A new look at lamprophyres and sanukitoids, and their relationship to the Black Flag Group and gold prospectivity

by

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The relative contributions that crustal and magmatic sources have made to the Archean gold endowment of the Eastern Goldfields Superterrane (EGST) of the Yilgarn Craton have been debated for several decades without any ensuing clear consensus. From an empirical perspective, several specific intrusive magma types have been directly linked to gold mineralization. These include lamprophyres (e.g. Rock and Groves, 1988; Rock et al., 1989) and high-Mg dioritic to granodioritic magmas derived from metasomatized lithospheric mantle (i.e. sanukitoids; e.g. Beakhouse et al., 1999). Recent work has established a clear, statistically valid basis for these empirical observations (Witt et al., 2013, 2015; Witt, 2016).

A significant increase in the amount of high-quality lithogeochemical data from volcanic and subvolcanic rocks of the EGST further allows a robust assessment of links between calc-alkaline lamprophyric intrusions and trace element-enriched sanukitoid intrusions, links between these and felsic volcanic rocks (including the Black Flag Group) and links between all of these and gold prospectivity.

To do this, we used an extract from the larger geochemical dataset currently being accumulated as part of the Eastern Goldfields greenstone geochemical barcoding project, an initiative under the Exploration Incentive Scheme (EIS) that aims to geochemically characterize greenstone stratigraphy throughout the EGST. The data subset initially comprised 845 analyses of volcanic and subvolcanic rocks, with broadly contemporaneous crystallization ages between 2.69 and 2.64 Ga. The number of analyses was reduced to 691 after filtering to only include the 'least-altered'. The broad geochemical patterns observed within the remaining dataset appear most consistent with igneous processes, and suggest that our sampling and filtering strategies considerably minimized the number of samples with whole-rock compositions that were significantly affected by metamorphism or hydrothermal alteration. Sampling has a significant bias to the Menzies–Kambalda portion of the Kalgoorlie Terrane (Fig. 1), primarily because this was the region selected for the initial phase of the Eastern Goldfields greenstone geochemical barcoding project.

Current petrogenetic models discount a direct genetic relationship between sanukitoid and calc-alkaline lamprophyric magmas, because the former are often found to be more primitive than the latter (e.g. Stern et al., 1989). However, our study, which considers only samples with a close spatial relationship, supports the suggestion that the EGST sanukitoids are in fact directly related to lamprophyric magmas (Fig. 2; Perring and Rock, 1991) through a liquid line of descent involving hornblende fractionation, rather than through direct extraction from lithospheric mantle.

Together, lamprophyre and sanukitoid define a low-Nb, high-P_2O_5 and high La/Nb magmatic association that distinguishes them from all other Archean magmatic associations of the EGST, except for the Mafic granites, one of the four main granite groups of the Yilgarn Craton (Champion and Sheraton, 1997; Cassidy et al., 2002). More than 75% of Mafic granites also fall within this association and are sanukitoid intrusions. Most significantly, more than 75% of the igneous rocks forming the Black Flag Group also fall within this distinct 'enriched' association (Figs 3, 4), that is, most Black Flag Group rocks are volcanic equivalents of evolved sanukitoid. Smaller occurrences of similar felsic volcanic rocks lie throughout the EGST.

The origins of the enriched magmas can be traced back to a metasomatized lithospheric source, thus the occurrence of such magmas indicates proximity to a translithospheric structure. The significance of a genetic link between lamprophyric magmas and sanukitoid, and further to more evolved dacitic compositions of the Black Flag Group, is that intrusion and fractionation of wet, hornblende-bearing lamprophyric magma involves exsolving large volumes of relatively oxidized fluids, which are subsequently also channelled along translithospheric pathways.

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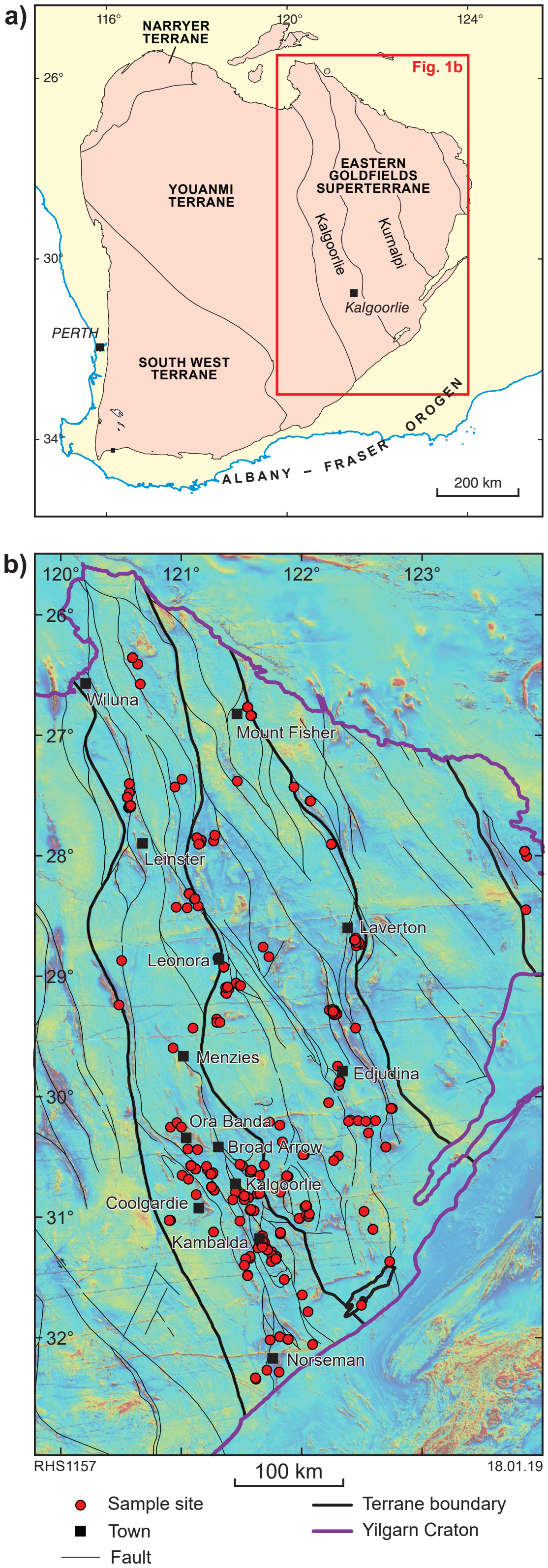

Figure 1. a) Terrane subdivision of the Yilgarn Craton, with outline indicating the study area shown in b); b) aeromagnetic image of the Eastern Goldfields Superterrane (EGST) showing the locations of samples used for this study. Note that many sites represent the location of a diamond drillhole, cores from which commonly yielded several samples

Even if such fluids are not initially intrinsically gold rich, they likely scavenge a significant metal cargo as they ascend through the crustal greenstone sequences. Additionally, even if such a process seldom directly produced primary gold mineralization, it may have represented a critical enrichment process along long-lived fluid pathways. The extraordinary gold endowment of the areas within and peripheral to the Black Flag Group might indicate that these very shallow systems reflect the most favourable crustal level in terms of (magmatic) gold enrichment. Alternatively, the extraordinary volume of lamprophyre–sanukitoid magmatism in that region might reflect either an extremely efficient translithospheric fluid pathway, or a particularly volatile-rich and fertile lithospheric mantle source, or a combination of all these factors.

The regional distribution of Mafic granites and the composition of felsic volcanic and subvolcanic units, in terms of their ‘enriched’ or ‘unenriched’ characteristics, remain poorly established but potentially significant indicators of gold prospectivity.

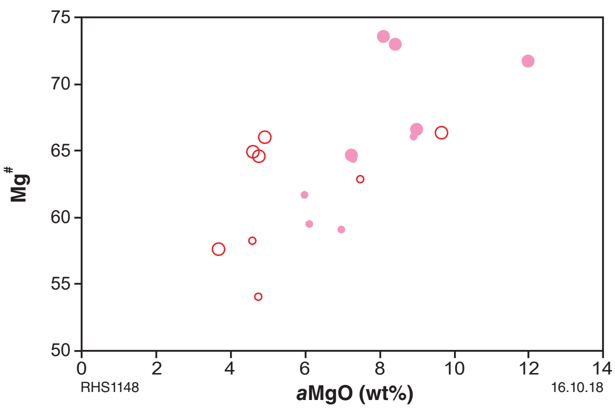

Figure 2. Variation of Mg# with *a*MgO (MgO calculated on an anhydrous basis) for closely spatially associated lamprophyric rocks (open red circles) and associated enriched diorites (sanukitoid = pink circles) from two diamond drillcores taken from the Kambalda region (CD16056A = larger symbols; LD7006 = smaller symbols). In both cases, when spatially associated magmas are independently assessed, lamprophyric magmas have more primitive compositions than the associated sanukitoid and clearly permit a direct genetic relationship

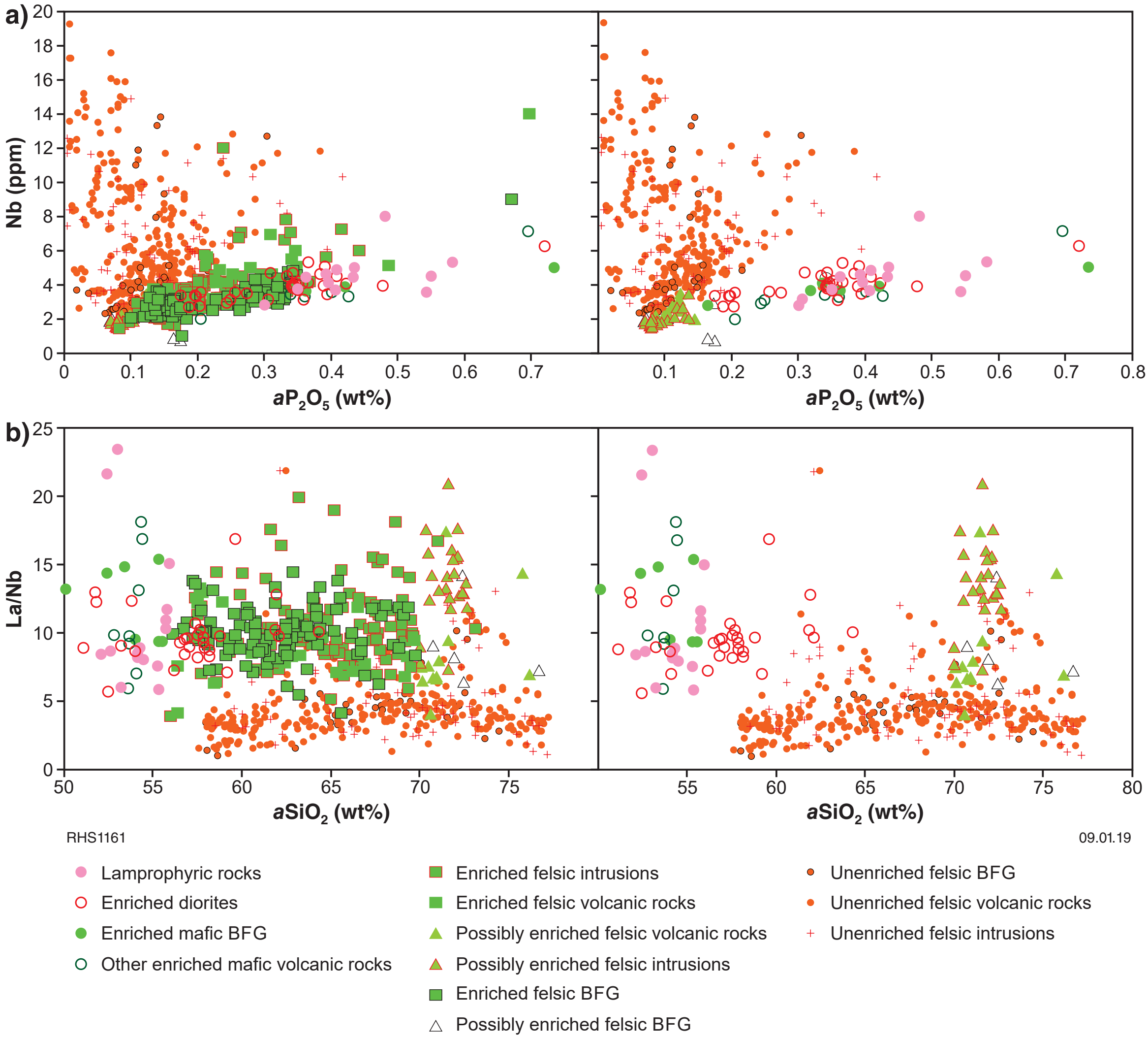

Figure 3. **a) Variation of Nb with aP_2O_5 (P_2O_5 calculated on an anhydrous basis); b) variation of La/Nb with $aSiO_2$ (SiO_2 calculated on an anhydrous basis). Plots on the left show all data. Data for the enriched felsic rocks (volcanic and subvolcanic) have been removed from the plots on the right so that the compositional range of the unenriched felsic rocks can be more readily distinguished. BFG, Black Flag Group**

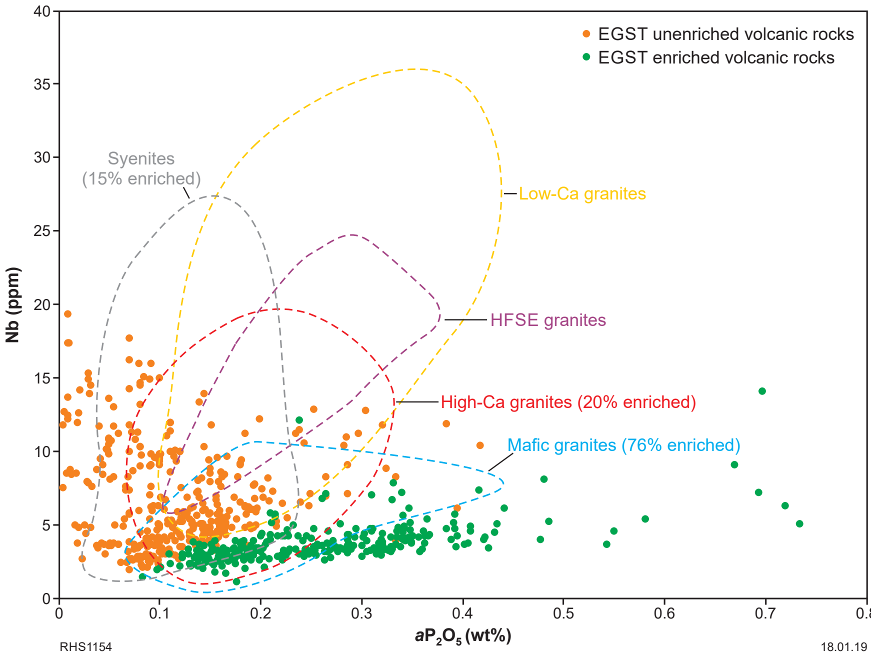

Figure 4. **Variation in Nb with aP_2O_5 comparing the enriched and unenriched felsic rocks (volcanic and subvolcanic) with Yilgarn Craton granitic rock groups described by Champion and Sheraton (1997) and Cassidy et al. (2002). Also indicated for some granitic rock groups are the proportions of samples that fall within the field for 'enriched' rocks as defined here. In the case of the Mafic granite group, 76% overlap the enriched volcanic rock field defined by the spread of green circles**

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