THE GEOSYNCLINAL DEVELOPMENT OF THE RHEINISCHE SCHIEFERGEBIRGE (RHENOHERCYNIAN ZONE OF THE VARISCIDES; GERMANY)[1,2]

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ABSTRACT

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The Palaeogeographical distribution and evolution of facies in the Rheinische Schiefergebirge reflect the geosynclinal development of the Mid-European part of the Rhenohercynian zone of the Variscan geosyncline.

The geosynclinal development of the Rheinische Schiefergebirge was strongly influenced by the Mid-German Crystalline Rise in the south and by the Old Red Continent in the north. From late Precambrian up to Early Ordovician, the Mid-German Crystalline Rise has been a zone of rapid accumulation of sediments and volcanics, thus indicating an early tensional phase and the beginning of fracturing and mobilization of the European crust. With that the Variscan geosyncline proves to belong to a Proterozoic-Palaeozoic, resp. Caledonian-Variscan megacycle. The tension of the crust did not lead to the creation of an ocean in the described area.

The Mid-German Crystalline Rise delivered debris into the southern part of the Rheinische Schiefergebirge during the Early Devonian. But the main part of this episialic sea was characterized by a large deltaic spread off the Old Red Continent. The delivered material accumulated in rapidly subsiding shelf troughs which followed asymmetrical graben-like structures and which retreated episodically northward. Tension at this time is also proved by an important volcanic activity. Outside of the shelf areas relatively thin pelagic sediments were deposited in a relatively stable basin of no great depth.

The Givetian transgression caused a maximum of reef development. After the suppression of reefs by another global event in the late Frasnian, the further development led to an equalization of relief and facies. The pre-flysch phase in the Dinantian is characterized by another tensional episode with basic volcanism and by regionally limited deposition of limestone turbidites.

The first occurrence of flysch sediments, delivered from the Mid-German Crystalline Rise, is already low in the Upper Devonian. A prominent acceleration of flysch accumulation and of northward shifting of the trough began in the late Dinantian. Already during the Namurian the flysch trough gradually changed into a molasse trough with paralic conditions.

INTRODUCTION

As early as 1949, SCHMIDT published a facies cross-section through the Rheinische Schiefergebirge, comprising only Devonian time. His presentation and his interpretation of the facies and facies development is still valid in most of its parts. KREBS (1974) gave a review of the facies distribution in the basin areas and GOLDRING & LANGENSTRASSEN (1979) of that of the shelf areas. The geosynclinal development has been described by WALLISER (1977, 1980), FRANKE ET AL. (1978) and BEHR ET AL. (1980). Therefore in this paper the description of the geosynclinal development can be restricted to the main steps. The relevant voluminous literature is given in the publications mentioned above.

[1] This work forms part of the research programme of the Sonderforschungsbereich 48 'Entwicklung, Bestand und Eigenschaften der Erdkruste, insbesondere der Geosynklinalräume' at the University of Göttingen. Funds for this work were provided by the Deutsche Forschungsgemeinschaft.

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REMARKS TO THE MAIN DRAWING (Encl. I)

I deliberately based the design of enclosure I on SCHMIDT's (1949) excellent drawing. Unlike Schmidt's figure, however, it takes the Devonian-Carboniferous boundary as a horizontal reference line. As a consequence the differences in the geosynclinal development in Devonian and Carboniferous times become more obvious.

The section uses the observations made within a more or less narrow strip, rather than at a line (see inset of the enclosure). Strictly, the section is valid only for this strip, but it demonstrates the general development of the whole area.

The vertical scale for the thickness is twice that for the horizontal one. The length of the profile has been extended in those parts with large overthrusts (as e.g. north of the Hörre Syncline). To demonstrate the true proportions, a palinspastic reconstruction has been added. The section shows a few of the numerous formation names in order to give some reference points for identification. In spite of the larger scale for the thickness, only the general features of the different facies could be represented. Details, especially in sequences with a low rate of sedimentation as e.g. in the pelagic facies, could not be presented, although there exist relatively large differences, which even may be very important for understanding of the geosynclinal development. To demonstrate this, one example is shown in figure 1.

SOME ASPECTS OF THE FACIES PATTERN

Sediments reflect in some degree the kinematics of the geosyncline, i.e., their palaeogeographical distribution and chronological development mirrors the movement of the seafloor and of the surrounding areas as well as the geological processes, including oscillations of the sea level.

The neritic facies[4]

The neritic facies is widely distributed during the Lower and Middle Devonian. Thereby those sediments which developed under restricted environmental conditions retreated in the course of time to the northwestern areas. Typical features for those sediments are red-beds, conglomerates and even root horizons, together representing a deltaic sedimentation, ranging from the delta front to lagoons and to the proximal part of the delta plain, the latter partly occupied by plants which grew below, at and above the water level. Thus, these sediments with root horizons are not necessarily indications for prominent land areas, as interpreted by KAISER ET AL. (1978). Further characteristics for these restricted environments are specific ichnofossils (GOLDRING & LANGENSTRASSEN, 1979), layers with monotypic pelecypods, as well as eurypterids and special agnathians and arthrodires . All transitions into full-marine conditions are present. The distribution and facial development of the neritic sediments indicate, that all the siliceous debris, coming from the north, has been delivered by only one delta system. The source area is the Old Red Continent, perhaps the molasse of the young Caledonian orogen. But it should also be noted, that land areas immediately north of the Rheinische Schiefergebirge at least participated in delivering material.

The delta with its changing positions gave rise to the development of the large shelf areas. The physical and chemical conditions on this shelf may well have been comparable to those of modern shelfs. But the general configuration was quite different in so far as the difference between the shelf edge and the seafloor in the adjacent basin did not exceed a few hundred metres.

Pelagic facies

The question of the depth of the basin is closely related with the problem of the bathymetry of the pelagic facies. At numerous places in the Rheinische Schiefergebirge, bioherms have grown at the top of volcanic elevations of a few hundred metres, clearly indicating a relatively shallow basin (compare Fig. 1). The facies array on these elevations, namely clay – clay with calcareous nodules – cephalopod limestone – crinoidal limestone – biohermal limestone, confirms other observations (e.g. by TUCKER, 1973; WALLISER, 1977; VAI, 1980) that many Devonian cephalopod limestones were deposited above the aphotic zone. 'Similar sets of relationships between the Lower Carboniferous bedded cherts (Lydite, Kieselschiefer) and cephalopod limestones show that these bedded cherts can have been formed at comparatively moderate depth'. 'Of course, bedded cherts may elsewhere be found to have developed on the floor of deep oceans also; but within the Rheinische Schiefergebirge and the Harz Mountains they have been deposited at a depth of a few hundred meters and somewhat beyond, but certainly not at abyssal depth' (WALLISER, 1980-a: 186). Thus, some of the main arguments, viz. abyssal cephalopod limestones and abyssal bedded cherts in combination with basaltic lava, for a Mid-European ocean (e.g. LAURENT, 1972; BURRET, 1972; JOHNSON, 1973; DEWEY & BURKE, 1973; RIDING, 1974) in the region of the Rheinische Schiefergebirge are readily refuted, at least for Devonian and Carboniferous times.

The continuous facial development has been interrupted at several times, mostly by black shales. Those, as for example the Wissenbach Shales (late Emsian), the Odershausen horizon (Eifelian/Givetian boundary), the Kellwasser horizon (later part of the Frasnian), the *annulata* horizon (later part of the Famennian) and the Dinantian alum shales, are present in

[4] Although the term 'neritic' originally was used only in a biological or ecological sense, this term came into use also for sediments or facies which developed in shallow-marine environments (e.g. in shelf areas), normally containing a predominance of benthic organisms due to the relative degree of water movement and high amount of oxygen. That is the classical 'rhenish' (rheinische) facies. Analogously the term 'pelagic' is now also used for sediments or facies developed in mostly deeper and quiet environments with only few or no benthic organisms but a predominance of nectic and/or planktic or pseudoplanktic organisms. That is the classical 'hercynian' (herzynische) facies. For intermediate facies the term 'hemipelagic' is used.

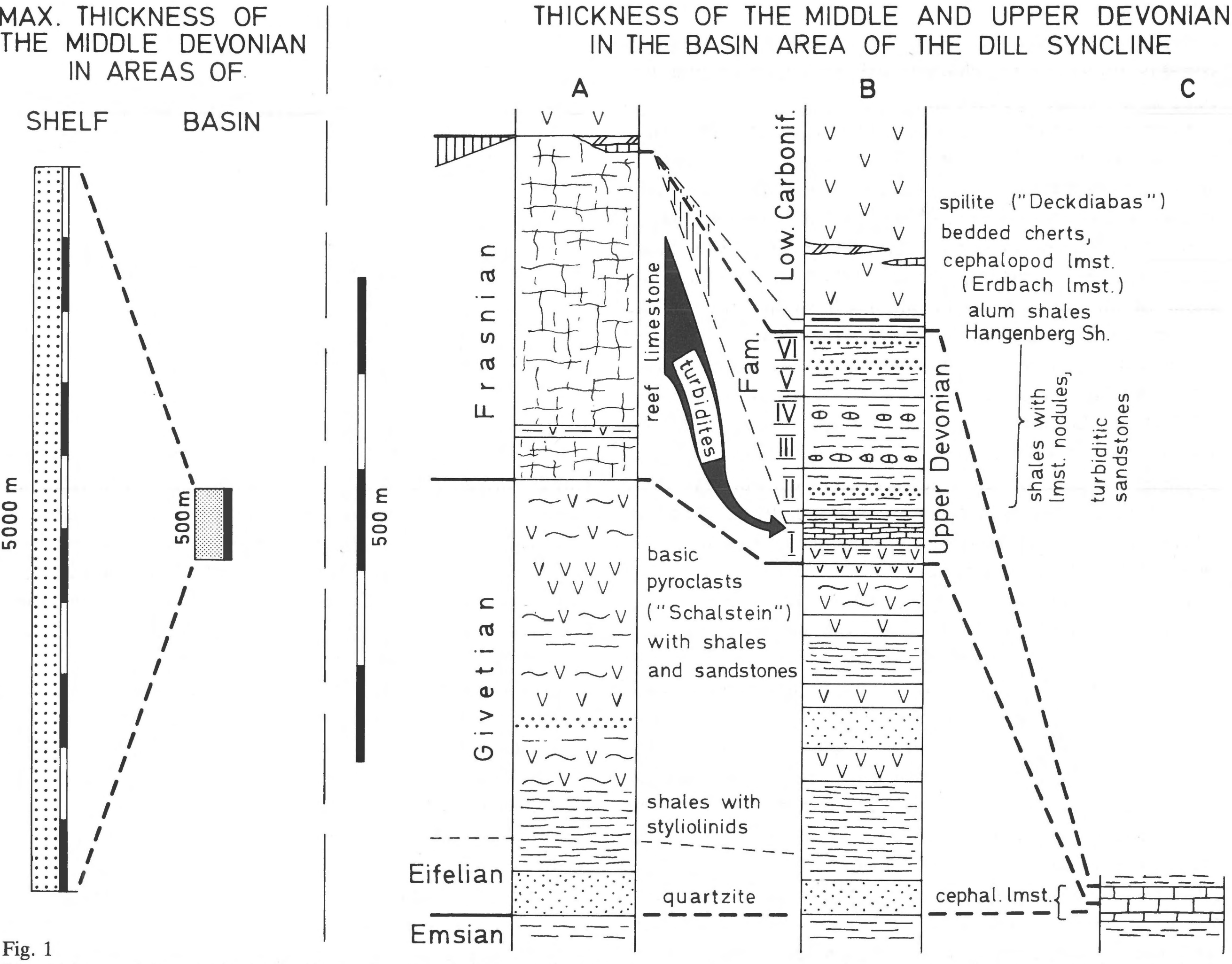

Fig. 1
The thickness of deposits in the shelf areas reaches 10 times that in the basin. But with respect to thickness and facies also the basin areas show enormous differences.
In section A (Erdbach-Langenaubach reef) a reef developed upon a submarine volcano. This proves that the seafloor at this time was not deeper than a few hundred metres. The reef, which stopped growing within the Frasnian, became covered by sediments not before Dinantian time. These 'transgressing' deposits yield conodonts of all Famennian zones, thus indicating that during the Famennian the former reef projected over the depositional level as a submarine elevation.
Section B, not more than 1000 m off the atoll reef comprises a complete section. Its thickness and facies indicate that, during the Famennian, the pre-existing relief between the former reef and the surrounding seafloor has been filled up.
Section C (Bicken Rise), some kilometres from section B, contains a complete section of only some ten metres of cephalopod limestones, representing one of the structures with a remarkably stable position during 2/3 of the Devonian time.

many sections all over the world. This indicates, that these facies developed independently of the regional evolution, but rather have been caused by a global event, such as an oscillation of the sea level.

GENERAL REGIONAL AND CHRONOLOGICAL SETTING

The area described belongs to the northern branch (Rhenides) of the central European Variscides. Based on KOSSMAT's (1927) subdivision, one can distinguish north of the central crystalline ridge (Moldanubian zone): the internally situated Saxothuringian zone, the Mid-German Crystalline Rise and the externally situated Rhenohercynian zone, bordered in the north by the Subvariscan molasse foredeep (Westfalian zone).

AUBOUIN (1965), who subdivided geosynclines into an internal eugeosynclinal realm and an external miogeosynclinal realm, compared the northern part of the Rhenohercynian zone with his miogeosynclinal furrow, the central part with the miogeosynclinal geanticline and the southern part with the eugeosynclinal furrow. But even if the area of the Lahn and Dill Synclines and their continuation are interpreted as a miogeosynclinal anticline, we have to state that nowhere within the Rheinische Schiefergebirge sequences exist which could be interpreted as characteristic for eugeosynclinal furrows in the sense of Aubouin.

Furthermore the internal part of the Rhenides, the Saxothuringian zone, lacks a significant amount of those features which are interpreted as being eugeosynclinal, but it has much in common with those of the Rhenohercynian zone. Considerable differences between the Rhenohercynian and the Saxothuringian zones exist in so far as, in the latter, the development of an initial basin began much sooner, i.e. at the beginning of the Caledonian cycle. This asymmetric basin had its depositional maximum in the northern part, which became later the Mid-German Rise with a development independent of that of the remaining Saxothuringian zone. The tectogenesis of this latter zone is strongly influenced by its position marginal to the relatively rigid central crystalline ridge. On the other hand, the peculiarities in the development of the Rhenohercynian zone can be explained by its neighbourhood to the Caledonides.

Concerning the chronological subdivision of the geosynclinal development, it may be useful to modify slightly the terminology of AUBOUIN (1965), which is based on the knowledge of many previous workers. Since the late- or post-orogenic molasse troughs evolved successively from the flysch troughs, the molasse stage is included in what we call the Geosynclinal Period (without distinguishing a Geosynclinal Period sensu stricto and a Late-Geosynclinal Period). The Geosynclinal Period can be subdivided into the following four stages: (1) Generative (or Initial) Stage, (2) Pre-Flysch Stage, (3) Flysch Stage and (4) Molasse Stage. Thereby we should be aware of the following facts: the Generative Stage merges gradually into the Pre-Flysch Stage; the stage with the unsatisfactory name Pre-Flysch Stage comprises the most extensive part of the whole development; the Pre-Flysch Stage and the Flysch Stage overlap in time, due to the centrifugal migration of the flysch trough; the different stages may occur at different times in different regions of the geosyncline.

Furthermore two terms should be defined: the Variscan geosyncline is that one which leads to the Variscan orogeny; the Variscan cycle comprises the time between the end of the Caledonian orogeny and the end of the Variscan orogeny. Using these definitions, we shall see that the Variscan geosyncline has its Generative Stage at least partly already at the beginning of the Caledonian cycle. The Caledonian and Variscan cycles are parts of a superposed 'Proterozoic-Palaeozoic geosynclinal and orogenic evolution' (KREBS & WACHENDORF, 1973) of Europe. Using the megacycle of CHAIN (1968), we may call this the Caledonian-Variscan megacycle.

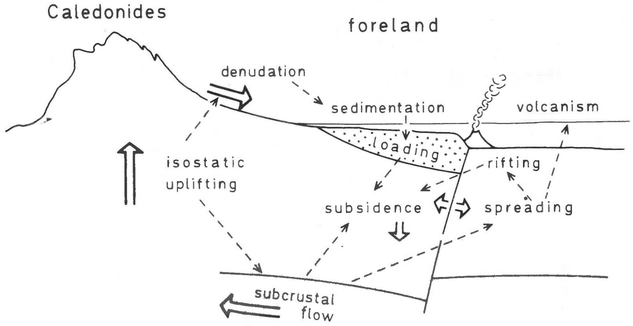

Fig. 2
Interdependence between events in the Caledonides and the development of shelf troughs in the Rheinische Schiefergebirge.

THE GEOSYNCLINAL DEVELOPMENT

Sediments of pre-Devonian age are exposed only in a few places in the Rheinische Schiefergebirge. In the northern part, the cores of the Remscheid-Altena Anticline and of the Ebbe Anticline consist of an incomplete Ordovician sequence. These sediments are interpreted as belonging to marginal parts of the Caledonian geosyncline. In this northern area Silurian is only present by sediments of Late Silurian age. Their facies resembles those of the overlying Devonian sediments and should be interpreted as representing the earliest sediments of the Variscan cycle in this area.

More pre-Devonian sediments occur in the eastern part of the Rheinische Schiefergebirge. Relicts of Ordovician shallow-water quartzites are only known from the area of Gießen, whereas Silurian shallow-basinal sediments obviously have a wide distribution.

Quite a different development took place immediately south of the Rheinische Schiefergebirge and the Harz Mountains, which is characterized by the deposition of a sequence of about 3,000 m thickness. Its metamorphosed sediments and volcanics are comparable with unmetamorphosed sequences of late Precambrian and early Palaeozoic age, which occur more to the south in the Saxothuringian zone. Although all correlations are not yet well established (VON GAERTNER, 1934; NEUMANN, 1974; HOTH, 1968; HOTH ET AL., 1968; WERNER, 1974), the general distribution of facies and thicknesses shows that in the late Precambrian south of the Rheinische Schiefergebirge and Harz Mountains an asymmetric basin occurred, with a maximum of subsidence in its northernmost part. This configuration in connection with the frequently distributed volcanics indicates a tensional phase. This coincides with the occurrence of graben-like rift systems in other regions as e.g. in the Moldanubian zone and with the initial subsidence of the Caledonian geosyncline. Obviously this marks the beginning of fracturing and mobilization of the European crust east of the Tornquist line.

The mentioned region, that is the northern part of the Saxothuringian zone, became later the so-called Mid-German Crystalline Rise or Mid-German Crystalline Zone. But it is still unclear if and when this zone became folded and metamorphosed before the final Variscan orogeny (different opinions are most recently discussed in DORNSIEPEN, 1978, 1979; ZWART & DORNSIEPEN, 1980; and in WEBER, this issue.

The area of the Rheinische Schiefergebirge became influenced by the Mid-German Crystalline Rise as early as in Early Devonian times. As the borehole Saar I shows, a granitic intrusion of early Devonian age is overlain by a non-metamorphic sequence, beginning in the Middle Devonian. In the time between the intrusion and the Middle Devonian, the cover of the granite had been eroded, delivering this material northward and giving rise to the accumulation of thick sequences of Early Devonian neritic sandstones and of the Hunsrück Shale. During the Variscan cycle the main part of the Rheinische Schiefergebirge was strongly influenced also by the Old Red Continent in the north. In the Early and Middle Devonian large quantities of siliceous debris (interpreted as an offshoot of the Caledonian molasse) derived from there probably via only one large delta system; they accumulated in rapidly subsiding shelf troughs. Offshoots of the shelf sediments have been transported by turbidites into the adjacent basin.

Important features of the shelf troughs are: (1) the position of each of the successive troughs has been more or less constant; (2) thc troughs shiftcd northward not continuously but rather episodically; (3) the troughs have a constant configuration, as e.g. the Eifelian-Givetian trough, which has been asymmetrical with the maximum of subsidence and sediment accumulation near its southern bounds; (4) input of debris and subsidence have been balanced over millions of years; (5) the total thickness of depositions in the region of the shifting troughs, which overlap each other, reached approximately 5,000 m; (6) the neritic sediments of the trough phase are followed by pelagic sediments.

The reasons for the combined features (1) to (4) can be explained by a close interdependence between the orogenic uplift of the Caledonides and initial subsidence as well as tension with graben-like structures in the foreland of the Caledonides (compare Fig. 2). Further evidence for structural lines of considerable length parallel to the main strike direction are volcanic belts or submarine ridges with highly reduced depositions of chiefly cephalopod limestones. The extension in this region has also been stated by ZIEGLER (1978).

The mentioned feature (6) can be explained by the termination of subsidence always following the end of the influx of material after some delay. Because of this after-effect, the hitherto shallow seafloor subsided so far that pelagic conditions came to prevail.

Due to a remarkable transgression, the input of terrigenous material from the Old Red Continent nearly stopped within the Givetian, creating the conditions for the onset of reef growth on the shelf platform. Normally the first settlement began with organisms adapted to biostromal conditions, distributed over large planes of the shelf platform. However, afterwards bioherm-constructing organisms prevailed due to the still persisting subsidence. From the talus of those reefs calcareous debris was transported into the surrounding areas by turbidites (Flinz limestones).

The world-wide extinction of the reefs in the later part of the Frasnian must have been caused by a change of the environmental conditions. This global event is documented by the black sediments of the Kellwasser horizon and probably has a causal connection with the enormous rise of $\delta^{34}S$, which has been recorded by HOLSER (1977).

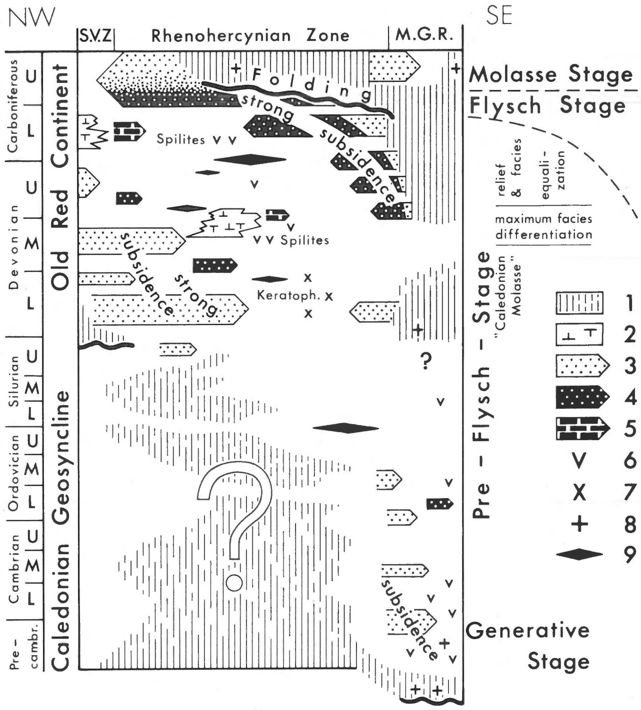

Fig. 3
Diagrammatic sketch of the main features of the geosynclinal development of the Rheinische Schiefergebirge and immediately neighbouring areas (not to scale).
S.V.Z. = Subvariscan Zone (molasse fore-deep); M.G.R. = Mid-German Crystalline Rise; 1 = land areas; 2 = reef limestones; 3 = neritic sediments; 4 = psammitic turbidites; 5 = limestone turbidites; 6 = basic volcanics; 7 = acidic volcanics; 8 = granite intrusions; 9 = facies-controlling global events.

In Givetian and early Frasnian times there was also a peak in the basic volcanism, whereas previously mainly keratophyres have been produced. The Givetian and early Frasnian spilite volcanism and the reefs on the former shelf and on volcanic elevations in the basin intensified the morphological differentiation of the seafloor, causing a maximum of facies differentiation (compare Fig. 3).

The reef extinction was followed by a phase of degradation of the relief and also by a diminishing of the facies variation, due to a higher amount of sedimentation in the deeper part of the topography. Turbidites, still derived from the northern shelf, were occasionally intercalated within the pelitic background sedimentation. In more elevated positions, around and/or upon the former reefs and on the persisting rises, cephalopod limestones accumulated. The tops of many of the dead reefs. still protruding above the level of sedimentation, were repeatedly settled by brachiopods, crinoids etc., producing smaller amounts of carbonate.

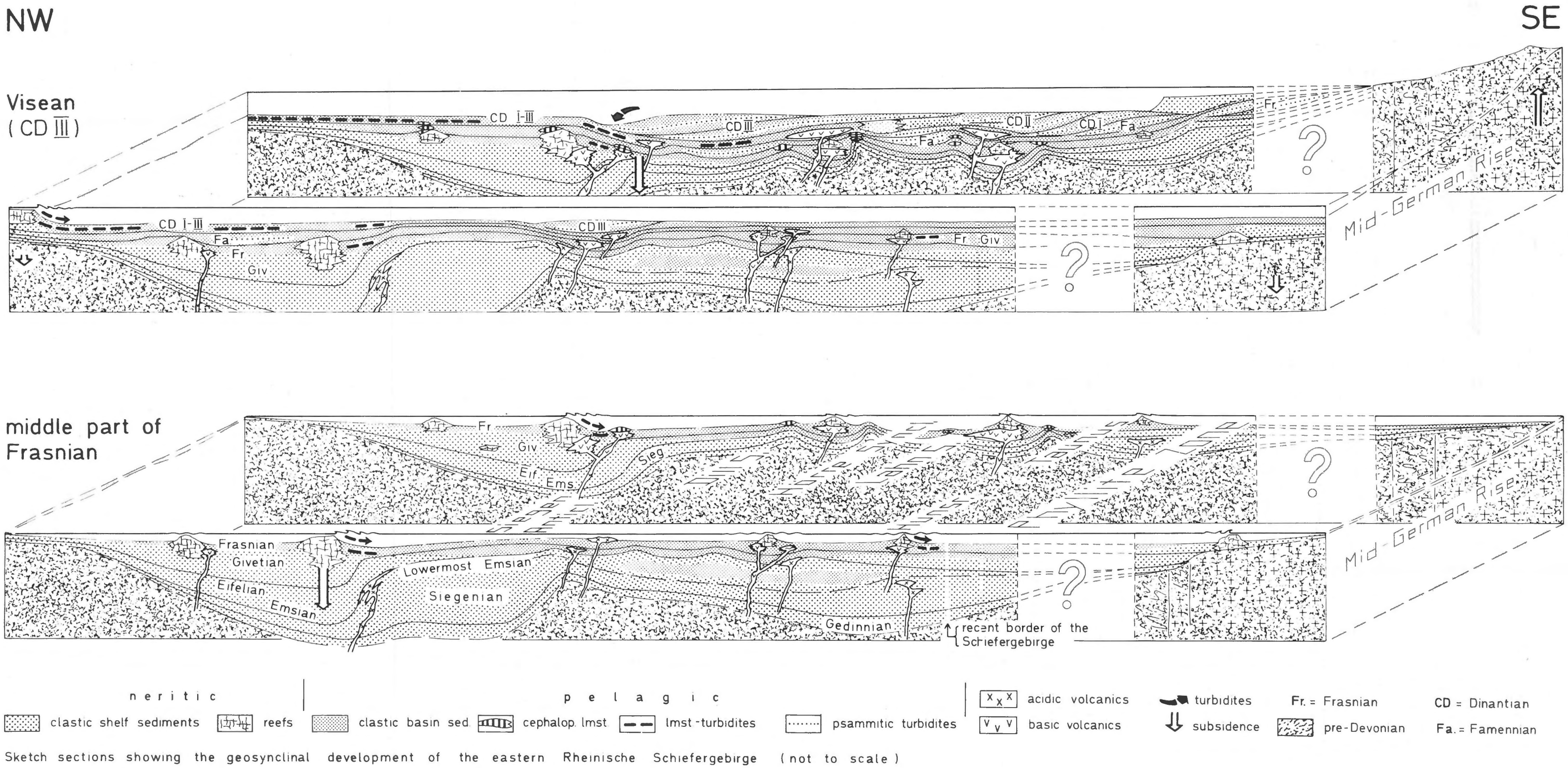

Fig. 4
Sketch sections across the Rheinische Schiefergebirge, west and east of the main section figured on enclosure I. The sections are elongated further southward up to the Mid-German Crystalline Rise, also considering the loss of a crustal stripe by subfluence in the region between the Rheinische Schiefergebirge (including the Phyllite Zone) and the Mid-German Crystalline Rise.
The sections show some of the characteristic features in the geosynclinal development: northward shifting of the northern shelf troughs; the centres of accumulation lie in the western (anterior) section, whereas the areas of the eastern (posterior) section received much less clastic debris; regional relation between sedimentation and vulcanism; 'transgression' of pelagic facies over the former shelf areas; the northward shifting flysch trough developed only in the regions outside of those areas with former (Early and Middle Devonian) considerable accumulation of sediments; the Mid-German Crystalline Rise shows important regional differences as e.g. during Visean time: in the Saar region (anterior section) sedimentation prevailed, whereas the more eastern part (posterior section) served as a source area for the flysch sediments.

Within the area of the Rheinische Schiefergebirge, obviously the degradation of the topography was nearly complete at the end of Famennian time. The simultaneous decrease of facies variation was accelerated by another global event, viz. (after the regressive tendency in the Famennian) a world-wide transgression at the Devonian-Carboniferous boundary. In the course of this transgression a change of environmental conditions caused the extinction of all the organism groups whose distribution had been controlled by the hitherto cephalopod limestones and closely related facies. These are e.g. all of the clymeniids and most of the goniatites, some groups of the trilobites, conodonts etc.. Connected with this event is the facies of the Hangenberg Shales, followed by the Early Carboniferous alum shales, both covering almost the entire geosynclinal area, each with a nearly constant thickness and composition. Only in a few areas did the last influx of siliceous material from the north continue.

After a regional limited reappearance of cephalopod limestones in the upper part of the Hangenberg Shales (Gattendorfia Stage, cd I), alum shales (Alaunschiefer), bedded cherts (Kulm-Kieselschiefer) and dark shales (Kulm-Tonschiefer) followed. Beginning with the bedded cherts, these facies could be subject to the influence of turbidites, derived from the northern carbonate shelf (outside of the section presented here) as well as from other areas, where Carboniferous sediments have now been eroded (e.g. Latrop Anticline) or elsewhere are now covered by Mesozoic sediments (east of the Rheinische Schiefergebirge) (WITTEN, 1979). At this time, the last of the remaining dead reefs were covered by sediments.

Whereas during the Famennian the volcanic activity decreased, it reached another maximum within the Early Carboniferous ('Deckdiabas'). The extruded spilites were, in the main, confined to the same areas of structural zones as the Middle Devonian ones, thus indicating a reactivating of old structures as well as another tensional phase. According to the data given by AHRENDT ET AL. (1978) this tension occurred simultaneously with the first orogenetic shortening further to the south.

During the Late Devonian and Early Carboniferous part of this Pre-Flysch Phase, whose peculiarities had been controlled to some extent by events in the northern continent, the diachronous arrival of the Flysch Phase took place. These flysch sediments derived from a deltaic shelf prograding northwards in front of the upwarping Mid-German Crystalline Rise. The earliest flyschoid sediments occurred as early as Frasnian in the southernmost part of the Rhenohercynian zone. Then the flysch trough shifted centrifugally, i.e. northward, having its depocentres always outside of those areas in which formerly prominent shelf sequences had been deposited. Transfering the development of the southern Harz Mountains, we may conclude, that also in the southeastern part of the Rheinische Schiefergebirge, Famennian and earliest Carboniferous flysch has been deposited. An offshoot of these sediments caused the special facies of the Hörre Syncline.

The main phase of the Flysch Stage began in the late Visean (cd III) with acceleration of the rate of deposition and of the speed of northward migration of the trough. As has been shown in the Harz Mountains (FRANKE, 1973; RIBBERT, 1975), there was no pre-existing trough. Rather, the flysch trough subsided and migrated during the course of accumulation of flysch greywackes. The trough widened to the west only in Namurian time, when it reached the area north of the Middle Devonian shelf trough. In Namurian time, under the influence of the main orogenic phase, the flysch greywackes gradually passed into molasse sediments. Already in the late Namurian the deposition rate exceeded the rate of subsidence, so finally introducing the paralic sequence of sediments within the Subhercynian molasse foredeep.

Large olisthostromes as described from the eastern Harz Mountains (e.g. by REICHSTEIN, 1965; LUTZENS, 1972; SCHWAB, 1974) are not yet known from the Rheinische Schiefergebirge, even if the existence of minor mass flows can not be excluded (STOPPEL, 1977; ALBERTI & WALLISER, 1977). Moreover, in the southeastern part of the Rheinische Schiefergebirge (Gießen area), and in the northeastern continuation of that region (Werra-Grauwacken Gebirge), nappes are developed, similar to those in the southern Harz Mountains (compare WEBER, this issue).

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