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THE VARISCAN FRONT NORTH OF THE ARDENNE-RHENISH MASSIFS[1]

by

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(8 Figures)

To my friends Jos Bouckaert, Martin Bless and Jaroslav Dvorak.

RESUME.- Les massifs ardenno-rhénans, leur hinterland et leur plateforme d'avant-pays se sont développés de manière intimement liée entre eux. La sédimentation et la déformation sont des manifestations d'une même dynamique. La tectonique synsédimentaire est commune et importante. Les charriages de Dinant-Aachen sont interprétés comme résultant principalement d'une formation synsédimentaire; au moins près de leur extrémité orientale dans la région d'Aachen, le déplacement horizontal le plus grand du charriage s'est produit au début du Namurien, quand l'Avant-Fosse Subvarisque a commencé à se développer à l'est du massif protérozoïque «Mid Netherlands-Krefeld».

Le Front varisque, la limite entre le tectogen (au sud) et la plateforme ou la plaque (au nord), est estimé avoir pris place (du SW au NE) :

- entre le massif subautochtone de Rocroi (au sud) et le Synclinorium de Dinant (au nord);
- dans la faille allochtone de Raeren-Mausbach au sud d'Aachen et au nord du massif de Stavelot-Venn;
- au nord de l'Eifel et au sud de Cologne;
- au nord du massif rhénan, près de l'affleurement des roches du Namurien moyen, le houiller s'étant constitué sur la plateforme.

Les développements différents, en Ardenne, dans l'Eifel et dans le massif rhénan sont interprétés comme étant liés aux différentes positions et réactions des lèvres bordant la plateforme protérozoïque qui à leur tour peuvent être expliquées en liaison avec des taux différents de subfluence sous l'Ardenne-Eifel et le massif rhénan.

ABSTRACT.- The Ardenne-Rhenish massifs, their hinterland and their foreland-plate developed in intimate dependance on each order. Sedimentation and deformation were manifestations of the same dynamic frame. Synsedimentary tectonics are common and important. The Dinant-Aachen overthrusts are interpreted as mainly of synsedimentary formation; at least near their easterly termination in the Aachen area the largest horizontal displacement on the overthrusts may have occurred in the early Namurian, when the Subvariscan Foredeep began to develop east of the Proterozoic Mid Netherlands-Krefeld massif.

The Variscan Front, the boundary between tectogen (in the south) and platform or plate (in the north) is thought to have run (from SW to NE) :

- between the subautochthonous Rocroi massif (in the south) and the Dinant syncline (in the north);
- in the allochthonous Raeren-Mausbach fault south of Aachen and north of the Stavelot-Venn massif;
- north of the Eifel and south of Cologne;
- north of the Rhenish massif, near the outcropping mid-Namurian rocks. The coal measures have been formed on the platform.

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The different developments in the Ardenne, the Eifel and the Rhenish massif are interpreted as being related to the different position and reaction of the bordering limbs of the Proterozoic platform which in turn may be explained in connection with a different rate of subfluence beneath the Ardenne-Eifel and the Rhenish Massif.

ZUSAMMENFASSUNG.- Das Ardennisch-Rheinische Schiefergebirge entwickelte sich in engster Abhängigkeit von seiner Vorland-Plattform. Sedimentation und Deformation werden als Wirkungen derselben Kräfte aufgefasst. Die Dinant-Aachener Ueberschiebungen werden als wesentlich synsedimentär entstanden gedeutet. Mindestens in ihren östlichen Teilen, bei Aachen, ist das Deckensystem im ältesten Namur über eine rel. lange Strecke transportiert worden (15 km), zur gleichen Zeit, als die Subvariscische Saumsenke östlich des Proterozoischen Mittel-Niderländisch-Krefelder Massivs angelegt worden ist.

Der Verlauf der Variscischen Front, der Grenze zwischen Tektogen (im Süden) und Vorland-Plattform (im Norden) wird angenommen :

- zwischen dem sub-autochthonen Rocroi-Massiv (im Süden) und der Mulde von Dinant (im Norden);
- in der allochthonen Raeren-Mausbacher Ueberschiebung südlich von Aachen und nördlich vom Stavelot-Venn-Massiv;
- nördlich der Eifel und südlich von Köln;
- nördlich des Rheinischen Schiefergebirges, etwa entlang einer Linie, die dem ausstreichenden Mittel-Namur folgt. Das Steinkohlengebirge ist auf der Plattform entstanden.

Die unterschiedliche Entwicklung der Ardennen, der Eifel und des Rheinischen Schiefergebirges dürfte mit der unterschiedlichen Lage und Reaktion der Plattform-Schollen an ihrem Nord-Rand zusammenhängen; und diese wiederum können auf eine unterschiedliche Subfluenz-Geschwindigkeit unter den Ardennen und der Eifel einerseits, unter dem Rheinischen Schiefergebirge andererseits weisen.

1.- INTRODUCTION

The central and west European Variscides are a complex of small units that share a linked and integrated history of development; separate terranes cannot be distinguished. The mainly bio- and lithostratigraphical experiences of the author made it - up to the present - impossible to accept any of the plate tectonic hypothesis that have been published for this area: on the contrary, the common characteristics of the stratigraphy, diagenesis/metamorphism and ore deposits seem to indicate an essentially fixistic Variscan development, with an original distribution of geologic units nearly comparable to their present state. Biostratigraphic characters are still the most reliable witnesses that testify the development of geological units. This is an attempt to make better use of them, without pretending to solve the problem definitively.

In mid-Europe, the Variscides end at the border of the Proterozoic = Prae-Cambrian East-European platform. This terminal position probably did not result in effects strongly atypical of the belt as a whole.

Caledonian events are difficult to detect in the area considered here (Michot, 1980; Walter, 1980). The twofold Variscan tectonization of the Stavelot-Venn massif (Schreyer, 1975; Fielitz, 1985; Kramm *et al.,* 1985a, 1985b) which may perhaps be transferred to the Givonne, Rocroi and Serpont massifs, too, seems rather to be related to that characteristic for inversion structures (even if presumably assigned to a Caledonian event; Spaeth *et al.,* 1985). A Caledonian tectonization of the Brabant massif comparable to that of the British-Scandinavian area is not known. Thermal events or perhaps tectonothermal events (Zwart, 1986: 29-31) of «Caledonian» age (400 to 550 Ma) in the Brabant-southern North Sea region may have been triggered by the near-by Caledonian orogeny of northern Britain and Scandinavia.

The Midi overthrust is supposed by Raoult & Meilliez (1986, 1987; Raoult, 1986) to continue below the Ardenne massifs and the Paris basin for 100 to 120 km southwards, following seismic interpretations. This idea is beyond discussion here, given the wealth of possibilities to interprete seismic sections even if there were boreholes to calibrate the physical results.

The mid-European Variscides are supposed to have developed in a weak zone of the crust in Laurasia when the plate collided with the Gondwana plate. They were characterized by low pressure and high temperature metamorphism (Zwart, 1976). During the Variscan development, the dynamic framework was therefore the same

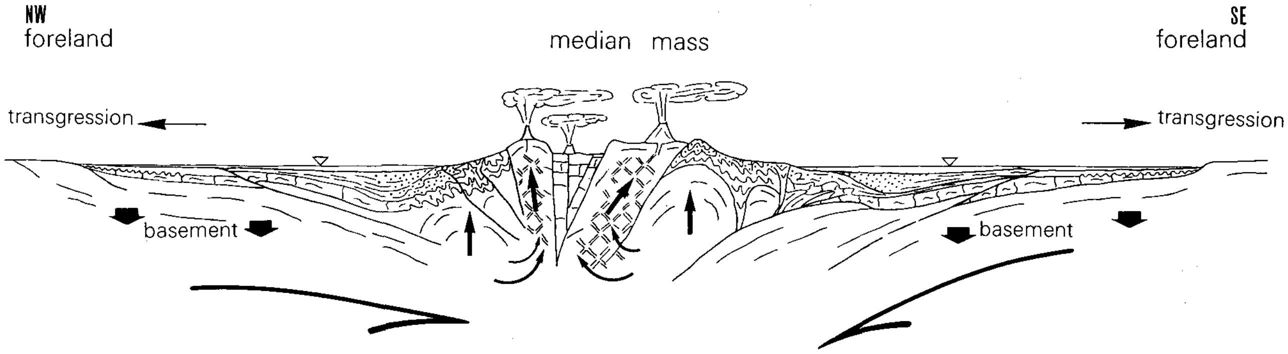


Figure 1.- Development of the mid-European Variscides.
Strongly simplified, no scale. Subfluence of the basement directed from the foreland-platforms (foreland plates) in the NW (nord) and SE (south) to the central Variscides. Intrusion of granitoid magmas into and uplift of the median mass.
Open triangles : sea level. (from Dvorak & Paproth, in press, slightly changed).

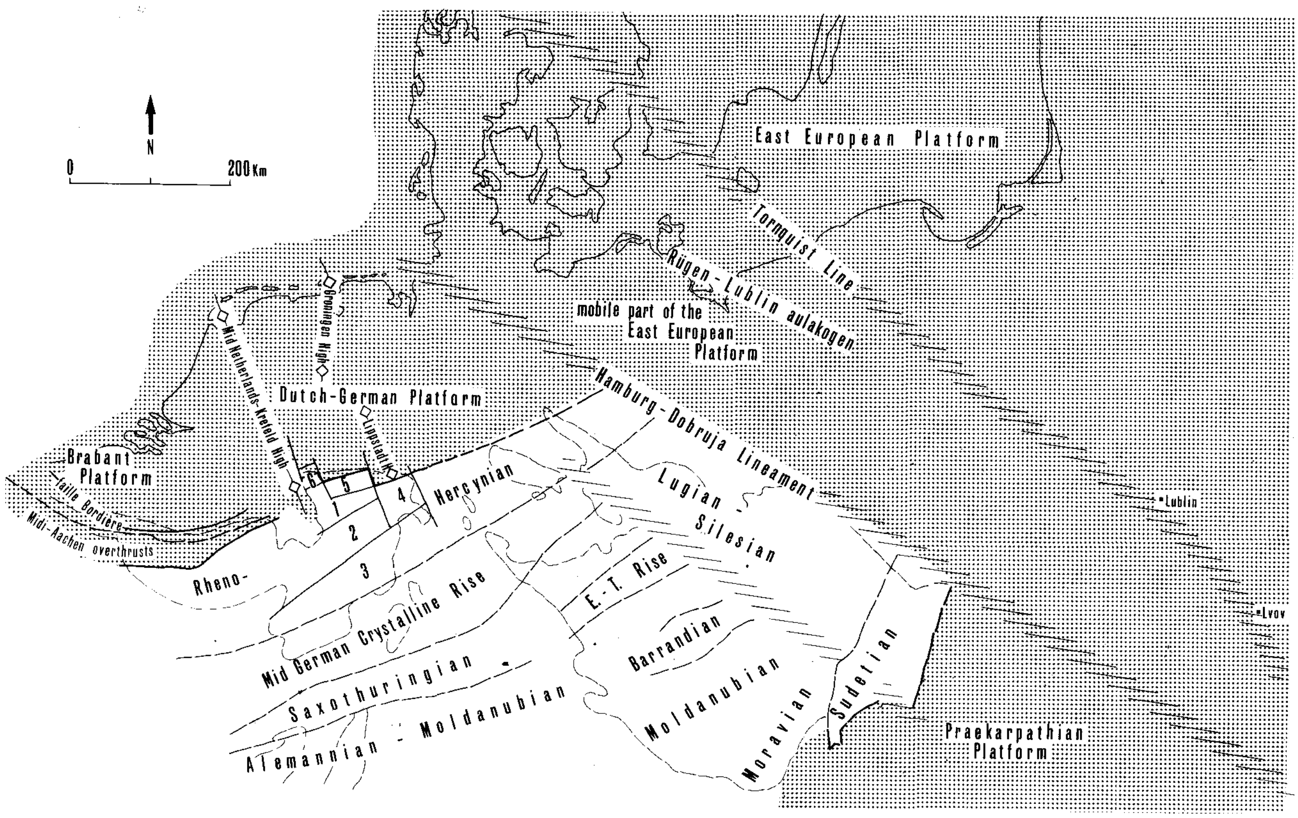


Figure 2.- Subdivision of the Variscides (Dvorak & Paproth, in press), their Rheno-Hercynian belt and their northern foreland-plate (darkish). (after Paproth *et al.*, 1986, Fig. 4, slightly changed).

from the beginning to the end of the movements which caused sedimentation and deformation (fig. 1); the high Variscan temperatures have locally influenced the dynamic field. A continuing N/S (NW/SE) oriented stress deformed the crust which was particularly thin in the weak zone. Subfluence of crustal material (attached to the upper mantle ?) was directed from below the foreland platforms in the north (NW) and south (SE) to inner parts of the tectogen (Weber, 1978) where melted crust material ascended and formed Variscan granitoids (Dvorak & Paproth, in press). The tectogen was uplifted, first in its inner zones and later also in its outer zones. Even bordering platform areas were uplifted in later times (from Westphalian-Moscovian on).

The mid-European Variscides are described as a qualitatively symmetric construction comprising northerly (NW) and southerly (SE) flanks, and a central Alemannian-Moldanubian axis (fig. 2). The Rhenohercynian and the Sudetian are corresponding belts. The southern (SE) flank of the

Variscides and its southern foreland, the Pre-Karpathian platform, are heavily affected by Alpine movements, whereas the northern flank has undergone only few important vertical and rotational movements since the Variscan.

The Rhenohercynian is relatively well known in the Ardenne and the Rhenish massifs (fig. 6); the Harz (Wachendorf, 1986; Führer, 1988) is not considered here. The Ardenne is clearly distinguished from the Rhenish part by large cores of metamorphosed pre-Devonian sediments -demonstrating a deeper level of the Variscides than crops out in the Rhenish part - and by several long overthrusts (Raoult & Meilliez, 1986). Other differences are the facies of Famennian (late Devonian) and Dinantian (early Carboniferous) sediments; the presence of a Subvariscan Foredeep in the east which is absent in the west; and the presence of early orogenic, palingene ore deposits and of volcanites in the east which are also absent in the west.

The essential cause for the different development of the Ardenne and the Rhenish massifs seems to lie in the structure and the response of their forelands. The tectonic deformation of the rocks in the tectogen is not considered here in detail.

The present distribution of pre-Variscan rocks seems to be comparable to that in Variscan times

- The (Proterozoic) Brabant massif formed a rigid block which was relatively upstanding. The W/E axis of the massif plunged to the east. To the south the proterozoic massif formed several broad steps, the southernmost of which sharply bordered the tectogen south of the Dinant syncline. The Rocroi-Serpont massifs seem to have been thrust somewhat on to the rigid platform border.
- Where the axis of the Brabant massif plunges to the east, parts of the tectogen (the Stavelot-Venn massif) were thrust on to the platform which was here in a somewhat deeper position than further west. The primary border between platform and tectogen may have been situated in the subsurface southeast of the allochthonous Stavelot-Venn massif, west of the Eifel. This boundary may be reflected and preserved in the allochthonous cover as the Raeren-Mausbach fault.

The relatively high position and the rigidity of the Proterozoic limbs may explain the exposure of deeper levels of the Variscan tectogen in the Ardenne than in the Rhenish part where the Proterozoic platform subsided deeply : the Ardenne massifs were forced to mount the platform border (Rocroi and Serpont massifs) or even to encroach upon it (Stavelot-Venn massif).

- The (Proterozoic) Mid Netherlands-Krefeld massif formed an elongate NNW/SSE directed narrow, rigid rib. Its longitudinal axis plunged to the south under the tectogen. Younger movements make it difficult to recognize or project its behaviour particularly near its southern border (Plein *et al.,* 1982; Klostermann, 1983: 41 ff., 48 ff.).
- North of the Rhenish massif, the much less rigid Proterozoic Dutch-German platform is deeply burried under late Carboniferous and younger sediments. It seems to have been relatively upstanding until the beginning of the Namurian when rapid subsidence lead to the formation of the Subvariscan Foredeep that was filled with nearly 3000 m of Namurian rocks and which remained the area of maximum subsidence (although less pronounced than in the Namurian) until about the late Westphalian at the northern flank of the Variscides.

The Subvariscan Foredeep has a sharp boundary in the south with the tectogen, here formed of the stabilized inversion structures of the Rhenish massif.

2.- THE RHENISH MASSIF AS POSSIBLE MODEL FOR DEVELOPMENTS IN VARISCAN EXTERNAL BELTS

The Rhenish massif is a complex structure, built by the assemblage of troughs (H. Schmidt, 1937; Kegel, 1950; Wo. Schmidt, 1952). In a framework of continuing N/S (NW/SE) compression stationary troughs were filled one after the other with some thousand metres of marine shallow water sediments. When the base of a trough had reached a certain depth - reached or trespathed a certain thermodynamic régime - the earlier (strong) subsidence changed into a (much less pronounced) vaulting upwards movement which resulted in an «inversion structure» (fig. 3; Dvorak, 1973). The vaulting upwards process was accompanied by enhanced heat flow which may have lasted longer than the movement (e.g. Velbert structure, Paproth & Struve, 1982: 370 ff.). The heat was transported by hydrothermal flow which caused early orogenic palingene ore deposits characteristic for each inversion structure (fig. 6; Hesemann, 1971 : 94, 1978; Storck *et al.,* 1973; Kaiser *et al.,* 1978 : 192). As a result of the movements and the temperature, sediments in inner parts of the structures were folded and acquired schistosity. The stabilization process resulted in a sedimentologically neutral structure which was neither subsequently strongly eroded

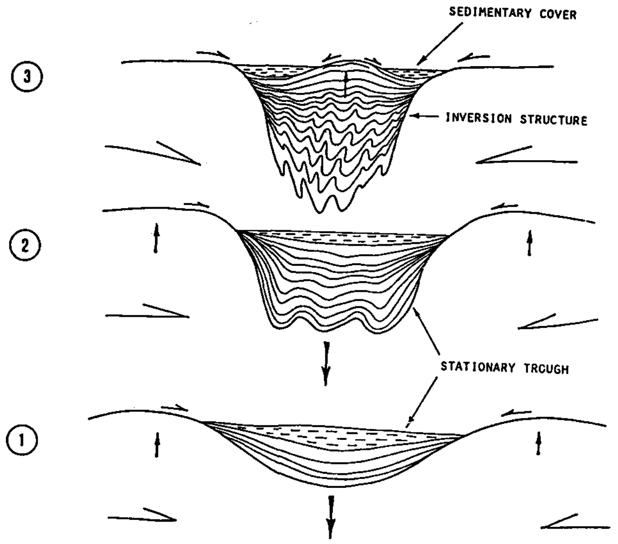


Figure 3.- Development of an inversion structure. Very simplified and exaggerated, no scale ! (from Dvorak, 1973, Abb. 3, slightly changed).

nor became the site of deposition of a thick cover of younger sediments. The sedimentary cover is less deformed and usually less metamorphosed than the rocks of the underlying inversion structure. Clear discordances between both are difficult to observe, as inner parts of the inversion structures were generally not exposed or eroded before the deposition of the sedimentary cover. Moreover, the heat flow that accompanied the stabilization process and may have affected older parts of the sedimentary cover, decreased only slowly (Paproth & Struve, 1982 : 370-373). The sedimentary cover of inversion structures tended to be the sites of sliding and slumping (Paproth, 1976a : 50; Kaiser *et al.,* 1978 : 192).

The (Rhenish) complex was subsequently subjected to a second phase of Variscan deformation that affected the inversion structures to a variable degree : e.g. structure 1 weakly, the nearby structure 6 more strongly (Paproth & Struve, 1982 : 370 ff.; Kaiser *et al.,* 1978).

In the Rhenish massif, the troughs or inversion structures followed one another in an anticlockwise spiral. The rotation of the depo-

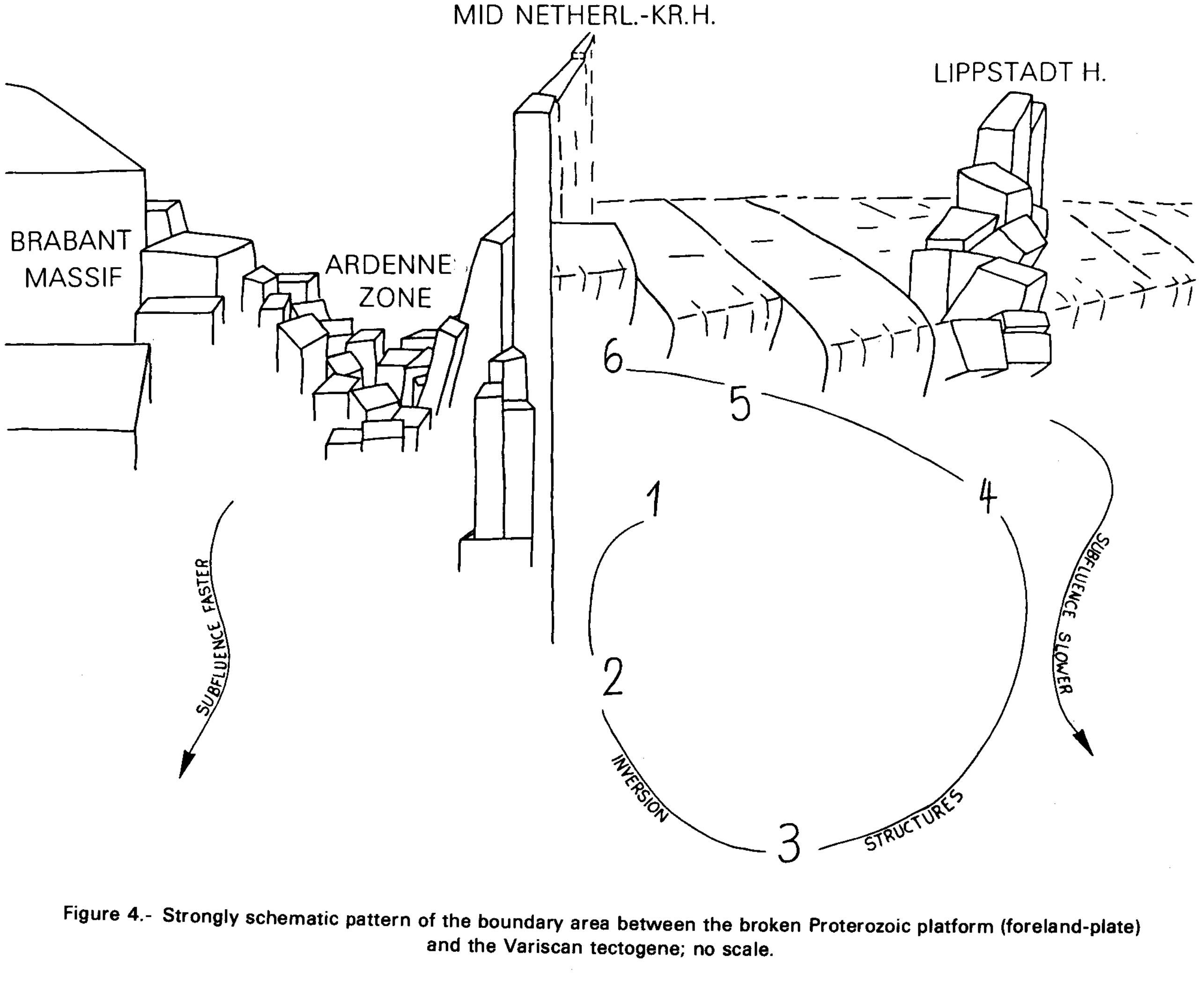


Figure 4.- Strongly schematic pattern of the boundary area between the broken Proterozoic platform (foreland-plate) and the Variscan tectogene; no scale.

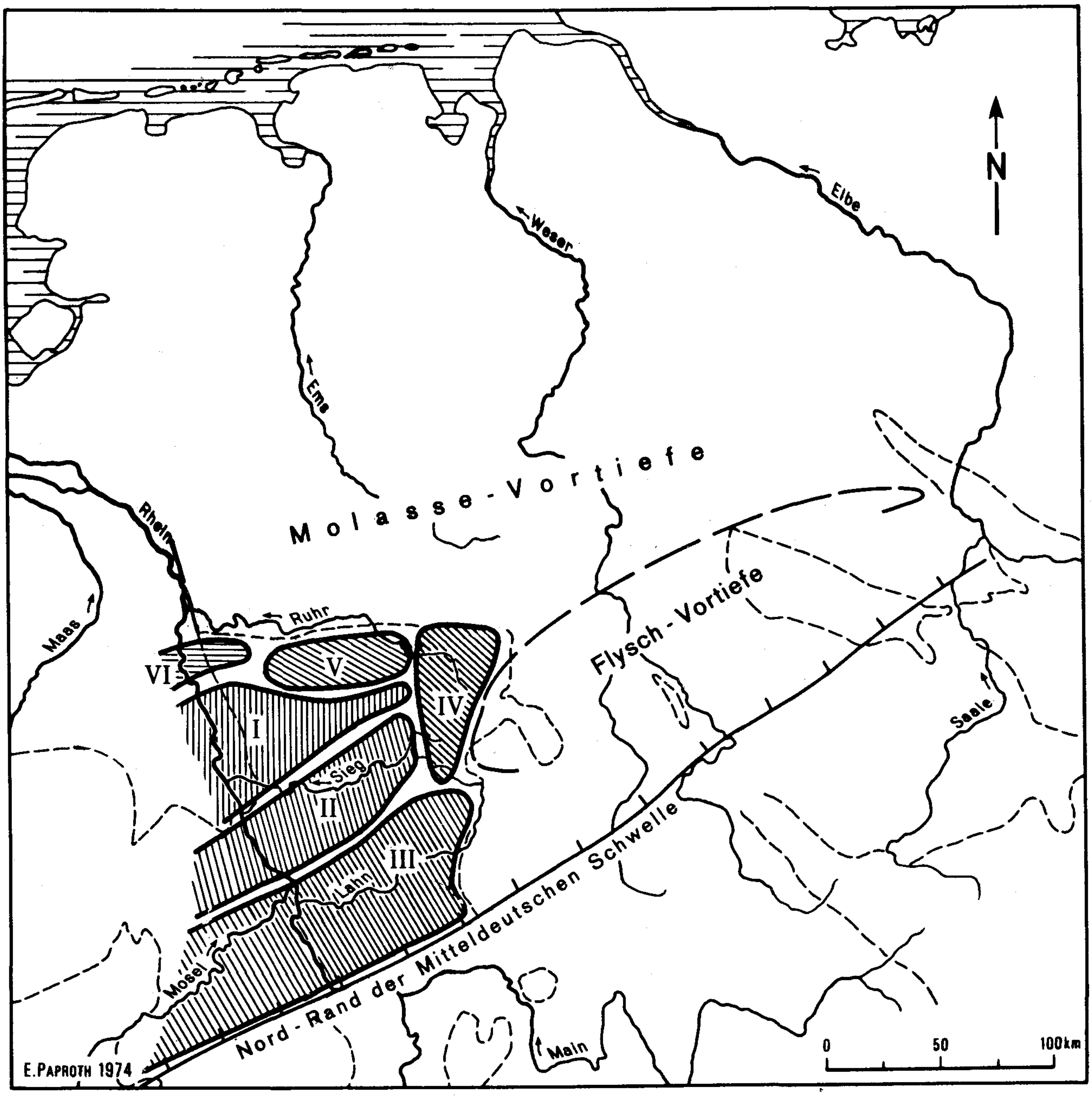


Figure 5.- Situation of the inversion structures I to VI, the foredeep of the Mid German Crystalline ridge («Flysch-Vortiefe der Mitteldeutschen Schwelle») in the tectogene, and of the Subvariscan Foredeep («Molasse-Vortiefe») on the Proterozoic foreland-plate (Paproth, 1976a, slightly changed).

center may reflect a whirl (figs 4 and 6) in the southwards directed subfluence of the basement that had formed in the slowly moving part east of the Mid Netherlands-Krefeld massif, at its boundary to the faster moving part west of it. This whirl may have resulted in the lack of strong compression in the Rhenish massif (in contrast to the Ardenne) and in the development of the Subvariscan Foredeep (from the earliest Namurian on), instead of nappe-like structures on or near the platform border as in the Ardenne.

The northerly shift of the ages of metamorphism at or near the eastern border of the Rhenish massif has been measured (Ahrend *et al.,* 1983). The ages are linked to the deformation of the foredeep of the Mid German Crystalline ridge (fig. 5) which naturally affected also bordering parts of the eastern Rhenish massif. Large parts of the Rhenish massif, however, have not been affected much or at all by this deformation (E. Schroeder, 1966; Voigt, 1969; Kaiser *et al.,* 1978). The Rhenish massif was **not** formed by a simple northerly or northwesterly displacement of basins and deformation. This fact has been printed out by several authors since Kegel's (1950) masterly publication; but it tends to be forgotten.

The following features have been described as inversion structures (figs. 5, 6; Dvorak, 1973; Paproth, 1976a):

1. Oberbergisch-Sauerland structure (filling and stabilization in the early Palaeozoic, Gedinnian at the youngest);
2. Siegen structure (filling and stabilization in about the Siegenian, early Devonian);
3. Nassau structure (filling and stabilization in about the early Emsian, early Devonian);
4. Ostsauerland Quertrog (filling and stabilization in about the early Eifelian, middle Devonian);
5. Lenne structure (filling and stabilization in about the later Eifelian to early Givetian, middle Devonian);
6. Velbert structure (filling and stabilization in about the later Givetian to Famennian, late Devonian).

The boundaries of the inversion structures were determined by lineaments or faults in the underlying Proterozoic basement (Dvorak& Skocek 1975; Paproth *et al.,* 1986 : figs 4-5).

The youngest Velbert structure (6) is best preserved. Facies distribution of late Devonian sediments reflects the developing inversion structure. The enhanced heat flow of the stabilization process lasted into the early Namurian (Paproth & Struve, 1982 : 370 ff).

In the Oberbergisch-Sauerland structure (1) graptolite-bearing Ordovician rocks of the Ebbe anticlinorium show the highest vitrinite reflectance measured in the Rhenish massif : 10 % (Wolf *in :* Grabert & Stadler, 1981). - In the sedimentary cover of that inversion structure, a conglomerate of perhaps early Devonian age (pre-Gedinnian, Gedinnian to Emsian ?) contains - amongst other clasts - many pebbles of iron ore from a near-by (eroded) ore deposit (Grabert & Stadler, 1981). They are similar to the type Lahn-Dill ore deposits in the middle/late Devonian and Dinantian sedimentary cover of the Nassau (3) inversion structure. - Iron ore deposits of the same type but very different age point to a similar development of inversion structures 1 and 3 and their sedimentary covers, at different times.

Recent work by Pirwitz & Werner (1984) provides hints that the inversion structures 1 to 6 passed through similar development at different times. They described conglomeratic layers in the late early Devonian (Emsian) rocks of the southern Eifel which although not as pebble-rich and finer grained are similar to the early (or pre-) Devonian iron-ore conglomerate of the Ebbe anticlinorium. Both have acid and intermediate igneous clasts which are exclusively volcanic in origin (pebbles of basic volcanic rocks also, are present in the Ebbe conglomerate), of the not abundant magmatites; both also contain pebbles of hematitic chert, and quartz with cataclastic fabric. The source area for the Emsian conglomerate material in the Eifel may have been the Manderscheid anticline (Lippert & Solle, 1937), the westerly part of the Siegen inversion structure (2).

In the sedimentary cover of inversion structure 1, west of the Ebbe anticlinorium low energy marine middle Devonian rocks overlie continental Old Red sediments. The diagenetic/metamorphic grade is low and suggests a relatively weak post-Devonian heating and deformation in this central part of the Rhenish massif (Kaiser *et al.,* 1978 : 188).

3.- THE VARISCAN FRONT

The development of the Variscan front is explained in three sections A-B, C-D and E-F (fig. 6) that cut crucial areas of the Ardenne-Rhenish massifs.

SECTION A-B,
cutting the Rhenish massif, its southerly and northerly borderlands

From south to north, section A-B (figs 6 and 6a) cuts granitoids of the Mid German Crystalline ridge in the Saar-Nahe graben, an intramontane Variscan basin filled mainly with Silesian and Permian continental sediments.

The nearly vertical South Taunus-Hunsrück fault forms the boundary between the Saar-Nahe graben and the Nassau (3) inversion structure. The sedimentary cover of the structure is exposed in the Olkenbach syncline (Solle, 1976) with late Emsian and younger sediments, in the eastern Lahn-Hörre-Dill area with middle Devonian to Dinantian rocks, off the line of section (cf. Paproth, 1976a : 50; Nesbor & Flick, 1987).

The sediments of early Emsian to Eifelian age reflect the development of this area in the Nassau (3) inversion structure near its northerly border to the Siegen (2) structure, with numerous synsedimentary movements of considerable magnitude (Solle, 1960, 1976 : 234 ff). The preferred directions of movement seem to be N/S and NNW/SSE which are thought to be related to the Eifel N/S zone (Solle, 1976 : 236).

The inner (western) parts of the Nassau (3) structure developed (by inversion) into the Hundsrück shoal of the late Early Devonian (Solle, 1970).

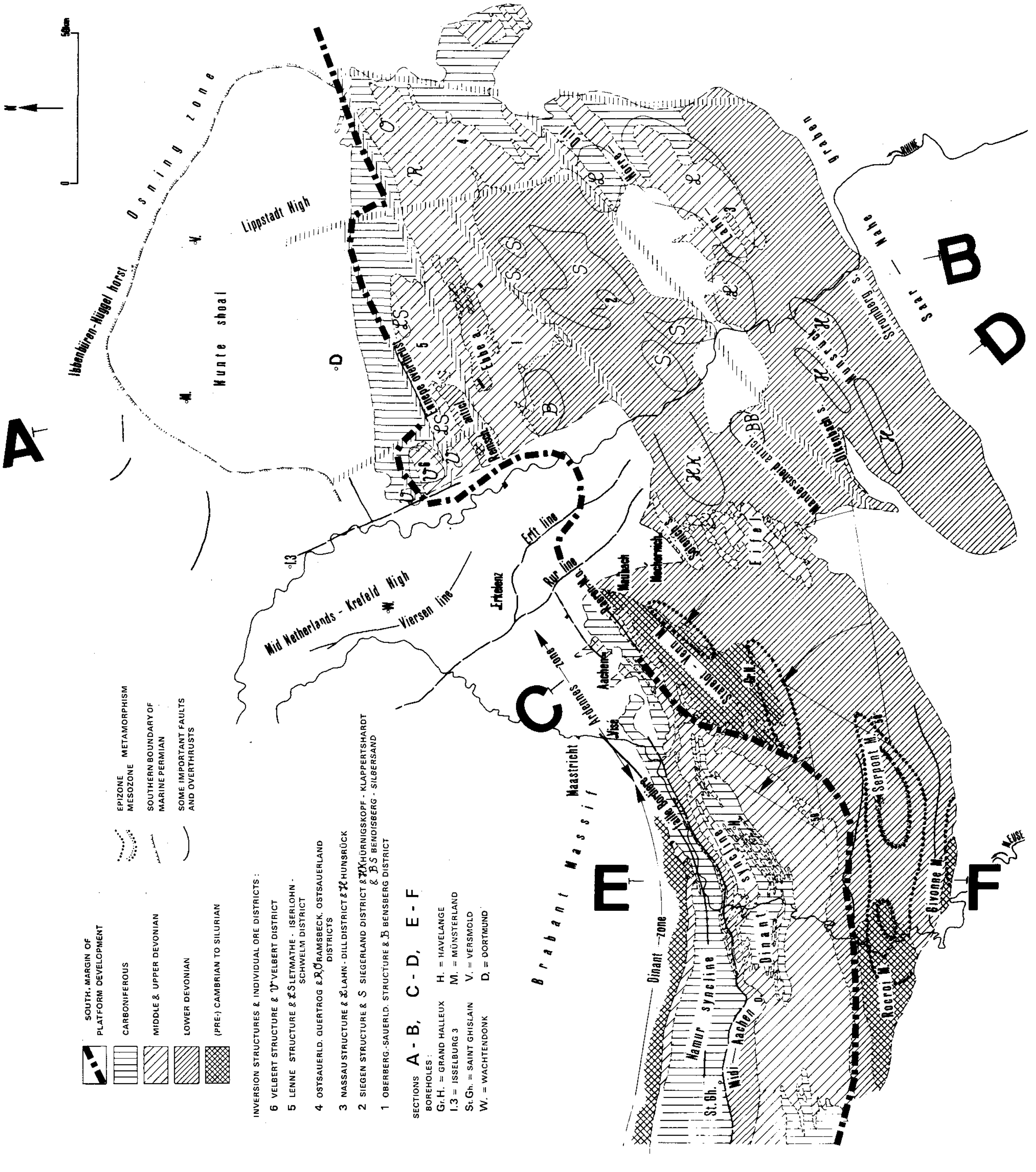


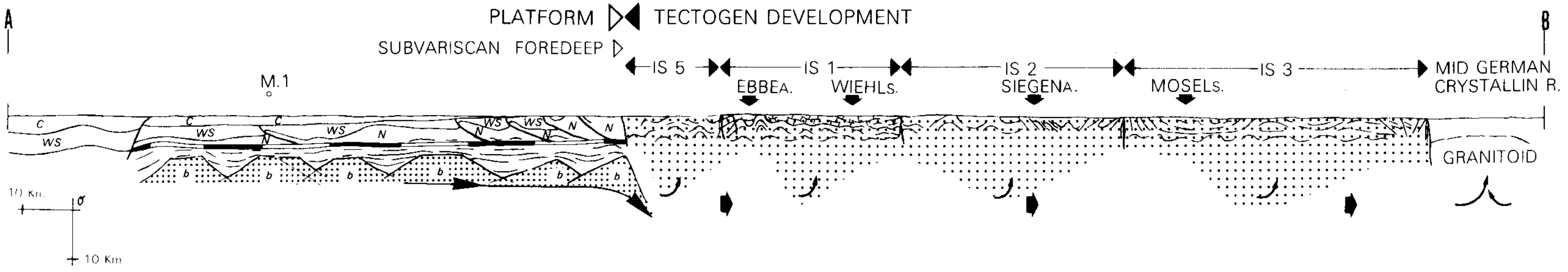
Figure 6.- Map of the Ardenne-Rhenish massifs and model sections A-B (Fig. 6 A), C-D (Fig. 6 B) and E-F (Fig. 6 C). Ardenne after de Béthune, Géologie 1 : 500 000, Atlas de Belgique, planche 8; ore districtis after Storck *et al.*, *Dipl.-Geol. L. Krahn, oral comm.*; sections after Meyer & Stets, 1975; Deutloff & Thome, Geologische Schnitte in : Deutloff, 1976; Kneuper, 1971; Meissner *et al.*, 1980.

The distribution of the coalification rank (Wolf, 1978) in the westerly part of the inversion structure (3) suggests that locally some shallow levels of it are preserved.

The regular decrease of the coalification rank in early to late Devonian sediments at a locality near the southern border of the Hunsrück Stromberg syncline (Wolf, 1978) may be due more to the activity of the Hunsrück fault during the Silesian and Permian than to a heat flow connected with the inversion structure.

In the Siegen structure (2) north of the Nassau structure (3), the neatly differentiated distribution of the coalification rank - and the absence of a sedimentary cover - suggest the exposure of an inner part (a deeper level) of the structure. Western parts of the structure developed by inversion to the Manderscheid anticline of the post-Siegenian palaeogeography (later Emsian to Eifelian; Lippert & Solle, 1937).

The oldest Oberbergisch-Sauerland structure (1) has in most parts its sedimentary cover (late



Sections A-B, C-D and E-F

tectogene development :

IS = inversion structure
wide screen = inversion structure
wall signature = sedimentary cover of inversion structures.

platform development :

b = basement

Section A-B

c = Cretaceous rocks
WS = Westfalian and Stephanian rocks
N = Namurian rocks
black and white stripe = Dinantian rocks
subhorizontal bedding pattern = Devonian and older paleozoic rocks

Section C-D

small points (sandy pattern) = middle Devonian to Carboniferous rocks

bedding pattern = early Devonian and older Palaeozoic rocks

below section C-D : model section of

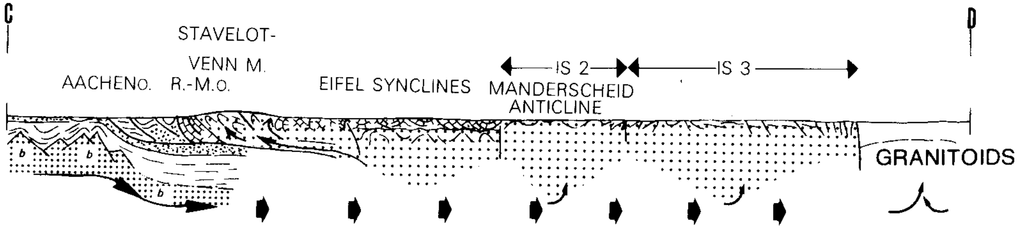
- uplift of the pressuring hinterland in the south,
- breaking up and subfluence of the basement,
- followed by the synsedimentary encroaching of the inversion structure (Stavelot-Venn massif) and its sedimentary cover onto the platform border,
- subsidence on top of the squeezed-out inversion structure, receiving the thick middle Devonian sediments of the Eifel synclines.

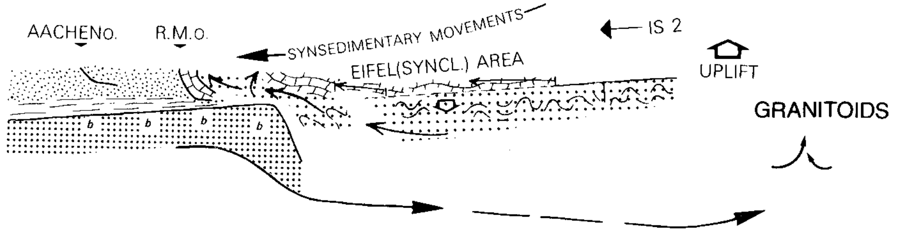
Section E-F

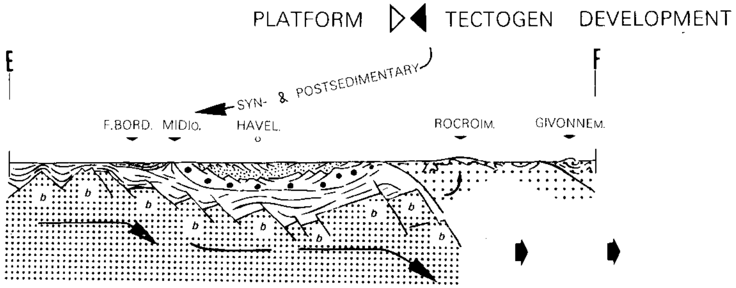
small points (sandy pattern) = middle Devonian to Carboniferous rocks

large black points = early Devonian rocks

bedding pattern = Silurian and older Palaeozoic rocks







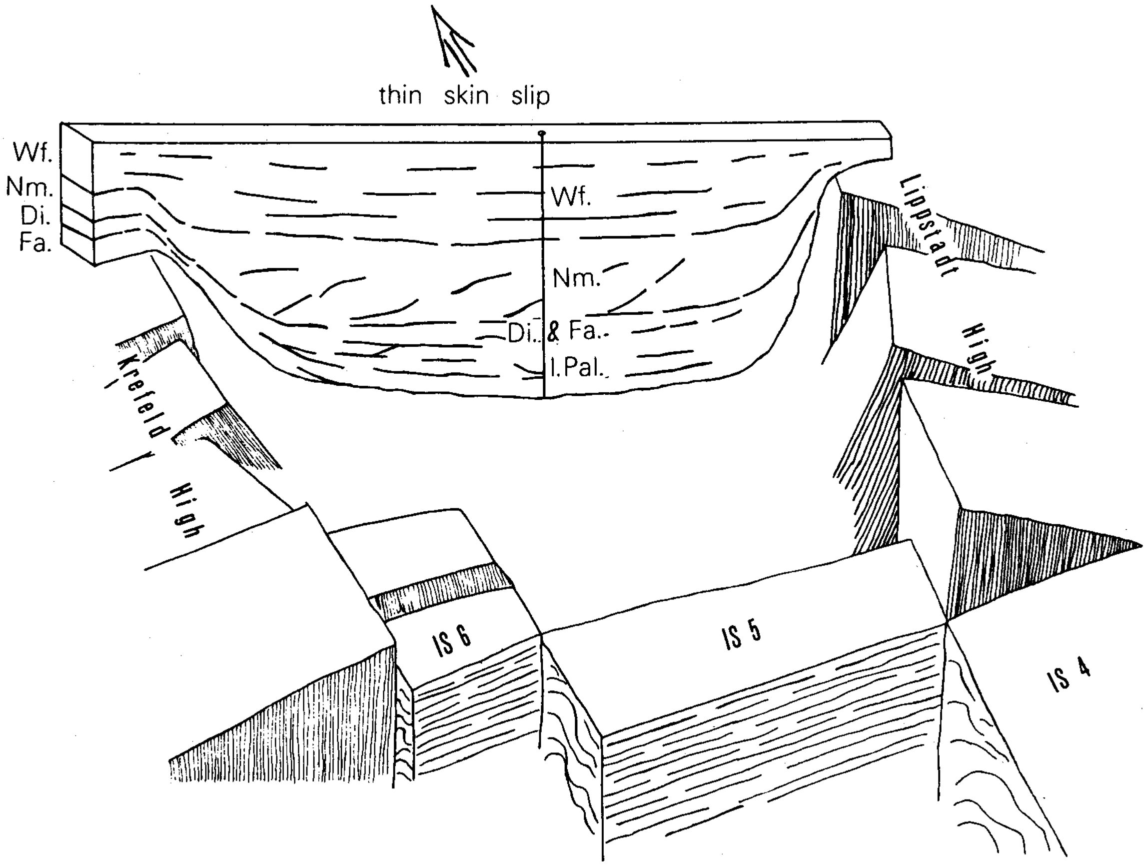


Figure 7.- Very simplified sketch of the northern border of the Rhenish tectogen upon its foreland; no scale.
Estimated thicknesses :

	Krefeld High	south of Dortmund	Lippstadt High
W'C	300 m	500 m	--
W' A + B	1000 m	2000 m	--
Namurian	800 m	2000 m	0 to 3000 m
Dinantian	500 m	100 m	100 m
Famennian	400 m	300 m	100 m
Middle +early Devonian	--	500 m	100 m

Early Devonian and Middle Devonian rocks) exposed. Inner parts of the inversion structure crop out only in the westerly Remscheid and the Ebbe anticlinoria with metamorphosed Ordovician sediments.

The younger Lenne structure (5) bears no sedimentary cover.

The youngest Velbert structure (6) is not cut by the section A-B. The stabilization heat flow was maintained there into the middle Namurian, although sediments of the same age belong already to the sedimentary cover, as is indicated by their reduced thickness and weaker tectonic deformation (Paproth, 1976a : 52).

The Proterozoic plate that bordered the inversion structures in the north, was certainly broken.

A labile part of the plate, east of the Mid Netherlands-Krefeld massif avoided the pressure from the south in the earliest Namurian by the beginning of an accelerated subsidence : the formation of the Subvariscan Foredeep. It was filled with some thousand metres of distal turbidites in the early and middle Namurian and «coal measures» in the late Namurian and Westphalian.

In the Rhenish massif and neighbouring areas an important change in sedimentary conditions from the late Dinantian to the early Namurian had been related to tectonic activities of Stille's orogenic Sudetic phase (cf. Paproth, 1960 : 412 ff).

Sediments of the foredeep, particularly of Namurian age, were considerably thinner on the

(Mid Netherlands-)Krefeld high, the Lippstadt high and other supposed NNW/SSE directed highs further east (fig. 7). This predisposed the area to thin skin tectonic. Underlying Dinantian rocks consist of black shales and cherts about 100 m thick. The Silesian rocks are thought to have slid in one act on this lubricated horizon after their first coalification, in the younger Silesian (M. & R. Teichmüller, 1971 : 53). The deformation style of the Silesian rocks which were the more disposed for intraformational sliding by their content of coal seams and shale horizons, suggests this type of deformation process rather than tectonic deformation by tangential pressure : the deformation process was a single phase; it took place at a shallow level; the deformation style is disharmonic and includes folded thrusts (Drozdzewski, 1980, 1985; Brix *et al.,* 1988).

The tongue-like Hunte shoal which continued the Rhenish shoal to the north from the Permian to the Cretaceous (Rosenfeld, 1978) may have been built mainly by this process. Only in the late Mesozoic, the formation of the Osning half graben permitted a transgression of the late Cretaceous sea from northern directions that stopped in the south only at the northern border of the Rhenish massif.

SECTION C-D, cutting the Rhenish massif and the eastern Ardenne massifs and their borderlands

From south to north, section C-D (figs 6a and 6b) crosses again the Saar-Nahe graben and the inversion structures 3 and 2, then the Eifel area. The sedimentary hinterland of the depositional areas of the present Eifel synclines was built by the Manderscheid anticline (Lippert & Solle, 1937), a southwestern part of the Siegen (2) inversion structure. The impossibility of differentiating between the sedimentary and the deformational history of a region is particularly evident in these parts (Struve, 1963).

In the Eifel area itself, no direct evidence for (or against) the existence of inversion structures have been found. But considering all facts, the existence of one or more inversion structures may be assumed : the low coalification rank (M. Teichmüller & R. Teichmüller, 1979 : 334 ff) and the deformation style suggest that the Eifel synclines form part of the sedimentary cover of one or more inversion structures. Facies boundaries, and shoals that became anticlines, suggest synsedimentary movements, with gravity sliding in northern (NW) directions (Struve, 1963; Paproth & Struve, 1982 : 368 ff). Important faults and thrusts which run subparallel to the fold axes (fig. 8) should have moved not only during, but also after sedimentation, particularly in the earliest Namurian when the Aachen nappe slid into about its present position.

This timing correlated with the pre-Arnsbergian (early Namurian A) sedimentation break west of the Rhine (Graulich, 1963; Bless *et al.,* 1976). It is consistent with the seismic reflection profile across the Stavelot-Venn massif and its northern foreland (Durst, 1985, fig. 2). «... a reflection band coming from the north runs southward underneath the Aachen overthrust at a depth of 2200-3700 m, decreasing in thickness» (Durst, 1985 : 445) would be the autochthonous «Carboniferous Limestone» overlying older Palaeozoic rocks on the Proterozoic platform. The layer thins in a southerly direction beneath the Venn massif and south of it to a few hundred metres and less. If the Aachen nappe is restored to about 15 or 20 km further south, then the postulated thickness of the Dinantian carbonates below the nappe would be comparable to those of the Inde syncline (north of the Venn anticline and south of the Aachen overthrust).

The Aachen Carboniferous Limestone was deposited near the hinterland (in the south; Kasig, 1980). The middle Namurian Grès d'Andenne-Gedau conglomerate on both sides of the Midi-Aachen overthrusts contains chert pebbles that were in part plastic during deposition (Scheere & van Leckwijck, 1963 : 574-575). In the Gedau conglomerate (south of the Aachen overthrust) radiolarians from the cherts were determined as of middle Viséan age (Klerkx, 1966 : B112 ff; Won, 1986 : 6). Middle Viséan radiolarian bearing cherts have been found in the Heugem 1 borehole (266,7 to 268 m; Bless *et al.,* 1981 : 359) about 10 km north of Visé, in a Carboniferous Limestone sequence (north of the Aachen overthrust).

In the Eifel area, Emsian (early Devonian) and middle Devonian rocks form erosional relics. Together, they are approximately 2700 m thick in the northernmost Sötenich syncline (Ribbert 1985) where the succession is :

about	500 m	supposedly eroded Givetian and perhaps late Devonian rocks
	+ 650 m	Givetian rocks
	+ 550 m	Eifelian rocks
+ about	1 000 m	Emsian Heisdorf and Klerf Formations
	2 700 m	

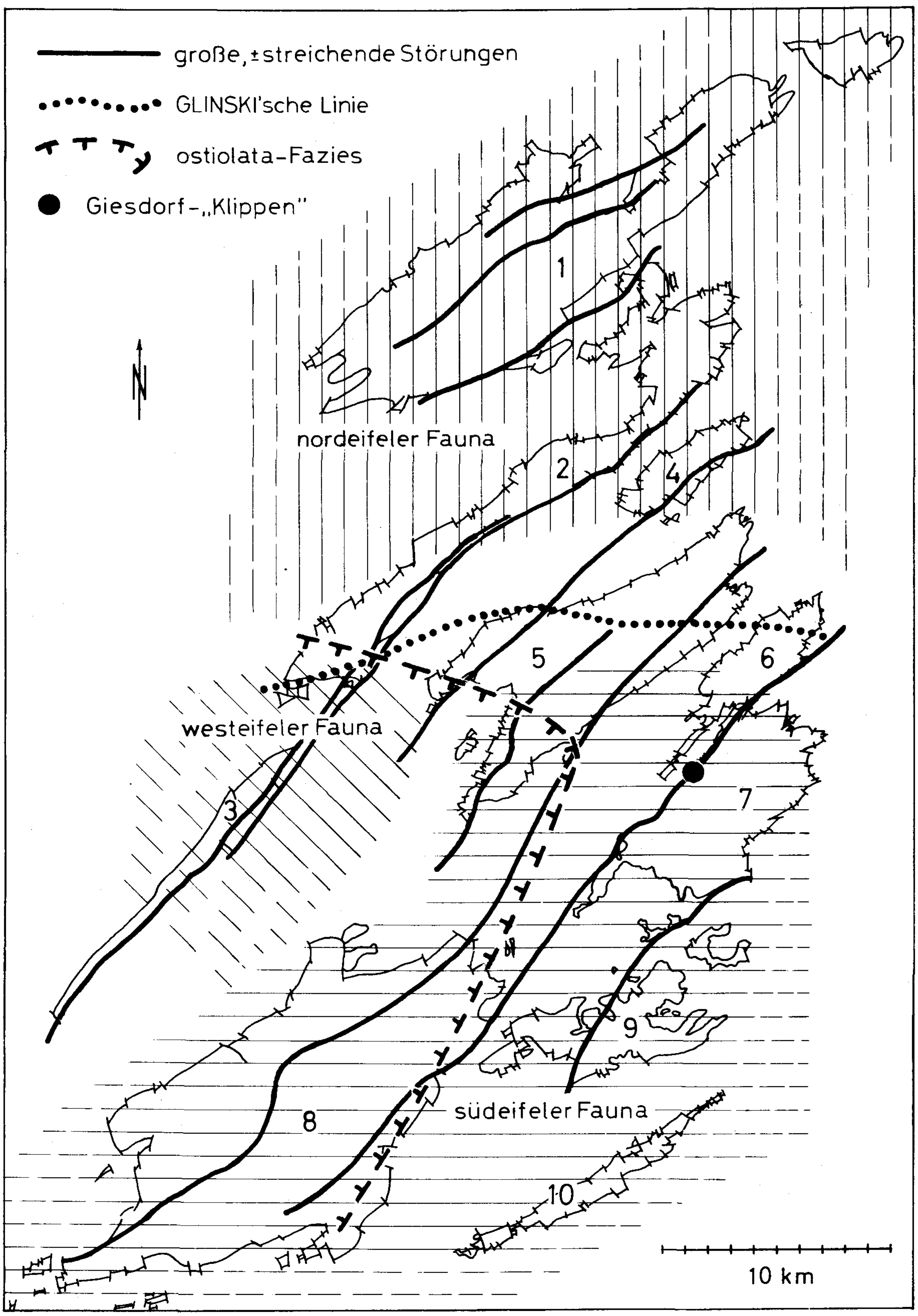


Figure 8.- Simplified map of the Eifel North-South Zone, with the Eifel synclines, showing phenomena which suggest nappe like structures of syn- and early post-sedimentary development (Paproth & Struve, 1982, Abb. 4) :

Large faults, (sub-) parallel to fold axes, with suppression or repetition of thick rock successions; - area of occurrence of northerly, westerly and southerly faunistic elements in the carbonate mid-Devonian of the synclines Zones; - «Glinsky'sche Linie» = southern boundary of colonial rugose corals (Columnaria, Disphyllum) in the Rohr Mb. of the Junkerberg fm.; - at the northern border of the Hillesheim syncline, relics of west-Dollendorf facies (Junkerberg Fm.), and particularly relics of west-Dollendorf and Prüm facies of the Giesdorf Mb. (Giesdorf «klippes»).

1 = Sötenich syncline; 2 = Blankenheim syncline; 3 = Schneifel-Neuenstein syncline; 4 = Rohr syncline; 5 = Dollendorf syncline; 6 6 = Ahrdorf syncline; 7 = Hillesheim syncline; 8 = Prüm syncline; 9 = Gerolstein syncline; 10 = Salmerwald syncline.

If Emsian rocks form the sedimentary cover to one or more of the inversion structures, it follows that the top of the structure(s) should lie more than 2700 m below the neighbouring rocks of the same age outside the proper Eifel synclines area (the Eifel N/S zone) east and west of Schenk's NW/SE axes ramps (1937 Taf. 1). In section C-D a vertical difference of 3000 m is drawn for the same stratigraphical level in the Eifel area and the neighbouring inversion structure 2. This difference may have mainly been reached by synsedimentary subsidence, during the late Early Devonian, the Middle Devonian and perhaps the Late Devonian-Dinantian.

The existence of the «Trier» and the «Mechernich Trias Bays» may be linked to younger movements in the same direction. Evidence for such movements in the latter are obvious (Plein *et al.,* 1982; Klostermann, 1983 : 41 ff, 48 ff).

In the Devonian and Carboniferous (and probably before), the Ardenne-Rhenish area was subjected to north-south directed pressure. Since the early Devonian (and before), internal belts of the Variscan tectogen were folded and uplifted. In the area considered here, this uplift may be observed in the Saar-Nahe region :

> In the Saar 1 borehole, the cooling age of the basal granite has been determined by Rb/Sr whole rock analysis as 381 ± 24 Ma (Lenz & Müller, 1976), that is Siegenian to Eifelian. The weathered granite is overlain by transgressive marine Eifelian carbonates (early Middle Devonian; cf. Paproth, 1976b : 395). The weathered surface of the granite proves the erosion of rocks overlying the granite which probably were at least 1000 m thick. A minimum uplift of 1000 m in the later Early Devonian may therefore be supposed.

The stress from the tectogene and the uplift of its internal belts in the south was transmitted to the foreland-plate. North of the Rhenish massif, a mobile part of the foreland-plate (the Dutch-German platform) gave way by subsiding and thus prepared the Subvariscan Foredeep. North of the Eifel and the Ardenne, the rigid foreland-plate could not subside. Adjoining parts of the plate broke to more or less broad stairs, the southernmost of which was exposed to the tectogen (an inversion structure) that was pushed by the rising hinterland (and submitted to the subfluence of the basement) on to the platform. By these movements, more proximal (southern) parts of the sedimentary cover of the foreland slid gradually during, and shortly after, their deposition on top of more distal (northern) parts, thus forming nappe-like structures. The northward sliding is thought to have worked during the Devonian, particularly the Middle Devonian, and was facilitated by evaporites in the predominantly carbonate sediments of that age. The movements continued into the Dinantian. The carbonate succession includes evaporites that were leached soon after deposition giving rise to solution collapse breccias. This certainly made the sediments instable and mobile (Delmer *et al.,* 1978, de Magnee *et al.,*1986).

The Eifel area was separated from the Rhenish massif in the east by a southern continuation of the Mid Netherlands-Krefeld massif which caused the rigid N/S directed axes ramp east of the Eifel N/S zone; the axes ramp west of it was less rigid and permitted a westerly continuation of fold axes (W. Meyer, oral comm.). - Another stable element was the Brabant massif in the northwest. Both Proterozoic complexes, the Brabant and the Mid Netherlands-Krefeld massifs, formed part of the foreland-plate. In this wedged-in position, the Eifel area was protected to some extent from the stress; parts of the foreland-plate east of the Brabant massif broke, possibly in smaller pieces, and subsided somewhat deeper so that the Stavelot-Venn massif - the core of an inversion structure - could encroach on it («Ardenne zone» in figs 4 and 6); the axis of the Brabant massif plunged to the southeast. This facilitated a movement of the «Ardenne zone»-Eifel area to the northwest. The relaxation created a (anticlockwise) rotation of the eastern parts of the Ardenne (by about 50°).

The (relative) rapid subsidence of the small area east of the Brabant massif is reflected in the great thickness of late Viséan carbonates which were penetrated by boreholes in an area from Maastricht to about 10 km east of the town, and in their high coalification rank (Thermae boreholes; Krings *et al.,* 1987; Wolf & Bless, 1987 : 82-83). The high rank has been interpreted as arising from a regionally limited heat flow which raised the temperature of the sediment up to 450°C for a short period not long after their deposition. This matches exactly the hypothesis of the wedged-in part of the foreland-plate that broke up, subsided and received a strong heat flow shortly after the deposition of the Viséan carbonates.

The fracturing and subsidence may also have triggered the squeezing out of inner parts of one or more inversion structures somewhere beneath the Eifel N/S zone. The autochthonous position of the Stavelot-Venn massif should correspond to that of the original position of the Rocroi and Serpont massifs (fig. 6). The squeezing out is thought to have started already in the Early Devonian and continued during the later Devonian possibly into the Dinantian. - The Stavelot-Venn massif is traceable by reworked sporomorphs only from the latest Early Devonian (late Emsian) onward; this is in contrast to the Brabant and Rocroi massifs, as well as the Mid German Crystalline ridge, which delivered reworked sporomorphs since at least the beginning of the Devonian (Colbeau *et al.,* 1977; Steemans, 1986 : 362 ff). - The eastern parts of the present Stavelot-Venn massif are believed to have had a negligible relief during the Devonian (W. Meyer, 1986 : 162 ff).

The squeezed out inner parts of an inversion structure now form the Stavelot-Venn massif and bordering Early Devonian rocks. The metamorphism of the Stavelot-Venn massif with its two deformation phases (Schreyer, 1975; Kramm, 1982; Kramm *et al.,* 1985a, 1985b) seems to be similar in this respect to that described from the youngest (late Devonian) Velbert (6) structure (Zimmerle & Zinkernagel, 1982 : 131, 133 f; Paproth & Struve, 1982 : 370 ff).

Some north facing overthrusts on the southern flank of the Stavelot-Venn massif, e.g. the Malsbenden and the Trois-Vierges faults, may partially be explained by the squeezing out movement. - The recumbent fold with a subhorizontal axial plain of Revinian beds in the Grand Halleux borehole (Vanguestaine, 1978) matches this interpretation. - The incongruence of age and metamorphic rank near the southern and southeastern border of the Stavelot-Venn pre-Devonian rocks may be linked to these movements : the inversion heat flow causing the metamorphism of the rocks continued during the NW transport, but stopped before the end of the movement. The same process may have worked to create the much slighter incongruence in the much less transported Rocroi and Serpont massivs.

Devonian and Dinantian rocks northwest of the Raeren-Mausbach overthrust were not deposited in the tectogen (in an inversion structure) in contrast to the rocks southeast of it, but on the Proterozoic plate. This is deduced from their platform and slope sedimentary environment, by their deformation style and coalification rank.

Near the Dinantian-Silesian boundary, before the Arnsbergian, an important event is thought to have resulted in the displacement of the nappe 15 to 20 km to the north. The originally southern, thin parts of the Dinantian Carboniferous Limestone (the Aachen Kohlenkalk) were emplaced on top of thicker Carboniferous Limestone which was formed on the inner (northerly) parts of the foreland-plate (Groessens *et al.,* 1979). This movement must have taken place on an older overthrust than the Aachen fault.

Silesian beds were deposited north and south of the Aachen overthrust very nearly in the position where they are now found. This is not necessarily contradicted by younger thrusted rocks, as younger movements certainly took place. The influence of evaporite solution on Westphalian sediment distribution and deformation was considerable. The area is distinguished by seismotectonic activity up to the present day (Ahorner, 1975).

The youngest thrusted beds south of the Aachen overthrust are of early Westphalian B age. There are two or three overthrusts above (south of) the Aachen thrustplane that bring Dinantian or Famennian rocks over the Namurian. The present distance between the Aachen overthrust (one of the youngest) and the Raeren-Mausbach thrust (one of the older) is 11 km. - The decisive displacement of the Aachen nappe in the earliest Namurian to about its present position probably used one of these southern faults (north of the Raeren-Mausbach fault).

Post-Westphalian deformation and mineralization by the solution of pre-Permian (mid-Devonian and Dinantian) evaporites in the subsurface are suspected in parts of the area beneath the Aachen nappe (in the subsurface of the Sötenich syncline, the Mechernich-Mausbach ore districts) and north of it (Visé-Puth, Wurm and Erkelenz districts; Bless *et al.,* 1980). Further west, the strong influence of evaporites and evaporite solution has been proved (de Magnée *et al.,* 1986).

SECTION E-F

cutting the Ardenne and their northern borderland

The section (figs 6 and 6c) starts in the south in the Givonne massif. Early and pre-Paleozoic rocks were subjected to epizone metamorphism. Further to the north, the section cuts a synclinorium with Siegenian sediments in the core, then the Rocroi massif (and its eastern prolongation ?, the Serpont massif). The «epizone» and «mesozone» metamorphism is concentrated near the axis of the Givonne massif, but slightly displaced to the south in the Rocroi and Serpont massivs. These are thought to have been thrusted a short distance on to the border of the foreland-plate, during the lasting stabilization heat flow (the inner parts of the anticlinoria are interpreted as the inner parts of one or more inversion structures in the tectogen).

In contrast, the northerly neighbouring parts of the Dinant synclinorium are thought to belong to the foreland-plate. This may be deduced from their sedimentary environment and their deformation and metamorphism which have been interpreted as mainly caused by halokinesis and gravity tectonics (Delmer *et al.,* 1978). The original boundary between the foreland-plate and the tectogen-inversion structure may be reflected by one or the other of the large faults that run subparallel to the fold axes for more than 80 km in Early Devonian rocks (fig. 6).

Middle and late Devonian and more so Dinantian sediments originally contained evaporites. Anhydrite is nearly the only evaporite mineral preserved, but in the Viséan anhydrite sequence of the St Ghislain drill hole «The presence of K Cl (sometimes in association with Ca SO_4) suggests that, at least locally, brines were present within the sequence which testify of an evolution beyond the gypsum and rock salt stages» (Vandelaannote *et al.,* 1986 : 104). Solution collapse breccias formed in early diagenesis and later (Mamet *et al.,* 1986). So the **dissolution of considerable evaporite bodies seems at least possible and Dinantian rocks may** have started to be deformed shortly after their deposition. Synsedimentary movements which change biotopes have been described, amongst others, from the Dinantian (Conil & Lys, 1977; Conil, Gilissen & Putter, ms). As middle Devonian evaporites are also known, appropriate «synsedimentary» or early diagenetic movements probably occurred.

A tectonic event with probably one of the longest horizontal transports may have occurred near the beginning of the Namurian. It was accompanied by a small uplift of the former depositional area and the Brabant massif : oldest Namurian marine sediments of Arnsbergian (E2) age overlie a Dinantian karst north and south of the Faille du Midi and the Brabant massif was gradually re-incorporated in the depositional area (Bless *et al.,* 1976, fig. 3). Facies, thickness and development of Namurian sediments are uniform on both sides of the fault (van Leckwijck, 1964). - Halokinetic movements heavily influenced the post-Dinantian sedimentation and deformation (de Magnée *et al.,* 1986). The main thrust movements may have continued in this area, as further west, until about the end of the Westphalian A (A. Delmer, oral. comm.).

In the «Dinant zone» of the Variscan front, several overthrusts exist; by convention, the highest of these is called «Faille du Midi». The Faille du Midi runs in Silurian or Early Devonian rocks. The soft, incompetent Silurian shales are interpreted as having been squeezed out of the subsurface of the Namur syncline, possibly by weight of the competent early Devonian rocks (Delmer & Graulich, manuscript).

4.- CONCLUSIONS

The Ardenne-Rhenish massifs, hinterland and foreland developed in intimate dependence on one another. It is not possible to draw a boundary between sedimentation and deformation. Both were manifestations of the same deep seated processes. The main directions were subparallel and did not change during sedimentation and deformation. The stress field was controlled by north/south or northwest/southeast compression, and varied by local temporary heat flows. Internal parts of the tectogen were uplifted.

The **Proterozoic plate** that formed the foreland of the tectogen was subdivided. The parts or limbs differred by their physical characters which were reflected in their relative levels. The rising tectogen in the south forced the adjoining parts of the foreland-plate to subside beneath the tectogen (subfluence). In the Ardenne, a deeper level of the Variscides is exposed in the Rocroi, Serpont, Givonne and Stavelot-Venn massifs than in the Rhenish part. This is explained by a higher position of the bordering foreland-plate in the west than in the east.

In the **Ardenne** and north of it, the Proterozoic foreland-plate formed a broad staircase (beneath the Dinant syncline) and at its southern border (to the tectogen) a ramp dipping beneath the tectogen. In the «Ardenne zone» (figs 4, 6) and the Eifel area and north of them the foreland-plate formed also a ramp dipping beneath the tectogen, but the «staircase» part of it reached deeper than that beneath the Dinant syncline west of it; the change must take place between the Brabant massif and the Mid Netherlands-Krefeld massif. East of the Proterozoic ridge forming the Mid Netherlands-Krefeld massif, a labile part of the foreland-plate was driven down north of the Rhenish massif and formed the Subvariscan Foredeep which was bounded to the east by Proterozoic highs one of which may be recognized in the NNW/SSE directed Lippstadt massif.

Vertical synsedimentary movements were the most important for the development of the **Rhenish part** of the Variscan orogene. It was constructed by inversion structures (sensu Dvorak, 1973) which began as stationary troughs and were filled one after the other in the early Palaeozoic and the Devonian with some thousand metres of shallow marine sediments. A stabilization process of the filled troughs formed consolidated structures that were affected later by a second deformation phase (in the later Carboniferous). The inversion structures may be overlain by a sedimentary cover that is less **influenced by temperature and deformation than their (stabilized) inner parts.**

In the Rhenish massif six inversion structures are recognized (there may be more). They are arranged in an anticlockwise whirl which may have formed in the more slowly moving part of the southerly directed subfluence current, at the border with the faster moving part. Speeds were slow, as the whirl took about (at least) the Devonian (50 ma) to form.

In the Eifel and the Ardenne, no direct evidence of the (non-) existence of inversion structures are known. This difficulty may be due, in part, to the more complicated structure than that of the Rhenish massif. In the Eifel, considerable parts of one or more inversion structures and their sedimentary cover are thought to have been moved in N or NNW direction during and shortly after sedimentation.

The Stavelot-Venn massif is interpreted as an inner part of an inversion structure which was queezed out to its present position from perhaps about beneath the present Eifel (-Olkenbach) area. The Eifel mid-Devonian sediments may be a particularly thick sedimentary cover deposited on the area that subsided because inner parts of the underlying inversion structure were queezed out in north-westerly directions.

The sharp boundary between tectogen (inversion structure) and foreland-plate is thought to be reflected by the (allochthonous) Raeren-Mausbach fault.

In the Ardenne, the Givonne, Rocroi and Serpont massifs are believed to expose inner parts of nearly autochthonous inversion structures. The sharp boundary between the tectogen and the foreland-plate is interpreted to lie north of the Rocroi massif and south of the Dinant syncline. The mid-Devonian to Dinantian sediments of the Dinant syncline (on the foreland-plate) are judged to have moved during and after sedimentation to the north. Movements were facilitated by evaporites.

In the early Namurian, strong stresses from the rising hinterland affected the Ardenne-Rhenish massifs :

- The Dinant-Aachen nappes moved considerably. At least in the Aachen area, the nappe(s) reached **about** their present position. In the «Dinant zone» (figs 4, 6), overthrusting continued until about the end of the Westphalian A (A. Delmer, oral comm.).
- Movements in the same directions and presumably often related to evaporites were the final phase of the construction of the present geological edifice. - South of the Brabant massif, the dissolution of Dinantian evaporites has extremely complicated the deformation of Dinantian and post-Dinantian rocks (de Magnée *et al.,* 1986).
- A stronger relative slip to the NW in the «Ardenne zone» (figs 4, 6) created an apparent rotation of the east Ardenne-Eifel-Stavelot-Venn-area. The Stavelot-Venn massif was squeezed out from deep levels in the subsurface of the Eifel area and joined that rotation.
- North of the Rhenish massif, the Subvariscan Foredeep started to develop in the earliest Namurian. The accelerated subsidence of the basement that initiated the foredeep development may have been facilitated by the previous formation of a whirl. - The Foredeep was filled by several thousand metres of siliciclastics (delivered from southerly source areas) which contain coal seams in their younger parts.
- The deformation of the Flözleeres and Steinkohlengebirge (Namurian and Westphalian north of the Rhenish massif) was caused mainly by gravity (thin skin tectonics) in the late Silesian, initiated by the still rising Variscides.

The different appearance of the present Ardenne (- Eifel) area with an important horizontal component, and the Rhenish area, with an important vertical component of **synsedimentary** and syngenetic movements may be explained by the different position and behaviour of the limbs of foreland-plate in relation to these areas; and that again may be in relation to a faster subduction movement of the basement beneath the Ardenne (- Eifel) area, than beneath the Rhenish area. The apparent rotation with a maximum in the Aachen-Stavelot-Venn area was caused by the plunging of the axis of the Brabant massif to the east, and the rigidity of the Mid Netherlands-Krefeld massif.

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