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Early "soft-sediment" and late "hard-rock" Variscan deformation features in the Namurian strata at the Namur citadelle (Belgium)

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ABSTRACT

In the Namurian strata at the Namur citadelle (Belgium) the macroscopic morphology of small-scale folds has been described as convolute bedding resulting from an Early Variscan "soft-sediment" deformation, *i.e.* by deformation of unconsolidated sediment. However, a microscopic study shows that these small-scale folds have an axial plane pressure solution cleavage, which developed on a strong, pre-existing bedding-parallel compaction fabric, indicative of a "hard-rock" deformation

KEYWORDS

Convolute bedding, Namur Parautochthon, Namurian, soft-sediment deformation, Variscan Front

Introduction

At the Namur Citadelle (Belgium) Namurian strata, forming part of the weakly S-dipping Devono-Carboniferous cover of the Lower Paleozoic Brabant Massif, are very well exposed. They are folded at different scales. Folds are traditionally interpreted to reflect a Variscan tectonic deformation (*e.g.* Kaisin, 1924), even though the outcrops at the Namur Citadelle are situated about 5 to 6 km north of the so-called Variscan Front.

Vandenberghe & Bouckaert (1984) argued that a number of the deformation features exposed at the Namur Citadelle would be better explained by penecontemporaneous deformation and gravity sliding in unconsolidated sediments rather than by Variscan hard-rock deformation. Arguments for a penecontemporaneous origin include (i) the occurrence of chaotic sandstone blocks in shales, (ii) the occurrence of chaotic shale masses, as well as (iii) the presence of convolute bedding (small cm-scale folds) near fault planes. According to Vandenberghe & Bouckaert (1984) and Bouckaert & Vandenberghe (1987) Variscan tectonics undoubtedly overprinted all the earlier deformation, but soft-sediment deformation and gravity sliding must have been very significant.

It remains unclear, though, exactly which structures in the outcrops can be attributed to early Variscan soft-sediment deformation and which structures can be attributed to late Variscan hard-rock deformation. Moreover, which structures exactly reflect an overprint of Variscan tectonic deformation on penecontemporaneous Namurian age soft-sediment deformation. As a contribution in this discussion, we carried out a microfabric analysis, using optical microscopy on a selection of thin sections of some of the cm-scale fold structures interpreted as convolute bedding by Vandenberghe & Bouckaert (1984) (*e.g.* see Fig. 12 - Vandenberghe & Bouckaert, 1984). According to these authors, these small-scale folds originally developed in not yet consolidated sediments, *i.e.* by a soft-sediment deformation.

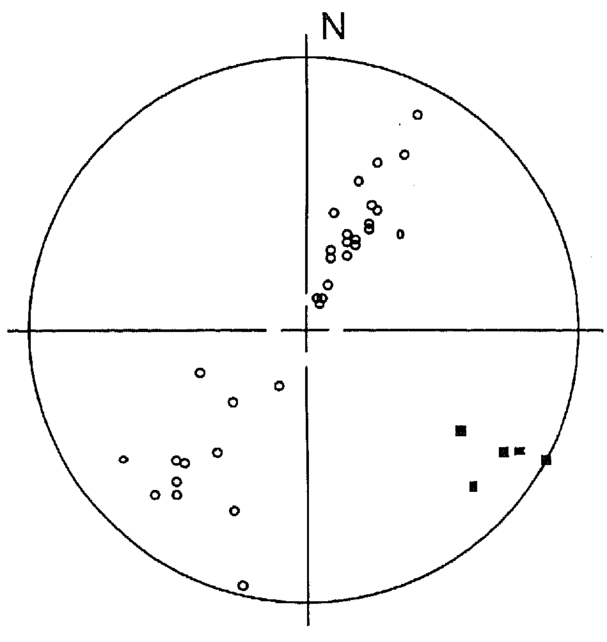


Fig. 1. Orientation of bedding and bedding-parallel foliation planes (S_1) (open circles) and fold axes (black squares) measured at the Namur citadelle. Lower-hemisphere equal-area projection.

Field observations

Oriented samples were taken from the small cm-scale folds ("convolute bedding") in outcops along the Route

Merveilleuse as well as northeast of the Donjon, directly below the Tour des Comtes (see Fig. 1 - Bouckaert & Vandenberghe, 1987). Sampled folds just look like those depicted in figure 12 from Vandenberghe & Bouckaert (1984). We refer to their paper for a more detailed field description of the deformation features. We would like to point out, though, (i) that fold axes of all of the different folds on all scales are oriented remarkably parallel, plunging 10 to 20° towards 120 to 130° (ESE) (Fig. 1), *i.e.* parallel to the dominant Variscan fold axes, (ii) that careful examination of the bedding-parallel foliation planes reveals slickenside striations, commonly oriented perpendicular to the fold axis, and that are folded by the folds, and (iii) that locally abundant fibrous quartz veins are present in folded and fractured parts of some of the larger folds, and which seem to be associated with the folding process. Note, (iv) that a well developed, penetrative bedding-parallel diagenetic foliation has been folded, suggesting that folding took place after a significant compaction.

Bouckaert & Vandenberghe (1987) assumed therefore, that a soft-sediment deformation must have taken place within the early Variscan stress field when sediments were already at a shallow burial dept of some tens of meter. This Namurian foredeep compression ultimately led to the Asturian folding and thrusting at the end of the Westphalian when the now exposed rocks at the Citadelle were buried by about 3 to 4 km. The brittle deformation features and quartz vein filling reflect this Asturian deformation according to these authors.

Microscopic observations

Study of thin sections shows that the samples studied consist of well-foliated sand- and claystones (shales) containing large amount of organic (optically opaque) material, bedding-parallel colorless micas, chlorites, and angular quartz grains.

The bedding-parallel diagenetic foliation (S_1) is a pressure solution cleavage, at least in the quartz-rich parts (Fig. 2a). Colourless micas and seams of organic material are oriented parallel to S_1. In the clay-rich parts the cleavage is more intense and mainly determined by the parallel orientation of colorless micas and seams of opaque organic material. The bedding-parallel foliation is folded in all of the observed folds, *i.e.* folding took place after the development of S_1. No evidence for phase 1 folding is observed. In some of the samples, abundant healed microfractures were observed in quartz grains (Fig. 2b). Healed fractures were mostly oriented perpendicular to S_1.

The small-scale folds where S_1 is folded show an irregularly anastomosing spaced pressure solution cleavage (S_2) developed parallel to the axial plane of the folds (Fig. 2.c,d,e). Quartz clasts are truncated by this cleavage. Originally bedding-parallel colourless micas and chlorites are folded, where phase 2 deformation was intense (Fig. 2d,e). Locally, abundant healed microfractures in quartz grains occur (fluid inclusion trails) (Fig. 2c,d). These are oriented perpendicular to S_2, interpreted to be indicative of a phase 2 origin. Note that S_2 is not always easy to recognize. It is, however, not observed in the field.

Phase 2 folding and foliation development seems to be closely associated with faults, which was already observed by Vandenberghe & Bouckaert (1984). Small-scale, sharp, shear faults crosscut bedding and S_1 and the intensity of S_2 commonly varies on either side of the faults. Orientation and sense of shear of the faults seems related to space problems during phase 2 folding.

Discussion and conclusion

Our microscopical observations lead to an apparent contradiction: while some of the macroscopic features can hardly be interpreted otherwise than as an early tectonic soft-sediment deformation, microscopic features are only indicative of a tectonic hard-rock deformation of the small-scale folds.

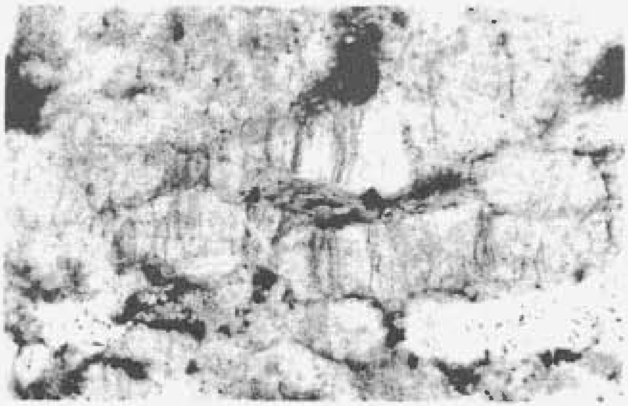
Intense bedding-parallel pressure solution cleavage development (S_1) must have taken place prior to the small-scale folding. A significant burial is needed to generate the penetrative bedding-parallel fabric. Rocks must therefore have been solid before the small-scale folding took place. The phase 2 folds show a microscopically visible axial plane pressure solution cleavage (S_2) indicative of solid state, hard-rock deformation. A tectonic origin of the small-scale folds is further suggested by the remarkable parallelism of the fold axes, the presence of slickenside striations on S_1 perpendicular to the phase 2 fold axes (indicative of flexural slip), the presence of (fibrous) quartz veins associated with the folding, the occurrence of healed microfractures in quartz, oriented perpendicular to S_2, and the microscopic shear faults associated with the small-scale folding.

Note that axial plane cleavage are also reported to occur in truly sedimentary slump folds (*e.g.* Williams *et al.*, 1969; Corbett, 1973; Tobisch, 1984). In these cases, however, the sedimentary cleavage developed by mechanical rotation of inequant grains (especially phyllosilicates), and mainly in disaggregated material in which bedding has been partly or completely destroyed. In our case, the axial plane cleavage (S_2) is a pressure solution cleavage, which in no way could develop by rigid body rotation of inequant grains.

In the light of the combined macroscopic and microscopic features it must be concluded that either some small-scale features have no soft-sediment deformation history, or that at the microscopic scale the soft-sediment deformational features are always entirely overprinted by later hard-rock deformation.

More selective and specific sampling is therefore necessary to detect the remains of an early soft-sediment deformation and to refine the criteria needed to determine the true origin of the features observed at the Namur Citadelle.

a.



b.

c.

d.

e.

Fig. 2. (a) Bedding-parallel cleavage (S_1 horizontal). Quartz grains are flattened and show abundant microfractures oriented perpendicular to S_1 (Long side of micrograph = 1.3 mm); (b) Bedding-parallel cleavage (S_1 horizontal). Flattened quartz grains contain abundant healed microfractures perpendicular to S_1 (Long side of micrograph = 0.65 mm); (c) Axial plane cleavage (S_2 vertical) (Long side of micrograph = 1.3 mm); (d) Enlargement of Fig. 2c.: Axial plane cleavage (S_2 vertical). Folded chlorite stack with axial plane parallel to S_2. Note occurrence of healed microfractures perpendicular to S_2 (Long side of micrograph = 0.5 mm); (e) Axial plane cleavage (S_2 vertical) with tightly folded colourless mica. Axial plane of folded mica is parallel to S_2 (Long side of micrograph = 0.5 mm).

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