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THE DINANT NAPPES : A MODEL OF TENSIONAL LISTRIC FAULTING INVERTED INTO COMPRESSIONAL FOLDING AND THRUSTING

BY

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ABSTRACT

The widely extended Midi-Aachen thrust faults (largely traced as a seismic reflector occurring at a depth varying between 2 and 8 km below the thrust-folded Dinant Nappes in Belgium and contiguous areas of the Federal Republic of Germany and northern France) presumably represent inverted listric growth faults. This is illustrated by the structural-depositional history of the Ardenne and Brabant Massifs, in which the gradual, diachronous change from a tensional into a compressional setting played a decisive part.

RESUME

Les grandes failles de charriage Midi-Aachen (tracées tel un réflecteur sismique présent à des profondeurs variant entre 2 et 8 km en-dessous de la nappe charriée et plissée de Dinant en Belgique et dans les régions limitrophes de la République fédérale d'Allemagne et du nord de la France) représentent probablement des failles listriques inversées. Ceci est illustré par l'histoire des dépôts et des structures des massifs ardennais et brabançon, dans lesquels les changements graduels, diachroniques, d'un système d'extension à un système de compression ont joué un rôle décisif.

KEY WORDS

Dinant Nappes, synsedimentary tensional faulting, inversion, compressional folding and thrusting.

MOTS CLE

nappes de Dinant, faille synsédimentaires distensives, inversion, plissement et charriage par compression.

1.INTRODUCTION

The Ardenno-Rhenish massifs in southern Belgium and the adjacent French border area, and the central-western part of the Federal Republic of Germany consist of Paleozoic rocks at or near the surface. To the north, these massifs are bordered by the Brabant Massif (characterized by Cambro-Silurian rocks directly overlain by post-Paleozoic deposits) in the west, the Lower Rhine Embayment (with lignite-bearing Cenozoic sediments) in the centre, and the Münster Basin (which came into existence during the Late Mesozoic, and largely masks the underlying coal-bearing Carboniferous of the Ruhr Basin) in the east. To the east of the Rhenish Massif, the Hessen Depression occurs with its thick infill of Permian and Mesozoic sediments, whereas the Late Paleozoic rocks of the Saar-Nahe Graben (almost perpendiculary interrupted by the roughly N-S directed Rhine Graben) form its southern flank. Finally, the northern outliers of Mesozoic and Cenozoic deposits of the Paris Basin extend over the southern and western parts of the Ardenne Massif.

Within the Ardenne Massif, three synclinoria (Neufchâteau, Dinant and Namur) can be distinguished, which are separated by the High Ardenne anticlinorium marked by outcropping, Caledonian deformed Cambro-Ordovician massifs (Rocroi, Serpont and Stavelot-Venn), and by the Midi-Aachen thrust faults. The Eifel area with its small, carbonate-filled meso-Devonian synclines separates the Ardenne and Rhenish Massifs. The Rhenish

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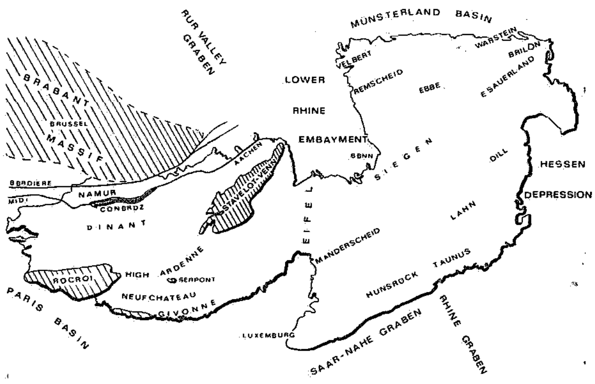

Figure 1. : Ardenno-Rhenish Massifs and location of some principal structural elements. Diagonal hatching : Cambro-Silurian rocks.

Massif is largely characterized by occasionally extremely thick (possibly well over 5 km) Early Devonian, siliciclastic deposits, which, especially in the south, may have been strongly affected by tectonic deformation (Hunsrück and Taunus). Younger Devonian (usually rather thin, up to a few hundred metres) and Dinantian sediments line the northern and eastern flanks of the Rhenish Massif. Cenozoic volcanic rocks locally disturb or mask the Paleozoic features in the central portion of the Rhenish Massif.

Biostratigraphic and lithostratigraphic investigations have resulted in detailed correlations between the Devonian and Carboniferous rocks in the Ardenno-Rhenish area, despite their frequent and often abrupt changes in facies and thickness and strong deformation by folding and faulting. For a better understanding of their paleogeographic context, it is, however, necessary to restore the actually folded and faulted rocks into their original palinspastic position (figure 2). This "ironing out" of tectonic deformation (exceeding 100 % in case of overturned deposits or some rocks telescoped by overthrusting) may result in a stretching of far more than 50 % of the actual length of cross-sections.

Calculation of the relative or absolute amount of tectonic shortening may be complicated by the fact that a distinction should be made between horizontal and vertical components of deformation. For example, vertical downwarp does not require horizontal stretching for a palinspastic restoration of a faulted section. Also, it might be possible that the actually observed tectonic shortening has been preceded by extension, so that a palinspastic reconstruction cannot be achieved by a simple stretching of folds and faults. In the case of synsedimentary faults, it has been observed that the rate of movement along the fault plane may strongly vary and even become inverted at intervals (figure 3, cf. Baldschuhn *et al.*, 1985 ; Kockel, 1987 ; Rossa, 1987). Lastly, and for many geologists perhaps superfluously, it is noted that there is no relationship between the observed length of a fault plane (whether this is a vertical or a horizontal one) and the amount of displacement along the same.

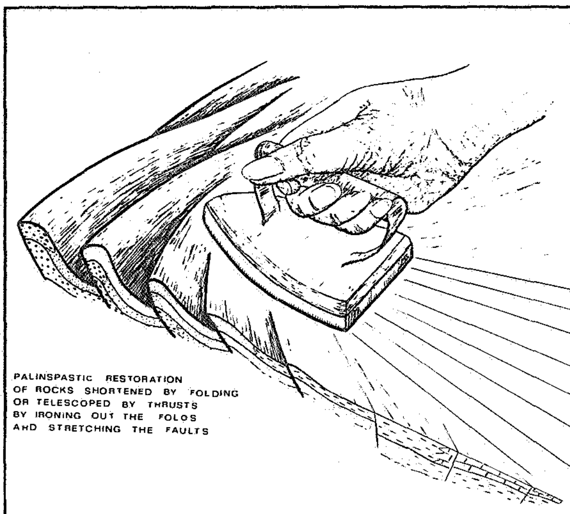

Figure 2. : Cartoon showing principle of "ironing out" rock deformation for reconstruction of paleogeography and sedimentary-structural history of an area.

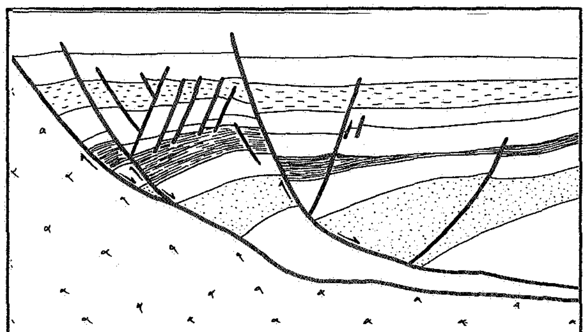

Figure 3. : Hypothetical model of listric growth fault (not to scale).

All these complications are encountered in the Belgian Ardenne, where the Midi-Aachen thrust faults have been interpreted in quite different ways in the recent literature (Bless *et al.*, 1977 ; Raoult & Meilliez, 1986 ; Michot, 1988 ; Paproth, 1988).

According to the classic model, the Midi-Aachen thrust faults show a minimum of lateral displacement ("aucunes des failles qui apparaissent dans le profil d'Aachen, depuis l'Aachener Ueberschiebung jusqu'à la Venn Ueberschiebung n'évoque autre chose qu'un chevauchement ordinaire dont l'ampleur est celle du rejet stratigraphique", Michot, 1988, p. 162 ; "dans le cadre de la Bande calédonienne de la Sambre-Meuse, il n'existe aucun fait, faciétal ou autre, qui permette de faire appel à des translations importantes", Michot, 1988, p. 166). One of the main arguments for this theory is the "bande silurienne de Sambre-et-Meuse" or "Condroz Anticlinorium", where presumed parautochthonous Silurian rocks separate the synclinoria of Dinant and Namur (Michot, 1988).

On the other hand, seismic exploration has revealed the existence of a shallow (2-6 km) reflector which can be traced from north to south over a distance of about 100 km into the Paris Basin (Cazes *et al.*, 1985 ; Raoult & Meilliez, 1986), and which somehow seems connected with the Midi-Aachen thrust faults in the north. This reflector has not only been observed in the western part of the Dinant Synclinorium, but also in the central part (Graulich, 1982 ; Havelange- Porcheresse borehole, Graulich *et al.*, 1989) and in the east around the Belgian-German frontier (Aachen-Hohes Venn area ; Bartelsen & Meissner, 1979 ; Durst, 1985 ; Betz *et al.*, 1988).

Because of the apparent continuity between the Midi-Aachen thrust faults and this reflector, the latter has been interpreted as a vast detachment or overthrust plane, separating the underlying basement from the overlying allochthonous Dinant Nappes (Bless *et al.*, 1977, 1980 ; M. & R. Teichmüller, 1979 ; Bois, 1988 ; figure 4).

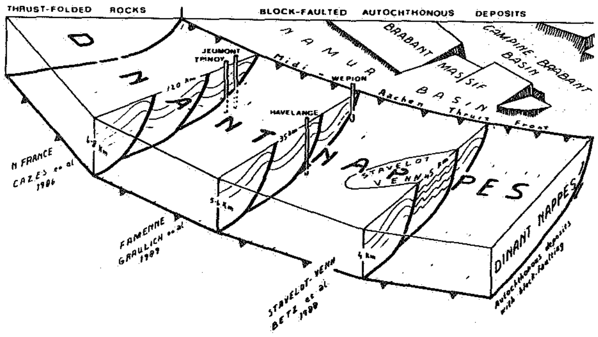

Figure 4. : Model of Dinant Nappes with thrust-folded rocks overlying autochtonous, block-faulted deposits (modified after Bless *et al.*, 1980).

Of course, this apparent continuity between the Midi-Aachen thrust faults and this reflector has not been accepted by everybody. For example, Michot (1988) seriously doubted this relationship ("En s'inspirant de la Faille d'Aachen, on a interprété ce réflecteur comme en étant le prolongement. Cette interprétation nous paraît peu correcte, car ce raccord proposé se fait de façon brusque, à angle vif, le réflecteur horizontal venant directement à l'encontre de la Faille d'Aachen d'inclinaison 20°S. Or telle n'est pas l'image que donnent les failles de charriage en profondeur").

As stated above, the recognition of a thrust plane that can be followed over a distance of about 100 km from the north to the south does not necessarily imply that the allochtonous northern front of the Dinant Nappes has been horizontally transported over the same distance, even so when a considerable overthrust has been proved by boreholes (Jeumont and Epinoy in northern France ; cf. Raoult & Meillicz, 1986).

Nevertheless, an important horizontal (northward) displacement of the Dinant Nappes was already proposed by Fourmarier (1913), who evoked the presence of coal-bearing Upper Carboniferous belonging to the Namur Basin below the Dinant Synclinorium (figure 5). This author accepted the presence of almost 1500 m of Early Devonian sediments immediately south of the Condroz Anticlinorium (whereas the Early Devonian is completely absent to the north of this structure in the Namur Synclinorium) as one of the most important arguments for a major displacement along the Midi Overthrust ("la preuve la plus convaincante de la grande distance qui séparait à l'origine ces deux régions").

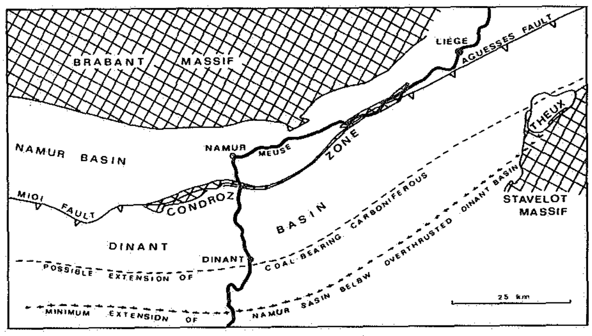

Figure 5. : Possible extension of autochthonous coal-bearing Upper Carboniferous strata and suggested miniumum extension of Namur Basin below overthrusted Dinant Basin according to Fourmarier (1913). For a review of the evolution of Fourmarier's ideas with respect to this problem, the reader is referred to Michot (1988).

However, this phenomenon may also be explained by adopting a different model. The rather abrupt disappearance of Early Devonian deposits to the north of the Condroz Anticlinorium might as well have been caused by erosion or by the presence of an Early Devonian shore line at the position of the present thrust fault. In this context, reference should be made to a paper by Sandberg *et al.* (1982), who claimed that "the present position of the late Early Mississippian shelf edge corresponds closely to that of the leading edge of the late Mesozoic Sevier thrust system (in the overthrust belt of Montana-Nevada, western United States), and the abrupt changes in thickness, bedding and competence of Mississippian rocks at this shelf edge may have been a factor in determining the position of later thrusting".

A similar coincidence is claimed here between the abrupt disappearance of the Early Devonian rocks at the northern border of the Dinant Synclinorium and the position of the outcrop of the Midi-Aachen thrust faults. This rather steeply inclined northern front of an otherwise almost subhorizontal thrust plane might be explained by accepting that the steeply dipping front originally developed as a normal (listric) growth fault during the Early Devonian. Similar listric, tensional faults may have preceded the thrust fault front along the High Ardenne (Rocroi-Serpont-Stavelot-Venn) Anticlinorium, and possibly the complex "Faille Bordière" separating the Namur Synclinorium and the Brabant Massif (Figure 6).

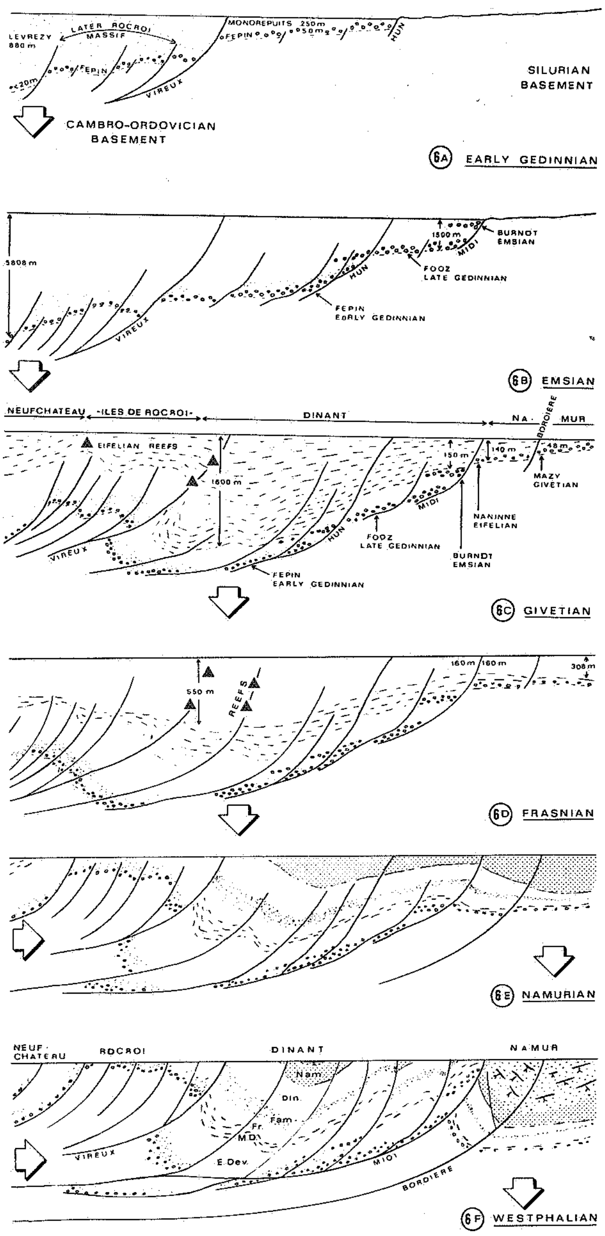

Figure 6. : Strongly schematized depositional-structural history of Belgian Ardenne Massif s.l. during the Devono-Carboniferous (no horizontal or vertical scale). Names and thicknesses are indicated only for overall orientation. Relative thickness of individual strata exaggerated in order to illustrate mechanism of shifting depocentres and interplay of tension-compression influences. Number and shape of faults and folds are completely fictitious.

In our opinion, this model somehow reconciliates the classic idea of a Midi thrust fault with only limited horizontal displacement and the undeniable presence of a widely extended seismic reflector that can be traced over a distance of about 100 km to the south of the outcropping Midi-Aachen thrust faults.

2. TENSION - COMPRESSION MODEL

In a recent study of the Early Devonian synsedimentary tectonics around the Rocroi Massif in southern Belgium and northern France, Meilliez (1987) discovered and described tensional (listric) faulting (fig. 7), which had produced a stepwise southward increasing thickness of Early Gedinnian sediments from 300 m in the north to 800 m in the south (cf. figure 6A). A similar listric faulting may have taken place along the southern flank of the Condroz area since the Late Gedinnian, where the Early Devonian sediments have an estimated thickness of 1400-1500 m (figure 6B). The absence of Early Devonian sediments in the Namur Basin north of the Condroz Anticlinorium is here interpreted by the acceptance of a shore line at the position of this anticlinorium. Rapid downwarp of the Dinant block would explain the considerable accumulation of Early Devonian siliciclastics to the south of a fault-bounded shore line, comparable to the Early Mississippian shelf edge in the western United States (Sandberg *et al.*, 1982).

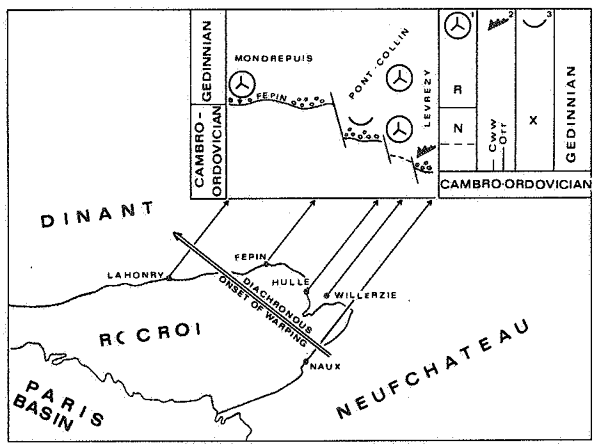

Figure 7. : Diachronous onset of warping and deposition in area of Rocroi Massif (after Meilliez, 1989). Biostratigraphic dating of strata based on spores (1; after Steemans, 1989), conodonts (2; after Borremans and Bultynck, 1986) and fossil fauna (3, after Milhau *et al.*, 1989).

Presumably, tensional listric faulting, marked by a stepwise increasing thickness of Devonian sediments, has not been limited to the Midi-Aachen and High Ardenne (Rocroi-Stavelot) lineaments. For example, the Bordière Fault (Faille Bordière of Legrand, 1968), which runs parallel to the southern border of the Brabant Massif within the Namur Basin, may have acted as a normal fault from the Early Givetian onwards (figure 6C). Also the distribution patttern of Frasnian reefs within the Dinant Basin (Tsien, 1981), roughly lined up parallel to the Midi-Aachen and High Ardenne lineaments, suggests the existence of several masked faults underneath (figure 8).

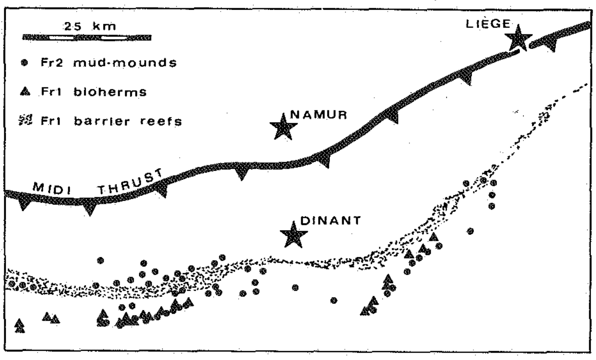

Figure 8. : Parallelism between Midi-Aachen thrust front and linear arrangement of some Frasnian reefs in Dinant Basin (after Tsien, 1981).

Although these lineaments are normally shown as uninterrupted lines on structural maps, they rather consist of a complex of small and not necessarily continuous faults, as suggested by the slightly different ages of individual fault activity. In addition, the areas in between these "Variscan" (E-W or NE-SW striking) lineaments are subdivided into smaller tectonic units, each of them having its own structural and sedimentary history. This can be deduced from the distribution pattern of Early Frasnian reefs in the Dinant and Namur synclinoria (cf. Tsien, 1981), and also from the extreme variation in thickness and facies of Dinantian deposits in the Namur Basin *sensu lato* from west to east (area west of Namur, "auge hennuyère" with more than 2000 m Dinantian carbonates and evaporites ; area to the east with less than 500 m ; Bless *et al.*, 1980). These and other examples indicate that the area south of the Brabant Massif was originally block-faulted (cf. Colbeaux *et al.*, 1977 ; Paproth *et al.*, 1986 ; Paproth, 1988).

Thus, during the Early Devonian, there existed extreme differences in the rate of downwarp along the Midi-Aachen and High Ardenne lineaments. This is illustrated by the variation in thickness of the deposits (cf. figure 6A-B ; thickness of Gedinnian deposits increasing from 1300 to 2200 m at the border between Dinant and Neufchâteau basins ; thickness of total Early Devonian increasing from 0 to 1500 m at the border between Namur and Dinant basins, reaching a maximum of about 5000 m in Neufchâteau basin).

From the Middle Devonian onwards, the rate of subsidence decreased considerably. This can be deduced from the maximum total thickness of these (except for the Famennian) frequently carbonate-dominated deposits of Middle Devonian to Late Dinantian age (figure 9). This period of almost 60.10^6 years may therefore be considered as a time of relative tectonic relaxation (interrupted by the Bretonnic movements during the Famennian, marked by increased influx and deposition of siliciclastics), as compared with the Early Devonian rapid downwarp of maximum 5000 m in the Neufchâteau Basin within a timespan of about 20.10^6 years.

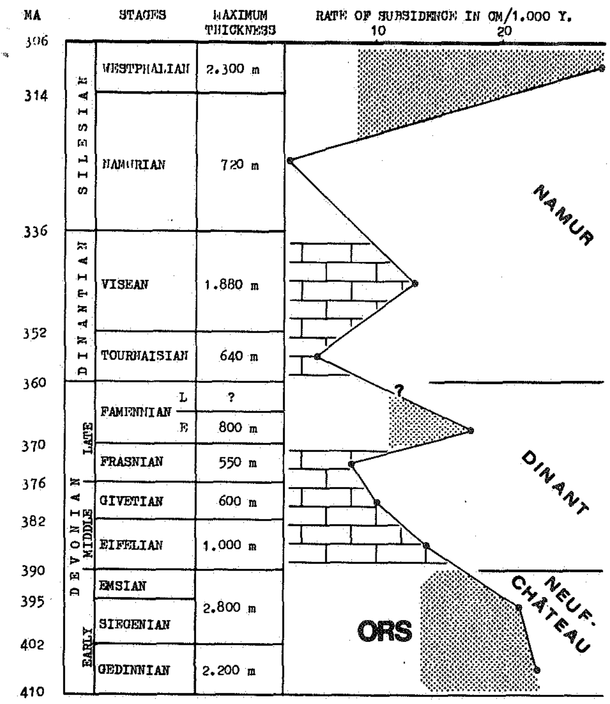

Figure 9. : Variation in maximum rate of subsidence (= maximum observed thickness : duration of stage in MA) in Ardenne Massif during Devono-Carboniferous. Chronostratigraphy form Haq & Van Eysinga (1987). Note that highest rates of subsidence occur during deposition of predominantly siliciclastics. Also note shift of maximum thickness of deposits from Neufchâteau (Early Devonian) through Dinant (Middle to Late Devonian) into Namur (Dinantian to Silesian) basins.

Comparison between the thickness of Devono-Dinantian deposits in the northern Dinant Basin and southern Namur Basin (figure 10) shows a similar trend : maximum difference of subsidence during the Early Devonian, minimum differences during the Eifelian-Frasnian and Dinantian, slightly increased difference during the Famennian (echoing the Bretonnic movements to the south in the Variscan internides).

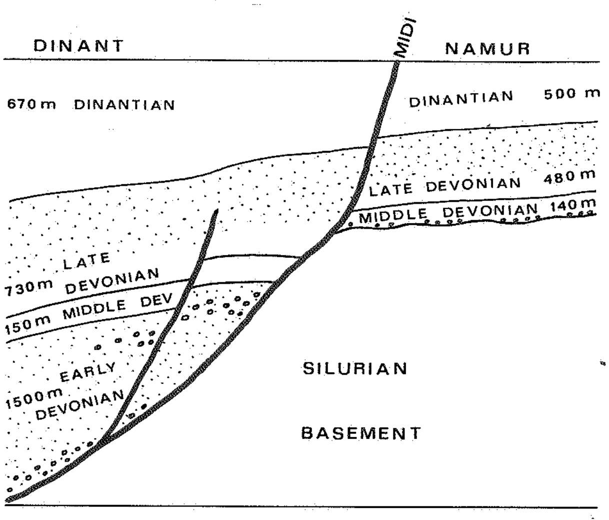

Figure 10. : Difference in thickness of Devono-Dinantian deposits on both sides of Midi Fault due to differential synsedimentary warping, starting earlier in Dinant Basin (Early Devonian) than in Namur Basin (Middle Devonian). Note that differential warping seems more pronounced during periods of predominantly siliciclastic deposition (Early Devonian, Famennian).

The slowdown of downwarp during the Middle Devonian was again a differential process (figure 9). In and around the area of the later Rocroi Massif (High Ardenne Lineament), subsidence must have been minimal and perhaps even temporarily inverted into upwarping during Eifelian times when small bioherms developed in that region ("Iles de Rocroi" of Tsien, 1981 ; cf. figure 6C). Presumably, transitory inversion of tectonic movements may have taken place at random in time and space within the Ardenno-Rhenish Massifs (also cf. Paproth *et al.*, 1986).

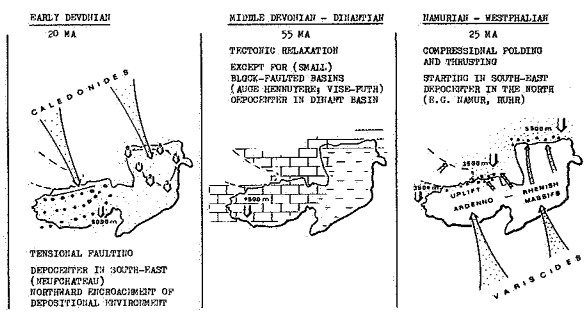

Figure 11. : Gradual change in structural-depositional setting of Ardenno-Rhenish Massif during Devono-Carboniferous. Depocentres indicated by downwardly directed arrows. Note counter-clockwise arrangement of (inverted) Early Devonian depocentres (1-6) in Rhenish Massif (based on Paproth, 1988)

From the Latest Dinantian to Early Silesian onwards, a new tectonic style becomes evident in the Ardenne area, when the first signs of foreland compression (replacing the tensional tectonics of the Early Devonian to Middle Dinantian period) appear in the south-east (Neufchâteau Basin and High Ardenne Anticlinorium) and subsequently spread to the north and northwest as a result of increasingly important Variscan (Sudetic) movements (figure 11).

In the Dinant-Namur region, the depocentre presumably shifts from the Dinant into the Namur Basin (figure 6D-F). Simultaneously, the Neufchâteau Basin and High Ardenne Anticlinorium become updomed and eroded, as illustrated by southerly-derived Namurian to Early Westphalian conglomerates (Burgholz/Walhorn, Gedau/Andenne and Finefrau ; cf. Bless *et al.*, 1980). Also the overall northward shift of the onset of paralic conditions (earliest Namurian, E2, north of the Stavelot-Venn Massif in the northeastern Dinant Basin ; late-Early Namurian, H1-2, in the Namur Basin, and Late Namurian, R2c-G1, in the Campine-Brabant and Ruhr basins ; cf. Bless & Paproth, 1989) yields good evidence of the northward migration of the Variscan foredeep (depocentre) conditions and of the area incorporated in compresional uplift and erosion. This northward shift of uplift, erosion and basin edge/axis seems to have started earlier in the east than in the west as illustrated by the diachronic westward extension of conglomerate facies (earliest Namurian Burgholz/Walhorn conglomerate limited to Aachen area in the north-east, late-Early Namurian Gedau/Andenne conglomerate irregularly distributed along line Aachen-Namur).

These compressional tectonics resulted in inverse movements along the former listric (tensional) fault planes. The originally more steeply dipping, ramp-like fronts now acted as natural buttresses for the shortening and telescoping process, whereas various sedimentary weakness zones (consisting of e.g. clay of evaporites) may have acted as subhorizontal shear (detachment) planes between the more or less undisturbed (only block-faulted) basement and the overlying strongly folded rocks.

Within the geological record of the Belgian Ardenne, the gradual change from a tensional into a compressional setting during the Devono-Carboniferous is not a unique process without precedents. On the contrary, the onset of subsidence in the southern Ardenne (Neufchâteau, Rocroi-Stavelot/Venn, southern Dinant) during the earliest Gedinnian succeeded a period of active uplift of that region during the Silurian (figure 12), when the Rocroi-Venn area supplied siliciclastics into the Condroz-Brabant region to the north as illustrated by the repeated presence of well-preserved reworked Ordovician acritarchs in the Silurian deposits of the Condroz Anticlinorium (Martin, 1968 ; Martin *et al.*, 1970). This situation was again preceded by a period of downwarp during the Cambrian when basinal facies prevailed in the Rocroi-Venn area against (outer) shelf conditions on the Condroz-Brabant blocks (Walter, 1980 ; Bless *et al.*, 1980).

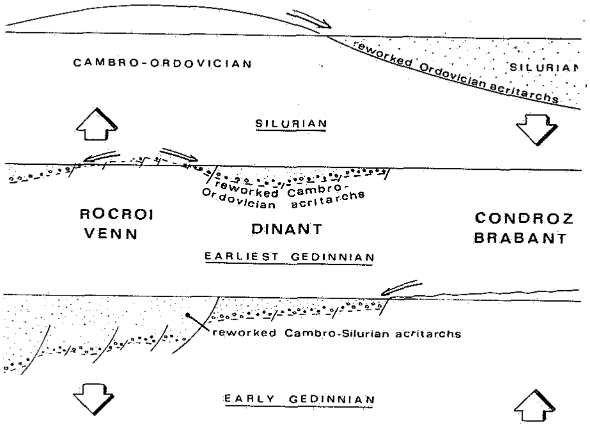

Figure 12. : Scheme of gradual change in structural-depositional setting in Ardenne and Brabant Massifs around the Silurian-Devonian boundary. During the entire Silurian (possibly already starting in Ordovician time) the Rocroi-Venn region forms part of the source area of siliciclastics deposited to the north and northwest (Condroz, Brabant Massif) as illustrated by repeated reworking of Ordovician acritarchs in the Early to Late Silurian strata of the Condroz (Martin, 1968, Martin *et al.*, 1970). Diachronous inversion of the warping started during the earliest Gedinnian and rapidly prograded to the north. During the earliest Gedinnian, the Rocroi-Venn region formed local sediment sources, as can be deduced from the relatively large number of reworked Cambro-Ordovician acritarchs in the basal Gedinnian deposits around the Rocroi and Stavelot-Venn massifs (Steemans, 1989). But, in slightly younger Gedinnian deposits, also reworking from the north (Condroz zone, Brabant Massif) becomes evident because of the increasing number of reworked Silurian acritarchs (Steemans, 1989).

This succession of tension-compression movements during the Paleozoic suggests rhythmic activity of deep-seated "blocks" in the basement, which apparently oscillate around a critical equilibrium (marked by periods of tectonic relaxation ?). It seems attractive to accept that the boundaries between the principal Devono-Carboniferous structural units (Neufchâteau, High Ardenne, Dinant, Condroz, Namur, Brabant) represent some of the long-lived lineaments separating these basement blocks.

In this context, reference should be made to the herringbone pattern of deep seismic reflectors within the Pre-Cambrian basement of the Brabant Massif (Bouckaert *et al.*, 1988). This pattern which shows some resemblance to the "crocodile tectonics" (Meissner, 1989) may be the result of the same oscillating movements during the Pre-Cambrian. This in turn implies that the here inferred lineaments are of Pre-Cambrian age (figure 13).

Lastly, the occurrence of Post-Paleozoic tectonic activity along at least some of these lineaments should be noted, as for instance, the Stavelot-Venn Massif (NE High Ardenne Anticlinorium), where repeated warping during the latest Createaceous (Campanian and Maastrichtian ; Demoulin, 1987a ; Bless & Felder, 1989) and Tertiary (Oligocene ; Demoulin, 1986) was each time succeeded by active uplift (as illustrated by present-day uplift and fault movements ; Demoulin, 1987b).

Late Cretaceous and Oligocene to Recent movements have also been detected along the Bordière Fault in Belgium (Legrand, 1968) and its eastern extension in the southeastern Netherlands (Bless & Bouckaert, 1988).

3. DISCUSSION

Repated warping and uplift of the present-day Ardenne and Brabant massifs as a result of an as yet not completely tangible succession of tension-compression movements since Pre-Cambrian times is evident from the now available data. These also illustrate that the gradual northward shift of the area involved in (maximum) subsidence and subsequent uplift during the Devono-Carboniferous only represents a (long-lasting) event within a succession of similar ones.

Inversion of tensional into compressional movements along the same fault planes in the Ardenne area explains the steeply inclined, ramp-like fronts of, for example, the Midi-Aachen thrust faults. Apparently, these fronts originated as normal faults during the initial phase of tensional subsidence. The dip of these fronts and the shape of the listric fault planes have been enhanced and deformed by additional faulting and folding during the later compression.

Additional faulting also seems responsible for the fact that some slices of rock could be "left behind" by the compressional thrusting. But, following the experience of the Havelange borehole (Graulich *et al.*, 1989), the age of such slices underneath the subhorizontal component of the thrust planes will never differ greatly from that of the overlying, thrust-folded deposits. On the other hand, however, synsedimentary underthrusting and subsequent overthrusting has produced extreme differences in the age of overlying rock masses near the fault fronts, as can be deduced from the data yielded by the boreholes of Epinoy, Jeumont and Wépion (cf. figure 4 ; Raoult & Meilliez, 1986).

Presumably, the inversion of tensional into compressional movements in the Ardenne area resulted in an overall restoration of the earliest Devonian setting. This explains the fact that no arguments have been detected in the sedimentary record which might prove or even indicate that these had been formed at considerable distances

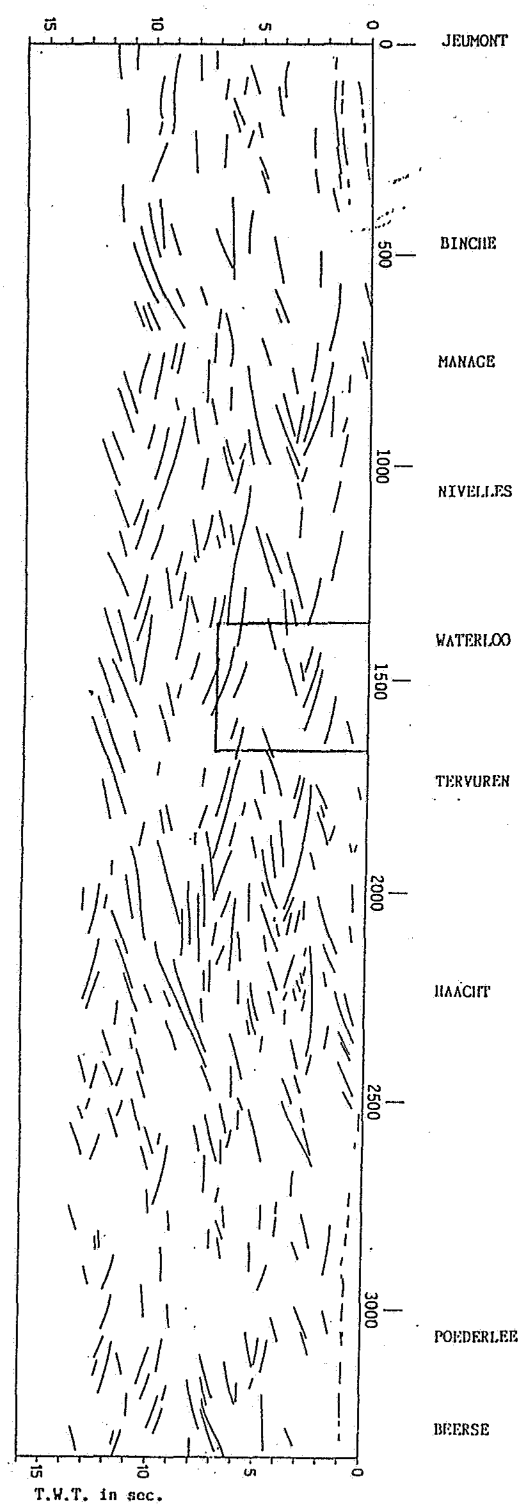

Figure 13. : Herringbone pattern of inferred deep seismic reflectors below Brabant Massif (from Bouckaert *et al.*, 1988), possibly caused by repeated inversion of structural setting of Ardenno-Brabant region. Fat lines mark boundaries between different dip trends.

from each other. On the contrary, independent of each other many authors have come to the conclusion that the paleogeographical (palinspastic) distance between the deposits of the thrust-folded Dinant Nappes and the area to the north has never been very large. In this context we may refer to Wrede (1989) for the Namurian and Westphalian deposits in the Inde and Wurm synclines, and to Poty (1989), Paproth *et al.* (1986) and Thorez & Dreesen (1986) for the Devono-Dinantian in the Dinant and Namur basins.

The hypothesis that the actual thrust faults originated as listric growth faults also explains the occasionally abrupt changes in thickness of deposits occurring on both sides. Because of the different rates of subsidence of the adjacent blocks, some of these faults may have produced natural ramps on the sea floor, which can be characterized either by narrow belts of special environments (e.g. Frasnian reefs and mudmounds ; cf. figure 8) or by rather abrupt changes in the lithofacies (e.g. Late Famennian model of synsedimentary tectonics described by Thorez & Dreesen, 1986).

The occasionally block-faulted appearance of the widely extended seismic reflector of the Midi fault (e.g. in Havelange area ; cf. Bless *et al.*, 1977) may have been produced by the short-cutting of the various subhorizontal weakness zones formed by the originally listric fault planes.

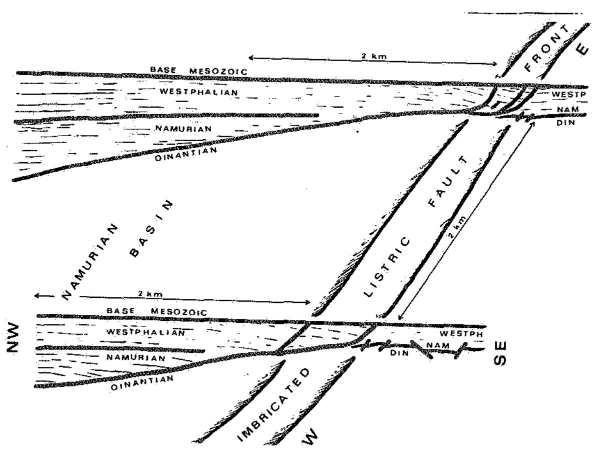

Figure 14. : Imbrication of (E-W directed) listric fault front in Silesian strata north of Brabant Massif. Sections based on (NW-SE directed) seismic lines 8011 and 8013 in the Meer area of northern Belgium (after Vandenberghme, 1984). The southward (near the listric fault front) wedging Namurian basin serves as a model for the listric origin of the Midi Fault, which borders the northwardly wedging Early Devonian deposits in the Dinant Basin. In a similar way, the structural-depositional history of the Westphalian sediments around this listric fault front seems to be similar to that of the Middle Devonian to Dinantian deposits around the Midi Fault (also compare figure 10).

Lastly, it should be noted that the frequently imbricated thrust front might be the inversion of an imbricated listric fault front. North of the Brabant Massif, for example, such imbricated listric fault fronts occur in Silesian

(Namurian/Westphalian) rocks in the subsurface of northern Belgium (figure 14 ; Vandenberghe, 1984).

Like all models, the one presented here is necessarily an oversimplification of an extremely intricate process. This process was in turn influenced by many other changes in the global environment not considered here (continental drift, climate, sea-level, vegetational and faunal communities, extinction events, rate of evolution, etc.). However, their role in the structural-depositional history of this area has been deliberately omitted from the discussion for the sake of clarity of the point to be emphasized here :

The widely extended subhorizontal seismic reflector below the Dinant Synclinorium indeed represents the southward prolongation of the Midi-Aachen Thrust Faults. However, this thrust plane largely consists of inverted and occasionally shortcut preexisting listric growth fault planes. There is no need to assume a horizontal displacement of the thrust-folded Dinant deposits that would exceed distances of a maximum of a few (tens of) kilometers;

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