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The deep structure of the Ardennes Variscan thrust belt from structural and ECORS seismic data: Reply

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Estimating the contribution of the Caledonian deformation on the final geometry of the Pre-Devonian inliers involved in the Ardennes Variscan belt is a long-standing problem. This has led, during the last decades, to two main theories, of which neither completely accounts for all the observed tectonic features: for details see, for example, Kaisin (1936), Waterlot (1937) and Hugon (1982). In such a context, the aim of my paper (Le Gall 1992) only consisted in providing additional constraints for modelling the Variscan deformation undergone by the Ardennes crust, rather than to elucidate the 'Caledonian' problem.

First, in order to correct any misunderstanding, I will recall some of the main concepts presented in the earlier paper (p. 540), which concern the existence of (1) a Caledonian deformation, and (2) a resulting infra-Devonian unconformity (more especially along the northern flank of the Rocroi Massif). However, it will be emphasized that these Caledonian structures have very little effect on the overall geometry of the Cambrian rocks because of the subsequent high strain and pervasive Variscan compressional deformation. In fact, it was also noted by Meilliez *et al.* that no clear Caledonian syncleavage folds have yet been observed in either the Rocroi or Stavelot pre-Devonian inliers.

Numerous microtectonic criteria, although disputed by Meilliez *et al.*, support my kinematic model, and this is further confirmed by deep seismic data.

(1) In agreement with previous detailed microtectonic studies (Hugon 1982), I interpret the Rocroi area in terms of a large-scale northerly-directed Variscan shear zone displaying an inhomogeneous strain that decreases in both vertical (upward) and horizontal (forelandward) directions. On a smaller scale, some rapid strain variations may also lead to close imbrications of highly sheared and low strained rocks. In the less deformed zones, some initial structures, such as for example the infra-Devonian unconformity, may be still partially preserved.

(2) Along the more strongly deformed southern flank, unquestionable microtectonic evidence testifies that the Cambrian–Devonian contact is here involved in a high strain shear zone (for example Roches à Corpias section). In addition, the Gedinnian basal conglomerates (Bogny Formation) are intensely sheared with a conspicuous stretching lineation and *S–C* fabric (Le Gall 1992, fig. 4b).

(3) Although much more debatable, the interpretation of the ECORS deep seismic data also reinforces the tectonic divisions applied to the pre-Devonian substratum of the Ardennes belt. This was achieved by imaging, beneath the shallow detached Devonian cover, two structurally contrasted domains: the Caledonian orogenic belt to the north (Brabant type), and its almost undeformed foreland to the south (Rocroi type).

It must be noted that a quite similar tectonic zonation has also been recognized further west, on the SWAT profiles, in the pre-Devonian crust of the SW British Variscides (Le Gall 1990, Bois *et al.* 1992). Such a large-scale zoning does not preclude, as claimed by Meilliez *et al.*, correlations between the Brabant area and the Midlands craton.

Most of the criticisms of Meilliez *et al.* about my interpretations of these Variscan structures can be answered as follows.

(a) The staircase geometry applied to the frontal fold–thrust system of the Namur external coalfield is constrained by most of the available surface and subsurface geometrical data, as shown on the two cross-sections (a and b) of the evolutionary thrust template (Le Gall 1992, fig. 7). This is corroborated by recent work (cited in Le Gall, p. 521) that demonstrates, with high quality seismic data, that ramp–flat thrust tectonics played a leading part in the shortening process in the Pas-de-Calais Carboniferous coalfield, and in the entire frontal belt of the N. France Variscides (Le Gall in press). In my view this thrust model provides a more suitable solution than the 'recumbent fold' concept, previously proposed by Raoult & Meilliez (1986), and which leads to unrestorable sections as discussed by Houchen (1988).

(b) Concerning the ECORS seismic data, it must be noted that my kinematic model is derived from a stack section which integrates unpublished explosive shot data, and these additional constraints significantly improve the seismic picture of the Ardennes crust with regard to the previous work of Cazes *et al.* (1985).

Although slightly oblique to the regional compression direction, the ECORS profile shows quite strikingly similar crustal structures to those observed on the nearby DEKORP line (DEKORP Research Group 1990) preferred by Meilliez *et al.*, and such correlations may reflect, in agreement with the regional tectonic pattern, significant lateral continuity (disputed by Meilliez *et al.*) of the overall Ardennes Variscan belt.

(c) A further point about the ECORS data is that, by providing a well-defined image of the deep structure of the northern France Variscan crust, they lead to discussion, with the usual cautions associated to any seismic studies, of the kinematics of the crustal processes that have controlled the initiation, as well as the subsequent inversion and deformation, of the Ardennes Devono-Carboniferous basins. Indeed, the prominent southerly-dipping seismic feature that dominates my kinematic model (structure 2–3 on section 5a) is regarded as a long-lived crustal structure, located along the southern edge of the Brabant Caledonian basement. Its multi-staged reactivation perfectly accounts for some important stratigraphic and tectonic aspects of the entire Ardennes Paleozoic succession, such as: (1) the dramatic southerly-thickening of the Devonian clastic sedimentary wedge; (2) the Rocroi basement hangingwall culmination; and (3) the overall bulk shortening experienced by the overlying Devonian detached cover.

All these concepts are ruled out by Meilliez *et al.*, which is surprising as one of the authors has recently applied quite a similar crustal kinematic model to the nearby Stavelot basement inlier by using DEKORP deep seismic data (Fielitz 1992).

Combining micro-scale up to crustal-scale tectonic criteria, as far as I know, constitutes the first attempt to define precisely the overall style of crustal deformation undergone by the external Variscides of Northern France. Such an approach may be one of the most fruitful ways to understand a fold–thrust belt.

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