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Shear zone junctions: Of zippers and freeways

Cees W. Passchier [a, *], John P. Platt [b]

[a] Institute of Geosciences, Johannes Gutenberg-University Mainz, J.-J.-Becher-Weg 21, 55099 Mainz, Germany
[b] Department of Earth Sciences, University of Southern California, Los Angeles, CA 90089-0740, USA

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ABSTRACT

Ductile shear zones are commonly treated as straight high-strain domains with uniform shear sense and characteristic curved foliation trails, bounded by non-deforming wall rock. Many shear zones, however, are branched, and if movement on such branches is contemporaneous, the resulting shape can be complicated and lead to unusual shear sense arrangement and foliation geometries in the wall rock. For Y-shaped shear zone triple junctions with three joining branches and transport direction at a high angle to the branchline, only eight basic types of junction are thought to be stable and to produce significant displacement. The simplest type, called freeway junctions, have similar shear sense in all three branches. The other types show joining or separating behaviour of shear zone branches similar to the action of a zipper. Such junctions may have shear zone branches that join to form a single branch (closing zipper junction), or a single shear zone that splits to form two branches, (opening zipper junction). All categories of shear zone junctions show characteristic foliation patterns and deflection of markers in the wall rock. Closing zipper junctions are unusual, since they form a non-active zone with opposite deflection of foliations in the wall rock known as an extraction fault or wake. Shear zipper junctions can form domains of overprinting shear sense along their flanks. A small and large field example are given from NE Spain and Eastern Anatolia. The geometry of more complex, 3D shear zone junctions with slip parallel and oblique to the branchline is briefly discussed.

1. Introduction

Deformation in the deeper crust and mantle is largely accommodated by ductile shear zones, and the geometry of these shear zones has therefore long been a subject of research in structural geology (Ramsay, 1980; Carreras et al., 2010). In many publications, ductile shear zones are treated as straight, homogeneous planar zones, which are uncomplicated with a simple shear flow regime if the wall rock is not deforming. However, such a description is only valid for some central, idealized sections of shear zone systems. Most shear zones form anastomosing branching networks connected by shear zone junctions. Well documented examples are shear zone systems in Brittany (Jégouzo, 1980; Faure et al., 2008), the Alps (Ramsay and Allison, 1979), the Sierra Nevada (Nadin and Saleeby, 2008), SW-Finland (Torvela, 2007), Sweden (Park et al., 1991), NE Brazil (Corsini et al., 1991; Vauchez and Silva, 1992; Davison and MacCarthy, 1995; Weinberg et al., 2004; Archanjo et al., 2008), the Arabian-Nubian shield (Abdelsalam and Stern, 1996; Meyer et al., 2014), the Canadian shield (e.g. Hanmer, 1997; Culshaw et al., 2011; Carreras et al., 2010) and Australia (e.g. Zegers et al., 1998; Raimondo et al., 2011; Zibra et al., 2014). In all these studies, attention mainly focused on the regional tectonic significance of shear zones or details of their internal structure, while little research has been done on actual shear zone junctions. Lamouroux et al. (1991) worked on geometries of conjugate shear zones in the Pyrenees, while Weinberg et al. (2004, 2005), Carreras, 2001, Carreras et al., 2010 and Fusseis et al. (2006) described shear zone junctions from Brazil, Canada and Spain. The work of Carreras (2001), Carreras et al. (2010) and Ponce et al. (2013) is most detailed, and describes the geometry of selected ductile shear zone junctions and the sequence in which they develop. Fliss et al. (2005) and Schwarz and Kilfitt (2008) described fault junctions and experiments on the formation of

* Corresponding author.
E-mail address: cees.passchier@uni-mainz.de (C.W. Passchier).

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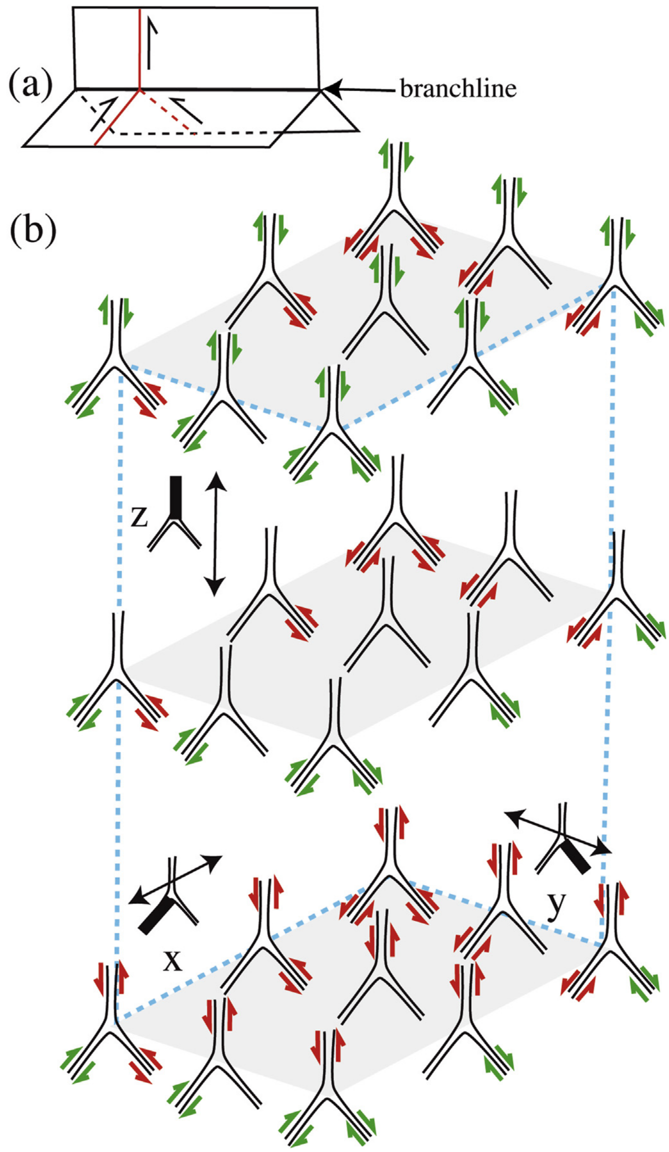

Fig. 1. (a) Shear zone junctions with three branches meeting in a single branchline and with slip direction on the branches normal to the branchline can have dextral, sinistral and no slip. (b) This results in 27 possible geometries. Along each axis of the 3D diagram the shear sense changes on one of the three branches, indicated by the heavy black line in the black-and-white cartoons beside the axis. The blue dotted line connects stable geometries that can accumulate significant slip. Further explanation in text. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

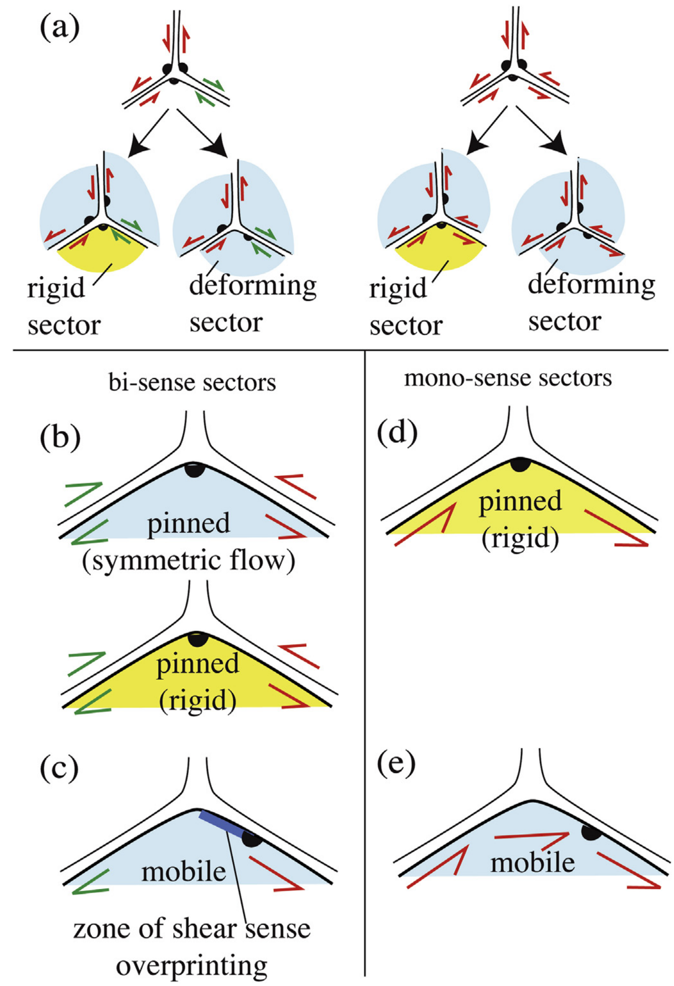

Fig. 2. Shear zone junctions with the same shear sense on branches can show different flow and deformation patterns in individual rock sectors bound by the shear zone branches. (a) Example of two triple junction types with different flow in sectors, but similar shear sense on branches. One or two of the sectors bounding a junction can be rigid, and still allow shear zones to operate. The black marks near the branchline shows whether a sector is fixed or moving with respect to the branchline. (b) Bi-sense sector pinned to the branchline. (c) Bi-sense sector not pinned to the branchline, with overprinting of dextral by sinistral shear sense markers near the branchline, in the zone highlighted in blue. (d) Mono-sense sector pinned with respect to the branch line, which only applies when it is rigid. (e) Mono-sense sector mobile with respect to the branch line, without shear sense overprint. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

such structures. Froitzheim et al. (2006) described junctions that produce extraction faults, and this concept was applied by Mohn et al. (2012) and Fossen et al. (2014).

Previous studies focussed on the geometry of natural shear zone junctions and on the variation in geometry that has been found to date. Although this approach assures that only realistic geometries are studied, it suffers from the inherent problem that only the familiar will be recognised: unusual structures may be overlooked. We therefore take the opposite approach, treating shear zone junctions as a purely geometrical phenomenon and exploring the mathematically possible shapes and arrangements. Although this has the disadvantage that some geometries may be kinematically unlikely, it is a way to draw attention to structures that may exist in nature, but have not been recognised and described to date. We illustrate this theoretical approach with some natural examples with the caveat that they are only examples of what is presently understood, while the theoretical examples we give may encourage discovery of new, unexpected junction types. Our study applies to all scales, from triple junctions between crystals to strike-slip junctions of tectonic plates (Platt and Passchier, 2016).

2. In-plane shear zone junctions

Imagine three shear zone branches meeting at a branchline, bounding three sectors of rock in a 3D cylindrical situation, where