FAMENNIAN PALEOGEOGRAPHY AND EVENT STRATIGRAPHY
OF NORTHERN EUROPE

by

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(8 figures)

ABSTRACT. - The distribution of red beds, evaporites, pedogenic carbonates in the late Devonian of northwestern Europe, and the type of floral assemblages as well as the high feldspar content and the common occurrence of tempestites in the Upper Famennian arkosic sands of the "Psammites du Condroz", are symptomatic of the then prevailing semi-arid climatological conditions of a tropical trade wind belt. A possible source area is here proposed for the latter arkosic sands. The paleogeographical evolution of the Ardenno-Rhenish Massif during the Upper Famennian, is largely the result of an interaction between a strong, southern equatorial current (the deflected Western Boundary Current) and the episodic reactivation of blockfaults (Ardenne) and/or inversion structures (Rheinisches Schiefergebirge). Some regional tectono-sedimentary events as well as some probable worldwide paleoclimatological events are briefly discussed.

RESUME. - La distribution de couches rouges, d'évaporites et de carbonates pédogénétiques à la fin du Dévonien du N-W de l'Europe et le type de flore, la présence commune de tempestites et la haute teneur en feldspaths des sables arkosiques des "Psammites du Condroz" au Famennien supérieur, témoignent de conditions climatiques semi-arides prédominantes dans une ceinture tropicale à régime d'âlizés. Une source est proposée pour ces sables arkosiques. L'évolution paléogéographique du Massif ardenno-rhénan pendant le Famennien supérieur est, en majeure partie, le résultat d'une interaction entre un fort courant sud-équatorial (le "Western Boundary Current" dévié) et la réactivation épisodique d'un système de blocs faillés (Ardenne) et/ou d'inversion de structures (Rheinisches Schiefergebirge). Quelques phénomènes tectono-sédimentaires régionaux ainsi que des événements paléoclimatologiques probablement d'ampleur mondiale, sont discutés brièvement.

1. LATE DEVONIAN CLIMATE

During the late Devonian, the Ardenno-Rhenish-Polish sedimentary realms were occupied by shallow epicontinental seas bordering the southern parts of the Old Red Continent. This Continent was intersected by the Caledonian mountain belt.

The frequent occurrence of red beds, evaporites and pedogenic carbonates (caliche, calcrites) on and around the Old Red Continent is symptomatic of prevailing semi-arid climatic conditions of the tropical wind belt (between 10° and 30°S paleolatitude; fig. 1). Similar climatic conditions might explain the abundance of fresh feldspars in the Upper Famennian Condroz arkosic sands in the Belgian Ardenne (Thorez et al., 1986, Thorez & Dreesen, 1986).

The large amount of continental clastics (in the Old Red Sandstone facies) and marine clastics (in the Condroz Sandstone facies) along the European side of the Caledonian mountain belt resulted from the rising and cooling of westward trade winds (T.W.) over these mountains, carrying moist air from the Paleotethys and from the shelf seas to the East of the Old Red Continent. This cooled moist air produced abundant rainfall and subsequent shedding of siliciclastics to the East. The large amount of clastics associated with evaporites (predominantly anhydrite and gypsum) in Europe is in sharp contrast with North American carbonate-associated evaporites because the trade winds carried practically no moist air over the Caledonides.

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MIDDLE FAMENNIAN PALEOGEOGRAPHY OF THE ARDENNO-RHENISH AREA

**Legend**

- Continental Lowland
- Supposed Well-aerated Water Area
- Supposed Shelf-type "Condroz Sandstone Facies"
- Supposed Quiet Water Area
- Supposed "Hereynian Facies"
- Barrier System
- Shoals (Submarine and Subtidal)
- Sandstone-Siltstone
- Mudstone-Siltstone
- Nodular Limestone
- Turbidity Current Direction
- Sea Current Directions: Non-Turbiditic Transport

**Figure 2**
Figure 3
and became so highly dessicating that rock salt and potash salt were formed (Heckel & Witzke, 1979).

The occurrence of thick coal-bearing clastics in the Upper Devonian of the Canadian Arctic Islands seems to be related to the doldrum rainfall in the near-equatorial tropical rain belt (Heckel & Witzke, 1979), whereas the abundant floral remains in the Famennian swamps of the Appalachians (Banks et al., 1985) are consistent with the temperate humid belt (30° to 40°S paleolatitude) on the windward, rainy side of the Aca- dia mountains. The Famennian humid belt floral assemblage contained conspicuous near-swamp lycopod tree communities (Scheckler, 1986a) which is in contrast with the coeval North European trade wind belt flora: here levees and floodplains were colonized by Archaeopteris whereas Rhaeopteron dominated the coastal marshes and alluvio-lagoonal ponds (Fairon-Demaret, pers. commun.).

There is also a fundamental difference in fluvial regime between both areas: in the late Devonian Catskill Delta, sediments of numerous meandering streams in lowland interfluves and floodplains have been observed (Scheckler, 1986b) whereas the streams tended to be rather "flasby" in the NW European lowlands. The frequency of tempestites and that of hummocky stratification within the late Devonian Condroz Sandstones ("Psammites du Condroz") in the Belgian Ardennes, is consistent with the distribution of Paleozoic hurricane deposits which may be expected from latitudes of about 10° to 45°S, with a maximum between 10° and 20°S (Duke, 1985).

In the then southern hemisphere, the easterly trade winds were accompanied by a warm equatorial westward sea current between the equator and about 20°S (Heckel & Witzke, 1979). This southern equatorial current flowed through the Paleotethys towards central Europe, split at the southeastern side of the Russian Platform, with one branch moving southwestward through the intricately subdivided basinal area of Central Europe as a western boundary current (W.B.C.) (fig. 1).

A branch of the western boundary current may have been deflected by numerous shoals and islands formed by the in situ nascenti Variscan tecton. There is no evidence for strong sea currents in the Polish, Czechoslovakian or German outcrops. Very remarkably is the survival of stromatoporoid facies in the Famennian in Moravia and neighboring areas near the Pre-Carpathian Platform (Dvořák, 1986).

A more northerly branch of the same current passed through the Polish Basin and was then deflected by the Old Red Continent, where it passed through (rather) narrow seaways in between the emerging Ardenno-Rhenish Shools (cf. the "Vesdre Corridor", fig. 6), redistributing the alluvial discharges of prograding deltas which came from the Old Red Conti- nent in the Netherlands and North German Lowlands. Thus the classical Upper Famennian "Psammites du Condroz" originated through a current-induced destruction of delta lobes and a subsequent westward redistribution of the pro-delta sands. Although "flasby" fluvial regimes with episodic, high discharge periods are more likely to supply coarse sediments to a delta (e.g. the Old Red Sandstones of the British Isles), the Condroz Sandstones are fine-grained. This results most probably from the reworking of an originally oolitic-alluvial sediment which derived from a nearby, supposedly Pre-Cambrian gneissic source rock area, the Mid-Nether- lands High.

Evidence exists in South America (North Brazil), and possibly also in Central Africa, for an early to late Famennian glaciation (Caputo, 1985; Streeł, 1986). It might have caused a global narrowing of the warm climatic belts, sharp regressions and increased silici- clastic sedimentation. Together, with the reciprocal effects at the end of the glaciation this should have resulted in important facies changes in the world geo- logical record.

2. STRUCTURAL FRAMEWORK

The southwestern boundary between the East European or Russian Platform and the Variscan tecton dominates the structural development of Central Europe (fig. 4). West of the Tornquist Line, the rim of the Platform seems to be broken into a chessboard-like structure. In Central Europe, a main line crossing the Platform and in parts forming the boundary between Platform and tecton is marked by the Hamburg-Cracow Lineament (Dvořák, 1968). Further to the West, the Platform seems to be even more fragmented in northern Germany, the Netherlands and northern Belgium. In the Netherlands and northern Germany, the long-lasting effects of both NNW/SSE and N/S trending structures are supposed to be inherited from Pre-Variscan and Pre-Cambrian basement (Pratsch, 1979; Bless et al., 1980).

One of the main NNW/SSE trending elements seems to be the Mid-Netherlands- (Zandvoort-Maasbommel)-Krefeld High. Our knowledge of it is scarce; the oldest direct hint to its existence are pebbles of epizonal metamorphic rocks in the Givetian Schwarz- bachtal-Konglomerat North of Düsseldorf (Makrutzi, 1982; Neumann-Mahlkau, 1982). The influence of this structure can be traced from the Givetian into at least the Cretaceous (Van Staalduinen et al., 1979). Inversions of this "High" are well known (Klostermann, 1983). In the Famennian, it may have been a main source of siliciclastic detritus that was deposited in the Condroz Sandstones facies. In the long Post-Famennian history of this "High", lateral movements and rotations have certainly changed the topography particularly of the southern portion (Plein et al., 1982; Klostermann, 1983). Any reconstructions based on modern topo- graphy are hampered by these difficulties.
The Mid-Netherlands-Krefeld High and a line continuing it in a southern direction seem to bound two different areas:

- on the West: the area of the Brabant platform is marked by a shallower level of the basement, that gradually rises northwards until it reaches its highest level North of the Faiile du Midi or near the Faiile Bordière (Legrand, 19).

- in the East: the area of the Dutch-German Platform is marked by a deeper position of the basement; it finally drops steeply beneath the Variscan tectogen.

3. - FAMENNIAN PALEOGEOGRAPHY AND EVENTS

3.1. - GENERALITIES

In the early Famennian, the beginning of a Famennian glaciation may have caused a cooling of the ocean waters. The worldwide refrigeration would explain the increase in clastic sedimentation (i.e. the "Psammites du Condroz") in areas where tropical biochemical sedimentation (e.g. the extensive Givetian and Frasnian carbonate shelves with reef belts) pre-
viously predominated. Moreover, the first appearance of plant seeds in the late Famennian (VCo spore zone) coincides with this “event”. Would this indicate an evolutionary adaptation of plant life to an increasingly dry environment (Gillespie et al., 1981; Faron-Demaret, 1986)?

Near the Devonian-Carboniferous boundary, a general climatic change - the end of the Famennian glaciation? - may have affected the southeastern borders of the Old Red Continent. The effects of a “worldwide” post-glacial warming of the ocean waters may have been intensified by the simultaneous northward shift of the Old Red Continent crossing the equator. This post-glacial warming of the ocean waters in the latest Famennian and a small northern shift of the Old Red Continent (5° at the most) towards the equator might well explain the reappearance of stromatoporoids and calcareous ooids (Étroeungt and Hastière Limestones in Belgium) in the area here described.

Famennian stromatoporoid reef facies seems to be restricted in Central Europe to the shelf regions without siliciclastic sedimentation such as those bordering or near the Pre-Carpathian Platform. Crinoidal debris “reefs” and cryptagal sponge-bearing carbonate buildups could exceptionally develop within the northern siliciclastic shelf settings in NW Europe, on pre-destined highs during a temporary waning of the siliciclastic supply (Dreesen et al., 1985). Carbonate buildups such
as the "Baele reefs", represent a Famenian "reef" episode that coincides with a short transgressive pulse resulting in the temporary appearance of protected shelf carbonates and in the immigration of primitive pluri-locular Foraminifera (Conil et al., 1986). This short-term transgressive event in the northern Ardenne shelf area possibly matches a coeval deepening event on the platform settings of the western United States (Johnson et al., 1985).

Other interregional or worldwide transgressive pulses so far observed in the Famenian are few, and the interpretation that these were caused by transgressions seem to be traditional rather than based on facts. Effects of the extensive "Annulata Black Shale" event in Germany have been recognised in North America (event Q of House, 1983), and might also be recognizable in Belgium. Indeed, conspicuous black shales (up to 15 m thick) interrupt the younger sandstone units of the "Psammites du Condroz" at a level approximatively corresponding to the base of the P. postera conodont Zone (top of the German Platyclymenia Stufe). Another supposed deepening event is observed in the Wocklumeria Stufe in Germany, producing few centimeters of alum shales with Cymacylmenia evoluta.

However, the most striking event observed within the Upper Famenian shallow shelf area is a regional regression which is characterized by the progradation of alluvio-lagoonal coastal barrier and tidal flat complexes, South and Southeast of the London-Brabant High (Thorez, 1969; Thorez et al., 1977; Thorez & Dreesen, 1986). This offlap is rhythmic and is apparently associated with episodic reactivation of small tectonic blocks producing differential subsidence and the persistence of non-depositional areas (Thorez & Dreesen, 1986).

At about the same time, inversion structures became reactivated in the Rheinisches Schiefergebirge (Rhenish Shoals) - the increase of these morphological structures as potential source for the siliciclastics may have been caused by the regression - producing and triggering turbidites towards depocenters in the immediate surroundings (Nehdenian and Dasbergian Sandstones in Germany). An incipient mountain chain, the Mid German Shoals, gradually risen in the southern geosynclinal areas, announcing the forthcoming flysch stages (greywackes).

The tectonic blocks in the Ardenne (Thorez & Dreesen, 1986) and the inversion structures in the Rhenish Massif are bordered by NNW/SSE and WSW/ENE directed block faults which are supposed to have been inherited from the basement.

3.2. - THE WESTERN AREAS

The influence of synsedimentary tectonic movements is demonstrated by the paleogeographic evolution of the "Psammites du Condroz" case study in the
eastern part of the Dinant Synclinorium (Thorez & Dreesen, 1986). The reconstruction has been completed on the basis of a slice-by-slice framework that includes eleven superposed sedimentary phases, matched by the "rhythmstratigraphy", the interpretation of the depositional environmental conditions (at different scales of the sedimentation) within the eastern part of the Dinant Synclinorium, and by micropaleontological arguments (the mgm or "micropaleontologic guide marks" proposed during the 1974 Namur Symposium, Bouchaert & Strel, Eds.; Thorez et al., 1977). Three of these partial reconstructions are here reproduced (Fig. 6, 7, 8). They concern the Upper P. crepida—Lower P. rhomboidea, the Lower S. velifer, and the VCo biostratigraphical intervals. However, these three paleogeographic reconstructions are not based on a palinspastic development as presented in Thorez & Dreesen (1986). As emphasized by Thorez & Dreesen (1986) the progradational evolution of the "Psmmites du Condroz" in their type-area was controlled by the interplay of paleomorphology, paleohydrodynamics, paleotectonics (block-tilting) and paleoclimatology.

For the first time, also, sedimentary and stratigraphic relationships between the Upper Famennian of Germany and Belgium are here forwarded. This circumstance has favoured a broad picture of the entire depositional framework during this crucial period in the Old Red Continent evolution. The reconstructed depositional system of the "Psmmites du Condroz" in Belgium sheds some light on similar but still not detailed patterns in the neighbouring area, particu-
of the persistent contamination by fine siliciclastics (pelites, silts) brought in from the Northeast by the longshore currents (Western Boundary Current).

The episodic reddening of muds and carbonate sediments in the more basin-like areas matches the episodic occurrence of oolitic ironstones on the Condroz shelf with synsedimentary volcanic activity in the Lahn-Dill area (Dreesen, 1981, 1982). Although Dvofák (1985) related the red colour of pelites and associated coarser siliciclastics in the Rheinisch Schiefergebirge (during Nehdenian times) to periodical detrital influx from inversion structures, a volcano-sedimentary origin (halmyrolysis of volcanic ash-falls) cannot be excluded (Dreesen & Thorez, 1980). Moreover, regularly interbedded shabkha-related red beds have been observed in the Dinant Syncinorium. These form excellent local marker beds within the youngest strata of the "Psammites du Condroz", especially along the southeastern border of the London-Brabant High (Thorez et al., 1986).

The shallow Condroz shelf area and its lateral equivalents formed the recipient of predominantly coarser siliciclastics, the Condroz sandstones. Thorez (1969) has demonstrated that those sandstones are, in fact, very fine-grained micaceous arkoses. For a long time, geologists have been puzzled by their exact origin and source area. The concept of a remote, northern Caledonian or Scandinavian source area should now be rejected in the light of the more recent knowledge on Fennoscandian climatic and paleogeographic conditions: the presence of a high fresh feldspar content would have been practically impossible to meet under the humid tropical conditions which presumably influenced the Scandinavian area. Instead, a progressive physical weathering under dry, semi-arid conditions is suggested here, of a nearby (supposedly Precambrian gneissic and granitic?) source rock: the core of the Mid Netherlands High, figures 1, 4, 5). This would explain both the high mica (muscovite plus biotite) and fresh feldspar content. Furthermore, the fineness and good sorting of those sands would best be explained by a trade wind-induced eolian transport of the siliciclastics from the above source area to the adjacent lowlands. A subsequent episodic alluvial transport by "flashy" rivers would have transported the reworked eolian sands to a high-destructive wave-influenced delta lobe where (Fig. 1, Thorez et al., 1986) strong longshore currents (W.B.C.) picked up the prodelta sands, reworking them towards the western shallow shelf areas; there the coarser material (sands) was resedimented as longshore coastal sand bars, and the finer clastics (silts and muds), as offshore silty shales. The gradual increase of the feldspar/quartz ratio and the gradual decrease of the mica content towards the younger formations of the "Psammites du Condroz" are possibly explained by a gradual change of the source rock composition: a progressive denudation, or "peeling", of a metamorphic basement rock (the Mid-Netherlands-Krefeld High) would have produced successively phyllitic, micaschist and, then gneissic detrital material. Furthermore, the sudden drop of the feldspar content.
(from about 50 °/o in the youngest Evieux Formation, to 5 °/o in the Strunian) could be related to a final leveling of the suggested source area and/or by a climatic change (a temporary increase of the number and length of the wet periods?).

### 3.3. - THE EASTERN AREAS

In the Rhenish Massif, East of the Rhine river, incompletely studied sediments of the Condroz Sandstone facies crop out in the Velbert Anticline. During the Famennian, the actual Velbert Anticline was a rapidly subsiding trough (the youngest of the inversion structures, nr 6, fig. 5) where presumably some 1000 m thick fine-grained shallow-water siliciclastics accumulated. The boundary between the "Condroz Sandstone" facies Velbert Formation, and the typical quiet water ("basinal") facies to the East is sharp and crops out at Wuppertal. The very sharp facies boundary indicates no great differences in water depth, the main difference between the facies belts was possibly the relative water energy (Schmidt, 1935).

On top of the Mid-Netherlands-Krefeld High and East of it, in the southerly parts of the Dutch-German platform, only few boreholes have penetrated sufficiently deep into Famennian rocks for a tentative interpretation. The differences in thickness and grain-size of Famennian Condroz Sandstone facies siliciclastics suggest a decreasing energy of marine currents for the Münsterland-1 borehole area. This may have been caused by an increased width of the sea way thus suggesting the existence of a bay matching the Ems Low trend.

In the "basinal" areas of the Variscan tectogen, greywacke sands were transported by turbidity currents into rapidly descending basins in proximal parts of the geosyncline (Andelska Hora Formation in Moravia, Urfer Grauwacke and equivalents in West Germany). The erosion of the Mid German shoals and islands started during this period.

Another source of siliciclastic detritus was the rising Rhenish Massif where the inversion structures 1 to 5 (Figs. 4, 5) were locally eroded, producing small amounts of detritus. Eastern (and northern in the Netherlands) fringes of the Rhenish shoals area were more eroded than inner and western parts of the region (Kayser et al., 1978). A particular feature is the Hörre-Kellerwald-belt, where longitudinal transport of siliciclastics started in the narrow basin persisted intermittently into the Visean (Homrichhausen, 1979).

Sedimentary areas that were not easily reached by the siliciclastics mentioned above were covered - so far as known - by nodular limestone material with varying contents of argillaceous and silty material, depending on whether they were in distal reach or not of the source areas.

Water energy and consequently aeration of the sea waters and the sea bottom were weak. Benthonic fossils may locally occur but are not common.

### REFERENCES


