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Interactive comment on "Magnetic properties of pseudotachylytes, Jämtland, central Sweden" *by* Hagen Bender et al.

Hagen Bender et al.

bjarne.almqvist@geo.uu.se

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Dear editor and reviewers,

Here we address the comments raised by the two reviewers of the manuscript. Our answer to a comment is bounded by dashed lines, to make it easier to separate comment and question. Significant changes have been made to the manuscript, in order to attempt clarification of the objective and message of the paper. We have also made a change to the authorship list, whereby Bjarne Almqvist is now listed as lead author and Hagen Bender is the second author. This change in authorship has been approved by all authors of the manuscript.

The title of the paper has changed to: "Magnetic properties of pseudotachylytes from

western Jämtland, central Swedish Caledonides"

Thank you for your consideration. Bjarne Almqvist and Hagen Bender

The authors examine the magnetic properties, including magnetic fabric in small samples taken from rocks from the Köli Nappe complex. Although the original goal of the authors was to use magnetic fabrics to gain a better understanding of kinematics of a ductile-to-brittle shear zone, they could only show that very small samples may not accurately reflect detailed kinematic information within the shear zone. There were a number of studies that tried to use magnetic fabrics in large-scale shear zones in the early 1970's thru 1980's to gain kinematic information. Many of these were unsuccessful, which led to the suggestion that non-homogenous deformation within the shear zone, or in some cases, late stage deformation overprinting any earlier fabrics due to retrograde metamorphism were responsible for the observed magnetic fabrics. It was not until Ferré and co-workers work that this problem has been looked at by focusing on pseudotachylytes. There are some interesting points made in this paper, such as the fact that one needs to consider whether a "sample" is representative of a larger volume of rock, or what fabric is one observing if a rock has undergone inhomogeneous deformation or multiple deformation phases. The authors, however, need to better develop these points in the manuscript in order that it makes a significant contribution to the field.

——————- In the revised manuscript we have tried to develop these points and improve the clarity of the manuscript in general (see also the answers to comments of the first reviewer). ——————-

The following are comments are in relationship to the magnetic fabrics, and these can be divided into the directional information, or the degree and shape of the AMS ellipsoids. Note that numerous studies have shown that AMS is very good in reflecting preferred directions of deformation. The degree of anisotropy is also often related to the degree of deformation, but not always, and the shape of the AMS ellipsoid is often poorly constrained or at least the most variable parameter.

Directional data from magnetic fabrics agrees with petrofabric and indicates that the host rocks and rocks from the fault developed in the same strain field. Is there any indication that the petrofabric post-dates the faulting? This is an important question in phyllosilicates carry the AMS and these arise from alteration after the faulting event.

——————- There is some indication that at least part of the pseudotachylyte has altered after faulting. This is indicated as altered pseudotachylyte in the manuscript, which has some features of different mineral composition (including mineral magnetic properties) compared to the original pseudotachylyte. ——————-

Can neo-formation of mica and/or biotite account for the common fabric in all rocks? Could Ti-rich oxide be contributing to the paramagnetic contribution? How homogeneous is the mineralogy in the different categories?

——————- There are differences in the mineral composition of the categories of rock considered in this study. Most notably, the host rock is different in mineral composition compared to the rocks that experienced brittle deformation. Notably the biotite is largely absent in the faulted rocks. Chlorite is a potential phase that contributes to AMS in the chloritized fault rock, and the altered pseudotachylyte (pst) contains more chlorite than the pristine pst. It is noted that bulk susceptibility in altered pst is consistently higher than the pristine pst, which appears to arise from a paramagnetic source (i.e., chlorite) rather than a ferromagnetic source (i.e., magnetite), judging from the thermomagnetic curves. In contrast, the pristine pst does contain magnetite, as seen from the susceptibility vs temperature measurements. ——————-

There is a clear relationship between the degree of AMS (Pj) and the "not normalized" mean susceptibility, and the error in mean susceptibility versus sample size, which leads the authors conclude the sample size affects Pj. There are a couple of points that need more clarification. 1) How were the samples measure with the manual 15-position scheme, 3 rotation planes, or "single" rotation scheme?

——————- (1) The samples were measured with the 3 rotation planes scheme. We have now indicated this in the methods section of the text. ——————-

2) What is the analytical error (km standard error) shown in Fig. 12 c; is it obtained from the SAFYR program?

——————- (2) The standard error is obtained from the SAFYR program. We show how this parameter is specifically calculated in the methods section of the text now. ——————-

3) Is the higher P-value related to a weak susceptibility? Normally this is found when mean susceptibility is close to "zero", due to a diamagnetic component of the susceptibility balancing out a para-/ferromagnetic component. In this case is it due to the fact that the small sizes leads to a susceptibility that gets within the accuracy range of the bridge?

——————- (3) Indeed, the measurements tend to have a higher standard error as a function of bulk susceptibility (km). The samples are however clearly paramagnetic, although when the sample size is very small the susceptibility is also very small. Clearly, if the bulk susceptibility would be higher, such as in a magnetite-rich or strongly paramagnetic sample, it is likely that the standard would be reduced even for such small samples. We therefore interpret this effect as a combination of the sample's inherent bulk susceptibility, as well as the volume of the sample itself. We have made a comment on this in the text, on the discussion of the sample size (section 7.5). We have included a figure to highlight this relationship between bulk susceptibility and standard error. ——————-

4) It appears that the grain size of samples is much smaller that the sample size, but is this really the case, i.e., are there enough grains to reflect the anisotropy of a larger volume? I once tried with a shale/slate sample and a biotite crystal to reduce sample size of a cube to see if this affected the AMS. Although I did not go below a 1-cm edge, I did not see an effect. But in these cases, I had very fine grain sizes with respect to

volume or a single crystal.

——————- We believe that the grain size is small enough to sample thousands of grains in the sample (even though it is limited to ∼0.3 cm sides). The are some larger crystals in the host rock, in particular mica, which can more greatly influence susceptibility and its anisotropy. The pseudotachylytes and are considerably more fine grained ——————-

5) Going back to the point with directional data, how variable is the mineralogy between the different types of samples? How variable is the high-field susceptibility extracted from the magnetization versus field measurements?

——————- In regards to the first point, please see answer above regarding the difference in mineral composition (homogeneity of the mineralogy). The high-field susceptibility varies about an order of magnitude, and is typically higher in the altered pst, which coincides with the low field susceptibility measurements. The Ms is higher in the pristine pseudotachylytes, but this is likely due to the contribution of magnetite in these samples. The high-field susceptibility is presented in Table 2 of the manuscript. ——————- 6) Shape is often never a good parameter in looking at deformation, and it is not surprising that the shapes are so variable.

——————- We haven't made a change in the manuscript in regards to this comment, but we acknowledge and agree with this comment. ——————-

Minor comments 1) The authors mention frequency-dependent susceptibility, but do not mention it further in the text. Did they try to measure the AMS at different frequencies, e.g., in the PST APST samples?

——————- We only measured the frequency dependence of bulk susceptibility, but not frequency dependency of AMS. Although this would have been interesting, we didn't note any significant frequency dependence of the bulk susceptibility and therefore did not pursue AMS frequency dependence. The purpose of the freq. dep.

measurements were to identify/investigate the possible contribution of authigenically formed superparamagnetic magnetite in the pseudotachylyte. However, this could not be done based on the results. We have added text to the results section and a new figure, and incorporated these results into the section on results of AMS (the new section is called Anistropy of magnetic susceptibility and frequency dependent susceptibility). ——————-

2) I am not sure how significant an isolation of a ferromagnetic component is in the host rock or APST. I would put little faith in trying to extract a saturation magnetization. They are surely artefacts and I would not even show. In this case, it would have been better to measure the acquisition of IRM. One could have probably gotten a convincingly significant signal that would allow for comparison. ——————-

Indeed the Ms and Mrs in the host rock and APST are artifacts and we have made a note of this in the in the discussion part on the source of magnetic susceptibility and magnetic fabric (although we kept the images in the figure). We agree that IRM acquisition curves would have provided useful results for comparison and determination of saturation remanent magnetization (as well as coercivity of remanence). Unfortunately, we did not have the possibility to carry out such measurements for the revised manuscript. ——————-

Line 18: remove hyphen in information

——————- done ——————-

Line 35: 2.1 instead of 1.1

——————- done ——————-

Lines108-109: in the case that T = 1 or -1, then the ellipsoid is rotationally oblate, respectively prolate. The ellipsoid is still oblate for T> 0, and prolate for T < 0.

——————- We have text to indicate that the ellipsoids are rotational oblate and prolate at T=1 and T=-1, respectively. In the following sentence we now note that the ellipsoid is oblate for T>0 and prolate for T<0. —————–

Line 122: Note that frequency dependence should be detected for particles between ca. 16 to ca. 30 nm for 976 Hz and ca. 15 – ca. 30 nm for 15616 Hz (cf., Hrouda, 2011, GJI).

—————– We have added a point on this in the methods description with reference to Hrouda's 2011 paper. —————–

Line 189: I am not sure what is meant by homogeneous AMS fabrics? Can there be inhomogeneous fabrics?

—————– The wording has been changed as to not create confusion with the term "homogeneous" —————–

Note that numerous references within the manuscript or not in the reference list. The authors should go through this carefully. Some reference for generic information are not needed are do not really reflect the authors who originally presented an idea.

—————– We have sorted the references and removed references deemed not needed, and added the missing references. —————–

Fig. 9: complete figure caption or state that the lower figure shows only the heating curves for a) – c) without labelling.

—————– A sentence has been added at the end of the figure caption to indicate that (d)-(f) are shown for increased visibility of the heating curves. —————–

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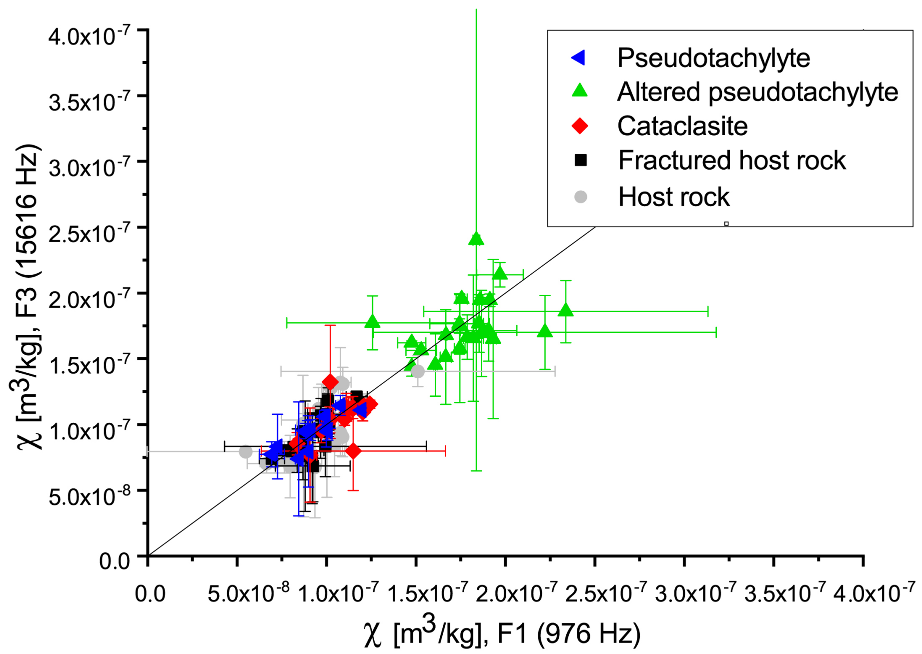

Figure 9. Mass dependent susceptibility (χ) measured as a function of frequency. Error bars represent one sigma standard deviation from repeat measurements of bulk magnetic susceptibility (8 ≥ n ≥ 3). Note that the presentation format of data for the different rock types differ compared Figures 7 and 8, which present the mean magnetic susceptibility, km = (k1 + k2 + k3)/3.

Fig. 1. Figure 9 (new to manuscript)

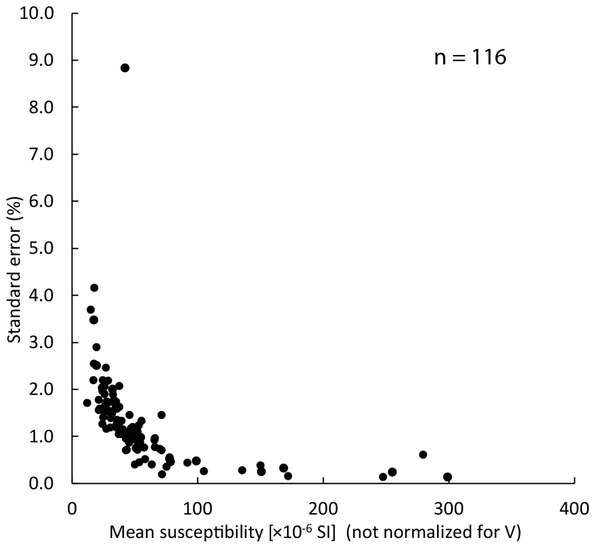

Figure 14. Standard error of the mean susceptibility (expressed in %) as a function of mean susceptibility (not normalized for volume).

Fig. 2. Figure 14 (new to manuscript)