

THE DISTRIBUTION OF GONDWANA-DERIVED TERRANES IN THE EARLY PALEOZOIC

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INTRODUCTION

The present day Variscan basement areas of Europe have been recognized as generally derived from Gondwana, based on fauna, facies and detrital zircons distributions. These areas represent only a portion of Europe (Iberia, France, Central Europe), but it is obvious that similar Variscan basements are present in the whole Alpine and Mediterranean areas too, up to the Caucasus. In tracing these terranes back to their possible position around Gondwana, it became obvious that they could not all be positioned north of Africa, as generally shown on reconstructions. We developed the concept of a ribbon like Galatian superterrane that comprised most of these "European" Variscan elements. In Ordovician times, this superterrane extended from the north of South America to South China (located in continuity to Africa). Along such a length, the geodynamic evolution was not the same, but presents strong similarities. Geodynamic scenarios for the whole Paleozoic have been developed for the different segments, thus allowing us to re-distribute the subterranees in a coherent way. The diachronous openings of the Rheic *s.l.* ocean, then of the Paleotethys, represent the main reconstruction guidelines, together with major magmatic activity distribution in space and time.

LATE CADOMIAN CYCLE AND GEODYNAMIC CONSTRAINTS FOR THE NORTH CHINA DOMAIN

Before the Ordovician most of the Variscan areas had been affected by the Cadomian event, viewed as the accretion along the Gondwana margin of amalgamated arcs, some derived from Gondwana, some from the North China domain. This is supported by the numerous types of late Proterozoic magmatic rocks found in the Cadomian terrane assembly. This accretion to Gondwana was followed by a new pulse of magmatism all along the Gondwana margin in Late Cambrian Ordovician times, the margin evolving as a cordillera.

It is well accepted today that South China was a part of Gondwana since the Late Proterozoic (Wilhem, 2010). The overall geometry of Gondwana consisted of a right angle between the African segment and the

South Chinese segment (Fig. 1). Starting from the easternmost part of this cordillera, Cambrian opening of back-arc basin (Fig. 1A) resulted in the detachment from the South Chinese segment of the Qilian Terrane (e.g. thermal history, paleontologic and stratigraphic affinities between South China and Qilian) (Tung et al., 2007). In Late Cambrian (Figs. 1B and C), the arc migrated alone toward Baltica leaving the Qilian microcontinent behind surrounded by passive margins (e.g. platform deposits and North China type fauna) (Xu et al., 2006). During the Late Cambrian and Ordovician time, the migrating arc was colliding both with the Gondwana and North China margins, turning the latter margin from passive to active after subduction reversal (Sinian-Cambrian passive margin and beginning of arc magmatism in Late Cambrian) (e.g. Yang et al., 2001; Ratschbacher et al., 2003). A back-arc basin was then developed within the southern margin of North China (Figs. 1C and D) and formed the Qilian-Erlangping Terrane (Xia et al., 2003), which successively collided with the Qilian and future Hunian terranes (Figs. 1D and E) (formation of the Ordovician North Qaidam and North Qilian sutures) (e.g. Yang et al., 2006). This new-amalgamated terrane was accreted in turn to North China (Fig. 1F) in the Silurian (i.e. flysch, molasse, intrusions, deformation) and a new active margin took place under North China (i.e. Upper Silurian arc magmatism) (e.g. Ratschbacher et al., 2003).

FROM ACTIVE TO PASSIVE MARGIN, OPENING OF THE RHEIC

After accretion of the arc to North Gondwana, cordillera collapse took place north of Africa, whereas back-arc opening north of South-America had already triggered the detachment of Avalonia and the opening of the Rheic ocean *s.str.*. The margin setting along Gondwana (von Raumer et al., 2002) is characterised by an active margin since the early Ordovician, and the subsequent opening of the Rheic ocean, after a period of subsidence and rifting behind Avalonia-Hunia (e.g. von Raumer and Stampfli, 2008). Consequently, the basement areas of these regions show a strong activity of crustal extension and rifting during the early Ordovician, accompanied by the intrusion of granitoid rock series at different crustal levels (e.g. Ollo de Sapo granitoids; Montero et al., 2007; Bea et al., 2010). The detachment of Hunia from Gondwana gave birth to the eastern branch of the Rheic ocean, slightly younger (c. 460 Ma) (i.e. constraints coming from the geodynamic scenario for the North China Domain) than the western branch (c. 480 Ma). In the eastern part of the Gondwana margin, comprising among others the Alpine domain, the period of Ordovician active margin setting started later than in the west. The stepwise magmatic evolution in the Austroalpine basement with granitoids (orthogneisses) and mafic rock suites (metagabbros, metabasites, eclogites) (Schulz et al., 2008) began with a Cadomian (550-530 Ma) volcanic arc basalt mafic suite with Th/Yb typical of subduction-related magmatism, and subsequent 470-450 Ma old I- and S-type granitoid intrusions, followed by alkaline within-plate basalt to MORB-type mafic suites around 430 Ma (eastern Rheic spreading). In the external domain of the Alps, the magmatic evolution of the Ordovician active margin is equally documented by the intrusion of granitoids and mafic rock suites between 470-450 Ma (e.g. Bussy et al., this volume).

Thus, the overall geodynamic scenario can be followed through the cessation of magmatic activity north of Gondwana and the diachronous onset of passive margin settings during the Ordovician. Geometries and velocities of tectonic plates at that time are also strongly constraining the origin of Avalonia and Hunia. Avalonia had to be accreted to Baltica-Laurentia and Hunia to North China during the Silurian (Fig. 1).

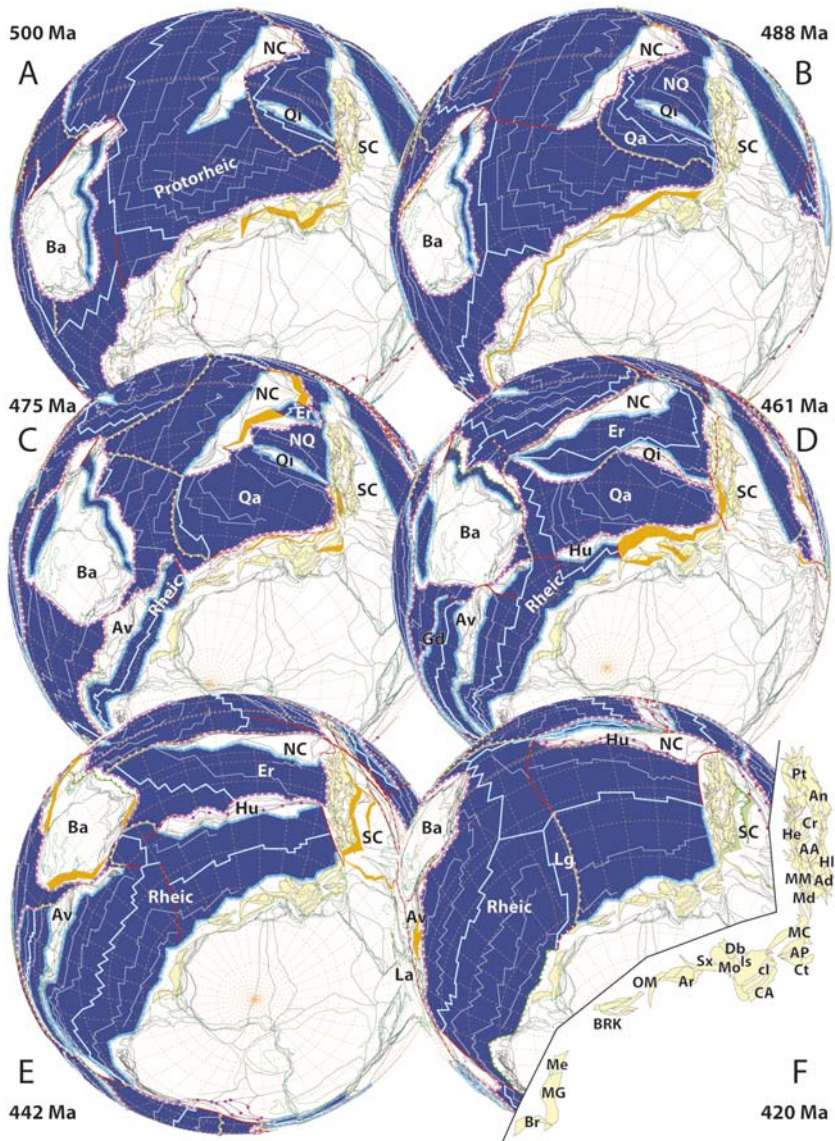


Figure 1. Global reconstructions for the Late Cambrian to the Silurian. Av, Avalonia; Ba, Baltica; Er, Erlangping; Gd, Gander arc; Hu, Hunia; Lg, Ligerian arc; NC, North China; NQ, North Qilian ocean; Qa, Qaidam ocean; Qi, Qilian; SC, South China. The Galatian superterrane (F inset) is made of 4 sub terranes, from bottom to top. The Meguma terrane: Br Brunswick; MG Meguma; Me, Moroccan Meseta. The Armorica terrane: BRK, Betics-Rif-Kabillies; OM, Ossa Morena; Ar, Armorica s.str; Sx, Saxothuringia; Mo, Moesia; Db, Dobrogea; Is, Istanbul. The Ibero-Ligerian terrane: cl, central Iberia; CA, Cantabria; Ct, Catalonia; AP, Aquitaine Pyrenees and Corsica; MC, Massif Central; Md, Moldanubian. The intra-Alpine terrane: MM, Montagne Noire-Maures; Ad, Adria and Sardinia; AA, Austroalpine; He, Helvetic; Cr, Carpathian; HI, Hellenidic; An, Anatolic; Pt, Pontides. Along the Eurasian margin, the opening of the Rheohercynian ocean has detached the Hanseatic terrane from the mainland: eM, eastern Meseta; Po, south Portuguese; Ch, Channel; MR, mid-German rise; CC, Caucasus. Major rifts are shown in darker grey.

OPENING OF PALEOTETHYS

We are departing here from our previous model (Stampfli et al., 2002) where Hunia was considered as the main ribbon like microcontinent leaving Gondwana during the opening of Paleotethys in the Silurian. The Silurian accretion of Hunia to North China implies that this accretion took place when the Paleotethys was not yet opened. Thus, Hunia represents a first train of terranes leaving Gondwana more or less at the same time than Avalonia (during the Ordovician). The second train of terranes leaving Gondwana in the Devonian has been called the Galatian superterrane (von Raumer and Stampfli, 2008).

In the late Ordovician, both western and eastern segments of the Rheic made a single oceanic domain. North of Africa, the passive margin of Gondwana became again an active margin during the Devonian. This followed the collision of the margin with an intra-oceanic arc (Ligerian) and the obduction of part of the back-arc oceanic crust, followed by subduction reversal (Fig. 2). This is well recorded by HP metamorphism corresponding to the eo-Variscan tectonic event (from c. 400 Ma to c. 370 Ma), and the emplacement of Devonian ophiolites along the Gondwana margin in Spain, France and Central Europe. In this suture are also found remnants of older oceans, either the Ordovician Rheic ocean (c. 460 Ma and younger) or older fragments (c. 500 Ma, e.g. Arenas et al., 2007, 2009) related to the Qilian arc and brought to the surface during the rifting and detachment of the Hun terranes, thus forming the toe of the Gondwanan Ordovician passive margin.

From the upper Ordovician to the Silurian, crustal extension is observed along the Gondwana margin through the sedimentary record (e.g. Schönlaub, 1997), the subsidence patterns, the interruption of sedimentation and the intrusion of basic volcanics at different places (von Raumer et al., 2008). New monazite age-data (Schulz and von Raumer, in press) confirm an early Silurian thermal event for the Aiguilles Rouges area. Located along the S-Chinese (Gondwana) margin this area is the witness of the transform type Rheic margin. The emplacement of 450 Ma gabbros at different places and the many early Silurian acidic volcanics of the Noric Terrane, again, are the signature of an extending crust in the Alpine domain; the older ones (450-420 Ma) are related to the eastern Rheic opening, the youngest (410-380 Ma) to the opening Palaeotethys (von Raumer et al., 2011).

THE GALATIAN TERRANE ACCRETION TO EURASIA

The Galatian superterrane was detached from Gondwana in segments, starting from the west, north of N-Africa with the detachment of the Armorica *s.l.* segment around 400 Ma, then the Ibero-Ligerian fragment after the eo-Variscan collisional event (c. 390 Ma) and the Intra-alpine segment just after (c. 380 Ma). A triple junction was established around the Arabian promontory, corresponding to the three branches of Paleotethys. The Iranian seaway separated the Iranian-Afghan domain from South China, the Sulu-Dabie seaway separated South China from the intra-Alpine terrane, and the N-African seaway separated Gondwana from Armorica-Iberia.

These oceanic branches were back-arc basins that merged to give the Devonian Paleotethys. During their drifting the Iberian-Intra-Alpine segment passed behind the Armorican one. This imbrication was even exaggerated when Armorica collided with the Hanseatic arc detached from Eurasia in the late Devonian. This arc extended from New-Foundland up to the Caspian area, the back-arc basin is represented by the Rhenohercynian oceanic domain in the west and the Paphlagonian pelagic domain in the east (e.g. Stampfli and Kozur, 2006). The Hanseatic arc is represented by terranes such as the S-Portuguese, Channel,

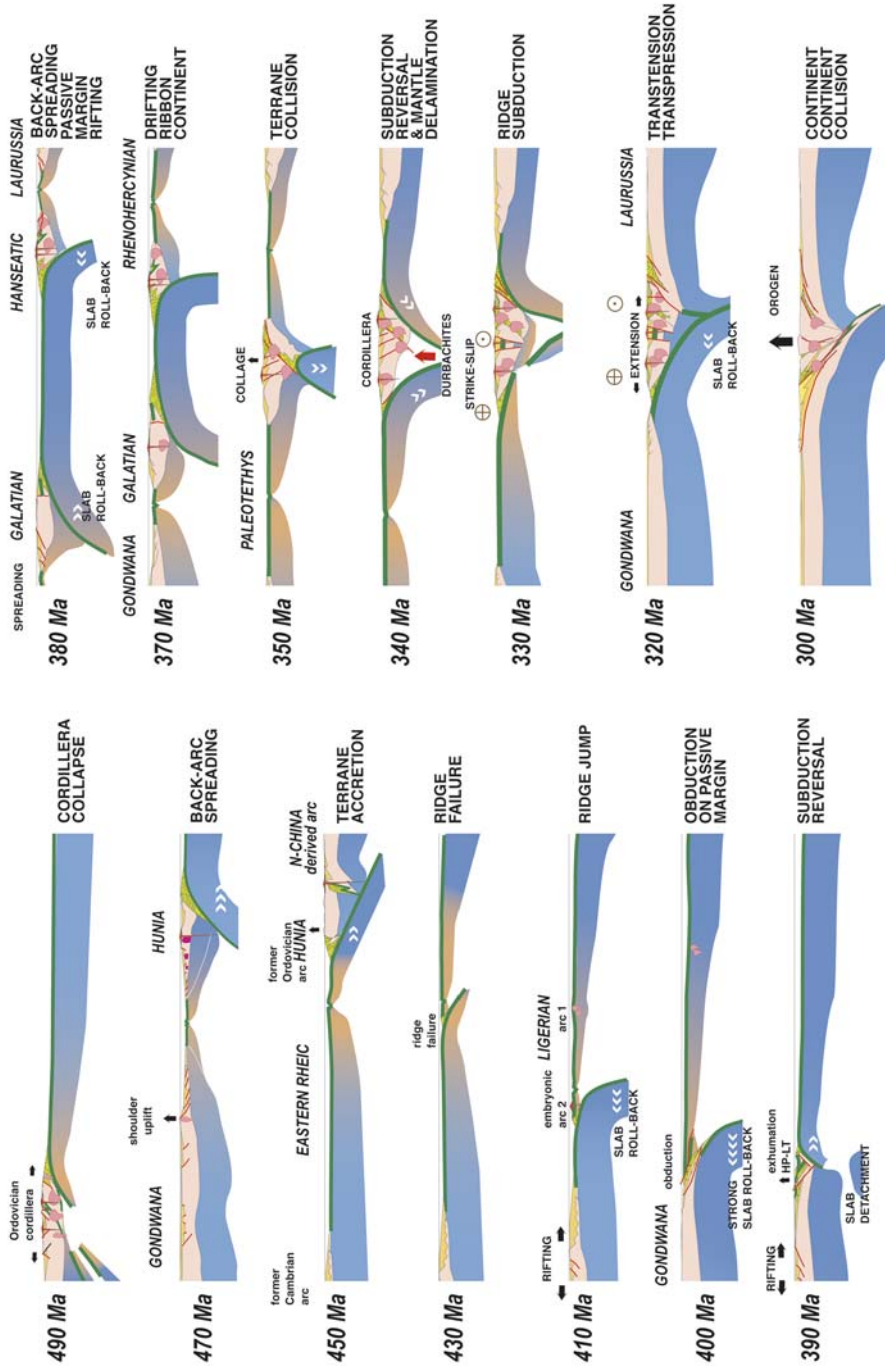


Figure 2. Cross section models of the evolution of the Gondwana margin from 490 to 300 Ma. The sections are tied to Gondwana, so the continent to the right is changing through times. For the left part of the figure North China elements are facing Gondwana, whereas for the right side of the figure it is Laurussia. The horizontal scale is not respected.

East-Meseta and Mid-German Rise, and part of the Caucasus and Black-sea in the east. The Hanseatic terranes were imbricated with fragments of the Armorican or Meguma terranes around the Iberian landmass. We follow here the imbrication model of Martínez Catalán et al. (2007), where the amalgamated Armorican and Rhenohercynian terranes were indented by the Iberian promontory around 360-350 Ma. Terrane duplication took place further east too, due to the counter-clockwise rotation of Gondwana/Paleotethys with regards to Europe. Finally in the Late Carboniferous, Gondwana collided with the terranes accreted around Laurasia, given birth to the final Variscan tectonic event.

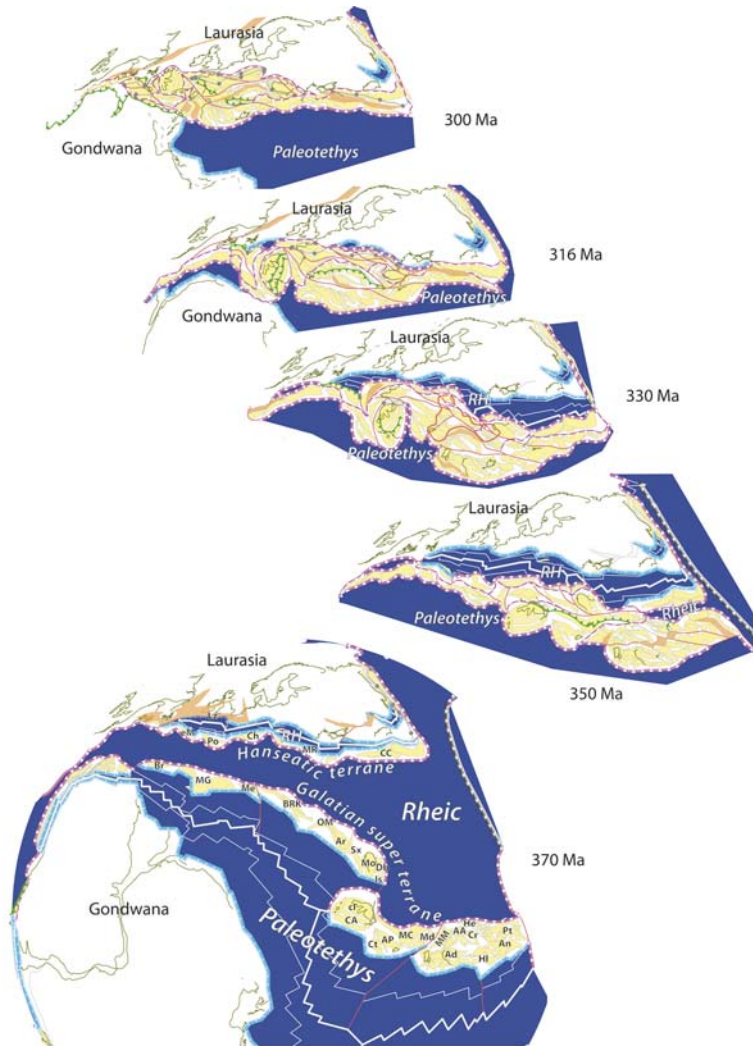


Figure 3. Reconstructions of the Variscan domain from 370 to 300 Ma, this model shows how the GDU (light grey) implied in the Variscan collision can be restored into a single ribbon like superterrane before 370 Ma (see Fig.1). Main rift zones are shown in darker grey.

CONCLUSIONS

The duplication, rotation and oroclinal bending of the amalgamated Variscan terrane had to be deciphered before to be able to restore the Galatian superterrane geometry, then the Ordovician margin of Gondwana. Markers such as the Cadomian suture zones, the eo-Variscan obduction events, or the Paleotethys passive margin sequences were used to establish the former sub-linear geometry of the superterrane. Other aspects such as the distribution of Cambrian carbonates, the Hirnantian glacial deposits or the detrital zircon distribution were used to better constrain the position of the superterrane geodynamic elements (GDU) around Gondwana. The global reconstruction model and database elaborated at the Lausanne university (Hochard, 2009) using plate tectonic and synthetic isochrone principles (Stampfli and Borel, 2002) was of a great help in constraining geometries and plate velocities. These factors are fundamental when considering the wandering of a large plate such as Gondwana. But this would be useless without the repeated efforts of several generations of field geologists that gathered key information from the Variscan basement areas, their work is strongly acknowledged here.

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