Geochemical constraints on tectonic models and the importance of lithochemical data in exploration

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ABSTRACT

When coupled with careful geological mapping and petrographic studies, major and trace element geochemical studies of metavolcanic rocks offer a versatile and powerful adjunct to regional mapping and exploration programs. This paper focuses on several western Tasmanian examples of the application of geochemical studies in mapping and exploration, and emphasises that different element 'analytical' packages serve different purposes, and should be tailored for the task at hand. All such applications of geochemical data are exercises in comparative geochemistry, and thus require large and representative databases of reliable, quality analyses to be useful.

INTRODUCTION

Most of the volcanic rocks in foldbelts are degraded to varying degrees by low-grade regional (burial) metamorphism. Element mobility during such alteration is demonstrable for the alkalis and CaO and related trace elements (Ba, Rb, Sr), but a large suite of elements, including the so-called high-field strength elements (Ti, Zr, Y, Nb, Hf, Ta, Th), the transition metals (Ni, Cr, V), and Sc, have been shown to be essentially immobile in most alteration systems. These elements are most useful in trying to decipher the tectonic setting of the metavolcanic rocks in a particular region, but are also of use in determining the protolith (e.g. andesitic or felsic?) of highly-altered lavas. Of particular value are the rare earth elements (REE), both for purposes of identification of magmatic lineages or tectonic settings of eruption, and for local correlation of mappable units.

I suggest that major element analyses are useful for all applications of whole-rock geochemical data, whether for alteration studies (e.g. Na depletion around VHMS deposits), identification of discrete geochemical (magmatic) units to aid in mapping programs, or more broad tectonic interpretations. Whole-rock major element analysis, normally performed by XRF techniques, should be complemented by trace element data packages designed specifically for particular purposes. If tectonic discrimination is involved, the analysis for Ti, Zr, Th, Hf, Cr and REE is recommended for most metavolcanic rock suites. I have found that levels of Nb and Ta in 'arc-type' suites of basalt-andesite-dacite-rhyolite are too low to be useful, and that Y values are too variable and dispersed to be of any value. The REE, Hf, Th and Cr are all easily analysed for by instrumental neutron activation analysis as a single package, whereas the useful Zr, Ti (and Nb, Y, V and Sc) are best analysed for by XRF. As analytical methods are improved using ICP-MS, a large range of elements may be available from a single aliquot of dissolved sample, although for Zr and Cr, for example, accurate determinations of ppm abundances will depend critically on the total dissolution of the sample, including relatively insoluble zircon and chromite.

We have assembled a large database of compositional data for Cambrian metavolcanic rocks in western Tasmania, including those from the Crimson Creek Formation and correlated basalts, the lava carapace of the so-called 'ophiolites', and for the complex and important Mount Read Volcanics. Successful application of geochemical data towards interpreting each of these suites are described below.

CRIMSON CREEK FORMATION AND CORRELATES

Comparisons with modern rift tholeiite suites have shown clearly that the Crimson Creek Formation basalts in the Dundas Trough, and correlates on Macquarie Harbour (Double Cove area), in the Smithton Basin, in the Dial Range region (Motton Spilite), and elsewhere (O'Connors Peak for example) are Late Proterozoic or Early Cambrian rift tholeiites. Moreover, detailed transects of the ~1 km-thick basalt pile at Double Cove have shown that the uppermost 100 m of lavas here have refractory compositions with distinctive low TiO_2 (<0.6%) contents and strong light REE depletion. Such magmas are referred to as second-stage melts, as they are generated via partial melting of very depleted mantle peridotite from which (the underlying) tholeiitic basalts had been previously extracted; they would normally be expected to be at the top of the lava pile, as they effectively represent the 'last gasp' of magmatism in an evolving rift setting.

Similar refractory compositions have been documented among the Crimson Creek Formation correlates at Grassy on King Island, and as dykes in the Smithton Basin. Such differences in the compositional spectrum of these basalts offer the possibility of testing 'younging directions' in a basalt pile where other evidence may be unavailable. This may be of particular value in the Dial Range region, were early geological mapping had difficulty in determining

CRAWFORD, A. J. 1992. Geochemical constraints on tectonic models and the importance of lithochemical data in exploration. *Bull. geol. Surv. Tasm.* 70:56–57.

relative age relationships between the Barrington Chert and the Motton Spilite.

THE MAFIC–ULTRAMAFIC COMPLEXES

Petrological-geochemical studies of the lava carapace of the western Tasmanian 'ophiolites' have demonstrated that these rocks are not typical oceanic crust at all, but are more typical of the crustal section of the forearc of an intra-oceanic island arc. This interpretation played a major role in developing a new tectonic model for the geological evolution of western Tasmania (Crawford and Berry, in press, *Tectonophysics*), which hinged on identification of unusual high-Si, high-Mg, low-Ti lavas, including boninites and magnesian quartz tholeiitic basalts making up most of the lava pile. Given the elevated PGE contents of such magmas relative to typical mid-ocean ridge basalts or rift tholeiites, this identification has enhanced the PGE prospectivity of the cumulate pile which make up significant volumes of the mafic-ultramafic complexes in western Tasmania. Furthermore, the possible presence of PGE (and Au)-enriched mafic-ultramafic rocks in the ophiolite sheet(s) in the substrate of the Mount Read Volcanics provide one reason as to why the VHMS deposits in the Mount Read Volcanics are so Au-rich relative to many other similar Kuroko-type deposits.

THE MOUNT READ VOLCANICS (MRV)

Detailed petrological-geochemical studies of the MRV have shown that they are not, as was generally thought, an Andean-type convergent margin basalt-andesite-dacite-rhyolite suite. Rather, they are a magma suite emplaced in post-collisional relaxation rifts after collision of an oceanic arc with a thinned, rifted passive margin emplaced the mafic-ultramafic complex onto the passive margin.

Geochemical studies have proven very effective in two other applications within the MRV. Firstly, ratios such as Ti/Zr, for example, show a smooth variation from basalt to rhyolite, and remain little changed during even intense alteration. Thus a near terminally-chloritised lava may be successfully assigned to derivation from an andesite or a rhyolite, for example, where petrographic evidence for the protolith has been obliterated. Secondly, geochemical studies have proven valuable in regional correlation of volcanic units in the MRV. For example, identification in the Lynchford area of very unusual P_2O_5-light REE-enriched shoshonitic basalts, such as are abundant in the Hellyer basalt pile, clarified stratigraphic relationships in this area, where the Lynchford basalts had previously been thought to dip below, and pre-date the Central Volcanic Complex. Furthermore, the commonly intrusive hornblende andesites, such as those at Crown Hill and Anthony Road, have been shown to be transitional compositionally, and almost certainly temporally, between the less enriched CVC andesite-dacite-rhyolite sequences, and the more enriched Hellyer-type shoshonite lava sequences. If a sufficiently comprehensive database is available, use of carefully selected geochemical parameters can be of great value on the scale of an exploration licence or mine lease in correlating lava units both locally and regionally.

SUMMARY

Geochemical studies of lava sequences in outcrop or drill hole have great potential to clarify local and regional correlation, as well as lend clues towards determining the tectonic setting of eruption and geological significance of volcanic rocks in fold belts. For the latter purpose, careful sample selection based on detailed petrographic studies is an important pre-requisite to a successful application of comparative geochemistry. For local and regional correlation, immobile elements are most useful, and the choice of element packages to be used may vary from sequence to sequence. Their successful application relies heavily on a comprehensive database for the regional volcanics, and sensible choice of elements to be used in the exercise. In alteration zones, immobile elements may be used to identify the protoliths of intensely-altered lavas, and to assess possible volume changes and mass balances involved in the alteration system.