Geological controls on the spatial variability of groundwater recharge and salinity in a regional-scale basalt aquifer in western Victoria

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Abstract

Airborne geophysical images have been used in combination with analyses of inert and reactive tracers in groundwaters to study the impact of aquifer lithology on the distribution of preferential recharge areas and recharge rates in a regional scale basalt aquifer in the eastern Hopkins catchment, western Victoria. Groundwater quality within this aquifer ranges from fresh water suitable for human consumption to saline brines. The results of the study show that the freshest groundwaters are generally found in close proximity to volcanoes, and that these groundwaters are mostly modern as a result of preferential recharge through the younger basalts and major eruption points (recharge rates up to about 50 mm/year). Recharge rates decrease to less than 1 mm/year through the thick clay-rich soil profiles of the older basalts, and groundwaters in these aquifers are therefore older and more saline.

1. INTRODUCTION

Poor groundwater quality and declining groundwater tables are common problems across most parts of western Victoria, reducing agricultural productivity and posing serious challenges to many communities. In the eastern Hopkins Catchment (Figure 1), this problem is particularly severe due to the current prolonged drought, and the demand for good quality groundwater has increased substantially. Furthermore, this catchment has been classified as high priority for further investigation into the causes and possible remediation of groundwater salinisation (Anderson, 2002).

In order to avoid aquifer over-exploitation and to manage the scarce water resource in a sustainable way, it is important to understand the principal factors controlling groundwater hydraulics and hydrogechemistry. In particular, it is necessary to delineate the major recharge areas and quantify recharge across the basalt plains; in the present study an array of methods has been applied to this problem, including remote sensing, hydraulic methods, groundwater dating, soil mapping and soil analysis.

2 GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The plains of the eastern Hopkins Catchment are composed of basalt flows of the Newer Volcanics, and can be differentiated into three broad age groups (<1 Ma, 2-3 Ma and 4-~8 Ma) based on radiometric age determinations, here called the first, second and third phase basalts. The first phase basalts were erupted as sheet-like flows 2 -10 m thick, and built up to great thicknesses in some locations, levelling out topographic irregularities in the deeply-weathered basement and overlying Tertiary sediments. The surfaces of the first phase basalts are usually deeply weathered, with thick pisolitic soil and mottled clay developed to depths of up to 10 m. The formation of these thick soil profiles occurred under a wet and possibly warmer climate during the Late Miocene (Joyce 2003).

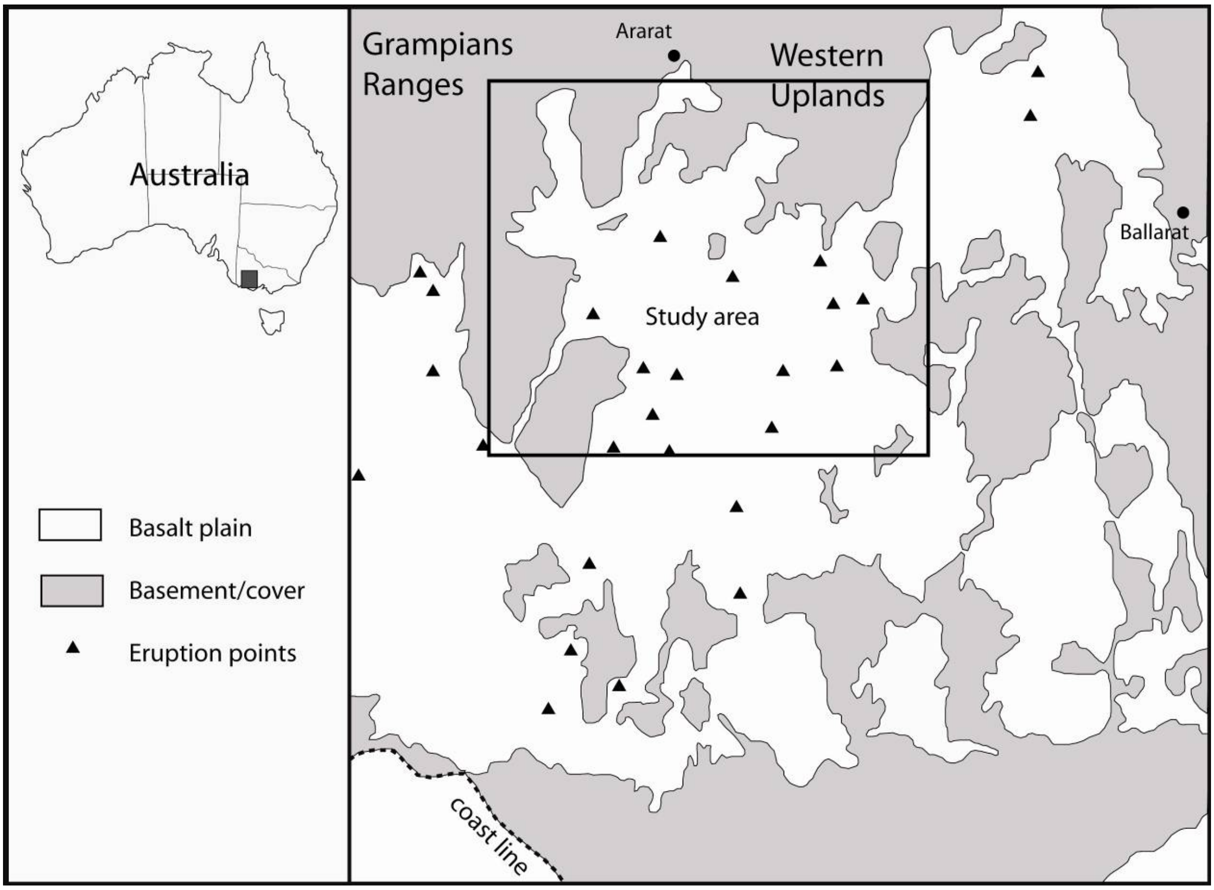

Figure 1 Location of study area

In contrast, the second phase basalts are commonly less weathered and are associated with soil profiles up to 3 m thick, and the youngest basalt flows (third phase), locally known as stony rises, have very thin soils. The third phase basalts generally have well preserved flow features with an irregular relief of up to 10 m consisting of pressure ridges, lava levees and hummocks separated by topographic depressions. Open polygonal joints radiate from the centre of the hummocks and gas escape tubes and blocky flow textures are also common features.

Most potable and stock water in the eastern Hopkins Catchment is sourced from the Newer Volcanic basalts, which form the surficial aquifer in this area. The variability of groundwater quality within the extensive basalt aquifer is substantial, ranging from water suitable for human consumption in the vicinity of eruption points to saline brines elsewhere.

2.1 Using Airborne Geophysical Mapping to Delineate Preferential Recharge Areas

Mapping the distribution of the different basalt phases and their associated soils is a very important step towards the delineation of the major recharge areas, and airborne radiometric images are a particularly useful aid in this regard. Airborne radiometric surveys record the gamma rays emitted from the natural decay of K, U and Th in the near-surface (uppermost 35 cm) soil/solid rock (Pain & Minty, 2005). Correlation of geological mapping of the basalts in the Newer Volcanic Province with the airborne radiometrics shows that high K signals (red in tertiary radiometric images) are typically associated with the 3rd phase basalts, whereas the older 1st and 2nd phase basalts commonly have high U (blue) or Th (green) signatures (Joyce, 2003). On this basis, the distribution of the different basalt phases in the eastern Hopkins Catchment was mapped, and verified by radiometric age determinations (Figure 2).

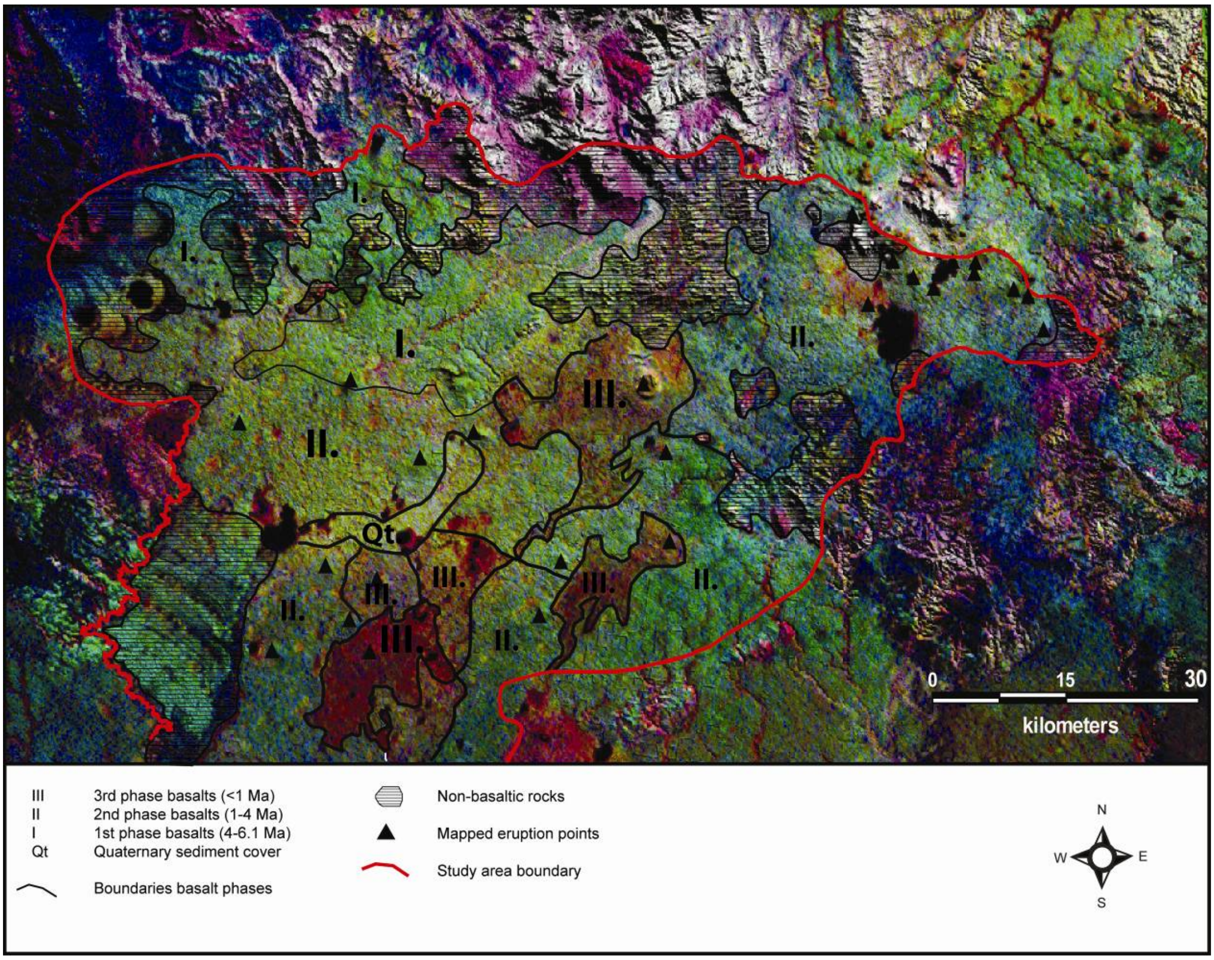

Figure 2 Ternary radiometric image (K = red, Th = green, U = blue) draped over a digital elevation model to map major recharge areas (data courtesy of Geoscience Victoria).

2.2 Environmental Isotopes and Groundwater Geochemistry as Indicators of Recharge

Groundwater quality in the study area is variable, ranging from very good groundwater in compliance with drinking water guidelines to saline brines. A map showing the groundwater salinity distribution (Figure 3) indicates that the location of the freshest groundwaters generally correlates well with the areas mapped as 3rd phase basalts using the airborne radiometrics (Figure 2).

In addition to major ion geochemistry, environmental isotopes were used as reactive tracers to study groundwater dynamics, in particular tritium (half-life 12.43 years) and ^{14}C (half life 5730 years). Shallow groundwaters in close proximity to eruption points contain a substantial amount of tritium and are therefore modern (<50 years old; Figure 3). Tritium activities of other groundwaters throughout the basalt aquifer are beyond the detection limit, suggesting that recharge across these areas occurred more than 50 years ago.

Radiocarbon groundwater ages show a similar pattern. Basalt groundwaters in close proximity to major eruption points such as Stockyard Hill/Black Lake or Mt. Fyans are comparatively young (Figure 3). Throughout the remainder of the basalt aquifer, groundwaters are generally old, with the oldest groundwater giving an age of more than 22000 yrs BP.

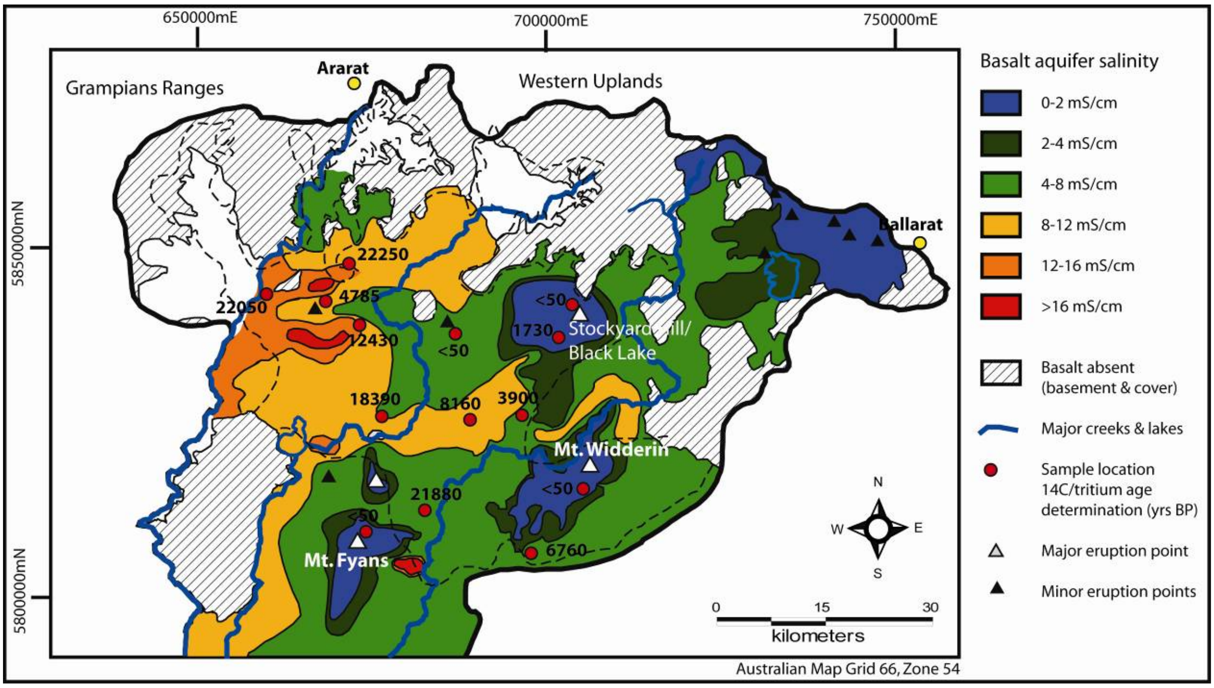

Figure 3 Groundwater salinity and age distribution within the basalt aquifer.

The salinity and age distribution of the basalt groundwaters indicates that these are predominantly recharged through the eruption points and third phase basalts, which are relatively young and characterized by thin soils and rocky outcrops. Where rainwater infiltrates through the thick soils of the first or second phase basalts, it remains in the unsaturated zone for a long time and recharge is diffuse and slow. As a consequence, dissolved solids accumulate due to evapotranspiration, and the groundwater recharged in these areas is more saline than in the vicinity of eruption points and third phase basalts.

2.3 Recharge Estimations

Accurate estimation of the rate of replenishment of an aquifer forms an important part of the water resource evaluation. Over recent decades a multitude of methods has been developed to estimate groundwater recharge rates (Scanlon *et al.* 2002). In this study the saturated zone chloride mass-balance approach has been applied; while this method has some limitations due to the uncertainties involved in the estimation of precipitation rates and the chloride concentration of the precipitation at the time of recharge, it nevertheless provides valuable point estimates of recharge rates (Scanlon *et al.* 2002). This point source information can then be integrated to derive the spatial distribution of recharge on the catchment scale.

Saturated zone chloride mass-balance analysis for numerous locations across the study area show that annual recharge rates range from <1 mm (<0.2% of annual rainfall) for areas composed of 1st or 2nd basalt phases to ~50 mm (~7% of annual rainfall) within third phase basalts in the vicinity of the youngest eruption points (Figure 4). This can be attributed to the distinct soil properties of the different basalt phases and is in good agreement with the interpretation of the airborne geophysical images and the isotopic analysis. While slow and diffuse recharge through the thick clay rich soil profiles yields old groundwater ages, the abundant fractures of the 3rd phase basalts form preferential pathways for infiltrating rainwater, resulting in a rapid replenishment of the aquifer with modern groundwaters in these areas.

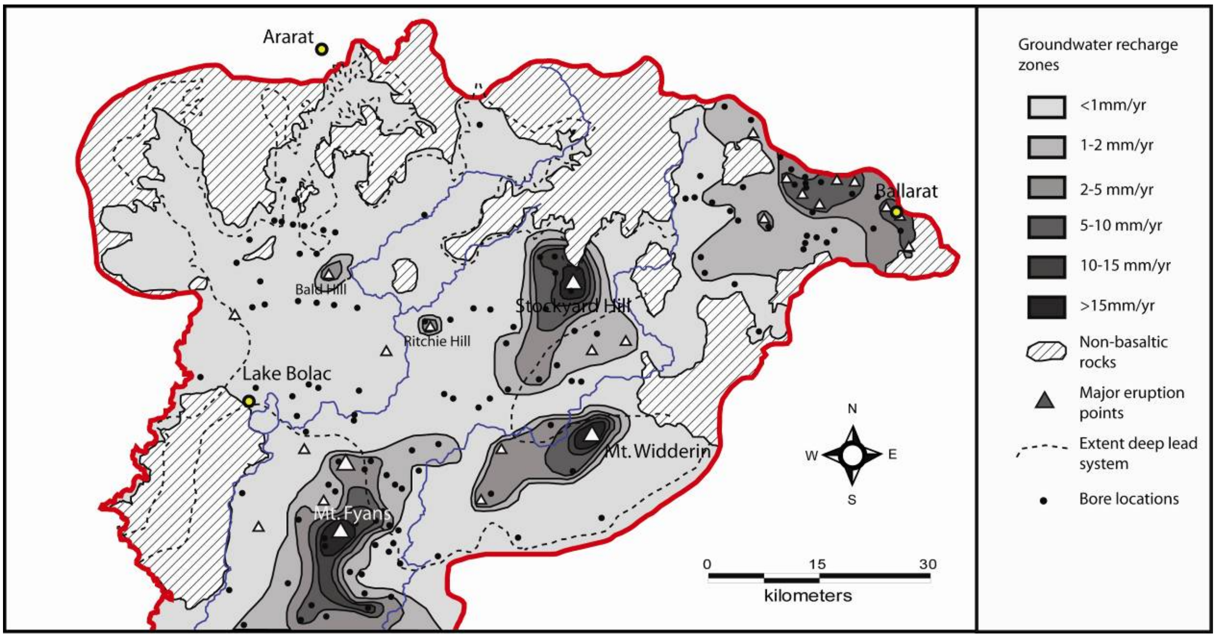

Figure 4 Map of estimated recharge distribution within the basalt aquifer based on the saturated zone mass-balance approach.

3. CONCLUSIONS

A multi-disciplinary approach combining airborne geophysics and tracer techniques has been applied to identify preferential recharge areas and estimate recharge rates across a large catchment in western Victoria, Australia. Groundwater ages obtained using tritium and ^{14}C show that groundwaters recharged through the youngest basalt phase are mostly modern, whereas the basalt groundwaters throughout the remainder of the basalt plain are generally old and clearly more saline.

The results of this study indicate that the distribution of the different basalt phases and their associated soils is the major factor controlling groundwater quality. In the vicinity of eruption points, where highly fractured rocky outcrops with thin soil cover are common, rapid recharge through preferential pathways results in low residence times in the unsaturated zone and hence, fresh and often modern groundwaters. By contrast, long residence times in the thick clay-rich soil profiles of the older basalt phases throughout the remaining plain result in old groundwater ages and the concentration of dissolved solids over time.

4. ACKNOWLEDGMENTS

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