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The control of Waulsortian mudmounds (Dinantian) on the geometry of Variscan folds and shear zones in calcareous-shaley series: a comparison between Belgium, Brittany and Southern Ireland

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ABSTRACT

The aim of this paper is to present a key of analysis and some results of our research on the tectonic behaviour (folding and shearing) and role of Waulsortian mudmounds in various sedimentary and tectonic settings of Western Europe, and particularly in Belgium, Brittany and Southern Ireland.

KEYWORDS

Ardenne, Brittany, Dinantian, Irish Variscides, Variscan, Waulsortian mudmounds

Waulsortian mudmounds

In the calcareous and shaley series of the Lower Carboniferous of Belgium, Southern Ireland and Brittany, the "reefal" Waulsortian facies are probably the most particular with regard to their role and behaviour during deformations.
In several papers, Lees and others have defined the "Waulsortian Mudmounds" as an accumulation of Waulsortian banks dominated by an association of polymuds with at least one of the defined grain-types assemblages and lying in the Upper Tournaisian or lowermost Visean (Lees *et al.*, 1985; Lees & Miller, *in press*). Lees & Miller (1985) have discussed the distribution of these mudmounds in Western Europe and North America and the geometry of Waulsortian banks and aggregates defined by the presence of flank and off-bank facies in their mode of aggregation and by the growth forms of Waulsortian banks (tabular, knoll-form, sheet-form, etc.). The classification of growth-forms has been revized by Lees (1994) on the basis of new descriptions in the Galway area to include the composite-forms and to distinguish banks with static margins from those which prograded.
Although the stratigraphical position and sedimentological significance of Waulsortian mudmounds is well known, their tectonic role and behaviour is poorly understood. As anisotropic objects in a well stratified series of limestones and shales and as aggregations constituted of heterogeneous and anisotropic lithosomes, the Waulsortian mudmounds have influenced the geometry of geological structures and the development of shear zones in some regions of the Variscan fold-and-thrust belt of Western Europe.
A structural study has been carried out in three Waulsortian area. From our experience at Furfooz (in the Dinant area), we have tried to project our results and observations on other sites selected for their facility of access and quality of outcrops:

- at Furfooz (Belgian Ardenne near Dinant in the Meuse Valley - Dinant Synclinorium);
- at Bouère and St-Pierre-La-Cour (in the Laval Basin and the small graben of St-Pierre-la-Cour, Brittany, France);
- at Ardmore (Co. Waterford), Loughbeg (Co. Cork) and Muckross (Co. Kerry) in the North Munster Shelf of Southern Ireland (Zone 1 and Zone of transition - Cooper *et al.*, 1986).

In this paper, we compare our results of structural analysis of the studied areas.

Chronology of deformation

In the Furfooz area (Dinant Synclinorium), the Dinantian succession containing the Waulsortian development shows several kinds of tectonic structures mainly of the Asturian orogenic phase: folds (with a syntectonic axial-planar cleavage in the shaley formations), faults and shear zones. The longitudinal fault Chaleux-Vêve has been described as one of the secondary faults of the main Variscan thrusting. Locally, the tectonic structures described are reflecting, in their particular location and attitude, a strong control due to variations of lithology and competence. In comparison with non-Waulsortian zones of the Furfooz area or elsewhere in the Dinant Synclinorium, the anisotropic lithosomes and the massive Waulsortian aggregations have affected the geometry of the tectonic structures: deviation of E-W axial planes of major folds, abnormal reversed fold limbs and strong inclination of local faults and folds axes. Other internal anisotropies in the Waulsortian aggregations have generated an N-S-oriented dextral shear zones (an *en echelon* narrow zone (400 m long), constituted of stretched biomicritic limestones).

In the Laval Basin, the same deformational sequence has been recognized in the quarries of Bouère and St-Pierre-La-Cour (folding and thrusting of the Sudetian-II orogenic phase and later brittle deformations). The Bouère build up was not directly tilted during folding - here accompanied by an axial-planar cleavage - but there is some evidence that its shaley envelope was a zone of preferential shear deformation. At St-Pierre-la-Cour, the N-S compression caused tilting and fracturing, together with local boudinage of a crinoidal bed. E-trending slickensides, present in both build-ups, resulted from shear along the lenticular lithosome at Bouère and from tardi-variscan tectonic NW-SE-oriented reactivating of planar structures at St-Pierre-La-Cour. A final event of brittle deformation produced faults, joints and tectonic veins. Particular structures as kink bands have been recognized in the shaley facies.

At Loughbeg (in the Cork Harbour) and Ardmore (Dungarvan), the folding, accompanied by an axial-planar cleavage, and longitudinal reverse faulting, associated with secondary cross-faults, are also the results of the S-N Asturian compression. The Waulsortian tabular developments have suffered the same kind of deformation as their lateral and surrounding facies. At Muckross (Killarney) we have described a NE-SW transpressive shear zones contemporaneous of the major anticlinal folding.

Structural lithofacies

In order to model the tectonic role and behaviour of the "reefy" and surrounding Waulsortian facies, seven structural lithofacies have been defined. This classification is the result of a close observation and analysis of the lithological and geometrical features of the beds and lithosomes, features that control their competence and aptitude to suffer various kinds of deformation and which define their mechanical particularities.

First of all, we have defined the "series" as (1) simply stratified and calcareous bedding and (2) stratified alternation of limestones and shales or shaley limestones. These planar series have been considered as the references of the "normal" geometry of the deformation, mainly folding, defining the regional tectonic style.

The "Waulsortian aggregates" have been classified in (3) tabular form and (4) lenticular types with significant slopes. The accumulation of this aggregates, with or without surrounding stratified facies of flank or off-bank facies, constitute the major Waulsortian accumulation (or aggregation) which could be have a development of 300 m and various slopes up to 12°.

Finally, three forms of particular "lithosomes" have been defined: (5) intercalations of crinoidal calcareous beds, (6) remote massive lenses and (7) anisotropic dolomitic masses. These lithosomes have been mainly recognized in the Waulsortian aggregations.

Principles of mechanical relations

The mapping and the detailed inventory of the various structures of deformation in the ductile, brittle or shearing conditions of the Variscan deformation have allowed the identification of five principles of mechanical relations between the structural lithofacies. Two of them concern relations between non-adjacent lithofacies and three have been described for adjacent structural lithofacies:

(1) the accordance of a lithofacies to an other non-adjacent lithofacies has been defined when the first adapts to deformations imposed by the other. As an example of this mechanism, we have described the tectonic mobility of remote lenses and dolomitic masses, two lithosomes of the Waulsortian build-ups, which have been tilted during deformations following the folding of the stratified series composing the envelope of the build-ups. These mobility is at the origin of important shear zones in the Waulsortian at Furfooz.

(2) the similarity of two non-adjacent lithofacies is present when they show similar responses and mechanical roles during deformation. The remote lenses and dolomitic masses have for example a similar tectonic behaviour. This similarity also define the same kind of folding of the crinoidal intercalations in the massive Waulsortian mudmounds and identical folding of the stratified series of limestones both from the sole and envelope of the Waulsortian aggregates at Furfooz.

(3) the solidarity of two adjacent lithofacies defines their similar response to deformations they have suffered jointly. At Loughbeg, for example, the Waulsortian lithosome constituted of a tabular aggregate has been deformed exactly like the normal stratified series in the same folding without forms of disharmony.

(4) the disharmony defines the independence of two adjacent lithofacies, which have different tectonic responses during a same participation to the deformation. It is the example of the lenticular aggregates lying in the Waulsortian of Furfooz and which has a different style of folding than the surrounded well-stratified limestones.

(5) the interaction of two adjacent lithofacies implies that one has suffered some deformation at the border of the other owing to the fact of tectonic mobility. The pre-deformation dolomitic lenses of Furfooz have, during their tilting (or tectonic mobility), interacted with the surrounding, more ductile, limestones and influenced the development of localized shear zones.

Models of tectonic behaviour and role

Two models of Waulsortian domain structuration, during the Asturian and Sudetian-II orogenic phases, have been carried out following these principles. In both models, folding is the essential mode of tectonic structuration, eventually accompanied by shear zones and brittle structures of regional importance or due to local effects of the lithofacies anisotropies.

With the strain and stress quantification applied on elliptical objects like crinoidal ossicles, it has been shown that the increase of the deformation in a major transversal shear zone is due to the strong heterogeneity induced by some variations of longitudinal fold geometry. These differences of folding have been controlled by the variable behaviour of

the structural lithofacies and their arrangement at the border of the Waulsortian aggregates or in the heart of them.

At Furfooz, Bouère and Muckross, where the Waulsortian has the form of lenticular-type aggregates or remote lenses, the type I of structuration was defined. It implies the accordance-interaction and disharmony mechanisms in ductile or shearing conditions. The accordance has justified the intrinsic interactions of Waulsortian mudmounds and the disharmony, their privileged role in the formation of abnormal major structures.

At Loughbeg, Ardmore and St-Pierre-La-Cour, where the Waulsortian aggregations are mainly of the tabular-type we have defined the type II of structuration. It has been described as the strong solidarity between Waulsortian limestones and the surrounding sequences in ductile, brittle or shearing tectonic conditions.

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