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Distinguishing syn-cleavage folds from pre-cleavage folds to which cleavage is virtually axial planar: examples from the Cambrian core of the Lower Palaeozoic Anglo-Brabant Deformation Belt (Belgium)

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Abstract

Within the Cambrian Jodoigne Formation in the easternmost part of the Anglo-Brabant Deformation Belt, sub-horizontal to gently plunging folds occur within the limbs of steeply plunging folds. The latter folds are cogenetic with cleavage and are attributed to the Brabantian deformation event. In contrast, although cleavage is also (1) virtually axial planar to the sub-horizontal to gently plunging higher-order folds, shows (2) a well-developed divergent fanning across these folds, (3) an opposing sense of cleavage refraction on opposite fold limbs, and (4) only very small cleavage transection angles, an analysis of the cleavage/bedding intersection lineation suggests that these higher-order folds have a pre-cleavage origin. On the basis of a comparison of structural and sedimentological features these higher-order folds are interpreted as slump folds. The seemingly 'normal' cleavage/fold relationship across the slump folds within the limbs of the large steeply plunging folds is due to the very small angle between cleavage and bedding.

As such, a 'normal' cleavage/fold relationship is no guarantee for a syn-cleavage fold origin. It is not unlikely that also within undeformed, recumbent slump folds, a well-developed compaction fabric, formed parallel to the axial surface of the slump folds, may show fanning and contrasting senses of cleavage refraction on opposite fold limbs.

Keywords: Avalonia; Cleavage fanning; Cleavage refraction; Lower Palaeozoic; Slate belt; Slump fold

1. Introduction

In order to determine the tectonic nature of folds, geologists conventionally rely on the geometrical relationship with related small-scale tectonic structures such as cleavage, fractures and other associated structures (e.g. cleavage/bedding intersection lineations, boudins, mullions) (Wilson, 1961; Ramsay, 1967; Ramsay and Huber, 1987; Price and Cosgrove, 1990). Within the predominantly fine-grained deposits of slate belts, where fractures, being restricted to the few more competent beds, may be scarce, often geologists have to rely on the cleavage/fold relationship in order to establish the syn-cleavage, tectonic nature of the folds and distinguish these from pre-cleavage folds (e.g. Debacker et al., 2001). If a fold has an axial planar cleavage, give or take a small cleavage transection (e.g. Johnson, 1991; cf. Johnson and Woodcock, 1991), and if this cleavage remains parallel throughout the fold or shows a fanning, symmetrical about the fold hinges, and if opposing senses of cleavage refraction occur on opposite fold limbs, most geologists will conclude a syn-cleavage and hence tectonic fold origin (e.g. Wilson, 1961). However, the presence of an axial planar foliation is not diagnostic of tectonic folds (e.g. Elliott and Williams, 1988). By coincidence, cleavage may be virtually axial planar to pre-cleavage folds, in which case it becomes difficult to determine the pre-cleavage nature of these folds (e.g. see contrasting interpretations of early structures in the Newfoundland Appalachians by Helwig (1970), Pickering (1987), Elliott and Williams (1988) and Blewett (1991)). This difficulty is likely to increase with decreasing amount of exposure, with increasing number of tectonic deformation phases and with increasing amount of structural complexity. Probably because of this difficulty, there are hardly any studies that illustrate the behaviour of a cleavage being axial planar to pre-cleavage folds. If cleavage happens to

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be virtually axial planar to a pre-cleavage fold, whether tectonic or due to slumping, does it show opposing senses of cleavage refraction on opposite fold limbs and a cleavage fanning symmetrical about the fold hinge as in the case of the syn-cleavage folds? Similarly, does the cleavage transection angle have an upper limit, beyond which folds can definitely be labelled as having a pre-cleavage origin?

The present study documents close to tight pre-cleavage folds, with a virtually axial planar cleavage, that occur within the limbs of steeply plunging tectonic folds within a low-grade, single-phase deformed slate belt. As will become apparent, pre-cleavage folds may show opposing senses of cleavage refraction on opposite fold limbs and cleavage fans oriented symmetrical about the fold hinges. In the examples shown, in the absence of other criteria, it appears that the best indication of a pre-cleavage origin is the variation of the cleavage/bedding intersection lineation across the folds, even when the axial cleavage transection and profile cleavage transection (*sensu* Johnson, 1991) are almost negligible.

2. Outcrop location and geological setting

The study area is the Jodoigne area, situated in the Grande Gette valley, in the eastern part of the Lower Palaeozoic Brabant Massif, easternmost Anglo-Brabant Deformation Belt (Fig. 1). In recent years, significant progress has been made in the understanding of the structural architecture and the deformation history of the Brabant Massif (e.g. Sintubin, 1997, 1999; Debacker, 2001; Verniers et al., 2002; Debacker et al., 2004, 2005a). Thus far, within the Brabant Massif, there is only evidence for one single-phase progressive deformation, considered to have taken place from the early Silurian to the late Early Devonian (Debacker, 2001; Verniers et al., 2002; Debacker et al., 2005b; cf. Van Grootel et al., 1997). This deformation mainly resulted in the development of folds and a well-developed cogenetic cleavage (Sintubin, 1997, 1999; Debacker, 2001; Debacker et al., 2004). Within the outcrop areas, all situated in the southern part of the massif, two main tectonic fold types can be recognised (Debacker et al., 2004; cf. Sintubin, 1997, 1999). Type A folds consist of sub-horizontal to gently plunging, upright to moderately inclined folds, with a slight south-verging asymmetry and gentle to close, occasionally tight, interlimb angles (Fig. 2). These folds abound within the Silurian and Ordovician southern part of the massif and also occur within the steep Cambrian core. Type B folds (Lembeek fold type of Sintubin (1997, 1999) and Sintubin et al. (1998)) are upright to steeply inclined, steeply plunging to reclined folds, with open to tight interlimb angles and commonly reflect a step-fold geometry (Fig. 2). In contrast to the type A folds, the type B folds are only observed within the steep Cambrian core of the Brabant Massif. As recently demonstrated, within the Cambrian core the transition between the type A and type B folds, both being genetically related to the same cleavage, occurs in a gradual fashion (Debacker et al., 2004). However, the origin of the type B folds remains uncertain. As proposed by several authors (see Sintubin et al., 1998; Sintubin, 1999; Debacker et al., 2004; Piessens et al., 2004), these folds may result from dextral transpression, caused by non-orthogonal shortening against the steep, oblique side of a low-density gravimetric anomaly body situated in the subsurface of the SW-part of the Brabant Massif (cf. Everaerts et al., 1996; Sintubin and Everaerts, 2002). From this model, type B folds would be expected to become scarcer towards the east. However, Fourmarier (1921) already documented the occurrence of steeply plunging folds at Jodoigne, in the easternmost outcrop area of the Cambrian core of the Brabant Massif, but considered these as local features of relatively minor importance. The initial purpose of

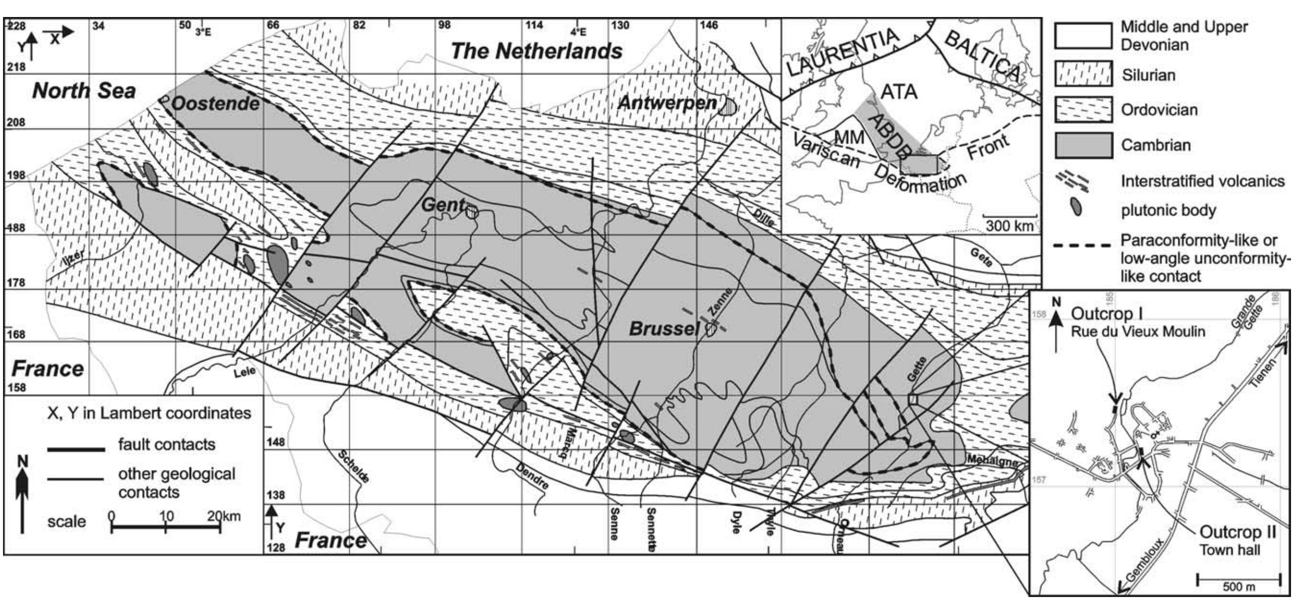

Fig. 1. Geological subcrop map of the Brabant Massif (after De Vos et al., 1993; Van Grootel et al., 1997) showing the position of the study area. The upper right inset shows the position of the Brabant Massif within the Anglo-Brabant Deformation Belt (ABDB) along the NE-side of the Midlands Microcraton (MM) in the context of Avalonia (ATA), Baltica and Laurentia. The lower right inset shows the location of the two studied outcrops at Jodoigne.