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# The Variscan Front and the Midi Fault between the Channel and the Meuse River

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**Abstract**—The ECORS seismic profile allows a new insight into the deep geology of northern France. Various geological data, such as ancient coal mines, surface mapping and boreholes, are used to interpret the seismic profile. A new cross-section, directly superimposed on the ECORS seismic profile (Cambrai-Dreux), is compared with a previous one, drawn along the Meuse River through the Ardenne Massif. The cylindrism and length-balancing hypotheses are discussed by comparing the two cross-sections. The main geological results are: (a) the emplacement of the Dinant Nappe is later than most of its internal deformation; and (b) major folding and thrusting give an approximate 30–35% shortening, without taking into account the internal deformation (minor folding and cleavage) and the unknown net translation vector of the Dinant Nappe (50 km at least, possibly 150 km).

**Résumé**—Le profil ECORS du Nord de la France permet un regard renouvelé sur la géologie profonde de cette région. Les données géologiques disponibles, anciennes et récentes (exploitation minière, cartographie de surface, forages d'exploration), permettent de tenter une interprétation géologique du profil sismique. Ceci est fait à l'aide de deux coupes, l'une le long du profil sismique, l'autre le long de la vallée de la Meuse au travers de l'Ardenne. Leur étude comparative conduit à discuter les hypothèses de construction (cylindrisme et équilibrage). Les principaux résultats géologiques sont l'*antériorité de la déformation interne* de la Nappe de Dinant sur sa mise en place finale, l'étendue vraisemblablement réduite du bassin houiller, vers le Sud sous la Faille du Midi; l'estimation approximative à 30–35% du raccourcissement par plis et failles, compte non tenu de la déformation interne (plis mineurs et schistosité) ni de la flèche de déplacement de la Nappe de Dinant (50 km au moins, 150 km peut-être).

## INTRODUCTION

THE ECORS seismic profile (ECORS = Etude des Continents et des Océans par Réflexion Sismique), carried out through northern France, shows that the Midi Fault corresponds to a reflector for more than 100 km in a north–south direction (Cazes *et al.* 1985). The Midi Fault therefore appears to be a major overthrust of the northern external Variscan belt (Fig. 1). Beneath this reflector, a second deeper one appears to cap the seismically transparent Brabant basement. Between these two reflectors lies a 2–3 km thick zone pervaded by numerous short seismic reflectors, with various attitudes. Northwards, this zone thickens as it becomes shallower, and appears to coincide with the coal basins of northern France and southern Belgium. This seismic image is therefore similar to that obtained from seismic profiles farther east, all of which are interpreted as indicating a deep overthrust underlying the whole Ardenne Massif (e.g. Teichmüller & Teichmüller 1979, Meissner *et al.* 1981, Graulich 1982, Murawski *et al.* 1983, Becq-Giraudon 1983). The new data corroborate a previous interpretation based on coal mines and surface geological surveying (Fourmarier 1913).

The aim of this paper is to suggest a geological interpretation of terranes located on either side of the Midi Fault. The data for this interpretation come from the ECORS profile, and from farther east, along the Meuse River, which exhibits good exposure through the Ardenne Massif. The seismic profiles delineate a framework within which geological mapping, coal mining, and ancient and recent boreholes (Fig. 1) provide compelling data for further interpretation.

## THE EPINOY CROSS-SECTION

Previous industrial seismic profiles, and the northernmost end of the ECORS profile, led to the line drawing presented here (Fig. 2). The Gouzeaucourt borehole at the SSW end of the profile was drilled down through the Mesozoic cover of the Paris Basin, then through Dinantian (Early Carboniferous) carbonates overlying a right-way-up Couvinian to Famennian (Middle to Late Devonian) series. Below this borehole, Early Devonian strata must occur above the Midi Fault, which

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✠ Professor Raoult died on 8 February 1987.

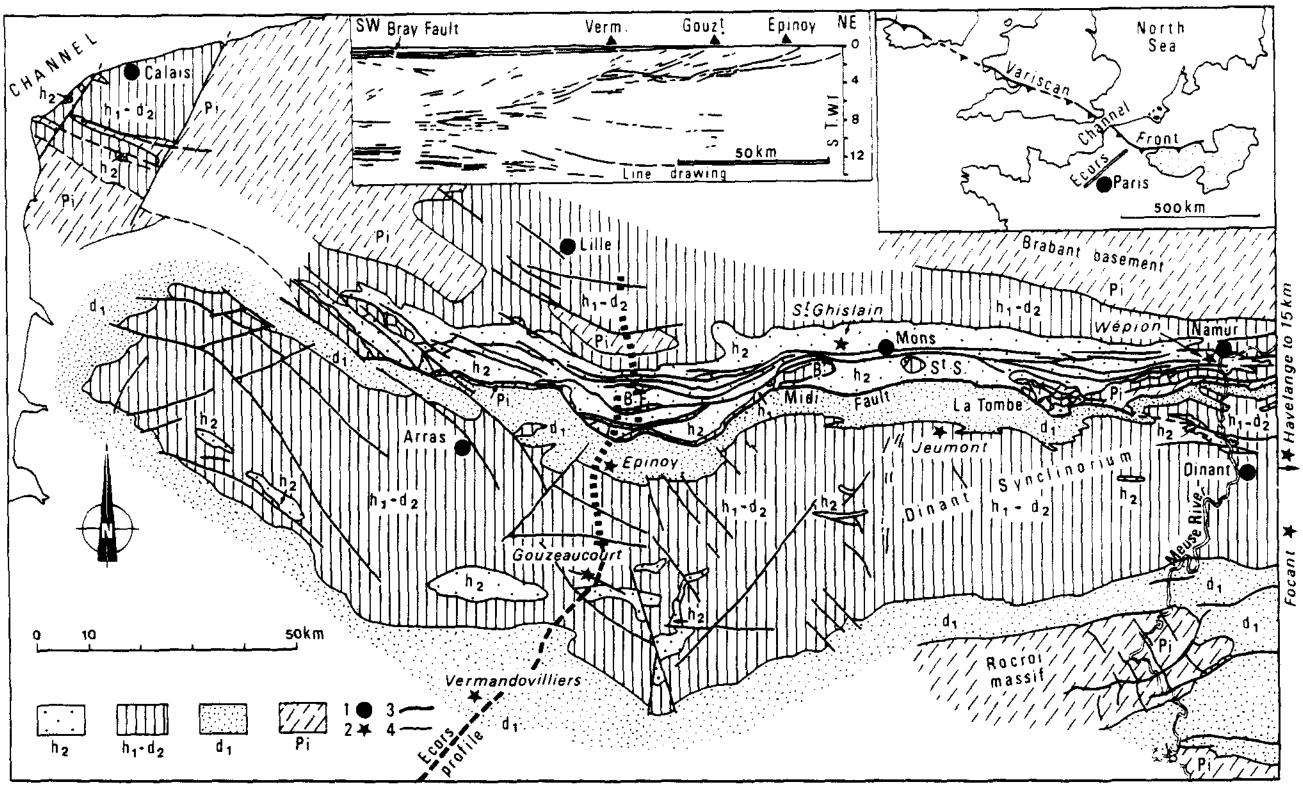

Fig. 1. Simplified map of the Palaeozoic rocks, at the surface and beneath the Mesozoic unconformity, between the Channel and the Meuse River. Insets show location of the ECORS profile, and the northern half of the line drawing. $h_2$, Silesian (Late Carboniferous); $h_1$–$d_2$, Dinantian (Early Carboniferous), Middle and Late Devonian; $d_1$, Early Devonian; Pi, Lower Palaeozoic; 1, city; 2, borehole; 3, fault; 4, stratigraphic contact. Note the difference between the Namur Series, where Middle Devonian unconformably overlies Lower Palaeozoic of the Brabant basement, and the Dinant Series, where Lower Devonian unconformably overlies Lower Palaeozoic of the Rocroi basement. Southwest of St Ghislain, B indicates the Boussu Massif with an overturned series ($h_1$, $d_2$, Pi), the base of which is truncated. Southeast of Mons, St-S indicates the St-Symphorien Klippe with a normal series ($d_2$, $h_1$, $h_2$), the base of which is truncated.

Fig. 1. Carte géologique simplifiée du Paléozoïque entre le Pas-de-Calais et la Meuse. En cartouches, localisation du profil ECORS, et pointé sismique de sa moitié nord. $h_2$, Silésien; $h_1$–$d_2$, Dinantien, Dévonien moyen et supérieur; $d_1$, Dévonien inférieur; Pi, Paléozoïque inférieur; 1, villes; 2, sondages; 3, contact anormal; 4, contact normal. Noter la différence entre la série de Namur, à Dévonien moyen discordant sur le socle paléozoïque inférieur du Brabant, et la série de Dinant à puissant Dévonien inférieur discordant sur le Cambrien du massif de Rocroi. Au Sud-Ouest de St.-Ghislain, le Massif de Boussu (B) comporte une série ($h_1$, $d_2$, Pi) renversée et tronquée basalement. Au Sud-Est de Mons, la Klippe de St.-Symphorien (St.S) comporte une série ($d_2$, $h_1$, $h_2$) normale et elle aussi tronquée basalement.

defines the base of this allochthonous unit. The very recent Epinoy borehole was successively drilled down through horizontal Cretaceous, Early Devonian slates and quartzites, the Midi Fault (2100 m) and finally Givetian–Dinantian (Middle Devonian to Early Carboniferous) limestones and Namurian (Late Carboniferous) molasse. The latter form a continuous sequence that is overturned as a whole, although in detail it is tectonically disturbed along Visean anhydrite beds. The Dinant Nappe (Fig. 2) is characterized by a pervasive cleavage and well-crystallized illite. Conversely, the essentially autochthonous strata from the Namur Synclinorium to the north (Fig. 1) do not show any cleavage, and illite crystallinity is weak. The final overthrusting must therefore be younger than cleavage generation within the Dinant Nappe.

Coal mining has revealed many thrusts, most of which are invisible on the seismic profile. A geologically interpreted section from such a profile will only yield an incomplete image of a tectonically complicated zone. The two strands of the Barrois Thrust (Fig. 2) can be traced to 1000–1200 m depth in coal mines, however. Moreover, mining work has revealed that the footwall of the Midi Thrust was formed by an overturned series at the level of the pre-Mesozoic erosion surface. Such a configuration is also known many kilometres farther east. The problem is to link the overturned series observed between the Midi Overthrust and the Barrois Thrust on the one hand, to the same series observed deeper in the Epinoy borehole on the other hand. A simple way to do it is to link both of them within a single large overturned limb, sheared off later by the Barrois Thrust, as suggested here (Fig. 3). If this interpretation is correct it leads to the following conclusions. (1) The coal basin is a huge recumbent syncline, sliced by subsequent thrusting. (2) The Namur Series (Middle Devonian to Upper Carboniferous) is the cover to the Brabant basement, but has suffered a large shortening. The deeper of the two strong seismic reflectors must therefore be an important detachment surface, at least south

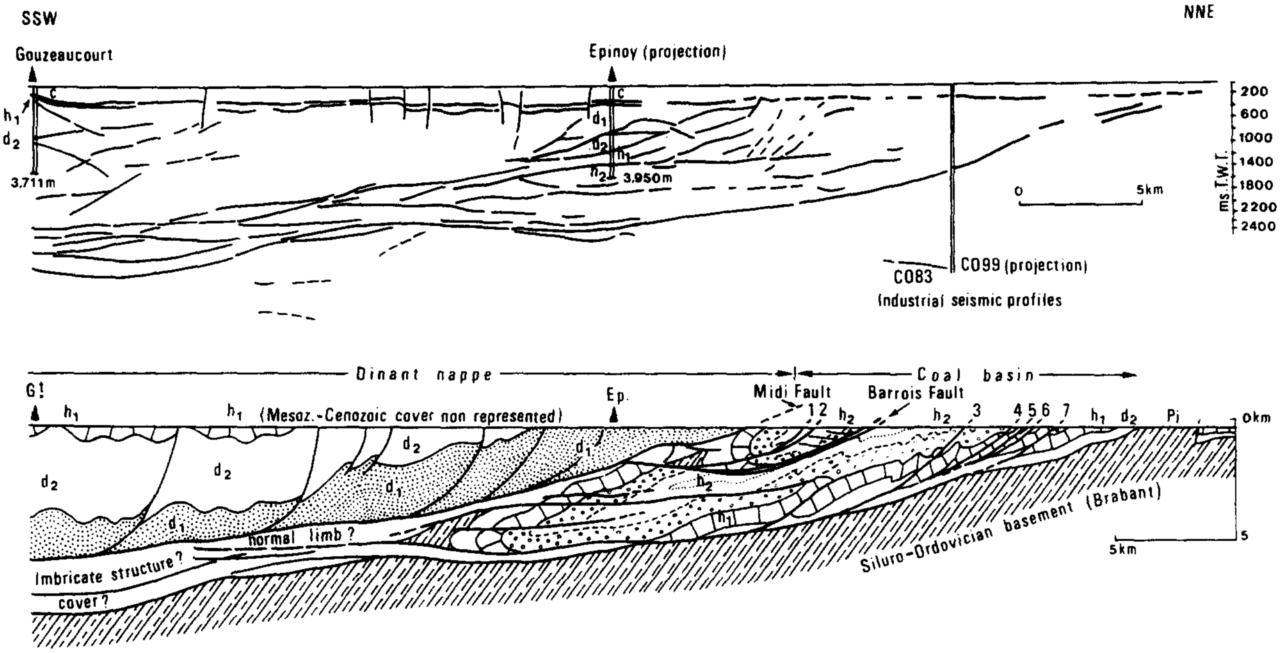

Fig. 2. The Epinoy cross-section. Top, line drawing from the seismic profile, with borehole sections. Bottom, proposed cross-section. $h_2$, Silesian (Namurian to Westphalian B); $h_1$–$d_2$, Dinantian, Middle and Late Devonian; $d_1$, Early Devonian; Pi, Lower Palaeozoic; 1, Midi d'Abscon Thrust; 2, Cran de Retour; 3, Stiévenard Thrust; 4, Fline Thrust; 5, Bouroz Thrust; 6, Pruvost Thrust; 7, Evin Thrust. The internal structure of the basement is not shown because of lack of data. The cross-section is based partly on the 1/50,000 map of 'Houillères du bassin du Nord et du Pas-de-Calais' (Bouroz *et al.*, 1963).

Fig. 2. La coupe d'Epinoy. En haut, pointé du profil sismique (Nord du profil ECORS et profils industriels C083 et C099) avec projection des sondages de Gouzeaucourt et d'Epinoy. En bas, coupe synthétique proposée. $h_2$, Namurien à Westphalien B; $h_1$–$d_2$, Dinantien, Dévonien moyen et supérieur; $d_1$, Dévonien inférieur (uniquement dans la série de Dinant); Pi, Paléozoïque inférieur; 1, Faille du Midi d'Abscon; 2, Cran de Retour; 3, Faille Stiévenard; 4, recoutelage de Flines; 5, Faille Bouroz; 6, Faille Pruvost; 7, Faille d'Evin. La structure interne du Siluro-Ordovicien n'est pas figurée, faute de données suffisantes. La coupe s'appuie en partie sur la carte à 1/50 000 des zones stratigraphiques à la cote–300 (Bouroz *et al.*, 1963). Dans cette coupe, les séries renversées sous la Faille du Midi au droit d'Epinoy et au front de celle-ci sont considérées comme appartenant au même grand flanc inverse cisaillé par la Faille Barrois. Le réflecteur profond marquant le toit du socle brabançon correspondrait à un contact stratigraphique au Nord, puis évoluerait, vers le Sud, en décollement mineur puis en cisaillement majeur, sous des écailles imbriquées.

of Epinoy (Fig. 2). (3) The easterly Jeumont borehole (Fig. 1) may be projected onto the present cross-section. It was drilled down through Givetian and Couvinian limestones overlying more than 2000 m of Lower Devonian clastics, then across the Midi Overthrust (2400 m) coinciding with the highest strong reflector; then cored through a normal Westphalian to Couvinian series, and stopped at 4938 m. The deepest strong reflector corresponds to Frasnian–Givetian limestones, not far from the contact between the basement and the Namur Series.

The Jeumont borehole can only be projected onto the Epinoy cross-section within the normal limb of the huge recumbent syncline (Fig. 3). This means that the Dinant Nappe must lie directly on this normal limb. So, either no overturned limb was formed in this area, or the necessary limb was sheared off and thrusted away northwards. The latter hypothesis is more likely than the former, since the Saint-Symphorien Klippe (St-S on Fig. 1) and the Boussu Massif (B on Fig. 1) support it. Geological mapping shows the northern boundary of the Boussu Massif to merge with the Barrois Thrust farther west (Fig. 1).

## ARDENNE CROSS-SECTION ALONG THE MEUSE RIVER

The Meuse Valley gives good exposure and is of great geological importance. The proposed section (Fig. 4) was first established on a 1/80,000 scale, according to the following data and principles (Raoult & Meilliez 1985). Geological maps (Belgian 1/40,000 scale; French 1/50,000 scale) show concentric folds. Thicknesses of competent formations were derived from published studies and geological maps.

Attention was then paid to three boreholes: Wépion, Havelange and Focant (Fig. 1). Seismic profiles are associated with the last two. They show that the Midi Overthrust fits the shallower strong reflector. The geophysical work in Focant area allows the deeper reflector (noted "Y" in Bless *et al.* 1977) to be identified.

According to most authors, the Midi Overthrust crops out between the Silurian rocks of Condroz (just south of Namur, Pi on Fig. 1) and the Lower Devonian of the Dinant Nappe. By analogy with the ECORS profile (Cazes *et al.* 1985) and easterly profiles (Meissner *et al.* 1981) it can be traced from these far to the south.

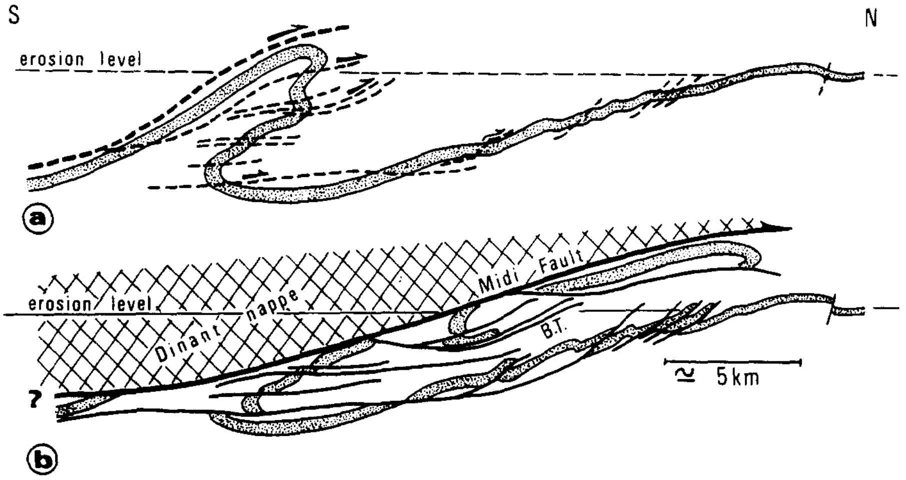

Fig. 3. Hypothetic kinematic reconstruction of the gross structure of the coal basin along the Epinoy cross-section. (a) Recumbent fold and trace of future shear planes, ramps and décollements (erosion level is a reference line); (b) final geometry after thrusting. Erosion may have stripped off 2 or 3 km. That means the base of the recumbent fold may have reached a depth of about 6 km. B. T., Barrois Thrust.

Fig. 3. Schéma théorique et hypothétique de la genèse des structures sur la coupe d'Epinoy. (a) Création d'un vaste pli déversé vers le Nord, avec traces en tiretés des futurs cisaillements, décollements et rampes locales (le niveau d'érosion indiqué est une simple ligne repère); (b) avancée de la Nappe de Dinant et acquisition de la structure après le jeu des divers contacts tectoniques. L'érosion aurait enlevé 2 à 3 km de terrains; la base du pli couché aurait été vers 6 km de profondeur (cf. Fig. 4, au droit de Focant); un style avec rampes et duplex est envisageable dans le flanc normal au Nord. B. T., Faille Barrois.

running at a roughly 8 km depth under the Lower Palaeozoic Rocroi Massif. This implies that the whole of the Haute Ardenne is an allochthon. Also by analogy with the ECORS profile, the second deep seismic reflector is drawn as a dashed line.

On the section, only first-order folds (well-known large anticlinoria and synclinoria), and second-order folds (0.1–1 km wavelength) are indicated. Small structures are omitted, being included in the internal deformation. The section has been length-balanced where possible. For this, the layers must be competent and concentrically folded. Only in the northern half of the section is such balancing possible, using the following four competent units, listed from top to base: Dinantian carbonates, Givetian limestones, Vireux sandstones and Anor sandstones. Some parts of the cross-section within the Lower Palaeozoic (e.g. Rocroi Massif) have not been balanced since these terranes have suffered repeated deformations. Moreover, non-cylindrical similar folds and pervasive cleavage are widespread within the slate-dominated series (Beugnies 1963, Hugon & Le Corre 1979, Meilliez 1981, Hugon 1983, Delvaux de Fenffe & Laduron 1984). The internal tectonic style has only been outlined, therefore.

Several important observations must be made. The autochthonous Brabant massif is formed of Lower Palaeozoic rocks pervaded by a steeply dipping cleavage. It is covered by an uncleaved, slightly folded, Devonian to Carboniferous series, which belongs to the right-way-up limb of the Namur Synclinorium. The latter has an uncleaved, overturned limb cored by the Wépion borehole (Graulich 1961) (Figs. 1 and 4). Farther south of Wépion, the footwall of the Midi Thrust is drawn with huge recumbent folds. These are documented by the Jeumont and Epinoy boreholes.

If this cross-section is correct, it implies that the Lower Palaeozoic Condroz zone (Fig. 4) is not an ancient high between the distinct paleogeographic Namur and Dinant areas (see e.g. Michot 1980). The Condroz zone could be a strongly sliced anticline, the internal geometry of which is still poorly known, with unsolved problems (e.g. the close proximity of cleaved and uncleaved Silurian terranes). The cover to the Brabant Massif (the Namur Series) has been strongly shortened as a whole. It is probably separated from the basement along a décollement zone, which may be the second deep seismic reflector.

Geometrical construction of the cross-section requires that all the major folds be truncated (Fig. 4). There is no evidence of folding and consequent erosion of anticlinal crests prior to the Dinant Nappe, so that there appears to have been tectonic truncation of the crests and troughs of the folds, resulting in a complex stacking of thrust sheets (e.g. sheets A or B on Fig. 4). A tectonic unit, similar to thrust sheet A, is seen within the Tombe Massif, west of the section (Fig. 1). In this region, there are a few normal or overturned series formed by upper Devonian to Westphalian beds.

The allochthonous Dinant Nappe encompasses, from north to south, the Dinant Synclinorium, the Haute Ardenne Anticlinorium (Rocroi Massif), the Neufchâteau Synclinorium and the Givonne Anticlinorium (Fig. 4). Within the Neufchâteau Synclinorium Lower Devonian alone is present and is about 6500 m thick. The Palaeozoic rocks plunge farther south under the unconformable Mesozoic series of the Paris Basin.

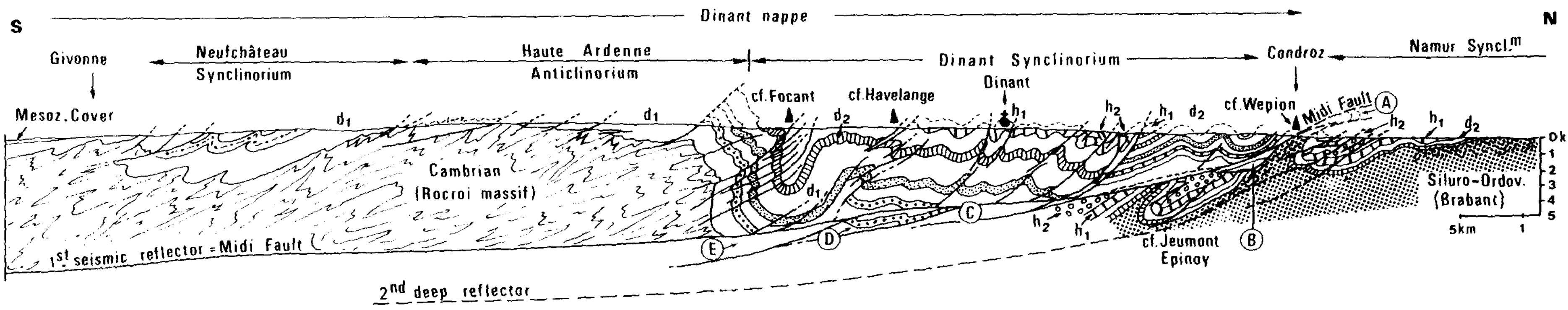

Fig. 4. Ardenne cross-section along the Meuse River. $h_2$, Silesian; $h_1$, Dinantian; $d_2$, Upper and Middle and Late Devonian; $d_1$, Early Devonian. A and B are thrust sheets derived from truncated anticlinal crests to the south, in the footwall of the Midi Overthrust. C, D and E are thrust sheets derived from the base of the allochthon. Boreholes are projected onto the cross section, with a cf. notation since they are not located on it.

Fig. 4. La coupe de l'Ardenne selon la vallée de la Meuse. $h_2$, Silésien; $h_1$, Dinantien; $d_2$, Dévonien moyen et supérieur; $d_1$, Dévonien inférieur (série de Dinant). A et B, écailles dérivant de la troncature sommitale des plis de la série de Namur sous la Faille du Midi (A est à comparer aux écailles du Massif de la Tombe, Fig. 1). C, D et E, écailles théoriques issues des troncatures basales des plis de l'allochtone. les sondages sont projetés sur la coupe, d'où les notations cf. Focant . . . (voir aussi Raoult et Meilliez, 1985).

The following points should be noted from the cross-section.

(1) Lower Palaeozoic rocks must lie below the Devonian series within the frontal fault slices; there, the Midi Overthrust cannot correspond to a virtual basal décollement as implied by the concentric fold model (Dahlström 1969).

(2) In front of the Rocroi Massif, the Focant borehole cored 3200 m of intensely folded and faulted, piled-up Famennian and Frasnian (Late Devonian) beds (the section only outlines the gross structure).

(3) Some independent thrust sheets, such as C, D or E (Fig. 4) lie between the two deep seismic reflectors. The Havelange borehole cored an upper tectonic surface (4900 m) with Gedinnian (Early Devonian) beds in the hangingwall. This surface corresponds to the first deep seismic reflector, interpreted as the Midi Overthrust. Farther down, the borehole touched Early Devonian beds (Emsian, then Siegenian) where it was stopped within garnet-bearing rocks. These beds must therefore belong to an allochthonous thrust sheet.

The actual structures must be much more complex than the cross-section suggests, but scarcity of data precludes an increased accuracy. As a result, shortening is underestimated. Along the Namur Series, shortening may be 20–23% as measured from the section. It reaches about 35% within the Dinant Nappe, without taking into account internal strain involved in cleavage and third-order folds. This cannot be estimated yet. The whole section, palinspastically restored, yields an initial length of about 140 km. The shortening due to internal strain and to the net translation vector of the nappe has to be added. This net translation could be between 40 and 120 km, without any possibility of better precision. Thus the initial length of the section might be 300–400 km. This might represent a Devonian continental margin and slope of similar dimensions to present examples.

## DISCUSSION AND CONCLUSIONS

The Epinoy cross-section presented here (Fig. 2) differs from the first interpretation of the ECORS profile (Cazes *et al.* 1985). In the latter, the second deep reflector is considered to be a stratigraphic boundary, based on data from the Jeumont borehole and outcrops further north. In this interpretation, the present coal basin is divided into two: the northern part would be autochthonous, and the southern part would be allochthonous. The southern part would have been displaced by a slip slightly less than that of the Dinant Nappe. This interpretation suggests that the coal-bearing series were not deposited in a single sedimentary basin, but this is not supported by any differences in stratigraphy. Also, the necessary tectonic boundary between the two parts cannot be identified. We therefore propose a cross-section (Fig. 2) that provides an alternative working hypothesis in order to resolve these problems.

In our interpretation, there is only one coal basin which was folded and sliced by thrusts. The second deep seismic reflector would be its sole, but varies laterally: it is a stratigraphic surface in some places and a tectonic surface at other places. At the northernmost end, it corresponds to the stratigraphic boundary between the Brabant basement and the Namur Series cover. Further south, below faults 3 and 4 (Fig. 2), it fits a minor décollement surface. It then passes into a major décollement, and then probably into a shear plane truncating folds. In this interpretation, the apparently continuous seismic reflector has a variable geological significance along its trace: stratigraphic in one place, tectonic elsewhere. It is therefore important to investigate whether details of the seismic signature of a reflector are really constant. A cautious interpretation is definitely of the utmost importance.

The mechanism by which tectonic structures of this portion of the Variscan Front were built up is another important problem. We shall focus on a few elements. The structures illustrated only locally include ramps and duplexes. A duplex model has been documented in some places (e.g. Boulonnais, see Cooper *et al.* 1983), where it provides a valid model for mesoscopic structures. A few successes induce many authors to apply that model as the only suitable explanation, which seems excessive. In particular, the duplex model seems inappropriate to explain 1000–2000 m thick overturned series. These need huge recumbent folds, subsequently sheared off by thrusts (Fig. 3). Ramps and duplexes may have been generated within either the normal limbs of such huge recumbent folds, or in the overturned limb, but in this case after the overturning. It is a different phenomenon from the recumbent folding itself.

Seismic profiles and boreholes therefore provide a new insight into this part of the Variscan Front, in agreement with similar previous investigations and interpretations obtained laterally on either side. The gross picture of the coal basin is then that of a continental accretionary prism in front of a nappe. The basal surface of that prism coincides with thrust and décollement surfaces, the displacement of which decreases towards the front. Cross-sections, like the one presented here, are insufficient to analyse the overthrusting kinematically. Moreover, transverse wrenching is not taken into account; and problems such as dating of the deformation and metamorphism of the allochthon are not treated.

Such cross-sections and their interpretations permit other problems to be discussed differently, especially paleogeography. Restorations of sedimentary basins and of their paleoenvironment have to be tested within this frame. They will either confirm the model or suggest new tectonic ideas. For example, establishing the Condroz zone as a true boundary between the Namur and Dinant areas implies that the coal basin narrows eastwards. Hence, reasoning leading to estimates of thrust displacement cannot be equally applied along an east–west trace. This problem cannot be solved only by seismic profiles.

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