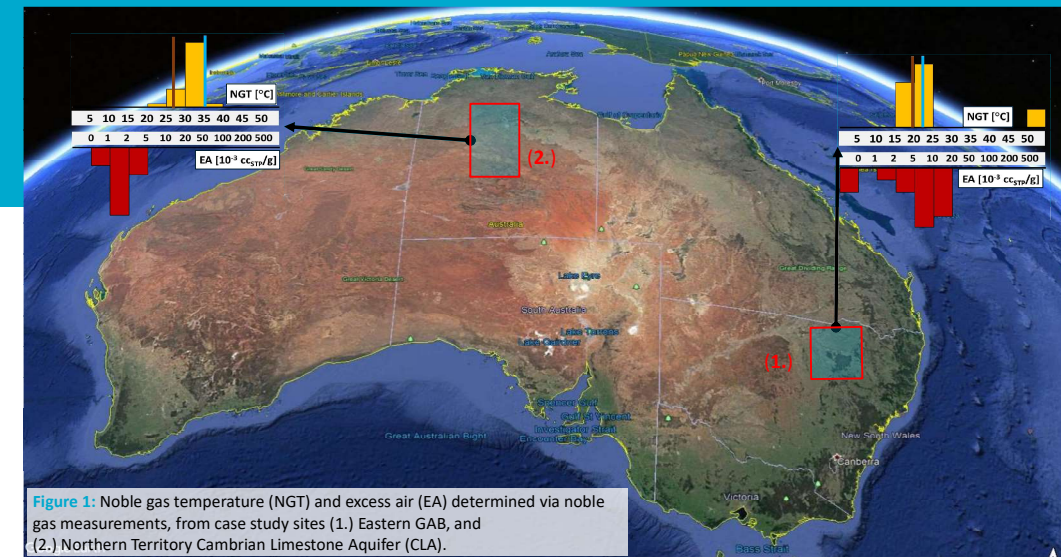


Figure 1: Noble gas temperature (NGT) and excess air (EA) determined via noble gas measurements, from case study sites (1.) Eastern GAB, and (2.) Northern Territory Cambrian Limestone Aquifer (CLA).

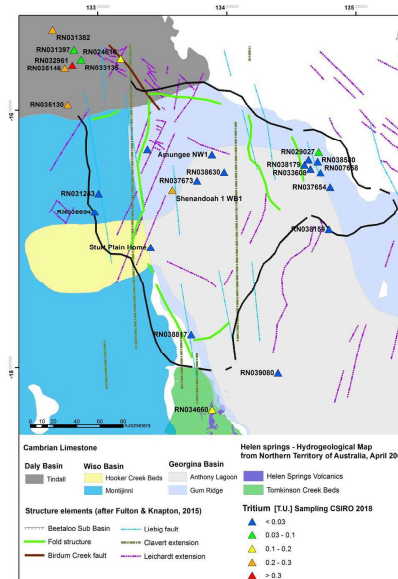


Figure 4: Map of ³H concentrations, uppermost limestone aquifer attribution and faults [3]

- ³H: variable across region, more modern in NW
- ³He/⁴He indicative of shallow-faulted fracture flow from below
- Noble gases (Fig. 1) show excess air is variable, and recharge temperatures are high (28-42°C)

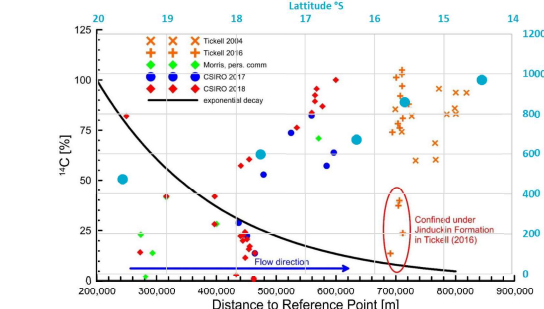


Figure 5: ¹⁴C along the flow path and (light blue) rainfall

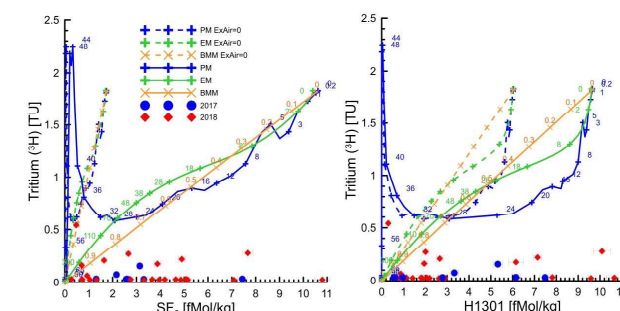


Figure 6: Modern gas tracers cross plots vs. ³H: (left) SF₆ and (right) Halon1310. (filled-dots) measured data, (lines) models indicating age

- ¹⁴C increases in the direction of hydraulic gradient, likely via addition of modern recharge (Fig. 5)
- Modern gases (SF₆, H1301, CFCs): many samples higher than equilibrium with air, excess air up to 25 cc/kg needed (Fig. 6)

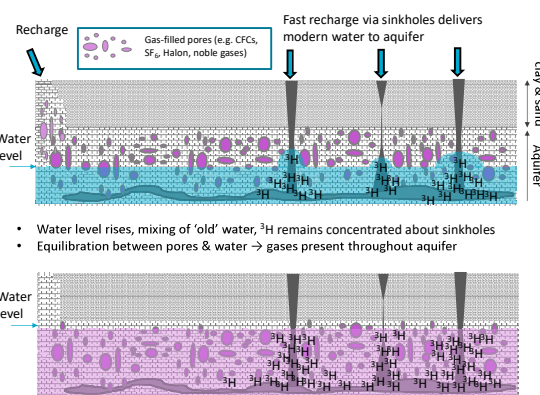


Figure 7: (top) sinkholes [4], (bottom) scheme for how sinkhole recharge affects modern tracer concentrations in groundwater

Present model: tracer results are dominated by fast recharge via sinkholes, providing ³H, large fluctuations of the groundwater table "pump" gas into the groundwater (Fig. 7).

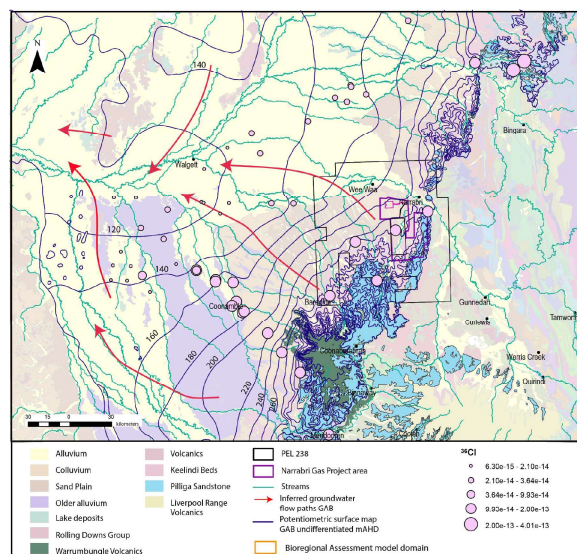


Figure 2: Hydraulic heads, flow lines and ³⁶Cl concentrations for sampled bores of the GAB study area

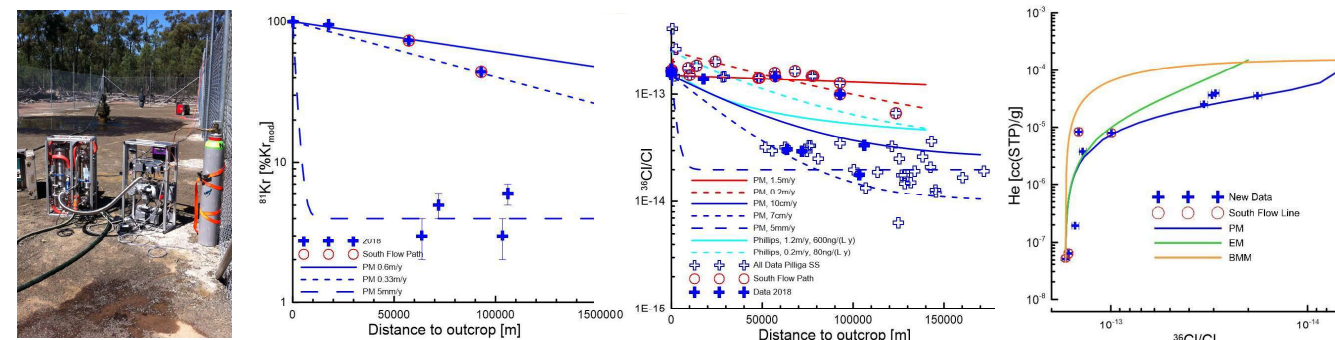


Figure 3: (left) CSIRO's portable field degassing unit used for ⁸¹Kr collection (right) tracer data and models [1] indicating groundwater flow velocities for ³⁶Cl/Cl, and ⁸¹Kr, and He

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FOR FURTHER INFORMATION
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[2] Smith, S.D. (2015) Geochemical baseline monitoring: quartz-helium trial. CSIRO
[3] Fulton, S., Knapp, A. (2015) Beetaloo Basin Hydrogeological Assessment. CloudGMS
[4] Picture credit: Sebastien Lamontagne, CSIRO