Setting and prospectivity of a large igneous province: the 1800 Ma Hart Dolerite, Kimberley region

by

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The 1800 Ma Hart Dolerite intrudes the Speewah and Kimberley Groups in the Kimberley region and constitutes a large igneous province. The Hart Dolerite contains orthomagmatic V–Ti and epithermal fluorite mineralization and may have significant potential for orthomagmatic Ni–Cu–PGE mineralization. However, little is known about its petrogenesis, duration of magmatism, and the crustal architecture into which it was emplaced, all of which are important in understanding its mineralizing systems. Historical and recently acquired geochemical and isotopic data from the Hart Dolerite also provide a window into the nature of the underlying Kimberley Craton, which is thought to comprise — at least in part — Archean or reworked Archean crust (Hancock and Rutland, 1984; Griffin et al., 2000). This basement is now unexposed, blanketed by sedimentary and volcanic cover of the Paleoproterozoic Speewah and Kimberley Groups (Fig. 1).

The Speewah and Kimberley Groups

The Speewah Group unconformably overlies Paleoproterozoic igneous and metamorphic rocks of the 1910–1800 Ma Lamboo Province (Halls Creek Orogen, Fig. 1). The Speewah Group is c. 1.5 km thick and comprises a dominantly fluvial succession of quartz and feldspathic sandstone, interbedded with mudstone and minor felsic volcanic rocks (Fig. 2). Paleocurrent data indicate that sediment was derived from the uplifted Lamboo Province to the northeast, and transported along a fault-bounded northeast-trending trough (Gellatly et al., 1975). Felsic volcanic rocks yield a SHRIMP U¬–Pb zircon age of 1835 ± 3 Ma for the group (Page and Sun, 1994; Sheppard et al., 2012), which indicates that basin formation was coeval with active-margin magmatism and deformation in the Lamboo Province, associated with collision of the Kimberley and North Australian Cratons (Sheppard et al., 2012).

The >1800 Ma Kimberley Group is c. 3 km thick and unconformably overlies the Speewah Group or, locally, Paleoproterozoic rocks of the Lamboo Province (Fig. 2). It comprises mineralogically and texturally mature siliciclastic rocks, intercalated with tholeiitic basalts of the Carson Volcanics. The Kimberley Group was deposited in a broad, semi-enclosed shallow marine basin, with paleocurrent measurements suggesting a dominant sediment supply from the north and northwest (Gellatly et al., 1970).

The Hart Dolerite

The Hart Dolerite underlies an area of about 160 000 km^2 of the Kimberley Basin and northeast into the Bonaparte Gulf, with an estimated volume of 250 000 km^3 (Griffin et al., 1993). It comprises a network of massive dolerite sills and less extensive dykes and granophyre that intruded the Speewah Group and can be traced up into the two lowermost units of the Kimberley Group (Fig. 2). Undated dolerite sills also intruded the upper part of the Kimberley Group, although these cannot be traced into stratigraphically lower units, and are not accompanied by granophyre (Fig. 2). Sills are up to 1.8 km thick, though commonly composite, with a combined thickness of up to 3 km (Plumb and Gemuts, 1976). Rock types include olivine dolerite and gabbro, quartz dolerite and granophyric dolerite, and diorite (Gellatly et al., 1975; Thorne et al., 1999). Locally olivine-bearing cumulates are present at the base of sills (Elemental Minerals, Fiorentini, 2007).

The Hart Dolerite was emplaced at 1797 ± 11 Ma, based on SHRIMP U–Pb crystallization ages for two samples of granophyre (Sheppard et al., 2012). These are inferred to be comagmatic with the Hart Dolerite based on their occurrence at the tops of sills, rare gradational relationships (Gellatly et al., 1975), consistent geochemical trends (Fig. 3), and similar initial $^{143}Nd/^{144}Nd$ ratios (Sheppard et al., 2012).

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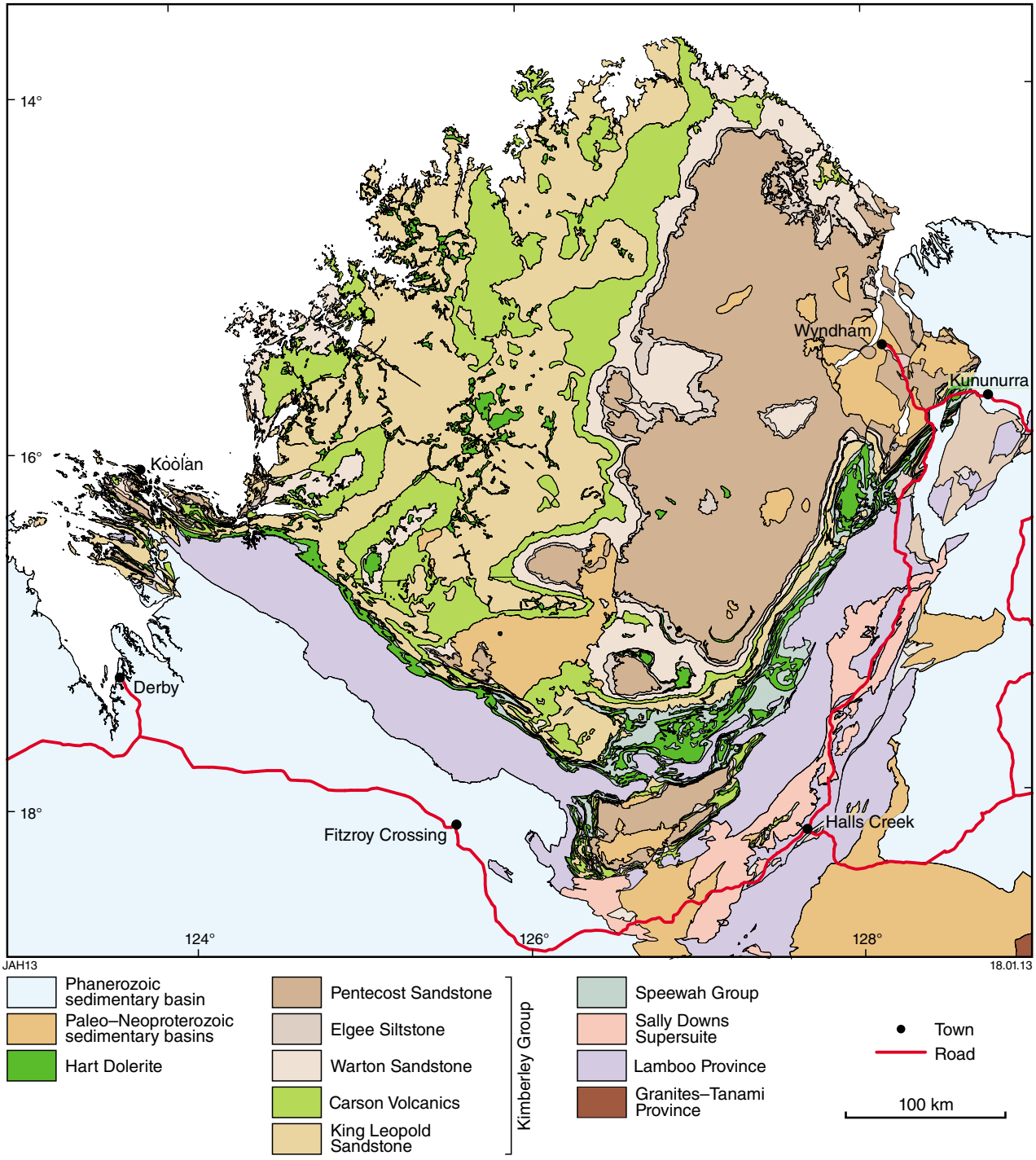

Figure 1. Distribution of the Hart Dolerite in the Kimberley region

Geochemical and isotopic character of the Hart Dolerite

Available geochemical data for the Hart Dolerite are mainly from the Speewah Dome, about 100 km southwest of Kununurra (Speewah Mining, Eves, 2010; Ramsay et al., 2011; 2012), and from near Lansdowne Homestead in the southernmost Lamboo Province, about 100 km west-northwest of Halls Creek (Elemental Minerals, Fiorentini, 2007). Limited regional data are available in Sheppard et al. (1997) and WACHEM (<www.dmp.wa.gov.au/geochem>).

The Hart Dolerite is dominantly tholeiitic basalt to basaltic andesite, though there is a considerable compositional spread, including picro-basalt, trachybasalt, and trachyandesite compositions. The bulk of available data have Mg numbers of 30–53 and 50–53% SiO_2, though there are indications of other significant compositional groups

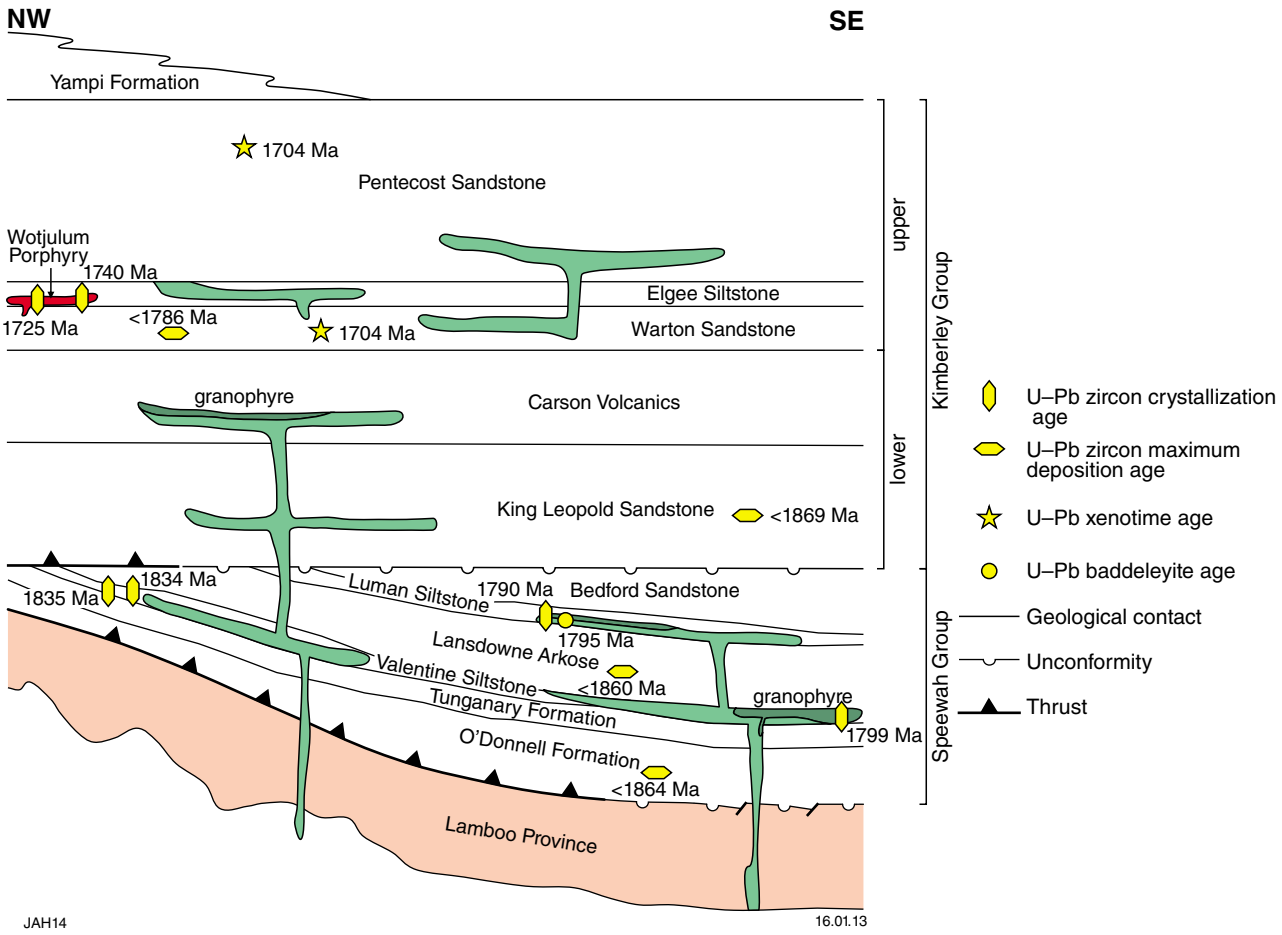

Figure 2. Schematic stratigraphic and structural relationships of the Kimberley and Speewah Groups (from Sheppard et al., 2012). Dolerite sills and dykes are shown in light green; granophyre in dark green.

characterized by distinct Mg numbers, SiO_2, TiO_2, and CaO content (Fig. 3). Correlation between Ni and MgO, and between Cr and MgO, probably reflects fractionation and accumulation of olivine and pyroxene. Ti-rich varieties (c. 4 wt% TiO_2) are characterized by low Mg numbers, with high TiO_2 also correlative with elevated Cu (Fig. 3).

All dolerite and granophyre samples have moderate rare earth element (REE) abundances, which, coupled with a weak negative Nb and Ta anomaly in most samples, indicates assimilation of crustal material during emplacement (see also Elemental Minerals, Fiorentini, 2007). The majority of dolerite samples are slightly (light) LREE-enriched with a weak negative to absent Eu anomaly, consistent with some fractionation of plagioclase. LREE-enriched varieties have strong negative Eu anomalies (Fig. 3). Granophyres show similar REE trends to the LREE-enriched Hart Dolerite, consistent with their formation by fractionation of the same, crustally contaminated source (Fig. 3). The granophyre and main group of the dolerite define a common $^{143}Nd/^{144}Nd$ vs $^{147}Sm/^{144}Nd$ array, also consistent with a common source (Sheppard et al., 2012).

Notably, the few samples of dolerite from the upper part of the Kimberley Group have distinctly high Mg numbers (65–69), low SiO_2 (44–46 wt%), and flatter REE curves with positive Eu anomalies and low total REE abundances. They have strongly radiogenic Nd, consistent with a distinct magmatic source (Sheppard et al., 2012) and may be unrelated to (and younger than) the Hart Dolerite.

Links with basaltic volcanism

The Carson Volcanics in the lower Kimberley Group comprise 10 to several hundred metres thick, regionally extensive, tholeiitic basalt flows intercalated with feldspathic and quartz sandstone and minor mudstone. These flows may have been comagmatic with the Hart Dolerite. The timing of volcanism has not been directly determined, though basalts are locally intruded by the Hart Dolerite, so must have been extruded between 1835 Ma and 1800 Ma. Available geochemical data for the Carson Volcanics are very limited, but show similar major, trace, and REE trends and ranges as the main cluster of Hart Dolerite data (Fig. 3).

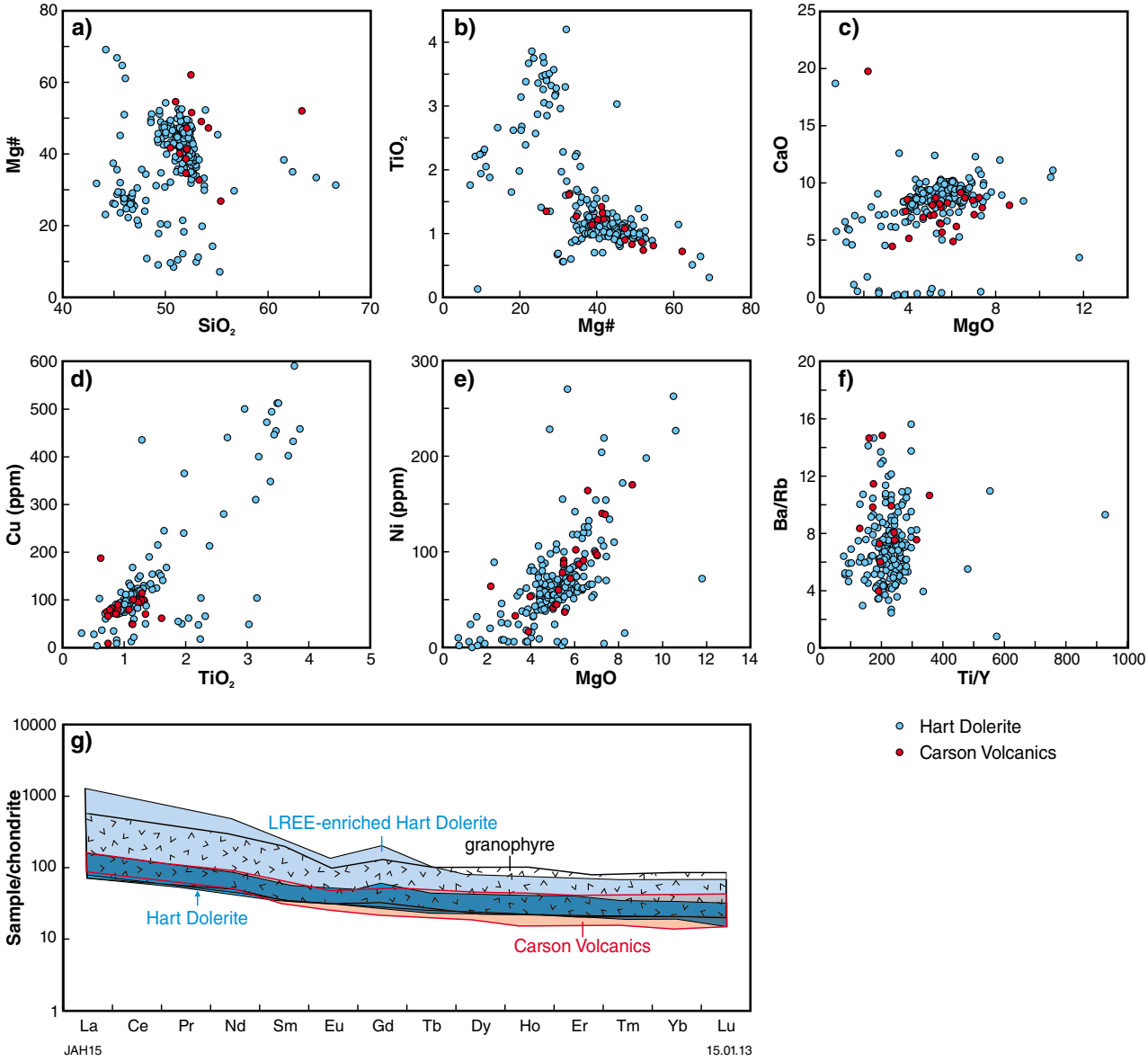

Figure 3. **a–f) Selected major and trace element variation diagrams showing the Hart Dolerite (blue) and Carson Volcanics (red); g) Chondrite-normalized REE variation diagram for the Hart Dolerite (dark blue), LREE-enriched Hart Dolerite (light blue), granophyre (stippled) and Carson Volcanics (red).**

Tectonic setting

Intrusion of the Hart Dolerite immediately follows 1835–1805 Ma magmatism in the Halls Creek Orogen, associated with c. 1820 Ma collision of the Kimberley Craton with the North Australian Craton. In the same period, a distinct change in provenance — from dominantly Paleoproterozoic to Archean sources — during deposition of the Speewah and Kimberley Groups, is recorded in their detrital zircon age spectra (Kirkland et al., 2010a; Kirkland et al., 2010b; Kirkland et al., 2010c; Kirkland et al., 2010d; Kirkland et al., 2010e; Kirkland et al., 2010f; Wingate et al., 2012). This suggests that the Hart Dolerite (and possibly also the Carson Volcanics) was the product of crustal thinning and mantle upwelling during post-collisional extensional uplift of the Lamboo Province, possibly also associated with plate reorganization during c. 1800 Ma collision of the North and West Australian Cratons (Sheppard et al., 2012).

Mineralization

Large igneous provinces are associated in particular with orthomagmatic Ni–Cu–PGE as well as Au, Cr, and Fe–Ti–V mineralization. Orthomagmatic V–Ti–Fe mineralization (and minor PGE+Au) has been reported from the Speewah Dome in the northeast of the Halls Creek Orogen (e.g. Eves, 2010; Ramsay et al., 2011, 2012). Speewah Mining reported a combined resource estimate of 4 712 Mt @ 0.30% V_2O_5 (using a 0.23% V_2O_5 cut-off). The vanadium is contained in titanomagnetite in a disseminated magnetite gabbroic phase of the Hart Dolerite. This gabbro is characterized by higher

magnetic susceptibility and lower SiO_2 (44–50 wt%) and Mg numbers (20–30) than unmineralized Hart Dolerite (Eves et al., 2010; Ramsay et al., 2011, 2012). The transition from a basal high-grade mineralized zone (15–20 m thickness) to lower grade is also marked by a laterally extensive PGE+Au reef (0.1 m) with a maximum PGE+Au content of c. 700 ppb (Ramsay et al., 2012). Fiorentini (2007) notes that samples from near Lansdowne Homestead (Elemental Minerals) have highly depleted PGE concentrations, also consistent with attainment of sulfide saturation in at least some of these dolerite sills.

The largest fluorite deposit in Western Australia is also hosted by the Hart Dolerite and sedimentary rocks of the Speewah Group in the Speewah Dome, where epithermal fluorite–barite– (Cu±Au) veins, associated with breccias and carbonate-rich veins, are related to north-northeast-trending faults associated with the Greenvale Fault (Hassan, 2000). Current drilling has delineated 6.7 Mt @ 24.6% CaF_2 (using a 10% CaF_2 cut-off, Ramsay et al., 2012).

Summary

The limited geochemical data available reveal the tholeiitic nature of the Hart Dolerite and Carson Volcanics, but also indicate diversity in the composition of the Hart Dolerite. This may be the product of multiple distinct magma batches and has, at least locally, been affected by epithermal alteration. The data indicate that the Hart Dolerite assimilated crustal material, increasing the potential for sulfide saturation and PGE mineralization. The recognition that V–Ti–Fe and PGE mineralization is restricted to a particular phase of the Hart Dolerite at Speewah Dome (Eves, 2010; Ramsay et al., 2011, 2012) has potential regional implications for targeting mineralization. The highest-level sills, in the upper Kimberley Group, are geochemically and isotopically distinct and may be part of an unrelated, possibly younger, dolerite; however, more data are required to verify this hypothesis. Additional data are also needed to determine the relationship between the Hart Dolerite and the Carson Volcanics, although limited data show common geochemical and isotopic trends. If the Carson Volcanics represent an extrusive phase of the Hart Dolerite, this significantly increases the volume of mafic magmatism in the Kimberley at 1800 Ma.

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