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Thickness–displacement relationships for deformation zones: Reply

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IN MY original Short Note (Hull 1988), I presented some empirical relationships between thickness (T) and displacement (D) for different types of natural deformation zones in quartzofeldspathic rocks. In the continuing effort for brevity, I will not quote large passages from that Short Note in reply to Dr Blenkinsop's Discussion. The interested reader is therefore urged to read the original note carefully.

Many of Blenkinsop's comments are simply in error. He incorrectly refers to the lines of unit slope in figs. 1 and 2 (Hull 1988) as "bounding limits". These lines illustrate constant D/T ratios *for reference only* and were never referred to as "bounding limits" or "bounds to the data". Blenkinsop is critical of my alleged use of laboratory data, but experimentally determined D–T values were *explicitly* omitted from the compilations. I stated in the original note that the data corresponded to "natural BDZ only" (Hull 1988). The 'displacements' on pseudotachylite-bearing faults from Scotland (Sibson 1975) are actually separations, as originally discussed by Sibson (1975) and repeated in my article. Blenkinsop is also wrong when he states that the pseudotachylite data are "uncorrelated". Sibson (1975) presented a linear relationship between log T and log 'D' for the pseudotachylites, and used this positive correlation to discuss heat-generating capacity and resistance to slip. Blenkinsop incorrectly refers to the data presented in figs. 1 and 2 (Hull 1988) as "completely heterogeneous"; in fact, these plots are dominated by a few individual populations of deformation zones, as will be discussed later.

Many of Blenkinsop's comments seem redundant. He criticizes the temporal growth models of Means (1984) as too "simple", but these models represent end-member behavior of idealized simple shear zones, not natural faults. Fault zones are naturally more complex. For example, "the margins of brittle deformation zones probably strain harden and the zones widen, but the fine-grained portions may eventually soften and accumulate high strains" (Hull 1988). Compare this statement with one of Blenkinsop's principal conclusions: "Different parts of the fault may widen or maintain constant thickness with displacement according to the local relative proportions of strain hardening or softening". The state of stress as a variable controlling T–D relationships, also mentioned by Blenkinsop, was carefully discussed in the original article (see also Robertson 1983, Scholz 1987). Blenkinsop briefly notes other concerns about measuring T and D, the use of average values, the assumption of a growth sequence,

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and the utility of the *T–D* relationships. Much more thorough discussions of all these issues can be found in Hull (1988) and the references cited therein.

One of Blenkinsop's two principal criticisms is that the *D–T* data in my fig. 1 (for example) are "completely heterogeneous" and that fault populations (sets of coeval fault zones) should be represented instead. Of the faults shown in fig. 1 (Hull 1988), six individual fault populations account for 90% of the data. As stated in the original manuscript, many individual populations of deformation zones show similar positive relationships between thickness and displacement (e.g. Engelder 1974, Aydin & Johnson 1978, Otsuki 1978, Mitra 1979, Robertson 1983, Segall & Pollard 1983, Chester & Logan 1986, Wallace & Morris 1986, Hull 1988, Marrett & Allmendinger 1988), comparable to the global population. Blenkinsop is not correct when he implies that populations of faults bear no relationship to the data shown in my fig. 1.

Blenkinsop devotes much of his Discussion to a previously unpublished description of one fault from Spain, along with some speculative remarks based on direct comparisons with laboratory experiments. This fault is defined by en échelon pods, and shows an abrupt variation in thickness with distance along the fault (contrast with Aydin 1978 and Segall & Pollard 1983, among others). Because of the geometry of the clay pods, 10% more strike slip in the direction shown will decrease pod thicknesses to near zero as the walls of the fault come into contact. Further slip along this fault will be halted, unless new fault systems develop or the direction of slip changes substantially; the pods are apparently transient features in the kinematic framework shown and perhaps are unrelated to gouge formation.

Blenkinsop's second principal criticism, based on the above example, is that thickness may vary even though displacement is constant. Nowhere in my Short Note did I claim that fault zone thickness was a single-valued function of displacement; such a claim would be inconsistent with the data, which show a wide variation in thickness for a given displacement (Hull 1988). I stated, for example, that *D/T* ratios "vary by at least two orders of magnitude".

At the end of the note, I referred to recent studies of fault surface roughness (Brown & Scholz 1985, Scholz & Aviles 1986). An alternate explanation to Blenkinsop's model for some of the variation in cataclasite thickness along faults is the interaction of asperities (e.g. Sibson 1986). Measurements of fault zone roughness, parallel to the direction of slip, reveal an approximately proportional relationship between the wavelength and amplitude of asperities (Power *et al.* 1987). With increasing amounts of slip, asperities with increasing amplitudes will interact. A model of asperity wear has been developed by Power *et al.* (1988), which predicts a linear relationship between displacement and thickness of cataclasite with a proportionality constant of approximately 50, similar to the *D–T* relationships seen for many fault systems. Thus individual fault zones would show a variable though characteristic relationship between thickness and displacement that reflects the degree of fault roughness. More studies of the surface roughness of fault zones are required to test the general applicability of this model.

I concluded my original note by emphasizing the obvious need for morphometric and structural studies of both individual faults and fault populations, to answer many of the questions raised by the analysis, and to test some of the hypotheses for fault zone growth (e.g. Otsuki 1978, Robertson 1982, Scholz 1987, Power *et al.* 1988, Yonkee & Bruhn 1988). I thank Dr Blenkinsop for his response.

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