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Geometric description of flanking structures

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Abstract

Present nomenclature of faults and flanking structures is ambiguous. This paper presents a system for description of flanking structures, based on geometric parameters and independent of kinematic frame. The description can be made using two levels of accuracy. A qualitative method is described using four geometric features: tilt, slip, lift and roll. This method is suggested for practical use in the field, since it does not involve measurements or complicated procedures. In parallel, a quantitative approach is also presented, based on analytical modelling of Bézier curves. This method requires measurement of geometric features and involves mathematical treatment, but allows comparison between different flanking structures.
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1. Introduction

Since the first applications of geology in underground mining, people have felt the need to classify geological structures such as faults according to orientation and displacement direction (e.g. Playfire, 1802). At first sight, the geometry of faults cross-cutting layering in rocks seems simple enough not to warrant further thought. Empirical data led to a simple scheme of normal faults, which were the most common in mining areas set in extensional basins, and reverse (or thrust) faults. Further detail was added by Suess (1885) and de Margerie and Heim (1888) who introduced the concept of *fault drag*, the deflection of layers in the vicinity of the fault. Later, fault drag was subdivided into *normal* and *reverse drag* by the work of Hamblin (1965).[1] In combination with the terms footwall and hanging wall, the system seems unambiguous. However, in the sedimentary basins where this fault nomenclature was mainly defined, fault drag usually involves little deflection of layering or foliation towards the faults. In metamorphic, highly deformed rocks, or in more complex systems of faults, geometries produced by fault drag can be more complex. A simple example can describe the kind of ambiguity that can arise in certain cases. The structure depicted in Fig. 1 is an example of a complex structure that deserves careful description in order to avoid misinterpretations. It can be originated in one single deformation episode (cf. Exner et al., 2004) and a natural example is shown in Fig. 8a. The structure can be described both as a normal fault or a thrust in the existing classification. An observer on the scale of the smaller box observes a displacement in the marker typical of normal faults. If the structure is observed only in the far-field (bigger box) one might interpret it as a thrust. This example shows the need of describing accurately the fabric of fault drag, combined with the far-field displacement, in order to make correct interpretations.

Passchier (2001) and Grasemann and Stüwe (2001) expanded the concept of fault drag and defined *flanking structures* also known as *flanking folds*, developed where a host element (HE) is deflected in the vicinity of a cross-cutting element (CE) (Fig. 2). The host element is a planar feature in the fabric of the rock, such as bedding, metamorphic foliation or compositional layering. The

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[1] Note that the widespread concept of *drag folds*, as defined by Leith (1914) and researched by Ramberg (1963) describes subsidiary folds, parasitic folds or minor folds produced by differential movement of adjacent layers.

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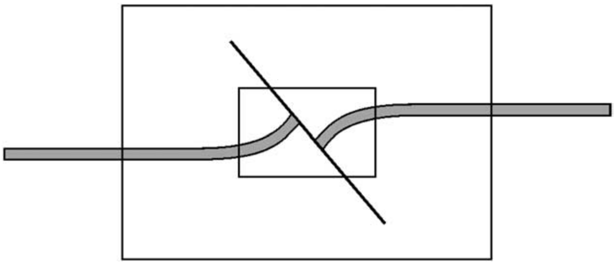

Fig. 1. Example of the ambiguity of fault nomenclature. Considering the arrangement of layering (bigger box) the structure may be classified as a thrust. However, based on displacement close to the fault (small box) the structure would be interpreted as a normal fault.

cross-cutting element is the central part of the flanking structure and can be a fault, a joint, a filled vein, a patch of melt or even a rigid object in the rock such as a mineral or a boudin (Passchier, 2001). Flanking structures were initially envisaged as sub-metre scale structures, but geometrically they can include features such as fault drag, fault bend folds, and any fold developed around an object in a matrix, such as metadolerite dykes (Gayer et al., 1978) and crevasses in ice (Hudleston, 1989). The concept can also include folds developed due to rotation of a rigid object in a matrix, such as the drag folds modelled and described analytically by Ghosh (1975).

Grasemann and Stüwe (2001) and Grasemann et al. (2003) investigated the development of flanking structures adjacent to a cross-cutting element, by simulation of flow around a slip surface in a viscous medium under general shear, by means of finite element modelling. Part of this work was a first attempt to classify flanking structures into three main categories: a-, s- and n-type flanking structures, which can be subdivided into 11 sub-types named A–K (cf. Passchier, 2001; Grasemann et al., 2003). Although this genetic classification, which presumes a known kinematic frame, has been used in forward modelling studies (Exner et al., 2004; Wiesmayr and Grasemann, 2004), field studies have shown that this classification is imprecise and ambiguous when describing natural flanking folds.

In this paper we propose a non-genetic uniform classification system for all types of flanking structures, based solely on geometric criteria in order to avoid upstream interpretation errors. This can be done with two levels of accuracy. A qualitative method is proposed as a descriptive tool to use in the field, while a quantitative method, based on analytical modelling, is also introduced where greater accuracy is needed, such as for comparison of flanking structures. With this method, the classification of flanking structures based on a-, s- and n-types and their 11 sub-types A–K becomes obsolete.

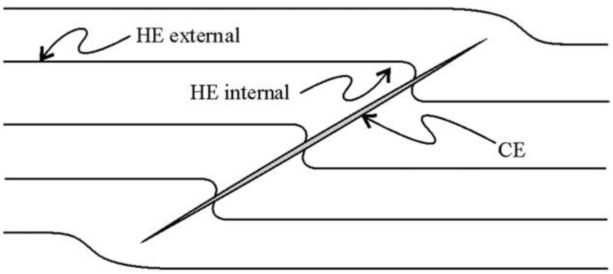

Fig. 2. Schematic representation of a flanking structure. HE—host element, the external far-field component is unaffected by the flanking structure; the internal part of the host element is folded and defines the flanking structure. CE—cross-cutting element.

2. Qualitative classification

The geometry of faults, objects or veins and associated flanking structures can be described by a HE and a CE (Fig. 2). The HE can be subdivided into an external unfolded part, parallel on both sides of the CE (far-field component), and an internal part where the HE can be folded in a complex way. Here we restrict ourselves to simple fold geometries, which are enough to fully describe and classify most flanking structures.

A flanking structure, on one side of the CE, can be described using four parameters, defined according to the geometric relations between the HE and the CE, in a fixed reference frame (Fig. 3). The origin of a Cartesian coordinate system is set at the intersection of the CE and HE. The *x-axis* is oriented to be parallel with the far-field HE, with its positive half according to the dip of CE. In the following text, only hanging wall positions above the CE are described, although the method equally applies to flanking structures in the footwall. In strike slip, this corresponds to the wall away from the observer. This means that the positive *y-axis* is always in the same block as the positive *x*-axis. Notice that by defining the origin in the HE–CE intersection, only the geometry of one side of the CE is described, and that two separate coordinate systems have to be drawn for each side of the CE. This may seem an unnecessary complication but is useful, since flanking structures in the same layer commonly have a different shape on both sides of the CE.

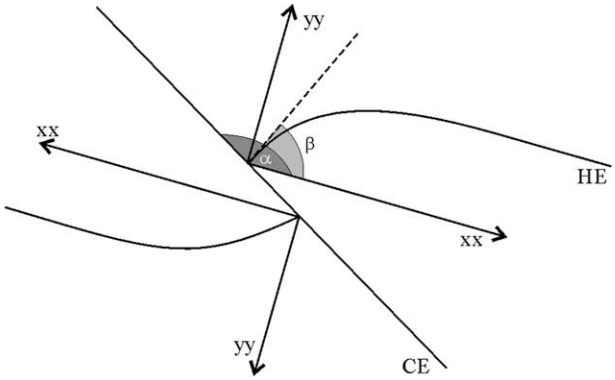

Fig. 3. Geometric features of an idealised flanking structure. HE—host element; CE—cross-cutting element; α—angle between CE and the *x*-axis; β—angle between the tangent to HE at the intersection with CE and the *x*-axis.

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