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DISCUSSION

Discussion of 'Classification of fault breccias and related fault rocks', by Woodcock & Mort: the particular problem of pseudotachylyte

Keywords: fault rocks, pseudotachylyte, fault breccia, friction melting, classification.

J. F. Magloughlin comments: I would like to compliment Woodcock & Mort on an important attempt to bring more order to the complex and under-attended world of fault rock classification. The authors aptly point out several of the persistent difficulties in fault rock terminology, such as the original cohesive-versus-incohesive dichotomy in Sibson's (1977) classification, and they appropriately attempt to create a more nongenetic classification scheme.

While understandably not the primary aim of the article, there are at least three issues pertaining to the description and disposition of pseudotachylyte under the proposed classification scheme. Under 'nature of the matrix' (Sibson, 1977; Killick, 2003), 'glass or devitrified glass' has been used as a defining characteristic for pseudotachylyte, and this is carried over into Woodcock & Mort's (2008) construction. The notion that pseudotachylyte is either glassy or devitrified glass (or, presumably, a mixture of the two) probably dates back to when firm identification of glass was technologically difficult, and thus 'glass' meant something similar to *optically isotropic behaviour*, or, by the mid-twentieth century, was thought to be composed of a disorderly arrangement of very small crystals (for a discussion, see Mysen & Richet, 2005). In a modern sense, glass is a solid phase formed by rapid melt quenching with a resultant lack of long-range atomic order, that is, a lack of crystals, though *not* lacking short range order.

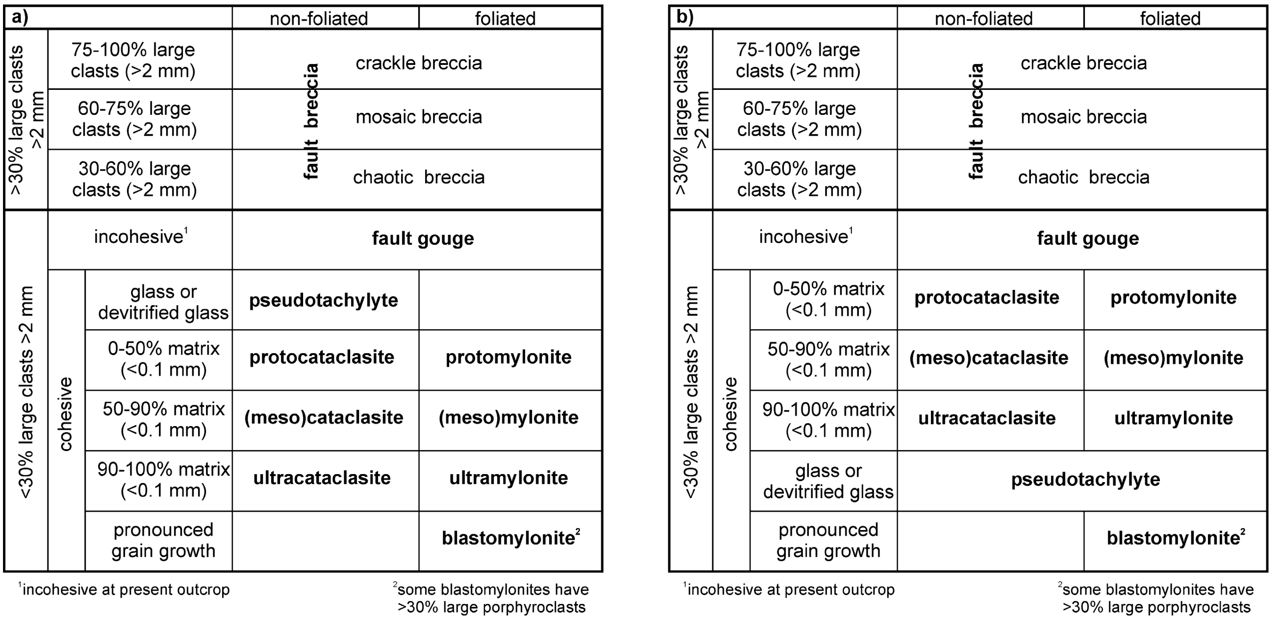
Although this may have been useful, in certain cases, in attempting to create a distinction between pseudotachylyte (produced by melting) and cataclasite (no melting), it also created a red herring resulting in the still-common assumption that the presence of glass or devitrified glass (barring later alteration or metamorphism) is *the* essential test for whether or not something is pseudotachylyte, at least in a tectonic or 'endogenic' (non-impact) setting. Indeed, such thinking may have led Wenk (1978) to state that 'the most important question is whether pseudotachylites intruded cracks as a liquid melt. . .', and then conclude, based on TEM study of a small suite of samples, that 'glass is generally absent' and pseudotachylytes were mostly *not* formed by melting but rather were products of cataclasis.

Despite early suspicions that melting was indeed involved in pseudotachylyte formation (Shand, 1916), it was never a requirement that glass be present initially (e.g. Allen, 1979). Magloughlin & Spray (1992) stated that, for a variety of reasons, '. . .the presence or absence of glass is not a test of a melt origin for pseudotachylyte'. Naturally this applies not just to glass but to devitrified equivalents as well. Thus, the 'glass or devitrified glass' ought to be dropped and replaced with 'evidence for the former presence of a melt phase'. It is this origin by melting that truly defines a pseudotachylyte, is what is sought in the lab if it is not evident in the field, and makes pseudotachylytes physically, energetically and mechanically unique among fault rocks.

Regarding breccias, Woodcock & Mort appropriately discuss the nature of the material in between the clasts, focusing on 'matrix' ('fine-grained particulate material') versus cement, as well as the dividing line between what constitutes 'clast' versus 'matrix', settling on 2 mm as the separation between the two, based on common usage and easy naked-eye visibility. A problem arises with breccias where the interclast material is pseudotachylyte rather than simply matrix or cement. Where pseudotachylyte forms the interclast material, the combination has been called 'fault breccia with pseudotachylyte matrix' or 'quasi-conglomerate with pseudotachylyte matrix' (Sibson, 1975), or 'pseudotachylyte breccia' (Bjørnerud & Magloughlin, 2004). This probably poses no topological problem for the authors' scheme, since chaotic, mosaic and crackle breccia types of pseudotachylyte breccias do exist, although as a result, owing to different scales of observation, pseudotachylyte winds up on both sides of the '30 % large clasts' cut-off. Alternatively, pseudotachylyte ought to be included as an additional type of matrix, although it is commonly easily distinguished from matrix and cement, and it was the difficulty in making a field differentiation between these latter two that led the authors to marginalize this distinction in the first place.

An argument can also be made to relocate pseudotachylyte beneath and adjacent to ultracataclasite *and* ultramylonite (see Woodcock & Mort, 2008, fig. 3), because, origins aside, pseudotachylyte can physically grade into either one (e.g. Magloughlin, 1992), the three can be confused in the field, and ultracataclasis, at least, is likely a common precursor to frictional melting (Spray, 1995). This would allow pseudotachylyte to transgress the non-foliated/foliated boundary, a change that previously occurred in the case of gouge (cf. Chester & Logan, 1987). Pseudotachylytes *are* commonly mesoscopically directionless in vein interiors, yet exceptions exist. Given a non-genetic definition for foliation such as 'a general term for a planar arrangement of textural or structural features in any type of rock. . .' (Bates & Jackson, 1987), it can be argued that particularly in the case of fault veins, features such as flow banding, textural and colour differences between vein margins and interiors, polycyclic (layered) veins, concentrations of clasts, and vesicle collapse features (Magloughlin, unpub. data) do constitute foliation, somewhat akin to the 'flow foliation' in felsic volcanic rocks, and more vaguely, to the 'flow foliation' in glacial ice.

N. H. Woodcock & K. Mort reply: J. Magloughlin usefully highlights the issue of where pseudotachylyte should fit in a classification of fault rocks. The main purpose of our original paper was to incorporate fault breccias more usefully into existing classifications. As Magloughlin recognizes, breccias with a pseudotachylyte infill between clasts fit comfortably into the new scheme. Indeed, these breccias typically show well the progressive fragmentation geometries from crackle breccia to mosaic and then chaotic breccia. As with conventional fault rocks, the 2 mm clast size



a)			non-foliated	foliated
>30% large clasts >2 mm		75-100% large clasts (>2 mm)	fault breccia crackle breccia	
		60-75% large clasts (>2 mm)	mosaic breccia	
		30-60% large clasts (>2 mm)	chaotic breccia	
<30% large clasts >2 mm	incohesive[1]		**fault gouge**	
	cohesive	glass or devitrified glass	**pseudotachylyte**	
		0-50% matrix (<0.1 mm)	**protocataclasite**	**protomylonite**
		50-90% matrix (<0.1 mm)	**(meso)cataclasite**	**(meso)mylonite**
		90-100% matrix (<0.1 mm)	**ultracataclasite**	**ultramylonite**
		pronounced grain growth		**blastomylonite**[2]

[1]incohesive at present outcrop [2]some blastomylonites have >30% large porphyroclasts

b)			non-foliated	foliated
>30% large clasts >2 mm		75-100% large clasts (>2 mm)	fault breccia crackle breccia	
		60-75% large clasts (>2 mm)	mosaic breccia	
		30-60% large clasts (>2 mm)	chaotic breccia	
<30% large clasts >2 mm	incohesive[1]		**fault gouge**	
	cohesive	0-50% matrix (<0.1 mm)	**protocataclasite**	**protomylonite**
		50-90% matrix (<0.1 mm)	**(meso)cataclasite**	**(meso)mylonite**
		90-100% matrix (<0.1 mm)	**ultracataclasite**	**ultramylonite**
		glass or devitrified glass	**pseudotachylyte**	
		pronounced grain growth		**blastomylonite**[2]

[1]incohesive at present outcrop [2]some blastomylonites have >30% large porphyroclasts

Figure 1. The classification of fault rocks (a) from Woodcock & Mort (2008) and (b) as revised here.

provides a useful boundary between pseudotachylyte and fault breccia with pseudotachylyte infill. Magloughlin is right that pseudotachylyte infill can often be distinguished from both a primary matrix and a secondary cement. If it needs to be grouped with one or the other, then it is indeed best regarded as matrix: a component typically generated at the time of brecciation rather than by later precipitation from aqueous solution.

Having limited first-hand experience of pseudotachylyte settings, we hesitate to comment definitively on Magloughlin's other two points. However, if a consensus is developing that pseudotachylyte can grade into foliated mylonite as well as non-foliated cataclasite, then there is clearly a case for expanding the pseudotachylyte box across the 'foliated' as well as the 'non-foliated' column (Fig. 1b), just as we were moved to do with the fault gouge box (Fig. 1a) as compared with previous schemes. This box might indeed then be better placed below the ultracataclasite and ultramylonite boxes.

In the revised version of our classification scheme (Fig. 1b) we have not, however, incorporated Magloughlin's suggestion that the criterion for recognizing pseudotachylyte be changed from the 'glass or devitrified glass' (Sibson, 1977) to 'evidence for the former presence of a melt phase'. This criterion seems too subjective, and seems to take the scheme away from our goal of a 'non-genetic classification ... that can easily be applied in the field' (Woodcock & Mort, 2008). We accept that some rocks identified as glass in the field may, with detailed laboratory analysis, turn out to be cataclasite rather than pseudotachylyte. Similarly it is well known that, under the microscope, some mylonites are revealed as foliated cataclasites. The potential for such revision is implicit in all field-based rock classification schemes, and a laboratory refinement of rock names is often needed for other problematic lithologies such as carbonates or fine-grained igneous rocks. However, we must still be pragmatic enough to allow the field geologist non-genetic rock classifications that can be applied at the outcrop. Qualifications and revisions to field identifications can then be explained explicitly in resulting publications.

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