Executive Summary

The Kalkarindji Flood Basalt Province of Australia: comparisons with the Siberian Traps CFBP and associated Norilsk Ni-Cu-PGE mineralization

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- The Kalkarindgi CFBP (c. 505 - 510 Ma) represents the most ancient example of an LIP for which significant thicknesses of the lava succession remain preserved. Due to erosion it remnants now consist of a scattered series of basaltic suites occurring across northern and central Australia; its eruptive volume is estimated as exceeding 5 x10^5 km^3 but, by analogy with other better preserved CFBPs elsewhere, its original volume may have been significantly greater than 1 x 10^6 km^3.

- Although scattered basaltic suites (e.g. Antrim Lavas) have long been documented across northern and central Australia, the Kalkarindgi CFBP has only recently been recognized (i.e. c.10 years) as a *bone fide* example of a once continuous CFBP. This lack of recognition is largely due to the inaccessibility of the region, a grave paucity of previous documentation and, hitherto, a lack of a commercial or academic motivation to invest the resource for detailed investigation.

- By comparison with the Siberian, Karoo, Deccan and Columbia River CFBPs, The Kalkarindgi CFBP still remains largely unknown. For instance, during the past 25 years the body of peer-reviewed research published detailing the Deccan Traps exceeds 500 papers (similar comparisons may be made for Karoo and Siberian Trap literature); by contrast the body of research detailing the Kalkarindji (or Antrim lavas) over the same period is likely less than 20 research papers in total. Accordingly, due to its obscurity, the Kalkarindgi CFBP potentially provides a highly fertile area for research investigation and investment both commercially and academically. Many regions within the postulated extent of this huge CFBP effectively represent 'virgin territory'.

- CFBPs are characterised by basaltic lavas which are derived from the partial melting of Earth's mantle; the mantle is the layer which exists beneath the continental (or oceanic) crust. Once the melt is generated it migrates surface-ward as a magma, usually via conduits (lower-crustal dykes) or else becomes stored in 'high level' chambers within the crust (>1

– 10 km depth); these are, in turn, then tapped by shallow conduits (higher-crustal dykes), and the magma is erupted at the surface as lavas.

- During ascent from the mantle, CFBP lavas pass through, or are stored and then tapped within, the continental crust. This ‘plumbing system’ allows the hot magma to interact with the continental crust, and scavenge elements from it. Those lavas which contain significant amounts of scavenged contaminants are termed ‘contaminated lavas’; they are often characterised by elevated K, Sr and Rb concentrations (as well as a suite of rarer, but petrogenetically significant elements such as Cu, Ba, and some rare earth elements (REEs)). However, although some degree of contamination is not unusual, as a rule highly contaminated lavas are a rarity in most CFBP successions. Accordingly, CFBP lava successions do not represent commercially extractable resources. However, the Norilsk-type deposits of the Siberian Traps represent a notable exception to this rule.

- The Norilsk -Talnakh is associated with the Siberian Traps CFBP. This nickel-copper deposit was formed 250 million years ago during the eruption of the Siberian Traps igneous province. Here lavas were erupted through tapping of a series of flat-lying lava conduits (sills). The ore bodies were was formed when the erupting magma encountered significant thicknesses of organic-rich sediment during its ascent and eruption; the magma became comtaminated and saturated in sulphur which formed sulphides. These molten sulphides sequestered trace elements (i.e. chalophile elements) from the erupting basaltic magmas during their passage through the crustal conduits. These sulphide phases became highly enriched in a range of commercially important elements. The sub-surface sill bodies are now host to commercially important ore bodies.

- The presence of organic-rich sediments in the Proterozoic basement through which the Kalkarindgi lavas were erupted provide a geological setting directly analogous to that which gave rise to the Norilsk-type mineralization associated with the Siberian Traps CFBP.

- Trace element enrichments in the Kalkarindgi basalts indicate they are highly ‘contaminated’; that is, they interacted with crustal materials during their ascent through the continental lithosphere. Current geochemical data reveal that the Kalkarindgi lavas commonly display significant crustal contamination (at enrichment levels which place them among the highest of all CFBP analyses). The only other CFB which displays this degree and frequency of contamination are the basalts of the Siberian Traps CFBP.

- Analysis reveals that both the Kalkarindgi and Siberian Traps basalts are relatively depleted in sulphur. This indicates that sulphur (both that derived from the primary magma, and from crustal contamination with organic-rich sediments) has itself effectively been sequestered prior to eruption. In the case of the Siberian Traps, the host bodies of this sulphur sequestration are the magmas frozen in the high-level sills and conduits which originally fed the surface eruptions. The assumption is that the same process operated during the eruption of the Kalkarindgi lavas, and that these sub-surface magma bodies await discovery.

- Of key importance to locating potential sulphide-hosted commercially significant element concentrations is the identification the high-level dyke conduits which fed the surface lava flows; a suite of these will typically indicate proximity to sill bodies in which the sulphide minerals have precipitated.

- The emplacement, distribution and orientation of feeder dykes (conduits to lava flows) are normally associated with crustal heterogeneities and or/weaknesses that are exploited during the surfaceward migration of magma. These weaknesses become particularly prone to exploitation when the crust is under stress (i.e. subject to extensional tectonic forces). Since many CFBPs are associated with episodes of crustal extension and/or continental rifting, those regions of the CFBP which were proximal or adjacent to the extension/rift axis will offer the greatest potential for hosting the CFBP magma plumbing system (i.e. dykes and sills).

- The tectonic setting of the wider Kalkarindgi CFBP is very poorly known. Based on state of the art Cambrian (500 – 550 Ma) palaeogreographic reconstructions for Australia and Antarctica, the most likely position of any extension/rifting likely to have been associated with the genesis of this CFBP would have been located along the NW Australian margin. This interpretation is broadly supported by geochemical modelling (Glass, 2002) which indicates significant crustal thinning in the NW prior to the eruption of the Kalkarindgi basalts, and the fact that typically thicker lava successions are preserved in the north compared with the south (i.e. Central Australia).

- Through detailed mapping and reconnaissance (October 2010), considerable advancement has been achieved in broadening our understanding of the volcanology and regional setting of the Waterloo and Wave Hill areas of the Kalkarindgi volcanics (for further detail, see report by Murphy et al. 2010). A relatively modest investment in field-based studies, and associated laboratory-based geochemical analyses, provides a cost effective method of targeting and/or verifying regional geophysical surveys. The paucity of geological information concerning the evolution and structure of the Kalkarindgi CFBP demands further investigation of this type if the apparently promising commercial prospects (described above, and in the detailed report; Murphy et al., 2010) are to be identified and realised.

- Since Norilsk-type deposits are so intimately associated with the emplacement Siberian Traps CFBP, there is a clear commercial potential for CFBPs exhibiting a similar geological setting and geochemistry. Since a considerable body of information on CFBP genesis resides in the academic realm, a programme combining commercial interest and academic expertise would provide the opportunity to develop a unique synergy of industrially- and research-based investigation for the Kalkarindgi CFBP.

- Further investigation using field-based programmes to inform sophisticated geophysical surveys is clearly warranted. Such linked investigative programmes should be considered for support over a 2 to 3 year period in order to provide the necessary context and detail. An identification of key areas for exploration is required in order to achieve a more thorough assessment of whether the Kalkarindgi CFBP indeed represents a Norilsk-type analogue with all its attendant associated commercial prospects.