# Advances in understanding hydrogeochemistry in Australia

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## Introduction

Mineral exploration is becoming increasingly expensive in Western Australia and throughout the world. Exploration targets are becoming more difficult to find and greater emphasis is being placed on exploring through deep (>30 m) transported cover and into basinal terrains. Groundwater interacting with mineralised rocks creates a geochemical signature that may be much greater in size than that for the unweathered rocks. This can reduce the required sampling density, assisting cost effective exploration in covered terrains. Hydrogeochemical exploration can be conducted at a number of scales and for various commodities. It is considered that most value add is assisting prospectivity mapping (regional-scale) and/or testing for drilling targets (prospect scale). This science is also helping understand weathering and dispersion processes.

## Regional Scale Prospectivity

The NE Yilgarn regional hydrogeochemical mapping project (Figure 1) was a test of concept for broad scale hydrogeochemistry, with potential for lithological mapping, establishment of environmental background and mineral exploration in other areas, especially outside recognised mineralisation belts. This approach has since been extended further in WA, and also to SA and NSW. Hydrogeochemical studies also provide information on rock weathering, useful for enhancing exploration effectiveness in regolith-dominated terrains.

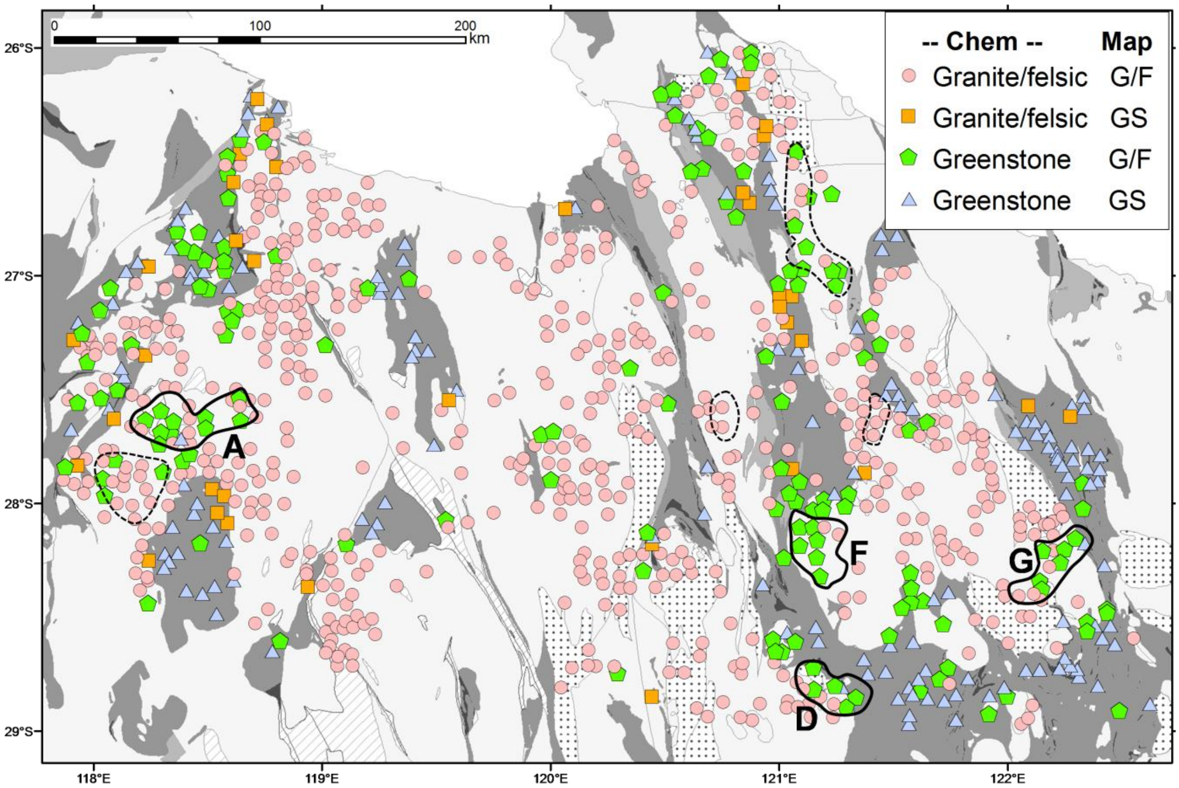

**Figure 1:** Lithological differentiation from GLM analyses of groundwater geochemistry for the NE Yilgarn Craton (using Rb, Cr, U, B, Ca, Cl, Sr, Ba, F, Mg, Co, HCO3, Br, V, Na). Dark areas are greenstone lithologies, light areas are granites.

Various lithological indicators were developed to map underlying rock through cover. Where there are discrepancies between groundwater results and previous geological mapping (e.g., the green pentagrams in Figure 1) there potential for previously unrecognised mineral exploration zones. Even in this highly explored region, new areas (now being actively explored) were identified in which prospective rocks are covered by granite or transported cover. Groundwater methods may also be applied in basin regions.

Regional sampling can also pick up large scale mineralisation systems. Use of chemical data to determine degree of groundwater saturation with respect to the secondary U mineral carnotite, particularly when combined with palaeodrainage mapping, may greatly improve exploration through cover where radiometric geophysics is not effective or available. Other indices, such as autinite saturation, may be useful in recognising primary sources. Combining Au, Ag and As data gives an index for delineation of major Au camps (Figure 2).

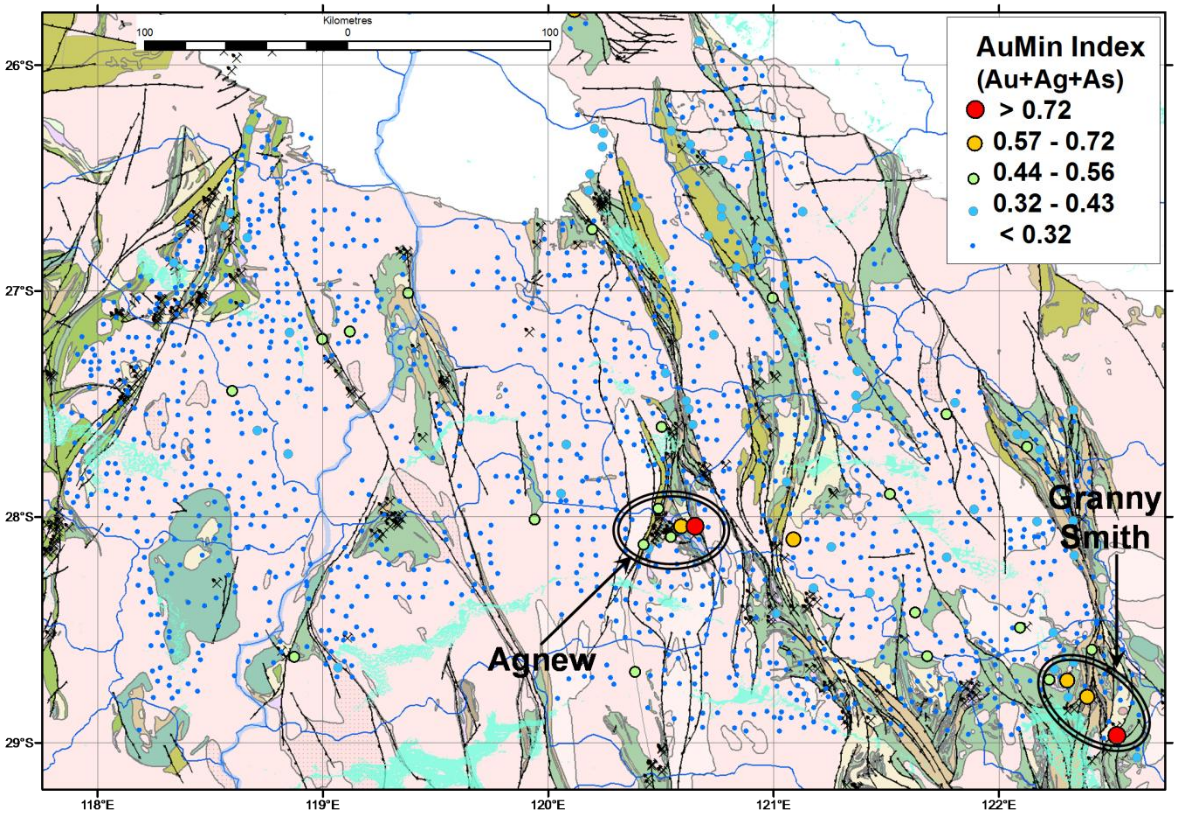

**Figure 2:** AuMin Groundwater Index for the NE Yilgarn Craton. Major anomalous areas indicate the Agnew and Granny Smith Mining Camps.

## Prospect Scale Exploration

Both U and Au can be also explored for at the prospect scale using hydrogeochemistry. For Au, other elements such as Mo, W and Rb may also be useful, in addition to Au, Ag, As. Both VHMS and Ni sulfide mineralisation is more effectively delineated at prospect scale, due to the small size of the mineral system signature.

Hydrogeochemical exploration for these sulfide-based commodities has been made more effective by understanding the complex weathering sequences in deep regolith. Initial sulfide alteration (e.g. pyrrhotite to pyrite), results in sulfate DEPLETION in groundwater,:

$$5FeS + SO_4^{2-} + 4H_2O \leftarrow\rightarrow 3FeS_2 + 2Fe(OH)_3 + 2OH-$$

In contrast, shallow oxidation of such secondary sulfides results in major sulfate enrichment, leading to groundwater sulfate depletion or enrichment, depending on depth (Figure 3). Plotting this sulfate anomalism delineates areas of sulfide-rich rocks. These sulfide weathering processes also release elements from the sulfides, and from the wall rocks due to the (generally transient) acid or alkaline conditions. Sulfide systems can be discriminated using newly-developed FeS (pH, Eh, Fe, Mn) and AcidS (Li, Mo, Ba, Al) indices, even when under more than 100 m of cover.

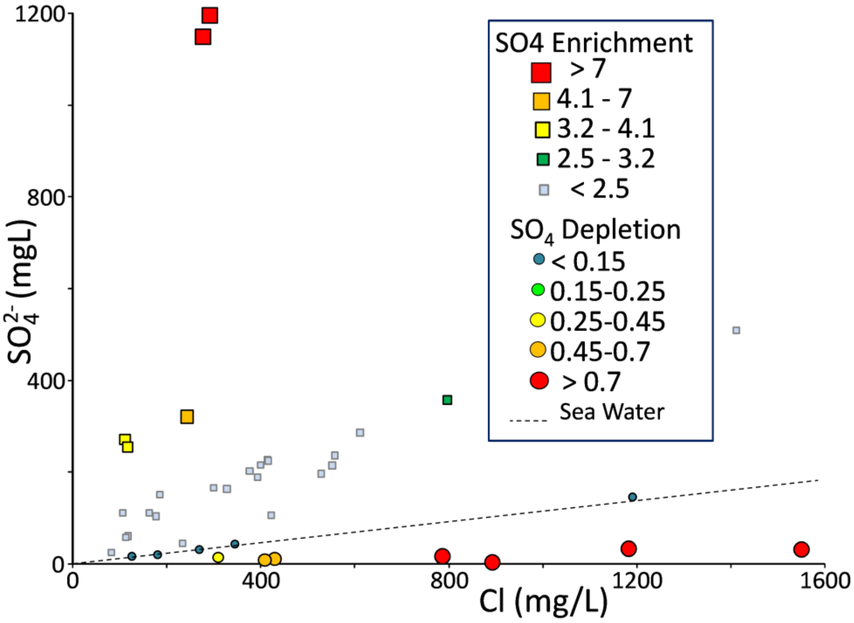

**Figure 3:** Groundwater sulfate vs chloride for Jaguar VHMS Mining Camp.

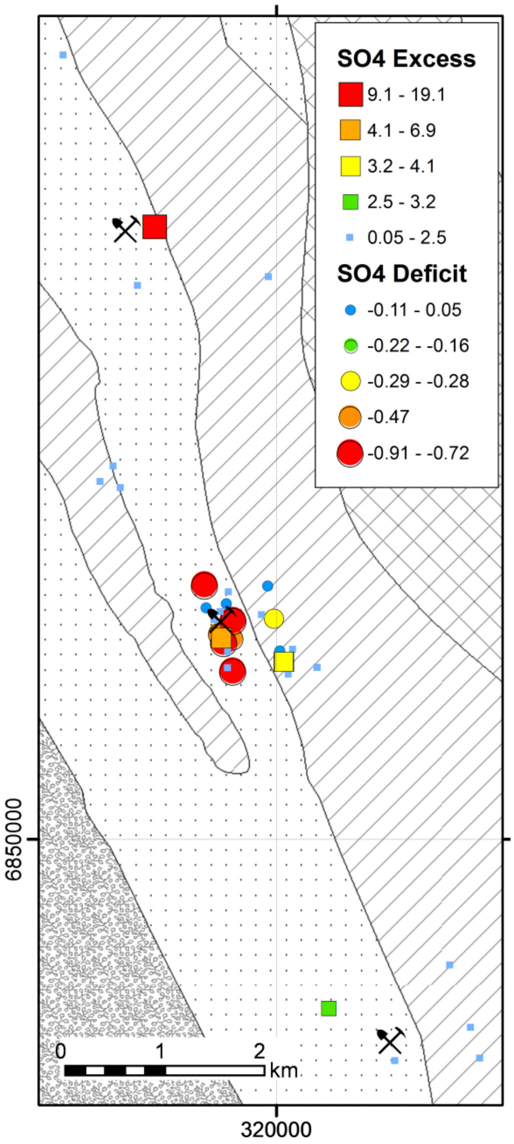

**Figure 4:** Groundwater sulfate excess or depletion (from Figure 3) for Jaguar VHMS Mining Camp.

Distinguishing VHMS and Ni sulfide systems from other non-economic sulfides is possible where there is little transported cover, using the relevant pathfinder metals, including Ni, Co, Zn, Pb and Cu. Delineation can be enhanced when groundwater saturation with respect to secondary minerals is used to partially "normalise" pH effects (Figure 5). The "patchiness" and limited areal extent of the dissolved metal signal is due to modification of the hydrogeochemical signal by adsorption effects that increase with depth, and become more problematic in areas of cover. Other elements such as Mn and Co show much lesser diminution effects, but these are much less selective indicators. There is also potential to utilise elements such as Pt or Ag for exploration.

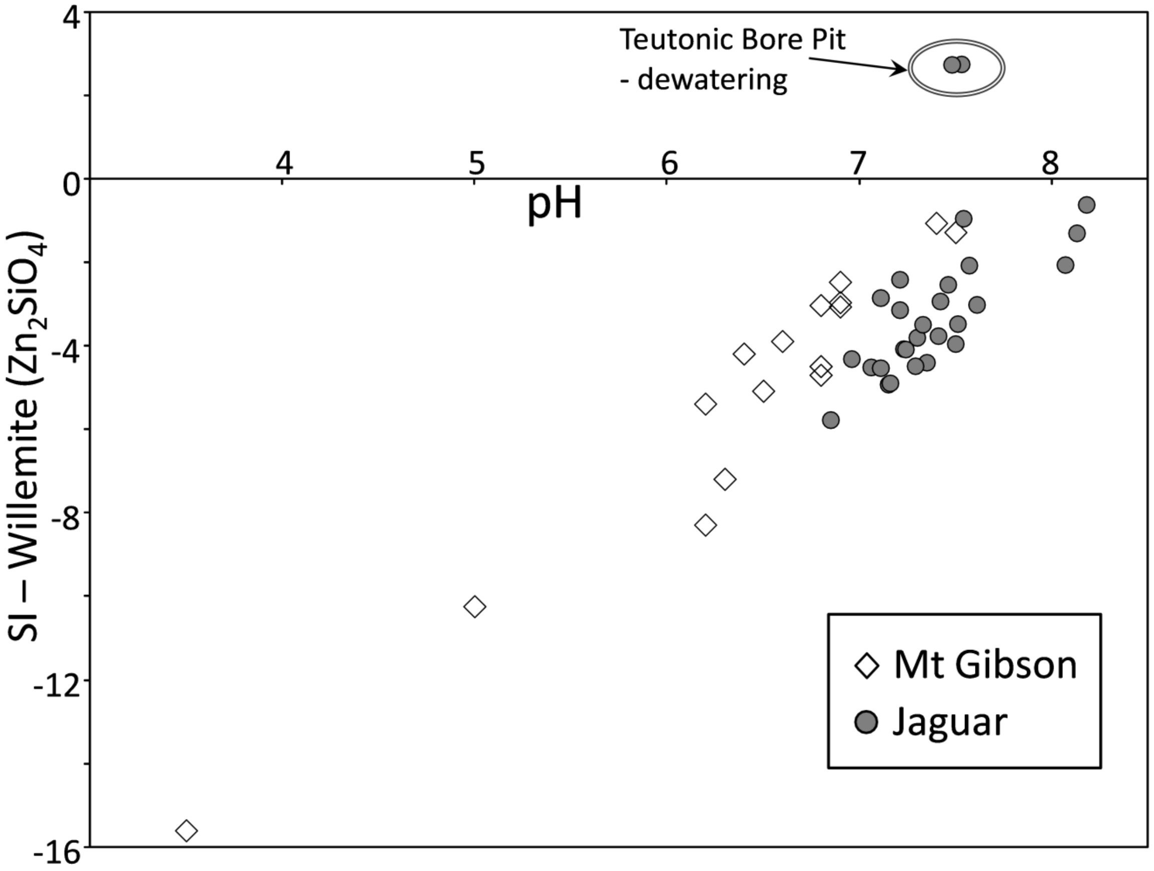

**Figure 5:** Groundwater saturation with respect to the secondary Zn mineral willemite for Jaguar and Mt Gibson VHMS camps, indicating saturation for ore body groundwaters, and oversaturation for pit waters.

## Conclusions

Hydrogeochemistry is being developed as an effective sample media, with consistent approaches to sampling, analysis and contamination testing. Outputs include:

- Lithological indicators separating greenstones from granites and mapping lithology through cover.
- Recognition of previously unrecognised zones for potential mineral exploration where interpretations from groundwater differ from previous geological mapping.
- Areas of sulfate enrichment related to varying geological areas and/or fault structures, indicating that these structures are still have active input into the surface environment.
- Anion excess and depletion methods have been developed and are a valuable, new application for detecting sulfides. This coupled with multi-element indices provides a solid platform for the use of hydrogeochemistry in exploration for sulfide systems.
- Various empirical and mineral saturation indices for Au, U, Ni sulfide and VHMS exploration

Overall, groundwater chemistry for samples collected from bores and wells provides a tool to enhance prospectivity and improve exploration success in areas of cover and difficult terrains.