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Tectonic and Plate Tectonic Units at the North Gondwana Margin: Evidence from the Central European Variscides

WOLFGANG FRANKE*)

2 Text-Figures

Variscan Belt
Central Europe
Terranes

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Tektonische und plattentektonische Einheiten am Nordrand von Gondwana: Hinweise aus mitteleuropäischen Varisziden

Zusammenfassung

Für die **Zeitscheibe des Mitteldevons** lassen sich im mitteleuropäischen Variszikum die folgenden **plattentektonischen Einheiten** unterscheiden:

- **Old Red-Kontinent**, bestehend aus **Laurentia + Baltica + Avalonia**.
  Am Südrand von Avalonia waren akkretioniert:
  - ein **silurischer Inselbogen** (das Resultat der Schließung des Rheischen Ozeans), und
  - „gestrandete“ **armorikanische Fragmente**
- **Schmaler Rhenohercynischer Ozean**
- **Saxothuringisches Terrane**
  (oder Terranes), bestehend aus der späteren Mitteldeutschen Kristallinschwelle und dem saxothuringischen Becken
- **Schmaler Saxothuringischer Ozean**
- **Bohemia** (oder Perunica)
- **Schmaler Moldanubischer Ozean**
- **Gondwana** (oder aber ein weiteres Fragment des Gondwana-Nordrandes).

Abstract

In **Middle Devonian** time, the following **plate-tectonic units** can be recognized in the Variscides of Central Europe:

- **Old Red Continent**, consisting of **Laurentia + Baltica + Avalonia**, with
  - a **Silurian arc** (resulting from the closure of the **Rheic ocean**) and
  - stranded **Armorican fragments** accreted to its southern margin.
- **Rhenohercynian narrow ocean**
- **Saxothuringian terrane or terrane(s)** (basement of the Mid-German Crystalline Rise and basement of the Saxothuringian basin)
- **Saxothuringian narrow ocean**
- **Bohemian terrane** (or Perunica)
- **Moldanubian narrow ocean**
- **Gondwana mainland** (or another Gondwana-related terrane).

*) Authors address: WOLFGANG FRANKE: Institut für Geowissenschaften, Justus-Liebig-Universität, Senckenbergstraße 3, D-35394 Giessen. e-mail: wolfgang.franke@geo.uni-giessen.de.

Identification of plate tectonic units (continents, microplates, "terranes") and reconstruction of their migration and assembly is a complex task. It requires all kinds of geological evidence, combined with palaeomagnetic, biogeographic and palaeoclimate data. These latter methods have large error bars, and mostly fail to reveal minor features. Hence, any attempt to summarize the state of the art has to start from geological field evidence. Therefore, the following abstract is "extended", and has to be based upon the recognition of tectonostratigraphic units in the Central European segment of the Variscan Belt (as they are seen today). These units are then translated, with the aid of complementary data, into plate tectonic entities. It is vital to distinguish between these two categories, which are often mixed up with each other. **Major** and minor **tectonostratigraphic units** (marked as **bold** and underlined respectively) are briefly described in order from N to S; ***palaeogeographic interpretations*** are shown in ***bold italics***. The locations of the tectonostratigraphic units are shown in Text-Fig. 1; the plate kinematic evolution is summarized in a cartoon (Text-Fig. 2).

The **Rhenohercynian belt** represents a passive plate margin, which originated from crustal extension in Early Devonian through to Early Carboniferous time.

The basement of the Devonian sequences is composite: Most of the extended continental crust belongs to the ***Avalonian microplate***, which forms the southernmost element of an assembly known as the ***"Old Red Continent"***: the Old Red composite plate resulted from the amalgamation of Avalonia with Baltica (in Silurian time), and Avalonia/Baltica with Laurentia (accomplished in the Silurian/Early Devonian). This Avalonian basement in the Rhenohercynian belt was formed or reactivated by a Cadomian event between ca 600 and 540 Ma. Rocks of this age are exposed in the Ecker gneiss (a roof pendant in the late Carboniferous Brocken granite of the Harz Mts.) and in the Wartenstein gneiss at the S margin of the Rhenohercynian west of the River Rhine. There is no indication of the latest Ordovician Saharan glaciation, and Ordovician volcanics in the British part of Avalonia (Wales) show intermediate palaeo-latitudes.

A more southerly part of the pre-Devonian basement is exposed in the Saar/Nahe region west of the Rhine and in the Taunus Mts. at the southern margin of the RH east of the Rhine (Phyllite Zone). These areas contain Silurian magmatic rocks (now in greenschist facies) whose geochemical fingerprints indicate an ***active margin (arc)*** setting. This magmatic belt is taken to represent ***closure of the Rheic ocean*** between Avalonia and Armorica. Rocks of the same age occur as pebbles in the Carboniferous flysch of south Cornwall (DÖRR et al., 1999).

The southernmost (i.e., the most distal) part of the Rhenohercynian passive margin is locally preserved in tectonic slices at the base of thrust sheets derived from the south. These are Early Devonian debris flow deposits and turbidites with clasts of Ordovician quartzites and Silurian to Early Devonian limestones, all of which have faunas of ***"Bohemian"*** (i.e., ***Armorican) affinities***. Ordovician quartzites (?Armorica) are also present at the southern margin of the Rhenohercynian belt in the Harz Mts.

The thrust sheets carrying these Armorican fragments are mainly composed of Early Devonian MOR-type metabasalts, overlain by condensed deep-water pelites and synorogenic greywackes of Frasnian through to Early Carboniferous age. Assemblages of this kind are known from the Giessen nappe in the E part of the Rhenish Massif, and its equivalents in the Harz Mts. along-strike to the NE. These rocks represent a narrow ***Rhenohercynian ocean*** (i.e., the drift stage of Devonian extension). Equivalents of the Giessen nappe and its basal Armorican slices are exposed in the Lizard and Carrick nappes of south Cornwall.

All these Rhenohercynian lithologies permit to deduce the following *plate tectonic development*: subsequent to the formation of the Old Red Assembly (Avalonia + Baltica + Laurentia), convergence between the Old Red and Armorica produced an island arc, which was accreted to the southern margin of the Old Red Continent. Continued convergence added Armorican fragments. All these units were overstepped by Devonian shelf sediments. Further south, a narrow oceanic domain was developed. Southward subduction of the Rhenohercynian ocean commenced in the Frasnian, and was followed by underplating of pre-Devonian basement from the Late Tournaisian onwards. Parts of the oceanic domain were transported as thrust sheets on to the northwestern foreland, carrying with them Devonian and pre-Devonian rocks of the distal passive margin (FRANKE & ONCKEN, 1995).

The **Mid-German Crystalline High (MGCR)** represents the ***source area for the synorogenic clastic sediments (active margin)*** deposited on the Rhenohercynian foreland in Frasnian through to Late Carboniferous time. Present day exposures in the Odenwald, Spessart and Thuringian Forest are mainly composed of *arc-related plutonic rocks of Late Devonian to Early Carboniferous age* (363–335 Ma). Magmatic arc rocks of Silurian age are exposed in the basement of the Permian Saar/Nahe basin W of the River Rhine, in the Spessart and in the Thuringian Forest. These are equivalents of the Silurian arc exposed in the Phyllite Zone at the southern margin of the RH, but were tectonically underplated under the MGCR and later exhumed in the core of an antiform within the upper plate (ONCKEN, 1997). For most of the metamorphic rocks contained in the MGCR, protolith ages and plate tectonic affiliations are unknown, and relationships with areas further S are therefore uncertain.

The **Saxo-Thuringian belt** is a ***Cambro-Ordovician rift basin*** developed on Cadomian crust. Late Proterozoic sediments with Cadomian deformation and low-grade metamorphism are exposed in the core of the Schwarzburg anticline and occur as pebbles within locally derived Frasnian conglomerates. Late Cadomian (550–540 Ma) granitoids are documented in the Erzgebirge antiform and in the Lausitz (Lusatia, E of the Elbe Fault Zone). A second pulse of rifting in the Frasnian is documented by bimodal intra-plate volcanic rocks, and clastic sediments derived from local halfgraben shoulders.

The basin was overthrust from the SE, by the active, northwestern margin of the Tepla-Barrandian terrane (see below). This is documented by tectonic klippen (Münchberg, Wildenfels, Frankenberg) which contain (from top to bottom) metamorphosed Tepla-Barrandian rocks, eclogites derived from ca 500 Ma MOR-type mafic rocks, and accreted slope sediments of the *Saxo-Thuringian margin*. The par-autochthon is characterized by shelf and hemipelagic sediments. The continental crust of the par-autochthon represents a ***Saxo-Thuringian terrane***. The continental source, which should be expected to the NW of the shelf, has not been preserved: paradoxically, the shelf is bounded to the NW by a belt with early Palaeozoic bimodal magmatic rocks (KEMNITZ et al., in press; Vesser unit), which represent another crustal-scale neck (the same problem is apparent from the Ordovician facies distribution in the Central Armorican zone and in the Central Iberian zone (ROBARDET & GUTIERREZ-MARCO, 1990).

Eclogite facies metamorphism in the Saxothuringian nappes predates 380 Ma Emplacement and refolding of the nappes occurred in latest Viséan time (330–325 Ma). The approach of the tectonic front is heralded by Frasnian through to Late Viséan synorogenic clastic sediments. Their composition contains a complete record of uplift and exhumation of the southeasterly sources (SCHÄFER et al., 1997).

The Saxonian granulites (type locality of the metamorphic facies!) are exposed in a metamorphic core complex within the Saxothuringian par-autochthon. Similar HP and HP/HT rocks occur in the Erzgebirge to the SE. These rocks are enigmatic, since isotopic studies suggest high grade metamorphism in Late Devonian/Early Carboniferous time, i.e., during the time of deposition of the overlying low-grade sequences. If the isotopic data are correct, the high grade rocks must have been emplaced under the floor of a subsiding marine basin (Dekorp and Orogenic Processes Research Groups, in press).

The eclogites of the Münchberg nappe are derived from a separate tectonic unit at the NW margin of the Tepla-Barrandian (see below), the Marianske Lazne meta-ophiolite. These metabasic units, both formed around 500 Ma, represent thinned continental crust or a ***narrow Saxothuringian ocean*** separating the Saxothuringian from the terranes adjacent to the south.

The main part of the **Tepla-Barrandian unit** forms the core of the Mid-European Variscides, and the zone of structural parting between the N and S flanks of the belt. It is floored by Late Proterozoic sedimentary and volcanic rocks with Cadomian deformation and low-grade metamorphism dated at ca 540 Ma. This pre-Variscan basement is intruded by bimodal intraplate magmatic rocks dated at 520–480 Ma (DÖRR et al., 1998; ZULAUF et al., 1997), and unconformably overlain by Cambrian through to Givetian sediments with a weak Variscan overprint. This Palaeozoic cover sequence records moderate Cambro-Ordovician extension and a Devonian epicratonic stage. The age of the extensional phase matches that of the Saxo-Thuringian belt. However, palaeomagnetic studies have revealed that the Tepla-Barrandian has been rotated counter-clockwise through more than 140° after the Silurian and before the Middle Devonian, whereas the Saxo-Thuringian terrane has maintained its orientation (TAIT et al., 1997). Hence, the Tepla-Barrandian must represent a separate microplate (***Bohemian terrane*** *or* ***Perunica***) within an ***Armorican terrane family*** (archipelago).

The **Moldanubian** (sensu stricto) to the W and S of the Tepla-Barrandian is entirely made up of high grade metamorphic rocks, whose protolith ages and palaeogeographic affinities are largely enigmatic. The Gföhl unit, composed of HP and HP/HT rocks, has been thrust towards the E/SE over the LP/HT rocks of the Drosendorf unit. The high grade nappes are usually taken to reflect subduction and obduction of rifted or even oceanic crust, representing a ***Moldanubian basin or narrow ocean***. This is tentatively correlated with the ***Massif Central ocean*** identified in the French segment of the orogen. Hence, the continental crust of the Drosendorf unit might represent **Gondwana mainland**. Closure of the Moldanubian-Massif Central ocean by northward subduction might be indicated by calc-alkaline metagranitoids of late Devonian age at the SE margin of the Tepla-Barrandian (KOSLER et al., 1993).

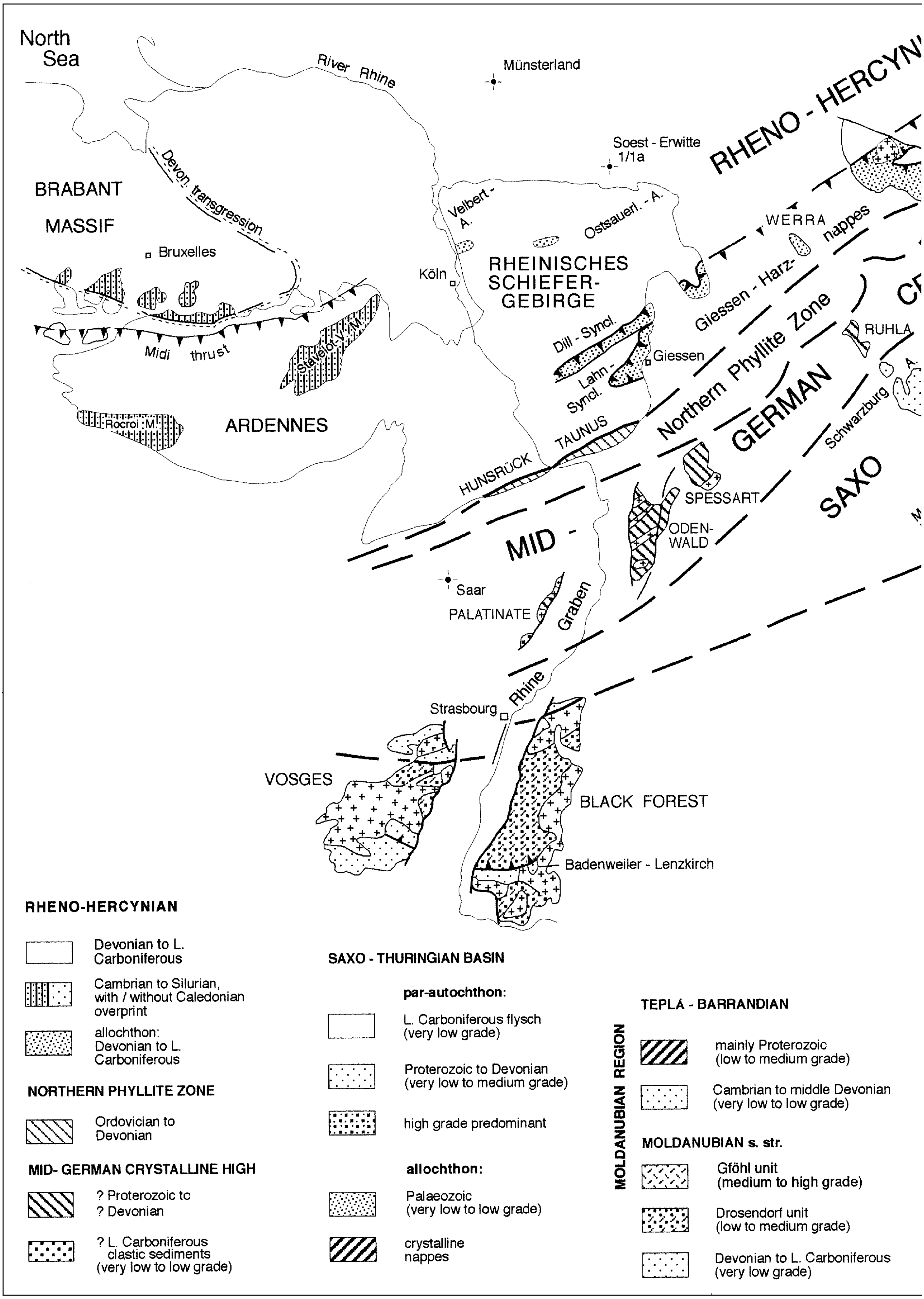
The NE margin of the Bohemian Massif is segmented by NW-trending, dextral strike-slip faults, of which the Elbe and the Intrasudetic fault zones are the most important. These latter fault zones contain, between them, an extremely complex association of rocks summarized as the **W-Sudetes**. Into this "megabreccia", OLIVER et al. (1993) have read an amalgamation of individual terranes, which are supposed to include the main ("Caledonian") suture between **Baltica** and **Gondwana**. However, FRANKE et al. (1993) and ZELAZNIEWICZ & FRANKE (1994) have identified, within the Sudetes, NE-ward continuations of tectonic units known from the more westerly part of the belt, displaced by the major dextral faults cutting across the main structural trend. This latter view is backed up by provenance studies of Cambrian clastic sediments (BELKA et al., 1997): K-Ar ages of detrital micas reveal that the boundary between Gondwana-related terranes and Baltica lies not only to the NE of the Sudetes, but even NE of the Holy Cross Mts.

The SE margin of the Bohemian Massif is complicated by the NE-trending "Moldanubian thrust", a first-order zone of dextral transpression which cuts off (i.e., postdates) the Elbe and Intrasudetic fault zones. The **"E-Sudetes"** SE of the fault zone contain Cadomian basement, overlain by Devonian platform and rift, and Carboniferous foreland basin sequences. These rocks represent an eastward continuation of the Rhenohercynian belt (i.e., ***Avalonia***), which has been bent into an orocline encircling the Bohemian massif in the E. Clockwise rotation of the E-Sudetes through ca 90° has produced a "Bohemian arc" proven by palaeomagnetic studies (TAIT et al., 1996).

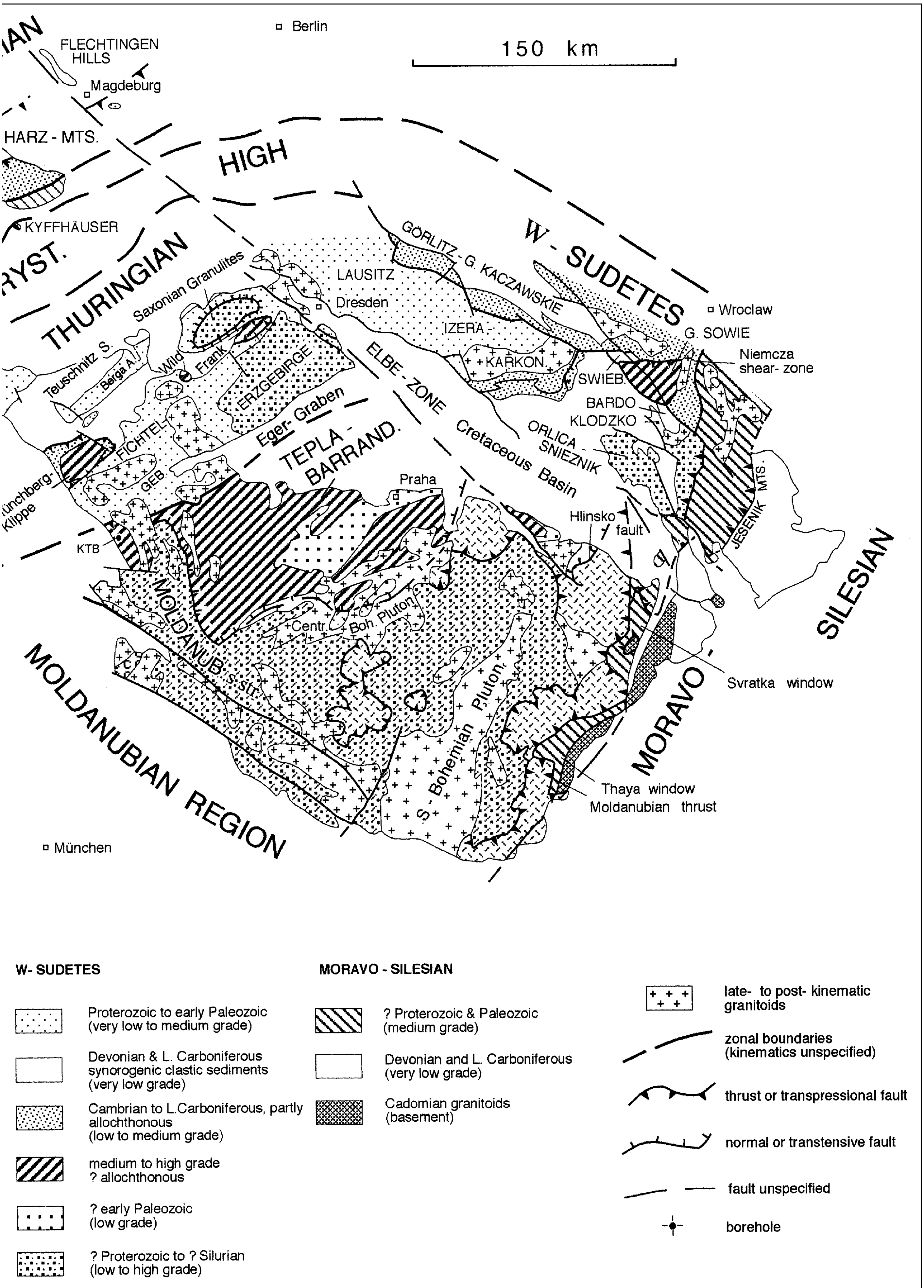
Taken altogether, the tectonic units of the Central European segment of the Variscides represent remnants of Avalonia and the Armorican terrane family. The boundary against Gondwana mainland is uncertain for several reasons:

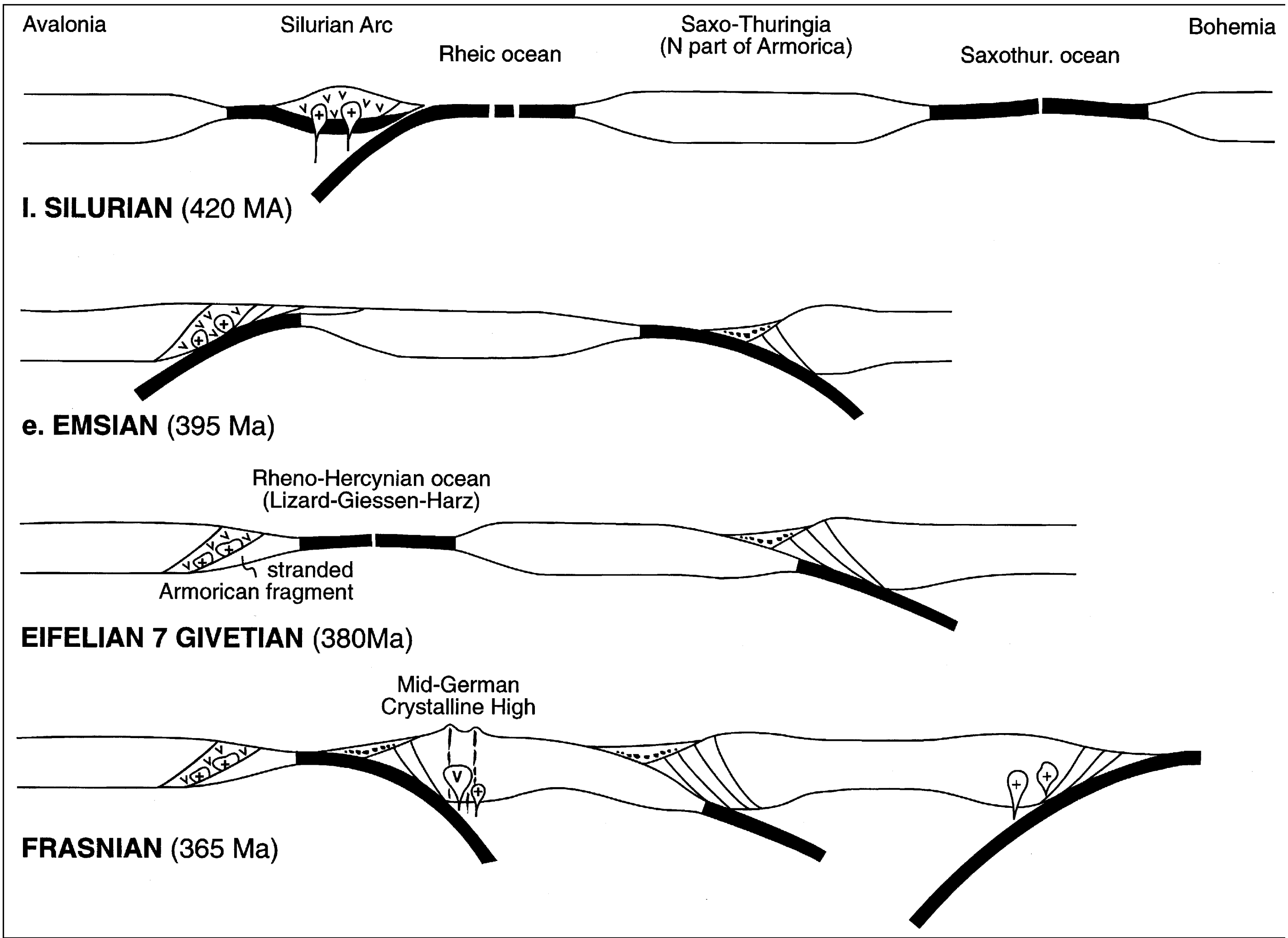
– In the Moldanubian zone, high grade metamorphism has obliterated any palaeogeographic clues;
– The "Bohemian arc" and the "Moldanubian thrust" have displaced rocks from the N flank of the Variscan orogen towards its SE margin. Therefore, we do not know, which terranes were originally adjacent to the units now contained within the Moldanubian region.
– All areas SE of the Bohemian massif have been strongly reworked and displaced during the Alpine cycle. A recent summary of the Pre-Alpine basement of the Alps is available in VON RAUMER et al. (eds., 1993). According to SCHÄTZ et al. (1996), the Variscan basement of the Northern Greywacke Zone (traditionally regarded as part of the Adriatic plate), in Silurian time, was situated at 50°S, as compared with 21°S and 28°S obtained for the Saxothuringian and Tepla-Barrandian, respectively. By the Devonian, this area had attained 30°S (SCHÄTZ et al., 1997), which is not significantly different from the palaeolatitude of the Saxothuringian and Rhenohercynian. If the South Alpine basement represents Gondwana, a major oceanic separation between Gondwana and the more northerly terranes either has never existed, or else must pre-date the Devonian. Alternatively, the South Alpine basement might represent a separate peri-Gondwanian fragment.

For future studies, palaeogeographic units on the N flank of the Variscan belt should be assessed from the Central European segment (Rhenish Massif and N parts of the Bohemian Massif). The S flank of the belt is best preserved in France and N Iberia.



Text-Fig. 1.
Geological map of the central European Variscides.


Berlin
FLECHTINGEN HILLS
Magdeburg
150 km
HARZ - MTS.
HIGH
KYFFHÄUSER
THURINGIAN
Saxonian Granulites
LAUSITZ
Dresden
GÖRLITZ - G. KACZAWSKIE
W - SUDETES
Wroclaw
G. SOWIE
IZERA
KARKON.
Niemcza shear- zone
SWIEB.
BARDO
KLODZKO
Teuschnitz S.
Berga A.
Wild
Frank.
ERZGEBIRGE
ELBE - ZONE
Eger- Graben
FICHTEL
GEB.
TEPLA - BARRAND.
Cretaceous Basin
ORLICA - SNIEZNIK
Praha
JESENIK MTS.
Klippe
KTB
Hlinsko fault
SILESIAN
MOLDANUB. s.str.
Centr. Boh. Pluton
S. - Bohemian Pluton
MORAVO -
Svratka window
Thaya window
Moldanubian thrust
MOLDANUBIAN REGION
München
W- SUDETES
Proterozoic to early Paleozoic (very low to medium grade)
Devonian & L. Carboniferous synorogenic clastic sediments (very low grade)
Cambrian to L.Carboniferous, partly allochthonous (low to medium grade)
medium to high grade ? allochthonous
? early Paleozoic (low grade)
? Proterozoic to ? Silurian (low to high grade)
MORAVO - SILESIAN
? Proterozoic & Paleozoic (medium grade)
Devonian and L. Carboniferous (very low grade)
Cadomian granitoids (basement)
late- to post- kinematic granitoids
zonal boundaries (kinematics unspecified)
thrust or transpressional fault
normal or transtensive fault
fault unspecified
borehole



Text-Fig. 2.
Plate kinematic cartoon for the central European Variscides, from late Silurian to late Devonian times.

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