The Use Of Hand-Held Magnetic Susceptibility Meters In The Field: An Invaluable Tool In Regional Studies Of Dyke Swarms

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Abstract

Diabase dykes and sills, unmetamorphosed to very weakly metamorphosed, are typically magnetic, enough to cause minor compass deflections and to attract a small hand-held magnet in the field. On aeromagnetic maps, such intrusions reveal themselves by more or less well-defined magnetic anomalies that contrast with more variable and typically less magnetic bedrock signatures. With some experience, one may be able to tell different dyke swarms apart simply by gauging the deflection of a hand-held magnet in the field, particularly in cases where weakly metamorphosed dykes—with a greatly reduced magnetic susceptibility due to alteration and metamorphic reactions of Fe-Ti oxides to secondary minerals such as chlorite—are intermixed with younger, less altered dykes. Nevertheless, this simple observation remains somewhat subjective and fails to take full advantage of the wide range of magnetic susceptibilities intrinsic to intrusive rocks of differing compositions.

Mafic dyke rocks show magnetic susceptibilities (MS) that may vary over two full orders of magnitude, from ~2 to ~200 x 10^{-3} SI units (factor not repeated hereafter). Most fresh diabase dykes have MS >20, whereas dykes affected by weak alteration or incipient metamorphic recrystallization typically have reduced MS values <10. Fully hydrated metadiabases have MS values <1, typically converging on 0.7 ± 0.2.

Here I present preliminary results on a systematic survey of dyke susceptibilities in various parts of Canada, and a comparison of the utility of two different hand-held susceptibility meters.

It is concluded that hand-held susceptibility meters are of great use in field studies of dykes, with applications ranging from distinguishing between different dyke sets, and defining heterogeneities within individual dykes, to resolving dyke intersections.

Instruments

Two models of small, hand-held, susceptibility meters are commercially available and have been tested against one another in the field for their utility, on numerous dyke swarms and in various settings: the KT-10 of Terraplus Inc. (**Fig. 1a**), and the SM-30 of ZHinstruments (**Fig. 1b**). Both models allow quick measurement and quantitative assessment of magnetic susceptibilities, but the KT-10 is preferred because of its better averaging routine and use of standard AA batteries.

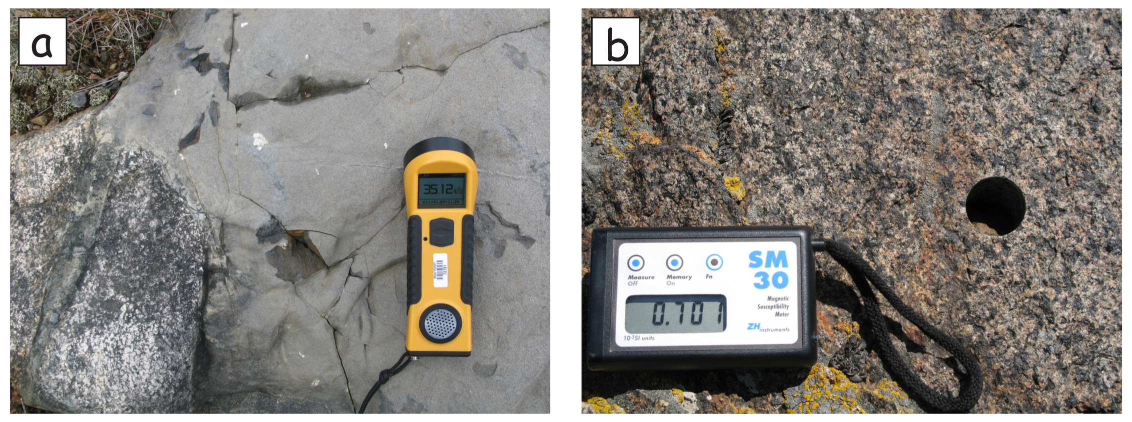


Figure 1: Hand-held susceptibility meters discussed in this study, shown here while measuring dyke rocks in the field. a) The KT-10 of Terraplus Inc., on a sparsely plagioclase phyric Sudbury dyke (ca. 1238 Ma), Ontario. A reading of ~35 is typical for these olivine diabase dykes, with an average of 41 ± 10 for the swarm. **b)** The physically smaller SM-30 of ZHinstruments, on a quartz-diorite dyke in Wyoming. This differentiated quartz-diorite core of the large Wind River dyke is poor in primary oxides and shows an MS value typical for hydrated metadiabase.

Both models allow quick measurement and quantitative assessment of magnetic susceptibilities, but the KT-10 is preferred because it has a much more useful averaging routine (running average and standard deviation) and uses standard AA batteries. The SM30 is less expensive and good for spot readings. The fact that it "times out" after seven seconds, between readings, is a major drawback. Also, on rough surfaces, it tends to give values that are up to ~20-30% low.

Applications

Here I list some of the specific examples in which field magnetic susceptibility measurements can make a significant contribution (see also Table 1, below).

In general, in a typical area with multiple swarms of different ages, MS measurements may allow one to quickly differentiate between different dyke sets, either because:

1) Older dykes have experienced more alteration and (or) cryptic metamorphism than younger dykes.

2) Dykes vary in composition and (or) mineralogy and thus have different intrinsic MS values.

As a simple 'rule of thumb', all else being equal, higher average MS values usually mean dykes of a younger age.

Table 1: Specific applications

1. Mapping heterogeneity of MS within a dyke or sill (**see Example 1**).
2. Correlating MS variation with petrographic and compositional observations.
3. Defining a characteristic MS value (average, standard deviation, range) for a dyke, and its swarm (**see Example 2**).
4. Assist in distinguishing different swarms based on their MS values.
5. Monitoring the degree of alteration in chilled margins.
6. Unambiguously differentiating metadiabases from less metamorphosed dykes, even when this may not be obvious otherwise.
7. Resolving critical dyke intersections (who cuts who? **See Example 3**).
8. Evaluating the contrasts in MS values between dykes and their host rocks (**Example 4** shows an extensive data set for the western Slave craton).
9. Correlating measured values with their expression on aeromagnetic maps.
10. Measuring MS values at paleomagnetic drill sites across a dyke, anticipating unstable behaviour in domains affected by cryptic alteration.

Areas affected by lightning strikes cannot be identified by MS values; it is the magnetization that is intense at such localities (visible with a compass) but MS values are relatively unaffected.

Example 1: MS profile across a dyke

A detailed MS profile is shown on the right (**Fig. 2**), across a ~35 m-wide Grenville swarm dyke (ca. 590 Ma), near Buckingham, northeast of Ottawa. The dyke intrudes alkaline (meta)volcanics of Mesoproterozoic age with unusually high but variable MS values. Systematic variation in MS across the dyke highlights different zones. The average for this and many other Grenville dykes is ~55 (x10^{-3}) SI units, but the coarse grained and slighly lighter coloured core of the dyke is a bit lower (reflecting differentiation?). Highest values are associated with dark pegmatoidal veins (see inset photo). MS values of the fine-grained chilled margins are also high, suggesting a grain-size control.

Figure 2, inset: Late-stage pegmatoid vein with peak MS values

Figure 2:

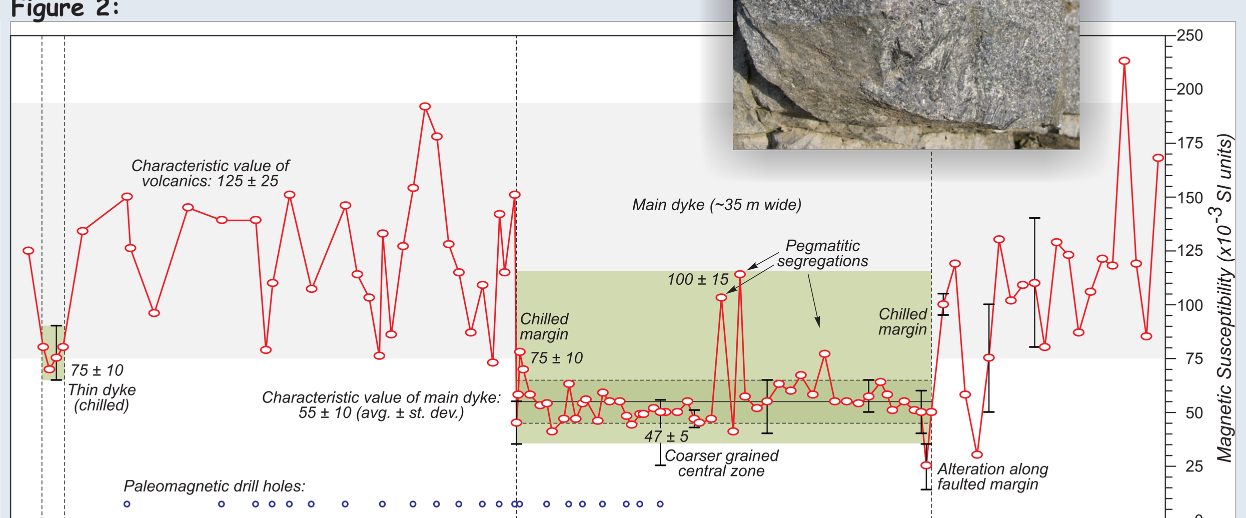
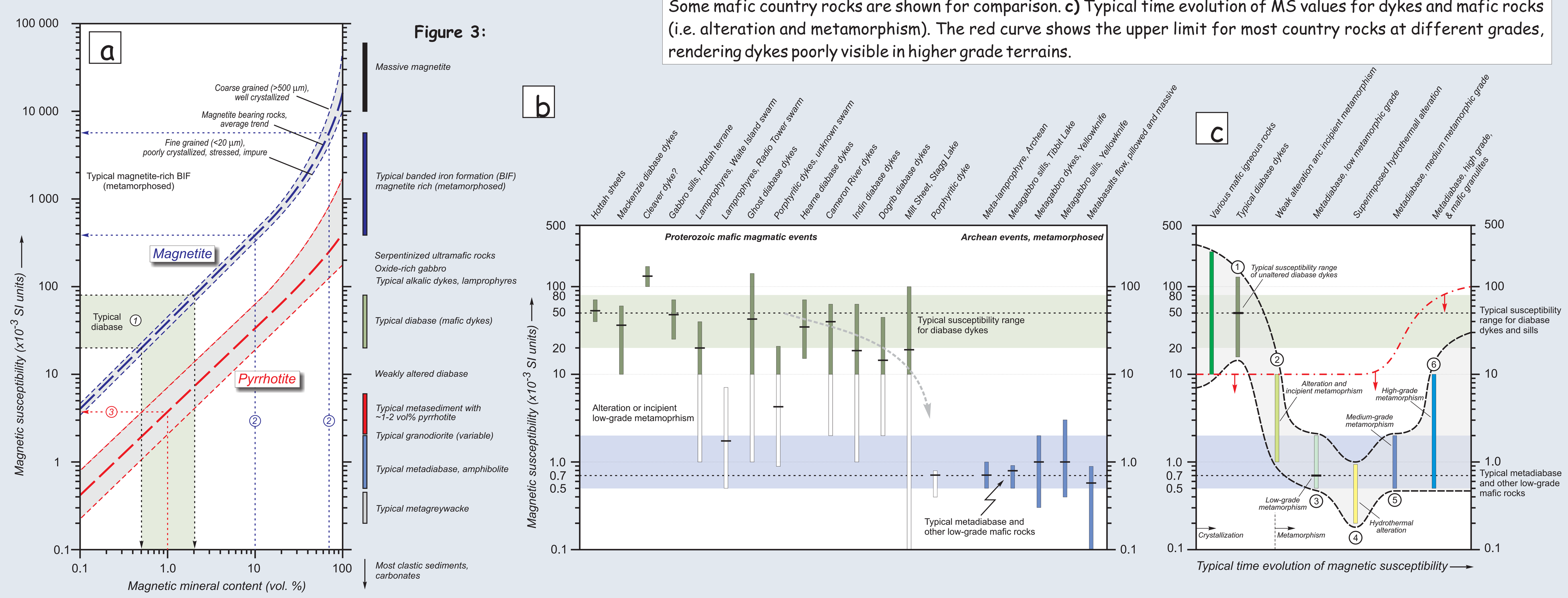


Figure 2, inset: Chilled margin, KT-10 unit for scale

Example 2
MS variation between dyke swarms and with time (metamorphism)

Figure 3: Magnetic susceptibility (MS) variations among various rocks, with an emphasis on diabase dykes.
a) MS as a function of ferromagnetic mineral content (magnetite and pyrrhotite). The ranges are for different grain sizes of ferromagnetic grains, as indicated for magnetite (after Clark, 1997). The typical range for unaltered diabase dykes (~20-80) is indicated (1). Other curves highlight the typical range for magnetite-rich BIFs (2) and (meta)sedimentary rocks with minor disseminated pyrrhotite (3). **b)** Variation of MS values for 14 dyke swarms, western Slave craton, Canada. The low "tails" (in white) of the MS ranges are due to alteration and cryptic metamorphism. Note that older dykes are more affected by such processes. One swarm is clearly metamorphosed. Some mafic country rocks are shown for comparison. **c)** Typical time evolution of MS values for dykes and mafic rocks (i.e. alteration and metamorphism). The red curve shows the upper limit for most country rocks at different grades, rendering dykes poorly visible in higher grade terrains.



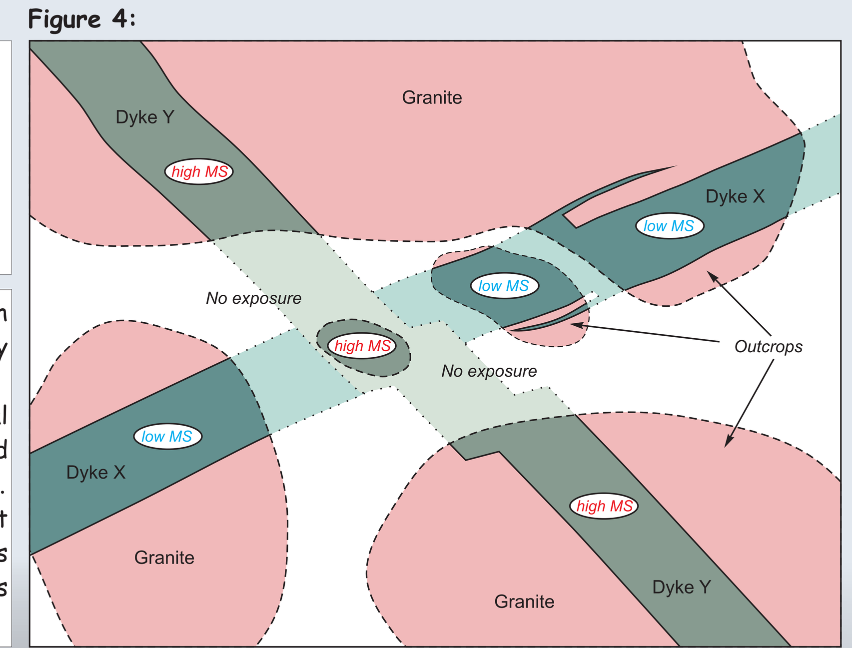
Example 3: Resolving incompletely exposed dyke intersections

An example of two cross-cutting dykes of different swarms (X and Y) is shown in Fig. 4. Such occurrences are critical for establishing relative timing relationships and for establishing primary thermoremanences by carrying out paleomagnetic "baked contact tests".

However, such localities are often incompletely exposed (as shown here), with the actual chilled margins covered by soil or vegetation. If the dykes have distinct MS values, as established away from the intersection area, a simple MS survey can clearly show whether X cuts Y or vice versa.

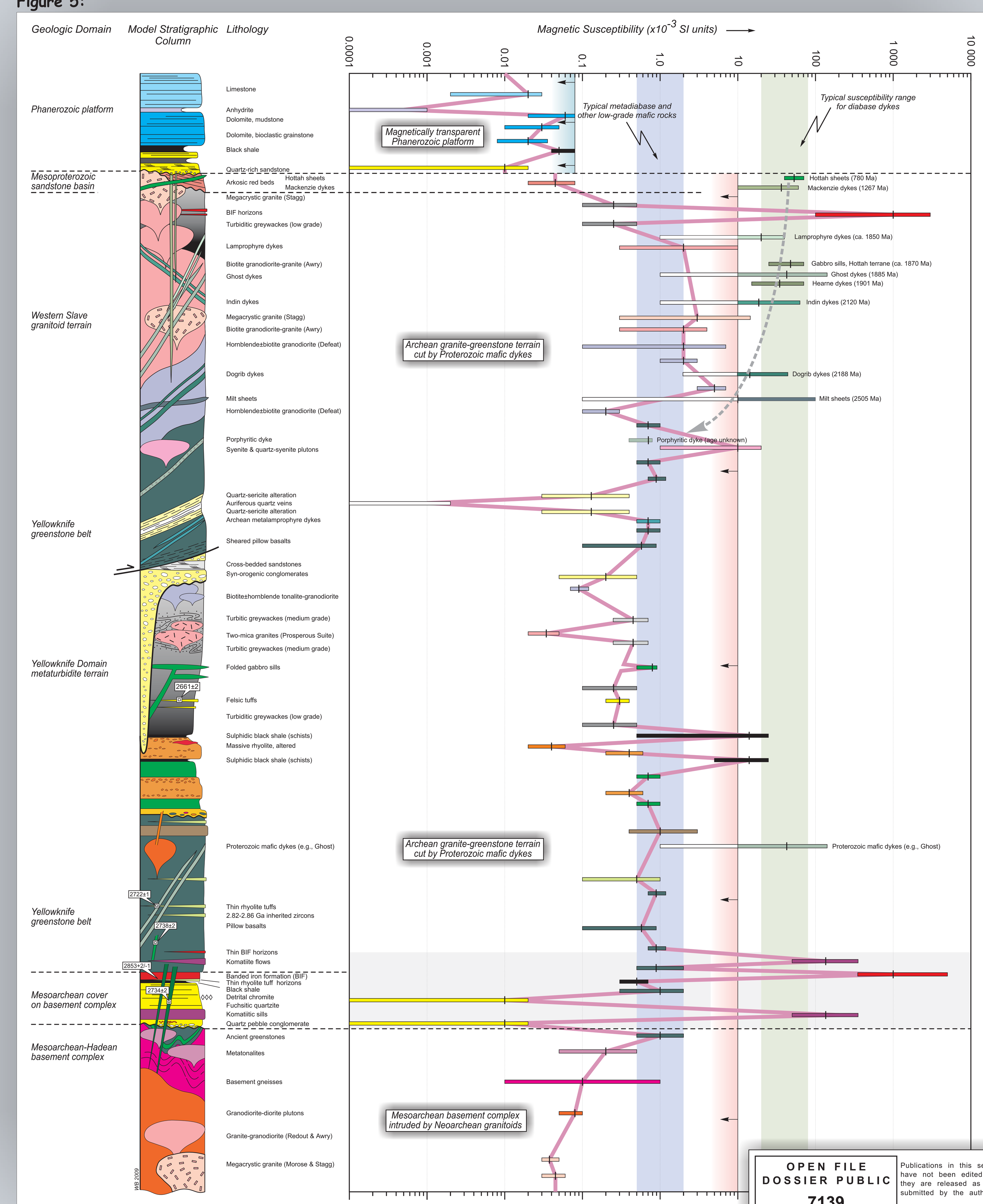
In the example shown the dyke outcrop in the middle has high MS and is thus shown to be part of Dyke Y. Therefore, Dyke Y must cut Dyke X, thus belonging to the younger swarm. Of course, this could be tested further with geochemistry or petrography, but with the susceptibility meter this can be resolved in the field quickly and unequivocally .

Figure 4:



Example 4: Variation of MS in a regional context, western Slave craton. How visible will dykes be in aeromagnetic data sets?

Figure 5:



Conclusions

A hand-held magnetic susceptibility meter is an indispensable tool for regional field studies of dyke swarms, in an ideal case allowing one to distinguish different swarms (if there is enough compositional variation), and to gauge the state of the oxide mineralogy in the field (pristine or altered), and thus often, by inference, to establish an approximate age (e.g., pre- or post-dating a weak metamorphic event). The susceptibility meter can also use it to track differentiation and heterogeneities within individual dykes. Most unaltered diabase dykes have MS values between 20-80 (x10^{-3}) SI units; even weak or cryptic alteration quickly reduces the MS values to <10 and most metamorphosed dykes yield values of 0.7 ± 0.2 (x10^{-3}) SI units (see also Clark, 1997).

The KT-10 of Terraplus Inc., although more expensive and slightly bigger (the size of a flashlight), is the preferred model because it allows one to accumulate a "running average" across a larger dyke or across an outcrop without "timing out". Results are displayed as an average ± one standard deviation. Because of the considerable natural variation in MS values, even in a single rock, of course it are average values, rather than individual spot measurements, that are most useful in characterizing a single dyke, a dyke swarm, or adjacent rocks units.

References

Clark, D.A., 1997. Magnetic petrophysics and magnetic petrology: Aids to geological interpretation of magnetic surveys. AGSO Journal of Australian Geology & Geophysics, v. 17(2), 83-103.

Acknowledgements

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