DISTRIBUTION OF PLIO-PLEISTOCENE BASALTS AND REGOLITH AROUND HAMILTON, WESTERN VICTORIA, AND THEIR RELATIONSHIP TO GROUNDWATER RECHARGE AND DISCHARGE

Darren A. Bennetts, John A. Webb & Chris M. Gray

Department of Earth Science, La Trobe University, VIC 3086

INTRODUCTION

Salinity is an inherent characteristic of the Newer Volcanics Basalt Plains of western Victoria, largely due to the disrupted surface drainage with many swamps and lakes, and high annual exceedence of evaporation over rainfall. The Basalt Plains within the Glenelg-Hopkins regional catchment area contain 10,700 ha of salinity-affected land (Munro 2000), but the controls on this salinity distribution are poorly understood. This study relates the location of groundwater recharge and discharge areas to the distribution of basalts in the Hamilton region, where 3 separate phases of volcanic activity can be identified.

GEOLOGICAL SETTING

The Newer Volcanics Province of western Victoria, Australia, is an extensive plain of Late Tertiary to Quaternary basalt lavas, tholeitic to transitional in composition, and containing some 400 eruption points (Abele *et al.* 1988). The study area covers 4600 km^2 of the basalt plains around Hamilton, and is bordered by the Mt Stavely Block to the east and the Dundas Tableland to the west. The basalts here overlie Palaeozoic basement in the north, and Tertiary sediments of the Otway Basin to the south.

METHODOLOGY

Early soil and landform mapping using aerial photography and field surveys, and later with radiometric imagery, identified three distinct phases of volcanic activity within the Plio-Pleistocene Newer Volcanics in the Hamilton region (~4 Ma, ~2 Ma and <0.5 Ma), each with distinctive regolith characteristics (Gibbons & Gill 1964, Mann 1992, Martin & Mayer 1987, Ollier & Joyce 1986). There is a strong correlation between thickness and extent of basalt weathering profiles and their age; the earliest of the basalts have thick, often kaolinitic, regolith profiles, whilst the youngest, stony-rise basalts, have thin, very rocky soils.

The present study used detailed airborne radiometric imagery (individual channel, ternary and total count imagery processed and compiled by the Geological Survey of Victoria) together with the digital elevation model (DEM; 100 m grid cell derived from 1:25,000 scale topographic contours and spot heights, supplied by the Centre for Land Protection Research, DPI Victoria), to map the extent of the three basalt phases in more detail than previously, including differentiating individual flows and eruption points. The use of airborne radiometric imagery for the mapping of *in situ* regolith proved problematic where Quaternary sediments obscured the underlying response, because the method only records the gamma radiation emitted from K, U and Th decay in the top 30 cm of the surface material (Dickson & Scott 1997). For example, basalts in the Condah/Branxholme region are overlain by a 20-60 cm thick quartz sand horizon, so differentiation of individual basalt flows is not possible using radiometrics. The calcareous aeolian Widgelli Clay also overlies the basalt plains around Hamilton (Ollier & Joyce 1986), however it is thin enough that the differing radiometric signatures of the three basalt phases are still evident. The radiometric response may vary within a single basalt flow, e.g., with increasing thickness of regolith away from eruption points, where soils are generally much thinner (a typical catena profile).

The radiometric mapping was then overlain on isotopic domains identified using an extensive suite of $^{87}Sr/^{86}Sr$ analyses from the basalts of the area (Price *et al.* 1997, Gray unpublished data). The Sr isotope signature of basalt is a powerful diagnostic tracer, particularly when combined with geochemical and geochronological data, for differentiating individual basalt flows or genetically related basalt flows, although the average $^{87}Sr/^{86}Sr$ ratio of the three different basalt phases at Hamilton is similar. Sr isotopes have been previously studied in other areas of the Newer Volcanics (Joyce *et al.* 1989, Price *et al.* 1997).

FIRST PHASE BASALTS (Qv_1)

The first major period of extrusion occurred in the Early Pliocene, at ~4 Ma (Figure 1). A 4.47 Ma basalt directly overlies Late Miocene sediments 5.5 km west of Hamilton, and probably represents the earliest of these eruptions (Turnbull *et al.* 1965, revised using updated decay constants) whilst an overlying flow at Mt Pierrepoint, 15 km east of Hamilton, is 4.0 Ma old (revised age from McDougall *et al.* 1966). This suite of basalts infilled pre-existing palaeovalleys and then deposited sheet-like flows over a planar surface. Intensive weathering has since formed a gently undulating plain, which south of Branxholme is strongly incised by drainage lines associated with the Condah Swamp and Crawford River, forming resistant plateaus. Several different basalt flows are present south of Hamilton according to the ^{87}Sr/^{86}Sr data, but these cannot be differentiated topographically or radiometrically owing to the intensive weathering, incision, and cover of sandy top-soils.

The prominent hills of Mt Bainbridge and Mt Pierrepoint represent eruption points; at least two individual flows from each can be identified (Figure 1). To the north in the Moutajup area, another eruption point is surrounded by a younger second phase lava field, as is Gazette Hill, which forms a prominent topographic high between Mt Rouse and Mt Napier.

The intensive weathering of the first phase basalts is reflected in the deeply weathered and ferruginised regolith profiles, typically up to 15 m thick, which have been mapped as the Hamilton regolith terrain (Ollier & Joyce 1986) or the Hamilton-Branxholme Land System (Gibbons & Gill 1964). *In situ* profiles typically consist of a friable reddish-brown clay loam A_1 horizon, 30-40 cm in thickness, underlain by a light brown A_2 horizon 15-20 cm thick, with abundant sub-angular to angular pisoliths (60-80%), increasing in concentration with depth. The B_1 horizon comprises 50-60 cm of yellow-red clay, with a smooth transition into a kaolinitic clay B_2 horizon (saprolite), which has prominent yellow-red mottles ("tiger mottles"). This kaolinitic saprolite varies in thickness from 10 to 15 m, with a saprock zone toward the base. Bore logs indicate that the weathering front may extend downwards for up to 20 m (Mann *et al.* 1992). Profiles typically thin toward hilltops; on Mt Bainbridge the A_1 horizon is 10cm thick and A_2 horizon <40 cm thick, directly overlying saprock (B horizon is absent). Sandy clay soils replace the typical A and B horizons in the Branxholme/Condah region, and are readily identifiable in radiometric imagery as a series of near zero response curvilinear bands, owing to the quartz sand in the profile.

The first phase basalts on the plains generally have a very uniform low K and U and high Th response in radiometric imagery. Eruption points such as Mt Bainbridge and Mt Pierrepoint are readily identified by a relatively high K response, appearing red in ternary radiometric images. K within the basalts is probably largely contained in volcanic glass, and is quickly lost during weathering (Price *et al.* 1991), so fresh basalt has a higher K response than weathered material. The high K response of the eruption points reflects the shallow soils and occasional rocky outcrop, completely absent in the adjacent plains. The high Th content of the thick regolith of the plains basalts is probably due to the concentration of trace elements, including Th, in clay minerals and iron oxides and hydroxides during weathering (Dickson & Scott 1997, Price *et al.* 1991).

The first phase basalts can be traced in the subsurface using bore logs over most of the study area, except in the far north. These basalts are more strongly jointed and fractured than the overlying second phase basalts and give a higher downhole neutron log response, reflecting their greater porosity (Mann *et al.* 1992).

SECOND PHASE BASALTS (Qv_2)

The second major phase of volcanic activity occurred around 2 Ma, which marks the volumetric peak of extrusion for the Newer Volcanics Province (Price *et al.* 1997). Six new K-Ar dates on second phase basalts have been obtained in the study area (Gray unpublished data), ranging from 2.23 ±0.03 Ma (north of Cavendish) to 1.8 ± 0.03 Ma for a long flow (25-30 km) associated with the Lake Repose eruption point south of Dunkeld, with other dates of 1.88 ± 0.08 Ma (north-south flow in the Caramut region), 2.07 ± 0.01 Ma and 1.95 ± 0.02 Ma (east and north of Mt Rouse respectively; Figure 1).

The second phase basalts occupy the northern and eastern segments of the field area as a broad, gently undulating plain (Figure 1). Rocky outcrops and breakaways are typically associated with the edges of flows, allowing most flows to be recognised by their topographic expression. Lake Repose is a major eruption point in the east, with its crater now occupied by the lake; numerous flows radiate from this source. Basalts from Lake Repose and other eruption points in the Hamilton region (both first and second phase) generally flow towards a low-lying area extending south from Victoria Valley to Lake Linlithgow (Figure 1); this corresponds to a graben identified using drill hole data (Paine *et al.* in press). Mapping around Lake Linlithgow indicates that the lake sits on first phase basalts, and is constrained by surrounding second phase lavas. Lake Kennedy lies between first phase flows from Mt Pierrepoint to the west and second phase basalts to the east. In the Moutajup region second phase basalts have infilled the swales of Pliocene strandlines, which are exposed through the lava field, now appearing as low K, U and Th curvilinear anomalies in radiometric imagery.

Regolith profiles developed on the second phase basalts are markedly different from those on the first phase basalts, with the absence of intensive ferruginisation and kaolinitic saprolite, and have previously been mapped as the Dunkeld and Strathkellar Land-System and Dunkeld regolith province (Gibbons & Gill 1964, Ollier & Joyce 1986). Soil profiles typically comprise a brown silty loam A_1 (0-20 cm), underlain by a brown clay loam A_2 containing abundant pisoliths (50-60%). There is a sharp transition to a yellow clay B horizon that varies in thickness from 1 to 2 m and overlies weathered basalt saprock. Unweathered basalt is typically found at 5-10 m. The profile is also characterised by “floaters” or sub-angular to sub-rounded corestones exhibiting onionskin weathering.

Second phase basalts show a low to moderate Th, low U and moderate K radiometric response. They are marked in ternary imagery by a blue-green colour with red specks; the latter probably represent the abundant corestones in the profile giving a high K response. Eruption points also appear as K highs. The radiometric response may vary considerably within an individual basalt flow; the most variable signals are evident on the edges of the flows, probably due to the presence of rocky outcrop.

THIRD PHASE BASALTS (Qv_3)

The third phase lavas were erupted from Mt Rouse (367 m AHD), Mt Eccles (177 m AHD) and Mt Napier (440 m AHD), which all rise well above the surrounding plain, Mt Napier being the highest volcano within the Newer Volcanics Province (Rosengren 1994). The surrounding lava aprons and valley filling flows (e.g., Harman Valley and Moyne River) are characterised by a very irregular ground surface covered by angular basalt blocks. Mt Rouse lavas are the oldest, with ages ranging from 0.31 Ma to 0.45 Ma (McDougall & Gill 1975), verified by dates of 0.33 ± 0.02 Ma and 0.34 ± 0.01 Ma obtained from the Moyne River flow during this study. A reported date of 1.8 Ma from the base of Mt Rouse (Ollier 1985) is probably from the surrounding 2 Ma lava field, as the more youthful regolith at Mt Rouse strongly contrasts with that on the surrounding ~2 Ma lavas. Mt Eccles and Mt Napier are younger than Mt Rouse, both with dates of ~30,000 yr BP (Head *et al.* 1991, Stone *et al.* 1997).

The youthfulness of the third phase flows is reflected in their high K signature, which appears red in ternary radiometric imagery, making the flows easy to trace down pre-existing river valleys to the coast (Figure 1). Mt Rouse has a slightly lower K signature than Mt Napier and Mt Eccles owing to its greater age. Regolith development on Mt Napier and Mt Eccles is restricted to red-brown loam soil between adjacent angular, closely packed boulders. Primary volcanic features, such as tumuli, lava caves, spatter ramparts, cinder cones and lateral barriers, are well preserved (Whitehead 1991). Regolith development is greater at Mt Rouse, with red-brown loam up to 60 cm in thickness between rounded to sub-rounded corestones with onion skin weathering. Black clays and peaty soils in depressions and swamps may be up to 1.5 m thick.

Individual third phase basalt flows cannot be easily distinguished using radiometric imagery, but previous detailed field mapping, petrographic and geochemical studies identified at least 4 individual flows at Mt Rouse, 3 at Mt Napier and 10 at Mt Eccles (Rosengren 1994, Whitehead 1991).

The Plio-Pleistocene basalts of the Hamilton area exert a strong control on the hydrogeology. Areas of thin soils and rocky outcrops (third phase basalts and eruption points on all terrains) are strongly correlated with high quality groundwaters (< 2 mS/cm; Figures 1 and 2). The area underlain by low salinity groundwater associated with these recharge sites also increases with increasing permeability and area of outcrop, e.g., third phase basalts are the most permeable across much of their surface and hence have the largest area of high quality water associated with them (Figure 2). Third phase basalts and major eruption points of all ages allow rapid infiltration of meteoric waters through joints and fractures to recharge the basalt aquifers, leaving little time for evapotranspiration to occur which would otherwise increase the salinity of the groundwaters. In contrast, waters seeping through thick clay soils, such as those on the first and second phase plains basalts, infiltrate slowly and hence are strongly affected by evapotranspiration, becoming saline. Relatively fresh groundwaters flowing away from the recharge areas of the volcanoes beneath the adjacent basalt plains gradually increase in salinity, as saline water infiltrating through the overlying thick clay soils is progressively added. Mapping of eruption points is thus very important in identifying groundwater recharge areas and related potential groundwater resources, as well as defining areas susceptible to groundwater contamination given the rapidity of recharge.

The distribution of basalt flows also plays a major role in governing the location of groundwater discharge sites (Figure 3). Most discharge occurs where the watertable is exposed at the break of slope along the edge of basalt flows, or along incised drainage lines. Mapping of basalt flow boundaries is therefore useful for identification of areas of present and future groundwater discharge and salinisation, because any increase in the number and area of discharge sites will largely be confined to the flow margins. In addition, this mapping can be further used to understand the processes of salinisation and prioritise areas for remediation.

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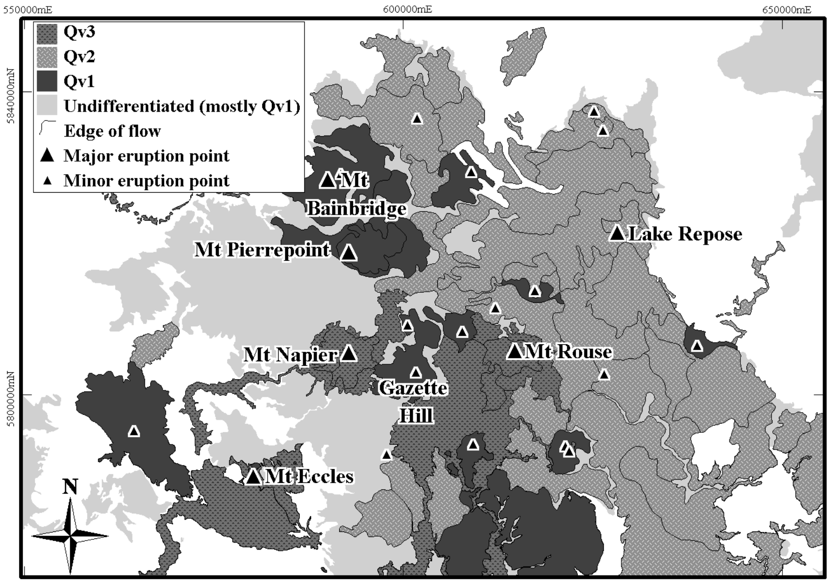

Figure 1. Mapped basalt flows and eruption points, western Victoria. Mt Napier and Mt Rouse flows are from Whitehead (1991). Non-basaltic rocks >4Ma shown in white in all figures.

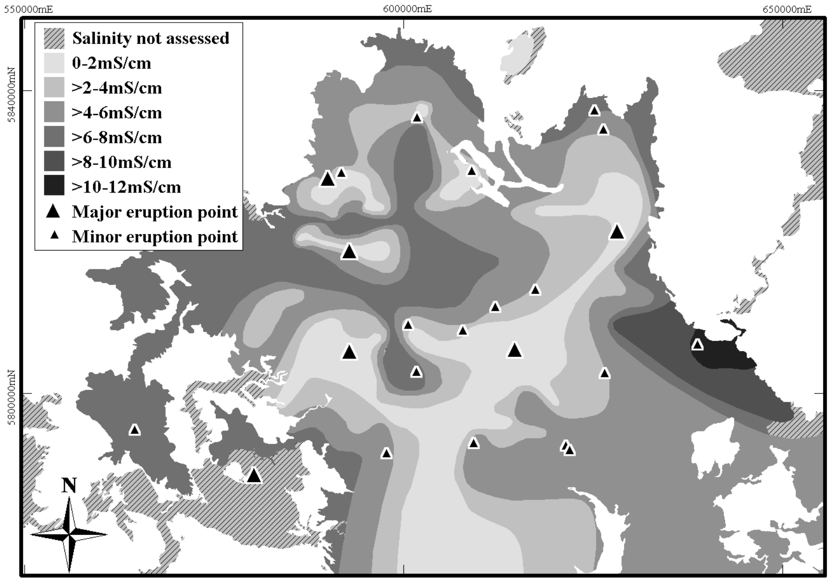

Figure 2. Comparison of eruption points with groundwater salinity distribution for basalt aquifer.

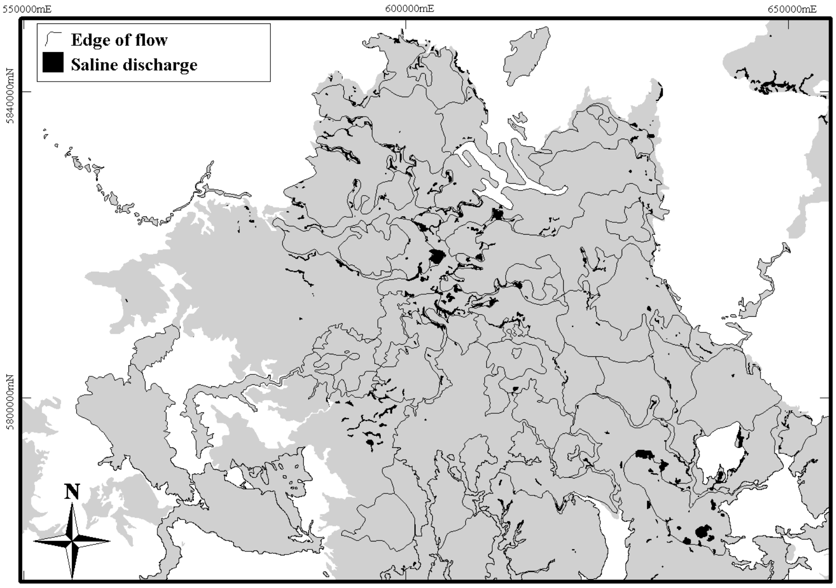

Figure 3. Comparison of basalt flows with occurrence of saline discharge areas (Munro, 2000).