

Tracing kimberlitic indicators to their kimberlite source at Chidliak, Nunavut, Canada, re-visited: the unexpected accuracy of a simplified Mahalanobis-distance approach

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Introduction

Peregrine Diamonds has previously reported on the evolution and refinement of efforts to trace kimberlitic indicators recovered from till sampling campaigns to their kimberlite source(s) at the Chidliak project on Baffin Island, Canada (see Neilson et al., 2012; Pell et al., 2013). Our earlier work capitalized on the comparative abundance of fresh peridotitic ± eclogitic garnets in till samples, and leveraged Mn-thermometry applied to Cr-pyrope compositions (after Grütter and Tuer, 2009) to reveal distinct Temperature-TiO₂ profiles (TTiPs) that match equally distinct TTiPs in up-ice kimberlite sources (see Fig. 1 for TTiP explanation and Fig. 2 for an example from northern Chidliak). Simple visual comparison of TTiPs has served to conclusively “fingerprint” and resolve several sources, but we have encountered ambiguous TTiP-source interpretations in settings where:

- Similar TTiPs occur in closely spaced known sources (e.g. Fig. 7 of Neilson et al., 2012);
- One or more known source(s) contain log-orders more indicators per kilogram of kimberlite, and consequently “swamp” the TTiP signal from nearby source(s) that have low indicator counts;
- A high sample density reveals many till samples with a near-uniform “bulk-average” TTiP, resulting in ambiguous interpretations of potentially unique sources (e.g. Fig. 5 of Neilson et al., 2012). This “problem” is particularly conducive to analysis by Mahalanobis-distance techniques due to an anchoring effect provided by the common “bulk-average” (or mean) TTiP.

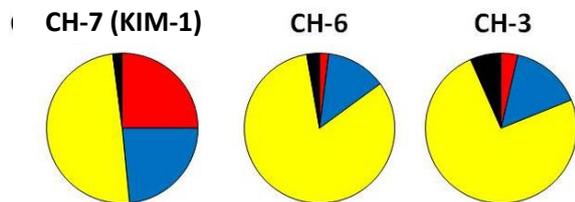


Figure 1 (above): Pie-charts showing temperature-TiO₂ profiles (TTiP’s) for Cr-pyrope populations from the CH-7 (KIM-1), CH-6 and CH-3 kimberlites. Mn-in-pyrope thermometry classes are: graphite-facies (T-Mn < 900°C, yellow), shallow diamond-facies (T-Mn 900 to 1100°C, blue), deep diamond-facies (T-Mn > 1100°C, red), and high TiO₂ (G1 and G11 garnets with TiO₂ > 0.6 wt%, black). The Mahalanobis-distance technique espoused in this work easily differentiates the CH-6 TTiP from the CH-3 TTiP, even though they appear visually similar.

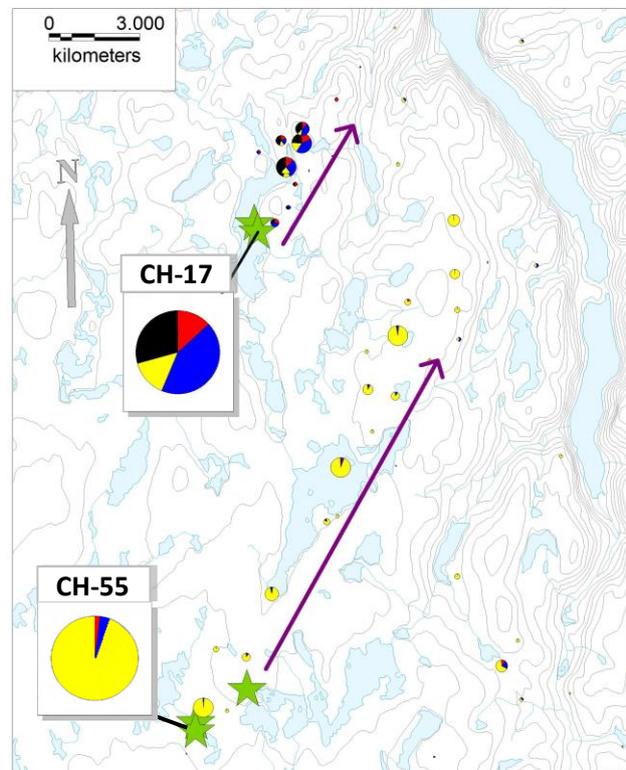


Figure 2 (at right): Temperature-TiO₂ profiles of kimberlites CH-17 and CH-55 are very distinct, and remain distinct in till samples defining northeastward down-ice glacial dispersion (after Fig. 3 of Neilson et al., 2012).

The Mahalanobis distance

We have compiled an intuitive definition from several sources, and describe the Mahalanobis distance (MD) as “a unitless descriptive statistic that measures the relative distance of a datum from a common point (i.e. a standardized residual relative to a mean). It is used to gauge the similarity in attributes of a given sample to the mean of the same attributes in a population. Mahalanobis is scale-invariant and differs from Euclidean distance as it accounts for correlations within multi-variate data”. A graphical representation is shown in Fig. 3.

In practise, we isolate all Cr-pyrope data from the area of interest, and for each (till) sample we calculate

$$MD = TTiP_{(area_mean)} - TTiP_{(sample)},$$

subject to $n \geq 5$ Cr-pyrope analyses per sample. We exclude sample X-Y coordinate data from our TTiP-based MD calculation, even though generic MD applications often promote X-Y coordinates or nearest-neighbour attributes to be factored into MD calculations (i.e. cluster analysis). Our MD calculation quantifies two questions:

- How different is the TTiP of this (till) sample from the mean TTiP in this area ?
- Which samples in this area have a similar MD and could belong to the same TTiP population ?

An example outcome: The CH-6 area

Outcomes of our MD calculations are typically examined at the ~ 4 to 12 km scale that Cr-pyrope garnets spread away from a (presumed) kimberlite source; the related detail is difficult to reproduce in the format of this long abstract. We show the outcome of MD calculations in the area of the CH-6, CH-20, CH-10 and CH-22 kimberlites as an example (Figure 4). The following notes apply:

- Forty-three of 85 till samples collected in the CH-6 area are represented by five or more analysed Cr-pyrope garnets. Our MD calculations are based on the 1,338 Cr-pyrope analyses from these 43 samples because we consider them statistically representative of the area of interest.
- 511 Cr-pyrope analyses from 17 of 43 samples define a dominant near-mean MD population (within 0.46 standardized units). Figure 4a) shows the TTiP for Cr-pyropes from these samples comprises $89.4 \pm 2.6\%$ graphite-facies temperatures (yellow), $9.8 \pm 2.8\%$ shallow diamond-facies temperatures (blue) and - significantly - no high-TiO₂ grains. The near-mean population occurs in a western spatial subset of Cr-pyropes occurring down-ice of CH-6 (see Fig. 4a).
- 517 Cr-pyrope analyses from 7 of 43 samples define another significant MD population, though with off-mean MD values (at 0.53 to 1.7 standardized units). Figure 4b) shows the TTiP for Cr-pyropes from these samples comprises $81.2 \pm 7.0\%$ graphite-facies temperatures (yellow), $16.7 \pm 6.5\%$ shallow diamond-facies temperatures (blue) and - significantly - 2% high-TiO₂ grains (black). Application of the MD technique has clearly differentiated the subtly different TTiP attributes of this population; that this population occurs in a distinct spatial subset down-ice of CH-6 (see Fig. 4b) provides empirical validation that the MD technique can capably resolve relative differences in the 2% to 7% range.
- 310 Cr-pyrope analyses from 19 of 43 samples define a second population with off-mean MD values (at 0.53 to 1.3 standardized units). Figure 4c) shows the TTiP for Cr-pyropes from these samples comprises $90.7 \pm 11.5\%$ graphite-facies temperatures (yellow), $8.4 \pm 11.3\%$ shallow diamond-facies temperatures (blue) and - significantly - no high-TiO₂ grains. This population defines a lower-abundance and eastern spatial subset of Cr-pyropes occurring down-ice of CH-6. Low-incidence grains scattered in the west could possibly be related to the dominant near-mean population (compare Fig. 4a with Fig. 4c).

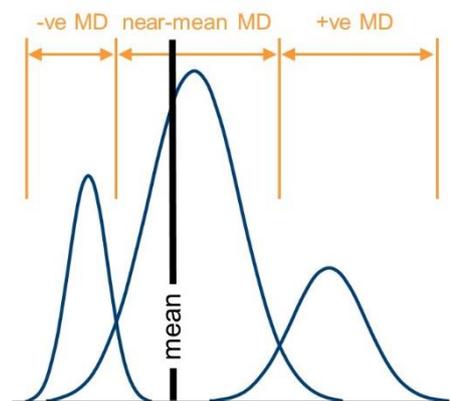


Figure 3: In this hypothetical example, the mean of three populations marks Mahalanobis-distance (MD) = 0, relative to which a range of (standardized) negative, near-mean or positive MD's distinguish each population. We calculate a single MD across all four attributes that specify the TTiP for a Cr-pyrope population.

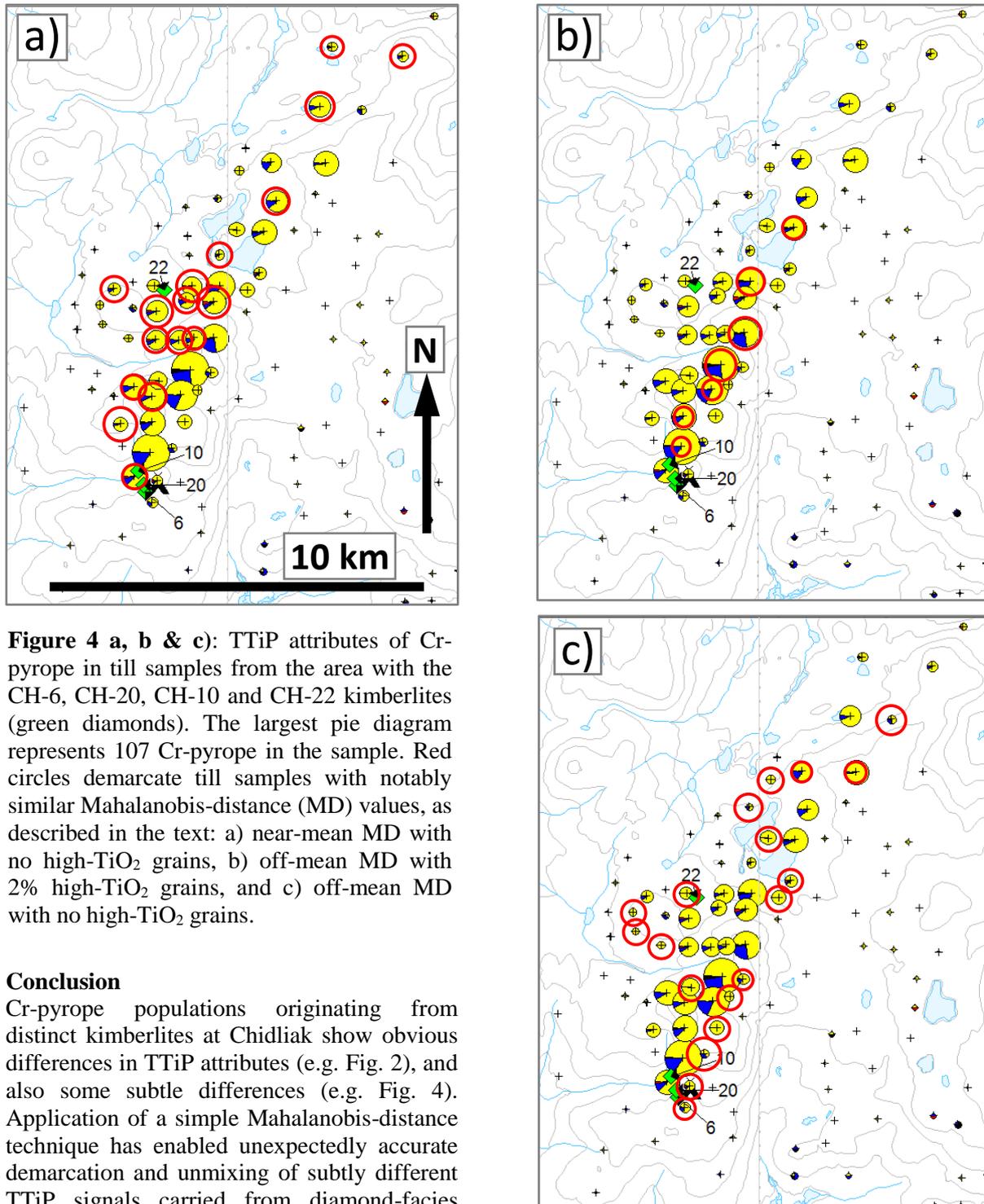


Figure 4 a, b & c): TTiP attributes of Cr-pyrope in till samples from the area with the CH-6, CH-20, CH-10 and CH-22 kimberlites (green diamonds). The largest pie diagram represents 107 Cr-pyrope in the sample. Red circles demarcate till samples with notably similar Mahalanobis-distance (MD) values, as described in the text: a) near-mean MD with no high-TiO₂ grains, b) off-mean MD with 2% high-TiO₂ grains, and c) off-mean MD with no high-TiO₂ grains.

Conclusion

Cr-pyrope populations originating from distinct kimberlites at Chidliak show obvious differences in TTiP attributes (e.g. Fig. 2), and also some subtle differences (e.g. Fig. 4). Application of a simple Mahalanobis-distance technique has enabled unexpectedly accurate demarcation and unmixing of subtly different TTiP signals carried from diamond-facies mantle environments by Cr-pyrope populations.

References

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